INSTITUTO NACIONAL DE ECOLOGÍA
SEMARNAP

EPA

PROGRAMA DE INVENTARIOS DE EMISIONES PARA MÉXICO

-Manuales y Reportes-

PRESENTACIÓN
ÍNDICE

PRESENTACIÓN

A través de la cooperación técnica del Acuerdo de la Paz firmado por México y los Estados Unidos en el año de 1983, el Instituto Nacional de Ecología de la SEMARNAP, con el apoyo de la Agencia de Protección Ambiental de los Estados Unidos (EPA) y la Asociación de Gobernadores del Oeste (WGA), inició en 1995 el *Proyecto de Inventarios de Emisiones para México*, cuyo objetivo es dotar de herramientas básicas para la planeación, desarrollo y mantenimiento de esta componente estratégica para llevar a cabo programas de mejoramiento y preservación de la calidad del aire en México.

El proyecto comenzó con la elaboración de una Metodología para México y de un Plan de Ejecución e incluye así mismo un curso completo de inventarios de emisiones, manuales para la planeación y estimación de las emisiones de las fuentes contaminantes, estudios de aplicación de la Metodología, entre otros.

Esta versión electrónica del documento tiene como propósito proporcionar el material ya elaborado en idiomas ingles y español, que seguramente tendrá una audiencia nutrida.

A lo largo del proyecto hemos tenido la valiosa supervisión del *Comité Binacional Asesor*, que ha sido integrado por los siguientes expertos:

William B. Kuykendal, U.S. Environmental Protection Agency
Gerardo Rios, U.S. Environmental Protection Agency
William Jones, U.S. Environmental Protection Agency
John R. Holmes, State of California Air Resources Board
Carl Snow, Texas Natural Resources Conservation Commission
Gary Neuroth, Arizona Department of Environmental Quality
George Mike, Arizona Department of Environmental Quality
John T. Leary, Western Governors Association
Richard Halvey, Western Governors Association
Victor Hugo Páramo F., Instituto Nacional de Ecología
Jorge Sarmiento Rentería, Instituto Nacional de Ecología

Las fases iniciales del proyecto fueron contratadas con la compañía consultora Radian Internacional y posteriormente con sus sucesoras que han brindado la expertise de sus ingenieros y científicos a lo largo del proyecto.

Los materiales subsecuentes que se vayan elaborando podrán ser obtenidos directamente de la página Web del INE:

http://www.ine.gob.mx/dggia/cal_aire/

Dr. Adrián Fernández Bremauntz
Director General de Gestión e
Información Ambiental
Instituto Nacional de Ecología

INDICE DE DOCUMENTOS

Methods Evaluation and Proposal for

Mexico Emissions Inventory Program

Prepared for:

Western Governors' Association and
Binational Advisory Committee
Denver, Colorado

August 1995

670-017-05-01
August 24, 1995

John T. Leary
Project Manager
Western Governors' Association
600 17th Street
Suite 1705, South Tower
Denver, CO 80202

Subject: Mexico Inventory Methods Evaluation and Proposal

Dear John:

Please find enclosed the revised Methods Evaluation and Proposal for the Mexico Inventory Program. Previously, we submitted these materials in draft form as two separate documents. For the final submittal, we have combined the draft materials into one consistent document. The enclosed material also reflects the comments we received from INE.

If there are any questions regarding the enclosed material, you may call me at 916-857-7467.

Sincerely,

Ronald J. Dickson
Senior Staff Engineer

c: Binational Advisory Committee
Dr. José Ortega, Corporación Radian

670-017-05-01

METHODS EVALUATION AND PROPOSAL

FOR

MEXICO EMISSIONS INVENTORY PROGRAM

FINAL

Prepared for:

Western Governors' Association
Denver, Colorado

and

Binational Advisory Committee

Prepared by:

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August 23, 1995

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LIST OF ACRONYMS

AIRS - Aerometric Information and Retrevial System

AMS - Area and Mobile Sources

BAC - Binational Advisory Committee

CAINTRA - Cámara de la Industria de la Transformación

CEC - Commission of the European Communities

CEM - Continuous Emissions Monitor

CO - Carbon Monoxide

DDF - Department of the Federal District

EEA - Energy and Environmental Analysis, Inc.

EPA - Environmental Protection Agency

FIRE - Factor Information Retrevial System

FTIR - Fourier Transform-Infrared

FTP - Federal Test Procedure

GHG - Greenhouse Gas

IMP - Mexican Petroleum Institute

INE - National Institute of Ecology

INEGI - Instituto Nacional de Estadística, Geografía e Informática

LIDAR - Light Detection and Ranging

LULC - Land Use/Land Cover

MARI - Mexico City Air Quality Research Initiative

NO - Nitrogen Oxide

NO_x - Oxides of Nitrogen

LIST OF ACRONYMS (CONTINUED)

PEMEX	-	Petróleos Mexicanos
PM_{10}	-	Particulate Matter Less than 10 Micrometers in Aerometric Diameter
$PM_{2.5}$	-	Particulate Matter Less than 2.5 Micrometers in Aerometric Diameter
QA	-	Quality Assurance
QC	-	Quality Control
SCC	-	Source Classification Codes
SIP	-	State Implementation Plan
SO_2	-	Sulfur Dioxide
TSP	-	Total Suspended Particulate
U.S.	-	United States
VKT	-	Vehicle Kilometers Traveled
VOC	-	Volatile Organic Compound
WGA	-	Western Governors' Association
WHO	-	World Health Organization

FINDINGS AND PRELIMINARY RECOMMENDATIONS

This document presents an analysis of emission estimating techniques (or methods) that could be applied to develop a comprehensive inventory for the country of Mexico. The analysis focuses on methods that can be used in the near term to develop initial estimates as well as more sophisticated methods that can be developed and used over time to refine the initial estimates.

Prior to conducting this analysis, the current inventory status in Mexico was examined. The materials presented in this document build upon the on-going inventory efforts in Mexico City and other urban areas.

Identification of Inventory Methods

The inventory methods discussed in the methods analysis were identified by examining techniques currently used in Mexico, Europe, Asia, and the United States (U.S.). Inventory techniques developed by the World Health Organization (WHO) and techniques used to develop global scale greenhouse gas (GHG) emissions inventories were also evaluated. Six different methods formed the basis of this analysis:

- Source sampling (direct and indirect);
- Modeling;
- Surveying;
- Use of census-based emission factors and activity data;
- Material balance (raw materials, fuel consumption); and
- Extrapolation.

In some cases, two or more of these methods were combined in order to produce hybrid methods to better address the needs of the Mexican inventory process.

Methodology Evaluation Approach

The analysis was performed using a set of criteria that examined the cost effectiveness, practicality, uncertainty, and upgrade potential for each method. Each inventory method was evaluated for its general application in Mexico and also on a source type basis. This detailed methods evaluation was performed in a matrix format by ranking each method using the four criteria. This approach results in the identification and analysis of several candidate methods for each source type.

Summary of Methods Evaluation Findings

Our understanding of the current status of emissions inventory development in Mexico, Europe, and Asia indicates that U.S. methods are typically applied throughout the world. Thus far, we have not identified any new or significantly different approaches for developing emissions inventories from the methods that are typically used in the U.S.

Our review of the *Rapid Source Inventory Techniques (Economopoulos, 1993)* developed in Greece for the WHO indicates a very simple emission factor approach is recommended for developing countries. The country of Mexico is capable of supporting a more sophisticated approach, yielding more precise estimates than can be developed with the WHO approach.

The available documentation for the WHO approach provides a tabular listing of emission factors without any supporting documentation. Therefore, the source and derivation of these emission factors is not clear to us at this time. In terms of ease of use, the WHO emission factors are generally equivalent to U.S.-based emission factors, although in some instances, the WHO factors may be easier to apply because some process operations have been aggregated into one emission factor. For example, several petroleum refinery sources are aggregated into one single emission factor. This aggregation, and the lack of emission factors for many processes, will tend to yield a higher level of uncertainty if only the WHO emission factors are used.

The approach to developing GHG inventories is intriguing, and in some cases, potentially beneficial to the development of the Mexico Inventory Program. Some of the concepts used in developing GHG inventories appear to be useful in the context of developing *emission estimation models*. The approaches taken in GHG inventory development also appear promising as inventory evaluation tools. We envision that most emission estimates in Mexico will be developed at the local and state level using source sampling, surveys, and census-based emission factors (i.e., a bottom-up approach). The top-down approaches used to develop GHG inventories are not considered as accurate, but they can be used to evaluate the reasonableness of emission estimates developed from bottom-up techniques.

The remainder of this section summarizes the findings for the general applicability to Mexico of each inventory method evaluated.

Source Sampling. For many large point sources, source sampling will be the most appropriate method for estimating emissions. As part of this effort, we evaluated the potential benefits of using indirect source measurement techniques, such as Fourier transform-infrared (FTIR) remote sensing. We examined this technology to see if it could possibly streamline and simplify the source sampling process. We determined that remote sensing provides numerous benefits when monitoring speciated emission estimates (e.g., air toxics) or volume sources that do not have stack emissions, such as open burning dumps. Remote sensing, however, has two important limitations when considered for routine monitoring of stack emissions. An FTIR system has a rather high purchase cost (~$180,000 per unit) and requires specialized training and expertise to use properly. Advantages include quick and efficient measurement of speciated hydrocarbons such that when applied on a large scale basis, capital costs are offset. Nonetheless, these constraints may limit the widespread use of this technology.

Emission Models. To aid in the methods evaluation, we continually asked ourselves: How could emission estimates be developed if there were no source sampling, survey, or statistical information available upon which to base emission calculations? For many source types, answering this question resulted in the concept of a "multivariate model." In this approach, emission estimates would be expressed as a function of a set of variables that help characterize a system. For example, satellite imagery data could be used to develop a predictive model for all non-industrial source emissions associated with typical day-to-day human activity (e.g., residential fuel consumption, residential solvent use, open burning, etc.). Non-industrial emissions could be characterized as a function of standard of living, population density, climate, and social practices. By combining micro-inventory and field survey techniques with socioeconomic information, predictive models could be developed with land use/land cover (LULC) data obtained from satellite imagery as the basis. This would result in an emissions flux that would be a function of the LULC type (e.g., agricultural land will have different emission characteristics than high density urban land). This approach could be further augmented using the concepts of fuzzy logic to help factor in geographic and standard of living differences.

A multivariate modeling approach appears most applicable to regions that have insufficient information to apply traditional inventory techniques and for source types where it is difficult to develop activity data, such as nonroad mobile sources and solvent utilization. This approach will require a greater amount of initial resources to develop, but it will be less resource intensive to apply and maintain. Section 3.0 provides further examples and detail on this new concept.

Even if a multivariate approach is not taken, serious consideration should be given to developing satellite imagery data for the entire country. These data can used to augment not only the air quality planning process but possibly other environmental programs as well. We currently estimate the cost of obtaining and processing satellite imagery data for the country of Mexico at $1.3 million.

Surveying. This is a useful tool so long as the information needed for emission calculations can be obtained through a survey. The National Institute of Ecology (INE) is currently using a survey approach to gather information that is used to develop a national point source inventory. This survey effort primarily collects combustion emissions, and in the Mexico City area and some other regions, source test results are reported in the survey responses. As the survey effort is expanded to include other source types and more geographic regions, emission factors will be required to estimate some emission estimates. The representativeness of survey-based emission estimates in Mexico for non-combustion source types is therefore highly dependent upon the applicability of current emission factors to Mexico. The extent to which current emission factors are applicable to Mexico is currently unknown and should be evaluated as a part of this overall effort. Recommendations to address this issue will be presented in the Task 6 Implementation Plan.

Use of Census-Based Emission Factors and Activity Data. This approach represents a quick and efficient method for developing emission estimates. This method also tends to have a higher level of uncertainty than other methods. When current census-based emission factors are applied in Mexico, the uncertainty is expected to be even larger because of socioeconomic and cultural differences between Mexico and the regions from which the available emission factors were developed. As stated above for surveying, additional research is needed to determine the applicability of the existing census-based emission factors to Mexico and refine them as necessary. This includes developing geographic-specific emission factors for different regions of Mexico.

Material Balance. Material balance calculations can also have a large degree of uncertainty compared to other methodologies. Nonetheless, there appear to be certain area source categories where a material balance may be the most cost effective and practical approach. A few potential examples for Mexico include national and/or regional fuel and solvent balances.

The use of material balances may also be a viable method for evaluating emission estimates developed with other methods, such as surveys. A material balance can be used to check the reasonableness of emission calculations performed using other methods.

Extrapolation. This is generally considered the least accurate method for estimating emissions. For several of the source types evaluated, extrapolation was considered as an emissions inventory development methodology with emissions extrapolated from one geographic region to another. Extrapolating emissions from the U.S. to Mexico has limited applicability because of socioeconomic and cultural differences between the two countries.

Care must also be taken in extrapolating emissions from one region in Mexico to another. The recently completed Mexico City Air Quality Research Initiative (MARI) determined through air quality modeling and data analysis techniques that the 1991 base year VOC inventory used for MARI was low by a factor of four (LANL and IMP, 1994). This conclusion was reached through air quality modeling and ambient monitoring data combined with data analysis techniques. Therefore, extrapolating emissions from Mexico City may result in an underestimation of emissions in other regions. This finding clearly indicates that careful consideration must be given to the development of adequate inventory methods and tools in order to more accurately reflect conditions in Mexico.

Methodology Proposal. With the exception of extrapolation, the methodology proposal uses each of the six methods detailed above. For some source types, two or more methods are combined resulting in hybrid methods that allow for better emissions estimates.

Several of the methods contained in this methodology proposal also rely on emission factors. For both point and area sources, the applicability of existing emission factors to Mexican sources is largely unknown. At this time, we know that emission factors used in Mexico City have been modified for asphalt paving and consumer solvents. We also suspect that the combustion of combustóleo will result in different emission characteristics that cannot be represented by existing emission factors. As part of the implementation plan, we recommend establishing a process to evaluate the existing emission factors with source test results that have already been conducted in Mexico. This process would be carried out under the project's Phase II activities.

Finally, it should be noted that the methods evaluation conducted under Task 4 was extended to provide a ranking for each inventory method/source type combination in the context of an inventory program by considering application of the method in the near- and long-term. We added this distinction to recognize that the inventory program can not initially apply the most desirable method for each and every source category. Resource and time constraints will require the application of simpler methods for certain source categories in the near-term that will be refined over the long-term as the inventory program matures. The methods proposal, therefore, is presented here in light of future updates so that the INE and other agencies in Mexico can build upon this effort.

In the near term, the methodology proposal relies extensively on the use of emission factors. As the emission factor evaluation is performed, simple adjustments to the factors should be developed, if possible. Developing these adjustments is the first step in developing multivariate emission models.

Point Source Methodology Proposal

Table 1 lists the recommended methods for each point source type. For many point sources, source sampling and/or surveying is the recommended approach. Source sampling every point source is impractical; therefore, source sampling resources should be used for the largest emission sources, such as electric utilities. Emission estimates for many of the sources that are not sampled can be developed using a facility survey and emission factor approach. The combination of source sampling and surveying is not new to Mexico. These activities have been on-going at INE for some time. To develop a complete point source inventory, we recommend increasing the amount of source sampling and surveying that is currently being performed.

Table 1

Proposed Methods for Point Sources

Major Category	Subcategory	Priority[a]	Near - Term Recommendation	Long - Term Recommendation
Electric Utility	Combustion by Fuel Type	1	Source Sampling / Direct	Source Sampling / Direct
Industrial and Commercial Fuel Combustion	By Fuel Type	1	Surveying / Emission Factors	Source Sampling / Direct
Chemical Manufacturing	Process Emissions	1	Surveying / Emission Factors	Source Sampling / Direct
	Combustion Emissions	1	Surveying / Emission Factors	Source Sampling / Direct
	Fugitives From Equipment Leaks	1	Survey / Multivariate Model	Source Sampling / Indirect
	Storage Tanks	1	Survey / Mechanistic Model	Survey / Mechanistic Model
	Miscellaneous Solvent Usage	3	Survey / Material Balance	Survey / Material Balance
Petroleum Refining	Process Emissions	1	Source Sampling / Direct	Source Sampling / Direct
	Combustion Emissions	1	Surveying / Emission Factors	Source Sampling / Direct
	Fugitives From Equipment Leaks	1	Survey / Multivariate Model	Source Sampling / Indirect
	Storage Tanks	1	Survey / Mechanistic Model	Survey / Mechanistic Model
	Miscellaneous Solvent Usage	3	Survey / Material Balance	Survey / Material Balance
Primary Metal Production	Process Emissions	1	Source Sampling / Direct	Source Sampling / Direct
	Combustion Emissions	1	Surveying / Emission Factors	Source Sampling / Direct

Table 1

(Continued)

Major Category	Subcategory	Priority[a]	Near - Term Recommendation	Long - Term Recommendation
	Fugitive Emissions	2	Survey / Material Balance	Survey / Material Balance
Secondary Metal Production	Process Emissions	2	Surveying / Emission Factors	Source Sampling / Direct
	Combustion Emissions	1	Surveying / Emission Factors	Source Sampling / Direct
Cement Production	Process Emissions	1	Surveying / Emission Factors	Source Sampling / Direct
	Combustion Emissions	1	Surveying / Emission Factors	Source Sampling / Direct
	Fugitive Emissions	2	Surveying / Emission Factors	Source Sampling / Indirect
Miscellaneous Mineral Products (e.g. lime and aggregate kilns)	Process Emissions	1	Surveying / Emission Factors	Source Sampling / Direct
	Combustion Emissions	1	Surveying / Emission Factors	Source Sampling / Direct
	Fugitive Emissions	2	Surveying / Emission Factors	Source Sampling / Indirect
Automotive Industry	Process Emissions	1	Surveying / Emission Factors	Source Sampling / Direct
	Combustion Emissions	1	Surveying / Emission Factors	Source Sampling / Direct
	Fugitive Emissions	2	Surveying / Emission Factors	Source Sampling / Indirect
Wood Pulping Operations	Process Emissions	1	Surveying / Emission Factors	Source Sampling / Direct
	Combustion Emissions	1	Surveying / Emission Factors	Source Sampling / Direct

Table 1

(Continued)

Oil and Gas Production	Process Emissions	1	Surveying / Emission Factors	Source Sampling / Direct
	Fugitive Emissions	1	Surveying / Emission Factors	Source Sampling / Indirect
	Combustion Emissions	1	Surveying / Emission Factors	Source Sampling / Direct
	Storage Tanks	1	Survey / Mechanistic Model	Survey / Mechanistic Model
Printing and Publishing	Process Emissions	1	Surveying / Emission Factors	Surveying / Emission Factors
	Fugitive Emissions	2	Survey / Material Balance	Survey / Material Balance
Surface Coating	Process Emissions	1	Survey / Material Balance	Survey / Material Balance
	Degreasing Emissions	1	Survey / Material Balance	Survey / Material Balance
	Fugitive Emissions	1	Survey / Material Balance	Survey / Material Balance
Bulk Fuel Terminals	Loading Operations	1	Surveying / Emission Factors	Surveying / Emission Factors
	Storage Tanks	1	Survey / Mechanistic Model	Survey / Mechanistic Model
Mining and Quarrying	Process Emissions	1	Surveying / Emission Factors	Source Sampling / Indirect
	Fugitive Emissions	2	Surveying / Emission Factors	Source Sampling / Indirect
Wood Products Manufacture	Process Emissions	2	Surveying / Emission Factors	Surveying / Emission Factors
	Combustion Emissions	2	Surveying / Emission Factors	Source Sampling / Direct
Sugar Production	Process Emissions	2	Surveying / Emission Factors	Source Sampling / Direct
	Combustion	2	Surveying / Emission Factors	Source Sampling / Direct

Table 1

(Continued)

	Emissions			
	Fugitive Emissions	2	Surveying / Emission Factors	Source Sampling / Indirect
Tanning and Leather Finishing	Process Emissions	2	Surveying / Emission Factors	Source Sampling / Direct
	Combustion Emissions	2	Surveying / Emission Factors	Source Sampling / Direct
	Fugitive Emissions	2	Surveying / Emission Factors	Source Sampling / Indirect
Glass Production	Process Emissions	2	Surveying / Emission Factors	Source Sampling / Direct
	Combustion Emissions	2	Surveying / Emission Factors	Source Sampling / Direct
	Fugitive Emissions	2	Surveying / Emission Factors	Source Sampling / Indirect
Rubber and Plastic Parts	Process Emissions	2	Surveying / Emission Factors	Surveying / Emission Factors
	Combustion Emissions	2	Surveying / Emission Factors	Source Sampling / Direct
Fabricated Metal Products	Process Emissions	2	Surveying / Emission Factors	Surveying / Emission Factors
	Combustion Emissions	1	Surveying / Emission Factors	Surveying / Emission Factors
Textile Products	Process Emissions	2	Surveying / Emission Factors	Surveying / Emission Factors
	Combustion Emissions	1	Surveying / Emission Factors	Source Sampling / Direct
Solid Waste Disposal	Landfill Gas Emissions	3	Survey / Mechanistic Model	Survey / Mechanistic Model
	Open Burning Dump	2	Source Sampling / Indirect	Source Sampling / Indirect

Table 1

(Continued)

	Municipal Waste Combustors	1	Source Sampling / Direct	Source Sampling / Direct
Miscellaneous Industrial Activities / Processes	Process Emissions	2	Surveying / Emission Factors	Surveying / Emission Factors
	Combustion Emissions	2	Surveying / Emission Factors	Surveying / Emission Factors
	Fugitive Emissions	2	Survey / Material Balance	Survey / Material Balance
Government Facilities	Combustion Emissions	2	Surveying / Emission Factors	Surveying / Emission Factors
	Fugitive Emissions	2	Survey / Material Balance	Survey / Material Balance
Food and Agriculture	Process Emissions	3	Surveying / Emission Factors	Surveying / Emission Factors
	Combustion Emissions	1	Surveying / Emission Factors	Source Sampling / Direct
Asphalt Plants	Process Emissions	3	Surveying / Emission Factors	Surveying / Emission Factors
	Combustion Emissions	1	Surveying / Emission Factors	Source Sampling / Direct

[a] A priority has been assigned to communicate the current, perceived importance of each source type.

N / A = Not applicable.

With the exception of extrapolation, the other emission estimation methods are also proposed for specific source types where these methods appear to be the best alternative for estimating emissions. At this time, we don't recommend the use of extrapolation. A brief summary of the application of the other methods to point sources is presented below:

- A **mechanistic modeling** approach is recommended for liquid organic storage tanks and landfills;
- A **multivariate model** is recommended for petrochemical fugitive emissions from leaking components such as valves and flanges; and
- **Material balances** should be used for estimating facility-level VOC emissions from surface coating and solvent usage emission sources.

Area Source Methodology Proposal

Table 2 presents the methodology proposal for stationary area sources. Generally, the methods recommended for the near-term (e.g., census-based emission factors, material balance, extrapolation) make use of readily available information such as population or employment figures or fuel consumption data. In contrast, the methods often recommended for the long-term (e.g., surveying and multivariate models) would require further data collection or data analysis efforts, taking a longer time to implement.

Table 2

Proposed Methods for Stationary Area Sources

Major Category	Subcategory	Priority[a]	Near - Term Recommendation	Long - Term Recommendation
Stationary Source Fuel Combustion -Industrial and Commercial	By fuel type	1	Material Balance / AP-42 Emission Factors	Material Balance / Emission Factors
Stationary Source Fuel Combustion -Residential Commercial Fuels	Commercial fuels by fuel type	1	Material Balance / AP-42 Emission Factors	Material Balance / Emission Factors
Stationary Source Fuel Combustion -Residential Biomass or Waste-Derived Fuels	Biomass or waste-derived fuels by fuel type	1	Surveying / AP-42 Emission Factors	Surveying / Multivariate Model
Paved Road Dust	N / A	1	Mobile VKT / AP-42 Methodology	Mobile VKT / Surveying / AP-42 Methodology
Unpaved Road Dust	N / A	1	Surveying / AP-42 Methodology	Surveying / AP-42 Methodology
Surface Coatings and Clean-up Solvents - Industrial	By industrial sector	1	Extrapolation / Mexican Point Source Inventory	Surveying / Multivariate Model
Industrial Surface Cleaning (Degreasing)	By industrial sector	1	Extrapolation / Mexican Point Source Inventory	Surveying / Multivariate Model
Dry Cleaning	By solvent type	1	Census-based Emission Factors	Surveying / Multivariate Model
Consumer Solvents	By product type	1	Census-based Emission Factors	Surveying / Multivariate Model
Storage and Transport (Storage Tanks, Loading / Unloading Operations, and Fugitive Component Leaks from Pipelines, Bulk Terminals, Service Stations, and Transport Vessels / Trucks)	By product type	1	Material Balance / Mechanistic Models and Emission Factors	Material Balance / Mechanistic Models and Emission Factors

Table 2

(Continued)

Major Category	Subcategory	Priority[a]	Near - Term Recommendation	Long - Term Recommendation
Agriculture Production	Livestock	1	Census-based Emission Factor	Surveying / Multivariate Model
Waste Management - On-Site Incineration	N / A	1	Material Balance	Surveying / Multivariate Model
Waste Disposal - Refuse Burning	N / A	1	Surveying	Surveying / Multivariate Model
Fires	Wildfires	1	Surveying / AP-42 Emission Factors	Multivariate Model
	Prescribed burning	1	Surveying / AP-42 Emission Factors	Multivariate Model
Public Baths	N / A	1	Census-based / AP-42 Emission Factors	Census-based Emission Factors
Industrial Processes	By industrial sector	2	Census-based Emission Factors / GHG Inventory Technologies	Surveying / Multivariate Model
Surface Coatings and Clean-up Solvents - Architectural Coatings	N / A	2	Census-based Emission Factors	Material Balance
Surface Coatings and Clean-up Solvents - Auto Refinishing	N / A	2	Census-based Emission Factors	Surveying / Multivariate Model
Graphic Arts	N / A	2	Census-based Emission Factors	Surveying / Multivariate Model
Asphalt Application	N / A	2	Material Balance / AP-42 Emission Factors	Material Balance / Emission Factors
Agriculture Production	Pesticide Application	2	Material Balance	Surveying / Multivariate Model
	Fertilizer Application	2	Material Balance	Surveying / Multivariate Model
	Agricultural Burning	2	Surveying	Surveying / Multivariate Model

Table 2

(Continued)

Major Category	Subcategory	Priority[a]	Near - Term Recommendation	Long - Term Recommendation
	Tilling	2	Surveying / Multivariate Model	Surveying / Multivariate Model
Fires	Structures	2	Surveying / AP-42 Emission Factors	Surveying / Emission Factors
Waste Management - Wastewater Treatment	N / A	2	Surveying / AP-42 Emission Factors	Surveying / Multivariate Model
Open Sewage	N / A	2		
Street Vending / Cooking	N / A	2		
Domestic Ammonia Emissions	N / A	2	Census-based Emission Factors	
Tortilla Factories	N / A	2	Census-based Emission Factors	Census-based Emission Factors
Brick Manufacturing	N / A	2	Surveying	Surveying / Multivariate Model
Building Construction	N / A	3	Surveying / AP-42 Emission Factors	Surveying / Multivariate Model
Surface Coatings and Clean-up Solvents - Traffic Markings	N / A	3	Census-based Emission Factors	Material Balance
Rubber and Plastics Fabrication	N / A	3	Extrapolation / Mexican Point Source Inventory	Surveying
Waste Management - Landfills	N / A	3	Material Balance / Mechanistic Model	Surveying / Mechanistic Model
Bakeries	N / A	3	Census-based Emission Factors	Census-based Emission Factors

[a] A priority has been assigned to communicate the current, perceived importance of each source type.

N / A = Not applicable.

A brief summary of the methodology recommendation for stationary area sources is presented below:

- **Census-based emission factors and activity data** are recommended as the near-term method for various non-industrial surface coating and solvent area source types.

- **Surveying** is recommended as a near-term method for stationary area sources where a census-based approach is not available or is likely to introduce a very high degree of uncertainty if applied in Mexico (e.g., unpaved road dust, agricultural burning, fires). Surveying is also a method used to support long-term modeling methods.

- **Material Balance** is recommended for industrial and commercial fuel consumption (i.e., stationary area combustion sources) and to support modeling of emissions from material storage and transport.

  For surface coating and solvent usage, material balances may prove to be a helpful evaluation tool to check the "reasonableness" of the other recommended methods. This is important since an underestimation of VOC emissions from these area source categories could cause significant bias in the countrywide VOC inventory.

- **Multivariate models** are recommended as the long-term method for the majority of the stationary area source types in order to encourage the development of models based on Mexico-specific data. This approach will serve as a means of evaluating and expanding the near-term methods to be more applicable to Mexico. In general, the near-term methods can serve as the initial foundation and be upgraded to a multivariate approach over time.

  These multivariate models should also be designed to account for regional differences that are important to developing stationary area source emission estimates. For example, it is expected that many area sources in Mexico are geographically non-homogeneous. For example, the rate at which dry cleaning solvents are used probably varies with geographic location. Consequently, the use of single per capita emission factors will not reflect regional differences.

- **Mechanistic models** are recommended for liquid organic storage and transport, and for landfills. Surveying or material balances are secondary methods needed to support the data requirements of the mechanistic models.

- **Extrapolation** is recommended only as a near-term method for industrial surface coating and solvent use. Eventually, most of these industrial emissions should be incorporated into the Mexican point source inventory.

- **Source sampling (direct or indirect)** is not recommended for any stationary area source types.

Nonroad Mobile Source Methodology Proposal

Table 3 presents the methodology proposal for nonroad mobile sources. The approach for airports, shipping, and railroads relies primarily on surveying to gather activity data. Survey data would then be combined with emission factors to estimate emissions.

Table 3

Proposed Methods for Nonroad Mobile Sources

Category	Priority[a]	Near - Term Recommendation	Long - Term Recommendation
Aircraft	2	Surveying / AP-42 Emission Factors	Surveying / AP-42 Emission Factors
Railroads	2	Surveying / AP-42 Emission Factors	Surveying / AP-42 Emission Factors
Commercial Marine Vessels	2	Surveying / AP-42 Emission Factors	Surveying / AP-42 Emission Factors
Agricultural Equipment	2	Survey / Multivariate Model	Survey / Multivariate Model
Construction Equipment	2	Survey / Multivariate Model	Survey / Multivariate Model
Industrial Equipment	2	Survey / Multivariate Model	Survey / Multivariate Model
Light Commercial Equipment	2	Survey / Multivariate Model	Survey / Multivariate Model
Lawn & Garden Equipment	3	Survey / Multivariate Model	Survey / Multivariate Model
Recreational Equipment	3	Survey / Multivariate Model	Survey / Multivariate Model
Recreational Boats	3	Survey / Multivariate Model	Survey / Multivariate Model

The proposed approach for nonroad equipment emissions relies on multivariate models in both the near- and long-term. Developing emission estimates for nonroad equipment is extremely difficult, regardless of geographic location. Multivariate models are needed in the near-term to estimate the activity data for this group of sources so that emission estimates can be developed. The Methodology Evaluation Report presents several examples of how this approach would be applied to this group of sources.

On-Road Mobile Source Methodology Proposal

On-road mobile source emissions are calculated based on estimates of vehicle activity and emission factors. The methods chosen depend upon the geographic scope of the inventory and the extent of the available data. Development of the on-road mobile source inventory for this effort will depend upon existing data.

Motor Vehicle Activity Data

To estimate vehicle activity, the following types of data are commonly used for inventory purposes:

- Detailed vehicle kilometers traveled (VKT) estimates such as those developed from transportation models, comprehensive traffic counting programs and surveying, and detailed registration records;

- Regional VKT estimates based on traffic counting programs;

- Regional VKT estimates developed from on-road fuel use; and
- Regional VKT estimates developed from population and vehicle registration data.

These data sources are listed in the order of perceived accuracy (high to low).

The availability of these data will vary geographically across Mexico. For each region in Mexico to be inventoried, an analysis will be required to determine which data are available to estimate vehicle activity. For example, detailed VKT data are available for the larger metropolitan areas, such as Mexico City and Monterrey. The larger metropolitan regions have the available resources to develop these data as part of their transportation planning efforts. If detailed or regional VKT estimates are not available, then fuel usage should be used to estimate vehicle activity.

Motor Vehicle Emission Factors

The second part of the motor vehicle emission estimation process requires the development of emission factors representative of vehicles operating in a given region. A variety of sources are available to provide vehicle emission factors for this effort. These include the following:

- MOBILE-MCMA, an emission factor model developed for Mexico City;
- MOBILE5C, an emission factor model developed by U.S. EPA's office of Mobile Sources for regions outside of the U.S.;
- COPERT, Computer Programme to Calculate Emissions from Road Traffic;
- *Rapid Source Inventory Techniques,* a listing of emission factors that can be used to quickly estimate emissions; and
- PART5, U.S. EPA's particulate emission factor program.

These techniques are discussed in detail in the methods evaluation.

Proposed Methodology for Motor Vehicle VOC, NO_x, and CO

Based on our analysis, we recommend using the same emission factor approach that was taken to develop the MOBILE-MCMA program. This approach relies on developing an emission control technology equivalence matrix that relates basic emission factors in the MOBILE model to the Mexican vehicle fleet. The MOBILE-MCMA model was recently updated as part of a study conducted in the Monterrey Metropolitan Area (MMA). The new version of this model is referred to as MOBILE-MMAp, where *p* indicates *preliminary*. Additional work is needed to refine the emission control technology equivalence matrix so that this model can be used with more confidence in other areas of Mexico.

Refining the emission control technology equivalence matrix matrices would consist of using inspection/maintenance data from Monterrey (at idle conditions) to better match the MOBILE model's basic emission factors to the Mexican vehicle fleet. Over time, this approach can be updated by replacing the U.S.-derived basic emission factors with Mexico specific data.

Proposed Methodology for Motor Vehicle Particulate Matter

A similar approach is proposed for motor vehicle particulate matter. Estimates for this pollutant can be developed using the U.S. EPA's PART5 model. This is also a technology-based model and will require similar changes to those discussed above for MOBILE.

Proposed Methodology for Motor Vehicle SO_2

Finally, we recommend that emission estimates for motor vehicle SO_2 be based on material balances. The quantity of fuel consumed and the average sulfur content of the fuel can be used to accurately estimate SO_2 emissions.

Natural Source Methodology Proposal

Table 4

Proposed Methods for Natural Sources

Major Category	Priority[a]	Near - Term Recommendation	Long - Term Recommendation
Biogenic VOC	1	Multivariate Model	Multivariate Model
Windblown Dust	1	Multivariate Model	Multivariate Model
Soil NO_x	2	Multivariate Model	Multivariate Model
Soil NH_3	2	Multivariate Model	Multivariate Model
Lightning	3	N / A	Mechanistic Model
Geogenic	3	N / A	Field Research

[a] A priority has been assigned to communicate the current, perceived importance of each source type. The priorities assigned to each source type will be refined over time as feedback is obtained from INE and more Mexico-specific information is gathered.

N / A = Not applicable.

The methodologies used to estimate emissions from natural sources traditionally rely on emission models, especially the techniques used for biogenic hydrocarbon emission estimates. Table 4 presents the recommended natural source estimation methods.

Estimating emissions for the natural source categories will rely extensively on land use/land cover (LULC) data. For example, land use describes the type of vegetation that may be present (e.g., natural versus urban) and also the type of vegetation present (e.g., row crop versus orchard). Development of natural source emission estimates for Mexico would be greatly enhanced through the application of satellite imagery data to develop LULC data. These data could be used directly to develop biogenic hydrocarbon, soil NO_x, soil NH_3, and wind blown dust emissions.

Further field research is also warranted so that a more refined biogenic emission estimate can be developed for Mexico. The applicability of the current biogenic emission models may have limited applicability in many regions of Mexico. The work performed to develop the biogenic hydrocarbon inventory for the Grand Canyon Visibility Transport Commission found that biogenic emission estimates for the southwestern U.S. appear to be overestimated. It is possible that the scrubland LULC category for the southern U.S. and northern Mexico should incorporate a lower biomass than is currently used in the biogenic emissions calculations. No other biomass data are available for this region.

In summary, a large effort will be required to develop the necessary data for natural source emission estimates. Satellite imagery would greatly enhance the process, but additional fundamental research will be required to develop other model parameters. This includes soil parameters for soil NO_x and NH_3 estimates and biomass data to support the modeling of biogenic hydrocarbons.

1.0 INTRODUCTION

The U.S. and of Mexico have common needs for emissions inventory information. The Grand Canyon Visibility Transport Commission established by the U.S. Congress is sponsoring projects to develop an emission inventory for areas, including Mexico, that potentially contribute to regional haze on the Colorado Plateau. Mexico is conducting several air quality planning efforts that will benefit from country-wide emissions information. In particular, INE is interested in developing a national methodology for the Mexican emission inventory program. The focus of this effort is on species that are traditionally included in an emissions inventory. These species include volatile organic compounds (VOC), oxides of nitrogen (NO_x), carbon monoxide (CO), oxides of sulfur (SO_x), and particulate matter (PM). Ammonia (NH_3) is also included because of its potential to form secondary aerosols that influence visibility. Air toxics and GHGs are not presently included.

The Western Governors' Association (WGA) is the administrative arm of the commission. As such, it receives funds and administers grants on behalf of the commission. In addition, WGA is vested in working with the Mexican government in several economic and technical areas, including the development of an emissions inventory methodology for Mexico. A work plan describing the development of an emissions inventory methodology for Mexico has been prepared (Radian, 1994).

As described in the work plan, development and implementation of the inventory methodology will proceed in two phases:

- Phase I--Development of a methodology and implementation plan for the Mexico inventory; and
- Phase II--Implementation of the first steps of the Phase I plan, such as development of a portion of the emission inventory and emission inventory training.

The resources needed to perform a traditional inventory for Mexico emission sources are considerable. As a result, the commission is sponsoring the development of a creative, emissions methodology in Phase I tailored for the country of Mexico.

In Phase I, the available Mexico data sets and inventory methodologies will be evaluated, followed by the preparation of a detailed inventory development plan. The Phase I work is divided into seven tasks, as follows:

- Task 1: Work Plan Development;
- Task 2: Information Surveying;
- Task 3: Critical Review of Data;
- Task 4: Critical Review of Emissions Methodologies;
- Task 5: Methodology Proposal;
- Task 6: Implementation Plan; and
- Task 7: Technology Transfer.

Information from the first four tasks will be used to prepare a recommended methodology in Task 5 for the development of the emissions inventory. Furthermore, it is INE intention that this methodology become the set of national methods for inventory development in Mexico. To guide the methodology development, the Binational Advisory Committee (BAC), consisting of representatives from the U.S. and Mexico, will work in consultation with the commission's Project Manager and the staff of INE. The BAC will provide technical advice to the WGA Project Manager and recommend approval of the final selection of inventory methods in Task 5. An implementation plan will then be prepared in Task 6 to carry out a portion of the methodology under the Phase II program.

This document presents the results of Task 4 and Task 5. The objective of Task 4 was to identify and evaluate candidate emissions inventory methods that could be applied in the country of Mexico. These methods were evaluated with respect to the near-term goal of developing country-wide emission estimates and a long-term goal to develop an emissions inventory *program* in Mexico. The objective of Task 5 was to recommend the most appropriate methods that met the requirements of these goals.

Developing a national inventory program will require a combination of approaches.

No single inventory method can be used throughout Mexico for all emission source categories. We started with the commonly accepted methods for developing stationary and mobile source emission estimates. For this evaluation, the list of available methodologies was expanded to include emissions modeling techniques and new emerging technologies for estimating emission estimates. This expansion helped to identify new, creative approaches for developing emission estimates. In some instances, the combination of one or more methods results in a new and creative approach for developing regional emissions inventories.

The remainder of this document is organized as follows:

- Section 2.0 discusses the technical approach, including the evaluation criteria;
- Section 3.0 describes each of the inventory methods considered in the point and area (including nonroad mobile) source evaluation and provides an analysis of the applicability of the methods to Mexico;
- Section 4.0 presents the results of a detailed methods evaluation for on-road motor vehicles;
- Section 5.0 contains the methods evaluation for natural sources; and
- Section 6.0 contains the bibliography.
- Appendix A contains the critical review of point source emissions methods;
- Appendix B contains the critical review of stationary area source emissions methods;
- Appendix C contains the critical review of nonroad mobile source emissions methods;
- Appendix D contains the critical review of on-road motor vehicle source emissions methods; and
- Appendix E contains the critical review of biogenic and natural source emissions methods.

2.0 TECHNICAL APPROACH

This section summarizes the approach used to perform the inventory methods evaluation. Performing the evaluation required developing a source type list, evaluation criteria, and a rating system.

2.1 Source Typing for Methods Evaluation

Developing a list of source types was the first step for performing the evaluation. General practice is to divide emission sources into four key source types: point, area, mobile, and natural sources. Point sources are typically industrial facilities such as power plants and cement kilns. Conversely, area sources are typically defined as those sources that individually emit relatively small quantities of air pollutants, but can cumulatively result in significant emissions. This may initially include smaller facilities not inventoried in the point source component of the inventory system as well as other sources whose emissions occur over a broad geographic area, such as architectural surface coatings or consumer solvents. Mobile sources consist of on-road motor vehicles and nonroad sources (e.g. construction equipment, trains, planes, ships, agricultural equipment, etc). Natural sources include sources such as biogenic hydrocarbon emissions from natural, urban, and agricultural biomass; windblown dust; and geogenic sources, such as natural oil seeps.

Based on previous experience, we recommend structuring the Mexico inventory program around the major source types described above. Specific recommendations for defining point and area sources will be provided in the Phase II materials developed under this study. An arbitrary emission threshold is frequently used in the U.S. This practice need not be duplicated in Mexico.

Tables 2-1 through 2-4 list the key source types for point, area, mobile, and natural sources. These tables list the source types for which we *evaluated* the various methodologies. In the context of this evaluation, the term source type represents many similar source categories (e.g., point source electric utility fuel combustion includes different types of internal and external combustion sources burning multiple fuels). We collapsed the source categories to the source types shown in Tables 2-1 through 2-4 to facilitate the methodology evaluation. For the list of natural sources, no further disaggregation is recommended.

The actual inventory program for Mexico will consist of many more specific point and area source categories than the general source types summarized here. In addition, the lists of source types presented in Tables 2-1 through 2-4 are not meant to represent an aggregation scheme that would be used for preparing emission summaries. As stated previously, the lists of source types in Tables 2-1 through 2-4 was developed for the sole purpose of facilitating the methods evaluation.

We also attempted to tailor the list of source types with present-day Mexico-specific conditions in mind, specifically looking for unique sources of emissions in Mexico that are not commonly found in the U.S. So far, four unique area source categories have been identified: tortilla manufacturing, open burning dumps, public baths, street vendors, and brick kilns. For example, there are numerous facilities throughout Mexico that produce tortillas. The emissions from this potential source category result from the combustion of fuels used in the ovens. At this time, it is not clear if a separate area source category should be created for tortilla factories or if the fuel combustion should be inventoried under the major area source types of industrial and commercial fuel combustion.

As another example, brick manufacturing appears to be a definite, unique category that should be included in the inventory as an area source category. We understand there are numerous, small brick kilns located throughout northern Mexico. Many of these units are domestic operations, making it impractical to include them in the point source inventory. Fuels used in the kilns include waste derived materials, such as trash and waste solvents.

The search for unique source types in Mexico continues. We expect that as the inventory program in Mexico develops, the list of emission source categories will be continually refined.

2.2 Evaluation Criteria

We evaluated each inventory method based on the objective of this study: to develop an inventory program that can be efficiently applied throughout Mexico while allowing for continual improvement and refinement as the program matures. With this objective in mind, the following evaluation criteria were used.

Cost Effectiveness. What is the relative inventory development cost per magnitude of pollutant inventoried? Costlier options may be more appropriate for the largest source categories (either point or area) located in the more populated geographical areas. For this criteria, we used a qualitative approach. Actually developing quantitative estimates would be highly resource intensive and of little practical utility.

Practicality. Which activity data are more readily available? Public domain, municipality-wide population and employment data may be more useful than facility-based employment data that are confidential and/or proprietary. Which industries and/or geographical areas will participate in a surveying effort? Industries that are closely affiliated with the government—such as the Mexican petroleum refining company, PEMEX—may be more accessible as survey participants. Which source types and geographical areas are best suited to extrapolation techniques? For example, extrapolating nonroad mobile source emissions from U.S. to Mexico based on a population ratio may not be appropriate because of different socioeconomic conditions between the two countries. Which emission factors should be used? Where differences in control technology exist, aggregated emission factors described in the *Rapid Source Inventory Techniques* guidance document (Economopoulos, 1993) may be preferred to U.S.-based emission factors.

Uncertainty. How much imprecision and what biases are associated with each methodology? Can the uncertainty or bias be quantified? For example, use of U.S.-based, controlled emission factors in Mexico may introduce bias into the emission estimates. If this methodology is used, the magnitude of this bias should be estimated and confidence limits for the emission estimates should be determined. Generally, more expensive methodologies have lower associated uncertainty that can be more readily quantified. For example, the uncertainty range associated with an emissions sampling device may already be established, whereas determining the uncertainty associated with the use of a material balance approach is highly subjective and qualitative in nature.

Developing uncertainty estimates requires the development of data that can be used in statistical models to quantify imprecision. These data are rarely available, especially when discussing the general uncertainty of a specific inventory methodology. Therefore, the uncertainty analysis for the methods evaluation was by nature qualitative. Our approach to evaluating the uncertainty for each method was guided by the following:

- Emission measurements often have known uncertainty limits.
- A statistically sound survey effort has an inherently low uncertainty if properly implemented.
- The uncertainty associated with the emission factors used in emission calculations can sometimes be obtained from literature and a knowledge of the source characteristics. The applicability of the emission factor to the source and the variation among sources determines the level of uncertainty in emission factors.
- The uncertainty associated with the activity data often can be determined based on an understanding of the method by which the activity data were collected. Census-and other survey-based activity data have higher associated uncertainties than activity data based on overall material production and sales or fuel consumption data.
- The uncertainty and/or bias associated with the use of extrapolation techniques is dependent upon the socioeconomic and emission differences between two or more geographical areas or source categories.

Upgrade potential. Which emission estimation methodologies can be readily refined to yield a higher resolution inventory? For example, if a surveying approach is used, select sources can be targeted for future source sampling. The survey effort can also be modified/extended to cover more source types and larger geographical areas. If proper planning is applied, this is a minor concern. In properly designed programs, inventories are constantly updated with special studies designed to generate more refined data. Reconciliation methods are readily available to allow refinement at the device, facility, or source category level.

Ultimately, the unique combination of emission source types and socioeconomic factors in a given geographical area will lead to the appropriate selection of emission estimation methodologies. In addition, the end uses of the emissions inventory must be considered in the methodology selection. For example, source sampling and/or surveying may be used originally for large combustion sources, but over time this technology would be extended to other sources.

Lastly, it should be noted that three of the evaluation criteria—cost effectiveness, practicality, and uncertainty—are not independent parameters. A method that is practical also tends to be cost effective. At the same time, highly detailed methods that can provide more precise emission estimates may not be cost effective (i.e., the cost per unit of emissions inventoried does not justify the level of precision obtained). Nonetheless, these criteria provide a framework to sufficiently distinguish between the various methods evaluated on a source type basis.

2.3 Rating System

The product of this effort is an evaluation of the inventory methods in the context of the available data in Mexico and the needs of INE. To facilitate the evaluation and communication of results, a simple rating system was developed and applied. Different rating systems could have been applied, such as a numerical scoring system. Given the subjective nature of this type of evaluation, using a numerical system would consume additional resources with little value added. Rather, we chose to apply a rating system consisting of *favorable*, *neutral*, or *unfavorable* (+/0/-) categories to convey our opinions about the applicability of the method to each source type.

The rating system described above was applied to each method/source type combination (see Appendices A through E for results). For each combination, ratings were applied independently of the considerations pertaining to the development of an inventory program for Mexico. In other words, the ratings for cost effectiveness, practicality, uncertainty, and upgrade potential reflect our opinions regarding the merits of each method relative to the other methods for that source type. For example, it may be determined that direct source sampling is the best method for estimating emissions for one point source type, and therefore given a "+" rating. For another source type, direct source sampling may only be given a "0" rating. We evaluated each method relative to the other methods identified for a given source type. Therefore, in one instance, direct source sampling may be considered highly favorable relative to the other methods; however, for another source type, direct source sampling may not be the preferred approach relative to other methods applicable to that source type.

We extended the analysis to provide a score for the method/source type combination in the context of an inventory program by considering application of the method in the near- and long-term. The methods, therefore, were evaluated in light of future updates so that INE and other agencies in Mexico can build upon this effort. We added this second analysis to recognize that the inventory program can not initially apply the most desirable method for each and every source category. Resource and time constraints will require the application of simpler methods for certain source categories in the near-term that will be refined over the long-term as the inventory program matures.

Table 2-1

Point Source Types Used for Methods Evaluation

Major Category	Subcategories	Priority[a]	Pollutant	Comments
Electric Utility	Combustion by Fuel Type	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Category consists of internal and external combustion devices used to produce electricity.
Chemical Manufacturing	Process Emissions	1	VOC and NH_3	Typically VOCs generated during the manufacture of organic chemicals. Ammonia is emitted from some chemical processes, such as fertilizer manufacturing.
	Combustion Emissions	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuels burned to supply energy to the chemical manufacturing process.
	Fugitives From Equipment Leaks	1	VOC	Subcategory includes VOC emissions from such devices as pipeline valves and flanges, and compressor seals.
	Storage Tanks	1	VOC	Floating and fixed roof storage tanks release VOC emissions from tank breathing and the filling of the tank.
	Miscellaneous Solvent Usage	3	VOC	Organic solvents are used for equipment maintenance and can be an important source of VOC emissions.
Petroleum Refining	Process Emissions	1	VOC and NH_3	Example process emissions include fluid catalytic cracking units and vacuum distillate column condensers.
	Combustion Emissions	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuels burned to supply energy to the refining process.
	Fugitives From Equipment Leaks	1	VOC	Subcategory includes VOC emissions from such devices as pipeline valves and flanges, and compressor seals.
	Storage Tanks	1	VOC	Floating and fixed roof storage tanks release VOC emissions from tank breathing and the filling of the tank.
	Miscellaneous Solvent Usage	3	VOC	Organic solvents are for used equipment maintenance and can be an important source of VOC emissions.

Table 2-1

(Continued)

Primary Metal Production	Process Emissions	1	SO_x and PM	Subcategory includes numerous operations that occur during the smelting and refining of metals such as copper, lead, iron / steel, zinc, etc. Process emissions primarily consist of crushing and grinding of raw materials followed by pyrometallurgical and casting operations to produce metal ingots.
	Combustion Emissions	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuel burned to supply energy to the smelting and refining processes.
	Fugitive Emissions	2	PM	Subcategory includes TSP emissions from such devices as storage piles and entrained dust from unpaved roads.
Secondary Metal Production	Process Emissions	2	VOC and PM	Emissions from finishing process that produce VOCs and TSP.
	Combustion Emissions	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuel burned to supply energy to secondary metal finishing processes.
Cement Production	Process Emissions	1	PM	Emission sources include material handling and crushing and grinding of both raw and finished materials.
	Combustion Emissions	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuel burned to supply energy to the kiln.
	Fugitive Emissions	2	PM	Fugitive sources include piles and entrained dust from equipment operation on unpaved surfaces.
Miscellaneous Mineral Products (e.g. lime and aggregate kilns)	Process Emissions	1	PM	Emission sources include material handling and crushing and grinding of both raw and finished materials.
	Combustion Emissions	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuel burned to supply energy to the kiln.
	Fugitive Emissions	2	PM	Fugitive sources include piles and entrained dust from equipment operation on unpaved surfaces.

Table 2-1

(Continued)

Automotive Industry	Process Emissions	1	VOC	Emission sources include surface coating and other processes that emit VOCs.
	Combustion Emissions	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuel burned to supply energy for production of automobiles and associated parts.
	Fugitive Emissions	2	VOC	A variety of solvents are used in addition to the coating material. These solvents are used for such activities as wipe cleaning and thinning of coating materials.
Wood Pulping Operations	Process Emissions	1	SO_x, VOC, and PM	Manufacture of pulp involves numerous process operations such as digesters, evaporators, and oxidation towers that produce VOC, TSP, and sulfur compounds.
	Combustion Emissions	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Large quantities of fuel are consumed in the pulping process to provide heat to process operations and to recover chemicals used in the pulping process. In addition to liquid and gaseous fuels, large quantities of wood may also be burned.
Oil and Gas Production	Process Emissions	1	VOC	This subcategory applies mostly to the processing of natural gas. Example processes include gas sweetening and stripping operations.
	Fugitive Emissions	1	VOC	Subcategory includes VOC emissions from such devices as well heads and sumps/pits. It also includes pipeline valves and flanges and compressor seals.
	Combustion Emissions	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Liquid and gaseous fuels are burned to supply energy to the oil and gas process.
	Storage Tanks	1	VOC	Typically fixed roof storage tanks are used to store crude oil in the field. Releases of VOC emissions from the tank are a result of tank breathing and filling.

Table 2-1

(Continued)

Printing and Publishing	Process Emissions	1	VOC	Operations used in the printing industry (letter press, flexographic, lithographic, and gravure) produce VOC emissions.
	Fugitive Emissions	2	VOC	In addition to the printing operations, miscellaneous solvents are also used in the printing industry for thinning of inks and cleaning of equipment.
Surface Coating	Process Emissions	1	VOC	Application of coating materials results in significant VOC emissions.
	Degreasing Emissions	1	VOC	Degreasers are frequently used at facilities involved in coating operations. Solvent evaporation from the degreaser results in VOC emissions.
	Fugitive Emissions	1	VOC	A variety of solvents are used in addition to the coating material. These solvents are used for such activities as wipe cleaning and thinning of coating materials.
Bulk Fuel Terminals	Loading Operations	1	VOC	Loading and unloading of fuels into marine vessels, rail cars, and trucks results in VOC emissions. Also includes VOC emissions generated by spills.
	Storage Tanks	1	VOC	Floating and fixed roof storage tanks used at bulk terminals release VOC emissions from tank breathing and the filling of the tank.
Mining and Quarrying	Process Emissions	1	PM	There are many different mining operations that emit TSP, such as drilling/blasting, loading, and hauling.
	Fugitive Emissions	2	PM	Fugitive sources include piles and entrained dust from equipment operation on unpaved surfaces.
Wood Products Manufacture	Process Emissions	2	VOC and PM	The manufacture of finished lumber and plywood, etc. involves several processes such as pressure treating, drying, and sawing. VOCs generated in finishing process.
	Combustion Emissions	2	CO, NO_x, SO_x, VOC, PM, and NH_3	Various fuels, including wood, are used to provide the energy needed during the manufacturing process.

Table 2-1

(Continued)

Sugar Production	Process Emissions	2	PM	Processing of sugar results in some TSP emissions.
	Combustion Emissions	2	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuel burned to supply energy for sugar processing.
	Fugitive Emissions	2	PM	Possible fugitive VOC and TSP emissions from degreasing, maintenance or cleaning activities.
Tanning and Leather Finishing	Process Emissions	2	VOC	Substantial VOC emissions result from the tanning and finishing processes.
	Combustion Emissions	2	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuel burned to supply energy for tanning and finishing processes.
	Fugitive Emissions	2	VOC	Possible fugitive VOC emissions from processing activities.
Glass Production	Process Emissions	2	VOC and PM	Some TSP emission from the various glass manufacturing processes.
	Combustion Emissions	2	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuel burned to supply energy for glass manufacturing processes.
	Fugitive Emissions	2	VOC and PM	Possible fugitive VOC and TSP emissions from manufacturing processes.
Rubber and Plastic Parts	Process Emissions	2	VOC	Category includes such devices as tire manufacturing, fabricated plastic products, fiberglass resin products, and plastic foam products. These manufacturing operations use a variety of processes that mostly emit VOC.
	Combustion Emissions	2	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuel burned to supply energy to rubber and plastic fabrication processes.

Table 2-1

(Continued)

Fabricated Metal Products	Process Emissions	2	PM	Manufacture of fabricated metal products use process operations such as electroplating, conversion coating, abrasive blasting, and metal deposition. VOCs generated in the finishing process.
	Combustion Emissions	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Various fuels are burned in process heaters.
Textile Products	Process Emissions	2	VOC	Various chemicals/solvents are used in the production of textiles that may result in VOC emissions.
	Combustion Emissions	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuel burned to supply energy to textile manufacturing process.
Solid Waste Disposal	Landfill Gas Emissions	3	VOC	Solvents placed in landfills and biological decomposition of materials in landfills results in VOC emissions.
	Municipal Waste Combustors	1	CO, NO_x, SO_x, VOC, and PM	Combustion of municipal waste in incinerators at waste management facilities releases combustion pollutants and air toxics.
	Open Burning Dump	2	CO, NO_x, SO_x, VOC, and PM	Combustion pollutants are emitted during this process.
Miscellaneous Industrial Activities/Processes	Process Emissions	2	CO, NO_x, SO_x, VOC, and PM	There will be a number of industrial activities that don't fit into a traditional source category, such as semiconductor manufacturing. These facilities have process emissions that should be included in a point source inventory.
	Combustion Emissions	2	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuels maybe burned to support process operations. Fuels are also used frequently for space heating.
	Fugitive Emissions	2	VOC	Many miscellaneous facilities use solvents for such things as degreasing and wipe cleaning.

Table 2-1

(Continued)

Government Facilities	Combustion Emissions	2	CO, NO_x, SO_x, VOC, PM, and NH_3	Research and development, military, and other institutional facilities often burn fuels for space heating, or to a lesser extent, for process operations.
	Fugitive Emissions	2	VOC	Many facilities use solvents for such activities as degreasing and wipe cleaning. This can be a large source of VOC emissions.
Food and Agriculture	Process Emissions	3	VOC and PM	Category includes numerous food and agriculture related processes that generate primarily TSP and VOC. Examples include: alfalfa dehydration, coffee roasting, grain elevators, beer production, vegetable oil processing, etc.
	Combustion Emissions	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuels burned to supply energy to processing of agricultural products.
Asphalt Plants	Process Emissions	3	PM	Emission sources in this category include such groups as screens, bins, and mixers; heaters; and dryers.
	Combustion Emissions	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuel burned to supply energy to the asphalt plant.

[a] A priority has been assigned to communicate the current, perceived importance of each source type. The priorities assigned to each source type will be refined over time as feedback is obtained from INE and more Mexico-specific information is gathered.

Table 2-2

Stationary Area Source Types Used for Methods Evaluation

Major Category	Subcategory	Priority[a]	Pollutant	Comments
Stationary Source Fuel Combustion - Industrial and Commercial	By fuel type	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Subcategories include fuels such as coal, combustoleo, natural gas, and waste-derived fuels. This will be an important category initially, until many of the smaller sources are incorporated into the point source inventory.
Stationary Source Fuel Combustion - Residential Commercial Fuels	Commercial fuels by fuel type	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Subcategories include fuels such as coal, combustoleo, natural gas, etc.
Stationary Source Fuel Combustion - Residential Biomass or Waste-Derived Fuels	Biomass or waste-derived fuels by fuel type	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Subcategories include fuels such as wood, waste oil, tires, etc.
Paved Road Dust	N/A	1	PM	An important source of particulate matter.
Unpaved Road Dust	N/A	1	PM	An important source of particulate matter.
Surface Coatings and Clean-up Solvents - Industrial	By industrial sector	1	VOC	Subcategories include textile products, machinery & equipment, etc. This will be an important category initially until many of the smaller sources are incorporated into the point source inventory.
Industrial Surface Cleaning (Degreasing)	By industrial sector	1	VOC	Subcategories include fabricated metal products, industrial machinery & equipment, auto repair services, etc. This will be an important category initially until many of the smaller sources

Table 2-2

(Continued)

Major Category	Subcategory	Priority[a]	Pollutant	Comments
				are incorporated into the point source inventory.
Dry Cleaning	By solvent type	1	VOC	Subcategories include perchloroethylene, special naphthas, and other solvents.
Consumer Solvents	By product type	1	VOC	Subcategories include personal care products, household products, pesticides, etc.
Storage and Transport (Storage Tanks, Loading/Unloading Operations, and Fugitive Component Leaks from Pipelines, Bulk Terminals, Service Stations, and Transport Vessels/Trucks)	By product type	1	VOC	Subcategories include petroleum products (crude oil, gasoline, diesel, etc.) and may also include organic, inorganic, and bulk materials.
Agriculture Production	Livestock	1	PM and NH_3	Feedlots are a major source of NH_3 and a source of particulate matter.
Waste Management - On-Site Incineration	N/A	1	CO, NO_x, SO_x, VOC, and PM	Includes incineration of all industrial waste types.
Waste Disposal - Refuse Burning	N/A	1	CO, NO_x, SO_x, VOC, and PM	Includes agricultural and other types of open burning.
Fires	Wildfires	1	CO, NO_x, SO_x, VOC, and PM	May be a significant source of particulate matter.
	Prescribed burning	1	CO, NO_x, SO_x, VOC, and PM	May be a significant source of particulate matter.
Public Baths	N/A	1	CO, NO_x, SO_x, VOC, and PM	Magnitude of emissions is uncertain.
Industrial Processes	By industrial sector	2	CO, NO_x, SO_x, VOC, and PM	Subcategories include chemical manufacturing, rubber/plastics, food and kindred products (tortilla factories), brick manufacturing, etc. This could be an important category

Table 2-2

(Continued)

Major Category	Subcategory	Priority[a]	Pollutant	Comments
				initially, until many of the smaller sources are incorporated into the point source inventory.
Surface Coatings and Clean-up Solvents - Architectural Coatings	N/A	2	VOC	Architectural coatings are thought to be a significant source of VOC emissions in urban areas of Mexico.
Surface Coatings and Clean-up Solvents - Auto Refinishing	N/A	2	VOC	Auto refinishing is thought to be a significant source of VOC emissions in urban areas of Mexico.
Graphic Arts	N/A	2	VOC	Minor VOC source.
Asphalt Application	N/A	2	VOC	Includes application of various types of asphalt materials.
Agriculture Production	Pesticide Application	2	VOC	May be an important VOC source.
	Fertilizer Application	2	NH_3	May be an important NH_3 source.
	Crops	2	PM	May be an important PM source.
Waste Management - Wastewater Treatment	N/A	2	VOC and NH_3	Minor source of VOC, but a significant source of NH_3.
Open Sewage	N/A	2	VOC and NH_3	Most likely a minor source of VOC. Possibly a significant source of NH_3.
Street Vending/Cooking	N/A	2	CO, NO_x, SO_x, VOC, and PM	Magnitude of emissions is uncertain.
Domestic Ammonia Emissions	N/A	2	NH_3	Includes domesticated dogs and cats, human respiration, human perspiration, household ammonia use, cigarette smoke, and untreated human waste.
Fires	Structures	2	CO, NO_x, SO_x, VOC, and PM	Minor source of particulate matter.
Building Construction	N/A	3	PM	Building construction and demolition produce fugitive TSP emissions through processes such as site preparation and

Table 2-2

(Continued)

Major Category	Subcategory	Priority[a]	Pollutant	Comments
				mechanical/explosive dismemberment.
Surface Coatings and Clean-up Solvents - Traffic Markings	N/A	3	VOC	Traffic markings are thought to be a minor source of VOC emissions in Mexico.
Rubber and Plastics Fabrication	N/A	3	VOC	Minor source of VOC.
Waste Management - Landfills	N/A	3	VOC	Minor source of VOC.
Bakeries	N/A	3	VOC	Minor source of VOC.

[a] A priority has been assigned to communicate the current, perceived importance of each source type. The priorities assigned to each source type will be refined over time as feedback is obtained from INE and more Mexico-specific information is gathered.

Table 2-3

Mobile Source Categorization Used for Methods Evaluation

Category	Priority[a]	Pollutant	Comments
On-Road Motor Vehicles	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Category includes light-duty gas vehicles, light-duty diesel vehicles, light-duty gas trucks, light-duty diesel trucks, heavy-duty gas vehicles, heavy-duty diesel vehicles, and motorcycles.
Aircraft	2	CO, NO_x, SO_x, VOC, PM, and NH_3	Category includes commercial, military, and private aircraft.
Railroads	2	CO, NO_x, SO_x, VOC, PM, and NH_3	Category consists of diesel locomotives used only in switching and line haul application. Electric locomotives use electricity generated at stationary power plants (point sources), so these are not included as a nonroad source.
Commercial Marine Vessels	2	CO, NO_x, SO_x, VOC, PM, and NH_3	Commercial marine vessels include fishing vessels, harbor vessels, cruise ships, ferries, commercial ships, etc.
Agricultural Equipment	2	CO, NO_x, SO_x, VOC, PM, and NH_3	Agricultural equipment category includes tractors, combines, sprayers, harvesters, agricultural hydropower equipment, etc.
Construction Equipment	2	CO, NO_x, SO_x, VOC, PM, and NH_3	Category consists of pavers, rollers, excavators, cement mixers, cranes, off-highway trucks, bulldozers, backhoes, etc.
Industrial Equipment	2	CO, NO_x, SO_x, VOC, PM, and NH_3	Industrial equipment category consists of aerial lifts, forklifts, sweepers, abrasive blasters, industrial scrubbers/blowers/vacuums, airport service equipment, etc.
Light Commercial Equipment	2	CO, NO_x, SO_x, VOC, PM, and NH_3	Category includes generators, pumps, compressors, welders, etc.
Lawn & Garden Equipment	3	CO, NO_x, SO_x, VOC, PM, and NH_3	Category consists of lawnmowers, tillers, chainsaws, chippers, etc.
Recreational	3	CO, NO_x, SO_x,	Recreational equipment category includes all-terrain vehicles, off-road

Table 2-3

(Continued)

Equipment		VOC, PM, and NH_3	motorcycles, golf carts, etc.
Recreational Boats	3	CO, NO_x, SO_x, VOC, PM, and NH_3	Category includes inboard motors and outboard motors on recreational motorboats. This category also includes auxiliary motors on sailboats.

Table 2-4

Natural Source Categorization Used for Methods Evaluation

Major Category	Priority[a]	Pollutant	Comments
Biogenic VOC	1	VOC	Category includes isoprene, terpene, and other VOC emissions from natural, agricultural, and urban vegetative biomass.
Windblown Dust	1	PM	Wind erosion of crustal material can be a significant source of particulate matter. Although emissions originate primarily from disturbed lands (e.g., agricultural areas), emissions can also occur from undisturbed lands.
Soil NO_x	2	NO_x	Microbial nitrification and denitrification cycles in soil under certain conditions can result in significant releases of NO_x. NO is the principle nitrogen species emitted by soils (overall under certain conditions NO_2 comprises less than 10% of soil NO_x emissions).
Soil NH_3	2	NH_3	Through the natural ammonification cycle, soil surfaces can emit important amounts of NH_3.
Lightning	3	NO_x	Several studies have shown lightning to be a source of NO_x. On a regional basis, emissions are typically low compared to anthropogenic emissions.
Geogenic	3	SO_x, VOC, and PM	There are a number of geogenic sources that can be important sources of air emissions under certain conditions. Examples include volcanoes and natural oil and gas seeps that can emit sulfur, particulate matter and VOCs.

[a] A priority has been assigned to communicate the current, perceived importance of each source type. The priorities assigned to each source type will be refined over time as feedback is obtained from INE and more Mexico-specific information is gathered.

3.0 POINT AND AREA SOURCE INVENTORY METHODOLOGIES

This section summarizes inventory development methods for point and area sources and discusses their applicability to Mexico. Point and area (including nonroad mobile) inventory methods are discussed in Section 3.1. Detailed evaluation of the methods for each source type can be found in Appendices A through C.

3.1 Point and Area Source Methods Discussion

The following point and area source methods are discussed in this section:

- Source sampling (direct and indirect);
- Modeling;
- Surveying;
- Use of census-based emission factors and activity data;
- Material balance (raw materials, fuel consumption); and
- Extrapolation.

3.1.1 Source Sampling

This methodology is the most accurate and expensive option. It should only be considered for the most critical and undercharacterized (e.g., Mexico sources for which current emission factors have limited applicability) emission sources. Source sampling can be *direct* or *indirect* (Mobley and Saeger, 1993). These two approaches are discussed below.

Direct Source Sampling. This technique often refers to the use of in-stack sampling equipment. Direct sampling methods have been developed to measure stack gas concentrations for numerous pollutants, including speciated hydrocarbons. The resulting concentration data are then used to calculate emission estimates. Several of the methods require collecting samples that are sent to a laboratory for analysis. Real time data can be obtained through the use of a continuous emissions monitoring (CEM) device to measure stack emissions.

CEMs also measure other important stack parameters, such as flue gas flow rate and temperature. Direct source sampling is already effectively used in Mexico for compliance evaluation and recently to support the development of point source emission estimates. Continued development and use of direct source sampling equipment is highly recommended.

Indirect Source Sampling. This term refers to the use of a remote measurement technique, such as FTIR spectroscopy to measure gas concentrations in the open air (see Figure 3-1). This method is especially useful for characterizing emissions from numerous and dispersed sources like fugitive emissions from chemical plants or refineries (Mobley and Saeger, 1993; Spellicy et al., 1991).

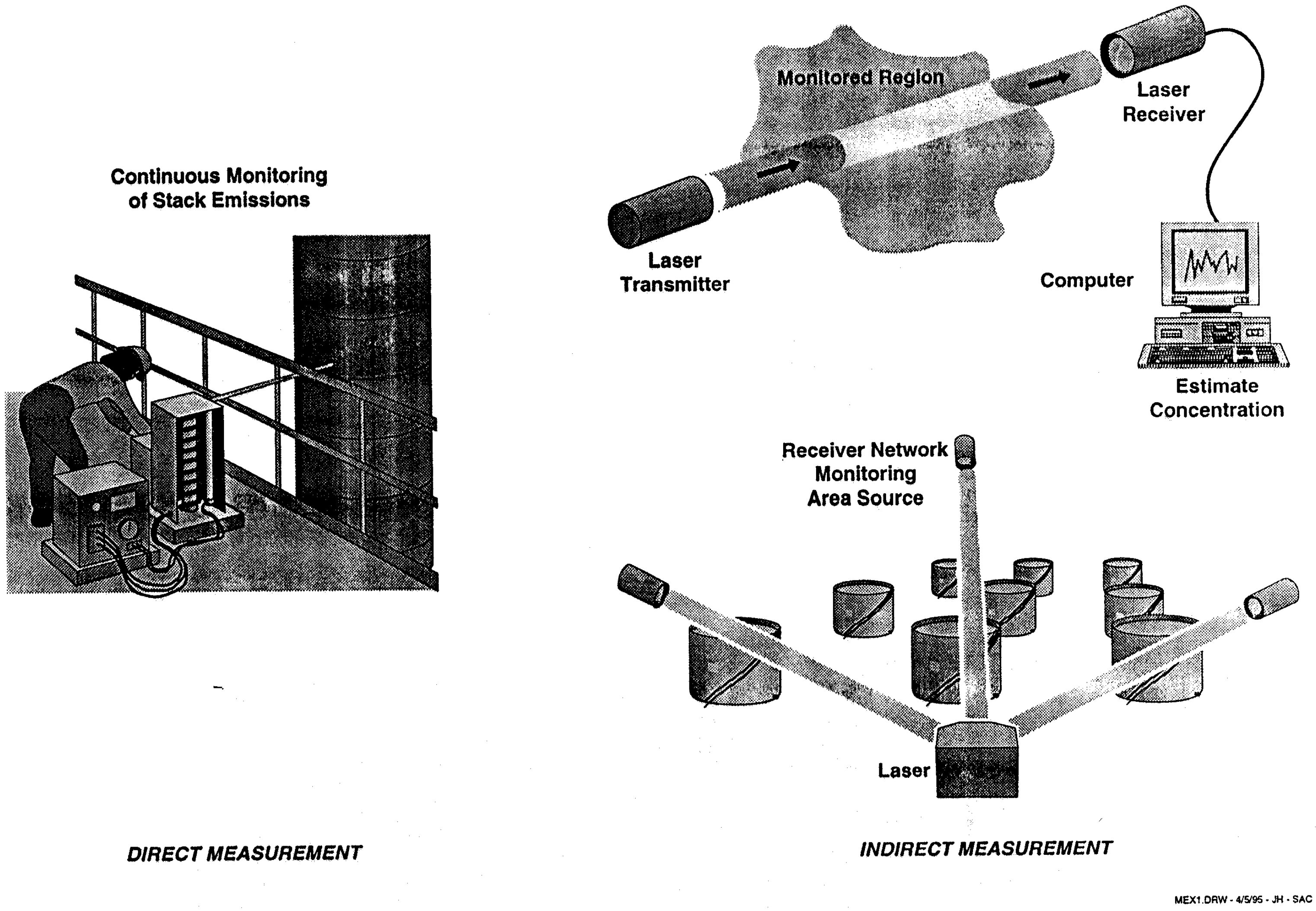

Figure 3-1. Comparison of Direct versus Indirect Emissions Measurement

Since Mexico is in its early stages of developing an inventory program, there is an opportunity to establish methods and procedures that are based on advanced technology without the need to apply current technology that may soon be out dated. Special consideration was given to indirect sampling as a means of creatively and more cost effectively developing emission estimates. Our findings are presented below.

Remote sensing is typically used in one the following ways:

- Development of emission fluxes from volume sources such as waste impoundments, landfills, or open burning dumps;
- Early warning systems for accidental releases of extremely hazardous substances;
- Fence line monitoring of air toxics; and
- Application as an extractive sampling device in a traditional stack sampling approach (i.e., a cart-mounted unit is used to measure gas concentrations extracted from a stack using standard stack sampling equipment).

We also considered the use of remote sensing as a potential emissions verification tool for a defined geographic region. This application has not yet been demonstrated.

Advantages of an FTIR system include: the ability to more easily monitor many constituents (e.g., air toxics) simultaneously on a real time basis, the ability to monitor acid gases, and low application costs relative to direct sampling. Disadvantages include: detection limit problems resulting from carbon dioxide and water, an inability to measure particulate, an inability to identify contributing sources, and a relatively high capital equipment cost (~ $180,000 per unit). Application of FTIR technology has been most successful when applied as a continuous monitoring device for accidental releases of extremely hazardous chemicals and monitoring of species for which the U.S. EPA has not developed a specific monitoring method (e.g., acid gases emitted from semiconductor facilities).

All of the technologies being applied to open-air atmospheric monitoring today are well established and have been in use in the scientific community for years. What is new, however, is their application to nonlaboratory environments. The U.S. 1990 Clean Air Act Amendments have provided greater impetus to apply this technology to atmospheric monitoring (Spellicy, 1991; Spellicy, 1993). The Europeans are also applying remote sensing technology; their applications are also for fence line monitoring for both routine and non-routine releases of emissions.

Use of light detection and ranging (LIDAR) remote sensing technology has been proposed for Ciudad Juárez by Los Alamos National Laboratory (Streit, 1995). This technology would be used to develop the wind fields needed for an air quality grid model and to identify areas of elevated particulate matter. This technology senses aerosols and can only determine relative differences between one region and another. For Ciudad Juárez, LIDAR was going to be used to identify areas with unpaved roads. Cost for the application of LIDAR in Juárez for this study was estimated at $3 million. This proposal was not considered to be cost effective.

Indirect sampling techniques are most applicable to volume sources where emissions are not emitted from defined stacks, such as waste impoundments. In these instances, indirect measurements can be combined with dispersion models to develop emission fluxes. Therefore, we see this technology as a possible means of refining and/or developing new emission factors for volume sources such as open burning, mobile sources, soil NO_x, and biogenic hydrocarbons. In these applications, indirect sampling would not be used to develop emission estimates; rather, it would be used to develop refined emission factors and emission estimating models specific to Mexico.

Another possible use of indirect sampling techniques may be in the area of verification and evaluation of regional emission estimates. By combining indirect sampling measurements with data analysis techniques, an emissions verification tool could possibly be developed. This would include the magnitude, temporal, and spatial characteristics of emission sources within a geographic region. Discussing this application with remote sensing experts suggests that this technology may be more applicable to examining the temporal and spatial characteristics of emission estimates rather than verifying the magnitude of emission estimates developed with traditional means. At this time, using remote sensing to verify emissions of a geographic region may only provide order of magnitude estimates, thus reducing its effectiveness in this application.

In summary, remote sensing can be used to develop better emission estimating tools for important volume sources. Discussions are under way at the U.S. Environmental Protection Agency (EPA) to use this technology as a technique to better characterize GHG emissions from open burning dumps and open sewage lines. For criteria pollutant emissions from defined stacks, standard source sampling is a practical choice for Mexico. Direct sampling equipment has a much lower capital cost and requires much less expertise to operate. Utilization of remote sensing equipment in Mexico may be limited to universities and properly trained staff at INE. Nonetheless, wide spread use of remote sensing would result in lower application costs and provide for more efficient collection of emissions data.

3.1.2 Emissions Models

Most emission estimates are developed assuming a linear relationship (i.e., an "emission factor") between the emission rate and a unit of activity (e.g., quantity of fuel consumed, population, employment, production rates, etc.). Although infrequently used, a more complex modeling approach is also applicable to many source types. This section describes the development and application of mechanistic, adaptive, and multivariate models that can be used to develop emission estimates.

Mechanistic Models. Under this modeling framework, "first principles" are used to develop algorithms that use the laws of chemistry and physics to describe the emission rate for a particular source category. Given the large number of source categories that are inventoried, this approach has only received modest use. The current U.S. EPA emission estimating algorithm for fixed roof storage tanks is the best example of this type of approach (see Figure 3-2). The fixed roof storage tank model applies heat transfer and other principles to model VOC emissions from the storage of organic liquids. A mechanistic approach has also been taken to describe the increased emissions that occur during hard accelerations of on-road motor vehicles (i.e., power enrichment).

Organic Storage Tank Breathing Losses

VOC emitted from vapor expansion and contraction due to changes in temperature and pressure.

Emissions $= f(V_V, W_V, \Delta P_V, P_{VA}, P_A, \Delta T_V, T_{LA})$

Where: V_V = vapor space volume of tank

W_V = vapor density of stored liquid

ΔP_V = daily vapor range of stored liquid

P_{VA} = vapor pressure at daily average liquid surface temperature

P_A = atmospheric pressure

ΔT_V = daily vapor temperature range of stored liquid

T_{LA} = daily average liquid surface temperature

Figure 3-2. Example of Mechanistic Modeling

A mechanistic model can potentially provide a more precise estimate if it is sufficiently robust. For Mexico, developing additional mechanistic models on a source category basis is impractical. Over time, additional models of this type will be developed. We recommend that Mexico apply these models as they become available, taking advantage of inventory research conducted elsewhere.

Adaptive Models. This is a relatively new technology that has received increased attention since the passage of the U.S. Clean Air Act Amendments and the requirement for continuous emissions monitoring of stack emissions at certain sources. Several companies have developed software systems that can be used to replace costly CEMs. These software systems are sometimes referred to as soft CEMs.

Soft CEMs rely on adaptive modeling software that integrate neural network, fuzzy logic, and chaotic systems into one software package (Collins and Terhune, 1994). During the setup stage, the software is trained with historic operating and emissions data (see Figure 3-3). Operating parameters are then monitored and used by the software system to predict emissions at a cost less than the application of a true CEM. Accuracy of the soft CEM is equivalent to a true CEM when properly trained.

Adaptive models are now being used or considered as emissions estimating techniques for both mobile and area sources. Radian staff have used adaptive modeling to model

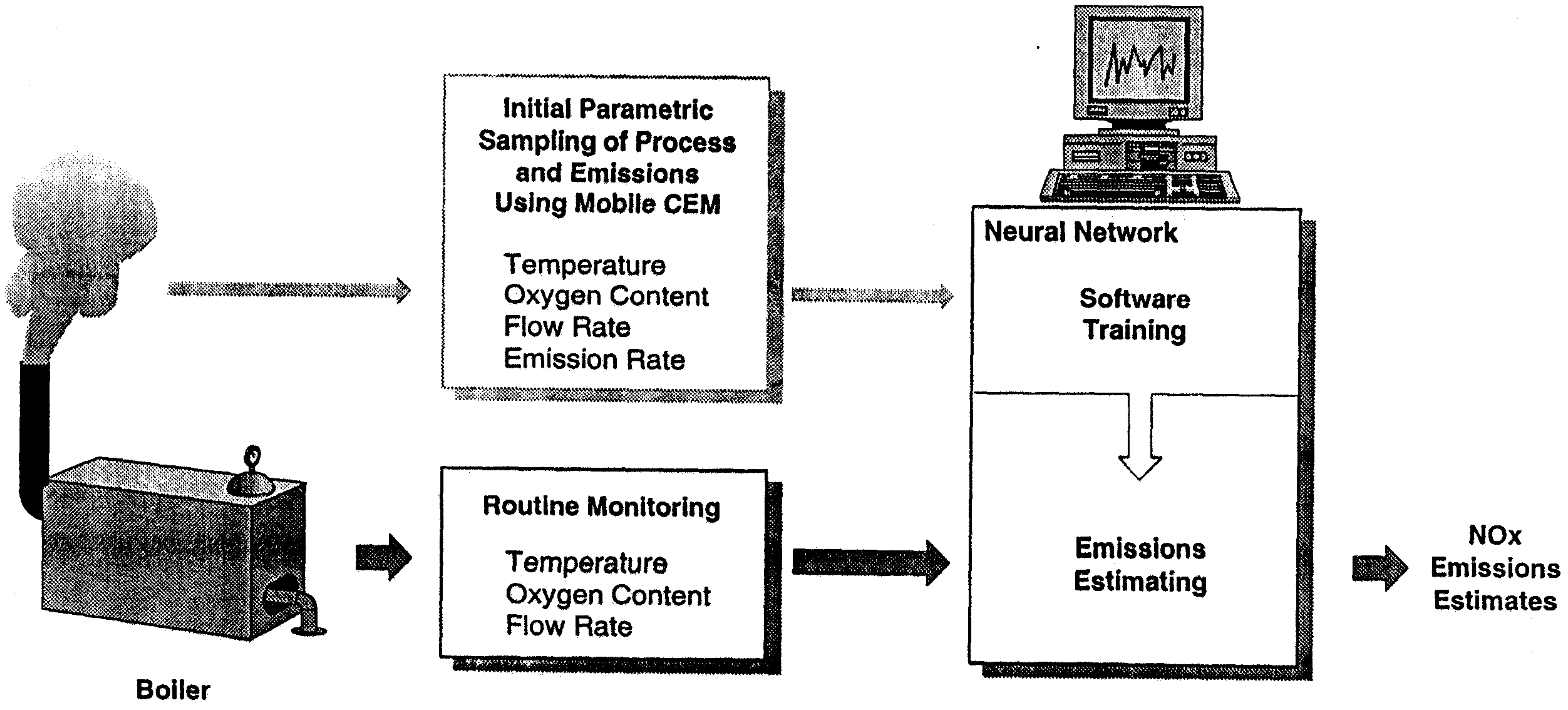

Figure 3-3. Example of Adaptive Model

oxygen levels for a fleet of cars by using just one car. In another effort, Waters et al. (1994) report that a fuzzy logic model is being developed to better estimate emissions from automobile refinishing. According to Waters et al., fuzzy logic is an approximate reasoning technique used in processing inexact information:

> "For example, if climate is a factor in an area's emission levels, then it could be classified as *dry, moderate, or rainy*. The type of area might also be loosely classified into three fuzzy sets *rural, suburban, and urban*. A typical fuzzy rule, based on expert opinion, may be expressed as "If the climate is *dry* AND the area is *rural* THEN emissions are *low*." Another rule may state "If the climate is *wet* AND the area is *urban* then emissions are *high*." These rules describe the increased likelihood of accidents and auto refinishing in a congested area with poor weather and vice versa. The fuzzy system uses the degree of membership of an input in a given set to determine to what degree the output belongs in any set (e.g., *low, medium, high*). This type of reasoning can augment the emissions prediction based on optimally correlated data."

This type of approach may be applicable for several area source categories in Mexico, especially where there are strong geographic differences in emissions magnitude for a particular source type. For example, dry cleaning emissions in urban Mexico City are expected to be different on a per capita basis compared to many rural areas in the country. At this time, we have not identified any specific regional emissions inventory applications of adaptive software that relies on neural network technology. It should also be noted that the purchase cost of adaptive software can be quite expensive, approaching $100,000.

Multivariate Emissions Models. This is a new term developed specifically for this project. In this approach, emission estimates are expressed in terms of a set of variables that help characterize a system. In some ways, this new approach can be thought of as a combination of traditional inventory approaches combined in an extrapolation framework. Therefore, this approach differs significantly from adaptive modeling software that uses complex mathematical concepts. A few examples are provided below.

At the outset of this study, several members of the Binational Advisory Committee expressed interest in using satellite imagery as a way of creatively estimating emissions.

Traditional use of this technology for emissions inventory development has been primarily limited to the development of biogenic emission estimates. Land use/land cover (LULC) data are used to support the estimate of the quantity and location of biomass needed in biogenic hydrocarbon emission calculations. We also explored the possibility of using this technology to identify other emission sources from satellite imagery, such as the occurrence of wild and prescribed fires as well as other geographic related area source categories such as unpaved road dust. As a potential example of the application of this technology, spatial interpretation studies could be undertaken to identify burned areas. The cost to acquire and process Landsat Thematic Mapper data is approximately $1.3 million. Therefore, the cost effectiveness of using these data in such a limited approach is not very practical. For other sources, such as unpaved roads, it may not be possible to identify this LULC type satellite imagery given the spatial resolution of the data (~ 30 meter pixels).

To improve cost effectiveness of satellite imagery as an emissions estimating tool, these data could be expanded into a modeling framework, where the LULC data are used not only to estimate biogenic but also anthropogenic emissions using a predictive model with the LULC data as the basis (Van Curren, 1995). For example, non-point emissions in a region are a function of the standard of living, population density, climate, and social practices. Using micro-inventory techniques combined with socioeconomic information, predictive models could be developed using LULC data as the basis. In essence, an emissions flux would be developed that relies on LULC data as the basis for the emission estimate. This approach could be used to account for many different area and mobile source categories in a quick and efficient modeling framework that could be updated and refined over time. This approach is most applicable for regions that have insufficient records and statistics to apply traditional inventory techniques. The concept of fuzzy logic could also be incorporated into this approach to augment the emission estimating technique. This may be especially important for Mexico were important emission differences are expected across geographic regions.

As a second example, multivariate models could be developed for individual area source categories, such as solvent use and agricultural equipment. Regardless of location, it is difficult to obtain the data needed to estimate emissions for these two area source categories. Stratified random surveys could be used to collect the needed data to develop the model. In this approach, a survey program would be designed to sample a subset of the source population with the results statistically extrapolated to the remaining population. Such an approach has been attempted for Southern California (Wyane, et al., 1989) and is currently being developed for the state of California (Roe and Jones, 1994). This concept has also been used to estimate agricultural equipment emissions in California's San Joaquin Valley where equipment use (and hence emissions) are considered to be a function of crop type and acreage. Figure 3-4 illustrates this concept for agricultural equipment.

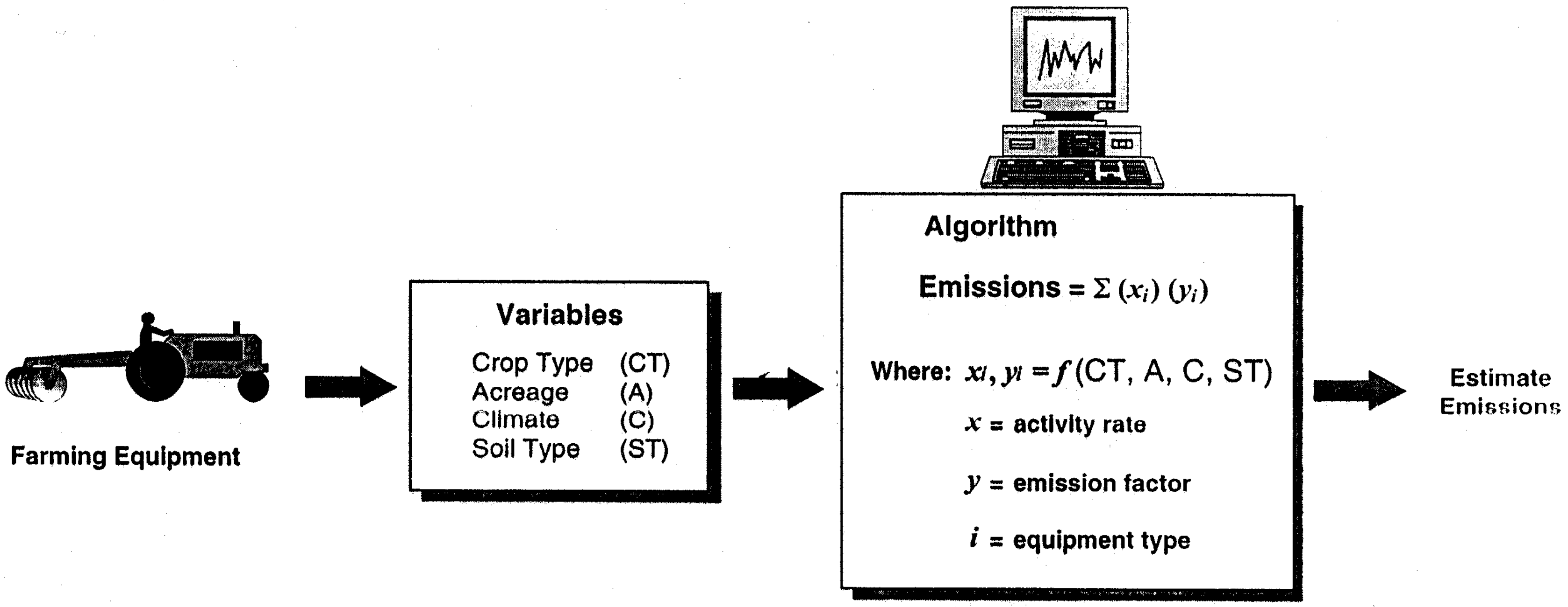

Figure 3-4. Example of Multivariate Emissions Model

Multivariate models may be also applicable to point sources. Consider petroleum refinery VOC fugitive emissions from leaking valves, flanges, and compressors. In the U.S., highly detailed and sophisticated emission techniques have been developed that require detailed component counts and, in some cases source screening data. Initially obtaining this level of detail in Mexico may be difficult. Therefore, a model could be developed to estimate emissions based on certain parameters that are easily obtained for each refinery. For example, refinery fugitive component emissions could be considered to be a function of the material throughput, age, product mix, and the use of an inspection/maintenance program at the refinery.

From the above examples, it can be seen that the use of multivariate models will have higher initial costs than other methods because of the model development step. However, ease of application and reduced future inventory maintenance costs make this a very attractive approach. Another key advantage is that the models would be developed for Mexico, and therefore, Mexico-specific emissions would be estimated. We believe that multivariate models could simplify the emission inventory development process in Mexico, and we have integrated this concept into the methodology proposal for those sources where this approach makes the most sense.

3.1.3 Surveying

A surveying methodology can be used to collect activity data to characterize emissions from certain source types (e.g., electrical utilities, commercial solvent usage, etc.) or in certain regions (e.g., highly industrialized areas). Surveying is applicable to both point and dispersed area sources. A successful survey effort obtains activity data (e.g., fuel consumption or material throughput) to combine with emission factors for calculating emissions and verifying emissions calculated (or measured) based upon the use of a different method. Figure 3-5 illustrates this concept.

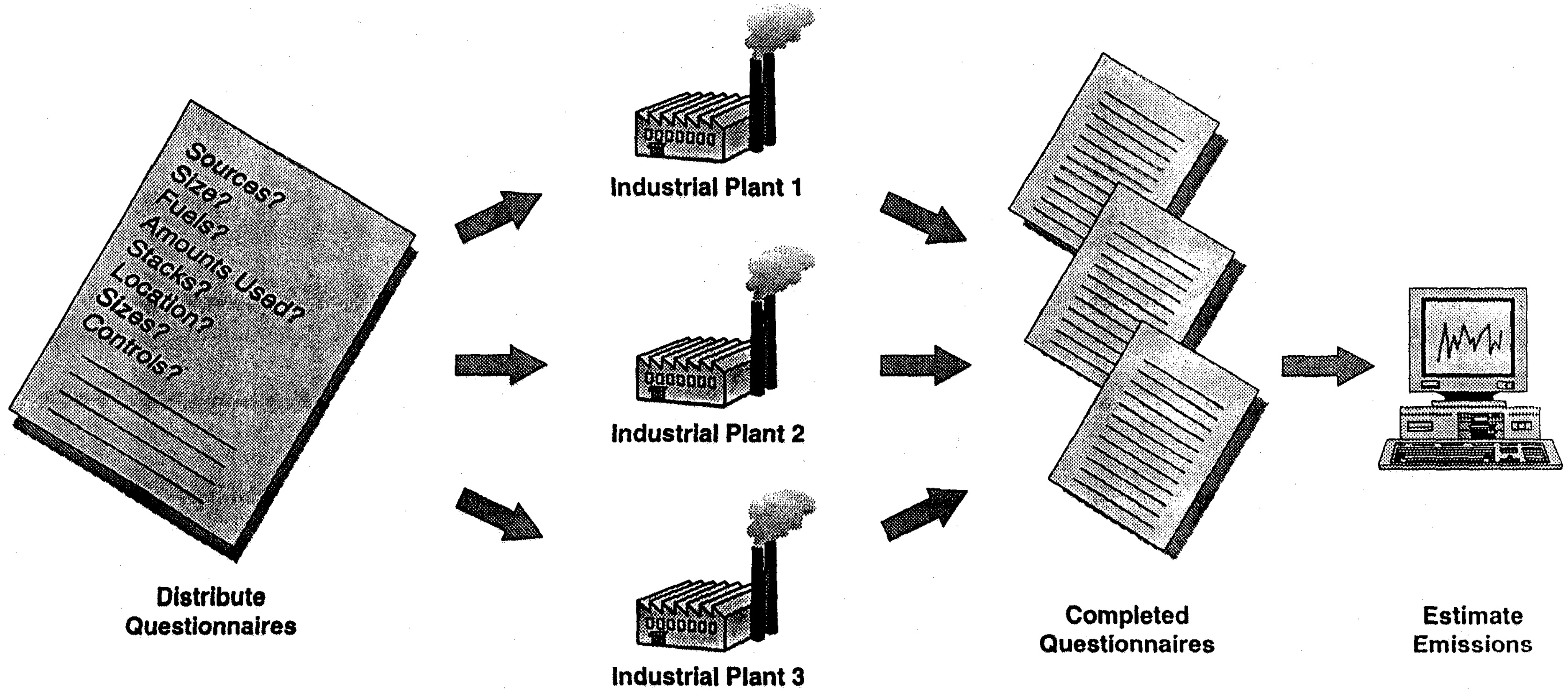

Figure 3-5. Example of Surveying

Much thought and planning must be dedicated to the design of a new questionnaire or modification of an existing one. The success rate of a surveying effort is largely dependent on whether the survey is backed by regulatory agency support and also on the conciseness, ease of use, and generality of the survey questionnaire. In addition, the questionnaire responses must be subjected to thorough quality assurance (QA) and quality control (QC) reviews to eliminate "bad" data (e.g., supersonic stack exit gas velocities). The cost of a surveying effort is a function of the completeness and specificity of the questionnaire, the extent of the target audience, and the thoroughness of the QA/QC and follow-on activities.

Survey methods for point sources are already being used in Mexico. Staff at INE use questionnaires to gather information for their national point source inventory. Questionnaires are also being used in Monterrey and Mexico City to gather point source data. Continued use of surveys is envisioned in the Mexico Inventory Program.

3.1.4 Census-Based Emission Factors and Activity Data

The emissions from area sources can be estimated using a variety of available data (e.g., survey data discussed in the previous section). This often involves the application of an emission factor representing the quantity of pollutant released as a result of some activity. U.S.-specific per capita emission factors for various activities are available from several sources including the U.S. EPA's FIRE emission factor data base, *AP-42 Compilation of Air Pollutant Emission Factors* and its Supplements F and G, the SIP guidance document, and AIRS/AMS *Short List of AMS SCCs and Emission Factors*. Non-U.S.-specific emission factors for various source aggregates are available from the *Rapid Source Inventory Techniques* guidance document developed for the WHO (Economopoulos, 1993) and various GHG inventory guidance documents (see e.g., IPCC, 1993a and b).

In the universe of emission factors and activity data, arguably the most "user-friendly" choices are those that are based on census data. Example census data include population, housing, and number of employees. Examples of source types that have census-based emission factors are dry cleaning, surface cleaning, and solvent use. In Mexico, population and housing data, and employment data by economic sector and municipality are available in printed and electronic format from the Instituto Nacional de Estadística, Geografía e Informática

(INEGI). Facility-specific, manufacturing employment data (by economic sector) are also available in electronic format from Cámara de la Industria de la Transformación (CAINTRA). The latter database is proprietary and available at a cost of $1,300. The use of census-based emission factors is especially attractive for dispersed and numerous emission source types that cannot be readily characterized by a knowledge of process rates, fuel consumption rates, and/or material feed rates. Care must be taken, however, to account for socioeconomic and control differences when transferring census-based emission factors from one country to another. For example, there is a census-based emission factor for consumer solvents (2.86 kilograms/year/person). For the Mexico City area source inventory, Department of the Federal District (DDF) has adjusted this emission factor down to 2.49 kilograms/year/person.

For many area source categories, the application of census-based emission factors is an appropriate method for estimating emissions in Mexico. As stated above, care must be taken to make sure that these factors are representative of Mexican conditions. Many of the existing factors may not represent conditions in Mexico. The census-based factors developed for the WHO could possibly be more applicable, but their derivation is not clearly documented. The *Rapid Source Inventory Techniques* guidance document is simply a tabular listing of emission factors with no supporting documentation. Although not census-based, Table 3-1 illustrates the presentation of the WHO emission factors for petroleum refining. It's possible that the census-based emission factors used in GHG inventories may be more applicable to Mexico than U.S. factors. Consequently, more evaluation is needed to determine which factors are most appropriate for Mexico.

3.1.5 Material Balance

In some instances, a material balance approach can be used to approximate the emissions. Material balances can be used directly, for example, by assuming that all the sulfur content of a fuel is emitted as SO_2. Alternately, a material balance can be used to establish an empirical equation taking into account the relationship between combustion reactants and products. Material balances can also be used in conjunction with non-census-based emission factors to estimate emissions, such as those based on the difference between the raw material and the product when the emission factor for a process is per unit of material consumed. In essence, material balances are often used in calculating emissions when activity data such as production and sales data and fuel composition data are used.

For example, material balances could be performed for area source emission calculations involving fuel manufacture, distribution, and consumption (see Figure 3-6). A material balance for fuel distribution and consumption was recently applied in the United States (De Luchi, 1993). A similar approach appears even more feasible in Mexico because fuel manufacture, distribution, and consumption are under government leadership. A national material balance for solvents for surface coating materials may also be the best method for estimating VOC emissions from this group of sources. We are currently exploring this potential application.

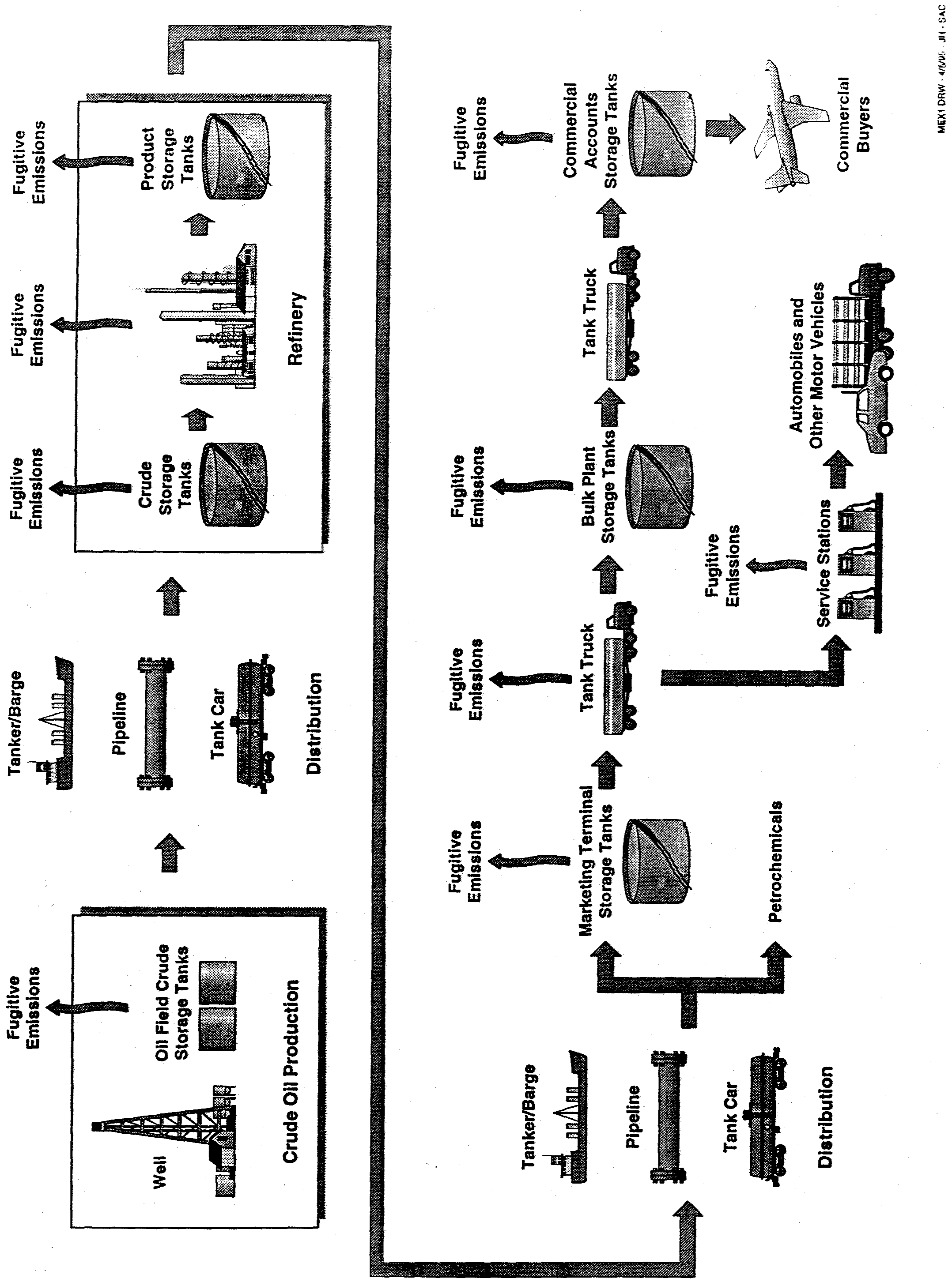

Figure 3-6. Example of Material Balance Highlighting Fugitive Emissions

Mexico Inventory Methods Evaluation

With the exception of the fuel and solvent use examples presented above, we see limited use of material balance calculations in Mexico as a primary method for estimating emissions. Rather, we envision the use of material balances as a top down method to evaluate the reasonableness emission estimates generated using other techniques.

3.1.6 Extrapolation

Extrapolation techniques can be used both to calculate emissions directly and to verify the emission estimates calculated using another approach. For example, source sampling data from one type of process or one facility can be extrapolated to other source types or facilities.   In other cases, if it can be argued that the socioeconomic conditions between two or more geographical regions are comparable, then the available area source emissions data for one region can be extrapolated to the remaining regions based on population/employment data. Figure 3-7 illustrates the concepts of emissions extrapolation. Emissions inventories compiled in the U.S. and in Europe can be used in this manner. Within Mexico, emissions inventories that have been compiled for Mexico City and that are being developed for other areas (e.g., Monterrey metropolitan area) can be used as a basis for QA and/or development of portions of the "new" emissions inventories for other regions.

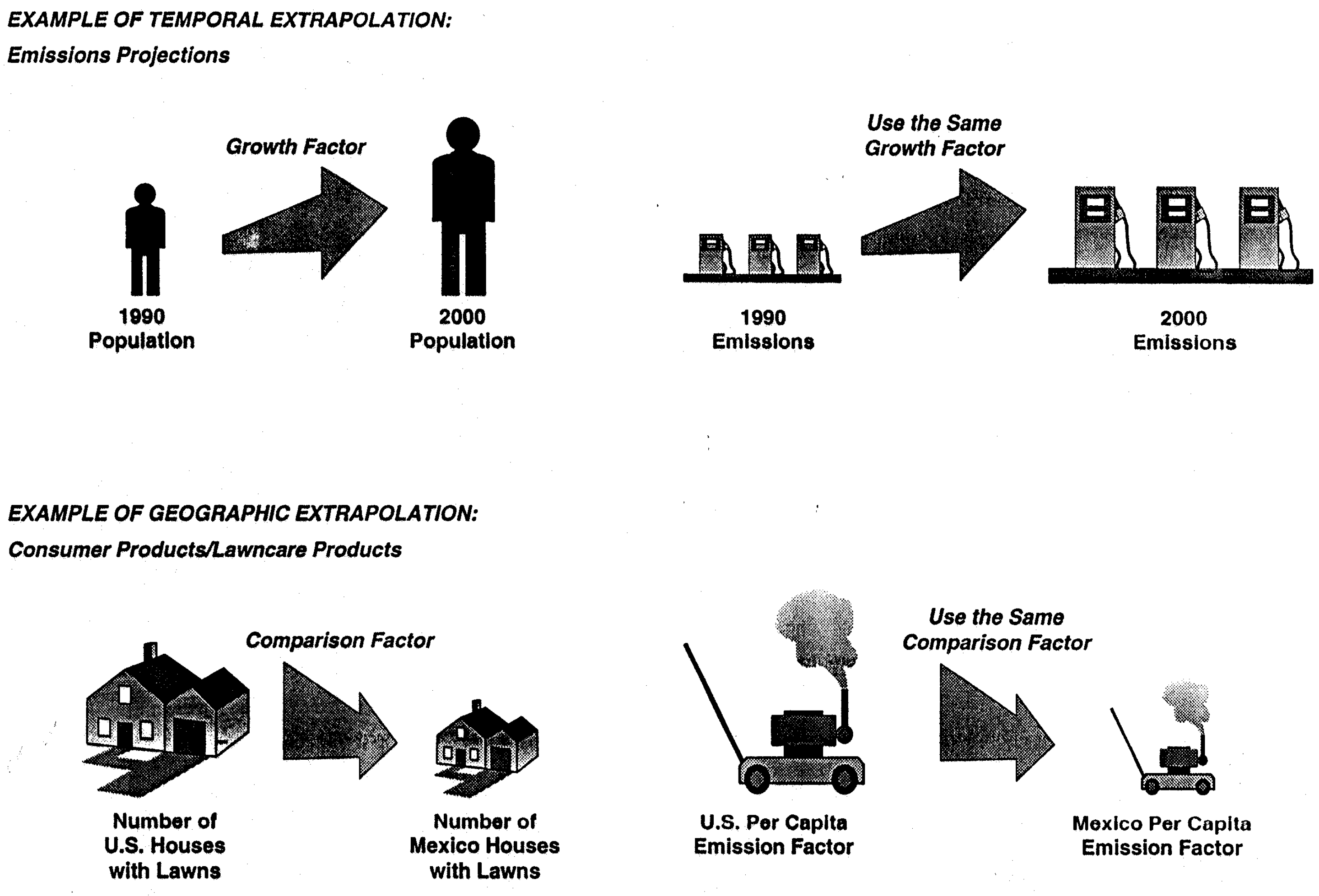

Figure 3-7. Examples of Extrapolation

We view straight extrapolation of emissions from one geographic region to another as the least desirable approach for emissions estimation. Such an approach may not properly account for important differences between two regions and may propagate biases from one inventory to another. For example, the recently completed Mexico City Air Quality Research Initiative (MARI) determined through air quality modeling, ambient monitoring, and data analysis techniques that the VOC inventory used for MARI is underestimated by a factor of four (LANL and IMP, 1994). To our knowledge, causes of this underprediction are currently unknown, although motor vehicle emissions and gasoline evaporation are strongly suspected (Striet, 1995). Recent air quality monitoring results also suggest that emissions from propane tanks used for cooking may also be a significant source of uninventoried VOC.

When combined in a modeling framework, however, extrapolation of emissions to regions where there is insufficient statistical information to estimate emissions using traditional approaches will be a practical and cost effective approach. This concept is discussed in greater detail above under the concept of "Multivariate Models."

3.2 Point and Area Source Methods Evaluation

A detailed methods evaluation was performed for each of the point and area source types listed in Section 2.0. The results of the evaluation are presented in tabular format to facilitate the review of this material. The evaluation results for point, area, and nonroad mobile sources are presented in Appendices A through C, respectively.

Two of the methods considered in this analysis rely on the use of emission factors (i.e., survey and census data combined with emission factors). At this time, we are aware of two different sets of emission factors available to make emission calculations. The first set are the standard emission factors used in the U.S., such as those found in AP-42. The other set of factors is contained in the *Rapid Source Inventory Techniques* guidance document (Economopoulos, 1993). At this time, the applicability of either set of these factors to Mexico is unknown. Therefore, another method that could be added to Appendices A through C is the concept of "pooled source testing" to develop Mexico-specific emission factors. We have not listed this as an approach in the following material because it is a refinement of the data that would be used in a method that is currently being evaluated. Nonetheless, an evaluation of existing emission factors is warranted, but beyond the current scope of the project's Phase I activities. The implementation plan (Task 6) will address this issue in more detail.

Table 3-1

Rapid Source Inventory Techniques Emission Factors for Petroleum Refining[a]

Process	Subprocess	Unit (U)	TSP kg/U	SO_2 kg/U	NO_x kg/U	CO kg/U	VOC kg/U
Misc. Operations[b]	N / A	m^3 of crude					0.4
Fluid Catalytic Cracking (FCC)	Uncontrolled	m^3 of FCC feed	0.695	1.413	0.204	39.2	0.63
	CO Boiler	m^3 of FCC feed	0.695	1.413	0.204		
	ESP & CO Boiler	m^3 of FCC feed	0.126	1.413	0.204		
Desulfurization of Source Gas[c]	N / A	kg of Sulfur in Gas	2(100-e) / 100				
		kg of Sulfur Recovered	2(100-e) / e				
Rail Tank & Tank Trucks Filling	Gasoline Loading Splash Loading	m^3 of Gasoline					1.43
		tn of Gasoline					1.94
	Submerged Loading [d] Normal Service	m^3 of Gasoline					0.59
		tn of Gasoline					0.80
	Vapor Balance Serv.	m^3 of Gasoline					0.98
		tn of Gasoline					1.33
	Vapor Controlled	m^3 of Gasoline					0.05
		tn of Gasoline					0.07
	Jet Naphtha Loading Splash Loading	m^3 of Gasoline					0.43
		tn of Gasoline					0.58

Table 3-1

(Continued)

Rail Tank & Tank Trucks Filling (Cont.)	Submerged Loading Normal Service	m^3 of Naphtha					0.18
		tn of Naphtha					0.24
	Vapor Balance Serv.	m^3 of Naphtha					0.30
Loading of Barges	Gasoline	m^3 of Gasoline					0.41
		tn of Gasoline					0.55
	Crude Oil	m^3 of Crude Oil					0.12
		tn of Crude Oil					0.137
	Jet Naphtha	m^3 Jet Nephtha					0.15
		tn of Naphtha					0.20
Loading of Ships / Ocean Barges	Gasoline	m^3 of Gasoline					0.215
		tn of Gasoline					0.291
	Crude Oil	m^3 of Crude Oil					0.073
		tn of Crude Oil					0.083
	Jet Naphtha	m^3 Jet Naphtha					0.06
		tn of Naphtha					0.08

[a] Emissions due to fuel burning are not accounted for and should be computed separately (see SIC No. 410).

[b] VOC emissions from typical sources within a refinery, such as storage tanks, API separators, blowdowns, fugitive sources etc. are included. The listed factor is based on detailed VOC emissions estimates in several refineries.

[c] "e" is the percent efficiency of the sulfur recovery plant. Typical values are for 2-stage plant controlled 92-95%, for 3-stage plant uncontrolled 95-97.5%. 4-stage plant uncontrolled 96-99%, and for controlled plant 99-099.9%.

[d] In the Vapor Balance Service the cargo truck retrieves the vapors displaced during the underground tank filling in service stations (see below, SIC 620). This operation increases the VOC concentration in the air within the empty truck and causes higher VOC emissions when the truck is filled. It should be noted in this regard that most of

Table 3-1

(Continued)

the VOC emissions reduction achieved through the balanced vapor filling of the service stations submerged tanks is offset by the resultant increased emission in the Truck Filling Station, unless of course a vapor recovery system is used in the latter. Reproduced from Economopoulus, 1993.

4.0 ON-ROAD MOBILE SOURCE INVENTORY METHODOLOGIES

On-road mobile source emissions are calculated based on estimates of vehicle activity and emission factors. The methods chosen depend upon the geographic scope of the inventory and the extent of the available data. Development of the on-road mobile source inventory for this effort will depend upon existing data.

4.1 Motor Vehicle Activity Data

To estimate vehicle activity, the following types of data are commonly used for inventory purposes:

- Detailed vehicle kilometers traveled (VKT) estimates;
- Regional VKT estimates;
- Regional estimates of on-road fuel use; and
- Regional population and vehicle registration data.

Each of these sources varies in accuracy and in the level of the assumptions required for its use. Table D-1 in Appendix D presents a detailed evaluation of these data sources. Each method is discussed below.

4.1.1 Detailed Urban VKT Estimates

These data represent the most accurate estimate of vehicle activity and are used extensively in emission factor models. In order to arrive at such data, it is necessary to determine the urban fleet's travel fraction. The travel fraction is based upon the breakdown of the entire fleet into individual model years, as well as the decomposition of total fleet VKT into VKT by model years. In general, the development of detailed urban VKT estimates requires the use of transportation models, comprehensive traffic counting programs and surveying, and detailed registration records. As a result, these data are usually only prepared for larger metropolitan regions which have the available resources to develop such data. Radian used data of this type in estimating vehicle emission for Mexico City (Klausmeier and Menendez, 1991). Detailed VKT estimates are also available for Monterrey and Ciudad Juárez. In general, the large metropolitan areas are expected to have transportation agencies which can provide detailed VKT estimates.

4.1.2 Regional VKT Estimates

Unlike detailed urban VKT estimates which focus on a single metropolitan area, these estimates cover a much larger geographical area, such as an entire state. They are usually based on traffic counting programs, but are usually less detailed than the urban VKT estimates. In order to use regional VKT estimates with emission factor models, various assumptions must be made in order to characterize vehicle activity. Some of these assumptions may involve the application of known vehicle fleet characteristics from one region to the vehicle fleet of another region. Unfortunately, such an application could result in substantial error and uncertainty. One possible problem is the level of non-registered vehicles. Although this is an issue that must be addressed with all vehicle fleets, this will be more of a problem in some regions than in others. Also, because of the influence of U.S. vehicles, the characteristics of the Mexican fleet in the border region could be significantly different from the fleet in the southern regions of Mexico.

4.1.3 Regional Estimates of On-Road Fuel Use

In some areas there are no direct estimates of VKT available. In these areas, the most common technique to estimate vehicle activity is to use fuel consumption data. Such data can be obtained on a regional basis from federal or state governments through fuel tax receipts. Also, these data can be obtained from the petroleum industry through the Mexican Petroleum Institute (IMP).

Regional VKT is estimated from fuel usage data and fuel economy data from the following equation:

$$VKT_{gasoline,diesel} = \frac{Regional\ On\text{-}Road\ Fuel\ Use_{gasoline,diesel}}{Fleet\ Average\ Fuel\ Economy_{gasoline\ diesel\ vehicle}}$$

Fleet Average Fuel Economy = $\Sigma(\text{Fuel Economy}_{\text{vehicle type}} * \text{Registration Fraction}_{\text{vehicle type}} * \text{Mileage Accumulation Rate}_{\text{vehicle type}}) / \Sigma(\text{Registration Fraction}_{\text{vehicle type}} * \text{Mileage Accumulation}$

$\text{Rate}_{\text{vehicle type}})$

Fuel use data are separated by fuel type (gasoline or diesel) for a region. It is important at this stage to distinguish off-road fuel use for industrial, construction, recreational activities from the on-road fuel use. The on-road fuel use represents usage for the entire fleet, and across all types of light and heavy duty passenger cars and trucks. To estimate regional VKT, the fuel use is divided by the fleet average fuel economy. Fuel economy for each vehicle type (light duty passenger cars, light duty trucks, heavy duty trucks) can be estimated from a number of local data sources, usually survey results or data recorded during emissions test qualification. Local data sources are preferred as they help account for differing local driving conditions. Finally, regional registration data and mileage accumulation estimates are used to develop the fleet average fuel economy estimate.

The estimate of the fleet average fuel economy can be subject to significant uncertainty, resulting from imprecision or assumptions in the three parameters used in the calculation. In particular, mileage accumulation rate data are often not available in the necessary detail and must be estimated using other data sources.

Fuel use estimates may also be used as a means of checking VKT estimates developed using transportation models and traffic counting programs. It should be recognized, however, there are a number of problems associated with this type of comparison. The same concerns regarding development of fuel economy estimates apply in this case as well.

4.1.4 Regional Population and Vehicle Registration Data

This method uses population or vehicle registration data. These data are combined with per capita or per vehicle emission factors to estimate emissions. This is the least accurate method of estimating vehicle activity and requires the largest number of assumptions. This method is useful as a quality control measure to check the accuracy of emissions estimated by one of the other methods described above.

4.2 Motor Vehicle Emission Factors

The second part of the motor vehicle emission estimation process requires the development of emission factors representative of vehicles operating in a given region. A variety of sources are available to provide vehicle emission factors for this effort. These include the following:

- MOBILE-MCMA, an emission factor model developed for Mexico City;
- MOBILE5C, an emission factor model developed by U.S. EPA's office of Mobile Sources for regions outside of the U.S.
- COPERT, Computer Programme to Calculate Emissions from Road Traffic;
- *Rapid Source Inventory Techniques,* a listing of emission factors that can be used to quickly estimate emissions; and
- PART5, U.S. EPA's particulate emission factor program.

The first two sources provide emission factors only for VOC, CO, and NO_x. The last source provides emission factors for particulate emissions. Emissions of SO_2 are generally estimated through material balances using overall estimates of fuel consumption and knowledge of fuel sulfur levels. Table D-2 presents a detailed analysis of these different sources. Additional discussion of these sources is provided below.

4.2.1 Emission Factor Models

U.S. EPA's MOBILE model has been adapted on two different occasions to Mexico. One of the first efforts was by Radian in which the MOBILE-MCMA model was developed. This model was developed by Radian for use in estimating emissions for Mexico City metropolitan area (Klausmeier and Menendez, 1991). It is based on the U.S. EPA's MOBILE4 model, but contains significant revisions and local data to reflect actual Mexico City conditions. This model represents the most comprehensive estimate of Mexico City emission factors for on-road vehicles. It will introduce a bias, however, when applied to other regions because it is based on an out dated version of the MOBILE model that tends to under predict emissions. In addition, MOBILE-MCA was designed to reflect the higher altitude of Mexico City.

The U.S. EPA has also recognized the need to develop a motor vehicle emission factor model for use in border studies. The control technology mix of the 49-state U.S. vehicle fleet has changed over time as manufacturers have met changing emission standards. Those 49-state emission standards have not coincided with Mexican standards and control technology and, consequently, the MOBILE5a source code and default data which describes the 49-state vehicle fleet by technology are not appropriate for use with other vehicle fleets.

Energy and Environmental Analysis, Inc. (EEA) was assigned the task of developing a version of MOBILE5 which can be used in Ciudad Juárez and El Paso. This "Mexican border version" of MOBILE5 could have been developed by replacing the U.S. specific default data with data that reflect the characteristics of the Ciudad Juárez vehicle fleet. However, this methodology would have resulted in a version of MOBILE5 that is useful only for Juárez, and if emission factors for other border towns (or Mexican interior towns) were desired, other versions of MOBILE5 or its successor would have to be developed. At EPA's suggestion, EEA has instead developed code for a new version of MOBILE5 (referred to as MOBILE5c) that can be used anywhere, be it non-California U.S., California, Mexico, or any foreign country.

Although flexible, our review of the MOBILE5c code indicates that the user must supply the basic emission factor database that drives the model, thus requiring a significant level of effort on the part of the user. At this time, the approach for developing MOBILE-MCMA appears to be the most appropriate. In this approach, an emission control technology equivalence matrix is developed and used in the model. In other words, the basic emission factors associated with the MOBILE5a model are mapped to the Mexican vehicle fleet to reflect the age of the fleet and level of emission controls. A preliminary, updated version of this code has been developed for application in Monterrey and is based on MOBILE5a. The name of this new model is MOBILE-MMAp (i.e., Monterrey Metropolitan Area—preliminary). Further refinement of this model is needed so that it can be applied with confidence elsewhere in Mexico. This refinement consists of using inspection/ maintenance data from Monterrey (at idle conditions) to refine the preliminary emission control technology equivalence matrix. Further refinement would consist of developing basic emission factors from a Mexico-specific testing data base.

Because the country of Mexico is in its early stages of developing an inventory program, there is an opportunity to establish methods and procedures that are based on advanced technology. Consideration was therefore given to using a modal modeling approach. Existing modeling techniques are based on composite emissions data collected over a defined driving cycle (typically a cycle such as the Federal Test Procedure or FTP). However, this requires an assumption that the cycle is representative of real-world driving behavior. In the modal modeling approach, emission factors are developed for discrete driving events or modes, such as engine starts, level cruise, acceleration, and full throttle acceleration. Emissions can then be "assembled" for any cycle by combining the emissions from a series of these discrete modes. In the future, this may become the preferred approach for estimating emissions from motor vehicles in the U.S.

Although we believe a modal modeling approach would be superior to the current method of estimating emissions, the measurement program required to develop the database needed to support this approach would be extremely high, on the order of millions of dollars. Given this high cost, we do not recommend pursuing this approach in Mexico at this time. Rather, Mexico would be better served to wait and take advantage of any research and development efforts conducted in the U.S and other countries, or combine Mexican efforts with other countries.

4.2.2 COPERT

This model was developed by the Commission of the European Communities (CEC). The development of this model occurred within the framework of the CORINAIR sub-activity of the CEC-sponsored CORINE project (Coordination of Information for the Environment). It reflects a somewhat different approach to emission factor estimation. COPERT uses an iterative method that calculates total fuel consumption and emissions without requiring extensive traffic data. Fuel consumption estimates are then compared to statistical fuel data in order to refine emissions estimates. It is thought that COPERT is more readily adapted to areas with different emission standards than the U.S. EPA's MOBILE5a model (Samaras and Zachariadis, 1993).

Although it appears that COPERT might be an option for estimating motor vehicle emissions in Mexico, the MOBILE-type emission factor models seem to be a more appropriate choice. First of all, COPERT does not include the effects of fuel volatility, altitude, and high engine load. All of these effects could be significant in the Mexico motor vehicle emissions inventory. COPERT also provides only rough estimates of evaporative emissions, whereas

MOBILE-type emission factor models include much more refined estimates. Finally, because the first version of COPERT appeared in 1989, its methodology and related data are not as developed as MOBILE which was first developed in 1978.

4.2.3 Rapid Source Inventory Techniques

This guidance document was developed in Greece for the WHO and contains two different methods for calculating mobile source emissions (Economopoulos, 1993). The first method uses simple mobile source emission factors based on the quantity of fuel consumed. These emission factors are distinguished by engine size and driving location. Because of the predominance of emissions from light duty gasoline powered vehicles, the *RAPID Source Inventory Techniques* document provides an additional method for calculating emissions from motor vehicles. This second method uses graphs and equations from the COPERT computer model (detailed above) which have been extended to include vehicles with catalytic technology.

We do not believe that the emissions estimating methodologies described in *Rapid Source Inventory Techniques* are appropriate for the development of Mexico's emission inventory. The simple mobile source emission factors fail to add adequate detail, while the second method is inappropriate for the same reasons outlined in the section describing the COPERT computer model, namely: insufficient treatment of evaporative emissions, inability to describe local conditions, and underdeveloped data.

4.2.4 PART5

This is the latest generation of the U.S. EPA's particulate emission factor model. It can be used to generate emission factors specific to vehicle types. It can also estimate size-specific emission factors for PM_{10} and $PM_{2.5}$ emissions. This model is also "technology" driven and therefore would have to be modified in the same manner as the MOBILE5a model. Modifying the PART5 code and developing the emission control technology equivalence matrix is relatively straightforward. It should be noted, however, that the emission estimates generated for diesel vehicles are based on an extremely limited database (approximately eight vehicles). Consequently, when this small database is extrapolated to different driving conditions, such as a change in speed, highly uncertain results are generated.

5.0 NATURAL SOURCE INVENTORY METHODOLOGIES

The methodologies used to estimate emissions from natural sources traditionally rely on emission models, especially the techniques used for biogenic hydrocarbon emission estimates. Appendix E presents the available natural source estimation methods.

Estimating emissions for the natural source categories will rely extensively on land use/land cover data (LULC). For example, land use describes the type of vegetation that may be present (e.g., natural versus urban) and also the type of vegetation present (e.g., row crop versus orchard). Development of natural source emission estimates for Mexico would be greatly enhanced through the application of satellite imagery data to develop LULC data. These data could be used directly to develop biogenic hydrocarbon, soil NO_x, and wind blown dust emissions.

Further field research is also warranted so that a more refined biogenic emission estimate can be developed for Mexico. The applicability of the current biogenic emission models may have limited applicability in many regions of Mexico. The work performed to develop the biogenic hydrocarbon inventory for the Grand Canyon Visibility Transport Commission found that biogenic emission estimates for the southwestern U.S. appear to be overestimated. It is possible that the scrubland LULC category for the southern U.S. and northern Mexico should incorporate a lower biomass than is currently used in the biogenic emissions calculations. No other biomass data are available for this region.

In summary, a large effort will be required to develop the necessary data for natural source emission estimates. Satellite imagery would greatly enhance the process, but additional fundamental research will be required to develop other model parameters. This includes soil parameters for soil NO_x estimates and biomass data to support the modeling of biogenic hydrocarbons.

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APPENDIX A

CRITICAL REVIEW OF POINT SOURCE EMISSIONS METHODS

Table A-1

Critical Review of Point Source Emissions Methods

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
Electric Utility Fuel Combustion	Source Sampling / Direct	+	0	+	N / A	+	+	With the small number of facilities in this category, source sampling is a relatively practical and cost effective way to develop emission estimates for this category of sources.
	Surveying / AP-42 Emission Factors	+	+	0	+	0	0	Emissions from utilities have been well studied in the U.S. Further evaluation is needed to determine if these emission factors are applicable to Mexico.
	Surveying / WHO Emission Factors	+	+	0	+	0	0	WHO emission factors have about the same level of source coverage as those in AP 42.
Industrial and Commercial Fuel Combustion	Source Sampling / Direct	+	0	+	N / A	0	+	For the largest sources, source sampling is a practical and cost effective way to develop emission estimates.
	Surveying / AP-42 Emission Factors	+	+	0	+	+	+	Emissions from industrial and commercial boilers have been well studied in the U.S. For the sources not source tested, surveying and application of emission factors is an appropriate approach. Further evaluation is needed to

Table A-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
								determine if these emission factors are applicable to Mexico.
Industrial and Commercial Fuel Combustion (Cont.)	Surveying / WHO Emission Factors	+	+	0	+	+	+	WHO emission factors have about the same level of source coverage as those in AP 42.
	Material Balance	+	+	--	+	+	+	Initially, not all facilities can be either tested or surveyed. Emissions from remaining facilities can be estimated using a material balance. Fuel balances for Mexico appear to be reasonably straight forward because of the central control and distribution of fuels. Emissions calculated using a material balance approach would be placed in the area source inventory.
Chemical Manufacturing (process emissions)	Source Sampling / Direct	0	0	+	N / A	0	+	For the largest sources, source sampling is a practical and cost effective way to develop emission estimates.
Chemical Manufacturing (process emissions) (Cont.)	Surveying / AP-42 Emission Factors	+	0	--	0	0	0	Sources that are not characterized through source sampling could be inventoried through surveying and application of

Table A-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
								emission factors. Given site specific factors, chemical manufacturing emission factors have a high degree of variability. U.S. Emission factors for this category of sources may have limited applicability in Mexico.
	Surveying/WHO Emission Factors	+	0	--	0	--	--	Same comments as above. Further evaluation is needed to determine extent of process coverage for WHO emission factors. Same level of information is needed to apply WHO factors for this category of sources as is needed for AP-42 emission factors.
Petroleum Refining (process emissions)	Source Sampling/Direct	0	0	+	N/A	+	+	For the largest sources, source sampling is a practical and cost effective way to develop emission estimates.
Petroleum Refining (process emissions) (Cont.)	Surveying/AP-42 Emission Factors	0	0	0	0	+	+	Sources that are not characterized through source sampling could be inventoried through surveying and application of emission factors. Given site specific factors, petroleum emission factors have a high degree of variability.

Table A-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
	Surveying/WHO Emission Factors	+	+	--	--	0	--	WHO provides simplified emission factors that group processes, fugitives and tanks together. These emission factors would be easier to apply than AP-42 factors, but they would have a higher level of uncertainty.
Chemical and Refinery Fugitive Equipment Leaks	Source Sampling/Direct	--	--	+	N/A	--	0	It's possible to conduct a site specific screening and bagging study at each facility. This approach is resource intensive and not very practical in the near term.
Chemical and Refinery Fugitive Equipment Leaks (Cont.)	Source Sampling/Indirect	0	0	0/+	N/A	0	+	On-site screening measurements can be collected at each facility and used in conjunction with leak/no leak emission factors, stratified emission factors, or correlation equations. Leak/no leak factors are the least rigorous and correlation equations are the most rigorous of this group. Screening methods vary by choice of factors.
	Surveying/AP-42 Emission Factors	0	0	--	--	+	0	Through surveys, the number of components at each refinery would be collected and combined with the emission factors. In the

Table A-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
								U.S., this approach tends to overestimate emissions.
	Surveying/WHO Emission Factors	+	+	--	--	+	--	The WHO emission factors are based on volume of crude oil processed. Available emission factor combines numerous emission sources such as fugitives, tanks, etc. into one factor. This approach will yield a highly uncertain emission estimate.
Chemical and Refinery Fugitive Equipment Leaks (Cont.)	Extrapolation	+	+	--	--	--	--	Using U.S. inventory data, factors based on quantity of crude could be developed for fugitives and applied in Mexico. This factor would be similar to the WHO factor, but based on current U.S. emission estimates. Uncertainty resulting from application of this factor would still be quite high.
	Surveying/ Multivariate Model	0	+	0	0	+	0	From U.S. emissions data, develop and apply multivariate emissions model. Variables would be material throughput, refinery age, product mix, and use of inspection/ maintenance program.
Organic Liquid	Mechanistic	0	0	+	+	0	+	Mechanistic model

Table A-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
Storage Tanks	Emissions Model							represents the best estimating tool currently available. The model could either applied by each facility and the calculated emissions reported, or each facility could be surveyed to obtain the required model parameters and emissions calculated at a central location.
Organic Liquid Storage Tanks (Cont.)	Extrapolation	+	+	--	--	--	--	Data from U.S. emission inventories could be used to develop average emission factors/rates that could be extrapolated to Mexico. While this would provide a quick and efficient approach, a tremendous amount of uncertainty would be associated with the emissions.
Primary Metal Production	Source Sampling/Direct	+	+	+	N/A	+	+	The small number of facilities in this category make source sampling a practical and cost effective way to develop emission estimates for this category of sources.
	Surveying/AP-42 Emission Factors	+	+	0	+	0	0	Smelter process operations tend to be variable, making it hard to develop accurate

Table A-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
								emission factors.
	Surveying / WHO Emission Factors	+	+	--	--	0	--	WHO emission factors are more generalized, making them easier to apply, but at the same time giving them a higher level of uncertainty.
Primary Metal Production (Cont.)	Material Balance	+	+	+	+	+	+	For some facilities and pollutants, a material balance would provide precise emission estimates. For example, SO_2 emissions from uncontrolled copper smelters can be easily estimated using a material balance.
Secondary Metal Production	Source Sampling / Direct	--	--	+	N / A	--	0	Metal recycling facilities are generally small emission sources. Source testing resources should be reserved for other source types.
	Surveying / AP-42 Emission Factors	+	+	--	+	+	0	A variety of emission factors are available from AP-42.
	Surveying / WHO Emission Factors	0	0	--	--	--	--	Only generalized emission factors are available for secondary copper.
Cement Production and Miscellaneous Mineral Products (e.g. lime and aggregate	Source Sampling / Direct	+	0	+	N / A	+	+	With the small number of facilities in this category, source sampling is a relatively practical and cost effective way to develop emission estimates for this category of sources.

Table A-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
kilns)								
	Surveying / AP-42 Emission Factors	+	+	0	+	0	0	Emissions from kilns have been well studied in the U.S. Further evaluation is needed to determine if these emission factors are applicable to Mexico.
Cement Production and Miscellaneous Mineral Products (e.g. lime and aggregate kilns) (Cont.)	Surveying / WHO Emission Factors	+	+	0	+	0	0	Emission factors for kilns are included in the WHO method. Coverage of emission sources appears to be similar to AP-42. Further evaluation is needed to determine if these emission factors are applicable to Mexico and if they would be more practical than AP-42 factors.
Automotive Industry	Source Sampling / Direct	+	0	+	N / A	0	+	With the small number of facilities in this category, source sampling is a relatively practical and cost effect way to develop emission estimates for this category of sources.
	Surveying / AP-42 Emission Factors	+	+	0	+	+	0	Emissions from the automotive industry and related industries have been well studied in the U.S. Current emission factors would provide a reasonable estimate of emissions.

Table A-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
	Surveying/WHO Emission Factors	0	0	--	0	--	--	WHO emission factors are somewhat limited for this source category.
Wood Pulping Operations	Source Sampling/Direct	+	0	+	N/A	0	+	With the small number of facilities in this category, source sampling is a relatively practical and cost effective way to develop emission estimates for this category of sources. Further evaluation is needed to see if this category even exists in Mexico.
	Surveying/AP-42 Emission Factors	+	+	0	+	+	0	Pulp mill emissions have been well studied in the U.S. Current emission factors would provide a reasonable estimate of emissions.
Oil and Gas Production	Source Sampling/Direct	--	--	+	N/A	0	0	It would not be practical to test every source. However, emission factors for this category of sources are limited. Additional source testing needed to develop more reliable factors.
	Source Sampling/Indirect	+	+	+	N/A	+	+	Many of the sources in this category are fugitive in nature. Indirect source sampling could be used to better characterize these emissions and develop better emission factors.

Table A-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
	Surveying / AP-42 Emission Factors	0	0	--	+	0	+	Limited factors are available. More research is needed in this area.
Oil and Gas Production (Cont.)	Surveying / WHO Emission Factors	--	--	--	--	--	--	Emission factors available only for desulfurization of natural gas. Application of this method would omit a number of source types and therefore create a bias in the inventory.
Printing and Publishing	Source Sampling	--	--	+	N / A	--	--	Source testing could be used to develop emission estimates, but it would not be a very cost effective approach. Source testing resources should be devoted to other source types.
	Surveying / AP-42 Emission Factors	+	+	0	+	+	+	Reasonable emission estimates can be developed with existing factors.
	Surveying / WHO Emission Factors	+	+	--	+	0	0	Factors available for most process operations. Method ignores miscellaneous solvent use, which would create a bias.
	Survey / Material Balance	+	+	+	+	+	+	This method should be used for fugitive solvent emissions.
Surface Coating	Source Sampling	--	--	0	N / A	--	--	Source testing could be used to develop emission estimates, but it would not

Table A-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
								be a very cost effective approach. Fugitive solvent emissions would also be difficult to measure. Source testing resources should be devoted to other source types.
	Surveying / AP-42 Emission Factors	0	--	--	0	--	--	Product specific emission factors are available, but they have a high degree of uncertainty due to large variations in VOC content of coating materials. U.S. data may also have limited applicability in Mexico (i.e., difference is VOC content). Emission factor approach also likely to exclude clean--up and other solvent use at coating facilities. Thus, the estimates could be biased low.
	Surveying / WHO Emission Factors	0	0	--	--	--	--	Simplified, non-product specific emission factors are available, but a large amount of uncertainty would be introduced into the estimates from their use. Similar concerns about biasing emission estimates low.
Surface Coating (Cont.)	Material Balance	0	0	+	+	0	+	Performing material balances at the facility level provides the most accurate emission

Table A-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
(Cont.)								estimate. However, this is a very resource intensive approach.
Bulk Fuel Terminals	--	--	--	--	--	--	--	See discussion under liquid organic storage tanks at the beginning of this table.
Mining and Quarrying	Source Sampling/Indirect	0	0	+	N/A	0	0	Mining operations consist of area sources that are not amenable to direct source testing. However, indirect sampling and analysis techniques could be used to evaluate the applicability of the available emission factors.
	Surveying/AP-42 Emission Factors	+	+	0	+	+	+	Emission factors for a variety of mining operations have been developed for use in the U.S. These factors could be applied in Mexico.
	Surveying/WHO Emission Factors	0	0	--	0	--	--	Limited factors are available, primarily for crushing and grinding. Other process operations and fugitive dust sources are not addressed.
Wood Products Manufacture	Source Sampling	--	0	+	N/A	--	0	Source testing could be used to develop emission estimates, but it would not be a very cost effective approach. Source testing resources should be devoted to other larger emitting

Table A-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
								source types.
	Surveying / AP-42 Emission Factors	+	+	0	+	+	+	Surveying data combined with emission factors would be the most cost effective way to develop emission estimates for this category of sources.
Sugar Production	Source Sampling	--	0	+	N / A	--	0	Source testing could be used to develop emission estimates, but it would not be a very cost effective approach. Source testing resources should be devoted to other larger emitting source types.
	Surveying / AP-42 Emission Factors	+	+	0	+	+	+	Surveying data combined with available emission factors would be the most cost effective way to develop emission estimates for this category of sources. Emission factors are somewhat limited.

Table A-1

(Continued)

Tanning and Leather Finishing	Source Sampling / Direct	+	+	+	N / A	+	+	The small number of facilities in this category make source sampling a practical and cost effective way to develop emission estimates for this category of sources.
	Surveying / Emission Factors	0	0	--	--	--	--	Emission factors for this source category are extremely limited.
Glass Production	Source Sampling	--	0	+	N / A	--	0	Source testing could be used to develop emission estimates, but it would not be a very cost effective approach. Source testing resources should be devoted to other larger emitting source types.
	Surveying / AP-42 Emission Factors	+	+	0	+	+	+	Surveying data combined with emission factors would be the most cost effective way to develop emission estimates for this category of sources.
	Surveying / WHO Emission Factors	+	+	--	+	0	0	Factors available for some process operations. Method ignores miscellaneous solvent use, which would create an inventory bias.
Rubber and Plastic Parts	Source Sampling	--	0	+	N / A	--	0	Source testing could be used to develop emission estimates, but it would not be a very cost effective approach. Source testing resources should be devoted

Table A-1

(Continued)

								to other larger emitting source types.
	Surveying / AP-42 Emission Factors	+	+	0	+	+	+	Surveying data combined with emission factors would be the most cost effective way to develop emission estimates for this category of sources.
Fabricated Metal Products	Source Sampling	--	--	+	N / A	--	--	Source testing could be used to develop emission estimates, but it would not be a very cost effective approach. Source testing resources should be devoted to other larger emitting source types.
	Surveying	--	0	0	0	0	0	Process emissions from this category of sources are minimal. Initial focus should be on combustion emissions. See discussion on industrial fuel combustion at the beginning of this table.
Textile Products	Source Sampling	--	--	+	N / A	0	0	Further evaluation of this source category is needed. If there are numerous operations, and the available emission factors are limited, then source testing is warranted.
	Surveying / Emission factors	+	+	0	+	+	+	Activity data collected through surveys could be used to characterize emissions with the available factors. (This source

Table A-1

(Continued)

								category is not addressed in the WHO emission factors.)
Landfill Gas Emissions	Source Sampling/Indirect	--	+	+	N/A	_	_	Landfills are minor VOC emission sources. Source testing resources should be devoted to more important point source categories.
	Surveying/AP-42 Emission Factors	+	+	0	+	0	0	Available emission factors can be used to estimate emissions.
	Surveying/WHO Emission Factors	N/A	N/A	N/A	N/A	N/A	N/A	Source type not addressed.
	Survey/Mechanistic Model	0	+	+	+	+	+	Survey data would be used in existing model to calculate emissions.

Table A-1

(Continued)

Open Burning Dumps	Source Sampling/Indirect	+	+	0	N/A	+	+	It would not be practical to sample every burning dump, but remote sensing should be used to refine the exiting emission factors.
	Surveying/AP-42 Emission Factors	+	+	_	+	+	+	Existing emission factors are easy to apply once activity data are obtained. Uncertainty expected to be large.
	Surveying/WHO Emission Factors	+	+	--	+	+	+	Same comment as above.
Municipal Waste Combustion at Waste Management Facilities	Source Sampling/Direct	+	+	+	N/A	+	+	With the small number of facilities in this category, source sampling is a practical and cost effective way to develop emission estimates for this category of sources.
	Surveying/AP-42 Emission Factors	+	+	0	+	0	0	An emission factor approach could be used in the near term with emission estimates upgraded through source testing.
	Surveying/WHO Emission Factors	+	+	0	+	0	0	Availability of emission factors appears to mirror those factors developed in the U.S.

Table A-1

(Continued)

Food and Agriculture	Source Sampling/Direct	--	0	+	N/A	--	--	Use sampling resources for higher priority sources.
	Surveying/AP-42 Emission Factors	+	+	0	+	+	+	Survey data combined with emission factors is the most practical way to develop emissions for this source type.
Asphalt Plants	Source Sampling	--	0	+	N/A	--	0	Source testing could be used to develop emission estimates, but it would not be a very cost effective approach. Source testing resources should be devoted to other larger emitting source types.
	Surveying/AP-42 Emission Factors	+	+	0	+	+	0	Available U.S. emission factors could be used to estimate emissions from this source type.
	Surveying/WHO Emission Factors	+	+	0	+	+	0	Coverage of WHO emission factors is similar to the U.S. factors. Further evaluation is needed to determine which set would be more applicable.

APPENDIX B

CRITICAL REVIEW OF STATIONARY AREA SOURCE EMISSIONS METHODS

Table B-1

Critical Review of Stationary Area Source Methods

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
Stationary Source Fuel Combustion - Industrial and Commercial	Material Balance / AP-42 Emission Factors	+	+	0	0	+	0	Collect total fuel usage by fuel type and geographic region (city, state, etc.) from PEMEX. Must reconcile with point sources. Material balance approach also is a useful tool to evaluate estimates made with other methods.
	Surveying / AP-42 Emission Factors	0	0	0	0	0	0	Conduct a stratified, random sampling survey to collect fuel usage in regions where fuel usage data are not available from PEMEX. Use these data to develop per capita or per-employee fuel consumption factors.
Stationary Source Fuel Combustion - Residential Commercial Fuels	Material Balance / AP-42 Emission Factors.	+	+	0	0	+	0	Collect total fuel usage by fuel type and geographic region (city, state, etc.) from PEMEX. Use heating degree day to help spatially disaggregate fuel consumption geographically.
Stationary Source Fuel	Surveying / AP-42 Emission Factors	0	0	0	0	0	0	Conduct a stratified, random sampling survey

Table B-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
Combustion - Residential Commercial Fuels (Cont.)								to collect fuel usage in regions where fuel usage data are not available from PEMEX and use these data to develop per capita or per-employee fuel consumption factors. This could be expanded into a multivariate modeling approach. For example, use heating degree day and other survey data to estimate emissions.
Stationary Source Fuel Combustion - Residential Biomass or Waste-Derived Fuels	Surveying / AP-42 Emission Factors	+	+	0	0	+	0	Conduct a stratified, random sampling survey to collect fuel usage data and use these data to develop per capita fuel consumption factors. Use heating degree day to help spatially disaggregate fuel consumption geographically.
Stationary Source Fuel Combustion - Residential Biomass or Waste-Derived Fuels (Cont.)	Surveying / Multivariate Model	0	0	+	+	0	+	Conduct a stratified, random sampling survey to collect fuel usage data and other variables (e.g., standard of living, climate, population density) to develop a multivariate model that

Table B-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
(Cont.)								incorporates fuzzy logic.
Paved Road Dust	Mobile VKT / AP-42 Methodology	+	+	0	0	+	0	Use VKT data from the mobile source inventory and combine with U.S. default values for silt loading and mean vehicle weight.
	Mobile VKT / Extrapolation / AP-42 Methodology	0	0	+	+	0	+	Use VKT data from the mobile source inventory. Develop Mexico-specific default values for silt loading (possibly by industry or public road type) and mean vehicle weight by extrapolating to Mexico using existing data.
Paved Road Dust (Cont.)	Mobile VKT / Surveying / AP-42 Methodology	--	--	+	+	--	+	Use VKT data from the mobile source inventory. Conduct a stratified, random sampling survey of public road conditions and vehicles to develop Mexico-specific default values for silt loading and mean vehicle weight. AP-42 public road silt loadings are provided by daily traffic level (i.e., high or low) and averaging period (i.e., annual, January-June, or

Table B-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
								July-December).
Unpaved Road Dust	Extrapolation / AP-42 Methodology	+	+	--	0	+	0	Use paved road VKT data from the mobile source inventory and extrapolate to estimate unpaved road VKT. Use as much Mexico-specific data as possible (soil characteristics, wind speeds etc.) to develop Mexico-specific default values.
	Surveying / AP-42 Methodology	+	--	+	+	--	+	Conduct a survey to estimate unpaved road VKT. Conduct a survey to gather Mexico-specific soil characteristics and wind speed data.
Surface Coatings and Clean-up Solvents - Industrial	Census-based Emission Factors	+	+	--	0	+	--	Use per-employee emission factors with employment data or per capital emission factors with population data. Adjust for average VOC content differences between the U.S. and Mexico.
	Extrapolation / Mexican Point Source Inventory	+	0	0	+	+	0	Use Mexican point source inventory emissions and employment figures to develop per-employee emission factors for the various industrial

Table B-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
								sectors.
	Material Balance	0	0	0	0	0	0	Use Mexico-wide material balance of industrial surface coatings to develop regional estimates. Approach would provide accurate state-wide totals, but uncertainty would increase as smaller regions were considered.
	Surveying	0	0	0	+	0	+	Conduct a stratified, random sampling survey to collect coating usage and use these data to develop simple emission factors for the various industrial sectors.
Surface Coatings and Clean-up Solvents - Industrial (Cont.)	Surveying / Multivariate Model	--	--	+	+	--	+	Conduct a stratified, random sampling survey to collect coating usage and other variables (e.g., population density, number of employees, production rate) to develop a multivariate model.
Industrial Surface Cleaning (Degreasing)	Census-based Emission Factors	+	+	0	0	+	--	Use census-based emission factors (i.e., per-employee emission factors with employment data or per capital

Table B-1

(Continued)

Category	Method	Cost Effectivenes s	Practicality	Uncertainty	Upgrade Potentia l	Near Term Rating	Long Term Rating	Comments
								emission factors with population data).
	Census-based Emission Factors / Population Data	+	+	0	0	+	--	Use census-based emission factors (i.e., AP-42 per capita emission factors with population data).
	Extrapolation / Mexican Point Source Inventory	+	0	0	+	+	0	Use Mexican point source inventory emissions and employment figures to develop per-employee emission factors for the various industrial sectors.
	Material Balance	0	0	0	0	0	0	Use Mexico-wide material balance of industrial degreasing solvents to develop regional estimates.
Industrial Surface Cleaning (Degreasing) (Cont.)	Surveying	0	0	0	+	0	+	Conduct a stratified, random sampling survey to collect coating usage and use these data to develop simple emission factors for the various industrial sectors.
	Surveying / Multivariate Model	--	--	+	+	--	+	Conduct a stratified, random sampling survey to collect coating usage and other variables (e.g., population density, number of employees, production rate) to

Table B-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
								develop a multivariate model.
Dry Cleaning	Census-based Emission Factors	+	+	--	0	+	--	Use census-based emission factors (i.e., AP-42 per-employee emission factors with employment data per capita emission factors with population data). Need to identify differences in the mix of solvents used for dry cleaning in the U.S. and Mexico.
	Material Balance	0	0	0	0	0	0	Use Mexico-wide material balance of dry cleaning solvents to develop per-employee or per capita emission factors.
Dry Cleaning (Cont.)	Surveying	0	0	+	+	0	+	Conduct a stratified, random sampling survey of a limited number of dry cleaning establishments to collect solvent usage data and develop per-employee or per capita emission factors.
	Surveying / Multivariate Model	--	--	+	+	--	+	Conduct a stratified, random sampling survey to collect solvent usage and other variables (e.g., population density,

Table B-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
								standard of living, number of employees) to develop a multivariate model.
Consumer Solvents	Census-based Emission Factors	+	+	--	0	0	--	Use per capita emission factor with population data. Review the basis for this value and try to account for differences in cultural practices between the U.S. and Mexico (e.g., minimal use of lawn care products by homeowners in Mexico).
	Extrapolation / Mexican Census-based Emission Factors	+	+	0	0	+	0	Use Mexico City area source inventory census-based emission factor (i.e., 2.49 kg / person / yr) with population data.
Consumer Solvents (Cont.)	Material Balance	0	0	0	0	0	+	Use Mexico-wide material balance of consumer solvents to develop per capita emission factors. For national estimates, this approach would provide reasonable estimates, but uncertainty would increase when applied to smaller regions. Special methods would be needed to spatially

Table B-1

(Continued)

Category	Method	Cost Effectivenes s	Practicality	Uncertainty	Upgrade Potentia l	Near Term Rating	Long Term Rating	Comments
								disaggregate emissions to smaller regions so that socioeconomic differences could be taken into account.
	Surveying / Multivariate Model	--	--	+	+	--	+	Conduct a stratified, random sampling survey to collect consumer solvent usage and other variables (e.g., population density, standard of living, etc.).
Product Storage and Transport (Petroleum Products, Organic and Inorganic Liquids, and Bulk Materials)	Material Balance / Mechanistic Models and Emission Factors	+	+	+	+	+	+	Use data available from PEMEX to estimate total gasoline consumption and combine with AP-42 emission equations (i.e., mechanistic models) to estimate emissions from storage tanks and loading and unloading operations at pipelines, bulk terminals, service stations, airports, and vessels.
	Surveying / U.S. EPA Emission Factors	0	--	0	+	0	0	Conduct a stratified, random sampling survey to estimate the number of each type of fugitive component associated with pipelines and bulk terminals and combine these data with U.S. EPA emission factors.

Table B-1

(Continued)

Product Storage and Transport (Petroleum Products, Organic and Inorganic Liquids, and Bulk Materials) (Cont.)	Model	0	0	0	0	0	0	Use VKT from the mobile source inventory and fuel economy factors to estimate total gasoline consumption. Develop a Stage II vehicle refueling emission factor developed from MOBILE or other similar emission factor model.
	Census-based Emission Factors	0	--	--	--	0	--	Where region-specific fuel usage data are not available, use a per capita or per-vehicle consumption factor developed for all of Mexico and apply to regional population or vehicle registration figures. For national estimates, this approach would provide reasonable estimates, but uncertainty would increase when applied to smaller regions.

Table B-1

(Continued)

Agricultural Production - Livestock	Census-based Emission Factors	+	+	--	0	+	0	Use per-head emission factors with animal population data. Adjust for livestock type differences between the U.S. and Mexico.
	Surveying/Multivariate Model	--	--	+	+	--	+	Conduct a stratified, random sampling survey to animal population data and other variables (e.g., commercial vs. household livestock, detailed livestock characterization) to develop a multivariate model.
Waste Management - On-site Incineration	Material Balance	+	+	0	0	+	0	Use material balance to estimate the total quantity of waste generated and combine with emission factors.
	Census-based Emission Factors	+	0	--	0	0	--	Very rough U.S. factors are available to estimate quantity of waste burned in on-site incineration on a per capita basis. However, the use of on-site incineration as a waste management technology may be more/less common in Mexico.
Waste Management - On-site Incineration (Cont.)	Surveying	0	0	0	0	0	0	Conduct a survey of on-site incineration operations to develop Mexico-specific per capita activity data.

Table B-1

(Continued)

								Also, conduct source testing of "typical" on-site incinerators burning "typical" wastes to develop emission factors.
	Surveying / Multivariate Model	--	--	+	+	--	+	Conduct a stratified, random sampling survey of on-site incineration operations to collect the amount and types of waste burned and other variables (e.g., employment statistics, etc.) to develop a multivariate model.
Waste Disposal - Refuse Burning	Surveying	0	0	0	0	0	0	Conduct a survey of open burning dumps to develop Mexico-specific per capita emission factors. Also, conduct remote sensing (e.g., FTIR spectroscopy) of "typical" open burning dumps to develop emission factors.
	Surveying / Multivariate Model	--	--	+	+	--	+	Perform survey / micro-inventory efforts to develop a multivariate model for application in regions were statistical data are not available.
Fires - Wildfires	Surveying / AP-42 Emission Factors	0	0	+	+	0	+	Survey forestry experts in Mexico to estimate the total acreage burned and average fuel loading factors.
	Extrapolation / AP-42	+	+	--	0	0	0	Collect total forested

Table B-1

(Continued)

	Emission Factors							acreage and extrapolate U.S. ratio of acreage burned:forested acreage to Mexico. Combine with AP-42 emission factors. Limit U.S. data to region with climate similar to Mexico (e.g., southwestern U.S.).
	Multivariate Model	--	--	0	+	--	+	Develop algorithm based on LULC data from a satellite imagery that estimates typical wildfire emission rates.

Table B-1

(Continued)

Fires - Prescribed Burning	Surveying / AP-42 Emission Factors	0	0	+	+	0	+	Survey forestry experts in Mexico to estimate the total acreage burned and average fuel loading factors.
	Extrapolation / AP-42 Emission Factors	+	+	0	0	+	0	Collect total forested acreage and extrapolate U.S. ratio of acreage burned:forested acreage to Mexico. Combine with AP-42 emission factors. Limit U.S. data to region with climate similar to Mexico (e.g., Southwestern U.S.).
	Multivariate Model	--	--	0	+	--	+	Develop algorithm based on LULC data from satellite imagery that estimates typical prescribed fire emission activity.

Table B-1

(Continued)

Public Baths	Census-based / AP-42 Emission Factors	+	+	+	+	+	+	Data from PEMEX and INEGI have been used previously to estimate emissions for this source category.
	Material balance / AP-42 Emission Factors	+	+	0	0	0	0	Rather than considering this as a separate category, include it with other commercial fuel consumption. Estimate emissions using material balance data obtained from PEMEX.
Industrial Processes (not included in point source inventory)	Extrapolation / Mexican Point Source Inventory	+	0	--	+	0	--	Use Mexican point source inventory emissions and employment figures to develop per-employee emission factors for the smaller facilities in various industrial sectors. High degree of uncertainty because emissions may not correlate well with number of employees.
	Surveying / Emission Factors	--	--	+	0	--	+	Survey to collect emissions from small facilities and use these data to develop per-employee emission factors.
Industrial Processes (Cont.)	Extrapolation / U.S. Point Source Inventory	+	+	--	0	0	--	Use U.S. point source inventory emissions to develop per-employee

Table B-1

(Continued)

								emission factors for the various industrial sectors. Approach would yield a rapid method for developing estimates, but estimates would not be specific to Mexico. Must adjust for differences in level of automation (affects number of employees) or control technologies used.
	Surveying / Multivariate Model	--	--	0	+	--	+	Conduct a stratified, random sampling of emissions and other variables (e.g., SIC, number of employees, materials produced, $$ revenue, value added) to develop a multivariate model.
Industrial Processes (Cont.)	Extrapolation / Plant Models	0	0	0	0	0	0	Create "typical" plant models. Assume a certain number and distribution of devices, and then add together the various device emission factors to develop plant-wide emission factors. Might develop "typical" plant of various sizes (e.g., small, medium, and large).
	Census-based Emission Factors / GHG Inventory	+	+	0	0	+	0	Viable approach for many source types

Table B-1

(Continued)

	Techniques							where plantwide emission factors can be developed and applied to publicly available industrial production statistics.
Architectural Coatings	Census-based Emission Factors	+	+	0	0	+	--	Apply AP-42 per capita emission factors with population data. Adjust for average VOC content and socioeconomic differences between the U.S. and Mexico.
	Surveying	--	--	+	+	--	0	Conduct a stratified, random sampling survey to collect coating usage from contractors and use these data to develop Mexico-specific per capita or per-building emission factors.
Architectural Coatings (Cont.)	Material Balance	0	0	0	0	0	0	Use Mexico-wide material balance of architectural coatings to develop per capita emission factors. Material balance approach also may be useful as a QA tool to evaluate emissions calculated by other methods.
Auto Refinishing	Census-based Emission Factors	+	+	0	0	+	--	Use census-based emission factors (i.e, per-employee emission factors with employment data or per capita

Table B-1

(Continued)

								emission factors with population data). Adjust for average VOC content socioeconomic differences between the U.S. and Mexico. May need to adjust for technology differences (e.g., level of automation, spray efficiency/thickness, etc.).
	Surveying	0	0	+	+	0	+	Conduct a stratified, random sampling survey to collect coating usage from a limited number of auto refinishing shops and use these data to develop per-employee or per capita emission factors.
Auto Refinishing (Cont.)	Surveying/Multivariate Model	--	--	+	+	--	+	Conduct a stratified, random sampling survey to collect coating usage and other variables (e.g., percent of population that are car owners, frequency of refinishing or custom paint jobs, size of the used car market) to develop a multivariate model.
Graphic Arts	Census-based Emission Factors	+	+	--	0	+	--	Use census-based emission factors (i.e., AP-42 per capita emission factors with population data). Adjust for average VOC content

Table B-1

(Continued)

								differences between inks in the U.S. and Mexico. Per capita emission factors developed in the U.S. likely to introduce high degree of uncertainty.
	Material Balance	0	0	0	0	0	0	Use Mexico-wide material balance of graphic arts solvents to develop per-employee or per capita emission factors.
Graphic Arts (Cont.)	Surveying	0	0	+	+	0	+	Conduct a stratified, random sampling survey of a limited number of graphic arts establishments to collect solvent usage data and develop per-employee or per capita emission factors.
	Surveying / Multivariate Model	--	--	+	+	--	+	Conduct a stratified, random sampling survey to collect solvent usage and other variables (e.g., population density, standard of living, number of employees) to develop a multivariate model.
Solvent Use - Asphalt Application	Material Balance / AP-42 Emission Factors	+	+	0	0	+	0	Use material balance to estimate total paving material usage for cutback asphalt and emulsified asphalt and combine with AP-42

Table B-1

(Continued)

								emission factors. Total paving material estimates may be available from PEMEX data or Federal Highway Agency information.
Solvent Use - Asphalt Application (Cont.)	Census-based Emission Factors	+	+	0	0	+	--	Use census-based emission factors (i.e., per capita emission factors for cutback asphalt and emulsified asphalt) and apply to all Mexican asphalt application types.
Solvent Use - Agricultural Pesticide Application	Surveying	0	--	+	+	--	0	Survey Mexican agricultural department offices or conduct a stratified, random sampling survey of farmer pesticide usage. Depending on data availability, develop crop-specific acreage emission factors or region-specific per-acre emission factors.
	Material Balance	0	0	0	0	0	0	Use Mexico-wide material balance of agricultural pesticide consumption to develop a national per-acre or crop-specific per-acre emission factors.
	Extrapolation	+	+	--	--	0	--	Use U.S. national average per-acre emission factor and extrapolate to Mexico.

Table B-1

(Continued)

Solvent Use - Agricultural Pesticide Application (Cont.)	Surveying / Multivariate Model	--	--	+	+	--	+	Conduct a stratified, random sampling survey to collect pesticide usage and other variables (e.g., crop type, farm size, climate, etc.) to develop a multivariate model.
Solvent Use - Agricultural Fertilizer Application	Surveying	0	--	+	+	--	0	Survey Mexican agricultural department offices or conduct a stratified, random sampling survey of farmer fertilizer usage. Depending on data availability, develop crop-specific acreage emission factors or region-specific per-acre emission factors.
	Material Balance	0	0	0	0	0	0	Use Mexico-wide material balance of agricultural fertilizer consumption to develop a national per-acre or crop-specific per-acre emission factors.
	Extrapolation	+	+	--	--	0	--	Use U.S. national average per-acre emission factor and extrapolate to Mexico.
Solvent Use - Agricultural Fertilizer Application (Cont.)	Surveying / Multivariate Model	--	--	+	+	--	+	Conduct a stratified, random sampling survey to collect fertilizer usage and other variables (e.g., crop type, soil type, farm size, climate, etc.) to develop a multivariate

Table B-1

(Continued)

								model.
Agriculture Production - Agricultural Burning	Extrapolate / U.S. EPA Emission Factors	+	+	--	--	0	--	Assume U.S. agricultural burning practices apply to Mexico to determine acres of land burned in Mexico by crop type.
	Extrapolation / WHO Emission Factors	+	+	--	--	+	--	Use extrapolation to estimate the total quantity of waste burned or the total area of cropland (m^2) and combine with crop type-specific (i.e., field, vine, weeds, orchard, forest residue) WHO emission factors.
	Surveying	+	+	0	0	+	0	Survey agricultural experts in Mexico to develop crop-specific waste quantity estimates and combine with existing emission factors.
Agriculture Production - Agricultural Burning (Cont.)	Surveying / Multivariate Model	--	--	+	+	--	+	Survey agricultural operations / experts to collect the quantity and type of wastes burned and other variables (e.g., crop type, climate, acreage, traditional farming methods) to develop a multivariate model.
Agricultural Production - Tilling	Surveying / Multivariate Model	0	0	+	+	0	+	Conduct a stratified, random sampling survey of agricultural tilling operations to collect variables (e.g., crop type,

Table B-1

(Continued)

								acreage, days of precipitation, traditional farming methods, mobile agricultural equipment) to develop a multivariate model. Will need to distinguish between subsistence and commercial farming.
Fires - Structures	Surveying / AP-42 Emission Factors	0	0	0	0	0	0	Survey fire departments in major Mexican cities to estimate the total number of fires and average fuel loading factors (i.e., quantity of material burned per fire).
Waste Management - Wastewater Treatment	Surveying / AP-42 Emission Factors	0	0	0	0	+	0	Conduct surveys to estimate the quantity of wastewater treated and combine with AP-42 emission factors.
	Multivariate Model	+	+	0	0	0	+	Expand survey efforts to develop model based on a number of variables such as population, employment, etc.
Open Sewage	Surveying	0	0	0	+	0	+	Conduct a stratified, random sampling survey to collect sewage generation data and develop simple emission factors.
	Surveying / Multivariate Model	--	--	+	+	--	+	Conduct a stratified random sampling survey to collect sewage generation data and

Table B-1

(Continued)

								other variables (e.g., population density, standard of living)

Table B-1

(Continued)

Street Vending / Cooking	Surveying	0	0	0	+	0	+	Conduct a stratified, random sampling survey of a limited number of street vendors to collect fuel usage data and develop simple emission factors.
	Surveying / Multivariate Model	--	--	+	+	--	+	Conduct a stratified random sampling survey to collect fuel usage and other variables (e.g., population density, industrial / commercial concentration, food consumption patterns) to develop a multivariate model.
Domestic Ammonia Emissions	Census-based Emission Factors	+	+	0	0	+	+	Apply existing ammonia per capita emission factors with population and other census data.
Tortilla Factories	Extrapolation / Mexico Point Source Inventory	+	0	0	+	+	0	Use Mexican point source inventory emissions and employment figures to develop per-employee emission factors. The Mexico City inventory only tracks fuel combustion emissions from tortilla factories. There may not be any tortilla factories currently included in the

Table B-1

(Continued)

								point source inventory.
	Surveying / Emission Factors	--	0	+	+	0	+	Conduct a stratified, random sampling survey to collect fuel usage and other material usage to develop census-based per-employee, per capita or per tortilla material consumption factors.
Brick Manufacturing	Surveying	+	+	+	0	+	0	Survey small facilities to collect emissions data.
	Surveying / Multivariate Model	0	0	+	+	0	+	Conduct a stratified, random sampling survey to collect emissions and other variables (e.g., fuel use, population density, number of employees, brick production) to develop a multivariate model.
Building Construction	Surveying / AP-42 Emission Factors	0	0	0	0	+	0	Conduct surveys to estimate the amount of construction activity and combine with AP-42 emission factors.
	Surveying / Multivariate Model	+	+	0	0	0	+	Conduct a stratified, random sampling survey of construction operations to collect variables (e.g., construction practices, types of construction equipment, acreage, soil types) to develop a multivariate model.
Traffic	Census-based Emission	+	+	0	0	+	--	Use census-based

Table B-1

(Continued)

Markings	Factors							emission factors (i.e., per-employee emission factors with employment data or per capita emission factors with population data). Adjust for average VOC content and socioeconomic differences between the U.S. and Mexico.
Traffic Markings (Cont.)	Material Balance	0	0	0	0	0	0	Use Mexico-wide material balance of traffic marking surface coatings to develop per-employee or per capita emission factors. Total traffic marking coatings estimates may be available from PEMEX data or Federal Highway Agency information.
Solvent Use - Rubber and Plastics Fabrication	Extrapolation / Mexican Point Source Inventory	+	0	0	+	+	0	Use Mexican point source inventory emissions and production-worker (non-sales) employment figures to develop per-production worker emission factors.
	Surveying	--	--	+	+	--	+	Conduct a stratified, random sampling survey of rubber and plastics plants and use these data to develop simple emission factors.
	Material Balance	0	0	0	0	0	0	Use Mexico-wide material balance of

Table B-1

(Continued)

								solvents used for rubber and plastics fabrication to develop per-employee or per capita emission factors. May spatially disaggregate by employment data.
Waste Management - Landfills	Material Balance / Mechanistic Model	+	+	0	0	+	0	Use material balance to estimate the total quantity of waste disposed and combine with the AP-42 mechanistic model (based on biodegradation).
	Survey / Mechanistic Model	0	0	+	+	0	+	Use surveys to gather data required to run mechanistic model.
Bakeries	Census-based Emission Factors	+	+	0	0	+	0	None.

APPENDIX C

CRITICAL REVIEW OF NONROAD MOBILE SOURCE EMISSIONS METHODS

Table C-1

Critical Review of Nonroad Mobile Source Methods

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
Aircraft	Source Sampling / Direct	--	--	0	0	--	--	Development of emission factors is possible using source sampling, but this would not be a very cost effective approach. Source sampling should be used for much more dominant source types.
	Surveying / AP-42 Emission Factors	+	+	0	+	+	0	Emissions from aircraft have been studied in the U.S. Emission factors need to be modified if there are significant differences in aircraft types, usage, and fuels.
Railroads	Source Sampling / Direct	--	0	+	0	--	--	Development of emission factors is possible using source sampling, but this would not be a very cost effective approach. Source sampling should be used for much more dominant source types.
Railroads (Cont.)	Surveying / AP-42 Emission Factors	+	+	--	+	+	0	Emission factors in AP-42 are based on limited sets of data. As a result, large uncertainty is possible. Emission factors need to be modified if there are significant differences in locomotive types, usage,

Table C-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
								and fuels.
Commercial Marine Vessels	Source Testing / Direct	--	0	+	+	--	--	Development of emission factors is possible using source sampling, but this would not be a very cost effective approach. Source sampling should be used for much more dominant source types.
	Survey / AP-42 Emission Factors	0	0	0	+	+	+	Survey individual ports to develop origin and destination data. Also request in port activities as part of survey.
	Extrapolation	0	+	0	+	0	0	Scale U.S. EPA nonroad engine equipment populations and usage data by appropriate Mexican activity indicators to determine emissions.
Agricultural Equipment	Extrapolation	+	+	--	0	0	--	Scale U.S. EPA nonroad engine equipment populations and usage data by appropriate Mexican activity indicators to determine emissions.
	Surveying	0	0	0	+	0	0	Conduct a stratified, random sampling survey of agricultural equipment usage to

Table C-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
								develop Mexico-specific emission estimates.
	Surveying / Multivariate Model	--	--	+	+	--	+	Conduct a stratified, random sampling survey of agricultural equipment to collect variables (e.g., crop type, acreage, usage patterns) to develop a multivariate model using LULC data.
Construction Equipment	Extrapolation	+	+	0	+	0	--	Scale U.S. EPA nonroad engine equipment populations and usage data by appropriate Mexican activity indicators to determine emissions.
Construction Equipment (Cont.)	Surveying	0	0	+	+	+	0	Conduct a stratified, random sampling survey of construction equipment usage to develop Mexico-specific emission estimates.
	Surveying / Multivariate Model	--	--	+	+	--	+	Conduct a stratified, random sampling survey of construction equipment to collect variables (e.g., standard of living, population density, local construction activity) to develop a multivariate

Table C-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
								model.
Industrial Equipment	Extrapolation	+	+	0	+	0	--	Scale U.S. EPA nonroad engine equipment populations and usage data by appropriate Mexican activity indicators to determine emissions.
	Surveying	0	0	+	+	+	0	Conduct a stratified, random sampling survey of industrial equipment usage to develop Mexico-specific emission estimates.
Industrial Equipment (Cont.)	Surveying / Multivariate Model	--	--	+	+	--	+	Conduct a stratified, random sampling survey of industrial equipment to collect variables (e.g., standard of living, "industrial density", industrial activity) to develop a multivariate model.
Light Commercial Equipment	Extrapolation / Population Data	+	+	--	--	+	--	Use U.S. EPA nonroad engine emission estimates and extrapolate for Mexico based on population. Unquantified differences between the two countries could lead to large uncertainty.

Table C-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
	Extrapolation	0	0	0	+	0	0	Scale U.S. EPA nonroad engine equipment populations and usage data by appropriate Mexican activity indicators to determine emissions.
	Surveying	0	0	+	+	0	+	Conduct a stratified, random sampling survey of light commercial equipment usage to develop Mexico-specific emission estimates.
Light Commercial Equipment (Cont.)	Surveying/ Multivariate Model	--	--	+	+	--	+	Conduct a stratified, random sampling survey of commercial equipment to collect variables (e.g., standard of living, "commercial density", commercial activity) to develop a multivariate model.
Lawn and Garden Equipment	Extrapolation	+	+	--	0	0	0	Scale U.S. EPA nonroad engine equipment populations and usage data by appropriate Mexican activity indicators to determine emissions.
	Surveying	0	0	+	0	+	0	Conduct a stratified, random sampling survey of lawn and garden

Table C-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
								equipment usage to develop Mexico-specific emission estimates.
	Surveying / Multivariate Model	--	--	+	+	--	+	Conduct a stratified, random sampling survey of lawn and garden equipment to collect variables (e.g., population density, standard of living, home / apartment ratio, park density) to develop a multivariate model.
Recreational Equipment	Extrapolation / Population Data	+	+	--	--	0	--	Use U.S. EPA non-road engine emission estimates and extrapolate for Mexico based on population. Unquantified differences between the two countries could lead to large uncertainty.
	Extrapolation	+	+	0	0	0	--	Scale U.S. EPA non-road engine equipment populations and usage data by appropriate Mexican activity indicators to determine emissions.
	Surveying	--	--	+	+	--	0	Conduct a stratified, random sampling survey of recreational

Table C-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
								equipment usage to develop Mexico-specific emission estimates.
	Surveying / Parametric Model	--	--	+	+	--	+	Conduct a stratified, random sampling survey of recreation equipment to collect variables (e.g., population density, standard of living) to develop a parametric model.
Recreational Marine Equipment	Extrapolation / Population Data	+	+	--	--	0	--	Use U.S. EPA non-road engine emission estimates and extrapolate for Mexico based on population. Unquantified differences between the two countries could lead to large uncertainty.
	Extrapolation	0	+	0	+	0	0	Scale U.S. EPA non-road engine equipment populations and usage data by appropriate Mexican activity indicators to determine emissions.
	Surveying	--	--	+	+	+	0	Conduct a stratified, random sampling survey of recreational equipment usage to develop Mexico-specific

Table C-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
								emission estimates.
	Surveying / Multivariate Model	--	--	+	+	--	+	Conduct a stratified, random sampling survey of recreation marine equipment to collect variables (e.g., standard of living, local water surface area) to develop a multivariate model.

APPENDIX D

CRITICAL REVIEW OF ON-ROAD MOTOR VEHICLE SOURCE EMISSIONS METHODS

Table D-1

Critical Review of On-Road Motor Vehicle Source Emission Factor Methods

Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
Rapid Assessment Inventory Technique	+	+	--	--	0	--	Two sets of generic emission factors. One set of factors requires simple VKT estimates and the other requires fuel consumption estimates. Local variability is not accounted for in these emission factors.
Use modified U.S. per capita or per vehicle emission factors with population or vehicle registration data.	0	0	--	--	0	--	U.S. emission factors must be modified to account for socioeconomic, cultural, and technological differences in Mexico. Currently, these emission factors and modification factors do not exist.
MOBILE-MCMA	0	0	0	+	0	+	Emission factors are based on Mexico City input parameters. These factors are not applicable for the entire country. Refinement of the model is required for application outside Mexico City. Refinement is taking place under projects conducted in Monterrey and Ciudad Juárez.
MOBILE5c	--	--	+	+	--	0	Model can be modified to reflect local conditions, however extensive testing and data development is required to determine some of the input parameters. Default parameters may not properly represent local conditions.
Modal Model Approach	--	--	+	+	--	0	This model currently does not exist. Instead of being a modified MOBILE model, it would be a new model that would more accurately represent mobile emissions in Mexico. It might model such things as different driving modes

Table D-1

(Continued)

Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
							and Mexico's unique vehicle mix. Very expensive to develop.
PART5	0	0	--	+	0	+	This method can only be used for determination of PM emissions. Emission factors are based on United States input parameters. Structure of this model is similar to MOBILE5A, so this model could possibly be modified to represent conditions in Mexico, much like MOBILE-MCMA is a modified version of MOBILE5A. Uncertainty of PART5 is higher than that for the MOBILE models because data sets are not as robust.
Sulfur Fuel Balance	+	+	+	0	+	+	This method can only be used for determination of SO_x emissions. Uncertainty from this method results mainly from uncertain fuel sulfur levels.

Table D-2

Critical Review of Methods for Estimating Vehicle Kilometers Traveled (VKT) or other On-road Motor Vehicle Source Activity Data

Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
Population / Vehicle Registration Data	+	+	0	--	+	--	These data are used only with per capita or per vehicle emission factors. These data are typically available through the national census and transportation organization.
Fuel Consumption Data	+	0	0	0	+	+	VKT can be indirectly calculated through fuel consumption. Fuel consumption data are usually derived from fuel distribution information. This is especially easy when the distribution system is concentrated among only a few entities. In the absence of fuel distribution information, fuel consumption can be calculated by fuel tax data. In the near term, fuel consumption data is useful when VKT is unavailable. As VKT information develops, fuel consumption data can serve as a reasonableness check.
"Simple" VKT Data	0	0	0	+	0	+	"Simple" VKT usually is estimated for a relatively large geographical area. Although simple VKT is commonly based on traffic counting programs, these programs tend to be geographically limited. Consequently, some assumptions must be used to "expand" the coverage of simple VKT.
"Complex" VKT Data	--	--	+	+	--	+	"Complex" VKT is usually only

Table D-2

(Continued)

Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
							determined for large metropolitan areas. Detailed VKT information is necessary in such urban areas with large numbers of mobile sources. Because these areas are relatively small, detailed VKT data can be determined by traffic control programs or transportation models.

APPENDIX E

CRITICAL REVIEW OF BIOGENIC AND NATURAL SOURCE EMISSIONS METHODS

Table E-1

Critical Review of Biogenic and Natural Source Emissions Methodologies

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
Biogenic VOC	Extrapolate U.S. Emissions	+	0	--	--	0	--	Initial biogenic emission estimates for Mexico could be extrapolated from U.S. estimates. Emission fluxes for specific LULC types would be develop from U.S. results and applied to Mexico. This approach would likely rely on hard copy maps and be highly labor intensive. However, we have seen this approach applied in California's Los Angeles Air Basin and in Taiwan.
	BEIS (Pierce et al., 1990)	0	0	0	--	0	--	U.S. EPA's BEIS model could be used to model biogenic emissions for the country of Mexico. Data demands for this model are modest; however, computational approach used in this model is somewhat outdated. Electronic file containing LULC data must be developed for use in Mexico.
Biogenic VOC (Cont.)	BIOME (Mayenkar et al., 1992)	--	--	+	+	--	+	This is a flexible modeling system designed to develop biogenic emission estimates from the bottom-up using plant species-specific emission factors rather than foliar mass emission factors such as those used in BEIS. System is written in SAS®

Table E-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
								and ARC/INFO® and therefore can be easily updated and tailored to Mexico. System currently uses Tingy algorithms for temporal adjustments; system should be updated to use the Guenther algorithms. Large effort would be required to develop LULC data and assemble/assign emission factors for LULC data.
Biogenic VOC (Cont.)	BEISII (Geron et al., 1994)	--	--	+	+	--	+	This new modeling system uses tree genus-specific emission factors in a FORTRAN modeling framework. Model was specifically designed for the eastern U.S. to match U.S. Forest Service LULC data. Application of this model in the southeast U.S. results in significantly higher biogenic emission rates (3 to 10 times higher) than previous modeling efforts. This model could be adapted to Mexico. Data development step would be similar to that of using BIOME. System currently uses Guenther temporal adjustment algorithms.
Windblown Dust	Extrapolate U.S. Emission	0	--	--	--	--	--	Extrapolation could be used to quickly develop emission estimates, but results would

Table E-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
	Rates							have a very large degree of uncertainty.
	Multivariate Model	0	0	+	+	+	+	U.S. EPA is currently developing a refined approach for wind blown dust from agricultural lands. Modeling framework should be applicable to Mexico.
Soil NO_x	Extrapolate U.S. Emission Rates	0	--	--	--	--	--	Very few soil NO_x emission estimates have been developed in the U.S.; there is not much to extrapolate from. Resulting uncertainty from this approach would be large.
	Multivariate Model	0	0	0	+	+	+	There has only been limited research in this area. Soil NO_x models are not yet well developed.
Soil NH_3	Extrapolate U.S. Emission Rates	0	--	--	--	--	--	Very few soil NO_x emission estimates have been developed in the U.S.; there is not much to extrapolate from. Resulting uncertainty from this approach would be large.
	Multivariate Model	0	0	0	+	+	+	There has only been limited research in this area. Soil NH_3 models are not yet well developed.
Lightning	Mechanisti	+	+	+	+	+	+	Reasonably simple mechanisms

Table E-1

(Continued)

Category	Method	Cost Effectiveness	Practicality	Uncertainty	Upgrade Potential	Near Term Rating	Long Term Rating	Comments
	c Model							have been developed that could be applied in Mexico.
Geogenic	N / A	N / A	N / A	N / A	N / A	N / A	N / A	Geogenic emissions are site specific and must be quantified through special studies.

Implementation Plan

Mexico Emissions Inventory Methodology

Version 2.0

Prepared for:

Western Governors' Association and
Binational Advisory Committee
Denver, Colorado

March 1996

670-017-06-01
March 19, 1996

John T. Leary
Project Manager
Western Governors' Association
600 17th Street
Suite 1705, South Tower
Denver, CO 80202

Subject: Transmittal of the Mexico Emissions Inventory Methodology Implementation Plan, Version 2.0

Dear John:

Please find enclosed a copy of the revised Implementation Plan for the Mexico Emissions Inventory Methodology Project. Copies have been sent to the members of the Binational Advisory Committee, INE, and to Jim Yarbrough of EPA Region 6. Bill Jones requested that we add Mr. Yarbrough to the distribution list for this project.

This version reflects the comments we received last fall in Mexico City and your comments of last week. The funding scenarios have also been modified to reflect current and anticipated funding.

If there are any questions regarding this version of the Implementation Plan, please call me at 916/857-7467.

Sincerely,

Ronald J. Dickson
Senior Staff Engineer

c: Binational Advisory Committee
Dr. José Ortega, Corporación Radian
Jim Yarbrough, EPA Region VI

670-017-06-01

IMPLEMENTATION PLAN

FOR

MEXICO EMISSIONS INVENTORY METHODOLOGY

Version 2.0

Prepared for:

Western Governors' Association
Denver, Colorado

and

Binational Advisory Committee

Prepared by:

Radian Corporation
10389 Old Placerville Road
Sacramento, CA 95827

March 19, 1996

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1.0 SUMMARY

Recently, there has been an increasingly larger degree of urbanization and industrial activity throughout Mexico, particularly in the Mexico/U.S. border region. Air quality has been impaired in several border regions, such as El Paso/Ciudad Juárez, Ambos Nogales, and Calexico/Mexicalli. In addition, there are significant air transboundary issues that must be better understood to address regional air pollution concerns pertaining to long range transport.

Air pollution results from a complex mix of literally thousands of sources ranging from industrial smoke stacks and motor vehicles, to the individual use of grooming products, household cleaners, and paints. Even plant and animal life can play an important role in the air pollution problem. The complex nature of air pollution requires the development of detailed plans on a regional level that provide a better understanding of the emission sources and methods for reducing the air quality impacts associated with air pollution. Mexico's National Institute of Ecology (INE) has expressed a desire to initiate the air quality planning process throughout the country of Mexico, including the border region. Consequently, both Mexico and the United States have a common need to develop inventories of emission sources and process operations to facilitate this planning activity.

Examples of air quality planning activities that require good emissions and process inventories include:

- Application of air quality models;
- Examination of source attribution for emissions control where deemed necessary;
- Characterization of process technologies and air pollution control methods used by industry;
- Development of emission projections to examine possible changes in future air quality;
- Analysis of emission trends; and
- Analysis of emissions transport from one region to another.

By conducting these types of activities, air quality planning in both Mexico and the United States will be enhanced. Development of a fundamentally sound inventory program (including emissions, process technologies, and air pollution control equipment) is a key first step towards achieving this goal.

Significant emissions inventory efforts and methodology development have already occurred in certain regions of Mexico, primarily Mexico City. Mexico's National Institute of Ecology desires to expand these efforts into other regions and to implement a national inventory program. As currently envisioned, emission estimates would be developed at the state and local level for point, area, and mobile sources and managed in a common database management system.

This document represents the final work product for Phase I of the Mexico Emissions Inventory Methodology Project. The purpose of the Implementation Plan is to prioritize activities that could be carried out in the Phase II portion of this effort to help Mexico establish a national inventory program. To assist in the allocation of potential resources, three funding scenarios have been developed to help establish priorities for the Phase II effort. Similarly, a detailed schedule has been developed illustrating the proposed sequencing of the recommended Phase II activities.

1.1 Phase II Activities

To establish the national program, the Phase II portion of this effort will consist of four elements:

- Development of inventory manuals;
- Development of training materials;
- Performance of various technical activities needed to develop certain information and data so that Mexico-specific emission estimates can be developed; and
- Development of a data management system.

A summary of the schedule for completing the Phase II activities is shown in Figure 1-1. Each of these four elements are summarized below.

Figure 1-1

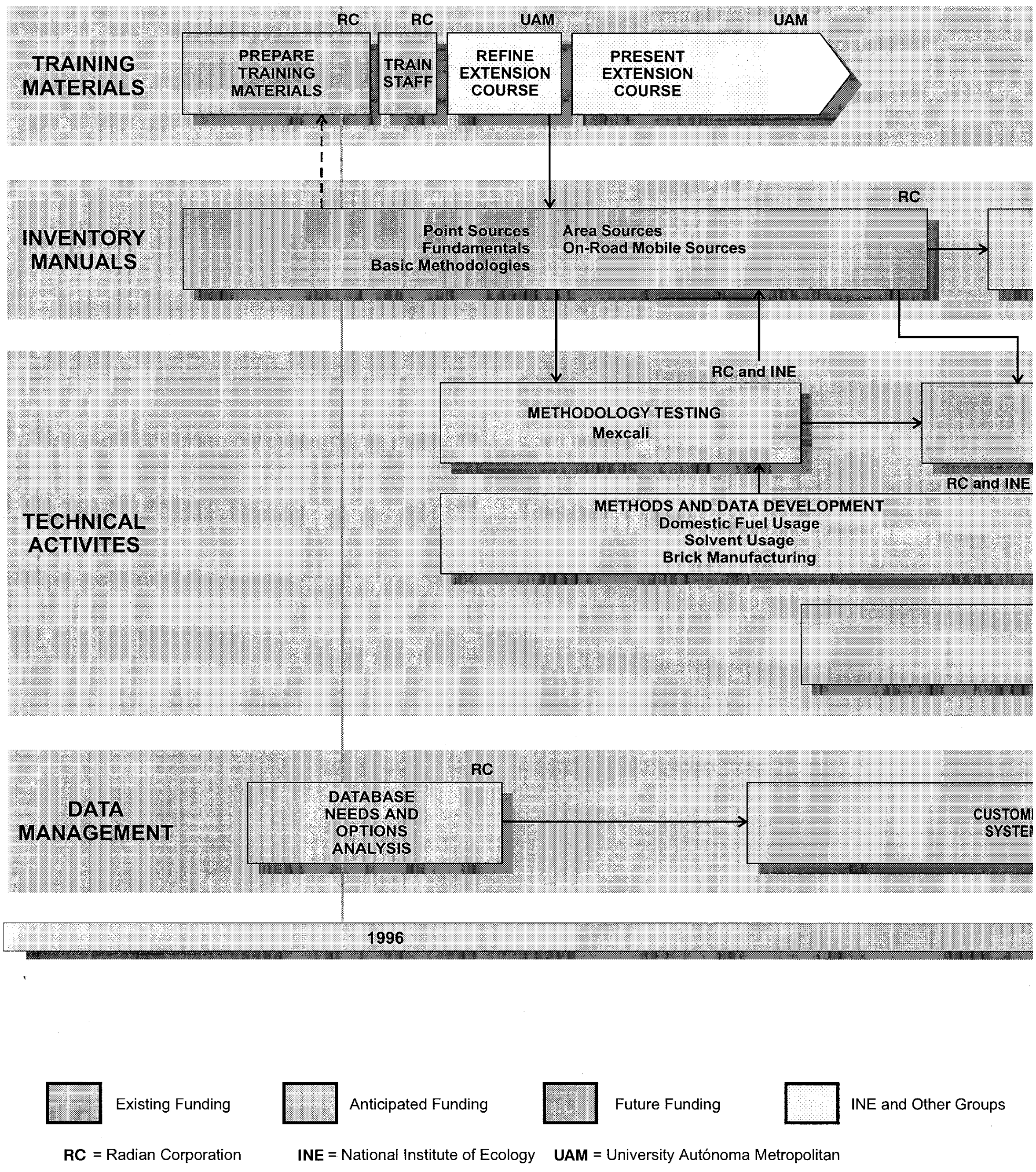
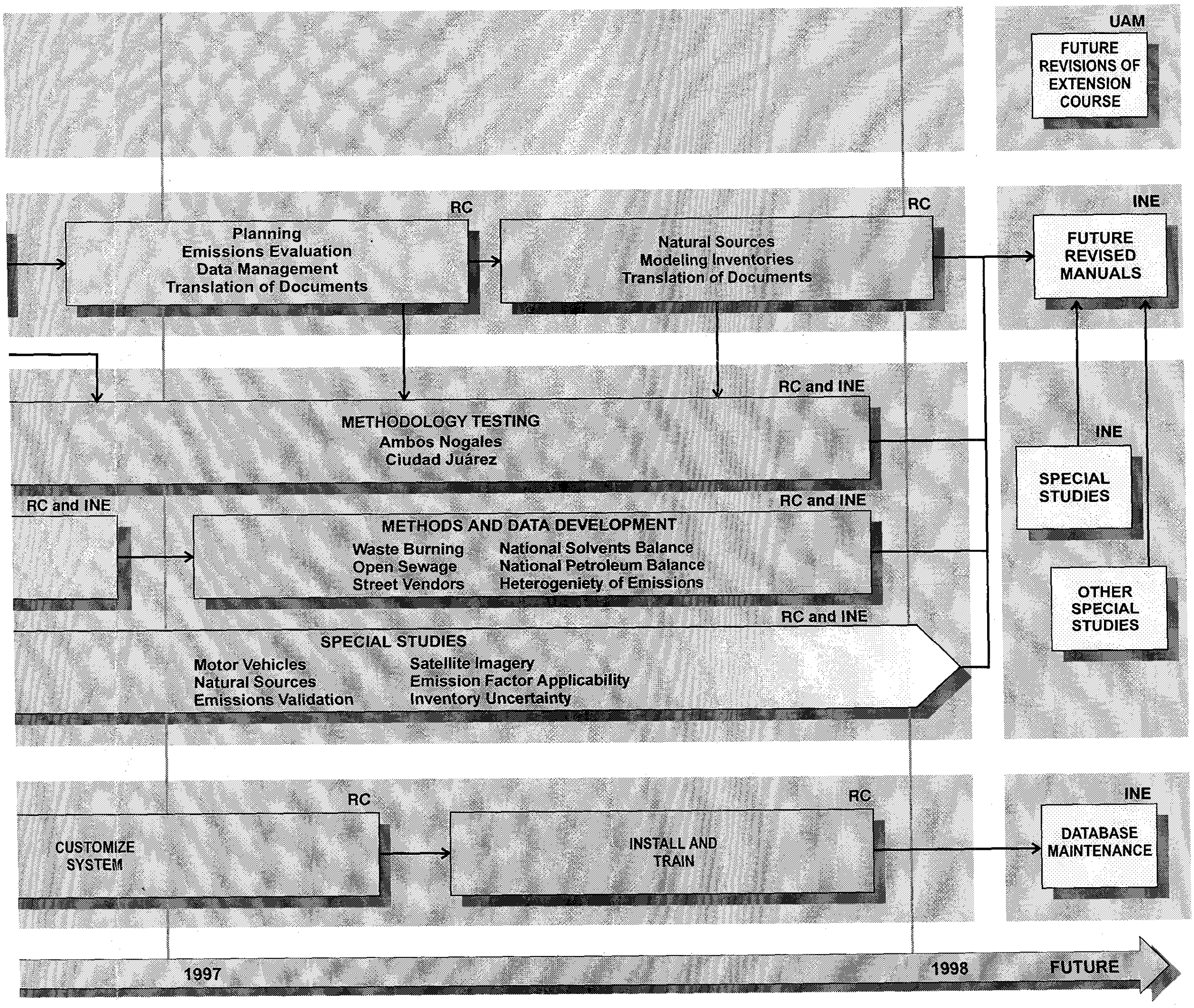

TRAINING MATERIALS
RC
PREPARE TRAINING MATERIALS
RC
TRAIN STAFF
UAM
REFINE EXTENSION COURSE
UAM
PRESENT EXTENSION COURSE
INVENTORY MANUALS
RC
Point Sources
Fundamentals
Basic Methodologies
Area Sources
On-Road Mobile Sources
TECHNICAL ACTIVITES
RC and INE
METHODOLOGY TESTING
Mexcali
RC and INE
METHODS AND DATA DEVELOPMENT
Domestic Fuel Usage
Solvent Usage
Brick Manufacturing
DATA MANAGEMENT
RC
DATABASE NEEDS AND OPTIONS ANALYSIS
CUSTOMI
SYSTEI
1996
Existing Funding
Anticipated Funding
Future Funding
INE and Other Groups
RC = Radian Corporation
INE = National Institute of Ecology
UAM = University Autónoma Metropolitan

Figure 1-1 (Continued)



er Groups

Figure 1-1.
Phase II Program

MEXAQ1.CDR - 03.19.96 - LCT - SAC

1.1.1 Inventory Manuals

INE staff have identified a specific need to develop a set of inventory manuals that can be used throughout the country to help coordinate the development of consistent emission estimates. In response to this need, conceptual plans for a set of manuals consisting of 11 volumes have been developed. These manuals will focus on the development of emission estimates, as well as program planning, database management, emissions validation, and other important topics. These manuals will assist the implementation of the inventory program and will provide a mechanism to maintain that program over time so that emissions and process technology inventories can be developed in periodic cycles and continually improved.

1.1.2 Training Materials

As currently envisioned, a college level extension course in emissions inventory development will be developed and given by staff at the University Autónoma Metropolitan - Azcotzalco (UAM). The course will be offered to state and local government staff to provide necessary training in emissions inventory development. Eventually, the class will be offered to industry and environmental consultants in Mexico to help promote the development of consistent and accurate emissions inventories. Developing this course will consist of three steps:

- Developing the course materials;
- Training UAM staff to teach the course; and
- Refining the course materials based on the review of knowledgeable inventory staff at INE and other organizations in Mexico.

1.1.3 Technical Activities

Several technical activities are envisioned for the Phase II effort so that specific data and information can be developed, allowing for the preparation of Mexico-specific emission estimates. Data are currently available to estimate emissions from most sources in Mexico, but the current emission factors and estimation methods do not always properly simulate conditions in Mexico. In addition, there are several emission sources unique to Mexico for which there is currently insufficient data and information to estimate emissions. To address these data and information limitations, various technical activities have been identified that fall into one of the following major areas:

- Special studies for area sources, including additional effort to develop the area source methodology (see previous report entitled *Methods Evaluation and Proposal for the Mexico Emissions Inventory Program*);
- Special studies for motor vehicles;
- Special studies for natural sources;
- Emission estimation methodology testing;
- Data and procedures for use in emissions validation;
- Emission factor applicability to Mexico; and
- Inventory uncertainty methodology and testing.

1.1.4 Data Management

For point sources, nearly all criteria-type emissions inventory data are collected by INE headquarters staff in Mexico City and by Regional Office personnel for designated cities in Mexico. These inventories are generated by INE staff on personal computers (PCs) using activity data (i.e., throughput, production, process rates, etc.) obtained from responses to annual questionnaires (encuestas) mailed to industrial facilities by INE. These responses are coupled with emission factors contained in the Sistema Nacional de Información de Fuentes Fíjas (SNIFF) or National System of Information on Stationary Sources. This is a Dbase III Plus format PC data handling system.

Data management at INE will be standardized on Oracle, Novell, and UNIX. They also plan on using Lotus Notes as a means to transfer and share large data sets or documents among multiple users. INE is currently in the process of developing a networked computer system at INE headquarters.

As part of this modernization effort, INE has requested technical support for the implementation of a more robust inventory data management system. The proposed approach to develop a new system for INE is described in Section 5.0. This effort will begin with a Database Needs Assessment and Options Analysis to select the approach best-suited to meet the requirements of the Mexico Emissions Inventory Program within schedule and budgetary constraints. During this analysis, the existing database system, SNIFF, will be evaluated, as well as other systems that have the potential to meet the data management requirements for this project. After the needs Assessment and Options Analysis is completed, decisions will be made to develop a new system or customize an existing system.

The newly developed or modified database design will be coded and tested. The finished product of this effort will consist of a completed and tested database system with supporting training and documentation.

1.2 Phase II Resource Estimates

Table 1-1 summarizes the resources required to fully implement the development of the manuals, training materials, and technical activities described in this document. At the start of this effort, it was recognized that Phase II resources would be insufficient to complete the $5M to $7M effort described here. Therefore, three different funding scenarios have been developed: (1) Existing Funding, (2) Anticipated Funding, and (3) Future Funding. These scenarios serve to identify priorities for carrying out the Phase II effort so that the most critical items can be addressed first, followed by other activities as funding becomes available. Tables 1-2 through 1-4 illustrate the activities that would be completed under each of these funding scenarios.

1.3 Phase II Schedule

Figure 1-1 illustrates the schedule for completing each of the recommended activities presented in this document. Full implementation of these activities will take several years. The schedule is quite aggressive, and completing all of these activities within the time frame shown is unlikely. Nonetheless, an aggressive schedule has been developed so that work can be initiated and completed as soon as possible.

Table 1-1

Summary of Phase II Implementation Costs

Program Element	Cost Estimate ($000)
Training Course	165
Inventory Manuals	350 - 480
Translation of Inventory Manuals	60
Area Source Methodology Development	300
Special Studies for Area Sources	550
Special Studies for Motor Vehicles	950 - 1,200
Special Studies for Natural Sources (Biogenics and Soil NO_x)	600
Methodology Testing (3 regions)	600
Emissions Validation Methodology	100
Data Management	160 - 1,100
Satellite Imagery Data	1,300
Emission Factor Applicability	250
Inventory Uncertainty Methodology and Testing	60
Total	5,400 - 6,800

Table 1-2

Technical Activities for Scenario #1 (Existing Funding)[a]

Primary Activity	Subactivities
Training for University	Develop Training Course Curriculum
	Train Staff
Manuals Development	Inventory Fundamentals Manual
	Basic Methodologies Manual
	Point Sources Manual
	Area Sources Manual
	On-Road Mobile Sources Manual

[a] Existing funds are approximately $345,000.

Table 1-3

Technical Activities for Scenario #2 (Anticipated Funding)[a,b]

Primary Activity	Subactivities
Expanded University Training	Additional Time for Training
Manuals Development	Program Planning Manual
	Emissions Evaluation Manual
	Data Management Manual
	Translation of Manuals from English to Spanish Manual
Area Source Special Studies	Fugitive Emissions from Domestic LPG Usage
	Solvent Use Study
	Emissions from Brick Manufacturing
Database Management	Needs Assessment Report
	Options Analysis Report
Methodology Testing	Mexicali Region[c]

[a] These activities are incremental additions to the activities shown in Table 1-2.

[b] Anticipated funds are approximately $900,000.

[c] Region selected because of its diverse industrial sources in comparison to other regims along the border.

Table 1-4

Technical Activities for Scenario #3 (Future Funding)[a,b]

Primary Activity	Subactivities
Manuals	Modeling Inventory Development Manual
Area Source Methodology Development	Multivariate Emission Models
Special Studies for Area Sources	Waste Burning
	Open Sewage
	Street Vendors
	National Solvents Balance
	National Petroleum Balance
	Heterogeneity of Emissions in Mexico
	Nonroad Equipment
Special Studies for Motor Vehicles	Driving Cycle Development
	Vehicle Testing
	Emission Factor Model Improvements
	I/M Effectiveness Analysis
	Tampering and Misfueling Analysis
	Unregistered Vehicle Study
Special Studies for Natural Sources	Biogenic Hydrocarbons
	Soil NO_x
Methodology Testing	Ciudad Juárez Region
	Ambos Nogales Region
Emissions Validation	Range Checks
	Top-Down Inventory Techniques
Data Management	Customize/Develop Database Management System
	Installation and Training
Satellite Imagery Data	N/A
Emission Factor Applicability	N/A
Inventory Uncertainty	N/A

[a] These activities are incremental additions to the activities shown in Tables 1-2 and 1-3.

[b] Estimated resource requirements for this scenario are $5.4 to $6.8 million.

2.0 INTRODUCTION

Significant inventory development efforts have occurred in Mexico City and other metropolitan areas of Mexico. These efforts must be expanded to all regions of the country in a systematic manner to achieve INE's goal of a national inventory. Developing emission estimates to meet air quality planning needs requires continual development and refinement; "one time" inventory efforts are not conducive to the air quality planning process. For lasting benefit, therefore, an *inventory program* must be developed so that accurate emission estimates can be developed for all important geographic regions, refined over time, and effectively applied in the air quality planning and monitoring process. To develop an inventory program, technical capacity needs to be developed throughout Mexico to sustain the national inventory program that is desired. This document describes the elements of a complete inventory program and presents the recommended schedule and resources required to accomplish this important goal.

The implementation plan presented here concludes the Phase I planning effort for the development of Mexico's inventory program. The Phase I planning effort consisted of the following key tasks:

- Task 1 - Work Plan Development;
- Task 2 - Information Surveying;
- Task 3 - Critical Review of Emissions Data;
- Task 4 - Critical Review of Emissions Methodologies;
- Task 5 - Methodology Proposal;
- Task 6 - Implementation Plan for the Methodology; and
- Task 7 - Technology Transfer.

The knowledge gained during the performance of these tasks is reflected in this implementation plan. As described below, Phase II activities will consist of training and further development of the inventory methodology.

Developing the inventory program will require training of Mexico staff and the performance of key technical activities so that inventory tools and databases can be tailored to Mexico. Current plans call for the development of a set of inventory manuals that will cover each element of the inventory program. These manuals will be used by local, state, and federal staff, as well as industry and private consultants, to guide the development of consistent emission estimates.

Work is also underway to develop a college level course in emissions inventory development. This course will be taught by the Environmental Engineering Department of the University Autónoma Metropolitan - Azcotzalco. Both the development of the manuals and the inventory course are described in Section 3.0 of this document.

Several technical activities have also been identified to better develop emission estimates that are specific to Mexico. These technical activities are described in Section 4.0. Data management issues are discussed in Section 5.0. Sections 6.0 and 7.0 describe the resource requirements and schedule, respectively, for carrying out the recommendations contained in this implementation plan.

Table 2-3

Mobile Source Categorization Used for Methods Evaluation

Category	Priority[a]	Pollutant	Comments
On-Road Motor Vehicles	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Category includes light-duty gas vehicles, light-duty diesel vehicles, light-duty gas trucks, light-duty diesel trucks, heavy-duty gas vehicles, heavy-duty diesel vehicles, and motorcycles.
Aircraft	2	CO, NO_x, SO_x, VOC, and PM	Category includes commercial, military, and private aircraft.
Railroads	2	CO, NO_x, SO_x, VOC, and PM	Category consists of diesel locomotives used only in switching and line haul application. Electric locomotives use electricity generated at stationary power plants (point sources), so these are not included as a nonroad source.
Commercial Marine Vessels	2	CO, NO_x, SO_x, VOC, and PM	Commercial marine vessels include fishing vessels, harbor vessels, cruise ships, ferries, commercial ships, etc.
Agricultural Equipment	2	CO, NO_x, SO_x, VOC, and PM	Agricultural equipment category includes tractors, combines, sprayers, harvesters, agricultural hydropower equipment, etc.
Construction Equipment	2	CO, NO_x, SO_x, VOC, and PM	Category consists of pavers, rollers, excavators, cement mixers, cranes, off-highway trucks, bulldozers, backhoes, etc.
Industrial Equipment	2	CO, NO_x, SO_x, VOC, and PM	Industrial equipment category consists of aerial lifts, forklifts, sweepers, abrasive blasters, industrial scrubbers/blowers/vacuums, airport service equipment, etc.
Light Commercial Equipment	2	CO, NO_x, SO_x, VOC, and PM	Category includes generators, pumps, compressors, welders, etc.
Lawn & Garden Equipment	3	CO, NO_x, SO_x, VOC, and PM	Category consists of lawnmowers, tillers, chainsaws, chippers, etc.
Recreational Equipment	3	CO, NO_x, SO_x, VOC, and PM	Recreational equipment category includes all-terrain vehicles, off-road motorcycles, golf carts, etc.

Table 2-4

Natural Source Categorization Used for Methods Evaluation

Major Category	Priority[a]	Pollutant	Comments
Biogenic VOC	1	VOC	Category includes isoprene, terpene, and other VOC emissions from natural, agricultural, and urban vegetative biomass.
Soil NO_x	2	NO_x	Microbial nitrification and denitrification cycles in soil under certain conditions can result in significant releases of NO_x. NO is the principle nitrogen species emitted by soils (overall under certain conditions NO_2 comprises less than 10% of soil NO_x emissions).
Soil NH_3	2	NH_3	Through the natural ammonification cycle, soil surfaces can emit significant amounts of NH_3.
Windblown Dust	1	PM	Wind erosion of crustal material can be a significant source of particulate matter. Although emissions originate primarily from disturbed lands (e.g., agricultural areas), emissions can also occur from undisturbed lands.
Lightning	3	NO_x	Several studies have shown lightning to be a source of NO_x. On a regional basis, emissions are typically low compared to anthropogenic emissions.
Geogenic	3	SO_x, VOC, and PM	There are a number of geogenic sources that can be important sources of air emissions under certain conditions. Examples include volcanoes and natural oil and gas seeps that can emit sulfur, particulate matter and VOCs.

[a] A priority has been assigned to communicate the current, perceived importance of each source type. The priorities assigned to each source type will be refined over time as feedback is obtained from INE and more Mexico-specific information is gathered.

3.0 TECHNOLOGY TRANSFER

The concept of technology transfer is a key element of this overall effort. The Phase II technology transfer activities will focus on the preparation of inventory manuals and the development of a college level course pertaining to emissions inventory activities. The proposed approach for these two activities is summarized below.

3.1 Development of Inventary Manuals

The Mexico Emissions Inventory Program Manuals will be developed as one of the major work elements in Phase II of the Mexico Emissions Inventory Project. The purpose of the manuals is to serve as a tool to support the development and implementation of an emissions

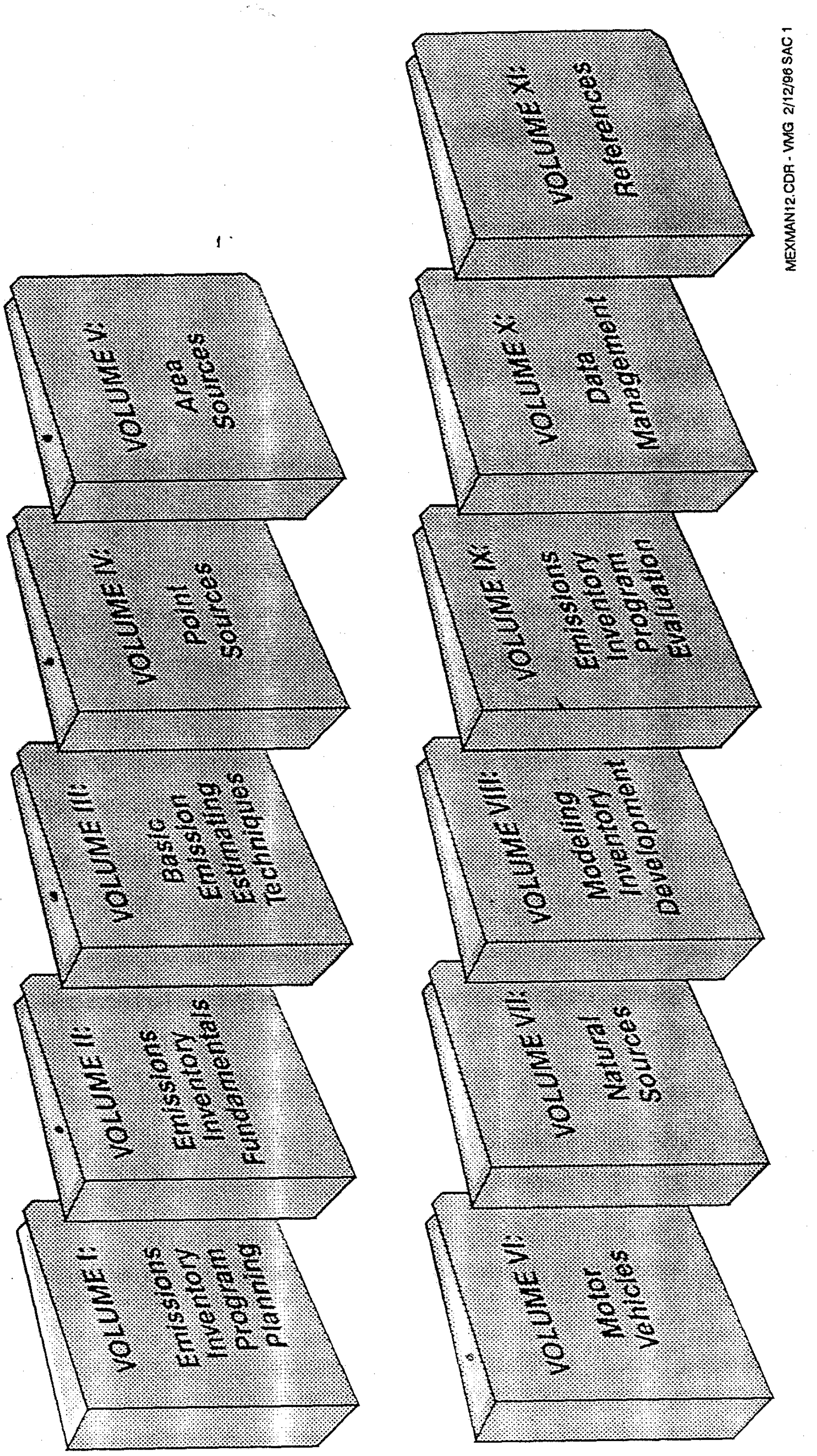


Figure 3-1 Mexico Emissions Inventory Program Manuals

inventory program in Mexico. Figure 3-1 shows the recommended series of manuals that should be developed to support a complete inventory program.

Currently, there is no consistent set of manuals that can be used directly to meet INE's needs. However, there are several existing reference documents and other materials that can be used to minimize required resources. In addition, the development of the manuals should closely follow the ongoing development of materials in the U.S. under the Emissions Inventory Improvement Program (EIIP). Radian staff are currently participating in the EIIP and will use these existing materials to the greatest extent possible.

Our conceptual approach for developing the Mexico Emissions Inventory Program Manuals consists of the following steps:

- First, a draft outline will be developed to present initial recommendations on the contents of each manual (see Appendix A).

- Second, a prioritization list will be made to determine the order in which the various manuals should be developed. Although it is likely that the development of multiple volumes will occur in parallel, the prioritization list is intended to help in the allocation of project resources and development of the manuals schedule. The prioritization is shown in Section 6.0.

- Next, work will begin on the high-priority manual(s). Based on the initial outlines, draft sections will be developed.

- To ensure that the manuals will serve as useful tools to INE, draft sections for at least the key documents will be prepared and submitted for review and comment. In this way, mid-course corrections can be made prior to completing and submitting the draft manual(s) for final review and comment.

- Last, the draft manuals will be finalized (in English) and translated into Spanish.

The first step, the development of a draft outline for the Mexico Emissions Inventory Program Manuals, has been completed and is presented in Appendix A as part of our implementation plan for technology transfer. The main purpose of each manual or volume is summarized below. A preface will be developed for each manual that describes the need for consistent and thorough inventory development throughout Mexico. The preface will also summarize the contents of each manual, providing the user with a quick reference guide to find the desired information.

Volume I—Emissions Inventory Program Planning. This manual will address the important planning issues that must be considered in an air emissions inventory program. Program planning will be discussed not as an "up-front" activity, but rather as an ongoing process to ensure the long-term growth and success of an emissions inventory program.

Volume II—Emissions Inventory Fundamentals. This manual will present the basic fundamentals of emissions inventory development. The objective is to discuss inventory elements that apply to multiple source types (e.g., point and area) in this one manual, so as to avoid the need for repetition in multiple volumes.

Volume III—Emissions Inventory Development: Basic Methodologies. This manual will present the basic methodologies used to develop emission estimates. Starting with information previously presented in the Methodology Proposal, this manual will provide additional detailed discussion of each methodology, including examples and sample calculations. Inventory tools associated with each methodology will be identified and included in Volume XI (References).

Volume IV—Emissions Inventory Development: Point Sources. This manual will provide guidance for developing the point source emissions inventory. A table will be developed to cross-reference each industry/device type combination (e.g., petroleum refining/combustion devices) with one or more of the basic methodologies presented in Volume III.

Volume V—Emissions Inventory Development: Area Sources (Includes Non-Road Mobile). This manual will provide guidance for developing the area source emissions inventory. After the presentation of general area source information, a table will be provided to cross-reference each area source category (e.g., asphalt application) with one or more of the basic methodologies presented in Volume III. Then, source category-specific information will be discussed for each source category defined in the table.

Volume VI—Emissions Inventory Development: On-Road Mobile Sources. This manual will explain the necessary steps for development of an emissions inventory for on-road mobile sources. Motor vehicles are a significant emissions source within the overall emissions inventory. Because motor vehicles are inherently different from point and area sources, the available estimation methods and required data are also different. To estimate emissions from these complex sources, models are the preferred estimation tool. Many of these models utilize extensive test data inputs applicable to a given country or region. This manual will focus primarily on the data development phase of estimating motor vehicle emissions.

Volume VII—Emissions Inventory Development: Natural Sources. This manual will provide guidance for developing the natural source emissions inventory (i.e., biogenic VOC and soil NO_x). In addition, this manual will include the theoretical aspects of emission calculations and discussion of specific models.

Volume VIII—Modeling Inventory Development. This manual will provide guidance for developing inventory data for use in air quality models and will address issues such as temporal allocation, spatial allocation, speciation, and projection of emission estimates.

Volume IX—Emissions Inventory Program Evaluation. This manual will consist of three parts: quality assurance/quality control (QA/QC), uncertainty analysis, and emissions verification. The QA/QC portion will define the overall QA/QC program and be written to complement source specific QA/QC procedures written into other manuals. The uncertainty analysis will include not only methods of assessing uncertainty in emission estimates, but also for assessing uncertainty in modeling values such as speciation profiles and emission projection factors. The emissions verification section will describe various analyses that can be done to examine the accuracy of the emission estimates. Examples include receptor modeling and trajectory analysis combined with specific data analysis techniques.

Volume X—Data Management. This manual will address the important needs associated with the data management element of a comprehensive emission inventory program. System and user's information will be provided in other documents. Volume X will describe the basic philosophy for collecting data and managing it in consistent manner for each region in Mexico. Responsibilities, schedules, and other relevant information will be presented.

Volume XI—References. This will be a compendium of tools that can be used in emission inventory program development. Inventory tools referenced in the other manuals will be included.

Development of Inventory Training Course Materials

This section describes the process for transferring the technical insights gained from the emission inventory development and implementation procedures to the academic and regulatory communities in Mexico. A Preliminary Draft Training Plan was submitted to the Binational Advisory Committee (BAC) and INE on 29 August 1995 (see Appendix B for the current plan). The Training Plan will be refined and expanded as the course content develops. A summary of the three major elements contained in the Draft Training Plan is presented below.

University Level Curriculum

The inventory training effort will be focused on the development of a university level extension course. The first step in the development of this curriculum includes developing a course syllabus, reading list, and workbook, on the emissions inventory (EI) process. Eventually the emission inventory course may be offered through university extension programs along the U.S. - Mexico border region. At some time in the future, the course may also be incorporated into environmental engineering curriculum at the University Autónoma Metropolitan - Azcapotzalco (UAM-AZC).

Prerequisites. Since the course is envisioned as a university extension course, most students will have had exposure to air pollution fundamentals in previous environmental engineering courses and practical work experience. Students should have reading skills in English equivalent to at least one year of university level English since most of the existing reference documents and computer models are in English.

Materials. Much of the technical material covered in the course will be drawn from Volumes II - VI, as described in Section 3.1. The manuals will contain example calculations which may be compiled into a workbook, along with other pertinent materials. The preparation of the Training Plan and the manuals began in parallel, but course development activities will soon outpace the much larger effort to develop the manuals. Thus, the emissions inventory course will include topics and example calculations for which the corresponding manual has not yet been developed. In these and other cases, the relevant course materials will be drawn from other sources.

Syllabus. The proposed EI course is designed for a 4-day university extension course meeting 8 hours per day. The contents of the proposed course are contained in Appendix B.

Reference List. A recommended list of references will be compiled. The list will include documents, research papers, conference proceedings, and background textbooks that students should consult throughout the course but especially for the execution of their assigned projects.

Materials. The following materials will be needed to complete this course:

- A 3-ring binder workbook of sample calculations and their solutions intended for the professor's use in assigning homework problems and developing test questions;
- Twenty-two sets of handouts and overhead presentation graphics (1 for each class meeting);
- Two copies of the written materials to be identified in the reading list; and
- All recommended computer models and their associated user guides. Note that UAM will need to furnish computer hardware that students can access to run their assigned software package or else suitable equipment may need to be purchased.

Except for the workbook, all of these materials should be assembled in one location at UAM to facilitate student access.

Couser for Trainer

Before the emissions inventory course can be given, training materials for future instructors must be developed. As the second element of the training effort, this material will be given to select professors who can then teach the full emissions inventory course to the professional air quality community. Initial students from the professional air quality community will be drawn from organizations such as INE, Mexico City metropolitan air pollution agency (Departamento de Distrito Federal - DDF), and Procuraduría Federal de Protección al Ambiente (PROFEPA).

The syllabus for the condensed course would cover the material presented in Appendix B. However, the emphasis may shift to more sophisticated topics such as emissions inventory program verification, given the audience's familiarity with basic air pollution and some emissions inventory concepts. This group of students may be asked to solve some or all of the workbook problems to assess the clarity of both the problems and the solutions.

Course Evaluation

The third element of the Training Plan is an ongoing evaluation strategy by which the effectiveness of the condensed course, the initial offering for air quality professionals, and the ultimate extension course can be assessed. This mechanism will allow appropriate adjustments in course content, presentation, and emphasis, as needed.

Radian is developing a training plan in close cooperation with Professor Alfonso Espitia, Director, UAM Environmental Engineering Program. Radian staff will lead the effort to develop a training plan and will be in frequent communication with Professor Espitia, including meeting with UAM staff and discussing preliminary work products before they are submitted to the Western Governor's Association (WGA), INE, and the BAC.

Several opportunities to evaluate and improve the course are envisioned including:

- Ongoing communication with Professor Espitia and the BAC team will focus the developing course to meet various technology transfer objectives.
- Radian and UAM will receive written evaluations (in lieu of examinations) from air quality professionals who take the initial condensed course. Their

answers to workbook problems will be used to refine the types of problems later posed to university students.

- Radian will devise a written course evaluation questionnaire that can be given to all students for ongoing feedback.

4.0 TECHINICAL ACTIVITIES

This section of the Implementation Plan presents recommended technical activities that should be considered for inclusion in the Phase II activities. Many of these technical activities are recommended so that emission estimates specific to Mexico can be developed.

4.1 Special Stidies and Further Development of Inventory Methodologies

This section addresses the need for further development of inventory methodologies that were presented in the Methodology Evaluation and Proposal Report. In particular, this section focuses on the development of the "multivariate model" methodology. This section also discusses the role of special technical studies in Mexico's emissions inventory program and provides a list of specific recommended studies.

Special studies are important to the Mexico emissions inventory program because they extend inventory coverage to include those source categories that have been previously uninventoried. In some instances, emissions for a particular source category have not been previously estimated because basic information needed for the emissions estimation has been unavailable. Also, some source categories have previously been thought to be insignificant or nonexistent in traditional inventories. Consequently, emissions estimation methodologies for these uninventoried categories do not exist for use in those areas where they actually are significant sources of emissions. Methods need to be developed for these unique source categories so that they can be included in the inventory process.

The following subsections present special technical studies and research that are needed for development and improvement of Mexico's emissions inventory program. The special technical studies have been divided into point, area, on-road mobile, and biogenic sources with an additional subsection describing necessary research for development of multivariate models. Each special study has also been assigned a priority ranking with a "1" indicating highest priority and a "3" indicating lowest priority. These priority rankings should be considered if there are limited resources for emissions inventory development. It should be noted that these special studies are only intended to aid in the development of emissions estimates for source categories that are unique to Mexico and known to have been previously uninventoried. These studies are not designed to identify new sources. Also, in most cases, these studies are not designed to verify existing emission estimates. Finally, these special studies are intended to support emissions estimation in all regions, as opposed to region-specific studies needed to develop geographic-specific data for source categories that are traditionally included in emissions inventories (e.g. fugitive dust or wildfires).

4.1.1 Point Soerce Special Studies

There is limited need for special technical studies in the development of emissions estimates for point sources. As indicated in the Methods Evaluation and Proposal Report, the estimation of emissions from point sources relies extensively on source sampling, emission factors, and surveys. Special studies would not significantly improve upon the source sampling methodology. The emission factor methodology would also be largely unaffected; however some care must be exercised concerning the applicability of non-Mexico emission factors to Mexico specific emission sources. This issue is discussed more fully in Section 4.3. Finally, there is one area of needed improvement related to the survey methodology. An improved point source questionnaire should be developed to improve the quality of data collected during surveying efforts of point sources.

Multivariate Model Development

Although the Methods Evaluation and Proposal recommends the use of source sampling, emission factors, and surveys for most point sources, a multivariate model is recommended for fugitive emissions from petroleum refineries and chemical manufacturing facilities. Furthermore, multivariate models are widely recommended for area sources in the Methods Evaluation and Proposal, particularly for the long-term. Before these individual multivariate models are implemented, however, significant research and development will need to be conducted.

Multivariate models are based on the concept that emission estimates can be expressed in terms of a set of variables that characterize a system. Further detailed discussion of multivariate models can be found in the Methods Evaluation and Proposal. It is quite likely that the set of applicable variables and its respective emissions estimation algorithm varies among source categories. As a result, several multivariate models will need to be developed in order to estimate emissions for all recommended source categories.

There will be some significant development costs associated with multivariate models. For example, a multivariate model has been recommended for fugitive emissions from petroleum refineries and chemical manufacturing facilities. At the current time, the development of this multivariate model has been assigned a priority ranking of "3." Development costs for this multivariate model have been estimated to be $10,000-20,000. It is likely that development costs for area source multivariate models will be higher than for this example. One possible reason for this is that model variables associated with fugitive emissions from petroleum refineries are probably closely related to actual refinery operations. These variables would be more easily quantified than area source multivariate model variables which might be more distantly related to the actual emission processes.

4.1.3 Area Source Special Stidies

Examination of the near-term recommended methods presented in the Methods Evaluation and Proposal Report for area sources reveals that there are several area source categories that have previously been uninventoried. These categories are the focus of special studies presented in this subsection. These special studies, along with their priority ranking and a brief description, are presented in Table 4-1.

Table 4-1

Special Studies for Area Sources

Subject of Special Study	Priority	Purpose and Scope of Special Study
Fugitive Emissions from Domestic Liquified Petroleum Gas (LPG) Usage	1	Determine areas of propane fuel use and quantities of use. Develop emissions estimating techniques, including source sampling if required.
Emissions from Residential Biomass or Waste-Derived Fuels	1	Determine areas of biomass / waste-derived fuel use, fuel composition, and quantities of use. Develop emissions estimating techniques using surveys and source sampling as required.
Emissions from Waste Burning (Refuse Burning / Open Burning Dumps)	1	Characterize extent of open burning dumps, quantity of refuse burned, refuse composition, and typical burning practices. Develop emissions estimating techniques which would likely include surveys and / or source sampling.
Emissions from Open Sewage	1	Characterize extent of open sewage and typical chemical composition of sewage. Develop emission estimating techniques, including source sampling if required.
Emissions from Brick Manufacturing	1	Determine areas with small-scale brick kilns, quantity of fuel used, and fuel composition. Develop emissions estimating techniques using surveys and / or source sampling.
Emissions from Street Vendors	2	Characterize extent of street vendors, quantity of fuel used, and fuel composition. Develop emissions estimating techniques using surveys and / or source sampling.
Solvent Usage	2	Conduct a stratified survey to develop solvent usage data by industrial / commercial sector. Develop emissions estimating techniques for solvent area source categories.
National Solvents Balance	2	Perform a national solvents balance based on information from appropriate manufacturers' association data, import / export records, and other data sources. Use results to develop or verify emissions estimates for solvent area source categories.
National Petroleum Balance	2	Perform a national level petroleum balance based on information from PEMEX and other data sources. Test and confirm the reasonableness of petroleum balance. Data used to supplement area source categories that consume petroleum-based fuels.
Heterogeneity of Emissions in Mexico	2	Identify region-specific factors that affect emission estimates. Assess qualitatively (and possibly quantitatively) what effects these factors have on various source categories. Develop procedures for adjusting emissions based on geographic differences.
Nonroad Equipment	3	Confirm that Mexico has a smaller engine population than the U.S. Conduct survey to quantify actual engine populations.

On-Road Mobile Source Special Studies

Due to fundamental differences in emissions from Mexico on-road mobile sources and U.S. on-road mobile sources, a substantial number of special studies are needed to accurately estimate emissions from this source category. Several of these studies focus on the development of basic data that are a central part of a Mexico-specific emission factor model. The remainder of the studies determine appropriate adjustment factors to account for differences between the emission factor model and various non-ideal conditions. All of these special studies are presented in Table 4-2.

Table 4-2

Special Studies for Mobile Sources

Subject of Special Study	Priority	Purpose and Scope of Special Study
Emission Factor Model	1	Develop an emission factor model from vehicle test data. Modify emission factor model by any applicable results from other special studies.
Driving Cycles	1	Quantify typical Mexico driving patterns. Use driving pattern data to derive an appropriate driving cycle to be used in vehicle testing.
Vehicle Registrations	1	Survey vehicle registration data at the local level. Confirm the accuracy of existing vehicle registration distributions.
Vehicle Testing	1	Measure emissions from a representative vehicle mix. Use emissions data to populate an emission factor model.
Emission Control Technology	2	Conduct a survey to confirm the extent of emission control technology in various types of vehicles. Use results to help develop mobile source emissions estimates.
Inspection and Maintenance (I/M) Programs	2	Conduct survey to determine the actual effectiveness of established I/M programs. Compare results to theoretical effectiveness of I/M programs. Information used to adjust emission factor model and emissions estimates.
Tampering and Misfueling	2	Conduct survey to establish the level of tampering and misfueling among those vehicles that have emission control technology. Data used to adjust emission factor model and emissions estimates.
Unregistered Vehicles	2	Conduct survey to quantify the number of unregistered vehicles present in the Mexico vehicle fleet. Data used to modify existing vehicle registration distribution data.

Natural Sources Special Studies

Algorithms and models are available for application in Mexico that could be used to develop emission estimates for natural source such as biogenic hydrocarbons and soil NO_x. Mexico-specific data to use in existing models, however, are limited and the data that are available may not reflect Mexico conditions. Special studies are needed to develop fundamental data for the natural source categories.

There are two special technical studies that are needed to estimate emissions from biogenic sources. The first study would develop land use/land cover (LULC) data for Mexico. The second study would develop biomass data for Mexico plant species and relevant emission factors. Further discussion concerning these data is presented below.

Estimating emissions for the natural source categories will rely extensively on land use/land cover data (LULC). For example, land use describes the type of vegetation that may be present (e.g., natural versus urban) and also the type of vegetation present (e.g., row crop versus orchard). Development of natural source emission estimates for Mexico would be greatly enhanced through the application of satellite imagery data to develop LULC data. These data could be used directly to develop biogenic hydrocarbon, soil NO_x, and windblown dust emissions.

Further field research is also warranted so that a more refined biogenic emission estimate can be developed for Mexico. The applicability of the current biogenic emission models may have limited applicability in many regions of Mexico. The work performed to develop the biogenic hydrocarbon inventory for the Grand Canyon Visibility Transport Commission found that biogenic emission estimates for the southwestern U.S. appear to be overestimated. It is possible that the scrubland LULC category for the southern U.S. and northern Mexico should incorporate a lower biomass than is currently used in the biogenic emissions calculations. No other biomass data are available for this region.

In summary, a large effort will be required to develop the necessary data for natural source emission estimates. Satellite imagery would greatly enhance the process, but additional fundamental research will be required to develop other model parameters. This includes soil parameters for soil NO_x estimates and biomass data to support the modeling of biogenic hydrocarbons.

Methodology Testing

In an earlier stage of this effort, a conceptual approach for developing emission estimates on a national level for Mexico was presented. After the method is further developed, testing of the method is desired before it is implemented on a national level. This section outlines our recommended approach for testing the methodology.

The methodology can be thought of in three parts:

- Use of questionnaires to collect point source emissions data, including process information, activity rates, and any available source test results;
- Use of census based emission factors and multivariate models for area sources; and
- Emission models for on-road motor vehicles.

Testing the methodology will require implementing all three methods in one or more region of Mexico. This effort can be divided logically into three parts: region selection and work plan development, emissions estimation, and emissions validation.

4.2.1 Region Selection and Work Plan Development

Most of the detailed emissions inventory work conducted in Mexico has been centered in Mexico City. To provide a more strenuous test, the testing effort should be focused on other regions that have not received as much attention. At the same time, however, there are several advantages of selecting regions that have on-going environmental analyses that would complement the testing effort and provide a synergistic effect. The testing effort should also be conducted by both Mexico and U.S. staff so that this effort can be used as a training exercise. Using these three criteria, several border regions appear to be logical choices: Mexicali, Ambos Nogales, and Ciudad Juárez. As part of the work plan development effort, this recommendation will be refined and specific regions will be selected and agreed upon followed by detailed planning. Additional thoughts on using these three cities as a test regions are presented below.

Mexicali is the leading candidate for emissions testing because of the diverse nature sources in this region. The region consists of a large urban environment, a large motor vehicle population, and the most diverse industrial base of the three regions selected. Therefore, Mexicali would provide the most streneous test.

Work will soon begin in Ambos Nogales to develop a PM_{10} and air toxics inventory. This inventory effort will be performed under an accelerated schedule to provide initial emission estimates. By choosing Ambos Nogales as a test site, the more rigorous methodology could be compared to the initial estimates to evaluate the incremental improvement of more robust estimating methods. In addition, a geographic information system (GIS) database has been developed that would facilitate the emission estimation process for area sources in this region.

Our interest in Ciudad Juárez stems primarily from the motor vehicle data that have been developed in that region. This includes not only the motor vehicle activity data that have been compiled, but also the emissions test data that are being collected. Point and area source emission estimates would also be developed.

Emissions Estimation

In this phase of the testing, needed data would be collected and used to develop emission estimates. For training purposes, this effort should be carried out by Mexico staff to supplement the classroom training that will be available from UAM. To the extent possible, the resulting emission estimates should be managed in the selected data management system to facilitate both reporting and data analysis functions.

Emissions Validation

Once the emission estimates have been completed, several "validation" analyses should be conducted. Section 4.3 discusses the different types of validation activities that could be implemented. At this time, range checks, development of alternative emission estimates, comparison of emission estimates with measured ambient concentrations, and the use of receptor models are recommended. These analyses will be designed to evaluate the completeness and precision of the emission estimates.

Validation of Emission Estimates

Developing accurate emission estimates is an important aspect of the air quality planning process. Historically, assessing the accuracy of an emissions inventory has been a very difficult process. A good point source inventory may contain over a thousand emitting devices, while a complete area source inventory can easily contain over 150 discrete source categories. When combined, these emissions constitute an emissions database with thousands of data points. This volume of data makes it very difficult to "validate" an emissions inventory.

For an air quality model, predictions are compared to observations to assess the performance of the model. Similar opportunities are difficult to find for the emissions inventory process and are often expensive to implement. Nonetheless, there are four methods that can be used in the emissions validation process:

- Quality assurance/quality control procedures that involve range checks to identify outliers;
- Development of alternative emission estimates for cross comparison;
- Comparison of emission estimates with measured ambient concentrations using data analysis techniques; and
- Analysis of emission estimates using air quality models such as receptor models and three dimensional grid models.

Of these potential approaches, range checks and calculation of alternative emission estimates should be adopted as routine procedures in Mexico's inventory development process. These techniques will be described in the inventory manuals (see Section 3.1) and presented such that they should be used routinely in the inventory development process.

Data analysis techniques involving comparisons with ambient measurement data and model predictions should be performed as special studies. These are expensive techniques that can not be performed on a routine basis. Nonetheless, when properly performed, they provide valuable insight into the uncertainty associated with an emissions inventory. Each of the validation methods is discussed briefly below.

4.3.1 Validation Through Range Checking

An emissions database consists of thousands of data points. Range checks can be applied to verify the accuracy for many of the data elements, such as stack parameters, missing pollutants, activity rates, source classification, etc. A few examples follow.

- Stack height, velocity/flow rate, and diameter should all be compared against typical values to identify outliers. For example, stack heights over 100 meters should be flagged and examined closely to validate their accuracy. Previous experience has also found many instances where the stack gas velocity, when computed from the stack diameter and flow rate, is greater than the speed of sound.

- Combustion devices should have emissions of combustion pollutants, such as NO_x and CO. Emitting devices burning certain fuels should also have SO_2 emissions. Surface coating and solvent usage sources should have VOC emission estimates; any combustion pollutants associated with VOC sources should be flagged and validated.

- Emission factors can be back calculated from an emitting devices activity rate and emissions and then compared to the standard emission factor. This type of check helps to identify devices that have been misclassified (i.e., they have been assigned incorrect Source Classification Codes).

- Typical ranges for the most important area source categories can be developed and applied to help identify suspicious area source emission estimates that require further checking and verification.

Many emissions inventory programs in the United States use range checking as a means of controlling the quality of data contained in their emissions database. The types of range checks currently used vary from simple to complex.

In summary, range checking should be incorporated into the Mexico Emissions Inventory Program. Section 6.0 presents cost estimates for developing this capability in Mexico.

Development of Alternative Emission Estimates

Developing alternative emission estimates is another method for assessing the validity of an emissions inventory. The methodology evaluation and proposal prepared under Tasks 4 and 5 described the possibility of developing alternative emission estimates using greenhouse gas (GHG) inventory techniques as a means of verifying emission estimates developed at the state and local level. The GHG approach uses general indicators of activity to estimate emissions for large geographic regions. In inventory terminology, this is referred to as a top-down approach. Conversely, detailed emission estimates developed from surveys and local statistical data are referred to as bottom-up estimates. Using top-down estimates to verify bottom-up calculations has been used in the U.S. to help identify inventory problems. At the same time, it may also create some new problems. Specifically, two different emission estimates are generated, and it may not be clear which estimate is the most accurate.

In spite of the problems that can arise with multiple emission estimates, INE staff should develop top-down emission estimates as a means of verifying the bottom-up calculations performed at the state and local level. The techniques used to develop GHG inventories appears to be an efficient mechanism for developing top-down estimates. Section 6.0 presents a cost estimate for developing this capability in Mexico.

4.3.3 Comparison of Emission Estimates with Ambient Measurements

As a check of the overall inventory, emission estimates can be compared to ambient measurements. In the past, simple comparisons of VOC to NO_x ratios were computed from the emission estimates and compared to the same ratio for the measurement data. More recently, this type of analysis has been expanded to include a comparison of speciated hydrocarbon emissions with ambient measurements of individual species. This type of analysis was performed for the Lake Michigan Ozone Study and in the South Coast Air Basin by the California Air Resources Board (Fujita et al., 1992). From the South Coast study, the researchers examined the possible underestimation bias in the motor vehicle emissions modeling process.

This type of analysis is not recommended for routine use as part of the emissions inventory development process. As special air quality planning studies are conducted in various regions of Mexico, however, this type of analysis should be included in the overall effort. The manuals will include reference materials that can be reviewed by INE and other staff to better determine how this type of analysis can be incorporated into a regional air quality study.

4.3.4 Evaluation of Emission Estimates Using Air Quality Models

This is a relatively new concept that is being used more frequently in the U.S. Application of air quality models in an emissions validation frame work helps to identify potential bias in the inventory. To our knowledge, two different modeling approaches have been used as emissions verification tools: receptor models and three dimensional grid models.

Evaluation of Emission Estimates Using Receptor Models. This technique has been used in several air quality studies in the U.S. Results of a receptor model show the contribution of major sources to either the particulate or VOC measured at an ambient monitor. This distribution can be compared to the distribution of estimated emissions in the inventory for the same source categories. Discrepancies in the source apportionment between the receptor model and the emissions model are investigated to identify potential problems with the emissions inventory. Two examples are summarized below.

In the Southeast Michigan Ozone Study, the University of Chicago at Illinois used VOC receptor modeling to evaluate the emission estimates from several major sources types: motor vehicles, gasoline distribution and handling sources, petroleum refining, graphic arts, surface coating, and coke ovens. Results of this analysis indicated that emissions from motor vehicles, gasoline vapor sources, architectural coatings, and coke ovens were reasonable. In contrast, the receptor model predicted more petroleum refinery and graphic arts emissions than were contained in the emissions inventory (Scheff et al., 1995).

The Desert Research Institute applied PM_{10} receptor modeling in the Phoenix metropolitan area to examine the sources of PM_{10} in that region. The emissions inventory indicated that large amounts of PM_{10} were being emitted from several sources, including entrained road dust. Results of the receptor modeling, however, indicated that the fugitive emission estimates were probably overstated, thus suggesting that refinement in the emission estimating technique is warranted (Watson, 1994).

Evaluation of Emission Estimates Using Three Dimensional Grid Models. Three dimensional grid models are also being used more frequently to help evaluate the uncertainty in the emissions inventory process (see e.g., Chang et al., 1993 and Mulholland and Seinfeld, 1995). Two recent examples include the Mexico City Air Quality Research Initiative

(MARI) and the Arizona Hazardous Air Pollution Research Program. In the MARI study, staff of Los Alamos National Laboratory and the Mexican Petroleum Institute concluded that VOC inventory for Mexico City is low by nearly a factor of four (LANL and IMP, 1994). This conclusion was reached through data analysis techniques, including trajectory analysis, as part of the model performance evaluation.

In the Arizona HAPs Research Program, Radian and other consultants are comparing modeling results with ambient measurements to evaluate the uncertainty in the emission estimates. Based on this results, specific areas of the inventory have been targeted for refinement.

Analysis of Existing Emission Factor Applicability to Mexico

A major concern with the existing emission estimates prepared for Mexico is that they rely extensively on inventory technology from the United States, including emission factors as well as general methodologies for calculating emission estimates. The extent to which U.S. emission factors adequately represent Mexican sources must be investigated. This evaluation should be performed through an analysis of Mexico source test data. These data will be used to:

- Confirm that Mexico's emission sources are comparable to those used to develop United States emission factors, and that AP-42 emission factors are valid for use in compiling Mexico's emission inventory; or

- Document that Mexican emission sources are significantly different for specific sources or source-types and that the source test-derived emission factors must be used in compiling the emission inventory.

This section presents an overview of emission factor application, a general discussion of how emission factors are derived from source measurements, and proposed methods for evaluating the applicability of current emission factors to Mexican sources. The evaluation should be performed in two steps:

1. Source identification and data collection.

2. Statistical comparison with existing emission factors.

Emission Factors and Their Appropriate Use

Depending on the source type and available information, emission estimates are determined using three approaches:

- Direct source measurement;
- Mass balance calculations; and/or
- Engineering calculations.

An emission factor is the average quantity of a pollutant released to the atmosphere during a known activity (e.g., road paving) or during the production of a known amount of material (e.g., tons of steel). It is usually expressed in units of weight of pollutant per unit of activity or quantity of production (e.g., kilograms of nitrogen oxide per kilogram of municipal waste burned, or kilograms of sulfur dioxide per kilogram of coal burned). Emission factors also may be based on continuous or batch (or cyclical) production schedules.

Examples of the assumptions which must be made during the plant-specific estimation process include:

- Process configuration (few facilities are identical);
- Process conditions (temperatures, hold times, use of proprietary catalysts, amount of water used);
- Quality and quantity of feedstock and/or chemicals used; and
- Age of plant and level of maintenance.

Many other parameters that vary somewhat from plant to plant may also need to be considered, even within the same industrial category. Of course, the type of control device and its efficiency of operation at a specific facility must also be taken into account.

The above discussion serves to illustrate the difficulties associated with developing emission factors. There is a general concern that sources in Mexico may be sufficiently different than sources in the U.S. where most of the currently available emission factors were developed. The following discussion describes the recommended process for determining if U.S. emission factors are representative of Mexico sources.

Source Identification and Data Collection

To adapt the U.S. EPA's AP-42 approach to Mexico, the emitting devices defined in AP-42 must be compared with industry operations in Mexico. Key source types must then be selected for the analysis. Resource and time constraints will prevent a comparison of the hundreds of emission factors that have been developed in the U.S. After identifying the sources to include in the analysis, properly documented source testing data should be collected from Mexico. The source testing data may be used to:

- Confirm or reject AP-42 emission factors; or
- Derive emission factors for new categories or for existing AP-42 categories whose data are incompatible with Mexico results.

Once source groups or process type categories have been defined, available source test data must be collected. Since all aspects of testing are important, each source test should be reviewed to determine that referenced protocols were followed. A quality assurance/quality control (QA/QC) program should be established to ensure that the quality of the data can be defined and that the results are defensible.

Complete records of facility production or activity must be collected and provided to the data analysis team. Since the emission factors are the ratio of emission-to-activity rate, the accuracy of the emission factor is equally dependent on the accuracy of both numbers. The testing should be conducted when the plant is operated in a conventional manner at or near capacity.

In addition, if the results are to be compared to U.S. emission factors, the unit of activity that is used and the control equipment that is installed should be consistent with that used in the development of the AP-42 emission factor.

4.4.3 Statistical Comparison Study Desing and Overview

Once valid source tests have been collected, a statistical comparison will be conducted. The objective of the study is to determine whether source sample-derived emission factors are statistically comparable to those presented for the same source types in AP-42. A detailed work plan should be prepared prior to initiating the analysis so that the statistical procedures can be identified and agreed upon. The remainder of this section discusses the statistical issues that must be addressed in the work plan.

The following three general categories of statistical applications can be used to provide a meaningful and valid comparison study:

- Descriptive statistics;
- Statistical significance testing for emission factor comparison; and
- Assessment of variability within and between sources.

Choosing a statistical comparison test will depend on the information available to characterize the emission factor distributions for each pollutant and source type. Several different tests may be used to accommodate varying levels of completeness in the emission factor datasets. Emission factor comparability for each source type can be determined using tolerance intervals, confidence intervals, t-tests, or Wilcoxon Rank-sum tests. The tolerance interval is recommended for most source types because the AP-42 data have limited information that would allow use of the other standard comparison tests. If adequate data are available, confidence intervals, t-tests, or the Wilcoxon Rank-sum non-parametric test should be performed. Each of these procedures will establish whether the source sample-derived emission factors are statistically comparable to the AP-42 emission factors, although the power of the tests and risk of false negative or false positive results may vary depending on the emission factor datasets.

The selection of statistical comparison tests should be based on the following criteria:

- The availability of a standard deviation or variance estimate for the emission factor. The AP-42 emission factors have a rating criterion to indicate the level of confidence in the factor, but do not have a standard deviation, which limits use of the t-test or calculation of confidence intervals.

- The number of measurements used to obtain the average emission factor. If an emission factor is based on a single or a few measurements, there may be less confidence in the representativeness or greater variability associated with that factor.
- The underlying distribution of source-specific emission factors. If the distribution is highly skewed or non-normal, the non-parametric comparison may be a more appropriate test.

The variability within and between sources or processes can be characterized from the source sample and activity data to provide a measure of the precision and accuracy that can be expected in the source-specific emission factors. These types of assessments will promote a better understanding of the precision of the average emission factors and emission inventory.

Expected relationships can be investigated by producing bivariate plots of source sample and activity data for each source type, and performing linear regression analyses to assess the goodness of fit. The scatter of data points is also of interest because it illustrates how closely the data follow the expected linear trend and provides a graphical representation of the variability from all aspects of the measurement procedures and process operations. If the data points show a highly skewed distribution (having most points occurring in the highest or lowest part of the range), several factors could be influencing the results and the average emission factor may not be representative of the source type.

Uncertainty Analysis

This section discusses the complex technical issues associated with estimating emissions uncertainty and outlines a process for addressing uncertainty in the Mexico inventory. To estimate uncertainty in the Mexico inventory, a needs analysis should be completed to better determine the degree of uncertainty analysis required by INE, the appropriate statistical approach must be selected, and finally, the uncertainty in the emissions inventory estimated for a specific geographic region to test the selected approach. As a first step, a work plan should be prepared that expands on the information presented in this section. The approach for assessing uncertainty will be refined and expanded as the corresponding manual addressing uncertainty analysis is also prepared.

To aid in the understanding of this material, a brief discussion of the statistical concepts of bias and variability (i.e., imprecision) are first presented. This material is followed by the proposed approach for establishing an uncertainty estimation process in Mexico.

Background

An appreciation for the various expressions of uncertainty is an important prerequisite to identifying the best approach. The term "uncertainty" comprises two types of error in estimation: bias and variability. These terms are defined below, followed by a historical perspective of uncertainty analysis.

Bias. This term defines the extent to which an estimate is persistently inaccurate. In emissions inventory data, bias results from a systematic error in which some aspect of the emissions process is misrepresented or not taken into account. For example, the tendency of older generation motor vehicle emission factor models to underestimate VOC emissions due to evaporative and running losses resulted in biased (low) estimates of VOC emissions from on-road motor vehicles.

Bias is typically represented in either of two ways:

- The *absolute bias* is the difference between the estimate and the true value. However, the true value is rarely known.
- The *relative bias* is the absolute bias expressed in percentage terms. For emissions inventory work, the relative bias is generally preferred over the absolute bias.

As part of the emissions development process, the goal is to reduce all known sources of bias, both across sources and within sources. If a bias is known to exist, then effort should be initiated to quantify and remove the bias. However, this may be difficult to accomplish because of a lack of resources, data, or other factors.

Variability. This term refers to the imprecision of an estimate. It is the difference due to random error or fluctuations between a measurement and its true value. In emissions inventory data, variability may result from temporal or spatial fluctuations in the parameters (activity data) used to estimate emission factors (i.e., hourly variation in the fuel sulfur content, heating value, and load for an industrial boiler). The imprecision may also result from sampling error due to the inability to obtain a comprehensive set of measurements for all sources or source conditions (i.e., one cannot perform source sampling on a given boiler under all conditions under which it may operate nor can one test all identical boilers).

Methodologies to Estimate Emissions Uncertainty. Most emission estimates are produced using a model that assumes emissions are the product of a series of independent parameters (i.e., emission factor times activity data times control factor times temporal adjustment, etc) of the form

$$ER_t = p_1 \, x \, p_2 \, x \ldots x \, p_n$$

where
ER_t = Emission rate for time t
p_i = Parameter used to estimate emissions
n = Number of parameters

In this context, a model is a simplified representation of the processes leading to the emissions. Model uncertainty stems from the inability of one to simulate the emission process completely with the resultant use of surrogate variables, exclusion of variables from the computation process, and over-simplification of emission process in the model.

This same general equation applies from the simple case of an emission factor (e.g., grams per kilogram combusted) times an activity datum (e.g., number of kilograms combusted per day) to the complex case where a model such as the BEIS model is used to estimate biogenic emissions or the MOBILE5 model is used to estimate on-road motor vehicle emission factors.

There are a number of real world problems and complexities associated with estimating emissions uncertainty when the above equation is used to develop the emission inventory. These problems include the inherent (and generally erroneous) assumption of independence of the individual parameters (i.e., no temporal or spatial correlation in emissions), the complications inherent in obtaining temporal, spatial, and speciated estimates of emissions from average values of emissions (e.g., obtaining gridded, speciated, hourly emission estimates from annual county-wide emission estimates), the limited amount of data that may be available for validation of estimates, and the difficulty posed by temporal and spatial data dependencies in validating those estimates even when data are available. The net result of ignoring these difficulties in an analysis of emissions uncertainty is that the uncertainty is underestimated.

Because of the complications associated with development of estimates of emission uncertainties, a number of methods have been applied to estimation of uncertainty. Table 4-3 presents a brief overview of six general methodologies that have or are currently being used to estimate emissions uncertainty. The methods range from the highly subjective expert estimation in Delphi-type techniques to the highly complex and computationally intensive direct simulation and inverse air quality modeling approaches.

Table 4-3

Overview of Common Methodology Used to Estimate Emissions Uncertainty

Methodology	Reference	Discussion
Data Quality Ratings	USEPA, 1985 Beck et al., 1994	Subjective rankings are assigned to each emission factor or parameter. In the DARS method, numerical values are then attributed to each ranking through objective methods.
Expert Estimation	Linstene and Turaff, 1975 SCAQMD, 1982 Horie, 1988 Horie and Shorpe, 1989	Emission distribution parameters (i.e., mean, standard deviation, and distribution type) are estimated by experts. Simple analytical and graphical techniques can then be used to estimate confidence limits from the assumed distributional data. In the Delphi method, expert judgment is used to estimate uncertainty directly.
Propagation of Errors	Mangat et al., 1984 Benkovitz, 1985 Benkovitz and Oden, 1989 Balentine et al., 1994 T.J. McCann & Associates, 1994	Emission parameter means and standard deviations are estimated using expert judgment, measurements, or other methods. Standard statistical techniques of error prorogation typically based upon Taylor's series expansions are then used to estimate the composite uncertainty.
Direct Simulation (e.g., Monte Carlo)	Freeman et al., 1986 Oden and Benkovitz, 1990 T.J. McCann & Associates, 1994	Monte Carlo, resampling, and other numerical methods are used to estimate directly the central value and confidence intervals of individual emission estimates. In the Monte Carlo method, expert judgment is used to estimate the values of the distribution parameters prior to performance of the Monte Carlo simulation. Other methods require no such assumptions.
Receptor Modeling (Source Apportionment)	Watson et al., 1984 Lowenthal et al., 1992 Chow et al., 1992 Sheff et al., 1992	Receptor modeling is an independent means to estimate the relative contribution of specific source types to observed air quality measurements. The method works best for non-reactive pollutants for which unique emission composition "fingerprints" exist for all significant source categories. The method provides a measure of the relative contribution of each source type but not absolute emission estimates.
Direct or Indirect Measurement (Validation)	Pierson et al., 1990 Fujita et al., 1992 Mitchell et al., 1995 Claiborn et al., 1995	Direct or indirect field measurement of emissions are used to compute uncertainty directly. These methods also provide data for validating emission estimates and models.
Inverse Air Quality Modeling	Chang et al., 1993 Mulholland and Seinfeld, 1995	Air quality simulation models are used in an inverse sense to estimate the emissions that would be required to produce the observed concentrations fields.

Subjective ranking methods such as that used for AP-42 emission factors (U.S. EPA, 1985) rely on a ranking of from A (best) to E (worst) for each emission factor. No numerical uncertainty values are associated with each rating. Newer methods such as the Data Attribute Rating System (DARS) (Beck et al., 1994) assign a numerical value to the quality of the various components of the emissions inventory and allow numerical manipulation of the uncertainty estimates of the system.

The expert estimation and propagation of errors methods rely on the assumption of independence between all the input emission parameters. They also assume the emission parameters obey a normal or lognormal distribution and require estimates of the parameters (means and standard deviations) required to define the distributions.These two methods tend to be relatively simple to implement but the assumption of independence is rarely achieved or verified. Direct simulation methods, using error minimization, Monte Carlo, and resampling approaches, are not limited by assumptions of independence but may require estimates of distribution type. These methods are very powerful, but they require sophistication in statistics and emissions analysis to implement properly.

Field measurement studies directly (or indirectly) estimate emissions and emissions uncertainty and provide data for use in validation of emission estimates. However, field data are valid only for those sources and conditions for which measurement were made. The inverse modeling procedures are very powerful procedures that yield direct estimates of uncertainty. However, they require considerable sophistication in advanced air quality modeling in addition to statistics and emissions analysis. They are also quite expensive and are subject to the inherent limitation that air quality simulation models are imperfect representations of the real world.

4.5.2 Needs Analysis for Mexico

To determine the degree and type of uncertainty analyses that will be appropriate for Mexico, a needs analysis should be conducted. This analysis would be part of the work plan development and should include definition of the type of uncertainty analysis required, geographic extent of the analysis, and the emission sources on which to focus. Source categories should be rank ordered to identify those categories that dominate the emissions inventory, and the uncertainty analysis should focus on those sources. Although it will often be of interest to refine average emission estimates in order to achieve finer temporal and spatial resolutions of the estimates, the cost of achieving a higher level of confidence should be evaluated. For example, a single municipality-wide emission estimate for VOC from surface coating may be spatially allocated to a uniform grid based upon population, and then temporally allocated to a set of hourly seasonal and day-of-week estimates. These kinds of adjustments introduce additional variability into the estimate but quantifying and eliminating this variability may not be warranted if VOC from surface coating is less than 1% of the inventory.

A qualitative approach to assessing the need for rigorous uncertainty analysis is recommended, based on such factors as:

- The appropriateness of emission estimation techniques and inventory methods;
- The level of quality assurance and verification used to develop the emission estimates; and
- The level of rigor used to develop the activity data for the emission estimates (i.e., were detailed surveys used or were emission estimates extrapolated from other geographic regions?)

Evaluation of Uncertainty Estimation Methods

The second step will be to select the appropriate methodology to use for estimating uncertainty in the emissions estimates. The specific method selected will depend on the results of the needs analysis. There are a number of general methodologies available for evaluation of uncertainty (imprecision and bias) in emission estimates (see Table 4-3). For this effort, developing a new method is not recommended, but rather applying and possibly refining an existing method.

There is a generally a tradeoff in the selection of the uncertainty estimation methodology. The simpler methods involving error propagation are easy to implement, require few resources, and are relatively inexpensive to use. However, they require the assumption of independence which is generally not met and which generally results in underestimating the amount of uncertainty in the emission estimates. The more sophisticated methodologies generally do not require the assumption of independence but tend to be computationally intensive and require considerable sophistication in their implementation and can be expensive. In addition, the data required to completely implement these methods generally do not exist and must be approximated, adding additional uncertainty to the analysis.

A major factor in the selection of the appropriate methodology is therefore the resources available for performance of the analysis. If data providing detailed information on the emissions and emission parameters are available due to field measurements or intensive inventory development programs, the sophisticated, computationally intensive methodologies can probably be used effectively. However, if there is very little, or no, data for the emission sources of concern, the more simplistic methodologies are likely more appropriate because the level of detail in the methodology should approximate the level of detail in the available data. For our work in Mexico, data availability will limited. Therefore, a less sophisticated methodology will likely be more appropriate for the analysis but a specific approach has not been selected. The actual selection of the appropriate methodology will be made during preparation of the workplan.

The workplan will review the available methodology in detail and develop a recommended methodology for estimation of emissions uncertainty. The use of a Monte Carlo approach to simulate directly uncertainty estimates for the Mexico inventory should be examined carefully. Three primary difficulties are invisioned that must be addressed in the selection of this emissions uncertainty methodology. Table 4-4 presents these three areas and our current thinking on the appropriate methodology for overcoming the difficulty. The information presented in this table is tentative and will be finalized as part of the workplan, along with the specific methodology to be used.

Table 4-4

Areas of Difficulty in Estimating Emissions Uncertainty for Mexico and Our Tentative Approach to Overcome the Difficulty

Area of Difficulty	Proposed Methodology	Discussion
Definition of the distribution type for each emission parameter	Define the distribution of each emission parameter as normal, lognormal, or weibull.	Because of the lack of data on emissions in Mexico, the use of the most sophisticated uncertainty analysis methods that do not require the definition of underlying distributions is probably unwarranted at this time. Consequently, informed judgments must be made regarding as the distributional nature of each required emission parameter.
Estimation of values defining the distribution for each emission parameter	Use expert judgment and published literature to estimate the mean and standard deviation for each emission parameter.	Without site-specific data available to define the distributional variables for individual parameters, the analysis is are limited to the use of expert judgment and literature values to estimate these key variables.
Lack of independence of the emission parameters	Define the dependent relationships between the various parameters and develop analytic functions that can be implemented as part of the Monte Carlo analysis.	The approach should analyze each of the emission parameters (e.g., population, employment, fuel use, etc) and develop an analytic formula to define the dependent relationship between these and all other factors used to estimate emissions for each source. These analytic relations will then be incorporated into the Monte Carlo analysis setup.

Development of Numerical Uncertainty Estimates

The third step of this process will involve testing the selected approach in a designated geographic area. This region could be one of the three test regions discussed in Section 4.2 or it could be another geographic region for which INE has special needs to assess uncertainty. Whatever region is selected, INE staff should participate in the effort so a training benefit is also realized.

5.0 DATA MANAGEMENT

Inventory data can be managed almost entirely by computer. During the inventory planning stages, an agency should anticipate the volume and types of data-handling needed in the inventory effort and should weigh the relative advantages of manual versus computerized systems. If an agency must deal with large amounts of data, maximizing the use of computerized inventory data-handling systems will allow the agency to spend more time gathering, analyzing, and validating the inventory data, as opposed to manipulating the data.

The computerized data-handling approach is superior for large areas with diverse sources. Computerized data handling becomes significantly more cost-effective as the database, the variety of tabular summaries, or the number of iterative tasks increase. In these cases, the computerized inventory requires less overall time involvement and has the added advantage of forcing organization, consistency, and accuracy.

Some activities that can be performed efficiently and rapidly by computer include:

- Printing mailing lists and labels for distribution of questionnaires and other correspondence;
- Maintaining status reports and logs;
- Calculating and summarizing emissions;
- Performing error checks and other audit functions;
- Storing source, emissions, and other data;
- Sorting and selectively accessing data; and
- Generating output reports.

The selection of a data management system will depend on several factors, such as:

- Type of computer system;
- Size of the inventory database;
- Complexity of the emissions calculations;
- Number of calculations to be made;
- Variety of tabular summarizes to be generated;
- Availability and expertise of clerical and data-handling personnel; and
- Time constraints.

Current Database System

For point sources, nearly all criteria-type emissions inventory data are collected by INE headquarters staff in Mexico City and by Regional Office personnel for designated cities in Mexico. These inventories are generated by INE staff on personal computers (PCs) using activity data (i.e., throughput, production, process rates, etc.) obtained from responses to annual questionnaires (encuestas) mailed to industrial facilities by INE. These responses are coupled with emission factors contained in the Sistema Nacional de Información de Fuentes Fijas (SNIFF) or National System of Information on Stationary Sources. This is a Dbase III Plus format PC data handling system.

SNIFF is comprised of 25 programs and 23 relational databases that are menu-driven to be more user-friendly. SNIFF consists of two main parts. The first, the National Census of Stationary Sources, contains general information about Mexican industrial facilities (e.g., name, address, license numbers, etc.). The second part, the National Inventory of Emissions, contains general source information and data on process type, raw materials, products, emissions, and control devices. Almost all emission factors in SNIFF were obtained from the U.S. EPA FIRE emission factor database. Data quality control consists of manual review of questionnaires and rudimentary data checks built into the SNIFF system.

INE staff have recognized the need for a more advanced and comprehensive data management system. Data management at INE will be standardized on Oracle, Novell, and UNIX. They also plan on using Lotus Notes as a means to transfer and share large data sets or documents among multiple users. INE is currently in the process of developing a networked computer system at INE headquarters.

INE staff have also been involved in preliminary efforts to evaluate software options. Over the past few years, Mexico has been working with the German and Japanese environmental protection agencies to develop a more adequate emissions inventory data management system. Prototype systems were documented and evaluated by Mexico. INE also considered using the German Information Management System as proposed by a German consulting firm, TUV Reinland. In addition, INE, in conjunction with Environment Canada, has evaluated the Regional Air Pollution Inventory Development System (RAPIDS) software.

Staff of INE have requested technical support for the implementation of a more robust data management system than is currently in place. The Phase II portion of the Mexico Emissions Inventory Program project will contribute to INE's ongoing software evaluation

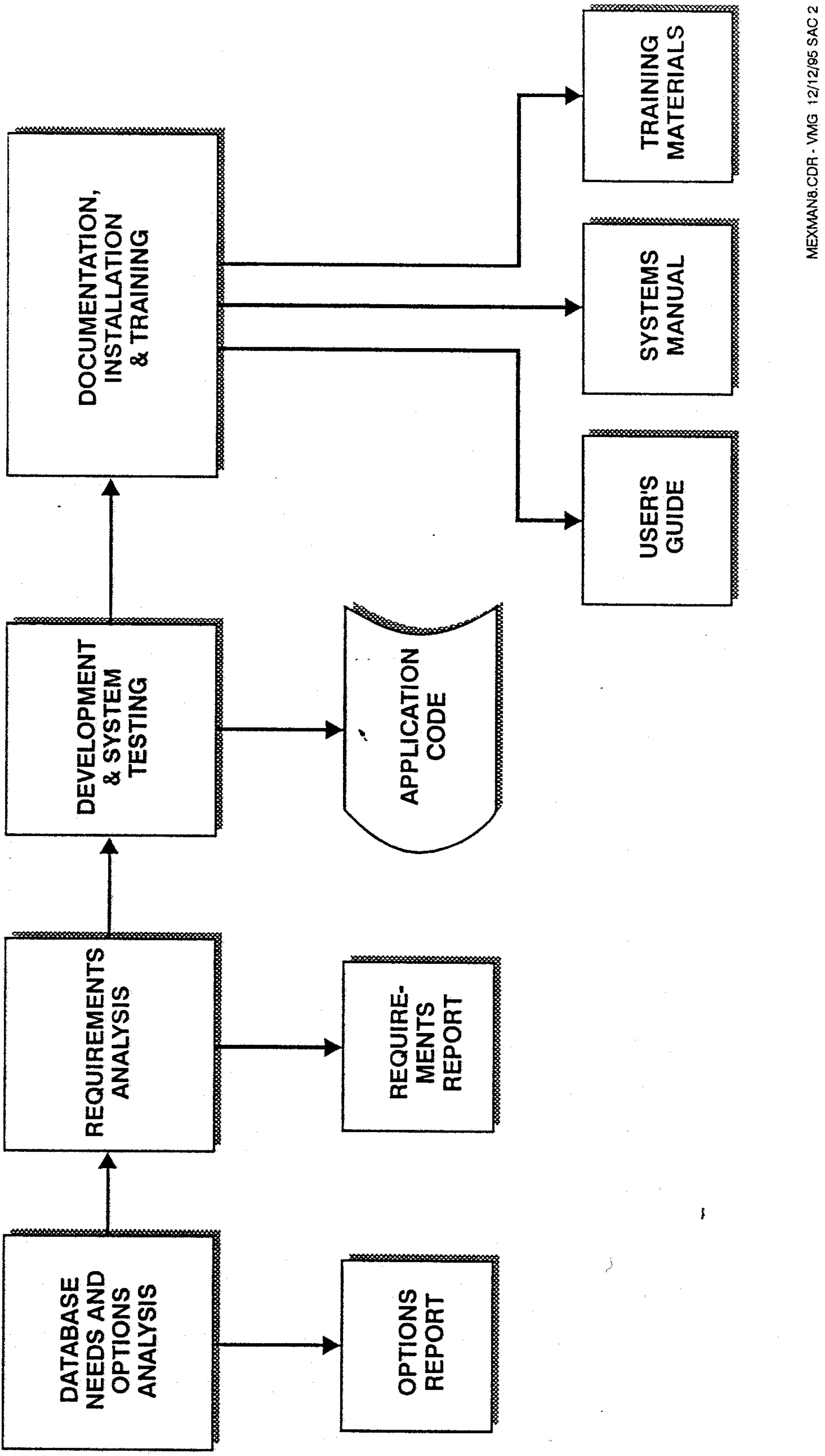


Figure 5-1. Data Management Development Process

efforts. The proposed approach to the development of a more advanced data management system for INE is illustrated in Figure 5-1 and further described by the following recommended technical activities.

Database Needs and Options Analysis

The development of relational databases for INE will begin with a Database Needs and Options Analysis to select the approach best-suited to meet the requirements of the Mexico Emissions Inventory Program within the schedule and budgetary constraints. The first step in this analysis will be to perform a needs analysis. The purpose of the needs analysis will be to determine the requirements of the system. For example, should the system contain both air toxics and criteria pollutant emissions? Should the system have a multimedia focus? How will data in the system be shared with other interested groups, such as the United States?

Following the needs assessment, various options will be evaluated. To begin, the existing database system, SNIFF, will be evaluated. Other systems will also be evaluated that have the potential to meet the data management requirements for this project. A Database Options Analysis Report will be prepared containing a recommendation on the most appropriate database for this project. Multiple database options will be considered that would allow INE to develop a new system, to use or modify a public-domain system, or to use a proprietary system. Example database options include:

- Develop new relational database system (using FoxPro, SAS®, Oracle, etc.);
- Regional Air Pollution Inventory Development System (RAPIDS);
- STEPS system commercially available from Pacific Environmental Systems;
- Aerometric Information Retrieval System (AIRS);
- California Emissions Inventory Development and Reporting System (CEIDARS) from the California Air Resources Board (CARB);
- Paradox system developed for the Arizona Department of Environmental Quality (AZDEQ); and

- GloTech/GloED used for managing global-scale emissions data.

This list will be expanded as necessary prior to the initiation of the database options analysis.

Database System Development

After the Options Analysis is completed, it is likely that either system development or customization of an existing system will be required. Therefore, the detailed requirements for the selected database system must be defined, including the queries, displays, and reports. These specifications should be presented in a written Requirements Analysis. The Requirements Analysis is necessary for the software programmers to code and test a new system or to customize an existing system.

The newly developed or modified database design must then be coded and tested, based on the Requirements Analysis. The finished product of this task will consist of a completed and tested database system.

Following the Options Analysis, decisions will be needed to determine who carries out the remaining tasks. For example, should the Options Analysis select RAPIDS as the database system, it is possible that INE may elect to work with Environment Canada on the Requirements Analysis and subsequent coding and testing.

System Installation and Training

Finally, written documentation for the database system must be provided in the form of a Systems Manual and User's Guide. The database system must be installed at INE and training classes conducted. Regardless of the system developed and/or selected, provisions should be made for ongoing technical support for approximately two years to ensure that INE fully implements the new system.

6.0 PROPOSED RESOURCE ALLOCATION

Developing costs and setting priorities for the activities needed to develop Mexico's national inventory program is subjective. The material in this section reflects our best professional judgement on resource needs and allocation of those resources. Consequently, the values presented in this section should be viewed from a planning standpoint rather than as exact values. Another level of cost estimation should be performed once the Phase II resources have been established. With this objective in mind, priorities have been assigned to each activity discussed in this report according to three different funding scenarios:

- Scenario 1 - approximately $400,000 is available in Phase II to establish the national inventory program;
- Scenario 2 - approximately $1M can be obtained; and
- Scenario 3 - the approximately $5M to $7M listed in Table 6-1 can be obtained to develop the program.

Table 6-1 presents detailed cost estimates for each of the program elements discussed in this plan. Where appropriate, cost ranges are presented. Total costs for the initiation of a complete inventory program in Mexico are estimated between $5.5M and $6.8M. Each line item listed in Table 6-1 is assigned to one of the three funding scenarios based on our perception of priorities. Scenarios 1 and 2 are presented at the end of this section.

Current funding available through the Western Governors' Association for the development of the inventory program is $345,000. This represents scenario #1. Anticipated funding is approximately $1M, and is shown as Scenario #2.

Table 6-1

Recommended Activities and Estimated Costs

Program Element	Activity	Funding Scenario[a]	Cost Estimate ($000)	Discussion
Training Course	Training Course Curriculum and Materials	1	100	This cost estimate assumes that some of the manuals can be used as text material in the course.
	University Autónoma Metropolitan - Azcaptzalco	1	15	UAM sponsorship for some of UAM's efforts in the development of the course materials.
	Train UAM Staff	1	50	Development of materials to train UAM staff.
	Translation of Materials	N/A	0	No funds have been budgeted for translating any of the training materials.
Inventory Manuals	Emissions Inventory Program Planning	1	15 - 20	This manual will address the important planning issues that must be considered in an air emissions inventory program. Program planning will be discussed not as an "up-front" activity, but rather as an ongoing process to ensure the long-term growth and success of an emissions inventory program.
	Emissions Inventory Fundamentals	1	12 - 18	This manual will present the basic fundamentals of emissions inventory development. The objective is to discuss inventory elements that apply to multiple source types (e.g., point and area) in this one manual, so as to avoid the need for repetition in multiple volumes.
	Basic Methodologies	1	20 - 28	This manual will present the basic methodologies used to develop emission estimates. Starting with information previously presented in the Methodology Proposal, this manual will provide additional detailed discussion of each methodology, including examples and sample calculations. Inventory tools associated with each methodology will be identified and included in Volume XI (References).
Inventory Manuals (Cont.)	Point Sources	1	50 - 75	This manual will provide guidance for developing the point source emissions inventory. A table will be developed to cross-reference each

Table 6-1

(Continued)

Program Element	Activity	Funding Scenario[a]	Cost Estimate ($000)	Discussion
				industry/device type combination (e.g., petroleum refining/combustion devices) with one or more of the basic methodologies presented in Volume III.
	Area Sources	1	75 - 100	This manual will provide guidance for developing the area source emissions inventory. After the presentation of general area source information, a table will be provided to cross-reference each area source category (e.g., asphalt application) with one or more of the basic methodologies presented in Volume III. Then, source category-specific information will be discussed for each source category defined in the table.
	On-Road Mobile Sources	1	60 - 80	This manual will explain the necessary steps for development of an emissions inventory for on-road mobile sources. Motor vehicles are a significant emissions source within the overall emissions inventory. Because motor vehicles are inherently different from point and area sources, the available estimation methods and required data are also different. To estimate emissions from these complex sources, models are the preferred estimation tool. Many of these models utilize extensive test data inputs applicable to a given country or region. This manual will focus primarily on the data development phase of estimating motor vehicle emissions.
Inventory Manuals (Cont.)	Natural Sources	3	30 - 40	This manual will provide guidance for developing the natural source emissions inventory (i.e., biogenic VOC and soil NO_x). In addition, this manual will include the theoretical aspects of emission calculations and discussion of specific models.

Table 6-1

(Continued)

Program Element	Activity	Funding Scenario[a]	Cost Estimate ($000)	Discussion
	Modeling Inventory Development	3	10 - 25	This manual will provide guidance for developing inventory data for use in air quality models and will address issues such as temporal allocation, spatial allocation, speciation, and projection of emission estimates.
	Evaluation	2	50 - 60	This manual will consist of three parts: quality assurance / quality control (QA / QC), uncertainty analysis, and emissions verification. The QA / QC portion will define the overall QA / QC program and be written to complement source specific QA / QC procedures written into other manuals. The uncertainty analysis will include not only methods of assessing uncertainty in emission estimates, but also for assessing uncertainty in modeling values such as speciation profiles and emission projection factors. The emissions verification section will describe various analyses that can be done to examine the accuracy of the emission estimates. Examples include receptor modeling and trajectory analysis combined with specific data analysis techniques.
	Data Management	2	30 - 40	This manual will address the important needs associated with the data management element of a comprehensive emission inventory program.
	Translation	NA	60	All manuals will be completed in English and then translated into Spanish.
Area Source Methodology Development	Develop Multivariate Emission Models	3	300	Cost estimate covers only the high priority area sources for which multivariate modeling approach has been recommended. Including all area source categories would increase this amount to approximately $700,000.
Special Studies	Fugitive Emissions from Domestic	2	50	Determine areas of propane fuel use and quantities

Table 6-1

(Continued)

Program Element	Activity	Funding Scenario[a]	Cost Estimate ($000)	Discussion
for Area Sources	Fuel Usage			of use. Develop emissions estimating techniques, including source sampling if required.
	Emissions from Waste Burning	3	75	Characterize extent of open burning dumps, quantity of refuse burned, refuse composition, and typical burning practices. Develop emissions estimating techniques which would likely include surveys and/or source sampling.
	Emissions from Open Sewage	3	25	Characterize extent of open sewage and typical chemical composition of sewage. Develop emission estimating techniques, including source sampling if required.
	Emissions from Brick Manufacturing	2	35	Determine areas with small-scale brick kilns, quantity of fuel used, and fuel composition. Develop emissions estimating techniques using surveys and/or source sampling.
	Emissions from Street Vendors	3	25	Characterize extent of street vendors, quantity of fuel used, and fuel composition. Develop emissions estimating techniques using surveys and/or source sampling.
	Solvent Usage	2	150	Conduct a stratified survey to develop solvent usage data by industrial/commercial sector. Develop emissions estimating techniques for solvent area source categories.
Special Studies for Area Sources (Cont.)	National Solvents Balance	3	30	Perform a national solvents balance based on information from appropriate manufacturers' association data, import/export records, and other data sources. Use results to develop or verify emissions estimates for solvent area source categories.
	National Petroleum Balance	3	25	Perform a national level petroleum balance based on information from PEMEX and other data sources. Test and confirm the reasonableness of

Table 6-1

(Continued)

Program Element	Activity	Funding Scenario[a]	Cost Estimate ($000)	Discussion
				petroleum balance. Data used to supplement area source categories that consume petroleum-based fuels.
	Heterogeniety of Emissions in Mexico	3	30	Identify region-specific factors that affect emission estimates. Assess qualitatively (and possibly quantitatively) what effects these factors have on various source categories. Develop procedures for adjusting emissions based on geographic differences.
	Nonroad Equipment	3	150	Confirm that Mexico has a smaller engine population than the U.S. Conduct survey to quantify actual engine populations.
Special Studies for Motor Vehicles	Driving Cycle Development	3	250 - 500	Quantify typical Mexico driving patterns. Use driving pattern data to derive an appropriate driving cycle to be used in vehicle testing.
	Vehicle Testing	3	300 to 500	Measure emissions from a representative vehicle mix in cities south of Mexico - U.S. border. Use emissions data to populate an emission factor model.
	Emission Factor Model	3	150	Refine emission factor model from vehicle test data. Modify emission factor model by any applicable results from other special studies.
Special Studies for Motor Vehicles (Cont.)	I/M Effectiveness Analysis	3	125	Conduct survey to determine the actual effectiveness of established I/M programs. Compare results to theoretical effectiveness of I/M programs. Information used to adjust emission factor model and emissions estimates.
	Tampering and Misfueling Analysis	3	75	Conduct survey to establish the level of tampering and misfueling among those vehicles that have emission control technology. Data used to adjust emission factor model and emissions estimates.

Table 6-1

(Continued)

Program Element	Activity	Funding Scenario[a]	Cost Estimate ($000)	Discussion
	Unregistered Vehicle Study	3	50	Conduct survey to quantify the number of unregistered vehicles present in the Mexico vehicle fleet. Data used to modify existing vehicle registration distribution data.
Special Studies for Natural Sources	Biogenic Hydrocarbons	3	350	Develop Mexico-specific biomass and emission factors for key plant species.
	Soil NO_x	3	200	Develop soil NO_x fluxes for Mexico specific conditions.
Methodology Testing	Develop Emissions Inventory for Ambos Nogales	3	150	Inventory effort will build upon planned efforts by Arizona Department of Environmental Quality for this region.
	Develop Emissions Inventory for Cd. Juárez	3	200	Inventory effort will build upon ongoing efforts by the Texas Natural Resources Conservation Commission to develop a motor vehicle emissions inventory. Point and area sources would also be included.
	Develop Emissions Inventory for Mexicali	2	250	This effort is expected to require more resources because little inventory work has been performed in this region.

Table 6-1

(Continued)

Emissions Validation	Develop Range Checks for Mexico Sources	3	50	Range checks would be used to validate emissions databases developed in the inventory program.
	Develop National Top-Down Inventory Techniques	3	50	Top down emission calculations would be performed by INE Headquarters staff as a means to evaluate emission estimates developed at the local and state levels.
Data Management	Conduct a Database Needs and Options Analysis	1	30	This task would identify and evaluate database management options. A recommended approach will be presented.
	Customize Database System for INE's use.	3	100 to 1,000	The range of costs for this task is large due to the wide range of available options. For $100,000, a simple customization of an existing system for INE use could be performed. The cost to develop a new system could approach $1M.
	Install and Train INE staff on Selected System	3	30 to 60	Includes development/refinement of system and users manuals.
Satellite Imagery Data	Gather and produce LULC data from satellite images.	3	1,300	Land use/land cover data needed for biogenic emission estimates and to facilitate the multivariate emissions modeling approach for area sources.
Emission Factor Applicability	Examine key Mexico sources and Evaluate Applicability of Existing Emission Factors	3	250	Key source types would be identified and ranked. Emission factors for key sources would be examined for applicability in Mexico.
Inventory Uncertainty	Develop and Apply Emission Uncertainty Methodology	3	60	A small effort would used to refine existing approaches with most of the resources applied to estimate uncertainty in emission estimates for one selected geographic region.

[a] Four different funding scenarios have been established: $500,000, $1M, $2M, and $5M - $7M. This table represents scenario #4.

N/A = Not applicable.

As a final point, developing the cost ranges presented in Table 6-1 required several key assumptions.

- Several of the costs associated with the technical activities are complimentary to the development of the manuals. For example, if the Evaluation Manual is not developed, then costs for the uncertainty method development will have to be increased.
- Costs for inflation have not been taken into account. Inflationary costs are assumed to be less than the imprecision of the cost estimates.
- Translation of materials from English to Spanish will only be performed for the manuals. No other translation costs have been included.
- For nearly all of the technical activities, such as the special studies for area sources, Mexican personnel are assumed to participate in the effort to provide in-kind support and to use the effort as a training exercise.

SCENARIO #1

Existing Funding ~ $345,000

Program Element	**Cost ($000)**
Training for University	120
Manuals Development	
Fundamentals	14
Basic Methodologies	26
Point Sources	50
Area Sources	75
On-Road Mobile Sources	60
Total	345

SCENARIO #2

Anticipated Funding ~ $1M

Program Element	Cost ($000)
Training for University	165
Manuals Development	
Program Planning	15
Fundamentals	14
Basic Methodologies	26
Point Sources	50
Area Sources	75
On-Road Mobile Sources	60
Emissions Evaluation	33
Data Management	30
Translation	60
Manuals Subtotal	355
Database Needs and Options Analysis	30
Area Source Special Studies	
Fugitive Emissions from Domestic Fuel Usage	50
Solvent Usage Study	150
Emissions from Brick Manufacturing	35
Area Source Subtotal	235
On-Road Motor Vehicle Special Studies	
Driving Cycle Study	0
Vehicle Testing	0
Methodology Testing	
Mexicali	250
Total	1,000

SCHEDULE

This section illustrates the anticipated sequencing and duration of each of the Phase II activities discussed in this report. Each activity is shown in the following scheduling chart.

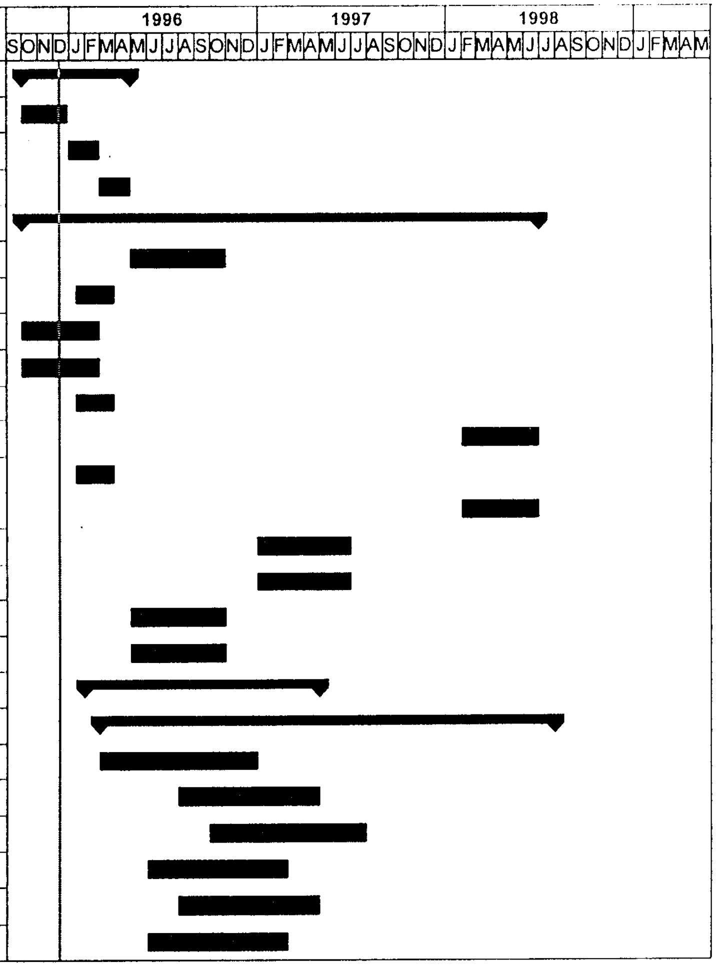
Completing all of these efforts will require several years. The current schedule illustrates that work on the Phase II activities will begin in October 1995 and conclude in December 1998. Although this represents slightly more than three full years to implement the activities discussed in this report, this is viewed as a very aggressive schedule. Completing all of these activities according to their individual durations is unlikely. Nonetheless, an aggressive schedule was developed so that work can be initiated and completed as soon as possible.

Higher priority items, such as those shown in Scenario 1 of Section 6.0, should be completed by mid 1996. Medium priority activities described in Scenario 2 would be completed by approximately the end of 1997. Several lower priority items would be completed by the end of 1998.

The most difficult scheduling issue appears to be the coordination of the development of the inventory manuals while additional methodology development and special studies proposed for area and mobile sources are taking place. Rather than delaying these manuals until these technical activities are completed, draft manuals should be developed, which would then be revised after the technical studies were completed.

Phase II Activities under the Mexico
Emissions Inventory Methodology Project

ID	Task Name	Days	Start	Finish
1	**TRAINING COURSE**	**153d**	**10/2/95**	**4/30/96**
2	Training Materials	66d	10/2/95	12/29/95
3	Train UAM Staff	44d	1/1/96	2/29/96
4	Prototype	43d	3/1/96	4/30/96
5	**INVENTORY MANUALS**	**718d**	**10/2/95**	**6/30/98**
6	Emissions Inventory Program Planning	132d	5/1/96	10/31/96
7	Emissions Inventory Fundamentals	55d	1/15/96	3/29/96
8	Basic Methodologies	110d	10/2/95	2/29/96
9	Point Sources	110d	10/2/95	2/29/96
10	Initial Area Sources	55d	1/15/96	3/29/96
11	Revised Area Sources	107d	2/2/98	6/30/98
12	Initial On-Road Mobile Sources	55d	1/15/96	3/29/96
13	Revised On-Road Mobile Sources	107d	2/2/98	6/30/98
14	Natural Sources	129d	1/1/97	6/30/97
15	Modeling Inventory Development	129d	1/1/97	6/30/97
16	Evaluation	132d	5/1/96	10/31/96
17	Data Management	132d	5/1/96	10/31/96
18	**AREA SOURCE METHODOLOGY DEVELOPMENT**	**325d**	**2/1/96**	**4/30/97**
20	**SPECIAL STUDIES FOR AREA SOURCES**	**631d**	**3/1/96**	**7/31/98**
21	Fugitives Emissions from Domestic Fuel Usage	218d	3/1/96	12/31/96
22	Emissions from Waste Burning	195d	8/1/96	4/30/97
23	Emissions from Open Sewage	217d	10/1/96	7/30/97
24	Emissions from Brick Manufacturing	195d	6/3/96	2/28/97
25	Emissions from Street Vendors	195d	8/1/96	4/30/97
26	Solvent Usage	195d	6/3/96	2/28/97



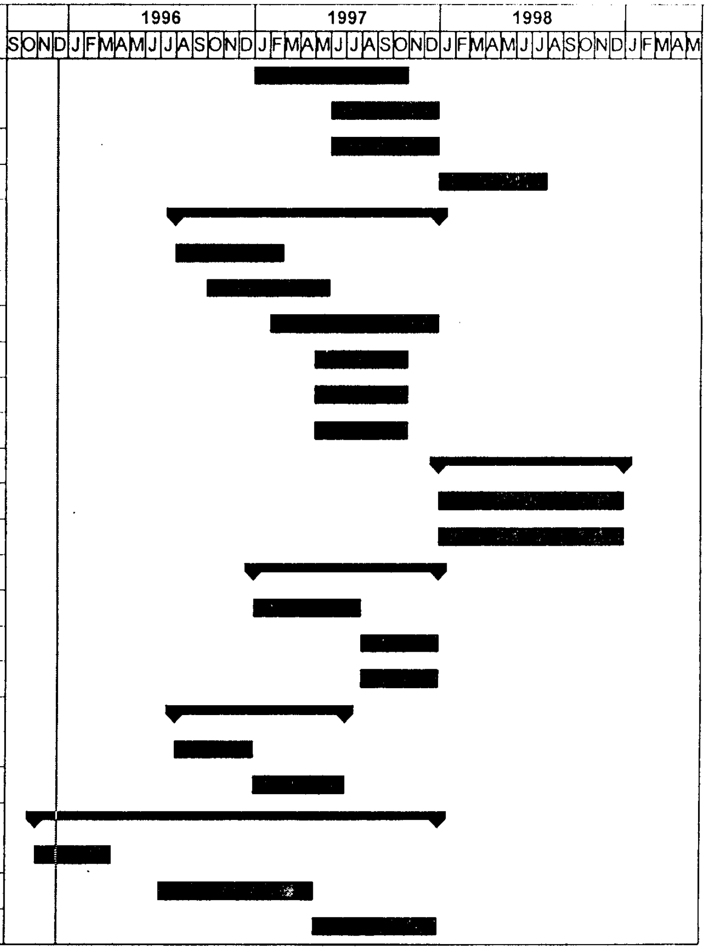
PROJECT SCHEDULE

Date Produced: 12/12/95

Task Summary ▼▬▼ Task ■

Phase II Activities under the Mexico
Emissions Inventory Methodology Project

ID	Task Name	Days	Start	Finish
27	National Solvents Balance	218d	1/1/97	10/31/97
28	National Petroleum Balance	153d	6/2/97	12/31/97
29	Heterogeneity of Emissions in Mexico	153d	6/2/97	12/31/97
30	Nonroad Equipment	152d	1/1/98	7/31/98
31	**SPECIAL STUDIES FOR MOTOR VEHICLES**	**370d**	**8/1/96**	**12/31/97**
32	Driving Cycle Development	152d	8/1/96	2/28/97
33	Vehicle Testing	174d	10/1/96	5/30/97
34	Emission Factor Model	238d	2/3/97	12/31/97
35	I/M Effectiveness Analysis	132d	5/1/97	10/31/97
36	Tampering & Misfueling Analysis	132d	5/1/97	10/31/97
37	Unregistered Vehicle Study	132d	5/1/97	10/31/97
38	**SPECIAL STUDIES FOR NATURAL SOURCES**	**261d**	**1/1/98**	**12/31/98**
39	Biogenic Hydrocarbons	261d	1/1/98	12/31/98
40	Soil NOx	261d	1/1/98	12/31/98
41	**METHODOLOGY TESTING**	**261d**	**1/1/97**	**12/31/97**
42	Ambos Nogals	152d	1/1/97	7/31/97
43	Cd. Juarez	109d	8/1/97	12/31/97
44	Mexicali	109d	8/1/97	12/31/97
45	**EMISSIONS VALIDATION**	**238d**	**8/1/96**	**6/30/97**
46	Develop Ronge Checks	109d	8/1/96	12/31/96
47	Develop National Top-Down Inventory Method	129d	1/1/97	6/30/97
48	**DATA MANAGEMENT**	**567d**	**11/1/95**	**12/31/97**
49	Conduct Database Options Analysis	109d	11/1/95	3/29/96
50	Customize System	218d	7/1/96	4/30/97
51	Install & Train	175d	5/1/97	12/31/97



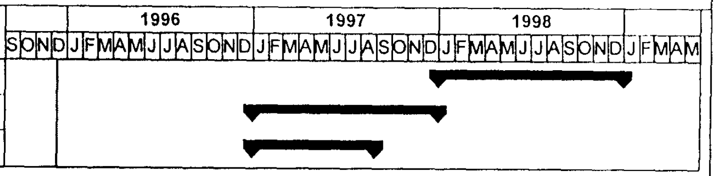
PROJECT SCHEDULE

Date Produced: 12/12/95

Task Summary ▼━━▼ Task ■

Phase II Activities under the Mexico
Emissions Inventory Methodology Project

ID	Task Name	Days	Start	Finish
52	SATELLITE IMAGERY DATA	261d	1/1/98	12/31/98
54	EMISSION FACTOR APPLICABILITY	261d	1/1/97	12/31/97
56	INVENTORY UNCERTAINTY	173d	1/1/97	8/29/97



PROJECT SCHEDULE

Date Produced: 12/12/95

Task Summary ▼▬▼ Task ▬

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APPENDIX A
DRAFT OUTLINE FOR THE MEXICO EMISSIONS INVENTORY PROGRAM MANUALS

This is a draft outline for the Mexico Emissions Inventory Program Manuals to be developed as one of the major work elements of Phase II of the Mexico Emissions Inventory Project. Each Roman numeral (i.e., I, II, III, etc.) in this outline represents a separate manual or volume. The major items or subjects proposed for each manual are presented below.

I. EMISSIONS INVENTORY PROGRAM PLANNING

PURPOSE: This manual will address the important planning issues that must be considered in an air emissions inventory program. Program planning will be discussed not as an "up-front" activity, but rather as an ongoing process to ensure the long-term growth and success of an emissions inventory program.

- Broad Purpose of the Emissions Inventory Program;
- Emissions Inventory End Uses (use of the data);
- Regulatory Requirements for Data Collection (including limits of regulatory authority);
- Coordination of Local/State/Federal Levels;
- Emissions Inventory Staff Requirements;
- Data Management Requirements (data handling and reporting);
- Emissions Inventory Software/Hardware Requirements; and
- Identification and Evaluation of Needs for Special Studies (e.g., emission factor applicability in Mexico, development of Mexico-specific emission factors, etc).

II. EMISSIONS INVENTORY FUNDAMENTALS

PURPOSE: This manual will present the basic fundamentals of emissions inventory development. The objective is to discuss inventory elements that apply to multiple source types (e.g., point and area) in this one manual, so as to avoid the need for repetition in multiple volumes.

- Introduction (how to use emissions inventory development manuals);
- Applicable Regulations (i.e., how emission regulations are applied in emission inventories through rule effectiveness and rule penetration);

- Rule Effectiveness (i.e., the adjustment of emissions to account for incomplete compliance with emission reduction regulations);

- Rule Penetration (i.e., the adjustment of emissions to account for emission sources exempt from requirements of emission reduction regulations);

- Identification of All Pollutants to be Included in the Emissions Inventory and their definitions (e.g., Volatile Organic Compounds [VOC], Reactive Organic Gases [ROG], oxides of nitrogen [NO_x] etc.);

- Point/Area Source Delineation; and

- Point/Area Source Reconciliation (i.e., to prevent double-counting of emissions in both the point and area source inventories).

III. EMISSIONS INVENTORY DEVELOPMENT: BASIC METHODOLOGIES

PURPOSE: This manual will present the basic methodologies used to develop emission estimates. Starting with information previously presented in the Methodology Evaluation and Proposal Report, this manual will provide additional detailed discussion of each methodology, including examples and sample calculations. Inventory tools associated with each methodology will be identified and included in Volume XI (References).

- Source Sampling;

- Emissions Models;

- Surveying;

- Emission Factors and Census-based or other Activity Data;

- Material Balance; and

- Extrapolation.

IV. EMISSIONS INVENTORY DEVELOPMENT: POINT SOURCES

PURPOSE: This manual will provide guidance for developing the point source emissions inventory. A table will be developed to cross-reference each industry/device type combination (e.g., petroleum refining/combustion devices) with one or more of the basic methodologies presented in Volume III.

- Cross-Reference Table of Industry/Device Type to Methodology (see Table A-1 for industry/device type listing);
- Stack Parameters (i.e., identify and provide guidance for collecting parameters);
- Control Devices (i.e., identify and provide guidance for collecting control information);
- Design and Process Considerations Influencing Emissions;
- Geographic Differences and Variability in Mexico;
- Quality Assurance/Quality Control (QA/QC);
- Typically Overlooked Processes and Ambiguities;
- Data Tables or References (emission factors, activity data, etc.);
- Data Collection Forms (questionnaires) and Instructions; and
- Notes or Special Considerations.

V. EMISSIONS INVENTORY DEVELOPMENT: AREA SOURCES (Includes Non-Road Mobile)

PURPOSE: This manual will provide guidance for developing the area source emissions inventory. After the presentation of general area source information, a table will be provided to cross-reference each area source category (e.g., asphalt application) with one or more of the basic methodologies presented in Volume III. Then, source category-specific information will be discussed for each source category defined in the table.

1. General Information
    - Definition of Area Sources and Source Categorization;
    - Typically Overlooked Processes and Ambiguities;

- Geographic Differences and Variability in Mexico;
- Quality Assurance/Quality Control (QA/QC); and
- Control Factors (i.e., based on emission reduction regulations).

2. Cross-Reference Table of Area Source Category to Methodology (See Table A-2 for Area Source Category listing)

3. Source Category-Specific Information (the following information will be provided for each source category in the cross-reference table)

    - Source Category Description;
    - Source Category Coding (i.e., numerical codes);
    - Data Tables or References (emission factors, activity data, etc.);
    - Data Collection Forms (Questionnaires) and Instructions; and
    - Notes or Special Considerations.

VI. EMISSIONS INVENTORY DEVELOPMENT: ON-ROAD MOBILE SOURCES

PURPOSE: This manual will explain the necessary steps for development of an emissions inventory for on-road mobile sources. Motor vehicles are a significant emissions source within the overall emissions inventory. Because motor vehicles are inherently different from point and area sources, the available estimation methods and required data are also different. In order to estimate emissions from these complex sources, models are the preferred estimation tool. Many of these models utilize extensive test data inputs applicable to a given country or region. This manual will focus primarily on the data development phase of estimating motor vehicle emissions.

- **Available Estimation Methods—**Travel-based estimation techniques, fuel consumption-based estimation techniques, and fuel balances;
- **Primary Data and Information—**Vehicle kilometers traveled (VKT), vehicle registration distribution, fuel consumption, fuel composition (% sulfur, % lead, etc.), emission control technology information, average vehicle speeds, and ambient temperature data;
- **Secondary Data and Information—**Inspection and maintenance (I/M) program

information, tampering and misfueling data, number of U.S. vehicles present in fleet (mainly applicable in the border areas), number of unregistered vehicles present in fleet, mileage accumulation rates;

- **Tertiary Data and Information—**Roadside surveys and driving pattern studies;

- **Source Category Information—**Description of vehicle categorization, numerical coding guidelines, and emission control technology equivalence matrix (equates Mexican vehicles to other vehicles with similar characteristics in order to utilize existing test data);

- **Emission Factor Data Sources—**U.S. EPA MOBILE-based emission factor model (for VOC, CO, and NO_x), U.S. EPA PART5-based emission factor model (for particulate matter), fuel balances (for SO_x);

- **Mexico-U.S. Differences—**Engine types (gasoline or diesel), vehicle types (light duty automobile, light duty truck, heavy duty truck, bus, etc.), control technology, and driving patterns;

- **Geographic Differences in Mexico—**Engine types, vehicle types, control technology, fuel specifications, driving speeds, driving patterns, I/M programs, temperature, altitude, etc; and

- **Quality Assurance/Quality Control (QA/QC)—**Comparison of mobile source emissions as a percentage of total inventory, comparison of gasoline mobile source emissions to diesel mobile source emissions, calculation of emissions per VKT or emissions per capita, and comparison of these estimates to similar regions.

VII. EMISSIONS INVENTORY DEVELOPMENT: NATURAL SOURCES

PURPOSE: This manual will provide guidance for developing the natural source emissions inventory (i.e., biogenic VOC and soil NO_x). In addition, this manual will include the theoretical aspects of emission calculations and discussion of specific models.

- Source Category Description (e.g., biogenic VOC and soil NO_x);

- Emission Mechanisms and Theoretical Aspects Influencing Emissions;

- Basic Emission Algorithms;

- Biomass Determination (biogenic VOC only);

- Land Use/Land Cover Data Development;

- Temporal and Meteorological Adjustments; and
- Emission Calculation Approaches.

VIII. MODELING INVENTORY DEVELOPMENT

PURPOSE: This manual will provide guidance for developing a modeling inventory and will address issues such as temporal allocation, spatial allocation, speciation, and projections.

- Definition of modeling inventory terms and purpose of data;
- Seasonal Adjustment (e.g., ozone-season day);
- Temporal Allocation (i.e., disaggregation of annual emission estimates to smaller time intervals, typically to produce hourly emission estimates for use in grid-based air quality models);
- Spatial Allocation (i.e., disaggregation of national or state emission totals to smaller spatial regions such as counties or municipalities, or even grid cells);
- Speciation (e.g., chemical speciation of VOC, PM, NO_x, and SO_x); and
- Projections (based on growth and control factors for future years from both an economic and a regulatory standpoint).

IX. EMISSIONS INVENTORY PROGRAM EVALUATION

PURPOSE: This manual will consist of three parts: quality assurance/quality control (QA/QC), uncertainty analysis, and emissions verification. The QA/QC portion will define the overall QA/QC program and be written to complement source specific QA/QC procedures written into other manuals. The uncertainty analysis will include not only methods of assessing uncertainty in emission estimates, but also for assessing uncertainty in modeling values such as speciation profiles and emission projection factors. The emissions verification section will describe various analyses that can be done to examine the accuracy of the emission estimates. Examples include receptor modeling and trajectory analysis combined with specific data analysis techniques.

1. Quality Assurance/Quality Control

    - Description of Inventory QA/QC Concepts and Definition of Terms;

    - Inventory Review Protocol (i.e., description of process that will be used to guide QA/QC program);

    - Completeness Review Procedures;

    - Accuracy/Reasonableness Review Procedures (e.g., data quality objectives); and

    - Consistency Review Procedures.

2. Uncertainty Analysis

    - Description of Uncertainty Analysis Concepts and Definition of Terms; and

    - Recommended Methodologies for Uncertainty Analysis.

3. Emissions Verification

    - Description of Emissions Verification Concepts and Definition of Terms (e.g., range checks, top-down versus bottom-up emission calculations, comparison with ambient monitoring data, use of air quality models, etc.); and

    - Applicable Methodologies for Emissions Verification.

X. DATA MANAGEMENT

PURPOSE: This manual will address the important needs associated with the data management element of a comprehensive emission inventory program.

- Introduction;

- General-Purpose Data Management Systems and Tools;

- Specific-Purpose Software Systems and Tools;

- Specific Data Items (e.g., coding system and confidentiality);

- Electronic Transmittal;
- Frequency of Updates;
- Recordkeeping (electronic and paper archives);
- Mexico-Specific Databases (e.g., industrial codes, emission factors, speciation profiles); and
- Reports (standard and user-defined).

XI. REFERENCES

PURPOSE: This will be a compendium of tools that can be used in emission inventory program development. Inventory tools referenced in the other Manuals will be included.

- Hardcopy documents;
- Electronic documents and databases (placed on a bulletin board); and
- Electronic models (TANKS, MOBILE5a, PART5 etc.).

Table A-1

Point Source Types to be Referenced in Manuals

Major Category	Subcategories	Priority[a]	Pollutant	Comments
Electric Utility	Combustion by Fuel Type	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Category consists of internal and external combustion devices used to produce electricity.
Chemical Manufacturing	Process Emissions	1	VOC and NH_3	Typically VOCs generated during the manufacture of organic chemicals.
	Combustion Emissions	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuels burned to supply energy to the chemical manufacturing process.
	Fugitives From Equipment Leaks	1	VOC	Subcategory includes VOC emissions from such devices as pipeline valves and flanges, and compressor seals.
	Storage Tanks	1	VOC	Floating and fixed roof storage tanks release VOC emissions from tank breathing and the filling of the tank.
	Miscellaneous Solvent Usage	3	VOC	Organic solvents are used for equipment maintenance and can be an important source of VOC emissions.
Petroleum Refining	Process Emissions	1	VOC	Example process emissions include fluid catalytic cracking units and vacuum distillate column condensers.
	Combustion Emissions	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuels burned to supply energy to the refining process.
	Fugitives From Equipment Leaks	1	VOC	Subcategory includes VOC emissions from such devices as pipeline valves and flanges, and compressor seals.
	Storage Tanks	1	VOC	Floating and fixed roof storage tanks release VOC emissions from tank breathing and the filling of the tank.
	Miscellaneous Solvent Usage	3	VOC	Organic solvents are for used equipment maintenance and can be an important source of VOC emissions.

Table A-1

(Continued)

Primary Metal Production	Process Emissions	1	SO_x and PM	Subcategory includes numerous operations that occur during the smelting and refining of metals such as copper, lead, iron / steel, zinc, etc. Process emissions primarily consist of crushing and grinding of raw materials followed by pyrometallurgical and casting operations to produce metal ingots.
	Combustion Emissions	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuel burned to supply energy to the smelting and refining processes.
	Fugitive Emissions	2	PM	Subcategory includes TSP emissions from such devices as storage piles and entrained dust from unpaved roads.
Secondary Metal Production	Process Emissions	2	VOC and PM	Emissions from finishing process that produce VOCs and TSP.
	Combustion Emissions	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuel burned to supply energy to secondary metal finishing processes.
Cement Production	Process Emissions	1	PM	Emission sources include material handling and crushing and grinding of both raw and finished materials.
	Combustion Emissions	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuel burned to supply energy to the kiln.
	Fugitive Emissions	2	PM	Fugitive sources include piles and entrained dust from equipment operation on unpaved surfaces.
Miscellaneous Mineral Products (e.g. lime and aggregate kilns)	Process Emissions	1	PM	Emission sources include material handling and crushing and grinding of both raw and finished materials.
	Combustion Emissions	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuel burned to supply energy to the kiln.
	Fugitive Emissions	2	PM	Fugitive sources include piles and entrained dust from equipment operation on unpaved surfaces.

Table A-1

(Continued)

Automotive Industry	Process Emissions	1	VOC	Emission sources include surface coating and other processes that emit VOCs.
	Combustion Emissions	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuel burned to supply energy for production of automobiles and associated parts.
	Fugitive Emissions	2	VOC	A variety of solvents are used in addition to the coating material. These solvents are used for such activities as wipe cleaning and thinning of coating materials.
Wood Pulping Operations	Process Emissions	1	SO_x, VOC, and PM	Manufacture of pulp involves numerous process operations such as digesters, evaporators, and oxidation towers that produce VOC, TSP, and sulfur compounds.
	Combustion Emissions	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Large quantities of fuel are consumed in the pulping process to provide heat to process operations and to recover chemicals used in the pulping process. In addition to liquid and gaseous fuels, large quantities of wood may also be burned.
Oil and Gas Production	Process Emissions	1	VOC	This subcategory applies mostly to the processing of natural gas. Example processes include gas sweetening and stripping operations.
	Fugitive Emissions	1	VOC	Subcategory includes VOC emissions from such devices as well heads and sumps/pits. It also includes pipeline valves and flanges and compressor seals.
	Combustion Emissions	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Liquid and gaseous fuels are burned to supply energy to the oil and gas process.
	Storage Tanks	1	VOC	Typically fixed roof storage tanks are used to store crude oil in the field. Releases of VOC emissions from the tank are a result of tank breathing and filling.

Table A-1

(Continued)

Printing and Publishing	Process Emissions	1	VOC	Operations used in the printing industry (letter press, flexographic, lithographic, and gravure) produce VOC emissions.
	Fugitive Emissions	2	VOC	In addition to the printing operations, miscellaneous solvents are also used in the printing industry for thinning of inks and cleaning of equipment.
Surface Coating	Process Emissions	1	VOC	Application of coating materials results in significant VOC emissions.
	Degreasing Emissions	1	VOC	Degreasers are frequently used at facilities involved in coating operations. Solvent evaporation from the degreaser results in VOC emissions.
	Fugitive Emissions	1	VOC	A variety of solvents are used in addition to the coating material. These solvents are used for such activities as wipe cleaning and thinning of coating materials.
Bulk Fuel Terminals	Loading Operations	1	VOC	Loading and unloading of fuels into marine vessels, rail cars, and trucks results in VOC emissions. Also includes VOC emissions generated by spills.
	Storage Tanks	1	VOC	Floating and fixed roof storage tanks used at bulk terminals release VOC emissions from tank breathing and the filling of the tank.
Mining and Quarrying	Process Emissions	1	PM	There are many different mining operations that emit TSP, such as drilling/blasting, loading, and hauling.
	Fugitive Emissions	2	PM	Fugitive sources include piles and entrained dust from equipment operation on unpaved surfaces.
Wood Products Manufacture	Process Emissions	2	VOC and PM	The manufacture of finished lumber and plywood, etc. involves several processes such as pressure treating, drying, and sawing. VOCs generated in finishing process.
	Combustion Emissions	2	CO, NO_x, SO_x, VOC, PM, and NH_3	Various fuels, including wood, are used to provide the energy needed during the manufacturing process.

Table A-1

(Continued)

Sugar Production	Process Emissions	2	PM	Processing of sugar results in some TSP emissions.
	Combustion Emissions	2	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuel burned to supply energy for sugar processing.
	Fugitive Emissions	2	PM	Possible fugitive VOC and TSP emissions from degreasing, maintenance or cleaning activities.
Tanning and Leather Finishing	Process Emissions	2	VOC	Substantial VOC emissions result from the tanning and finishing processes.
	Combustion Emissions	2	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuel burned to supply energy for tanning and finishing processes.
	Fugitive Emissions	2	VOC	Possible fugitive VOC emissions from processing activities.
Glass Production	Process Emissions	2	VOC and PM	Some TSP emission from the various glass manufacturing processes.
	Combustion Emissions	2	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuel burned to supply energy for glass manufacturing processes.
	Fugitive Emissions	2	VOC and PM	Possible fugitive VOC and TSP emissions from manufacturing processes.
Rubber and Plastic Parts	Process Emissions	2	VOC	Category includes such devices as tire manufacturing, fabricated plastic products, fiberglass resin products, and plastic foam products. These manufacturing operations use a variety of processes that mostly emit VOC.
	Combustion Emissions	2	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuel burned to supply energy to rubber and plastic fabrication processes.

Table A-1

(Continued)

Fabricated Metal Products	Process Emissions	2	PM	Manufacture of fabricated metal products use process operations such as electroplating, conversion coating, abrasive blasting, and metal deposition. VOCs generated in the finishing process.
	Combustion Emissions	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Various fuels are burned in process heaters.
Textile Products	Process Emissions	2	VOC	Various chemicals/solvents are used in the production of textiles that may result in VOC emissions.
	Combustion Emissions	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuel burned to supply energy to textile manufacturing process.
Solid Waste Disposal	Landfill Gas Emissions	3	VOC	Solvents placed in landfills and biological decomposition of materials in landfills results in VOC emissions.
	Municipal Waste Combustors	1	CO, NO_x, SO_x, VOC, and PM	Combustion of municipal waste in incinerators at waste management facilities releases combustion pollutants and air toxics.
	Open Burning Dump	2	CO, NO_x, SO_x, VOC, and PM	Combustion pollutants are emitted during this process.
Miscellaneous Industrial Activities/Processes	Process Emissions	2	CO, NO_x, SO_x, VOC, and PM	There will be a number of industrial activities that don't fit into a traditional source category, such as semiconductor manufacturing. These facilities have process emissions that should be included in a point source inventory.
	Combustion Emissions	2	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuels maybe burned to support process operations. Fuels are also used frequently for space heating.
	Fugitive Emissions	2	VOC	Many miscellaneous facilities use solvents for such things as degreasing and wipe cleaning.

Table A-1

(Continued)

Government Facilities	Combustion Emissions	2	CO, NO_x, SO_x, VOC, PM, and NH_3	Research and development, military, and other institutional facilities often burn fuels for space heating, or to a lesser extent, for process operations.
	Fugitive Emissions	2	VOC	Many facilities use solvents for such activities as degreasing and wipe cleaning. This can be a large source of VOC emissions.
Food and Agriculture	Process Emissions	3	VOC and PM	Category includes numerous food and agriculture related processes that generate primarily TSP and VOC. Examples include: alfalfa dehydration, coffee roasting, grain elevators, beer production, vegetable oil processing, etc.
	Combustion Emissions	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuels burned to supply energy to processing of agricultural products.
Asphalt Plants	Process Emissions	3	PM	Emission sources in this category include such groups as screens, bins, and mixers; heaters; and dryers.
	Combustion Emissions	1	CO, NO_x, SO_x, VOC, PM, and NH_3	Fuel burned to supply energy to the asphalt plant.

[a] A priority has been assigned to communicate the current, perceived importance of each source type. The priorities assigned to each source type will be refined over time as feedback is obtained from INE and more Mexico-specific information is gathered.

Table A-2

Stationary Area Source Types to be Referenced in Manuals

Major Category	Subcategory	Priority[a]	Pollutant	Comments
Stationary Source Fuel Combustion - Industrial and Commercial	By fuel type	1	CO, NO_x, SO_x, VOC, and PM	Subcategories include fuels such as coal, combustoleo, natural gas, and waste-derived fuels. This will be an important category initially, until many of the smaller sources are incorporated into the point source inventory.
Stationary Source Fuel Combustion - Residential Commercial Fuels	Commercial fuels by fuel type	1	CO, NO_x, SO_x, VOC, and PM	Subcategories include fuels such as coal, combustoleo, natural gas, etc.
Stationary Source Fuel Combustion - Residential Biomass or Waste-Derived Fuels	Biomass or waste-derived fuels by fuel type	1	CO, NO_x, SO_x, VOC, and PM	Subcategories include fuels such as wood, waste oil, tires, etc.
Paved Road Dust	N/A	1	PM	An important source of particulate matter.
Unpaved Road Dust	N/A	1	PM	An important source of particulate matter.
Surface Coatings and Clean-up Solvents - Industrial	By industrial sector	1	VOC	Subcategories include textile products, machinery & equipment, etc. This will be an important category initially until many of the smaller sources are incorporated into the point source inventory.
Industrial Surface Cleaning (Degreasing)	By industrial sector	1	VOC	Subcategories include fabricated metal products, industrial machinery & equipment, auto repair services, etc. This will be an important category initially until many of the smaller sources are incorporated into the point source

Table A-2

(Continued)

Major Category	Subcategory	Priority[a]	Pollutant	Comments
				inventory.
Dry Cleaning	By solvent type	1	VOC	Subcategories include perchloroethylene, special naphthas, and other solvents.
Consumer Solvents	By product type	1	VOC	Subcategories include personal care products, household products, pesticides, etc.
Storage and Transport (Storage Tanks, Loading / Unloading Operations, and Fugitive Component Leaks from Pipelines, Bulk Terminals, Service Stations, and Transport Vessels / Trucks)	By product type	1	VOC	Subcategories include petroleum products (crude oil, gasoline, diesel, etc.) and may also include organic, inorganic, and bulk materials.
Agriculture Production	Livestock	1	PM and NH_3	Feedlots are a major source of NH_3 and a source of particulate matter.
Waste Management - On-Site Incineration	N / A	1	CO, NO_x, SO_x, VOC, and PM	Includes incineration of all industrial waste types.
Waste Disposal - Refuse Burning	N / A	1	CO, NO_x, SO_x, VOC, and PM	Includes agricultural and other types of open burning.
Fires	Wildfires	1	CO, NO_x, SO_x, VOC, and PM	May be a significant source of particulate matter.
	Prescribed burning	1	CO, NO_x, SO_x, VOC, and PM	May be a significant source of particulate matter.
	Structures	2	CO, NO_x, SO_x, VOC, and PM	Minor source of particulate matter.
Industrial Processes	By industrial sector	2	CO, NO_x, SO_x, VOC, and PM	Subcategories include chemical manufacturing, rubber / plastics, food and kindred products (tortilla factories), brick manufacturing, etc. This could be an important category initially, until many of the smaller

Table A-2

(Continued)

Major Category	Subcategory	Priority[a]	Pollutant	Comments
				sources are incorporated into the point source inventory.
Surface Coatings and Clean-up Solvents - Architectural Coatings	N/A	2	VOC	Architectural coatings are thought to be a significant source of VOC emissions in urban areas of Mexico.
Surface Coatings and Clean-up Solvents - Auto Refinishing	N/A	2	VOC	Auto refinishing is thought to be a significant source of VOC emissions in urban areas of Mexico.
Graphic Arts	N/A	2	VOC	Minor VOC source.
Asphalt Application	N/A	2	VOC	Includes application of various types of asphalt materials.
Agriculture Production	Pesticide Application	2	VOC	May be an important VOC source.
	Crops	2	PM and NH_3	Agricultural tilling can be an important particulate matter source. Fertilizer application can be a significant NH_3 source.
Waste Management - Wastewater Treatment	N/A	2	VOC and NH_3	Minor source of VOC, but possibly a significant source of NH_3.
Open Sewage	N/A	2	VOC and NH_3	Most likely a minor source of VOC. Possibly a significant source of NH_3.
Street Vending/Cooking	N/A	2	CO, NO_x, SO_x, VOC, and PM	Magnitude of emissions is uncertain.
Domestic Ammonia Emissions	N/A	2	NH_3	Includes domesticated dogs and cats, human respiration, human perspiration, household ammonia use, cigarette smoke, and untreated human waste.
Building Construction	N/A	3	PM	Building construction and demolition produce fugitive TSP emissions through processes such as site preparation and mechanical/explosive dismemberment.

Table A-2

(Continued)

Major Category	Subcategory	Priority[a]	Pollutant	Comments
Surface Coatings and Clean-up Solvents - Traffic Markings	N / A	3	VOC	Traffic markings are thought to be a minor source of VOC emissions in Mexico.
Rubber and Plastics Fabrication	N / A	3	VOC	Minor VOC source.
Waste Management - Landfills	N / A	3	VOC	Minor source of VOC.

[a] A priority has been assigned to communicate the current, perceived importance of each source type. The priorities assigned to each source type will be refined over time as feedback is obtained from INE and more Mexico-specific information is gathered.

Table A-2

(Continued)

Recreational Boats	3	CO, NO_x, SO_x, VOC, and PM	Category includes inboard motors and outboard motors on recreational motorboats. This category also includes auxiliary motors on sailboats.

APPENDIX B

TRAINING PLAN

This Training Plan describes the process for transferring technical insights gained from the emissions inventory development and implementation procedures gained in the U.S. to the academic and regulatory communities in Mexico. The primary means of technology transfer will be through an emissions inventory course and its supporting materials. As currently conceived, the emissions inventory course will be offered through the extension program, Comisión de Apoyo y Desarrollo Académico (CADA), at the University Autónoma Metropolitan - Azcapotzalco Campus (UAM-AZC).

Radian is developing this Training Plan in close cooperation with Professor Alfonso Espitia, Director, UAM-AZC Environmental Engineering Program. Radian staff will lead the effort to develop the emissions inventory course but will be in frequent communication with Professor Espitia, including meeting with UAM-AZC staff and discussing preliminary work products before they are submitted to the Western Governor's Association (WGA), Instituto Nacional de Ecología (INE), and Binational Advisory Committee (BAC). Where appropriate, the Training Plan will note where resources of other organizations will be needed to accomplish the stated objectives.

Eventually the emission inventory course may be offered through university extension programs along the U.S.-Mexico border region. At some time in the future, the course may also be incorporated into the Environmental Engineering curriculum at UAM-AZC. However, current resources only extend to the initial offering through CADA.

The Training Plan consists of the following three major elements, and will be refined and expanded as the course content develops:

(1) Development of course materials;

(2) Presentation of a condensed course to train future instructors; and

(3) Critique session to further evaluate the course content and delivery.

These components are described in further detail in the following sections.

EMISSIONS INVENTORY COURSE CURRICULUM

The first element is the development of a course curriculum, including a course syllabus, reading list, examinations and workbook, on the emissions inventory process. Students will also be assigned homework problems and preliminary and final examinations will be given.

The emissions inventory course should attract students from various disciplines, such as industrial engineering and mechanical engineering. It is recommended that students have reading skills in English equivalent to at least one year of university level English since most of the existing reference documents and computer models are in English.

Materiales

Much of the technical material covered in the course will be drawn from Radian's Tier 1, Volumes II - VI inventory manuals, as described in Appendix A. The manuals will contain example calculations which may be compiled into a workbook, along with other relevant materials. The preparation of the Training Plan and the manuals began in parallel, but course development activities will soon outpace the much larger effort to develop the manuals. Thus, the emissions inventory course will include topics and example calculations for which the corresponding manual has not yet been developed. In these and other cases, the relevant course materials will be compiled from other sources, such as those listed below:

General Inventory Guidance

- *Procedures For Emission Inventory Preparation, Volume I: Emission Inventory Fundamentals,* EPA-450/4-81-026a, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1981.
- *Procedures For Emission Inventory Preparation, Volume II: Point Sources*, EPA-450/4-81-026b, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1981.

- *Procedures For Emission Inventory Preparation, Volume III: Area Sources*, EPA-450/4-81-026c, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1981.

- *Procedures For Emission Inventory Preparation, Volume IV: Mobile Sources*, EPA-450/4-81-026d, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1992.

The AP-42 Series

- *Compilation Of Air Pollutant Emission Factors, Volume I: Stationary Point And Area Sources*, Fifth Edition, AP-42, U. S. Environmental Protection Agency, Research Triangle Park, NC, January 1995.

- *Compilation Of Air Pollutant Emission Factors, Volume II: Mobile Sources*, Fourth Edition, AP-42, U. S. Environmental Protection Agency, Ann Arbor, MI, September 1985.

- *Supplement A To Compilation Of Air Pollutant Emission Factors, Volume II*, Fourth Edition, AP-42, U. S. Environmental Protection Agency, Ann Arbor, MI, January 1991.

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desconocido. **Syllabus**

The emissions inventory course is designed for a 4-day university extension course meeting 8 hours per day. A syllabus is presented in Table B-1.

Table B-1

Emission Inventory Course Syllabus

Day/Hours	Topic
1./0.5	Preliminary Exam
1/0.5	Course Overview
1/1	Principles of Air Pollution
1/1	Types of Air Pollutants
1/2	Emission Inventory Fundamentals
1/2	Point Sources
2/2	Point Source (continued)
2/6	Area Sources
3/6	Mobile Sources
3/2	Natural Emission Sources
4/2	Emission Factor Development
4/2	QA/QC
4/2	Uncertainty Analysis
4/1.5	Course Summary
4/0.5	Final Exam

Reference List

A recommended list of references will be compiled. The list will include documents, research papers, conference proceedings, and background textbooks that students should consult throughout the course. The list will include references in Spanish and in English.

Materials to be Prepared

The following materials will be prepared by Radian to support the emissions inventory course:

- Computer disks containing the Microsoft Power Point files of the course slides (approximately 300 slides will prepared in both English and Spanish for a total of 600 slides);
- A workbook of sample calculations and their solutions intended for the professor's use in assigning homework problems and developing test questions;
- Eight sets of handouts and overhead presentation graphics (one for each prospective instructor);
- Two sets of the written materials identified in the reading list (some references may be provided on CD-ROM);
- All recommended computer models and their associated user guides. Currently, three models have been identified, MOBILE5, TANKS2, and BEISII, to illustrate emission inventory concepts for motor vehicles, storage of organic liquids, and biogenic sources, respectively. Suitable computer hardware to run the models will be furnished by UAM-AZC;
- A preliminary and final examination to test the student’s initial understanding and final comprehension of course materials.

Except for the workbook, all of these materials will be assembled in one location at UAM-AZC to facilitate student access.

Before the emissions inventory course is presented through CADA, a condensed course, the second element of the Training Plan, was devised to serve as a course prototype in order to familiarize future instructors with course materials. On January 9 - 11, 1996, this Train-the-Trainers course was given to 4 professors from UAM-AZC and to 4 senior air quality professionals from INE to serve as a course prototype for the future instructors who will be presenting the critique session and ultimately the university extension course. Recipients of the Train-the-Trainers course took an examination both before and after the course to evaluate the efficiency of the course delivery.

CRITIQUE SESSION

The third element of the Training Plan is a Critique Session, tentatively scheduled for late April, 1996, in which UAM-AZC professors will present the 4-day course to approximately 20 air quality professionals from INE. Radian personnel will provide technical and other support, as needed, and will revise course materials according to Critique Session participants. This mechanism will allow appropriate adjustments in course content, presentation, and emphasis, as needed.

IMPLEMENTATION SCHEDULE

Table B-2 summarizes the training schedule and milestones.

Table B-2

Schedule of Activities for the Development of a University Level for the Emissions Inventory Course

Program Element	Responsibility	Completion Date
Training Plan and Outline of Related Materials	Radian	28 August 1995
Comments on Training Plan and Outline	UAM/WGA/INE/BAC	18 September 1995
Prototype of Training Materials	Radian	4th Quarter 1995
Comments on Prototype	UAM/WGA/INE/BAC	1st Quarter 1996
Draft Training Materials	Radian	1st Quarter 1996
Train-the-Trainers Session	Radian/UAM/INE	January 9 - 11, 1996
Critique Session	UAM/Radian/INE	Late April, 1996
Final Revision of Course Material	Radian/UAM	June, 1996

RCN 670017 5104

MEXICO EMISSIONS INVENTORY PROGRAM MANUALS

VOLUME II – EMISSIONS INVENTORY FUNDAMENTALS

FINAL

Prepared for:

Western Governors' Association
Denver, Colorado

and

Binational Advisory Committee

Prepared by:

Radian International LLC
10389 Old Placerville Road
Sacramento, CA 95827

December 1997

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The *Mexico Emissions Inventory Program Manuals* were the result of efforts by several participants. The Binational Advisory Committee (BAC) guided the development of these manuals. The members of the BAC were:

Dr. John R. Holmes, State of California Air Resources Board
Mr. William B. Kuykendal, U.S. Environmental Protection Agency
Mr. Gary Neuroth, Arizona Department of Environmental Quality
Dr. Victor Hugo Páramo, Instituto Nacional de Ecología
Mr. Gerardo Rios, U.S. Environmental Protection Agency
Mr. Carl Snow, Texas Natural Resource Conservation Commission

The Western Governors' Association (WGA) was the lead agency for this project. Mr. John T. Leary was the WGA Project Manager. Funding for the development of the workbook was received from the United States Environmental Protection Agency (U.S. EPA). Radian International prepared the manuals under the guidance of the BAC and WGA.

PREFACE

Air pollution can negatively impact public health when present in the atmosphere in sufficient quantities. Most rural areas rarely experience air quality problems, while elevated concentrations of air pollution are found in many urban environments. Recently, there has been an increasingly larger degree of urbanization and industrial activity throughout Mexico, resulting in air quality impairment for several regions.

Air pollution results from a complex mix of literally thousands of sources ranging from industrial smoke stacks and motor vehicles, to the individual use of grooming products, household cleaners, and paints. Even plant and animal life can play an important role in the air pollution problem. The complex nature of air pollution requires the development of detailed plans on a regional level that provide a full understanding of the emission sources and methods for reducing the health impacts associated with exposure to air pollution. Example air quality planning activities include:

- Application of air quality models;
- Examination of source attribution for emissions control where deemed necessary;
- Development of emission projections to examine possible changes in future air quality;
- Analysis of emission trends; and
- Analysis of emissions transport from one region to another.

Development of fundamentally sound emissions inventories is a key need for each of these air quality management and planning functions.

Developing emission estimates to meet air quality planning needs requires continual development and refinement; "one time" inventory efforts are not conducive to the air quality planning process. For lasting benefit, an *inventory program* must be implemented so that accurate emission estimates can be developed for all important geographic regions, refined over time, and effectively applied in the air quality planning and monitoring process. Consequently, a set of inventory manuals will be developed that can be used throughout the country to help coordinate the development of consistent emission estimates. These manuals are intended for use by local, state, and federal agencies, as well as by industry and private consultants. The purpose of these manuals is to assist in implementing the inventory program and in maintaining that program over time so that emissions inventories can be developed in periodic cycles and continually improved.

The manuals cover inventory program elements such as estimating emissions, program planning, database management, emissions validation, and other important topics. Figure 1 shows the series of manuals that will be developed to support a complete inventory program. The main purpose of each manual or volume is summarized below.

Volume I—Emissions Inventory Program Planning. This manual addresses the important planning issues that must be considered in an air emissions inventory program. Program planning is discussed not as an "up-front" activity, but rather as an ongoing process to ensure the long-term growth and success of an emissions inventory program. *Key Topics*: program purpose, inventory end uses, regulatory requirements, coordination at federal/state/local levels, staff and data management requirements, identifying and selecting special studies.

Volume II—Emissions Inventory Fundamentals. This manual presents the basic fundamentals of emissions inventory development and discusses inventory elements that apply to multiple source types (e.g., point and area) to avoid the need for repetition in multiple volumes. *Key Topics*: applicable regulations, rule effectiveness, rule penetration, pollutant definitions (excluding nonreactive volatile), point/area source delineation, point/area source reconciliation.

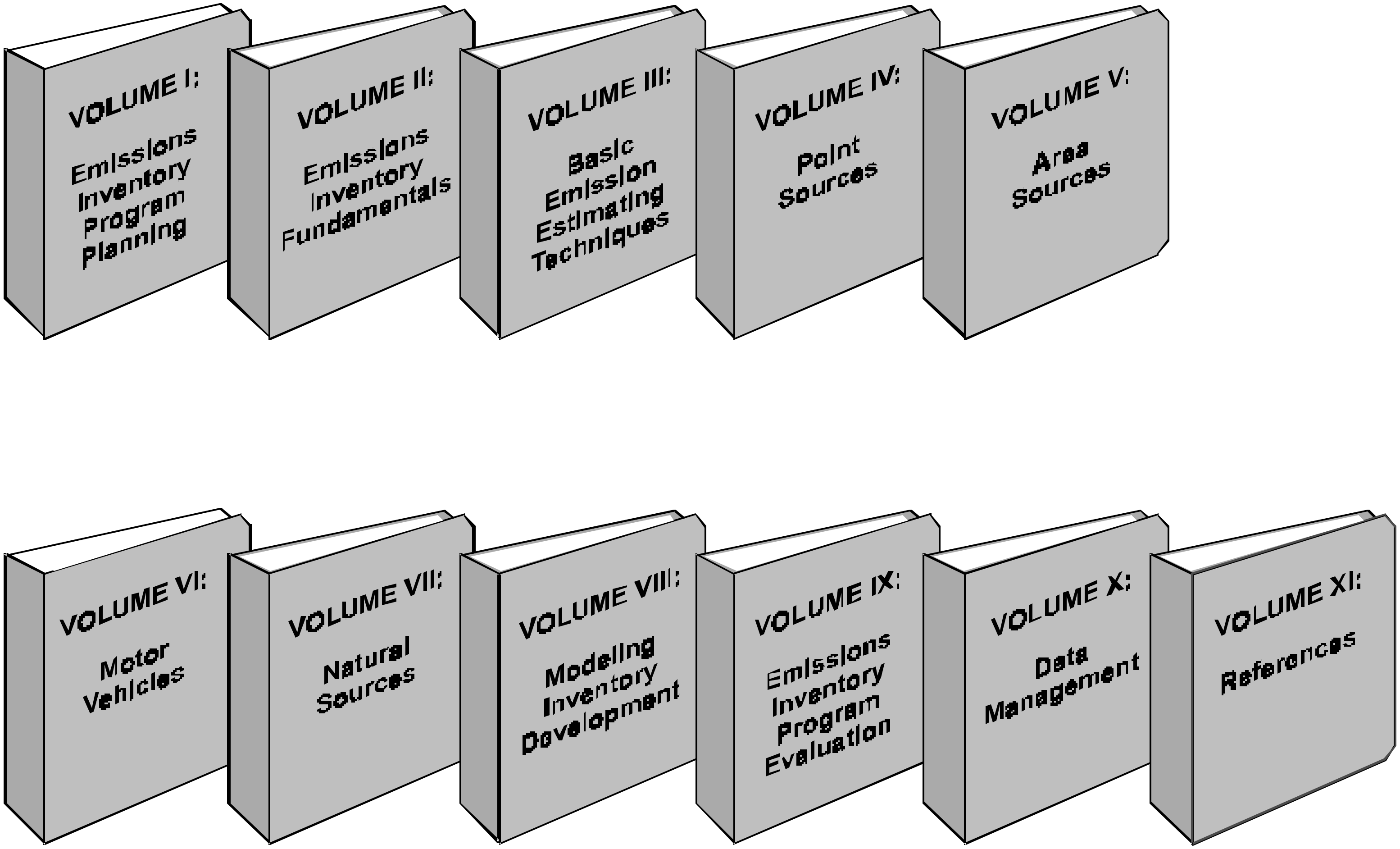

Figure 1. Mexico Emissions Inventory Program Manuals

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Volume III—Basic Emission Estimating Techniques. This manual presents the basic methodologies used to develop emission estimates, including examples and sample calculations. Inventory tools associated with each methodology are identified and included in Volume XI (References). *Key Topics*: source sampling, emissions models, surveying, emission factors, material balance, and extrapolation.

Volume IV—Emissions Inventory Development: Point Sources. This manual provides guidance for developing the point source emissions inventory. A cross-reference table is provided for each industry/device type combination (e.g., petroleum refining/combustion devices) with one or more of the basic methodologies presented in Volume III. *Key Topics*: cross-reference table, stack parameters, control devices, design/process considerations, geographic differences and variability in Mexico, quality assurance/quality control (QA/QC), overlooked processes, data references, and data collection forms.

Volume V—Emissions Inventory Development: Area Sources (Includes Non-Road Mobile). This manual provides guidance for developing the area source emissions inventory. After the presentation of general area source information, a table is provided to cross-reference each area source category (e.g., asphalt application) with one or more of the basic methodologies presented in Volume III. Then, source category-specific information is discussed for each source category defined in the table. *Key Topics*: area source categorization and definition, cross-reference table, control factors, geographic differences and variability in Mexico, QA/QC, data references, and data collection forms (questionnaires).

Volume VI—Emissions Inventory Development: Motor Vehicles. Because motor vehicles are inherently different from point and area sources, the available estimation methods and required data are also different. To estimate emissions from these complex sources, models are the preferred estimation tool. Many of these models utilize extensive test data applicable to a given country or region. This manual focuses primarily on the data development phase of estimating motor vehicle emissions. *Key Topics*: available estimation methods, primary/secondary/tertiary data and information, source categorization, emission factor sources, geographic variability within Mexico, and

QA/QC.

Volume VII—Emissions Inventory Development: Natural Sources. This manual provides guidance for developing a natural source emissions inventory (i.e., biogenic volatile organic compound [VOC] and soil nitrogen oxide [NO_X]). In addition, this manual includes the theoretical aspects of emission calculations and discussion of specific models. *Key Topics*: source categorization and definition, emission mechanisms, basic emission algorithms, biomass determination, land use/land cover data development, temporal and meteorological adjustments, and emission calculation approaches.

Volume VIII—Modeling Inventory Development. This manual provides guidance for developing inventory data for use in air quality models and addresses issues such as temporal allocation, spatial allocation, speciation, and projection of emission estimates. *Key Topics*: definition of modeling terms, seasonal adjustment, temporal allocation, spatial allocation, chemical speciation, and projections (growth and control factors).

Volume IX—Emissions Inventory Program Evaluation. This manual consists of three parts: QA/QC, uncertainty analysis, and emissions verification. The QA/QC portion defines the overall QA/QC program and is written to complement source specific QA/QC procedures written into other manuals. The uncertainty analysis includes not only methods of assessing uncertainty in emission estimates, but also for assessing uncertainty in modeling values such as speciation profiles and emission projection factors. The emissions verification section describes various analyses that can be performed to examine the accuracy of the emission estimates. Examples include receptor modeling and trajectory analysis combined with specific data analysis techniques. *Key Topics*: description of concepts and definition of terms, inventory review protocol, completeness review, accuracy review, consistency review, recommended uncertainty methodologies, and applicable emission verification methodologies.

Volume X—Data Management. This manual addresses the important needs associated with the data management element of the Mexico national emissions inventory program. *Key Topics*: general-purpose data management systems and tools, specific-purpose software systems and tools, coding system, confidentiality, electronic submittal, frequency of updates, recordkeeping, Mexico-specific databases, and reports.

Volume XI—References. This manual is a compendium of tools that can be used in emissions inventory program development. Inventory tools referenced in the other manuals are included (i.e., hardcopy documents, electronic documents, and computer models).

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APPENDIX B: HAZARDOUS AIR POLLUTANTS

FIGURES AND TABLES

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ACRONYMS

ARB	Air Resources Board
Btu	British thermal unit
C	Celsius
CAS	Chemical Abstract Service
CATEF	California Air Toxics Emission Factor Database
Cd	cadmium
CFC	chlorofluorocarbon
CFR	Code of Federal Regulations
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
Cu	copper
EC	elemental carbon
EtO	ethylene oxide
F	Fahrenheit
FIRE	Factor Information Retrieval System
g	gram
H_2SO_4	sulfuric acid
HAP	hazardous air pollutant
HC	hydrocarbons
HCFC	hydrochlorofluorocarbon
HDDV	heavy duty diesel vehicle

HDGV	heavy duty gas vehicle
HFC	hydrofluorocarbon
Hg	mercury
hr	hour
kg	kilogram
km	kilometer
LDDT	light duty diesel truck
LDDV	light duty diesel vehicle
LDGT	light duty gas truck
LDGV	light duty gas vehicle
LPG	liquefied petroleum gas
MC	motorcycle
Mg	megagram (i.e., 10^6 g = 1 metric ton)
N_2	nitrogen
N_2O	nitrous oxide
NH_3	ammonia
NH_4NO_3	ammonium nitrate
$(NH_4)_2SO_4$	ammonium sulfate
NMHC	non-methane hydrocarbons
NMOC	non-methane organic compounds
NMOG	non-methane organic gases
NO	nitric oxide
NO_2	nitrogen dioxide
NO_x	nitrogen oxides

O_3	ozone
OC	organic carbon
ODS	ozone depleting substances
OH	hydroxyl radical
Pb	lead
PFC	perfluorocarbon
PM	particulate matter
$PM_{2.5}$	particulate matter of aerodynamic diameter or 2.5 microns or less
PM_{10}	particulate matter of aerodynamic diameter or 10 microns or less
POTW	publicly owned treatment works
ppm	parts per million
QA	quality assurance
QC	quality control
ROG	reactive organic gases
SO_2	sulfur dioxide
SO_3	sulfur trioxide
SO_4^{2-}	sulfate
SO_x	sulfur oxides
SP	suspended particulate
THC	total hydrocarbons
TOC	total organic compounds
TOG	total organic gases
TSP	total suspended particulate
U.S.	United States

U.S. EPA	United States Environmental Protection Agency
UTM	Universal Transverse Mercator
VMT	vehicle miles traveled
VOC	volatile organic compounds
yr	year
µm	micrometer (micron)

1.0 INTRODUCTION

This manual presents fundamental concepts that underlie the development of emissions inventories. In general, these concepts apply to every emissions inventory -- from facility-level emission estimates to large-scale regional modeling inventories. These fundamental concepts represent basic background information that should be established prior to beginning actual data collection and emissions estimation. Some concepts will be used in every type of inventory, while other concepts may only be used in certain limited types of inventories. Specific details will vary for individual inventories, as well as the total level of effort. However, these fundamental concepts should be considered in every inventory effort to ensure a successfully completed inventory.

The remainder of this manual is organized as follows:

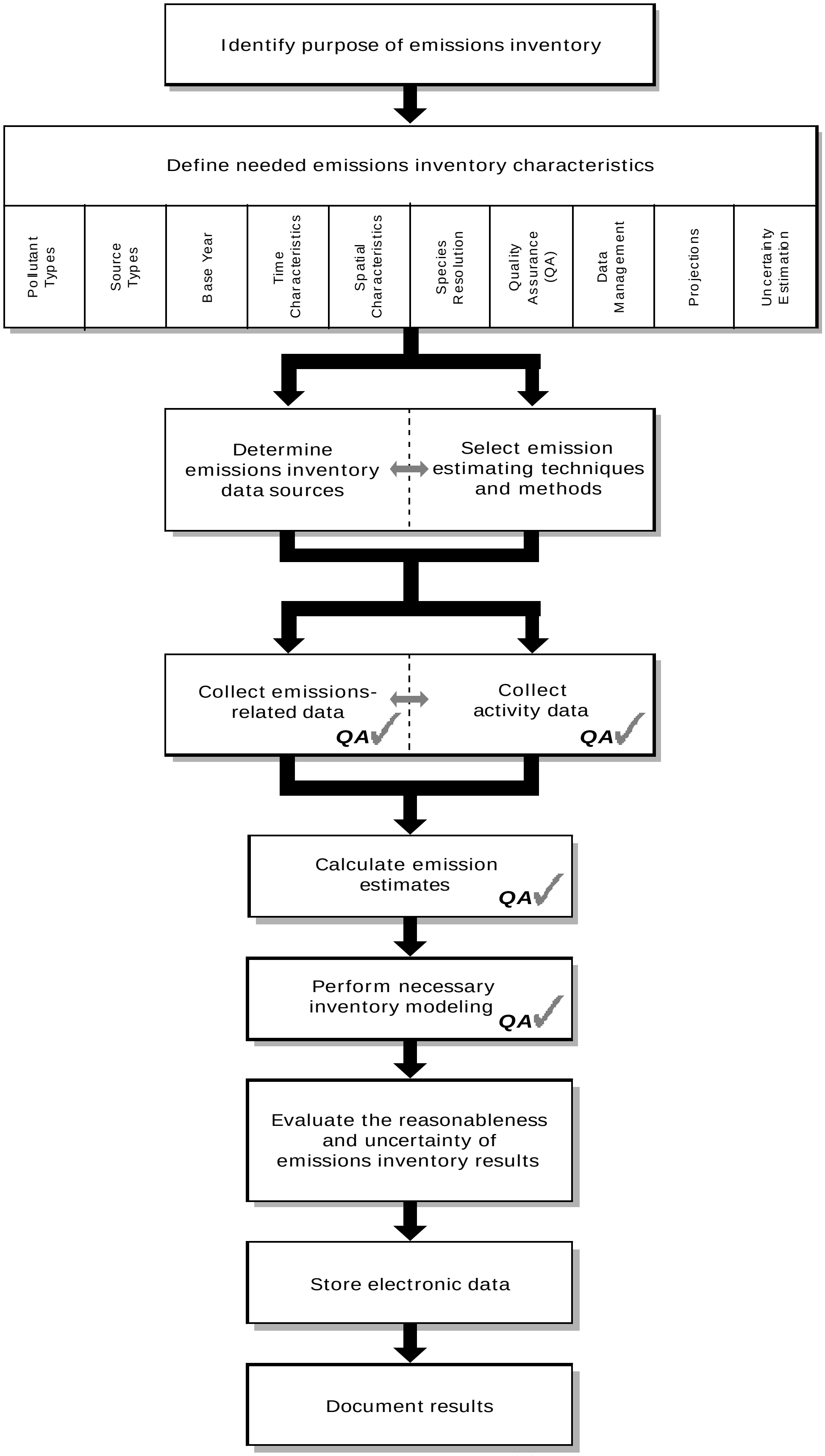
- Section 2.0 presents the technical steps of emissions inventory development and provides a brief explanation of each step;
- Section 3.0 addresses the importance of identifying the purposes of an emissions inventory;
- Section 4.0 provides a detailed description of various inventory pollutants;
- Section 5.0 discusses the various inventory source categories;
- Section 6.0 presents other necessary inventory characteristics;
- Section 7.0 discusses the concept of emissions inventory improvement through iteration; and
- Section 8.0 contains references.

2.0 TECHNICAL STEPS OF EMISSIONS INVENTORY DEVELOPMENT

The technical steps conducted during emissions inventory development are presented in Figure 2-1. The following paragraphs briefly describe each of these steps and identify other manuals from this series that can be consulted for further information. Supplemental information can be found in U.S. Environmental Protection Agency (U.S. EPA) documents (U.S. EPA, 1991a; EIIP, 1997).

Identify purpose of emissions inventory. As the first technical step of inventory development, it is crucial to identify the purpose or end use of the emissions inventory. The overall purpose will help determine many of the other subsequent steps. If the purpose is not clearly identified, then it is possible that the completed inventory will not meet its required needs. For example, the data needs for the development of a modeling inventory are significantly different than those for other types of inventories. Consideration should also be given to future inventory uses, as well as uses on a larger geographic scale. Further discussion of this step can be found in Section 3.0 of this manual.

Define needed emissions inventory characteristics. Every emissions inventory has several characteristics that describe the fundamental nature of the inventory (e.g., pollutant types, source types, base year, etc.). Ten separate inventory characteristics are identified in Figure 2-1. Some inventories may require conducting activities for only a few of these characteristics, while others may need all of them. Most of these characteristics will be determined by the purpose of the inventory (e.g., an ozone inventory will need to include TOG, CO, and NO_x as inventoried pollutants). Therefore, decisions are made that define each of the characteristics for an inventory. Additional information regarding the characteristics of emissions inventories is provided in Sections 4.0, 5.0, and 6.0.


Identify purpose of emissions inventory
Define needed emissions inventory characteristics
Pollutant Types
Source Types
Base Year
Time Characteristics
Spatial Characteristics
Species Resolution
Quality Assurance (QA)
Data Management
Projections
Uncertainty Estimation
Determine emissions inventory data sources
Select emission estimating techniques and methods
Collect emissions-related data
QA✓
Collect activity data
QA✓
Calculate emission estimates
QA✓
Perform necessary inventory modeling
QA✓
Evaluate the reasonableness and uncertainty of emissions inventory results
Store electronic data
Document results

Determine emissions inventory data sources/Select emission estimating techniques and methods. Once the required characteristics have been established, it is necessary to determine the sources of emissions-related data and select the emission estimating techniques and methods. These two steps are usually interrelated. In some situations, data availability will determine which estimating methods are feasible. In other instances, a desired technique will indicate which types of data must be collected. Data sources are discussed in detail in Volumes IV-VII of the Manual series (*Point Source, Area Source, Motor Vehicle, and Natural Source Inventory Development*). Specific emission estimating techniques are described in Volume III of the Manual series (*Basic Emission Estimating Techniques*).

Collect emissions-related data/Collect activity data. After the data sources and estimation methodologies have been identified, it is appropriate to collect relevant data. Emissions-related data include emissions factors, source test data, and emission factor model parameters. Some emissions-related data may already exist; other data may need to be developed for use in a specific inventory. Activity data typically include information such as hours of operation, fuel consumption, and other measures of process activity for identified sources. Because both emissions-related data and activity data are needed to estimate emissions, these two steps are often performed simultaneously. Both emissions-related data and activity data are discussed in detail in Volumes IV-VII of the Manual series (*Point Source, Area Source, Motor Vehicle, and Natural Source Inventory Development*).

Calculate emission estimates. Once all necessary data have been collected, it is necessary to perform the specific emission calculations. These calculations are performed as required by the selected emission estimating technique or methodology. Typically, these emission calculations are done electronically, particularly for more complex emissions inventories. Details related to emission calculations can be found in Volumes IV-VII of the Manual series (*Point Source, Area Source, Motor Vehicle, and*

Natural Source Inventory Development). Issues related to emission calculations, such as rule effectiveness and rule penetration, are also discussed in Volume III of the Manual series (*Basic Emission Estimating Techniques*). Rule effectiveness quantifies the ability of a regulatory program to achieve the required emissions reductions, while rule penetration measures the extent to which a regulation covers emissions from all sources within a source category.

Perform necessary modeling. After the emissions have been calculated, inventory modeling is performed if necessary. The modeling may include spatial and temporal distribution, species resolution, and emissions projections. Further discussion of modeling can be found in Volume VIII of the Manual series (*Modeling Inventory Development*).

Quality assurance. Quality assurance (QA) is not included as its own box in Figure 2-1 because it is an integral element of the entire emissions inventory development process. QA should be performed throughout the emissions inventory process. In particular, it should begin with the collection of emissions-related and activity data and continue through the emission calculations and the entire modeling process. This concept is indicated with multiple "QA checkmarks" in Figure 2-1. QA is discussed in Volume IX of the Manual series (*Emissions Inventory Program Evaluation*).

Evaluate the reasonableness and uncertainty of emissions inventory results. After the inventory has been completed, it is necessary to examine the inventory and evaluate the reasonableness and uncertainty of the results. Comparisons to expectations, previous experience, and similar inventories developed previously or for other geographic regions would be valuable at this time. Also, an examination of the inventory's uncertainty will reveal its strong areas, as well as those areas that could be the focus of future improvements. These issues are discussed in Volume IX of the Manual series (*Emissions Inventory Program Evaluation*).

Store electronic data. One of the final steps of emissions inventory development is the electronic storage of the inventory and related data. The integrity of the emissions inventory must be maintained as the basis for future inventory development. Electronic storage of data is addressed in Volume X of the Manual series (*Data Management*).

Document results. The last step of emissions inventory development is the documentation of results. In addition to the actual inventory results, the documentation should also include the methodologies, data, and assumptions that were used in the development process. In general, enough documentation should be provided to allow others to reproduce and analyze the inventory results. Inventory documentation serves as an important reference for future inventory efforts.

As can be seen by the brief descriptions given above, the Mexico Emissions Inventory Program Manuals provide comprehensive support for the technical steps associated with emissions inventory development.

3.0 PURPOSE OF AN EMISSIONS INVENTORY

As previously shown in Figure 2-1, the first technical step of emissions inventory development is the identification of the inventory purpose. Defining the inventory purpose is crucial to the success of inventory development, and it is important that it not be overlooked in the "rush" to begin the emissions inventory. The general nature as well as most of the characteristics of an emissions inventory are ultimately determined by its purpose. In many instances, an inventory will be constructed to meet two or three major purposes.

The purpose to be achieved by an emissions inventory will define the inventory's characteristics as well as subsequent steps of data collection and potential inventory modeling. For this reason, it is critical to reach agreement on all of the potential uses for the inventory. It is also important that the purpose of the inventory be identified before any substantive work is begun on the inventory. Otherwise, some of the work performed may not be of value for the inventory.

Furthermore, it is critical that the purpose of an emissions inventory be explicitly identified. This purpose is the "guiding principle" of the inventory and defines all of the appropriate steps to be performed during development of the inventory. A complete assessment of the inventory's purposes will ensure that the inventory proceeds along a development path fully consistent with its intended uses. Typically, the purposes of an inventory are described in a planning document that is prepared at the beginning of an emissions inventory effort. This planning document is sometimes termed a work plan or inventory protocol. In addition to the inventory purpose, the planning document will include a description of relevant inventory characteristics, as well as proposed technical steps. The planning document provides up-front guidance for the inventory developers and helps ensure successful inventory development.

There are many different inventory purposes which will vary depending upon specific needs and circumstances. For example, the purpose of an inventory for a single manufacturing facility is significantly different from the purpose of a large-scale regional modeling inventory. The inventory for the manufacturing facility might be used to determine compliance with specific regulations, whereas the regional modeling inventory might be constructed to support an air quality assessment of multiple source impacts. Several common reasons for developing inventories include the following:

- To estimate air quality impacts through modeling studies;
- To determine the applicability of permit and other regulatory requirements;
- To determine source compliance with permit conditions;
- To estimate changes in source emissions for permit applications;
- To determine the technical specifications of emission control equipment;
- To track emission levels over time;
- To identify emission contributions by source category or specific source;
- To identify potential emission trading opportunities;
- To meet emission reporting requirements; and
- To satisfy regulations requiring the development of comprehensive emission inventories.

All of the reasons given above for developing emissions inventories ultimately contribute to the process of air quality management.

As shown in Figure 3-1, the identification of the inventory purpose requires the input and opinions of many people. First, the input of the end-users of the emissions inventory is crucial. The desired end use, as well as the ease of use, often will be significant factors for consideration in the development of an emissions inventory. Moreover, because emissions inventories play a central role in air quality planning, the input of regulatory and governmental agencies responsible for air quality and related policy should be solicited. In many situations, these agencies' needs and objectives will be the key driving force behind a specific inventory. Relevant Mexico air quality regulations are discussed in Volume I of this Manual series, *Emissions Inventory Program Planning.* Finally, the input of those constructing the emissions inventory, including government, industry, and contractor staff, will be important. These individuals must clearly understand the purposes of the inventory so that their inventory results will meet each of the needs. In the end, the synthesis of all participants' ideas will define the purposes for the inventory.

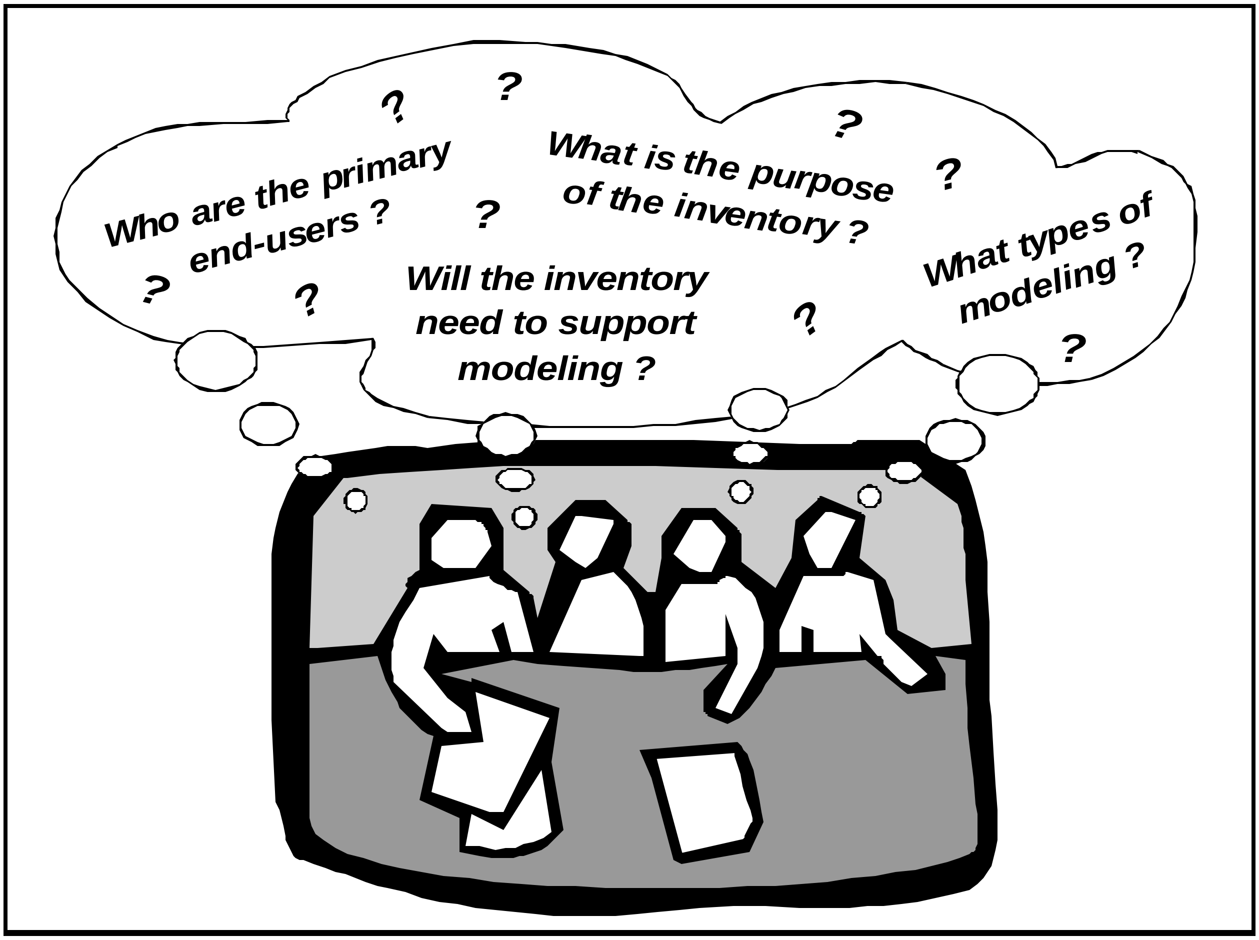


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Figure 3-1. Identification of the Inventory Purpose

Further, the purpose of an emissions inventory should address present and future air quality needs. An attempt should be made to identify future air quality needs during the scoping of the inventory. Sometimes these future needs will be difficult to project. In other cases, however, future needs will be clearer, and a small expansion of resources might significantly increase the ultimate utility of the inventory.

The determination of the purposes of an emissions inventory need not require a significant level of effort. A reasonable amount of time and effort invested at the beginning of the process to identify uses and establish the inventory purpose will help ensure the development of useful inventory data and information. With explicit purposes identified, the resulting inventory is much more likely to satisfy each of the expected uses of the data set.

4.0 INVENTORY POLLUTANTS

In general, an air pollutant may be defined as any substance released to the atmosphere that alters the air's natural composition and may result in adverse effects to humans, animals, vegetation, or materials. The established purposes of an emissions inventory will determine which pollutants should be included in the inventory. For example, a criteria pollutant inventory would include total organic gases (TOG), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x), particulate matter with an aerodynamic diameter less than 10 microns (PM_{10}), and lead (Pb). An ozone inventory, however, would focus on the precursors of ozone, namely TOG, CO, and NO_x. Finally a visibility inventory would include SO_x, NO_x, fine particulate matter (aerodynamic diameter less than 2.5 microns—$PM_{2.5}$), elemental carbon (EC), organic carbon (OC), and ammonia (NH_3) emissions.

Once it has been determined which pollutants should be included in the inventory, it is important to clearly define each pollutant. It is essential that each pollutant be clearly defined so that all collected data are consistent and yield accurate emission results of the desired pollutant. Though “conventional pollutant terminology” exists, it is recommended that all pollutants be clearly defined in writing at the beginning of an inventory effort, in order to reduce confusion regarding pollutants to be inventoried. Also, many pollutants are defined by their chemical names, which often may have synonyms and trade names. Trade names are often given to mixtures by manufacturers to obscure proprietary information, and the same components may have several trade names. For example Freon 11 is the commercial name for trichlorofluoromethane (CFC-11). In order to guarantee use of the proper chemical identification, the Chemical Abstract Service (CAS) number for the chemical should be consulted along with the list of synonyms. Finally, suppose it is only stated that a given inventory is to include “particulate” emissions. Then, different inventory developers might develop emission estimates of total particulate matter

(PM), particulate matter with an aerodynamic diameter less than 10 microns (PM_{10}), or $PM_{2.5}$. A significant amount of extra time and effort would be required to convert these different types of "particulate" emissions to the desired common basis. By explicitly defining the pollutants at the start of the inventory, this wasted effort could be avoided.

Sections 4.1—4.9 provide detailed definitions for commonly inventoried pollutants or pollutant categories.

4.1 Total Organic Gases/Reactive Organic Gases

Many different sources emit organic gases to the atmosphere. In general, however, organic gases are emitted from either combustion sources or evaporation sources. Collectively, the compounds that comprise hydrocarbon emissions are known as total organic gases (TOG). The concept of TOG includes all carbonaceous compounds except carbonates, metallic carbides, CO, carbon dioxide (CO_2), and carbonic acid. TOG are sometimes also referred to as total organic compounds (TOC), but usually only when discussed in an air quality context.

Some of the compounds in this pollutant category include aldehydes such as formaldehyde and acetaldehyde which are respiratory tract irritants as well as cancer-causing chemicals. Benzene, also a cancer-causing chemical, may be present as well. Short-term exposure to these chemicals may result in irritation of the respiratory tract. The potential for increased cases of cancer also exists for long-term exposures to some TOG species.

From an air quality perspective, it is important to note that some of the TOG emitted to the atmosphere have limited, or no, photochemical reactivity. Consequently, they do not participate in the formation of ozone. The U.S. EPA has identified the following compounds that have negligible, or no, photochemical reactivity:

- Methane;
- Ethane;

- Acetone;
- Perchloroethylene (tetrachloroethylene);
- Methylene chloride (dichloromethane);
- Methyl chloroform (1,1,1-trichloroethane);
- Various chlorofluorocarbons (CFCs);
- Various hydrochlorofluorocarbons (HCFCs);
- Various hydrofluorocarbons (HFCs); and
- Various perfluorocarbons (PFCs).

Additional information on these compounds, and a listing of a few more uncommon non-photochemically reactive compounds, can be found in the U.S. *Code of Federal Regulations* (CFR, 1997). This listing of non-reactive compounds is updated periodically as U.S. EPA designates new non-reactive compounds. The current listing is provided in Appendix A.

Chemicals considered to be photochemically reactive are termed reactive organic gases (ROG). By definition, therefore, ROG is a subset of TOG. ROG are photochemically reactive chemical gases, composed of hydrocarbons that may contribute to the formation of smog.

ROG are also sometimes referred to as volatile organic compounds (VOC). Emission factors published in U.S. EPA's AP-42 (AP-42, 1995) are presented almost exclusively for VOC. Other hydrocarbon definitions that occasionally appear in air quality and emission factor literature include: non-methane organic gases (NMOG), non-methane hydrocarbons (NMHC), total hydrocarbons (THC), and hydrocarbons (HC). Figure 4-1 graphically illustrates the relationship between these various hydrocarbon definitions. The shaded areas in Figure 4-1 indicate the compounds included in each definition. The definitions for NMOG, NMHC, THC, and HC are generally used for combustion processes only.

It is recommended that both TOG and ROG emission estimates be developed, so that the user may have the flexibility to choose the pollutant group that is needed for a particular inventory purpose. If emission factors for other less common hydrocarbons are used, they must

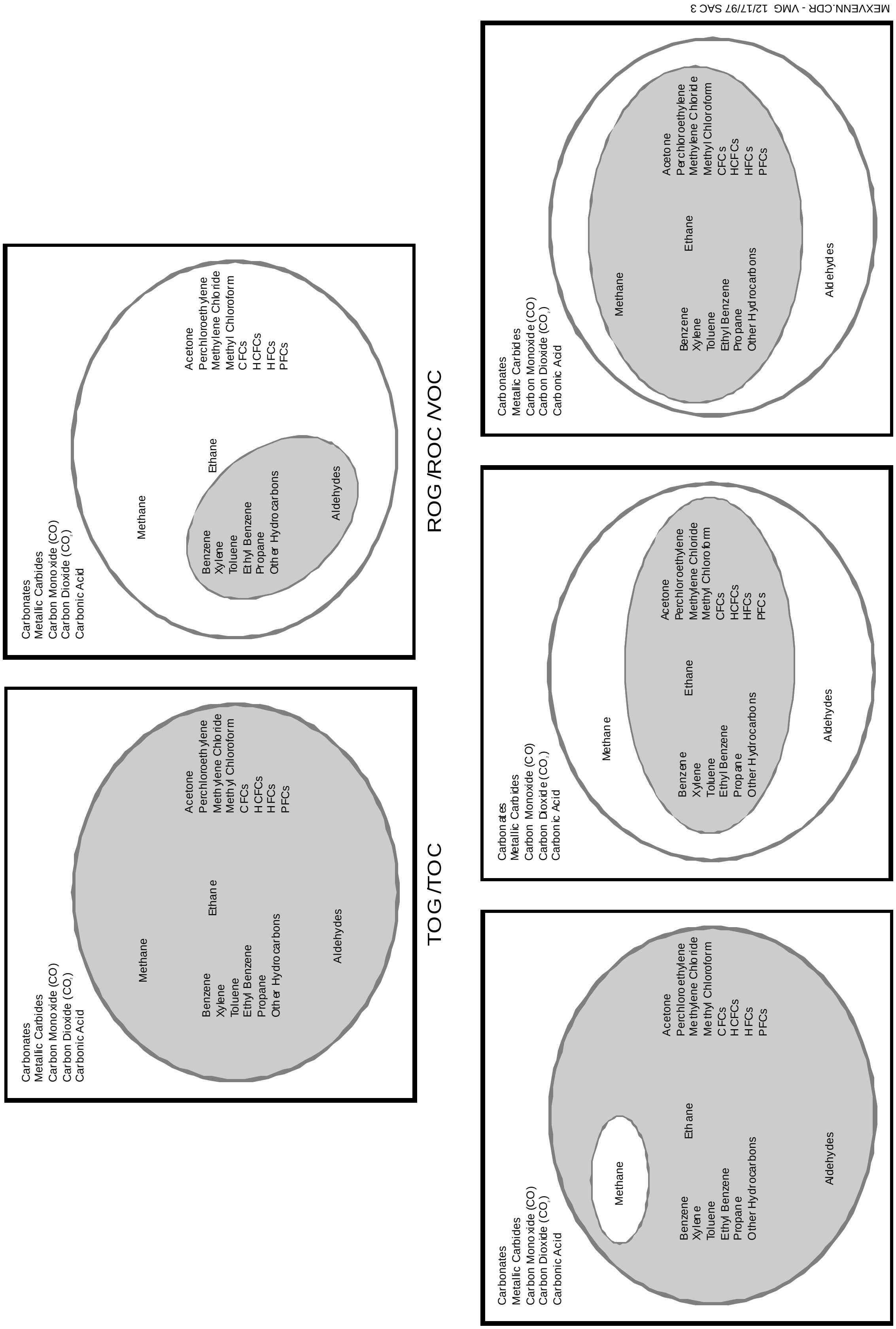

Figure 4-1. Description of Hydrocarbon Definitions

be adjusted to TOG and ROG to account for the presence/absence of methane, ethane, and aldehydes as shown in Figure 4-1. At first it may seem unnecessary to inventory TOG, but developing TOG emission estimates can facilitate a number of reporting functions for such emissions as greenhouse gases and air toxics. In addition, TOG emissions are better suited for use in three dimensional grid models used to simulate ozone and aerosol formation. This is because the models contain chemical mechanisms that use emission estimates based upon speciated TOG profiles.

4.2 Carbon Monoxide

Carbon monoxide (CO) is a colorless, odorless gas resulting from the incomplete combustion of fossil fuels. A significant amount of the CO emitted in urban areas is produced by motor vehicles. Exposure of non-smokers to CO at levels below 15 to 20 ppm does not appear to produce adverse health effects. At levels above this, the carboxyhemoglobin in the blood rises causing adverse effects on the nervous system and the cardiovascular system. Smokers have a higher carboxyhemoglobin level to begin with, so they may experience adverse effects from lower ambient levels of CO.

4.3 Nitrogen Oxides

Nitrogen oxides (NO_x) is a general term that includes nitric oxide (NO), nitrogen dioxide (NO_2), and other less common oxides of nitrogen. Nitrogen oxides are typically created during combustion processes and are ozone precursors. They are usually removed from the atmosphere by wet and dry deposition. NO is not expected to cause any adverse health effects at ambient air concentrations. Exposure to NO_2 can cause irritation of the respiratory tract and if the exposure continues, decrements in lung function can occur.

The primary NO_x combustion product is NO. However, NO_2 and other nitrogen oxides are usually emitted at the same time, and these may or may not be distinguishable in available test data. They are usually in a rapid state of flux, with NO_2 being the ultimate oxidation product emitted or formed shortly downstream of the combustion process. The general convention followed is to report the pollutant distinctions wherever possible, but to report total NO_x on the basis of the molecular weight of NO_2.

NO_x is formed in external combustion in primarily two ways: thermal NO_x and fuel NO_x. Thermal NO_x is formed when nitrogen and oxygen in the combustion air react at high temperatures in the flame. Fuel NO_x is formed by the reaction of any nitrogen in the fuel with combustion air. Thermal NO_x is the primary source of NO_x in natural gas and light oil combustion, and the most significant factor affecting its formation is flame temperature. Excess air level and combustion air temperature also are factors in the formation of thermal NO_x. Fuel NO_x formation is dependent on the nitrogen content of the fuel and can account for as much as 50% of the NO_x emissions from the combustion of high-nitrogen fuels, primarily coal and heavy oils.

4.4 Sulfur Oxides

Sulfur oxides (SO_x) is a general term pertaining to compounds of sulfur dioxide (SO_2), and other oxides of sulfur. Sulfur dioxide is a strong smelling, colorless gas that is formed by the combustion of sulfur-containing fossil fuels. Sulfur oxides are respiratory irritants and can cause an asthma-like response or aggravate an existing asthma condition. Signs of exposure to high ambient concentrations can include coughing, runny nose, and shortness of breath. These responses may be more severe in smokers.

Power plants, which may use coal or fuel oil high in sulfur content, can be major sources of SO_2. Emitted SO_2 sometimes oxidizes to sulfur trioxide (SO_3) and then to sulfuric acid ($H_2 SO_4$) or sulfate (SO_4^{2-}) aerosols. The general convention is to report the pollutant distinctions wherever possible, but to report total SO_x on the basis of the molecular weight of SO_2. The quantity of SO_x emissions from combustion sources is dependent upon the sulfur content of the fuel used.

Sulfur oxides contribute to the problem of acid deposition. Acid deposition is a comprehensive term for the ways that acidic compounds deposit from the atmosphere to the earth's surface. It can include wet deposition by means of acid rain, fog, and snow; and dry deposition of acidic particles (aerosols). Acid rain refers to precipitation that has a pH of less than 5.6. Neutral precipitation would have a pH of 7; however, the "natural" activity of rainwater has been estimated to be pH 5.6 when in equilibrium with the average atmospheric concentration of CO_2 (330 ppm) (Seinfeld, 1986). Principal components of acid rain typically include nitric and sulfuric acid. These may be formed by the combination of nitrogen and sulfur oxides with water vapor in the atmosphere. In addition, sulfate particles also tend to have a small size (0.2—0.9 µm diameter). Consequently, they can be a significant component of fine particulate and adversely affect visibility.

4.5 Particulate Matter

Particulate matter (PM) refers to any airborne solid or liquid particles of soot, dust, aerosols, fumes, and mists. Some classifications of PM include total particulate; primary and secondary particulate; total suspended particulate (TSP), suspended particulate (SP), PM_{10} and $PM_{2.5}$; and filterable and condensable particulate.

Primary particulate matter includes solid, liquid, or gaseous material emitted directly from the process or stack that would be expected to become a particulate at ambient temperature and pressure. Secondary particulate matter is an aerosol that was formed from gaseous material through atmospheric chemical reactions. Figure 4-2 illustrates the concepts of primary and secondary particulate matter. All PM emission factor references (e.g., AP-42) contain emission factors for primary particulate matter; therefore, the term "total PM" is used to describe emissions that represent only primary particulate matter.

TSP consists of all matter emitted from sources as solid, liquid, and vapor forms, but existing or "suspended" in the air as particulate solids or liquids. TSP may include particles

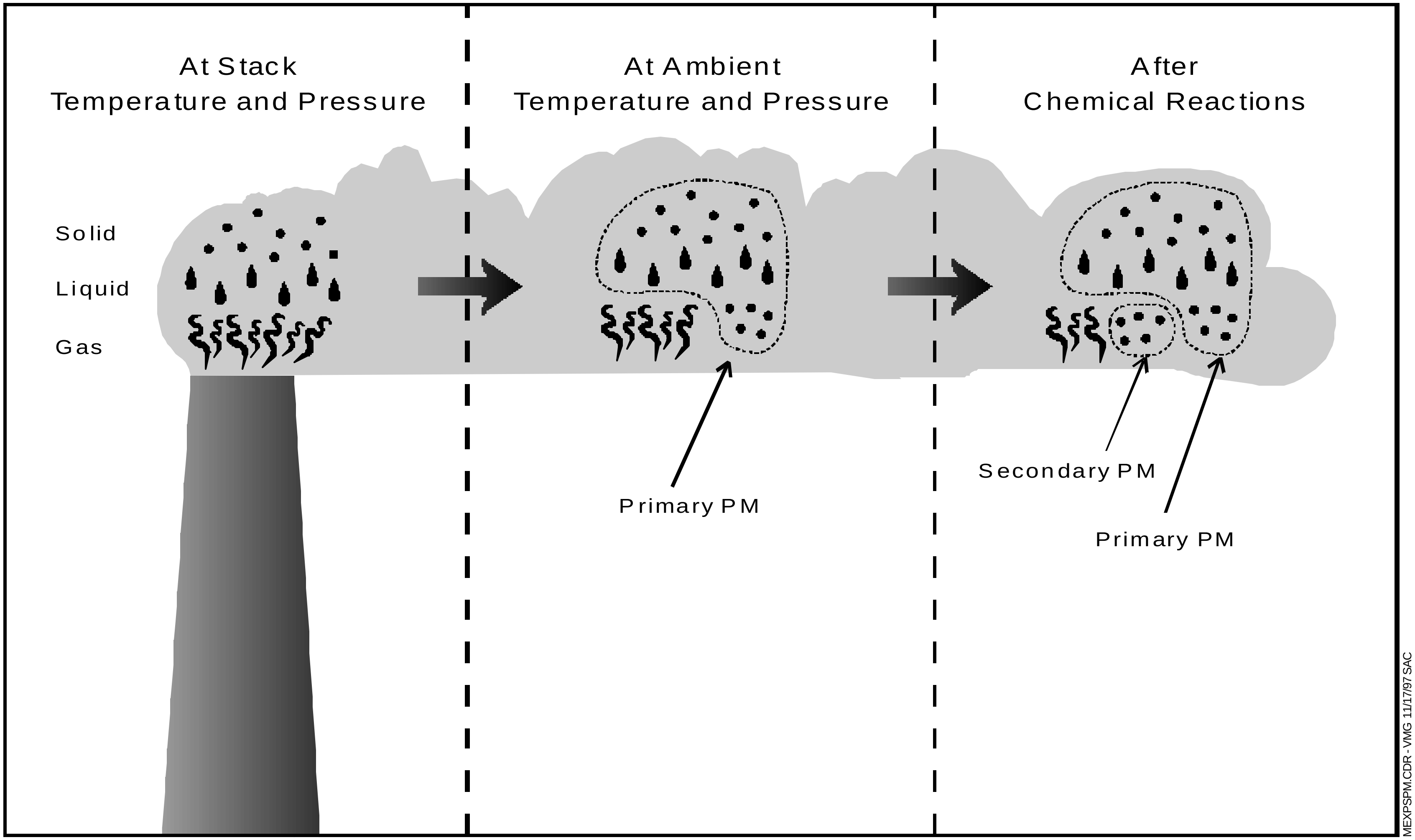

Figure 4-2. Primary and Secondary Particulate Matter

with an aerodynamic diameter up to 100 micrometers (µm); particles larger that 100 µm tend to settle out rapidly and should not be considered air emissions. Particles between 30 and 100 µm in diameter also typically undergo impeded setting. SP is usually defined as all particles with diameter less than 30 µm and is often used as a surrogate for TSP. PM_{10} describes primary particulate matter emissions smaller than 10 µm in aerodynamic diameter. Similarly, $PM_{2.5}$ is primary particulate matter smaller than 2.5 µm in aerodynamic diameter. TSP, PM_{10}, and $PM_{2.5}$ are demonstrated in Figure 4-3. The small size of PM_{10} or $PM_{2.5}$ particles allows them to easily enter the air sacs deep in human lungs where they may be deposited and result in adverse health effects. PM may cause coughing, wheezing, and respiratory function changes as well as changes in the lung itself. Increased levels of PM are believed to be responsible for increased mortality and morbidity in those with preexisting cardiovascular and/or respiratory conditions. However, it has been difficult to establish levels at which adverse effects occur because of other chemicals present which may be responsible for some of the adverse effects seen. In addition, $PM_{2.5}$ emissions are also a visibility concern.

In AP-42, total particulate emission factors may be split into filterable and condensable particulate emission factors. The filterable portions include material that is smaller than the stated size and is collected on the filter of the particulate sampling train. Unless noted, it is reasonable to assume that the emission factors in AP-42 for processes that operate above ambient temperatures are for filterable particulate, as defined by U.S. EPA Method 5 or its equivalent (a filter temperature of 121°C [250°F]). The condensable portions of the particulate matter consist of vaporous matter at the filter temperature that is collected in the sampling train impingers and is analyzed by U.S. EPA Method 202 or its equivalent. Total particulate emission factors are the sum of filterable and condensable particulate emission factors.

4.6 Ozone

Ozone (O_3) is a strong smelling, pale blue, reactive toxic chemical gas consisting of three oxygen atoms. It is the most abundant photochemical oxidant. Ozone and other

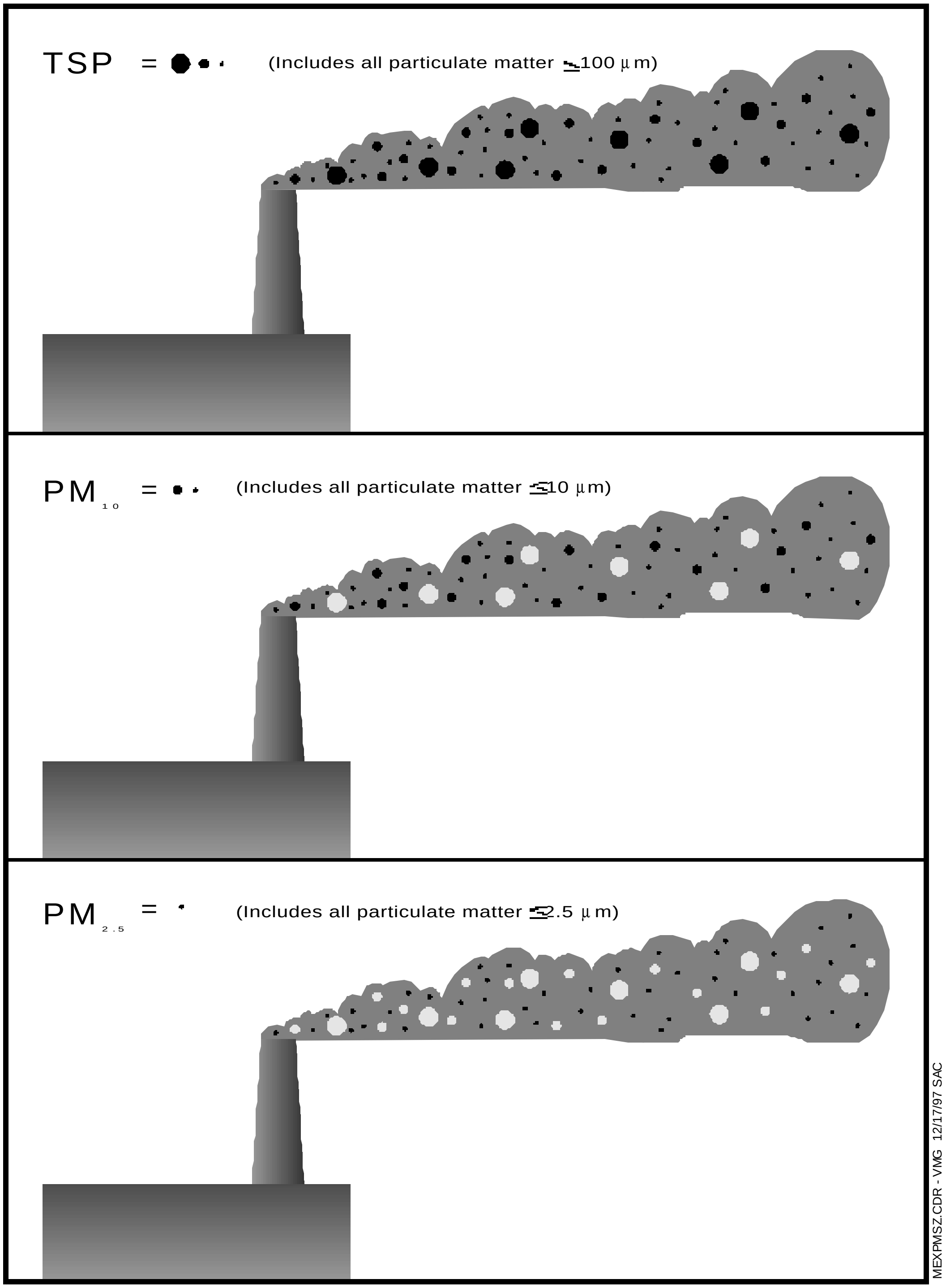

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Figure 4-3. TSP, PM_{10}, and $PM_{2.5}$

photochemical oxidants are not directly emitted to the atmosphere; instead, they are formed by the chemical reactions of hydrocarbons, CO, and NO_x in the presence of sunlight. Therefore, ozone is not estimated in emissions inventories. Its precursors, however, are estimated.

The general chemical equations describing ozone formation are presented below:

$$\begin{array}{llll} HO + RH & \rightarrow & H_2O + R & (R = \text{alkyl group}) \\ R + O_2 & \rightarrow & RO_2 & \\ RO_2 + NO & \rightarrow & RO + NO_2 & \\ NO_2 + h< & \rightarrow & NO + O & (h< = \text{ultraviolet photon}) \\ O + O_2 + M & \rightarrow & O_3 + M & (M = \text{third-body molecule}) \end{array}$$

Ozone and other photochemical oxidants are irritants that can have adverse effects on the lung. Exposure to high ambient levels can cause decrements in lung function. Shallow, rapid breathing; bronchitis; and emphysema are among the adverse health effects that may occur as a result of exposure to ozone. In addition, ozone is very effective in deteriorating rubber and other materials.

4.7 Visibility Species

Visibility degradation is caused by fine particles that absorb or scatter light in a direction different from that of the incident light. Some of these particles (primary particles) are emitted directly to the atmosphere; others (secondary particles) are formed in the atmosphere from gaseous precursors.

The extinction coefficient, the fraction of light that is attenuated by scattering or absorption as the light beam traverses a unit of atmosphere, is used in visibility measurements. The extinction coefficient indicates the rate at which energy is lost or redirected due to interactions with gases and suspended particles in the atmosphere. Particles with higher extinction coefficients will cause more visibility degradation.

The magnitude of these visibility degradation effects depends on several factors such as the size and composition of the particles and the wavelength of the incident light. Therefore, not all species have the same impact on visibility. The major sources of visibility impairment are organic carbon (OC), elemental carbon (EC) or soot, sulfates, and nitrates. Organic carbon and elemental carbon are significant sources of visibility degradation because they both scatter and absorb light. OC and EC are emitted as primary particles. All of the other visibility species mainly scatter light and are typically secondary particles formed from gaseous precursors. Sulfates and nitrates are primarily the results of various chemical reactions on SO_x and NO_x emissions. Ozone precursors may be also important because secondary aerosol is one of the end products from the photochemical smog cycle. Finally, ammonia (NH_3) is frequently considered as a visibility species because of its interaction with SO_x and NO_x to form ammonium sulfate, $(NH_4)_2 SO_4$, and ammonium nitrate, NH_4NO_3.

Particles and their precursors can remain in the atmosphere for several days and can be carried great distances downwind from their sources to affect visibility in remote areas. The emissions from many sources may mix together during transport to form a uniform widespread haze commonly known as regional haze. Changes in meteorological conditions, sunlight, and the size and proximity of emission sources are a few of the factors that will vary the degree of visibility impairment over time and from place to place.

4.8 Air Toxics/Hazardous Air Pollutants

Air toxics is a general term used to refer to a harmful chemical or group of chemicals in the air. They are sometimes called hazardous air pollutants (HAPs). They are considered air toxics because they either have shorter term (acute) effects or long term (chronic) effects. This pollutant category encompasses many chemicals with varying effects and concentrations at which those effects might occur. They range from cancer-causing chemicals such as 1,3-butadiene and vinyl chloride, to chemical solvents such as toluene and ethylbenzene which, at the concentrations found in ambient air, are likely to be limited to irritant effects.

Air toxics can exist in gaseous or particulate form. A few examples of common gaseous air toxics are benzene, toluene, xylene, and ethylbenzene. There are also a limited number of gaseous hazardous or toxic compounds that may not be TOG such as ammonia and chlorine. Many of the particulate air toxics are heavy metals such as lead, chromium, and cadmium. Appendix B contains a listing of the 189 U.S. Federal Hazardous Air Pollutants. This listing is not an exhaustive list of air toxics; in some inventory applications, other chemicals may need to be considered as HAPs.

Air toxics emissions should ideally be estimated using source test data or emission factors. Two possible sources of emission factors are U.S. EPA's Factor Information Retrieval System (FIRE) (U.S. EPA, 1995) and California Air Resources Board's (ARB) California Air Toxics Emission Factor Database (CATEF) (ARB, 1996). Additional engineering judgment is required to determine whether a particular emission factor is applicable for a given source. When air toxic emission factors are not available, then it is necessary to combine the total TOG or PM emission estimates with speciation profiles to estimate emissions of individual air toxics. However, because speciation profiles were not developed with the intent of estimating individual air toxics emissions, this approach is not generally recommended.

4.9 Greenhouse Gases

The greenhouse effect is the trapping of incoming solar radiation by a combination of radiatively active gases (i.e., greenhouse gases). Light energy from the sun (short wavelength radiation) that passes through the earth's atmosphere is absorbed by the earth's surface and re-radiated into the atmosphere as heat energy (long wavelength radiation). The heat energy is then trapped by the atmosphere, creating a situation similar to what occurs in a greenhouse or a car with its windows rolled up. Many scientists believe that the emission of greenhouse gases (carbon dioxide [CO_2], methane [CH_4], nitrous oxide [N_2O], chlorofluorocarbons [CFCs] and others) into the atmosphere may increase the greenhouse effect and contribute to global warming. Each of these greenhouse gases is described below.

Carbon dioxide (CO_2) is a colorless, odorless gas that occurs naturally in the earth's atmosphere. Significant quantities are also emitted into the air by fossil fuel combustion. The second most important source of global CO_2 emissions is from land use change and forests. Forests and other vegetation absorb CO_2 while growing. Therefore, loss of forest area (i.e., deforestation) leads to a reduction of CO_2 incorporation in future years or, in other words, a net increase of atmospheric CO_2. Cultivation or the burning and/or clearing of land for agricultural purposes can also result in an increase in the natural release or storage of CO_2 from soils (IPCC, 1993).

Methane (CH_4) is the most abundant and stable hydrocarbon gas in the atmosphere. The latest estimate of the atmospheric lifetime of methane is 11 years (IPCC, 1993). Chemical reactions involving methane in the troposphere can lead to ozone production, and reaction with the hydroxyl radical (OH) in the stratosphere results in the production of water vapor. This is important, because both ozone and water vapor are greenhouse gases, as is the final oxidation product of methane, carbon dioxide. Some important anthropogenic sources of methane emissions are coal mining operations, natural gas production, rice paddies, livestock, and biomass burning. Methane is also formed by decomposition of organic material by bacteria under anaerobic conditions (e.g., animal waste, domestic sewage treatment, and landfills).

Nitrous oxide (N_2O) is an important greenhouse gas with an atmospheric lifetime of about 110—168 years (WMO, 1992). After release it is practically inert and seldom involved in any chemical reactions in the troposphere. Nitrous oxide is also the primary source of NO_x in the stratosphere which is contributing to the depletion of stratospheric ozone. Over 20 percent of the total global N_2O emissions and 50 percent of the total N_2 emissions may be due to natural terrestrial emissions (IPCC, 1993). The most important anthropogenic source of N_2O is the increased use of nitrogen fertilizers. Nitrous oxide is produced naturally in soils by denitrification (i.e., the reduction of nitrite or nitrate to gaseous nitrogen as N_2 or as a nitrogen oxide) and nitrification (i.e., the oxidation of ammonia to nitrate). Commercial nitrogen fertilizers provide an additional nitrogen source, thereby increasing the emissions of nitrous oxide from the soil. Other potentially significant sources of N_2O include fossil fuel combustion, biomass burning, and adipic acid production for the nylon industry. Recently, the importance of mobile combustion as a source of N_2O emissions has been increasing due to the use of three-way catalysts to reduce NO_x emissions (De Soete, 1989).

Chlorofluorocarbons (CFCs) are any of a number of manmade substances consisting of chlorine, fluorine, and carbon. Some examples include dichlorodifluoromethane (CFC-12) and trichlorotrifluoroethane (CFC-113). CFCs are extremely stable due to full halogenation. They are also non-flammable and generally non-toxic at low doses. However, they have been identified as greenhouse gases, as well as ozone depleting substances (ODS). Because of the potential of ozone depletion, virtually all worldwide production of CFCs has ceased as set forth in the Montreal Protocol. CFCs have appropriate boiling points to make them excellent refrigerants. Their low surface tension and low viscosity make them ideal cleaning solvents. They also exhibit high evaporation rates and leave no residue. They are also used as inert carriers in ethylene oxide (EtO) sterilizers.

5.0 SOURCE CATEGORIES

Air pollution results from a complex mix of literally thousands of sources, ranging from industrial smoke stacks and motor vehicles to the individual use of household cleaners and paints. Even plant and animal life can play an important role in the air pollution problem. For emissions inventory purposes, emission sources are typically grouped into four different source types:

- Point sources;
- Area sources;
- Motor vehicle sources; and
- Natural sources.

This section provides a general description of these different types of emission sources, explains the concept of point/area source reconciliation, and presents a checklist of source categories that should be included (or at least considered) in every emissions inventory.

5.1 Point Sources

Volume IV of this Manual series, *Point Source Inventory Development,* presents detailed information about point sources. However, before beginning to develop a point source inventory, two important decisions must be made. First, a "point source" must be clearly defined (i.e., a point/area source delineation must be established). Second, the desired level of detail must be determined.

5.1.1 Point/Area Source Delineation

The division of emissions sources into "point" and "area" sources is arbitrary but necessary to allow for the efficient collection of information needed to support air quality programs. This division has important implications for both the development of regulatory programs and the amount and type of information needed to support those programs.

Detailed information on every "point" at which emissions are discharged to the atmosphere is desirable. While this would allow a detailed understanding of the characteristics of each such emission source, there is no practical way that such information can be collected. Treating all facilities as point sources may increase the accuracy of the inventory, but will require substantially more resources to compile and maintain the point source inventory. An alternative approach is to collect information on a simpler basis by aggregating related sources (e.g., all automobiles, all bakeries) into a single "area source."

In Mexico, point sources are defined in Article 6 of the *General Law for the Ecological Equilibrium and Environmental Protection on Air Pollution Control and Prevention* as any facility that is established in one place only, with the purpose of developing industrial or commercial processes, service works, or activities that generate or can generate air pollutant emissions (Fuente fija. Es toda instalación establecida en un solo lugar, que tenga como finalidad desarrollar operaciones o procesos industriales, comerciales, de servicios o actividades que generen o puedan generar emisiones contaminantes a la atmósfera).

As indicated in Article 111Bis of *the General Law for the Ecological Equilibrium and Environmental Protection* and Article 11 of the *Regulation of the General Law for the Ecological Equilibrium and Environmental Protection on Air Pollution Control and Prevention*, point sources under Federal jurisdiction include:

- The following industrial sectors: chemical, petroleum and petrochemical, paint and ink, automobile, cellulose and paper, iron and steel, glass, electricity generation, asbestos, cement and lime, and hazardous waste treatment;
- All facilities, projects, or activities (industrial, commercial, or service) conducted by Federal Public Administration entities;
- Facilities located in the Federal District adjoining zone; and
- Sources affecting the ecological equilibrium in an adjoining state or country.

These facilities must solicit a permit to operate through the Secretary (SEMARNAP). In addition, they must annually submit emission estimates and/or stack measurements for the facility.

Certain companies that have a microindustry certificate may be exempt from the licensing and operating certificate requirements for point sources if their activities are exempted in the *Agreement by which Point sources considered to be Small Businesses (microindustries) in Terms of the Law of the matter Published 17 May 1990 are Exempted from the Requirement of obtaining an Operating License (el Acuerdo por el que se Exceptúan del Trámite para la Obtención de la Licencia de Funcionamiento, a las Fuentes Fijas consideradas como Empresas Microindustriales en los Términos de la Ley en la materia publicado el 17 de Mayo de 1990).*

Point sources could also be specified in a number of other ways. These include defining a point source as follows (with all other sources included as area):

- Source of a given type (e.g., Fluidized Catalytic Cracking unit) or both type and size (e.g., boiler with heat input >10,000 British thermal units [Btu]/hr);
- Source that emits more than a specific amount of emissions determined on some consistent basis (e.g., boilers emitting more than 100 tons per year of NO_x);
- Every source (regardless of type, size or emissions) that is located in a facility of a given type (e.g., petroleum refinery) or type and size (e.g., steel foundry with steel production more than 1,000 tons/year); and
- Every source (regardless of type, size or emissions) that is located in a facility with more than a specified amount of emissions determined on some consistent basis.

Some examples of a consistent basis for determining the amount of emissions are:

- Actual emissions (what was actually emitted in some prior time period);

- Allowable emissions (the maximum that could be emitted under regulatory limits); and
- Potential emissions (what would be emitted if operated full time without control equipment).

In addition, these definitions can vary by regulatory region to account for different levels of severity of the air quality problem and/or the stringency of the regulatory program. As an example, a specific basis has been set in the United States for areas that exceed various ambient air quality standards. Depending upon the exceedance severity, the point source emissions cut-off is set at a different level. As a result, areas with the worst air quality have the lowest point source emissions cut-off. Furthermore, individual states have been encouraged to inventory sources below these cutoffs on an individual basis. The decision to set a lower cutoff depends on a number of local factors, usually available resources to obtain and manage the data.

Environmental programs in the United States have often used the last definition (i.e., facility-wide emission thresholds) based on actual emissions. These sources have been designated as "stationary sources" and are subject to more stringent regulations than sources that emit less. The United States Environmental Protection Agency (U.S. EPA) has expanded this regulatory definition into the realm of data management. U.S. EPA requires that state agencies submit data on the regulatory-defined stationary sources as "point sources"; all data on the remaining facilities must be submitted in aggregated form as "area sources."

As the Mexico emissions inventory program evolves, the established point source definition may be modified to add new significant sources that are identified or to eliminate insignificant sources. Again, the goal is to maximize the overall accuracy of the comprehensive emissions inventory (i.e., point, area, motor vehicle, and nature sources) within the allotted amount of available resources.

5.1.2 Level of Detail

Information on point sources is usually gathered by surveys. Point sources can be inventoried at the following three levels of detail (which are illustrated in Figure 5-1):

- Plant level, which denotes a plant or facility that could contain several pollutant-emitting activities;
- Point/stack level, where emissions to the ambient air occur; and
- Process level, representing the emission unit operations of a source category.

Whenever possible, emissions should be inventoried at the process level in order to support air quality activities such as regulatory development, compliance, tracking, and permitting. For example, identifying the processes or devices to which a future regulation might apply and then estimating the impact (i.e., costs and benefits) of that regulation would typically require estimating emissions for each process or device. Another equally important reason for collecting data at this level of detail is that it provides the agency with the information required to verify the facility-wide emissions estimates provided by the facility operators. Resource limitations, however, may dictate that emissions should be inventoried at the plant or point/stack level.

5.2 Area Sources

Area sources represent the emissions from sources that are too numerous and dispersed to efficiently include in a point source inventory. Collectively, however, area sources are significant emitters of air pollutants, and such pollutants must be included in an emissions inventory to ensure completeness. For example, gasoline stations and dry-cleaning establishments are often treated as area sources. Such facilities are typically not included in point source inventories because of the extensive effort that would be required to gather data and estimate emissions for each individual facility. Non-road mobile sources (e.g., industrial equipment, construction equipment, etc.) are often included with stationary area sources

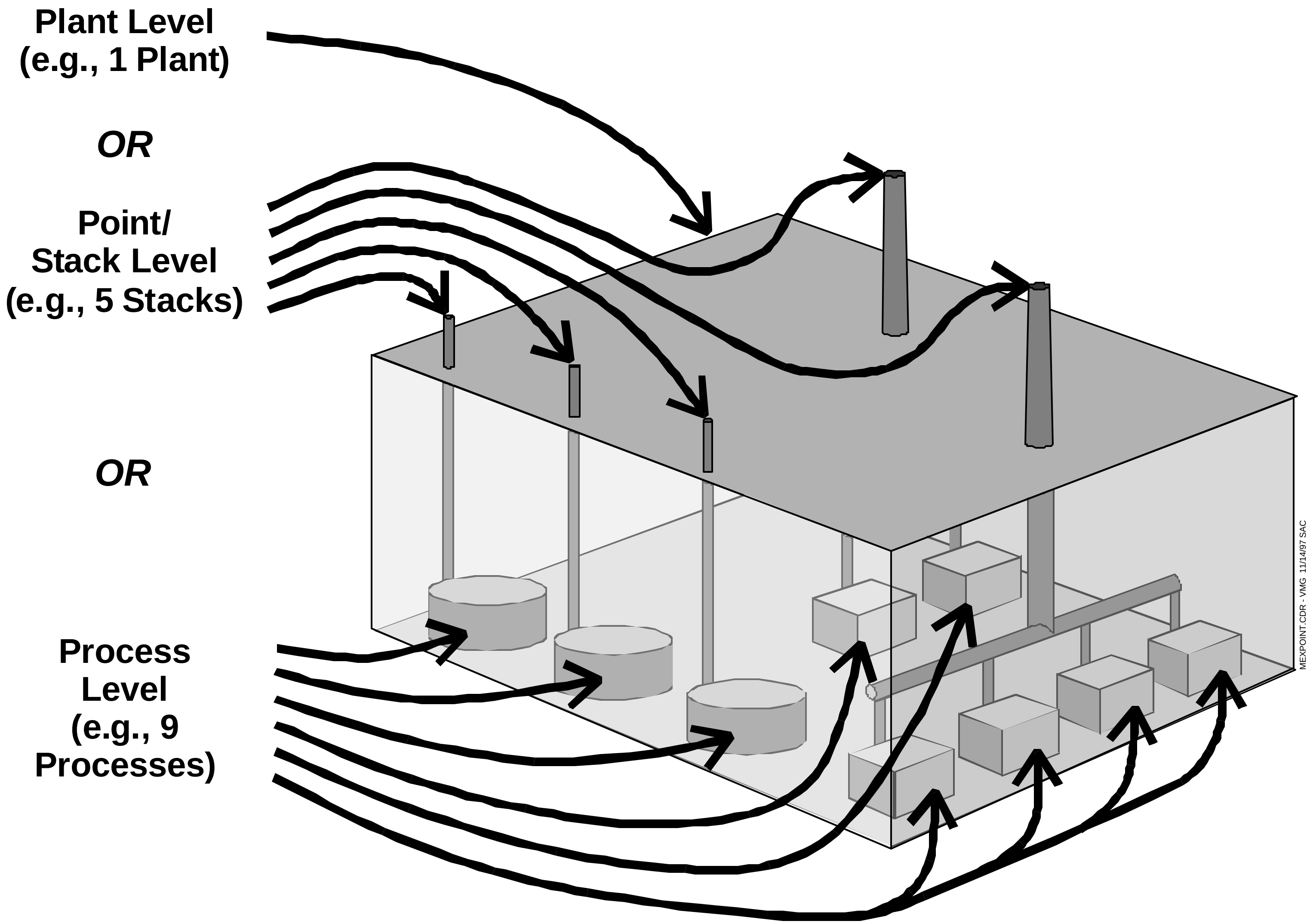


Figure 5-1. Different Point Source Inventory Levels

primarily because the methods used to estimate area and non-road mobile emissions are very similar. In contrast, the inventory methodology applied to motor vehicles is significantly different. More detailed information about area sources may be found in Volume V of this manual series, *Area Source Inventory Development.* Area source issues related specifically to emission calculations, such as rule effectiveness and rule penetration, are also discussed in Volume III of this Manual series, *Basic Emission Estimating Techniques*.

Instead of distinguishing between individual facilities and emitting devices as is done in point source inventories, area source inventories place emissions from similar sources into *categories*. An area source inventory generally consists of the following broad categories:

- Stationary source fuel combustion;
- Non-road mobile sources;
- Solvent use;
- Petroleum product storage and transport;
- Light industrial/commercial sources;
- Agriculture sources;
- Waste management sources; and
- Miscellaneous area sources.

Each of these categories is comprised of more specific source categories (e.g., organic solvent use includes commercial/consumer solvent use, dry cleaning, surface cleaning) that are defined by similar emission processes or a similarity in the methods that best estimate emissions. A comprehensive area source inventory may contain 150 or more individual source categories. For example, dry cleaning is typically represented by two or more source categories to account for the different solvents that are used (i.e., perchloroethylene versus petroleum-based solvents). Likewise, surface coating may have many source categories to account for the many different applications that exist (e.g., metal cans, metal coils, machinery, wood furniture, etc.).

Emissions from the broad source categories are produced through various mechanisms. Table 5-1 presents the different mechanisms associated with each broad area source category; sample specific source categories are also included.

5.3 Point and Area Source Reconciliation

When a point source inventory and an area source inventory include emissions from the same process, the possibility of double-counting emissions exists. In these situations, the area source emission estimate should be adjusted downward, if appropriate. Certain area source categories such as commercial/consumer solvent use and architectural surface coating do not require any point source adjustments. Other categories, such as fuel combustion, and solvent utilization, may share processes with point sources. To avoid double-counting, the point source activity is subtracted from the total activity for the combined point and area source categories. The resulting area source activity is shown in the following equation:

Area Source Activity = Total Activity of Source Category - Sum of Point Source Activyty

If the resulting area source activity is less than zero, the point source data should be reviewed for errors, and any errors found should be corrected. If area source activity is still less than zero, the area source activity is assumed to be equal to zero, with emissions only from point sources.

For example, if the area source emissions are calculated using employment, the number of employees at the point sources must be subtracted from the inventory region employment to give the area source employment. Likewise, if fuel sales statistics are used to estimate fuel use for area industrial fuel combustion, then fuel used at point source facilities should be subtracted from the overall fuel statistics. Another example illustrating graphic arts solvent use is presented in Figure 5-2.

Table 5-1

Emission Mechanisms for Various Area Source Categories

Source Category	Combustion	Evaporation	Mechanical Disturbance	Biological Process
Stationary Source Fuel Use	✓ (Residential Fuel Combustion)			
Non-Road Mobile Sources	✓ (Construction Equipment)	✓ (Recreational Equipment)		
Solvent Use		✓ (Degreasing)		
Petroleum Product Storage and Transport		✓ (Gasoline Distribution, LPG Leaks)		
Light Industrial/Commercial Sources	✓ (Brick Manufacturing)		✓ (Building Construction)	✓ (Bakeries)
Agricultural Sources	✓ (Agricultural Burning)	✓ (Pesticide Application)	✓ (Agricultural Tilling)	✓ (Animal Waste)
Waste Management Sources	✓ (Incineration)	✓ (Publicly Owned Treatment Works [POTWs])		
Miscellaneous Area Sources	✓ (Wildfires)		✓ (Road Dust)	✓ (Livestock Ammonia)

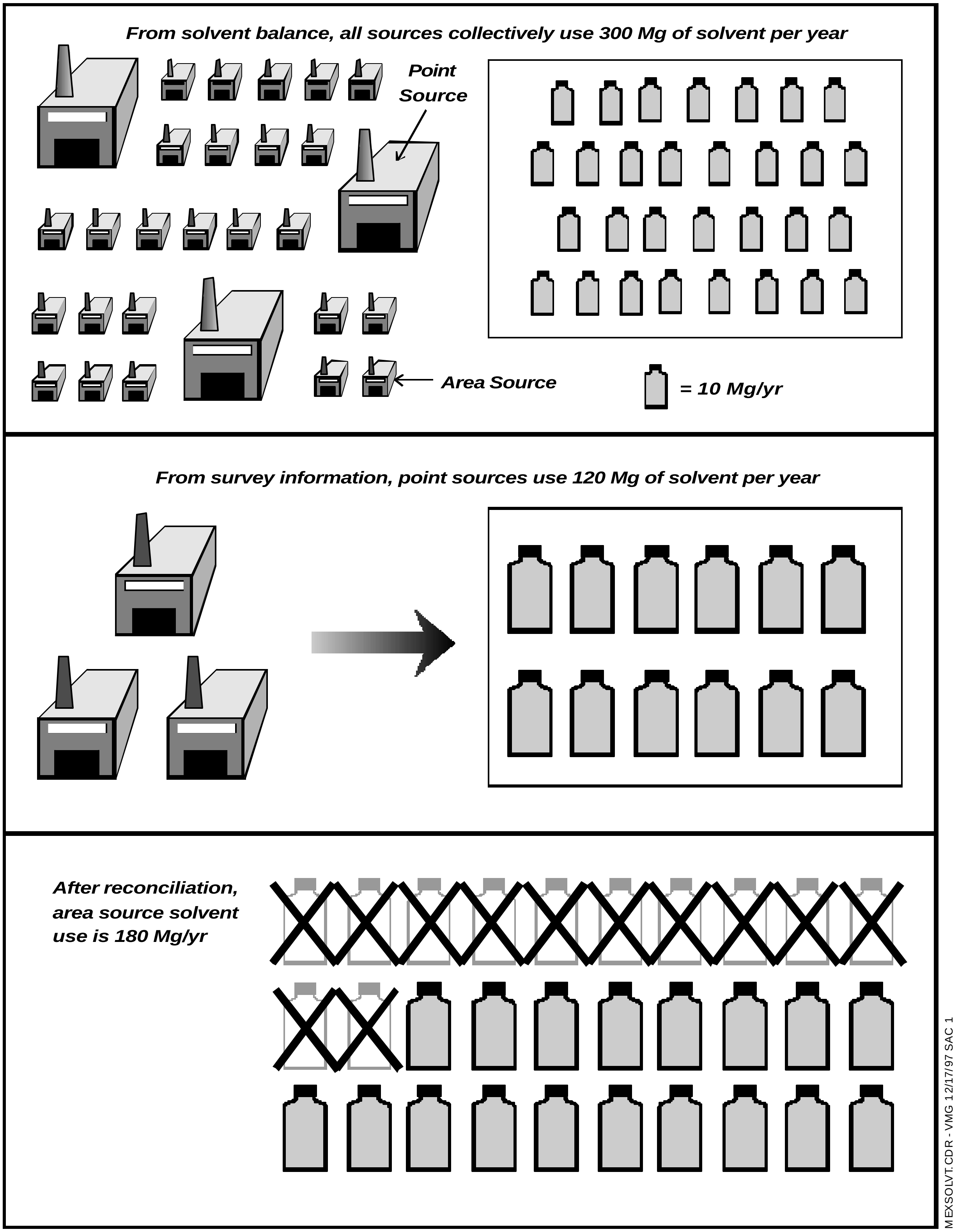


Figure 5-2. Hypothetical Point and Area Source Reconciliation for Graphic Arts Solvents

A point source adjustment is sometimes made by subtracting point source emissions from total source emissions, although this should be the method of last resort. If this method is used, uncontrolled emissions (from total combined sources and point sources) should be used. Any emission control adjustments needed for the area sources should be made after the point source adjustment.

5.4 Motor Vehicle Sources

On-road motor vehicles are those vehicles, such as autos, trucks, and buses, designed to operate on public roads. In most urban areas, on-road motor vehicles are major contributors of emissions of TOG, CO, NO_x, SO_x, PM, air toxics, and visibility-reducing species. Due to their large emissions magnitude and the special considerations required to develop emission estimates, on-road motor vehicles are addressed separately from other area sources. More detailed information about motor vehicle sources may be found in Volume VI of this manual series, *Motor Vehicle Inventory Development.*

Motor vehicle emissions consist of a large number of pollutants resulting from a number of different processes (see Figure 5-3). The most commonly considered are exhaust emissions, which result from fuel combustion and are emitted from the vehicle exhaust tailpipe, and a variety of evaporative emission processes. Evaporative emission processes result in TOG emissions only. These evaporative emissions include:

- **Hot soak emissions** – Emissions occurring due to volatilization of fuel in the fuel delivery system following engine shut-off. Residual engine heat volatilizes the fuel.
- **Running evaporative emissions** – Evaporative emissions from liquid or vapor fuel leaks occurring while the engine is operating.
- **Diurnal emissions** – Emissions from the vehicle fuel tank due to higher bulk liquid temperatures and fuel vapor pressure. These result from rising ambient temperatures, heat input from the vehicle’s exhaust system, or heat reflected from the road surface.

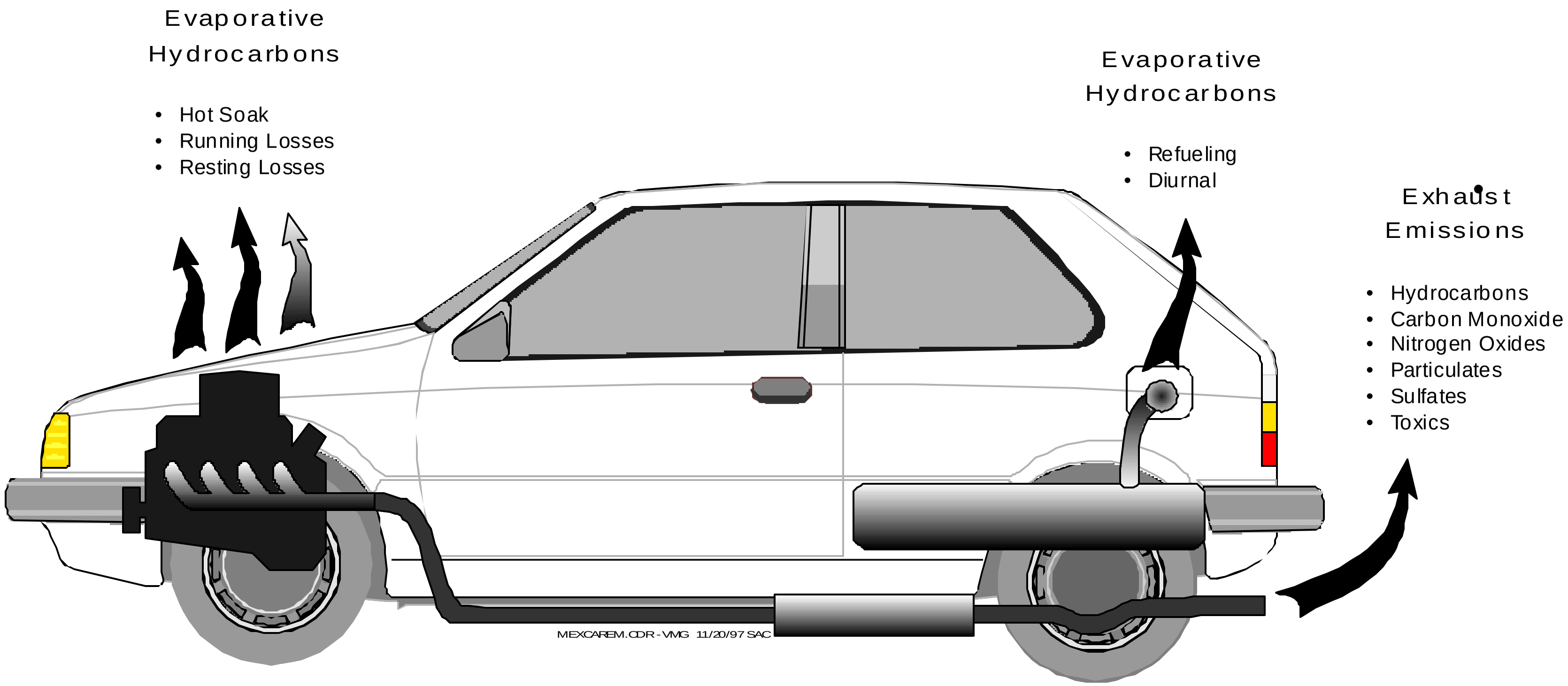


Figure 5-3. Motor Vehicle Emission Processes

Resting evaporative emissions – Evaporative emissions other than hot soak, diurnal, and refueling emissions that occur while the engine is not operating. Resting losses occur primarily from fuel leaks and permeation of vapor through fuel lines.

- **Refueling evaporative emissions** – Evaporative emissions displaced from the vehicle fuel tank during refueling. While the vehicle is the source of the emissions, they occur while the vehicle is stationary and at known locations, such as gasoline stations. Therefore, refueling emissions are typically treated as an area source and discussed in *Volume V: Area Source Inventory Development*. Refueling emission factors can either be estimated using the MOBILE model or obtained from other sources such as AP-42.

Interest in obtaining estimates of the on-road motor vehicle contribution to regional emissions inventories in Mexico has been increasing, leading to the development of motor vehicle emissions inventories for Mexico City, Monterrey, Ciudad Juárez, Guadalajara, and Toluca (Espinosa, et al., 1996). In order to account for potentially different vehicle fleets and driving behavior in Mexico, the U.S.-based MOBILE model has been modified for the Mexico City, Monterrey, and Ciudad Juárez metropolitan areas. The MOBILE model estimates motor vehicle emission factors, which then must be combined with appropriate activity data. Multiple modifications to the MOBILE model have been performed, because it is known that vehicle fleet mix, fuels used, and driving behavior/conditions are not homogeneous throughout Mexico. For example, in the border regions, the Mexican fleet may contain more U.S. vehicles and larger quantities of U.S. fuels may be used. As another example, the high altitude in Mexico City affects the fuel combustion process and, therefore, the emissions from motor vehicles.

5.5 Natural Sources

In addition to human activities, natural phenomena and plant and animal life can play an important role in the air pollution problem. In some areas where natural source emissions may be significant to the overall inventory, it is important to understand the contribution of natural sources, since implementing control strategies generally can not readily reduce these emissions. Two significant natural sources commonly considered in air emissions inventory efforts are described below.

Biogenic emissions. A number of researchers have established that vegetation (e.g., grass, crops, shrubs, forests, etc.) emits significant quantities of hydrocarbons to the atmosphere. Several studies (e.g., Pierce et al., 1990 and Robinson and Robbins, 1968) have shown that biogenic emissions may be comparable to, or exceed, the emissions of nonmethane hydrocarbons (NMHC) from anthropogenic sources in certain areas.

Emissions from soils. As mentioned earlier in the discussion about greenhouse gases in Section 4.9, nitrous oxide (N_2O) is produced naturally in soils by denitrification (i.e., the reduction of nitrite or nitrate to gaseous nitrogen as N_2 or NO_x) and nitrification (i.e., the oxidation of ammonia to nitrate). Commercial nitrogen fertilizers provide an additional nitrogen source, thereby increasing the emissions of N_2O from the soil. The rate of NO_x emissions from soils is also dependent on other variables such as soil type, moisture, temperature, season, crop type, and other agricultural practices. Emissions of NO_x from soils are estimated to be as much as 16 percent of the global amount of NO_x in the troposphere, and as much as 8 percent of the NO_x in North America (U.S. EPA, 1993).

Wind erosion is another natural phenomenon that generates emissions. However, because wind erosion emissions typically are associated with disturbed land, they are sometimes treated as area sources. More detailed information on wind erosion emissions is presented in Section 11.5 of Volume V of this Manual series, *Area Source Inventory Development.*

Some other smaller categories of natural sources include termites (CH_4), lightning (NO_x), and volcanoes and other goethermal activity (SO_x). More detailed information about natural sources may be found in Volume VII of this Manual series, *Natural Source Inventory Development.*

5.6 Typical Source Category Checklist

The sources to be included in the inventory should be prioritized based on their importance in the inventory. Resources should be allocated preferentially to the sources that are most important in meeting the end-uses of the inventory. High priority sources include those that are known to be significant contributors of air pollution, are known to be sources of specific targeted pollutants (e.g., PM_{10}), or are most likely to impact air quality.

Table 5-2 is a typical checklist of source categories that might be included in an inventory effort. For each source category, the primary expected emissions are presented by pollutant. **Please note that this checklist should only be used as a tool to begin the process of identifying the source categories to be included in an inventory. Region-specific conditions will likely lead to additions or deletions to this checklist in order to obtain a complete inventory.** For example, bus/truck terminal, small scale brick manufacturing, charbroiling, and street vendors are not source categories that are typically inventoried in the U.S., but they have been added to the checklist as potential source categories for Mexico.

Table 5-2
Example Checklist of Inventory Source Categories and Their Primary Pollutants

Source Category	Inventory Pollutants															
	TOG	ROG	CO	NO_x	SO_x	PM	PM_{10}	$PM_{2.5}$	NH_3	EC	OC	HAPs	CO_2	N_2O	CH_4	CFCs
Point Sources																
Electric Utility	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Chemical Manufacturing[a]	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓		✓		✓
Petroleum Refining[a]	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓				
Primary Metal Production[a]	✓	✓			✓	✓	✓	✓				✓				
Secondary Metal Production[a]	✓	✓				✓	✓	✓				✓				
Cement Production[a]	✓	✓	✓	✓	✓	✓	✓	✓				✓				
Miscellaneous Mineral Production[a]						✓	✓	✓		✓	✓	✓				
Automotive Industry[a]	✓	✓										✓				
Wood Pulping Operations[a]	✓	✓			✓	✓	✓	✓		✓	✓	✓				
Oil and Gas Production[a]	✓	✓			✓							✓				
Printing and Publishing	✓	✓										✓				
Surface Coating	✓	✓										✓				
Bulk Terminals	✓	✓										✓				
Mining and Quarrying[a]						✓	✓	✓				✓				
Wood Products Manufacture[a]	✓	✓				✓	✓	✓				✓				
Sugar Production[a]	✓	✓				✓	✓	✓				✓				
Tanning and Finishing[a]	✓	✓										✓				
Glass Production[a]	✓	✓				✓	✓	✓				✓				
Rubber and Plastic Parts Production[a]	✓	✓										✓				
Fabricated Metal Production[a]	✓	✓				✓	✓	✓				✓				
Textile Products[a]	✓	✓				✓	✓	✓				✓				
Landfills	✓	✓	✓	✓								✓	✓		✓	
Municipal Incinerators	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Open Waste Burning	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Asphalt Plants[a]	✓	✓				✓	✓	✓				✓				
Food and Agriculture[a]	✓	✓				✓	✓	✓			✓	✓				
Point Source Fuel Combustion	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	

Area Sources																

Table 5-2

(Continued)

Source Category	Inventory Pollutants															
	TOG	ROG	CO	NO_x	SO_x	PM	PM_{10}	$PM_{2.5}$	NH_3	EC	OC	HAPs	CO_2	N_2O	CH_4	CFCs
Industrial and Commercial/ Institutional Fuel Combustion	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Residential Fuel Combustion (Commercial Fuels)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Residential Fuel Combustion (Biomass or Waste-derived Fuels)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Locomotives	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Commercial Marine Vessels	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Aircraft	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Other Non-Road Mobile Equipment (Construction, Industrial, Recreational, etc.)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Border Crossings	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Bus/Truck Terminals	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Industrial Surface Coating	✓	✓										✓				
Auto Body Refinishing	✓	✓										✓				
Architectural Surface Coating	✓	✓										✓				
Traffic Paints	✓	✓										✓				
Industrial Surface Cleaning (Degreasing)	✓	✓										✓				
Dry Cleaning	✓	✓										✓				
Graphic Arts	✓	✓										✓				
Asphalt Application	✓	✓										✓				
Commercial/Consumer Solvent Use	✓	✓										✓				
Gasoline Distribution	✓	✓										✓				
Aircraft Refueling	✓	✓										✓				
LPG Distribution	✓	✓										✓				
Bakeries	✓	✓										✓				
Brick Manufacturing	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Construction Activities						✓	✓	✓		✓	✓	✓				
Charbroiling	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Street Vendors	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Pesticide Application	✓	✓										✓				

Table 5-2

(Continued)

Source Category	Inventory Pollutants															
	TOG	ROG	CO	NO$_x$	SO$_x$	PM	PM$_{10}$	PM$_{2.5}$	NH$_3$	EC	OC	HAPs	CO$_2$	N$_2$O	CH$_4$	CFCs
Beef Cattle Feedlots						✓	✓	✓	✓			✓				
Agricultural Burning	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Fertilizer Application									✓			✓		✓		
Animal Waste	✓	✓							✓			✓			✓	
Agricultural Tilling						✓	✓	✓		✓	✓	✓				
On-Site Incineration	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Waste Management—Open Burning	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Wastewater Treatment	✓	✓							✓			✓			✓	
Open Channel Sewage and Wastewater	✓	✓							✓			✓			✓	
Wildfires/Prescribed Fires	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Structure Fires	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Paved Road Dust						✓	✓	✓		✓	✓	✓				
Unpaved Road Dust						✓	✓	✓		✓	✓	✓				
Wind Erosion						✓	✓	✓		✓	✓	✓				
Domestic Ammonia Emissions									✓			✓				
Motor Vehicle Sources																
Light Duty Gas Vehicles (LDGV)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Light Duty Gas Trucks (LDGT)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Heavy Duty Gas Vehicles (HDGV)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Light Duty Diesel Vehicles (LDDV)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Light Duty Diesel Trucks (LDGT)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Heavy Duty Diesel Vehicles (HDDV)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Motorcycles (MC)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Natural Sources																
Biogenic Hydrocarbons	✓	✓														

Table 5-2

(Continued)

Source Category	Inventory Pollutants															
	TOG	ROG	CO	NO_x	SO_x	PM	PM_{10}	$PM_{2.5}$	NH_3	EC	OC	HAPs	CO_2	N_2O	CH_4	CFCs
Soil NO_x				✓										✓		
Termites															✓	
Lightning				✓												
Volcanoes/Other Geothermal					✓	✓	✓	✓				✓				

[a] Only includes process related emissions; point source fuel combustion is treated as its own subcategory.

6.0 OTHER EMISSIONS INVENTORY CHARACTERISTICS

Two of the ten emissions inventory characteristics (pollutant types and source types) were described in Sections 4.0 and 5.0. The remaining eight characteristics are described below. The definition of these characteristics is determined primarily by the established purpose of the inventory.

6.1 Base Year

The base year of an inventory identifies the year for which emissions are estimated and fixes an inventory's position in time. This provides a benchmark against which previous and subsequent inventories can be compared. It is important to establish a base year, so that all emission estimates have a common basis and represent activities occurring during the same period of time.

Any year can be used as the inventory base year, but it is usually determined by the established purpose of the inventory. For example, if it is desired to see the effects of recently implemented control strategies, then the base year will be some year prior to the implementation of control strategies. A comparison of current emission levels to historic levels might use a base year in the past. The base year of an inventory might also be dictated by various regulatory requirements. The main reason for this is so that emissions inventories from different regions can be easily compared with each other and regulatory standards. In other cases, data availability might determine what the inventory base year is. For example, it might be desired to develop an inventory for 1997, but if statistics to be used as activity data have only been compiled through 1995, then 1995 would probably be a better base year than 1997.

6.2 Time Characteristics

There are two main time characteristics that must be considered for every inventory: time period and temporal variability. Other minor time characteristics may be applicable for some inventories. Time period refers to the length of time represented by the inventory. Inventory emissions will be presented in units of mass of pollutant per inventory time period (e.g., kg CO/yr). For many large-scale inventories, the time period will typically be one year. However, some specialized inventory applications may require shorter periods of time (e.g., one day, one month, the summer ozone season, the heating season, etc.).

Temporal variability describes the variability of emissions over time. If emissions are constant over time, then temporal variability is not of much concern. However, most emissions do change over time. Depending upon the inventory requirements associated with the inventory purpose, the emissions variations might need to be described on a seasonal, monthly, or daily basis. Specialized inventories may even need emissions on an hourly (or shorter time period) basis. For instance, emissions from on-road motor vehicles are variable over different time periods due to different levels of activity. Weekday motor vehicle emissions might be higher than weekend emissions because of high levels of vehicle activity associated with commuting to and from work. Also, as shown in Figure 6-1, emissions in the morning and early evening are likely to be higher than emissions at noon or midnight because those times are characterized by heavy commuting traffic. Because the temporal distribution for motor vehicle activity presented in Figure 6-1 is U.S.-specific, Mexico motor vehicle activity may be distributed differently. Depending upon the purpose of the inventory, one or more of these temporal variabilities may need to be considered.

6.3 Spatial Characteristics

There are two primary spatial characteristics in any inventory: inventory domain and spatial resolution. The inventory domain represents the area for which air pollutant sources will be inventoried. The inventory domain is sometimes determined by the inventory purpose.

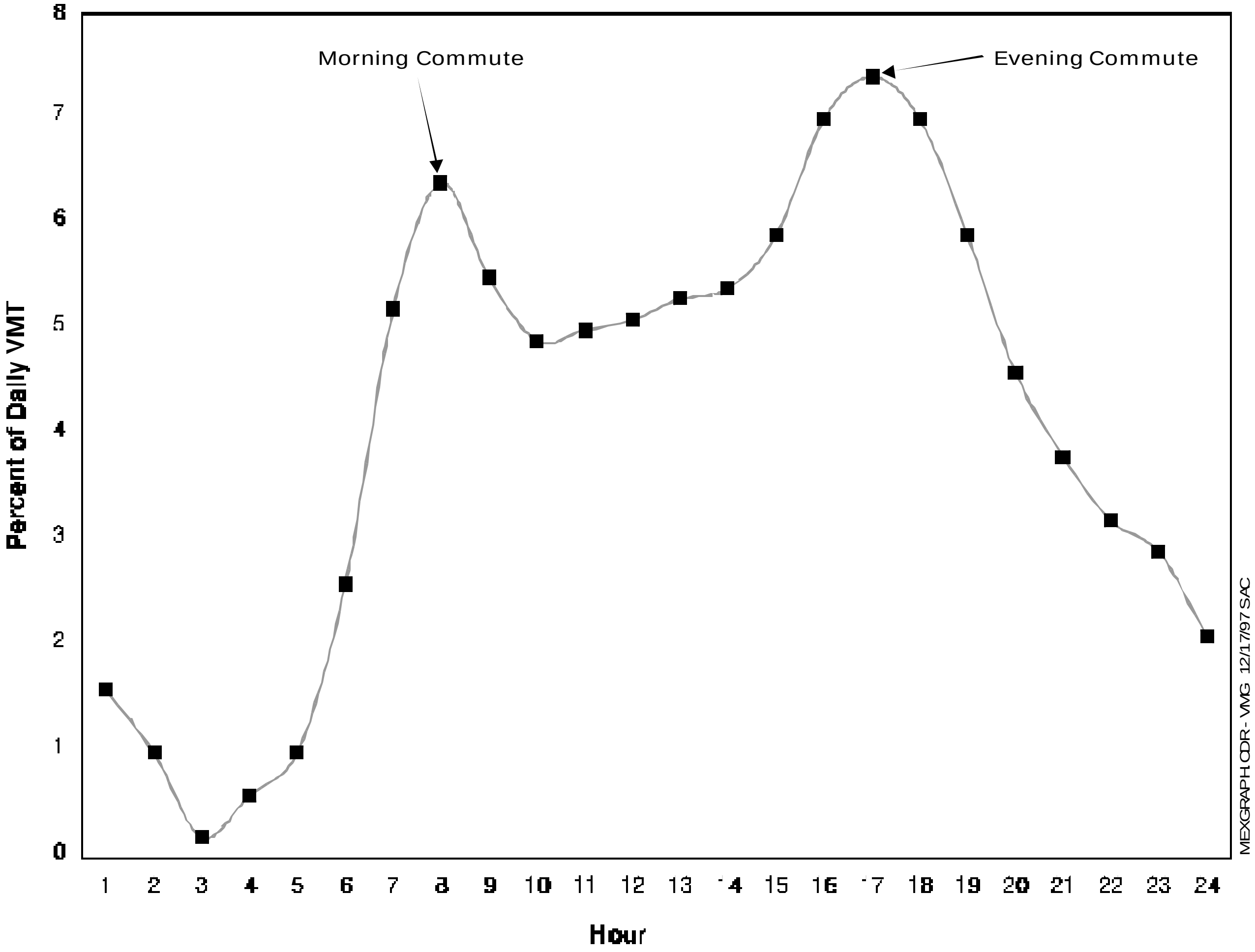


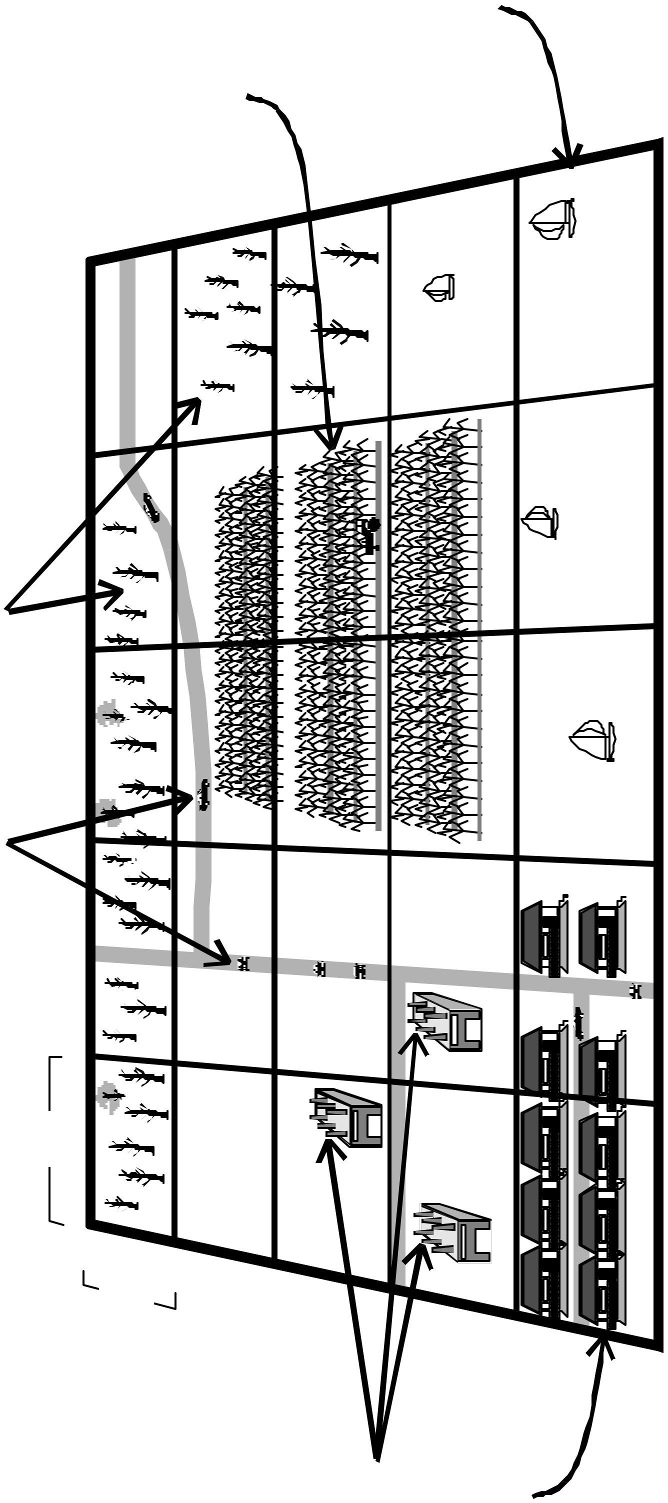
Figure 6-1. Hypothetical U.S. Temporal Distribution of Motor Vehicle Activity

Often, the inventory domain follows political, geographic, or air quality agency boundaries. Depending upon the inventory application, sources external to the defined inventory domain that exert influence upon air quality within the domain due to meteorological transport may also need to be addressed. A square hypothetical inventory domain measuring 25 km on a side is presented in Figure 6-2.

Spatial resolution describes how specifically the geographic location of pollution sources must be defined. Basic inventories will sometimes provide pollutant totals only for the entire inventory domain. More complex inventories, particularly those associated with air quality modeling efforts, will often require a more detailed description of emissions distribution. The resolution of area, motor vehicle, and natural sources within an inventory domain is usually done using grid cells. The inventory domain presented in Figure 6-2 contains 25 grid cells measuring 5 km on a side. Typically, the desired air quality accuracy determines the required grid cell size. However, in general, the required grid cell size is also indicated by the domain size – large inventory domains will have grid cells that typically measure several kilometers on a side, while smaller inventory domains can have grid cells that measure a few hundred meters on a side. From Figure 6-2, the following spatial distribution of emissions can be seen:

- Population/Residential Area Sources: Cells A1 and A2;
- Agricultural Area Sources: Cells B3, B4, C3, C4, D3, and D4;
- Marine Sources: Cells A3, A4, A5, and B5;
- Motor Vehicles: Cells A1, A2, B1, B2, C2, D2, D3, D4, E2, E4, and E5; and
- Natural Biogenic Sources: Cells C5, D5, E1, E2, E3, and E4.

For most types of inventories, point sources will need to be geographically located using either latitude and longitude coordinates or Universal Transverse Mercator (UTM) coordinates. For some complex inventory efforts, the required geographical accuracy for point



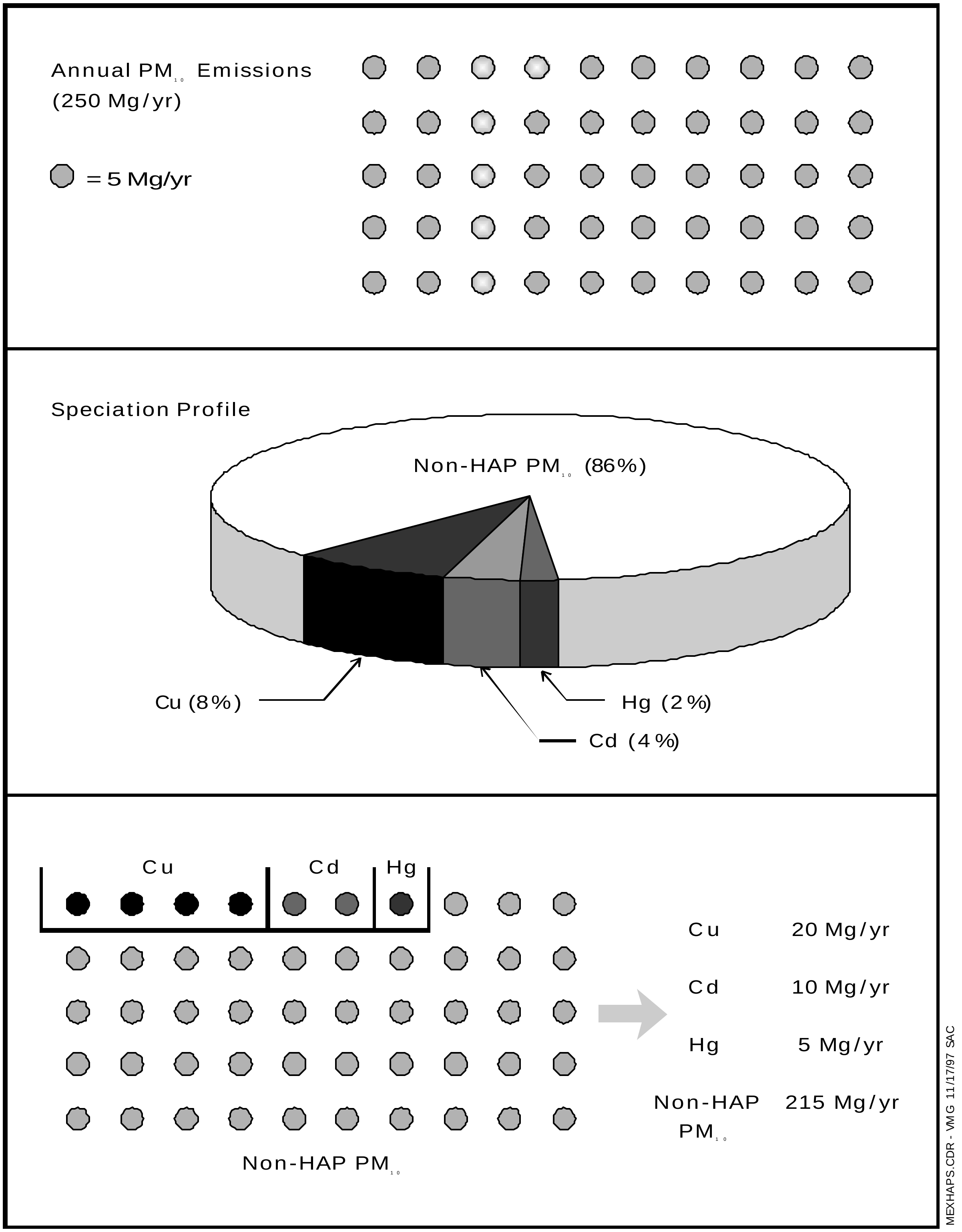
source locations may be as close as ±10 meters. In Figure 6-2, the three point sources located in cells B1, C1, and C2 will require detailed location coordinates.

6.4 Species Resolution

Species resolution refers to disaggregating an inventory pollutant (e.g., TOG, PM, etc.) into its individual chemical components (e.g., toluene, lead, EC, OC, etc.) or into specific groups (e.g., paraffins, aromatics, etc.). The need for species resolution, as well as the specific methodology, is determined by the inventory purpose. Species resolution is primarily performed using speciation profiles that describe the fraction of individual chemical species. Many inventories will not include detailed species resolution; other specialized inventory applications will require it. These applications include air toxics inventories, photochemical modeling, and chemical mass balance modeling used for source attribution.

As discussed in Section 4.8, air toxics inventories seek to quantify the amount of hazardous air pollutants (HAPs) that are emitted. Ideally, this would be performed using emission factors for individual HAPs. Although there are some HAP emission factors for combustion and other sources, emission factors often do not exist. As a result, individual HAP species frequently are disaggregated from TOG and PM by using speciation profiles. As mentioned in Section 4.8, this is not the preferred approach for estimating HAPs emissions. If this approach is used, it often results in an overestimation of HAPs. This approach is demonstrated in Figure 6-3.

In photochemical modeling, speciation is needed because emitted hydrocarbon species have different photochemical reactivities. Total hydrocarbon emissions are calculated and then speciated into different hydrocarbon groups. In order to properly represent the chemical reactions occurring in the atmosphere, each species group is assigned an appropriate level of photochemical reactivity.



Cu	20 Mg/yr
Cd	10 Mg/yr
Hg	5 Mg/yr
Non-HAP PM_{10}	215 Mg/yr

Figure 6-3. Hypothetical HAPs Speciation

Finally, source attribution (or receptor modeling) through the use of a chemical mass balance requires fairly detailed species resolution. Source attribution can be determined working backward from measured TOG and particulate concentrations at a monitoring site using computerized linear algebra matrix calculations. In this instance, species resolution provides the unique chemical content (usually for metals and hydrocarbons) of the emissions for each source type. This chemical content serves as the “fingerprint” for the presence of material from that source in ambient sample data at the receptor. Without species resolution, implementation of this application is impossible. More information on source attribution can be found in some recent source attribution studies (Watson et al., 1984; Chow et al., 1992; and Scheff et al., 1984).

6.5 Quality Assurance

Quality assurance (QA) is an indispensable element of any emissions inventory. Regardless of what type of inventory is being conducted, QA is necessary. The amount and focus of QA, however, will be variable depending upon the specific inventory purpose. For instance, a detailed large-scale modeling inventory will typically require significantly more QA than a facility-level reporting inventory would. Also, if one particular source type had been preliminarily identified as a large pollutant source, then more QA resources could be directed at this source type rather than at some of the more minor source types.

QA should be conducted throughout the development of the inventory rather than as an afterthought conducted at the last minute. Some example QA activities include:

- Using a source category checklist (such as the one presented in Table 5-2), confirm that all necessary source categories have been included in the inventory;
- Check sampling results and activity data for “outliers” prior to emission calculations;

- Confirm that all emission calculations have been performed properly; and
- Compare inventory results with emissions inventories in similar regions.

There are also many other QA activities not listed above that can be devised which will help ensure a high quality emissions inventory.

Although the results of an inventory might affect how QA is conducted later in the inventory effort, QA resources should be identified at the beginning. To the greatest extent possible, the type of QA (e.g., detailed “line-by-line” QA or high-level QA) and areas requiring concentrated QA should be designated at the outset of the inventory effort.

6.6 Data Management

Another essential emissions inventory characteristic is the data management required for the inventory. With the widespread use of computers and increasing inventory data requirements, virtually all inventory data are currently handled electronically. Consideration should be given to whether data management should be performed using a spreadsheet-type application or a database application. Spreadsheets tend to be easier to use, but databases are much more powerful. The method of transfer of inventory-related information and any data confidentiality requirements should also be established early in the inventory development process. The inventory purpose will help determine what type of data management is required. For instance, an inventory used as an air quality model input might require different data management than an inventory designed for regulatory compliance. Also, expected future uses of the inventory might influence the type of data management selected.

6.7 Projections

Projections forecast a base year inventory forward or backward in time. The use of projections is primarily determined by the inventory purpose. Many inventories will not develop projected emissions. Projections are mainly used to track past and future emission trends due to activity growth and implemented control strategies. Projections are also used extensively in theoretical analyses of various control strategies proposed for future implementation. For example, projections could be used to estimate future motor vehicle emissions based upon expected population growth. Likewise, projections could be used to track estimated emission reductions due to the proposed phase-in of reformulated paints that contain lower levels of solvents. Growth projections of emissions are usually based upon growth projections of other surrogates (e.g., population, economic activity). Control projections, on the other hand, are often based on estimated reductions from control strategies. Projection methodologies and required data should be established early in the inventory development process. U.S. EPA has published guidance regarding emissions projection that contains various references and methodologies (U.S. EPA, 1991b).

6.8 Uncertainty Estimation

The final emissions inventory characteristic is uncertainty estimation. Uncertainty estimates are a valuable tool to assess the accuracy of an emissions inventory.

Uncertainty can be estimated quantitatively or qualitatively. Quantitative uncertainty estimates are unusual. There are several reasons for this. First of all, there is no agreed upon method for making quantitative estimates of uncertainty. Also, the derivation of quantitative uncertainty estimates can become very statistically complex. Finally, a large number of assumptions typically are required to make quantitative uncertainty estimates.

In general, when uncertainty estimates are made, they are most commonly qualitative in nature. Qualitative estimates of uncertainty may focus on methodologies, activity data, emission-related data, underlying assumptions, or other components of inventory development. For example, an inventory assumption that emissions from surface coating operations are limited only to solvent contained in the applied surface coating (and not from surface preparation and/or cleanup solvents) will almost certainly lead to an underestimate of TOG emissions in the inventory. In a similar manner, an assumption that all point sources use the same fuel and operate on the same operating schedule will generate uncertainty in the inventory, although it may not be clear if this would result in an overestimate or an underestimate. Although qualitative estimates do not statistically calculate the uncertainty of an emissions inventory, they are valuable because they point out potential weaknesses in the inventory.

7.0 ITERATION OF INVENTORY PROCESS

The technical steps of emissions inventory development were previously shown in Figure 2-1. These steps begin with the identification of the inventory purpose and end with the documentation of the inventory results. It is important to note that even if all of the steps presented in Figure 2-1 are properly implemented during inventory development, it simply represents one iteration of emissions inventory development. Multiple iterations are usually required for the development of high quality emissions inventories. This iteration concept is represented by the puzzles presented in Figure 7-1. Early inventories will be characterized by missing information and other imperfections; subsequent updated inventories will gradually improve in quality.

The end goal is to develop an emissions inventory that is a comprehensive, accurate, and current accounting of air pollutant emissions and associated data from sources within a given geographic area over a specific time interval. However, practical limitations necessitate an iterative approach to accomplish this objective. Systematic, iterative inventory development, over time, will reduce the amount of inventory uncertainty and improve the overall quality of the emissions inventory.

An emissions inventory should be comprehensive, which is to say that all sources of the identified inventory pollutants should be included. Limited resources may reduce the number of inventoried sources to a subset of the total existing sources. Likewise, some emission sources may be unnoticed or overlooked during the initial inventory process. Subsequent inventory revisions are used to fill in missing sources.

To the greatest extent possible, an emissions inventory should also be accurate. Incorrect data or overly simplistic assumptions will introduce inaccuracies into the inventory. These inaccuracies can be corrected in later inventory iterations with more complete or improved information.

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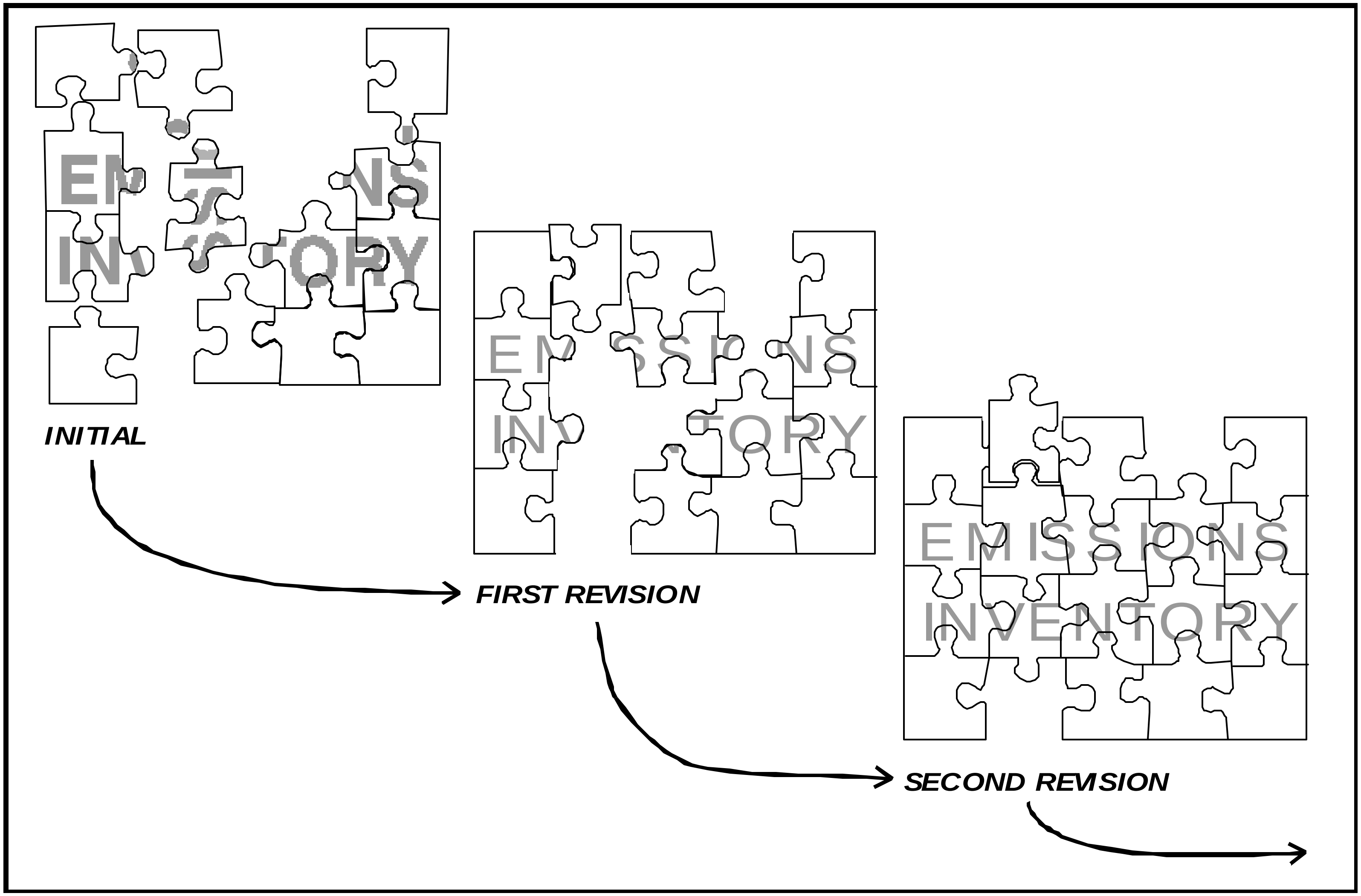

Figure 7-1. Emissions Inventory Iterations

Finally, an emissions inventory should represent current emissions. Some inventory applications will be updated every year and will require current information for that specific year. These inventories will be updated annually to track the increase of emissions due to growth in the emission-producing activity or the decrease of emissions due to the implementation of various emission control strategies. Outdated data and information should be updated in later inventory iterations.

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APPENDIX A

NON-REACTIVE HYDROCARBONS

U.S. EPA Photochemically Non-Reactive Compounds

Chemical	Synonym
methane	
ethane	
methylene chloride	dichloromethane
1,1,1-trichloroethane	methyl chloroform
1,1,2-trichloro 1,2,2-trifluoroethane	CFC–113
trichlorofluoromethane	CFC–11
dichlorodifluoromethane	CFC–12
chlorodifluoromethane	HCFC–22
trifluoromethane	HFC–23
1,2-dichloro 1,1,2,2-tetrafluoroethane	CFC–114
chloropentafluoroethane	CFC–115
1,1,1-trifluoro 2,2-dichloroethane	HCFC–123
1,1,1,2-tetrafluoroethane	HFC–134a
1,1-dichloro 1-fluoroethane	HCFC–141b
1-chloro 1,1-difluoroethane	HCFC–142b
2-chloro 1,1,1,2-tetrafluoroethane	HCFC–124
pentafluoroethane	HFC–125
1,1,2,2-tetrafluoroethane	HFC–134
1,1,1-trifluoroethane	HFC–143a
1,1-difluoroethane	HFC–152a
parachlorobenzotrifluoride	PCBTF
cyclic, branched, or linear completely methylated siloxanes	
acetone	
perchloroethylene	tetrachloroethylene
3,3-dichloro-1,1,1,2,2-pentafluoropropane	HCFC–225ca
1,3-dichloro-1,1,2,2,3-pentafluoropropane	HCFC–225cb
1,1,1,2,3,4,4,5,5,5-decafluoropentane	HFC–43–10mee
difluoromethane	HFC–32
ethylfluoride	HFC–161
1,1,1,3,3,3-hexafluoropropane	HFC–236fa
1,1,2,2,3-pentafluoropropane	HFC–245ca
1,1,2,3,3-pentafluoropropane	HFC–245ea
1,1,1,2,3-pentafluoropropane	HFC–245eb
1,1,1,3,3-pentafluoropropane	HFC–245fa
1,1,1,2,3,3-hexafluoropropane	HFC–236ea
1,1,1,3,3-pentafluorobutane	HFC–365mfc
chlorofluoromethane	HCFC–31

U.S. EPA Photochemically Non-Reactive Compounds (Continued)

Chemical	Synonym
1-chloro 1-fluoroethane	HCFC–151a
1,2-dichloro 1,1,2-trifluoroethane	HCFC–123a
1,1,1,2,2,3,3,4,4-nonafluoro-4-methoxy-butane	$C_4F_9OCH_3$
2-(difluoromethoxymethyl) 1,1,1,2,3,3,3-heptafluoropropane	$(CF_3)_2CFCF_2OCH_3$
1-ethoxy 1,1,2,2,3,3,4,4,4-nonafluorobutane	$C_4F_9OC_2H_5$
2-(ethoxydifluoromethyl) 1,1,1,2,3,3,3-heptafluoropropane	$(CF_3)_2CFCF_2OC_2H_5$
perfluorocarbon compounds which fall into these classes:	
(i) Cyclic, branched, or linear, completely fluorinated alkanes;	
(ii) Cyclic, branched, or linear, completely fluorinated ethers with no unsaturations;	
(iii) Cyclic, branched, or linear, completely fluorinated tertiary amines with no unsaturations; and	
(iv) Sulfur containing perfluorocarbons with no unsaturations and with sulfur bonds only to carbon and fluorine.	

Source: Federal Register, Vol. 62, No. 164. August 25, 1997. pp. 44900 – 44903.

APPENDIX B

HAZARDOUS AIR POLLUTANTS

United States Federal Hazardous Air Pollutants
(from Clean Air Act – Section 112(b))

CAS Number	Chemical Name
75-07-0	Acetaldehyde
60-35-5	Acetamide
75-05-8	Acetonitrile
98-86-2	Acetophenone
53-96-3	2-Acetylaminofluorene
107-02-8	Acrolein
79-06-1	Acrylamide
79-10-7	Acrylic acid
107-13-1	Acrylonitrile
107-05-1	Allyl chloride
92-67-1	4-Aminobiphenyl
62-53-3	Aniline
90-04-0	o-Anisidine
1332-21-4	Asbestos
71-43-2	Benzene (including benzene from gasoline)
92-87-5	Benzidine
98-07-7	Benzotrichloride
100-44-7	Benzyl chloride
92-52-4	Biphenyl
117-81-7	Bis(2-ethylhexyl)phthalate (DEHP)
542-88-1	Bis(chloromethyl) ether
75-25-2	Bromoform
106-99-0	1,3-Butadiene
156-62-7	Calcium cyanamide
105-60-2	Caprolactam
133-06-2	Captan
63-25-2	Carbaryl
75-15-0	Carbon disulfide
56-23-5	Carbon tetrachloride
463-58-1	Carbonyl sulfide
120-80-9	Catechol
133-90-4	Chloramben
57-74-9	Chlordane
7782-50-5	Chlorine
79-11-8	Chloroacetic acid
532-27-4	2-Chloroacetophenone
108-90-7	Chlorobenzene
510-15-6	Chlorobenzilate

United States Federal Hazardous Air Pollutants (Continued)

CAS Number	Chemical Name
67-66-3	Chloroform
107-30-2	Chloromethyl methyl ether
126-99-8	Chloroprene
1319-77-3	Cresol/Cresylic acid (mixed isomers)
95-48-7	o-Cresol
108-39-4	m-Cresol
106-44-5	p-Cresol
98-82-8	Cumene
94-75-7	2,4-D (including salts and esters)
72-55-9	DDE
334-88-3	Diazomethane
132-64-9	Dibenzofuran
96-12-8	1,2-Dibromo-3-chloropropane
84-74-2	Dibutyl phthalate
106-46-7	1,4-Dichlorobenzene
91-94-1	3,3'-Dichlorobenzidine
111-44-4	Dichloroethyl ether (Bis[2-chloroethyl]ether)
542-75-6	1,3-Dichloropropene
62-73-7	Dichlorvos
111-42-2	Diethanolamine
121-69-7	N,N-Dimethylaniline
64-67-5	Diethyl sulfate
119-90-4	3,3'-Dimethoxybenzidine
60-11-7	4-Dimethylaminoazobenzene
119-93-7	3,3'-Dimethylbenzidine
79-44-7	Dimethylcarbamoyl chloride
68-12-2	Dimethylformamide
57-14-7	1,1-Dimethylhydrazine
131-11-3	Dimethyl phthalate
77-78-1	Dimethyl sulfate
N/A	4,6-Dinitro-o-cresol (including salts)
51-28-5	2,4-Dinitrophenol
121-14-2	2,4-Dinitrotoluene
123-91-1	1,4-Dioxane (1,4-Diethyleneoxide)
122-66-7	1,2-Diphenylhydrazine
106-89-8	Epichlorohydrin (l-Chloro-2,3-epoxypropane)
106-88-7	1,2-Epoxybutane
140-88-5	Ethyl acrylate
100-41-4	Ethyl benzene
51-79-6	Ethyl carbamate (Urethane)

United States Federal Hazardous Air Pollutants (Continued)

CAS Number	Chemical Name
75-00-3	Ethyl chloride (Chloroethane)
106-93-4	Ethylene dibromide (Dibromoethane)
107-06-2	Ethylene dichloride (1,2-Dichloroethane)
107-21-1	Ethylene glycol
151-56-4	Ethylene imine (Aziridine)
75-21-8	Ethylene oxide
96-45-7	Ethylene thiourea
75-34-3	Ethylidene dichloride (1,1-Dichloroethane)
50-00-0	Formaldehyde
76-44-8	Heptachlor
118-74-1	Hexachlorobenzene
87-68-3	Hexachlorobutadiene
77-47-4	Hexachlorocyclopentadiene
67-72-1	Hexachloroethane
822-06-0	Hexamethylene diisocyanate
680-31-9	Hexamethylphosphoramide
110-54-3	Hexane
302-01-2	Hydrazine
7647-01-0	Hydrochloric acid (Hydrogen chloride [gas only])
7664-39-3	Hydrogen fluoride (Hydrofluoric acid)
123-31-9	Hydroquinone
78-59-1	Isophorone
N/A	Lindane (all isomers)
108-31-6	Maleic anhydride
67-56-1	Methanol
72-43-5	Methoxychlor
74-83-9	Methyl bromide (Bromomethane)
74-87-3	Methyl chloride (Chloromethane)
71-55-6	Methyl chloroform (1,1,1-Trichloroethane)
78-93-3	Methyl ethyl ketone (2-Butanone)
60-34-4	Methyl hydrazine
74-88-4	Methyl iodide (Iodomethane)
108-10-1	Methyl isobutyl ketone (Hexone)
624-83-9	Methyl isocyanate
80-62-6	Methyl methacrylate
1634-04-4	Methyl tert-butyl ether
101-14-4	4,4'-Methylenebis(2-chloroaniline)
75-09-2	Methylene chloride (Dichloromethane)
101-68-8	4,4'-Methylenediphenyl diisocyanate (MDI)
101-77-9	4,4'-Methylenedianiline

United States Federal Hazardous Air Pollutants (Continued)

CAS Number	Chemical Name
91-20-3	Naphthalene
98-95-3	Nitrobenzene
92-93-3	4-Nitrobiphenyl
100-02-7	4-Nitrophenol
79-46-9	2-Nitropropane
684-93-5	N-Nitroso-N-methylurea
62-75-9	N-Nitrosodimethylamine
59-89-2	N-Nitrosomorpholine
56-38-2	Parathion
82-68-8	Pentachloronitrobenzene (Quintobenzene)
87-86-5	Pentachlorophenol
108-95-2	Phenol
106-50-3	p-Phenylenediamine
75-44-5	Phosgene
7803-51-2	Phosphine
7723-14-0	Phosphorus
85-44-9	Phthalic anhydride
1336-36-3	Polychlorinated biphenyls (Aroclors)
1120-71-4	1,3-Propane sultone
57-57-8	beta-Propiolactone
123-38-6	Propionaldehyde
114-26-1	Propoxur (Baygon)
78-87-5	Propylene dichloride (1,2-Dichloropropane)
75-56-9	Propylene oxide
75-55-8	1,2-Propylenimine (2-Methylaziridine)
91-22-5	Quinoline
106-51-4	Quinone (p-Benzoquinone)
100-42-5	Styrene
96-09-3	Styrene oxide
1746-01-6	2,3,7,8-Tetrachlorodibenzo-p-dioxin
79-34-5	1,1,2,2-Tetrachloroethane
127-18-4	Tetrachloroethylene (Perchloroethylene)
7550-45-0	Titanium tetrachloride
108-88-3	Toluene
95-80-7	Toluene-2,4-diamine
584-84-9	2,4-Toluene diisocyanate
95-53-4	o-Toluidine
8001-35-2	Toxaphene (chlorinated camphene)
120-82-1	1,2,4-Trichlorobenzene
79-00-5	1,1,2-Trichloroethane

United States Federal Hazardous Air Pollutants (Continued)

CAS Number	Chemical Name
79-01-6	Trichloroethylene
95-95-4	2,4,5-Trichlorophenol
88-06-2	2,4,6-Trichlorophenol
121-44-8	Triethylamine
1582-09-8	Trifluralin
540-84-1	2,2,4-Trimethylpentane
108-05-4	Vinyl acetate
593-60-2	Vinyl bromide
75-01-4	Vinyl chloride
75-35-4	Vinylidene chloride (1,1-Dichloroethylene)
1330-20-7	Xylene (mixed isomers)
95-47-6	o-Xylene
108-38-3	m-Xylene
106-42-3	p-Xylene
N/A	Antimony Compounds[a]
N/A	Arsenic Compounds[a] (inorganic including arsine)
N/A	Beryllium Compounds[a]
N/A	Cadmium Compounds[a]
N/A	Chromium Compounds[a]
N/A	Cobalt Compounds[a]
N/A	Coke Oven Emissions
N/A	Cyanide Compounds[a,b]
N/A	Glycol ethers[c]
N/A	Lead Compounds[a]
N/A	**Manganese Compounds**[a]
N/A	Mercury Compounds[a]
N/A	Fine mineral fibers[d]
N/A	Nickel Compounds[a]
N/A	Polycyclic Organic Matter[e]
N/A	Radionuclides (including radon)[f]
N/A	Selenium Compounds[a]

[a] For all listings above which contain the word "compounds" and for glycol ethers, the following applies: Unless otherwise specified, these listings are defined as including any unique chemical substance that contains the named chemical (i.e., antimony, arsenic, etc.) as part of that chemical's infrastructure.

[b] X'CN where X = H' or any other group where a formal dissociation may occur. For example, KCN or $Ca(CN)_2$.

[c] Includes mono- and di- ethers of ethylene glycol, diethylene glycol, and triethylene glycol $R\text{-}(OCH_2CH_2)_n\text{-}OR'$
where:

n = 1, 2, or 3
R = alkyl or aryl groups
R' = R, H, or groups which, when removed, yield glycol ethers with the structure: $R\text{-}(OCH_2CH_2)_n\text{-}OH$.
Polymers are excluded from the glycol category.

United States Federal Hazardous Air Pollutants (Continued)

[d] Includes mineral fiber emissions from facilities manufacturing or processing glass, rock, or slag fibers (or other mineral derived fibers) of average diameter 1 micrometer or less.

[e] Includes substituted and/or unsubstituted polycyclic aromatic hydrocarbons and aromatic heterocycle compounds, with two or more fused rings, at least one of which is benzenoid in structure. Polycyclic Organic Matter is a mixture of organic compounds containing one or more of these polycyclic aromatic chemicals. Polycyclic Organic Matter is generally formed or emitted during thermal processes including (1) incomplete combustion, (2) pyrolysis, (3) the volatilization, distillation or processing of fossil fuels or bitumens, or (4) the distillation or thermal processing of non-fossil fuels.

[f] A type of atom which spontaneously undergoes radioactive decay.

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MANUALES DEL PROGRAMA DE INVENTARIOS DE EMISIONES DE MEXICO

VOLUMEN II – FUNDAMENTOS DE INVENTARIOS DE EMISIONES

FINAL

Elaborado para:

Asociación de Gobernadores del Oeste
Denver, Colorado

y

El Comité Asesor Binacional

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ACRÓNIMOS

AC	Aseguramiento de Calidad
ARB	Air Resources Board *(Junta de Recursos del Aire)*
Btu	British thermal unit *(unidad térmica británica)*
C	Celsius
CAS	Chemical Abstract Service *(Servicio de Resúmenes Químicos)*
CATEF	California Air Toxics Emission Factor Database *(Base de Datos de California de Factores de Emisión de Compuestos Tóxicos del Aire)*
CC	Control de Calidad
Cd	cadmio
CFC	clorofluorocarburo
CFR	Code of Federal Regulations *(Código de Regulaciones Federales)*
CO	monóxido de carbono
CO_2	dióxido de carbono
COT	compuestos orgánicos totales
COV’s	compuestos orgánicos volátiles
Cu	cobre
CH_4	metano
C	carbono
EtO	óxido de etileno
EU	Estados Unidos
F	Fahrenheit

FIRE	Factor Information Retrieval System *(Sistema de Recuperación de Información sobre Factores)*
g	gramo
Gas LP	gas licuado de petróleo
GOR	gases orgánicos reactivos
GOT	gases orgánicos totales
H_2SO_4	ácido sulfúrico
HAP	hazardous air pollutant *(contaminante peligroso del aire)*
HC	hidrocarburos
HCFC	hidroclorofluorocarburo
HCT	hidrocarburos totales
HDDV	heavy duty diesel vehicle *(vehículo diesel de trabajo pesado)*
HDGV	heavy duty gas vehicle *(vehículo de gas de trabajo pesado)*
HFC	hidrofluorocarburo
Hg	mercurio
hr	hora
kg	kilogramo
km	kilómetro
LDDT	light duty diesel truck *(camión diesel de trabajo ligero)*
LDDV	light duty diesel vehicle *(vehículo diesel de trabajo ligero)*
LDGT	light duty gas truck *(camión de gas de trabajo ligero)*
LDGV	light duty gas vehicle *(vehículo de gas de trabajo ligero)*
MC	motocicleta
Mg	megagramo (i.e., 10^6 g = 1 tonelada métrica)

N_2	nitrógeno
N_2O	óxido nitroso
NH_3	amoníaco
NH_4NO_3	nitrato de amonio
$(NH_4)_2SO_4$	sulfato de amonio
NMHC	hidrocarburos no metano
NMOC	compuestos orgánicos no metano
NMOG	gases orgánicos no metano
NO	óxido nítrico
NO_2	dióxido de nitrógeno
NO_x	óxidos de nitrógeno
O_3	ozono
C_{Org}	carbono orgánico
SAO	sustancias agotadoras del ozono
OH^-	radicales hidroxilo
Pb	plomo
PFC	perfluorocarburo
part.	partículas
PM_{10}	partículas de diámetro aerodinámico igual o inferior a 10 micrómetros
$PM_{2.5}$	partículas de diámetro aerodinámico igual o inferior a 2.5 micrómetros
POTW	publicly owned treatment works *(Obras de Tratamiento de Propiedad Pública)*
ppm	partes por millón
PS	partículas suspendidas
PST	partículas suspendidas totales

SO_2	dióxido de azufre
SO_3	trióxido de azufre
SO_4^{2-}	sulfato
SO_x	óxidos de azufre
U.S. EPA	United States Environmental Protection Agency *(Agencia de Protección Ambiental de los EU)*
UTM	Mercator universal transverso
VMT	vehicle miles traveled *(vehículos millas recorridas)*
μm	micrómetro

PREFACIO

La contaminación del aire puede tener impactos negativos sobre la salud pública cuando su concentración en la atmósfera alcanza niveles significativos. En la mayor parte de las áreas rurales los problemas de calidad del aire se dejan sentir sólo en raras ocasiones mientras que muchos ambientes urbanos con frecuencia registran elevadas concentraciones de contaminantes. Durante los últimos años, México ha tenido un gran crecimiento en la urbanización y en la actividad industrial, lo que ha generado serias preocupaciones acerca de la calidad del aire en diversas regiones del país.

La contaminación del aire resulta de una compleja mezcla de, literalmente, miles de fuentes, que van desde las chimeneas industriales y los vehículos automotores, hasta el uso individual de productos de aseo, limpiadores domésticos y pinturas; incluso la vida animal y vegetal puede desempeñar un papel importante en el problema. Debido a la compleja naturaleza de la contaminación del aire se requieren planes regionales detallados para identificar las fuentes de emisión, así como el desarrollo de métodos para reducir el impacto sobre la salud ocasionado por la exposición a los contaminantes. Entre algunos ejemplos de las actividades de gestión de la calidad del aire se encuentran:

- La aplicación de modelos de calidad del aire
- El examen de las fuentes emisoras de contaminantes para analizar el control de emisiones, cuando así se requiere
- El desarrollo de proyecciones de las emisiones para examinar posibles cambios en la futura calidad del aire
- El análisis de las tendencias de emisión
- El análisis del transporte de las emisiones de una región a otra.

El desarrollo de inventarios de emisión bien fundamentados es un aspecto clave en cada una de estas funciones de gestión de la calidad del aire.

El cálculo de estimaciones de emisión que cumplan con las necesidades de la gestión de la calidad del aire requiere de un desarrollo y refinamiento continuos; los esfuerzos de inventarios “de un solo paso” no son adecuados para el proceso de gestión de la calidad del aire. Para obtener un beneficio de larga duración debe instrumentarse un *programa de inventarios,* de manera que sea posible el desarrollo de estimaciones exactas de las emisiones para todas las regiones geográficas de importancia, que tengan la capacidad de ser refinadas con el paso del tiempo y que puedan aplicarse efectivamente en el proceso de gestión y monitoreo de la calidad del aire. De esta manera, se está desarrollando un conjunto de manuales de inventarios que puedan ser aplicados en todo el país para ayudar a coordinar el desarrollo de estimaciones de emisiones consistentes. Estos manuales han sido diseñados para ser utilizados por las autoridades locales, estatales y federales, así como por consultores privados e industriales. El propósito de estos manuales es ayudar en el proceso de instrumentación del programa de inventarios y en su mantenimiento a lo largo del tiempo, de manera tal que los inventarios de emisiones se puedan desarrollar en ciclos periódicos mejorándolos continuamente.

Los manuales abarcan elementos del programa de inventarios tales como la estimación de emisiones, la planeación del programa, manejo de bases de datos, validación de emisiones y otros temas de importancia. La Figura 1 muestra la serie completa de manuales que serán desarrollados para apoyar un programa de inventarios de largo alcance. A continuación se resume el propósito principal de cada manual.

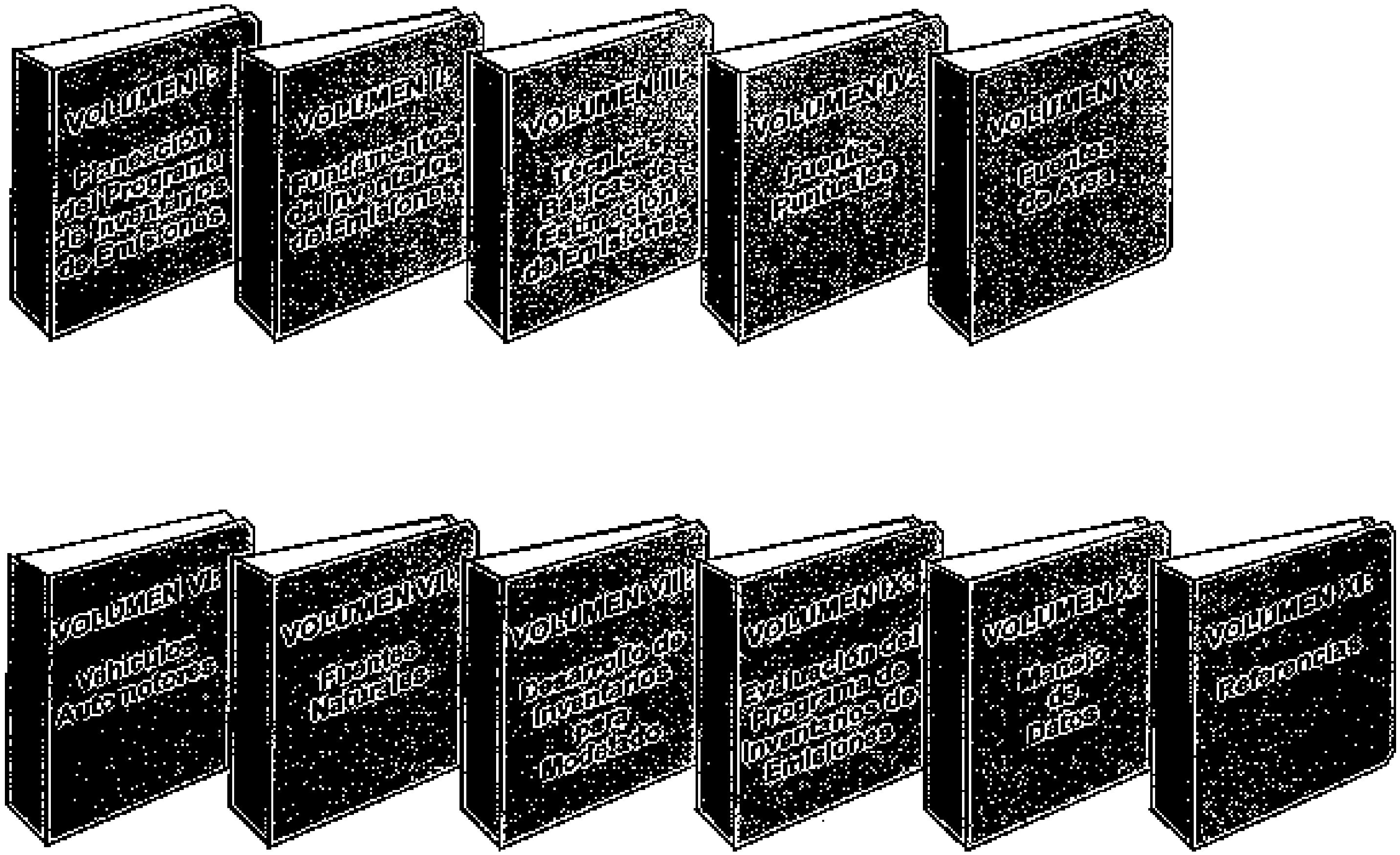


Figura 1. Manuales del Programa de Inventarios de Emisiones de México

Volumen I - Planeación del Programa de Inventarios de Emisiones. Este manual presenta los aspectos de gestión que deben ser considerados en un programa de inventario de emisiones al aire. La planeación del programa no se presenta como una actividad “terminal”, sino más bien como un proceso continuo para asegurar el crecimiento en el largo plazo y el éxito del programa de inventarios. *Temas Clave:* propósito del programa; usos finales del inventario; requerimientos regulatorios; coordinación en los niveles federal, estatal y local; requerimientos de personal y de manejo de datos; identificación y selección de estudios especiales.

Volumen II - Fundamentos de Inventarios de Emisiones. Este manual presenta los fundamentos básicos para el desarrollo de inventarios de emisiones, así como los elementos que son aplicables a los diversos tipos de fuentes (e. g., puntuales y de área), para evitar la necesidad de que sean repetidos en cada volumen. *Temas Clave*: regulaciones aplicables; efectividad de la regla; penetración de la regla; definiciones sobre contaminantes (e. g., cómo excluir de manera adecuada los compuestos volátiles no reactivos); definición de fuentes puntuales y de área; reconciliación de fuentes puntuales y de área.

Volumen III - Técnicas Básicas de Estimación de Emisiones (TEEs). Este documento presenta las TEEs básicas utilizadas para hacer estimaciones de emisiones, incluyendo ejemplos y cálculos como muestra. Por otro lado se identifican las herramientas para inventarios asociadas con cada metodología y se incluyen en el Volumen XI (Referencias). *Temas Clave*: muestreo en la fuente, modelos de emisiones, encuestas, factores de emisión, balance de materiales y extrapolación.

Volumen IV - Fuentes Puntuales. Este manual proporciona guías para elaborar inventarios de emisiones de fuentes puntuales. Incluye una tabla de referencias cruzadas para cada combinación de industria y tipo de dispositivo (e. g., refinación de petróleo y dispositivos de combustión), con una o más de las TEEs presentadas en el Volumen III. *Temas Clave:* tabla de referencias cruzadas; parámetros de chimenea; dispositivos de control; consideraciones de diseño y de proceso; diferencias geográficas y variabilidad en México; aseguramiento y control de calidad (AC/CC); procesos omitidos; referencias de datos y formas para recopilación de datos.

Volumen V - Fuentes de Area (incluyendo fuentes móviles que no circulan por carreteras). Este manual contiene los lineamientos para el desarrollo de inventarios de emisiones de fuentes de área. Además de presentar información general sobre las fuentes de área, se proporciona una tabla de referencias cruzadas entre cada categoría de fuente de área (e. g., aplicación de asfalto) con una o más de las TEEs básicas incluidas en el Volumen **III.** Posteriormente, se discute la información específica para cada categoría de fuente definida en la tabla. *Temas Clave:* categorización y definición de fuentes de área; tabla de referencias cruzadas; factores de control; diferencias geográficas y variabilidad en México; AC/CC; referencias de datos; formas para recopilación de datos (cuestionarios).

Volumen VI - Vehículos Automotores. Debido a que los vehículos automotores son intrínsecamente diferentes a las fuentes puntuales y a las de área, tanto los métodos de estimación disponibles como los datos requeridos son también diferentes. Los modelos han sido las herramientas preferidas para estimar las emisiones de estas complejas fuentes. Muchos de estos modelos utilizan datos de pruebas extensivas aplicables a un país o a una región determinados. Este manual se enfoca principalmente en la fase de desarrollo de datos para la estimación de emisiones de vehículos automotores. *Temas Clave:* métodos de estimación disponibles; datos e información primarios, secundarios y terciarios; clasificación de fuentes; fuentes de factores de emisión; variabilidad geográfica dentro de México, AC/CC.

Volumen VII - Fuentes Naturales. Este manual proporciona los lineamientos para el desarrollo de inventarios de emisiones de fuentes naturales (e. g., compuestos orgánicos volátiles biogénicos [COVs] y óxidos de nitrógeno [NO_x]) en suelos. Además, incluye los aspectos teóricos de los cálculos de emisiones y la discusión de modelos específicos. *Temas*

Clave: clasificación y definición de fuentes; mecanismos de emisión; algoritmos básicos de emisión; determinación de biomasa; desarrollo de datos de uso y cobertura del suelo; ajustes temporales y meteorológicos; enfoques para el cálculo de emisiones.

Volumen VIII - Desarrollo de Inventarios para Modelado. Este manual proporciona los lineamientos para el desarrollo de datos de inventarios que serán utilizados en modelos de calidad del aire, y trata aspectos tales como la localización temporal y espacial, la especiación y la proyección de estimaciones de emisiones. *Temas Clave:* definición de términos de modelado; ajuste estacional; localización temporal y espacial; especiación química y proyecciones (factores de crecimiento y control).

Volumen IX - Evaluación del Programa de Inventarios de Emisiones. Este manual consta de tres partes: AC y CC, análisis de incertidumbre y verificación de emisiones. La parte de AC y CC define el programa global de aseguramiento y control de calidad, y ha sido escrito para complementar los procedimientos de AC y CC para fuentes específicas que se presentan en otros manuales. El análisis de incertidumbre no sólo incluye métodos para evaluar la incertidumbre en las estimaciones de emisiones, sino también para evaluar la incertidumbre en los valores de modelado tales como los perfiles de especiación y los factores de proyección de emisiones. La sección de verificación de emisiones describe varios análisis para evaluar la exactitud de las estimaciones. Los ejemplos incluyen modelos de receptores y análisis de trayectoria, combinados con técnicas específicas para el análisis de datos. *Temas Clave:* descripción de conceptos y definición de términos; protocolo de revisión de inventarios; evaluación de integridad, exactitud y consistencia; TEEs de incertidumbre recomendadas, y metodología aplicable para la verificación de emisiones.

Volumen X - Manejo de Datos. Este manual trata de las necesidades asociadas con los aspectos del manejo de datos del programa nacional de inventarios de emisiones de México. *Temas Clave:* sistemas y herramientas generales para el manejo de datos; sistemas y herramientas de software específicos; sistemas de codificación; confidencialidad; presentación electrónica; frecuencia de actualizaciones, mantenimiento de registros; bases de datos específicas de México y reportes.

Volumen XI - Referencias. Este manual es un compendio de las herramientas que pueden utilizarse en el desarrollo de un programa de inventarios de emisiones. Se incluyen las herramientas citadas para hacer inventarios en los otros manuales (e. g., documentos impresos y electrónicos, así como modelos de computadora).

1.0 INTRODUCCIÓN

Este manual presenta los conceptos fundamentales que sostienen el desarrollo de los inventarios de emisiones. En general, estos conceptos se aplican a todos los inventarios, desde las estimaciones de emisiones a nivel planta, hasta los inventarios para modelado regional a gran escala. Estos conceptos fundamentales representan la información básica antecedente que debe establecerse antes de iniciar la verdadera recopilación de datos y las estimaciones de emisiones. Algunos conceptos se usarán en todos los tipos de inventarios, mientras que otros sólo se usarán en ciertos tipos de manera limitada. Los detalles específicos variarán tanto para los inventarios individuales como para el nivel de inventario total. Sin embargo, estos conceptos fundamentales deben considerarse en cualquier inventario para asegurar que éste se lleve a cabo exitosamente.

El resto de este manual está organizado de la siguiente manera:

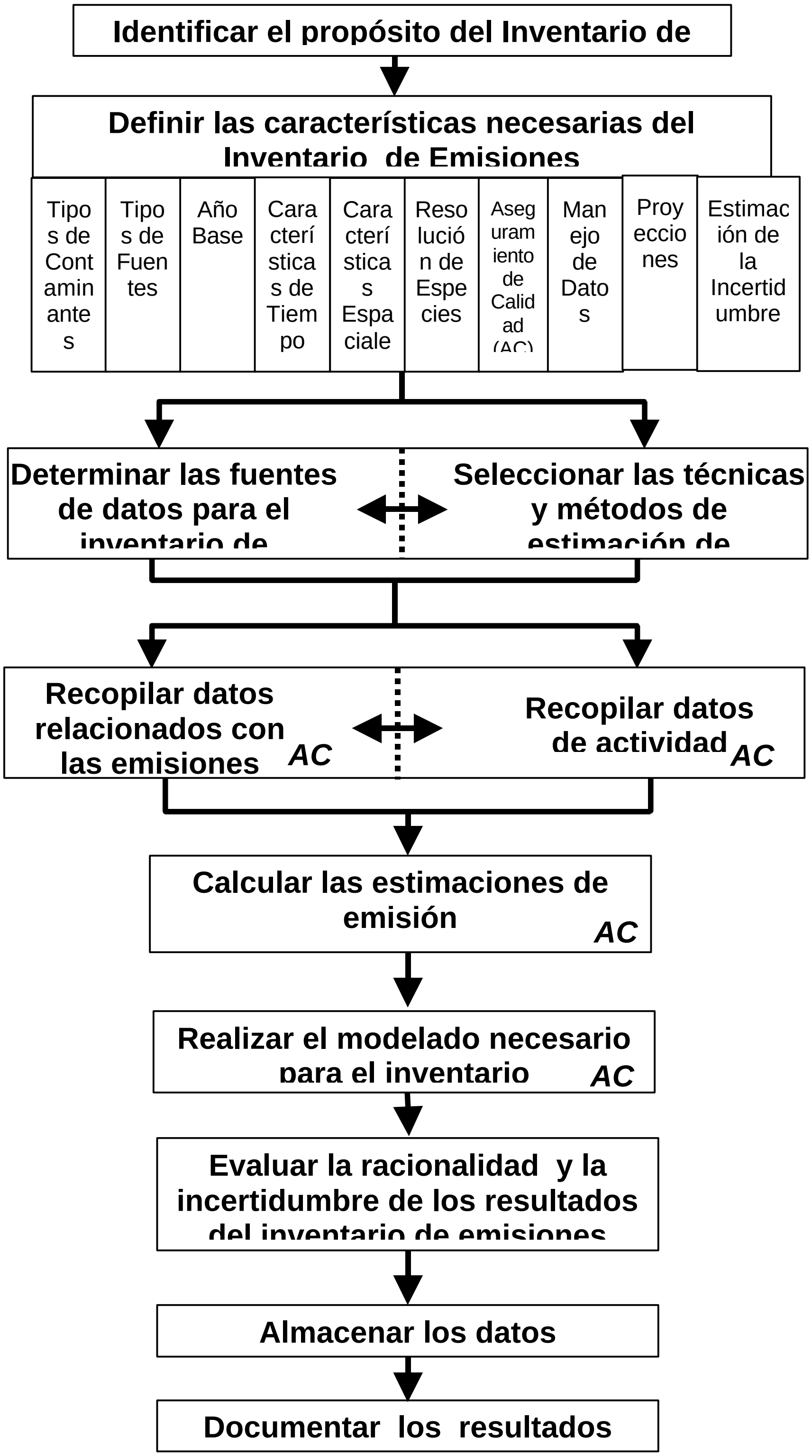
- La Sección 2.0 presenta los pasos técnicos para hacer un inventario de emisiones y los describe brevemente;
- La Sección 3.0 se refiere a la importancia de identificar los propósitos de un inventario de emisiones;
- La Sección 4.0 da una descripción detallada de varios contaminantes de un inventario;
- La Sección 5.0 presenta las diversas categorías de fuentes en un inventario;
- La Sección 6.0 presenta otras características necesarias de un inventario;
- La Sección 7.0 presenta el concepto de cómo mejorar un inventario de emisiones por iteración y
- La Sección 8.0 contiene referencias.

2.0 PASOS TÉCNICOS PARA DESARROLLAR UN INVENTARIO DE EMISIONES

La Figura 2-1 presenta los pasos técnicos que se siguen durante el desarrollo de un inventario de emisiones. En los siguientes párrafos se describen brevemente cada uno de estos pasos y se identifican otros manuales de esta serie que se pueden consultar para obtener mayor información. Se pueden hallar datos adicionales en los documentos de la U.S. Environmental Protection Agency (U.S. EPA) (U.S. EPA, 1991a; EIIP, 1997).

Identificar el propósito de un inventario de emisiones. Como primer paso técnico en el desarrollo de un inventario resulta fundamental el identificar su propósito o uso final. El propósito global ayudará a determinar muchos de los pasos siguientes. Si el propósito no se identifica con claridad es posible que el inventario terminado no cumpla con las necesidades requeridas. Por ejemplo, los datos necesarios para desarrollar un inventario para modelado son significativamente diferentes de aquellos para otros tipos de inventarios. También deben considerarse los usos futuros del inventario así como su empleo a una mayor escala geográfica. En la Sección 3.0 de este manual se puede encontrar una discusión más detallada de este paso.

Definir las características necesarias del inventario de emisiones. Cada inventario de emisiones tiene varias características que describen su naturaleza fundamental (e. g. tipos de contaminantes, tiposde fuentes, año base, etc.). En la Figura 2-1 se presentan diez características separadas de un inventario. Algunos inventarios pueden requerir el desarrollo de actividades para sólo algunas de estas características, mientras que otros pueden necesitarlas para todas. La mayor parte de estas características serán determinadas por el propósito del inventario (e. g., un inventario de ozono deberá incluir a los GOT, el CO y los NO_x como contaminantes inventariados). Por lo tanto será necesario tomar decisiones para definir cada una de las caacterísticas del inventario . En las secciones 4.0, 5.0 y 6.0 se da información adicional sobre las características de los inventarios de emisiones.


Identificar el propósito del Inventario de
Definir las características necesarias del Inventario de Emisiones
Tipos de Contaminantes
Tipos de Fuentes
Año Base
Características de Tiempo
Características Espaciale
Resolución de Especies
Aseguramiento de Calidad (AC)
Manejo de Datos
Proyecciones
Estimación de la Incertidumbre
Determinar las fuentes de datos para el inventario de
Seleccionar las técnicas y métodos de estimación de
Recopilar datos relacionados con las emisiones AC
Recopilar datos de actividad AC
Calcular las estimaciones de emisión AC
Realizar el modelado necesario para el inventario AC
Evaluar la racionalidad y la incertidumbre de los resultados del inventario de emisiones
Almacenar los datos
Documentar los resultados

Determinar las fuentes de datos para el inventario y seleccionar las técnicas y métodos de estimación de las emisiones. Una vez que se han establecido las características que se requieren es necesario determinar las fuentes de datos relacionados con las emisiones, así como seleccionar las técnicas y métodos más adecuados para estimar éstas. Por lo general estos dos pasos están interrelacionados. En algunos casos, la disponibilidad de los datos determinará qué métodos de estimación son factibles. En otros casos, una cierta técnica que se desée usar determinará el tipo de datos que deben recopilarse. Las fuentes de datos se discuten en detalle en los volúmenes IV-VII de esta serie de manuales *(Desarrollo de Inventarios de Fuentes Puntuales, de Fuentes de Área, de Vehículos Automotores y de Fuentes Naturales)*. Las técnicas específicas de estimación de emisiones se describen en el Volumen III de la serie (*Técnicas Básicas de Estimación de Emisiones).*

Recopilar datos relacionados con las emisiones y datos de actividad. Después de identificar las fuentes de datos y las metodologías de estimación se deben recopilar los datos relevantes. Los datos relacionados con las emisiones incluyen factores de emisión, datos de muestreos en la fuente y parámetros de los modelos de factores de emisión. Es posible que algunos de los datos relacionados con las emisiones ya existan mientras que otros necesiten desarrollarse para usarlos en un inventario específico. Por lo general los datos de actividad incluyen información sobre las horas de operación, el consumo de combustibles y otras medidas de la actividad de los procesos para fuentes identificadas. Debido a que tanto los datos relacionados con las emisiones como los datos de actividad son necesarios para estimar las emisiones, con frecuencia estos dos pasos se ejecutan de manera simultánea. Ambos tipos de datos se discuten con detalle en los volúmenes IV – VII de la serie de manuales *(Desarrollo de Inventarios de Fuentes Puntuales, Fuentes de Área, Vehículos Automotores y Fuentes Naturales)*.

Calcular las estimaciones de emisiones. Una vez que se han recopilado todos los datos necesarios se hacen los cálculos de emisión específicos. Estos cálculos se realizan conforme a la técnica o metodología de estimación de emisiones seleccionada. Por lo general estos cálculos de emisión se hacen de manera electrónica, en particular para los inventarios de emisiones más complejos. Algunos detalles relacionados con el cálculo de emisiones se encuentran en los volúmenes IV-VII de esta serie de manuales *(Desarrollo de Inventarios de Fuentes Puntuales, de Fuentes de Área, de Vehículos Automotores y de Fuentes Naturales)*. Otros temas también relacionados con el cálculo de emisiones, como la eficacia y la penetración de la regla, también se discuten en el Volumen III de esta serie de manuales *(Técnicas Básicas de Estimación de Emisiones)*. La eficacia de la regla cuantifica la habilidad de un programa regulatorio para lograr las reducciones requeridas en las emisiones mientras que la penetración de la regla mide el grado en el que una regulación cubre las emisiones de todas las fuentes dentro de una cierta categoría.

Aplicar la modelación necesaria. Después de que se han calculado las emisiones de ser necesario se aplica la modelación del inventario. Esta modelación puede incluír la distribución espacial y temporal, la resolución de las especies y las proyecciones de las emisiones. En el Volumen VIII de esta serie *(Desarrollo de Modelos de Inventarios)* se presenta una discusión más completa sobre modelación.

Aseguramiento de la Calidad. El aseguramiento de la calidad (AC) no se incluye en un cuadro específico en la Figura 2-1 debido a que es un elemento integral de todo el proceso de desarrollo de inventarios de emisiones. El aseguramiento de la calidadse debe hacerse a lo largo de todo este proceso. En particular, se debe empezar con la recopilación de los datos relacionados con las emisiones y con los datos de actividad, continuar durante los cálculos de emisiones y durante el proceso completo de modelado. Este concepto se indica con múltiples "marcas de AC" en la Figura 2-1. El aseguramiento de la calidad se discute en el Volumen IX de esta serie de manuales *(Evaluación del Programa de Inventarios de Emisiones).*

Evaluar la racionalidad y la incertidumbre de los resultados de los inventario de emisiones. Después de que se ha terminado el inventario es necesario examinarlo y evaluar la racionalidad y la incertidumbre de los resultados. En este punto, las comparaciones con las expectativas, con la experiencia previa y con los inventarios similares que se hayan hecho con anterioridad para otras regiones geográficas, pueden ser valiosas. Asimismo, al examinar la incertidumbre del inventario se revelarán sus áreas de fortaleza así como aquellas que pudieran ser el punto focal de futuras mejoras. Estos aspectos se discuten en el Volumen IX de esta serie de manuales *(Evaluación del Programa de Inventarios de Emisiones)*.

Almacenamiento electrónico de datos. Uno de los pasos finales del desarrollo de un inventario de emisiones es el almacenamiento electrónico del inventario y de los datos relacionados. Se debe mantener la integridad del inventario de emisiones como la base para el desarrollo de inventarios en el futuro. El almacenamiento electrónico de datos se trata en el Volumen X de esta serie de manuales (*Manejo de Datos*).

Documentar resultados. El último paso del desarrollo de un inventario de emisiones es la documentación de resultados. Además de los resultados reales del inventario la documentación también debe incluir las metodologías, datos y suposiciones que se usaron en el proceso de desarrollo. En general, se debe proporcionar información suficiente para permitir que otras partes interesadas reproduzcan y analicen los resultados. La documentación del inventario sirve como una referencia importante para los futuros inventarios.

Como se puede ver en las breves descripciones anteriores los Manuales del Programa de Inventarios de Emisiones de México brindan un amplio soporte para los pasos técnicos asociados con el desarrollo de inventarios de emisiones.

3.0 PROPÓSITO DE UN INVENTARIO DE EMISIONES

Como se muestra en la Figura 2-1 el primer paso técnico en el desarrollo de un inventario de emisiones es la identificación de su propósito. La definición del propósito del inventario es crucial para el éxito de su desarrollo y es importante que no se pase por alto en la prisa por iniciar las actividades. A la larga, la naturaleza general de un inventario de emisiones así como la mayor parte de sus características son determinadas por su propósito. En muchos casos se calculará un inventario para satisfacer dos o tres propósitos principales.

El propósito que se debe lograr con un inventario de emisiones definirá tanto sus características como los pasos subsecuentes para la recopilación de datos y un modelado potencial. Por esta razón es crítico llegar a un acuerdo sobre todos los usos potenciales del inventario. También es importante identificar el propósito del inventario antes de iniciar cualquier actividad importante. De otra manera, es probable que parte del trabajo realizado carezca de valor para el inventario.

Mas aun, es fundamental que el propósito de un inventario de emisiones se identifique **explícitamente**. Este propósito es el “principio rector” del inventario y define todos los pasos apropiados que se deben seguir durante el proceso. Una evaluación completa de los propósitos del inventario asegurará que éste se lleve a cabo siguiendo una ruta consistente con los usos que se le pretenden dar. En general, los propósitos de un inventario se describen en un documento de planeación que se prepara al principio de los trabajos. A veces este documento se conoce como plan de trabajo o como protocolo de inventario. Además del propósito del inventario el documento de planeación incluye una descripción de las características más relevantes del inventario así como los pasos técnicos propuestos. Este documento constituye una guía para los responsables del cálculo del inventario y les ayuda a asegurar que su desarrollo sea exitoso.

Existen muchos propósitos diferentes para un inventario los que varían dependiendo de las necesidades y las circunstancias específicas. Por ejemplo, el propósito de un inventario para una sola planta manufacturera es muy diferente al propósito de un inventario regional a gran escala con fines de modelado. El inventario para la planta manufacturera puede usarse para determinar el grado de cumplimiento con regulaciones específicas, mientras que el inventario regional para modelado puede hacerse para soportar una evaluación de la calidad del aire debida al impacto de varias fuentes. Algunas de las razones mas comunes para desarrollar inventarios incluyen:

- Estimar los impactos en la calidad del aire a través de estudios de modelado;
- Determinar la aplicabilidad de las licencias y otros requerimientos regulatorios;
- Determinar el grado de cumplimiento de una fuente con las condiciones de la licencia;
- Estimar los cambios en las emisiones de la fuente para las aplicaciones de la licencia;
- Determinar las especificaciones técnicas del equipo de control de emisiones;
- Rastrear los niveles de emisión en el tiempo;
- Identificar las contribuciones de la emisión por categoría de fuente o por fuente específica;
- Identificar las oportunidades potenciales de canje de emisiones;
- Cumplir con los requerimientos de reporte de emisiones y
- Cumplir con las regulaciones que requieren el desarrollo de inventarios de emisiones muy completos.

En el largo plazo, todas las razones anteriores para desarrollar inventarios de emisiones contribuirán con el proceso de gestión de la calidad del aire.

Como se muestra en la Figura 3-1, la identificación del propósito del inventario requiere de la información y la opinión de muchas personas. En primer lugar, la información de los usuarios finales del inventario es crucial. Con frecuencia, el uso final que se desea así como la facilidad de uso son factores significativos que deben considerarse al desarrollar un inventario de emisiones. Más aun, debido a que los inventarios desempeñan un papel fundamental en la planeación de la calidad del aire se debe solicitar información inicial por parte de las agencias regulatorias y gubernamentales responsables de la calidad del aire y de las políticas relacionadas con ésta. En muchos casos, las necesidades y objetivos de estas agencias serán la fuerza motora clave que se encuentra detrás de un inventario específico. Las regulaciones más importantes sobre la calidad del aire en México se presentan en el Volumen I de esta serie de manuales, *Planeación del Programa de Inventarios de Emisiones*. Finalmente, la participación de quienes desarrollarán el inventario de emisiones, incluyendo al gobierno, la industria y los contratistas será importante. Estos individuos deben comprender con claridad los propósitos del inventario para que sus resultados cumplan con todas las necesidades. Al final, la síntesis de las ideas de todos los participantes definirá los propósitos del inventario.

Figura 3-1. Identificación del Propósito del Inventario

Además, el propósito de un inventario de emisiones debe referirse a las necesidades presentes **y** futuras de la calidad del aire. Se debe hacer un intento para identificar las necesidades futuras de calidad del aire al determinar el alcance del inventario. Algunas veces puede ser difícil proyectar estas necesidades futuras. En otros casos, sin embargo, estas necesidades serán mas claras y con una pequeña ampliación de los recursos se puede aumentar de manera significativa la utilidad final del inventario.

La determinación de los propósitos de un inventario de emisiones no tienen que requerir un gran esfuerzo. Una cantidad de tiempo y de esfuerzo razonables invertidos al principio del proceso para identificar los usos y establecer el propósito del inventario, ayudará a asegurar el desarrollo de datos y de información útiles. Una vez que los propósitos han sido identificados de manera explícita, es mucho más probable que el inventario resultante satisfaga cada uno de los usos esperados del conjunto de datos.

4.0 CONTAMINANTES DE UN INVENTARIO

En general, un contaminante del aire puede definirse como cualquier sustancia que al ser liberada en la atmósfera altera la composición natural del aire y puede ocasionar efectos adversos en los seres humanos, los animales, la vegetación o los materiales. Los propósitos que se establezcan para un inventario de emisiones van a determinar los contaminantes que deben ser incluidos. Por ejemplo, un inventario de contaminantes criterio incluiría gases orgánicos totales (GOT), monóxido de carbono (CO), óxidos de nitrógeno (NO_x), óxidos de azufre (SO_x), partículas de diámetro aerodinámico inferior a 10 micrómetros (PM_{10}) y plomo (Pb). En cambio, un inventario de ozono se enfocaría en sus precursores es decir, GOT, CO y NO_x. Finalmente, un inventario de visibilidad incluiría las emisiones de SO_x, de NO_x, de partículas finas (de diámetro aerodinámico inferior a 2.5 micrómetros - $PM_{2.5}$), de carbono elemental (CE), de carbono orgánico (C_{org}) y de amoniaco (NH_3).

Una vez que se ha determinado cuales son los contaminantes que deben ser incluidos en el inventario es importante definir claramente a cada uno de ellos. Esto es importante para que todos los datos recopilados sean consistentes y den resultados exactos sobre la emisión del contaminante deseado. Aunque existe una “terminología convencional para los contaminantes” se recomienda que todos sean claramente definidos por escrito al inicio del inventario con el fin de reducir confusiones respecto a los contaminantes por inventariar. Por otra parte, muchos contaminantes se definen por sus nombres químicos los que con frecuencia pueden tener sinónimos y nombres comerciales. A menudo los fabricantes dan nombres comerciales a las mezclas buscando así ocultar información protegida por derechos de marca, por lo que los mismos componentes pueden tener varios nombres comerciales. Por ejemplo, Freón 11 es el nombre comercial del triclorofluorometano (CFC-11). Para garantizar la identificación apropiada de un compuesto químico se debe consultar el número que le corresponde en la clasificación del Chemical Abstract Service (CAS) junto con la lista de sinónimos. Finalmente, supongamos que sólo se dice que un inventario debe incluir emisiones de “partículas". Entonces, diferentes personas podrían calcular estimaciones de emisiones de partículas totales, de PM_{10} ó de $PM_{2.5}$. Para convertir estos diferentes tipos de emisiones de "partículas" a la base común deseada se requeriría mucho tiempo y esfuerzo adicionales. Al definir de manera explícita los contaminantes desde el inicio del inventario se podría evitar este desperdicio.

Las secciones 4.1 a 4.9 proporcionan definiciones detalladas de los contaminantes o de las categorías de contaminantes que es común incluir en los inventarios.

4.1 Gases Orgánicos Totales / Gases Orgánicos Reactivos

Existen muchas fuentes que emiten gases orgánicos a la atmósfera. Sin embargo, en general los gases orgánicos son emitidos por fuentes de combustión o de evaporación. De manera colectiva, los compuestos comprendidos en las emisiones de hidrocarburos se conocen como gases orgánicos totales (GOT). Este concepto incluye a todos los compuestos carbonáceos excepto carbonatos, carburos metálicos, CO, dióxido de carbono (CO_2) y ácido carbónico. A veces se conoce a los GOT como compuestos orgánicos totales (COT) aunque sólo en el contexto de calidad del aire.

Algunos de los compuestos en esta categoría de contaminantes incluyen algunos aldehídos como el formaldehído y el acetaldehído que son irritantes del tracto respiratorio y compuestos químicos carcinogénicos. El benceno, que también es carcinogénico, puede estar presente. Las exposiciones de corta duración a estos compuestos puede ocasionar irritación del tracto respiratorio. También existe el potencial para un incremento en los casos de cáncer cuando hay exposiciones largas a algunas especies de GOT.

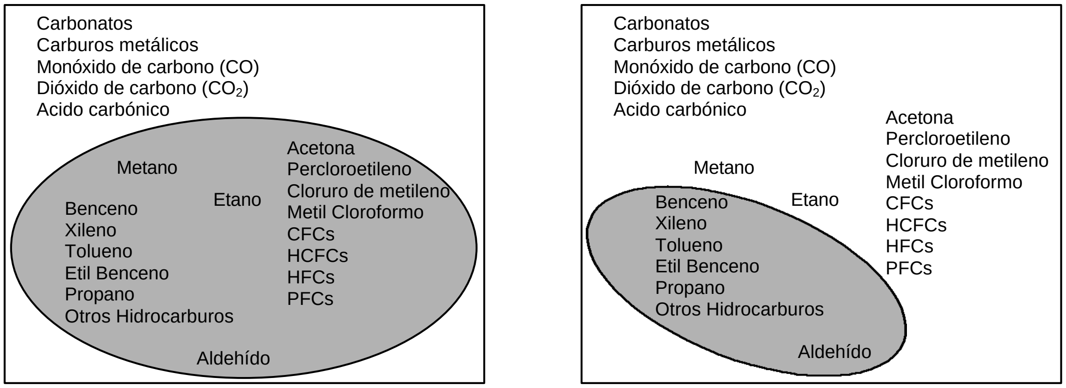
Desde una perspectiva de calidad del aire es importante señalar que algunos de los gases orgánicos totales que se emiten a la atmósfera o no tienen reactividad fotoquímica o la tienen muy baja. En consecuencia, no participan en la formación de ozono. La EPA ha identificado a los siguientes compuestos cuya reactividad fotoquímica es nula o despreciable:

- Metano;
- Etano;
- Acetona;
- Percloroetileno (tetracloroetileno);
- Cloruro de metileno (diclorometano);
- Metil cloroformo (1,1,1- tricloroetano);
- Varios clorofluorocarburos (CFCs);
- Varios hidroclorofluorocarburos (HCFCs);
- Varios hidrofluorocarburos (HFCs) y
- Varios perfluorocarburos (PFCs).

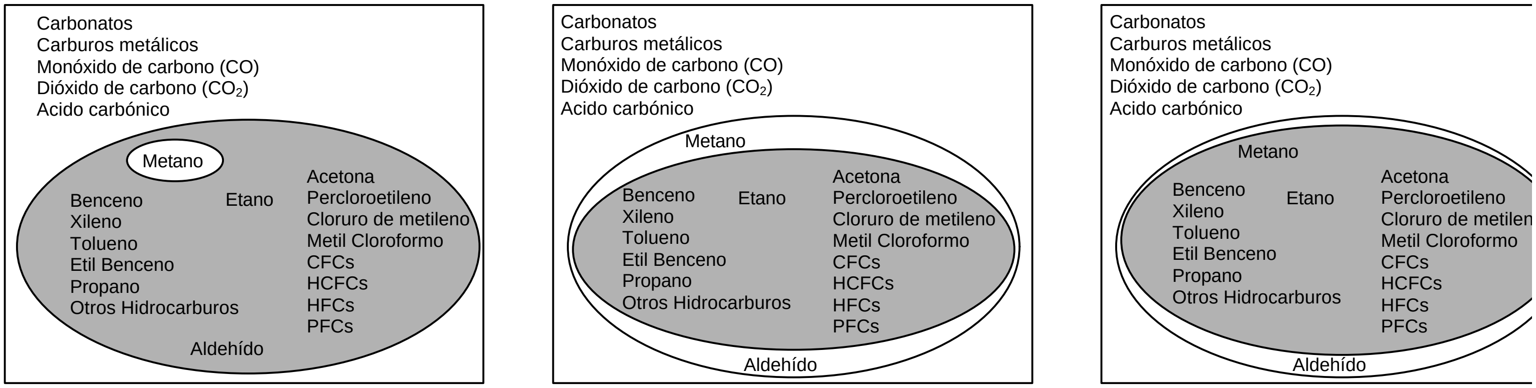
Se puede encontrar información adicional sobre estos compuestos así como un listado de otros compuestos menos comunes que tampoco son reactivos en *el U.S. Code of Federal Regulations* (CFR, 1997). Este listado de compuestos no reactivos se actualiza periódicamente a medida que la EPA designa nuevos compuestos. La lista actual se presenta en el Apéndice A.

Los compuestos químicos considerados reactivos se conocen como gases orgánicos reactivos (GOR). Entonces, por definición los GOR son un subconjunto de los GOT. Los GOR son gases fotoquímicamente reactivos compuestos de hidrocarburos que pueden contribuir a la formación de contaminación fotoquímica.

A veces los GOR se denominan compuestos orgánicos volátiles (COVs). Los factores de emisión publicados en el AP-42 (AP-42, 1995) de la EPA se presentan casi exclusivamente para COVs. Otras definiciones de hidrocarburos que en ocasiones aparecen en la literatura sobre calidad del aire y sobre factores de emisión incluyen la de gases orgánicos no metano (NMOG, por sus siglas en inglés), hidrocarburos no metano (NMHC, por sus siglas en inglés), hidrocarburos totales (THC, por sus siglas en inglés) e hidrocarburos (HC).La Figura 4-1 ilustra gráficamente la relación entre estas varias definiciones de hidrocarburos. Las áreas sombreadas indican cuales son los compuestos incluidos en cada definición. En general, las definiciones para NMOG, NMHC, THC e HC se usan sólo para procesos de combustión.



GOT ó COT **GOR, COR VOC**



NMOG ó NMOC **NMHC** **THC ó HC**

Figura 4-1. Descripción de las Definiciones de Hidrocarburos

Se recomienda que se hagan estimaciones de emisiones tanto para GOT como para GOR de manera que el usuario pueda tener flexibilidad para escoger el grupo de contaminantes que se necesiten para un inventario con un propósito particular. Si se usan factores de emisión para otros hidrocarburos menos comunes se deben ajustar dichos factores a los GOT y los GOR para tener en cuenta la presencia o ausencia de metano, etano y aldehídos como se muestra en la Figura 4-1. En un principio podría parecer innecesario inventariar los GOT pero el cálculo de sus estimaciones de emisión puede facilitar la presentación de las emisiones como gases con efecto invernadero y como compuestos tóxicos del aire. Además, las emisiones de GOT se adaptan mejor para usarse en los modelos tridimensionales de cuadrícula que se emplean para simular la formación de ozono y de aerosoles. Esto se debe a que estos modelos contienen mecanismos químicos que usan estimaciones de emisión basadas en perfiles de GOT especiados.

4.2 Monóxido de Carbono

El monóxido de carbono (CO) es un gas incoloro e inodoro que resulta de la combustión incompleta de combustibles fósiles. Una cantidad significativa del CO emitido en áreas urbanas es producida por los vehículos automotores. Parece que cuando no fumadores se exponen a niveles de CO inferiores a 15 a 20 ppm no se producen efectos adversos sobre la salud. A niveles superiores a éstos la carboxihemoglobina en la sangre se eleva causando efectos adversos en el sistema nervioso y en el cardiovascular. Por otro lado y para empezar, los fumadores tienen un nivel más alto de carboxihemoglobina por lo que pueden experimentar efectos adversos aun a niveles ambientales inferiores de CO.

4.3 Oxidos de Nitrógeno

El término óxidos de nitrógeno (NO_x) es un concepto amplio que incluye al ácido nítrico (NO), dióxido de nitrógeno (NO_2) y otros óxidos de nitrógeno menos comunes. En general estos compuestos son formados durante los procesos de combustión, son precursores del ozono, y normalmente son eliminados de la atmósfera por deposición seca y húmeda.

No se considera que el NO cause efectos adversos sobre la salud en concentraciones ambientales; sin embargo, la exposición al NO_2 puede ocasionar irritación del tracto respiratorio y, si la exposición se prolonga, puede causar decrementos en la función pulmonar.

El NO_x más importante que se produce en la combustión es el NO. Sin embargo, al mismo tiempo es común que se emitan NO_2 y otros óxidos de nitrógeno los que pueden o no distinguirse en los datos disponibles de muestreos. En general, estos compuestos evolucionan constantemente siendo el NO_2 el último producto de oxidación emitido o formado corriente abajo del proceso de combustión. La convención general que se sigue consiste en reportar las distinciones de los contaminantes siempre que esto sea posible pero reportar los NO_x totales en base al peso molecular del NO_2.

Los NO_x se forman en la combustión externa de dos maneras principales: los NO_x térmicos y los NO_x provenientes del combustible. Los NO_x térmicos se forman cuando el nitrógeno y el oxígeno en el aire de combustión reaccionan a altas temperaturas en la flama. Los NO_x del combustible se forman por la reacción de cualquier nitrógeno contenido en el combustible con el aire de combustión. Los NO_x térmicos son la fuente principal de NO_x en la combustión de gas natural y de aceites ligeros y el factor más significativo que afecta su formación es la temperatura de la flama. Un nivel excesivo de aire y la temperatura del aire de combustión también son factores que influyen en la formación de los NO_x térmicos. La formación de los NO_x del combustible depende de su contenido de nitrógeno y puede constituir hasta el 50 por ciento de las emisiones de NO_x de la combustión de productos ricos en nitrógeno, sobre todo carbón y aceites pesados.

4.4 Óxidos de Azufre

Óxidos de azufre (SO_x) es un término general que se refiere al dióxido de azufre (SO_2) y otros óxidos de este elemento. El SO_2 es un gas incoloro de olor fuerte que se forma en la combustión de combustibles fósiles que contienen azufre. Los óxidos de azufre son compuestos irritantes del sistema respiratorio que pueden ocasionar una respuesta similar al asma o bien agravar una condición asmática preexistente. Los síntomas de una exposición a altas concentraciones ambientales pueden incluir tos, goteo de la nariz y falta de aliento. Estas respuestas pueden ser más severas en fumadores.

Las plantas termoeléctricas que usan carbón o combustóleo con alto contenido de azufre pueden ser fuentes importantes de SO_2. Algunas veces el SO_2 emitido se oxida a trióxido de azufre (SO_3) y después a ácido sulfúrico ($H_2 SO_4$) o a sulfatos (SO_4^{2-}) como aerosoles. La convención general consiste en reportar las distinciones de los contaminantes siempre que esto sea posible pero reportar los SO_x totales con base en el peso molecular del SO_2. La cantidad de emisiones de SO_x de fuentes de combustión dependen del contenido de azufre del combustible usado.

Los óxidos de azufre contribuyen al problema de la deposición ácida. Este es un término muy amplio que se refiere a las formas en las que los compuestos ácidos de la atmósfera se depositan en la superficie de la tierra. Puede incluir la deposición húmeda a través de la lluvia ácida, la niebla y la nieve, así como la deposición seca de partículas ácidas (aerosoles). La lluvia ácida se refiere a la precipitación que tiene un pH inferior a 5.6. La precipitación neutra tendría un pH de 7; sin embargo, se ha estimado que la actividad “natural” del agua de lluvia tiene un pH de 5.6 cuando está en equilibrio con la concentración atmosférica promedio de CO_2 (330 ppm) (Seinfeld, 1986). Por lo general, los principales componentes de la lluvia ácida incluyen a los ácidos nítrico y sulfúrico que pueden formarse por la combinación de los óxidos de nitrógeno y los de azufre con el vapor de agua en la atmósfera. Además, las partículas de sulfatos también tienden a ser pequeñas (de diámetro entre 0.2 y 0.9 µm). En consecuencia, pueden ser un componente significativo de las partículas finas y afectar negativamente la visibilidad.

4.5 Partículas

El térmico partículas se refiere a cualquier sustancia en fase sólida o líquida que se encuentre en el aire. Pueden ser hollín, polvos, aerosoles, humos o neblinas. Algunas clasificaciones de las partículas incluyen a las partículas totales; partículas primarias y partículas secundarias; partículas suspendidas totales (PST), partículas suspendidas (PS), PM_{10} y $PM_{2.5}$ así como partículas filtrables y partículas condensables.

Las partículas primarias incluyen a los materiales sólidos o líquidos emitidos directamente del proceso (o de la chimenea) que se espera que se conviertan en partículas a la temperatura y presión ambiente. Las partículas secundarias son aerosoles que se forman en el aire a partir de gases por medio de reacciones químicas atmosféricas. La Figura 4-2 ilustra los conceptos de partículas primarias y partículas secundarias. Todas las referencias sobre factores de emisión de partículas (e. g., el AP-42) contienen factores de emisión de partículas primarias por lo que el término "partículas totales" se usa para describir las emisiones que representan sólo a las partículas primarias.

Las PST consisten de toda la materia emitida como sólidos, líquidos y vapores pero que están “suspendidas” en el aire como partículas sólidas o líquidas. Las PST incluyen a todas las partículas de diámetro aerodinámico inferior o igual a 100 µm. Las partículas con más de 100µm tienden a depositarse rápidamente y no deben considerarse como emisiones al aire. En general, las partículas de diámetro entre 30 y 100 µm también se sedimentan con dificultad. Las partículas suspendidas se definen a menudo como todas las partículas de diámetro inferior a 30 µm y con frecuencia se usa el término como equivalente de PST. El término PM_{10} se refiere a las emisiones de partículas de diámetro aerodinámico inferior o igual a 10 µm. De manera similar, $PM_{2.5}$ se refiere a las partículas de diámetro aerodinámico igual o inferior a 2.5 µm. La Figura 4-3 ilustra las PST, PM_{10} y $PM_{2.5}$. El pequeño tamaño de las PM_{10} ó las $PM_{2.5}$ les permite entrar fácilmente en los alvéolos pulmonares donde se pueden depositar causando efectos adversos sobre la salud. Las partículas pueden causar tos, jadeos y cambios, tanto en la función respiratoria, como en el pulmón mismo. Se cree que el aumento en los niveles de partículas es responsable del incremento en las tasas de mortalidad y de morbilidad en individuos con condiciones cardiovasculares y/o respiratorias preexistentes. Sin embargo, ha sido difícil establecer los niveles en los que se presentan efectos adversos debido a la presencia de otros compuestos químicos que podrían ser responsables de algunos de los efectos observados. Además, las emisiones de $PM_{2.5}$ también son un problema para la visibilidad.

En el AP-42, los factores de emisiones de partículas totales se pueden dividir en factores de emisión de partículas filtrables y de partículas condensables. Las primeras incluyen material de tamaño menor al establecido y que se colecta en el filtro del tren de muestreo de partículas. A menos que se indique, es razonable suponer que los factores de emisión en el AP-42 para los procesos que operan a temperaturas superiores a la ambiente son para partículas filtrables, de acuerdo con la definición del Método 5 de la EPA o su equivalente (temperatura de filtro de 121°C [250°F]). Las porciones condensables de las partículas consisten de vapores a la temperatura del filtro que se colectan en los burbujeadores del tren de muestreo y se analizan por el Método 202 de la EPA o su equivalente.

Los factores de emisión de partículas totales son la suma de los factores de emisión de partículas filtrables y de partículas condensables.

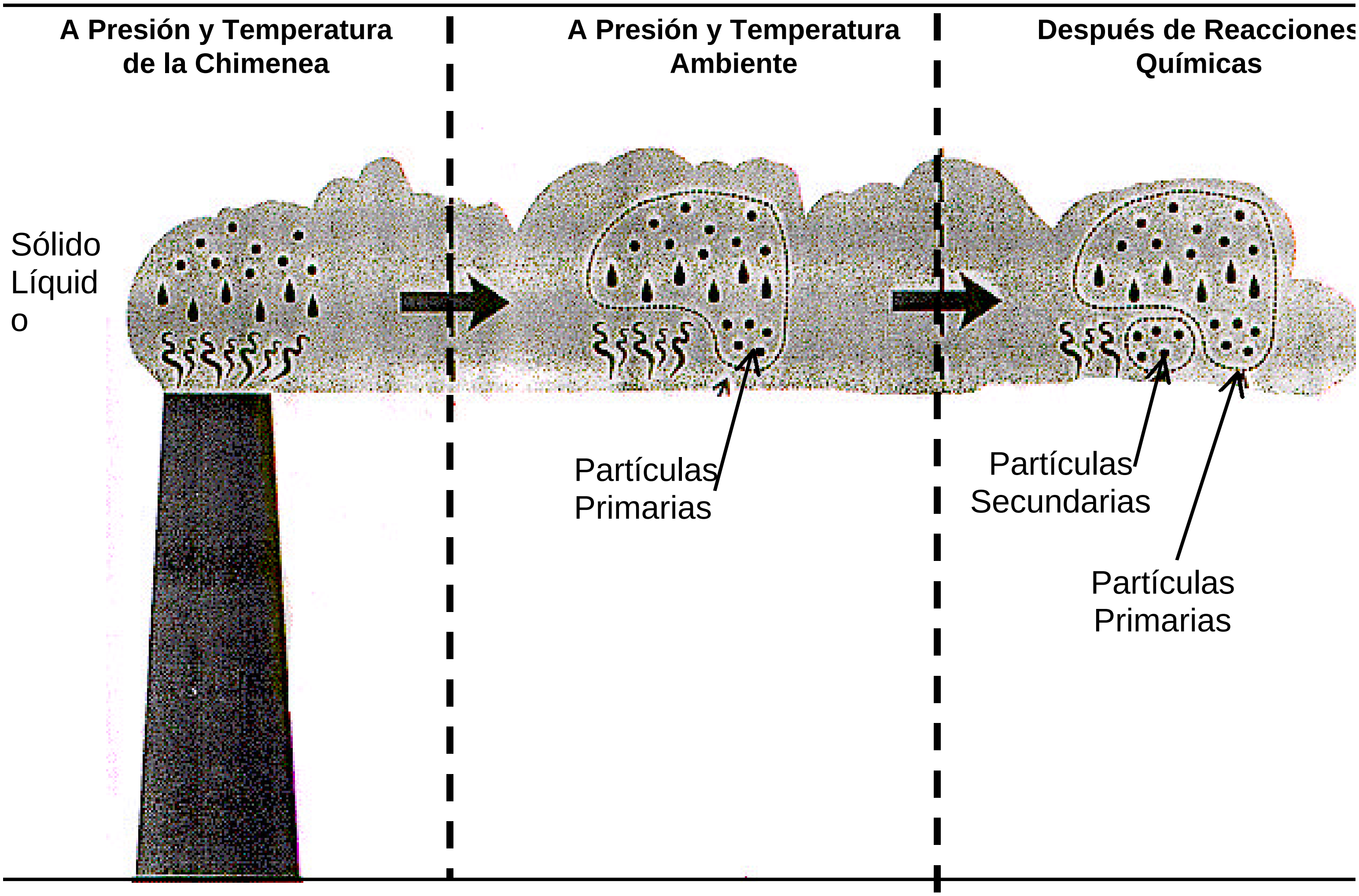


Figura 4-2. Partículas Primarias y Secundarias

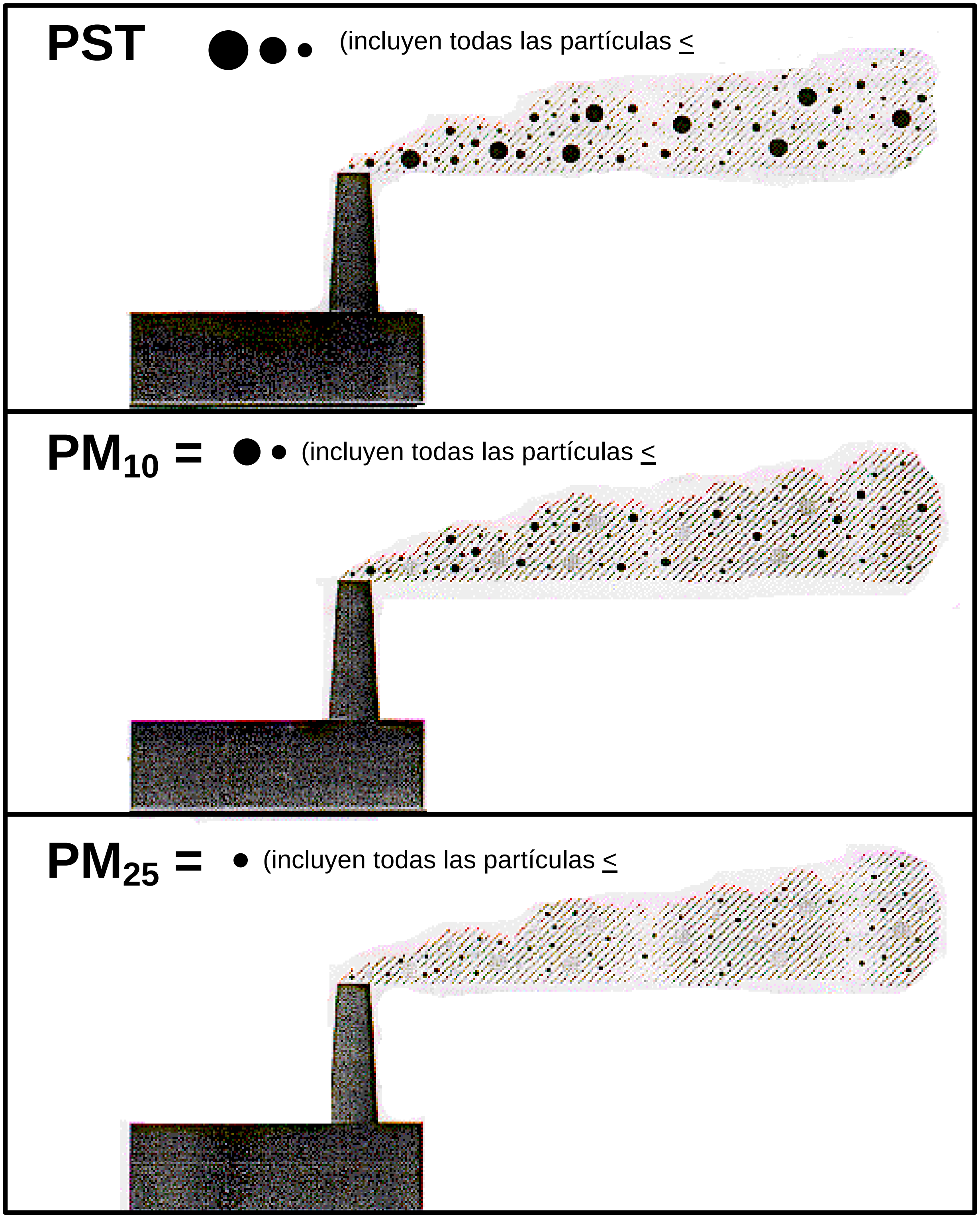


Figura 4-3. PST, PM_{10} y $PM_{2.5}$

4.6 Ozono

El ozono (O_3) es un gas tóxico y reactivo, de olor fuerte y color azul pálido formado por tres átomos de oxígeno. Es el oxidante fotoquímico más abundante. El ozono y los otros oxidantes fotoquímicos no se emiten directamente a la atmósfera si no que se forman por las reacciones químicas entre los hidrocarburos y los NO_x en presencia de luz solar. Por lo tanto no se estima en los inventarios de emisiones. En cambio, se estiman sus precursores.

A continuación se presentan las ecuaciones químicas generales que describen la formación del ozono:

$HO + RH \rightarrow H_2O + R$ (R = grupo alquilo)

$R + O_2 \rightarrow RO_2$

$RO_2 + NO \rightarrow RO + NO_2$

$NO_2 + hv \rightarrow NO + O$ (hv = 1 fotón del ultravioleta)

$O + O_2 + M \rightarrow O_3 + M$ (M = molécula de un tercer cuerpo)

El ozono y otros oxidantes fotoquímicos son irritantes que pueden tener efectos adversos en los pulmones. La exposición a altos niveles ambientales puede ocasionar disminución en la función pulmonar. Entre los efectos adversos a la salud que pueden presentarse como resultado de la exposición al ozono están la respiración rápida y poco profunda, la bronquitis y el enfisema. Además, el ozono es muy eficiente para deteriorar el hule y otros materiales.

4.7 Especies que reducen la Visibilidad

La degradación de la visibilidad es ocasionada por partículas finas que absorben o que dispersan la luz en una dirección diferente a la de la luz incidente. Algunas de estas partículas (partículas primarias) se emiten directamente a la atmósfera; otras (partículas secundarias) se forman en la atmósfera a partir de precursores gaseosos.

En las mediciones de visibilidad se utiliza el coeficiente de extinción, que es la fracción de luz atenuada por dispersión o por absorción cuando un haz de luz atraviesa una unidad de atmósfera. El coeficiente de extinción indica la tasa a la que se pierde o se redirecciona la energía debido a las interacciones con los gases y las partículas suspendidas en la atmósfera. Las partículas con más altos coeficientes de extinción causarán mayor degradación de la visibilidad.

La magnitud de estos efectos de degradación de la visibilidad dependen de varios factores tales como el tamaño y composición de las partículas, y la longitud de onda de la luz incidente. Por lo tanto, no todas las especies tienen el mismo impacto sobre la visibilidad. Las mayores fuentes de deterioro de la visibilidad son el carbono orgánico (C_{org}), el carbono elemental (CE) u hollín, los sulfatos y los nitratos. El carbono orgánico y el carbono elemental son fuentes significativas de degradación de la visibilidad debido a que ambas dispersan **y** absorben la luz. Las dos formas de carbono se emiten como partículas primarias. Todas las demás especies que reducen la visibilidad sobre todo dispersan la luz y en general son partículas secundarias formadas a partir de precursores gaseosos. Los sulfatos y los nitratos resultan, sobre todo, de varias reacciones químicas con las emisiones de SO_x y NO_x. Los precursores de ozono también pueden ser importantes debido a que los aerosoles secundarios son algunos de los productos finales del ciclo fotoquímico del llamado smog. Por último, el amoniaco (NH_3) es considerado con frecuencia como una especie que reduce la visibilidad debido a su interacción con los SO_x y los NO_x para formar sulfato de amonio, $(NH_4)_2\ SO_4$ y nitrato de amonio (NH_4NO_3).

Las partículas y sus precursores pueden permanecer en la atmósfera varios días y transportarse a grandes distancias desde sus fuentes de emisión, afectando la visibilidad en áreas remotas. Las emisiones de muchas fuentes pueden mezclarse durante el transporte para formar una neblina uniforme y extensa conocida como neblina regional. Los cambios en las condiciones meteorológicas, la luz solar y el tamaño y la proximidad de las fuentes son algunos de los factores que modifican el grado de deterioro de la visibilidad en el tiempo y de un lugar a otro.

4.8 Compuestos Tóxicos y Contaminantes Peligrosos del Aire

El término general compuestos tóxicos del aire se usa para referirse a un compuesto o grupo de compuestos químicos nocivos que se encuentran en el aire. A veces se le llama contaminantes peligrosos del aire (HAPs, por sus siglas en inglés). Son considerados tóxicos porque pueden tener efectos en el corto plazo (agudos) o en el largo plazo (crónicos). Esta categoría de contaminantes agrupa a muchas sustancias con efectos variados, a diferentes concentraciones a las que dichos efectos pueden presentarse. Los compuestos van desde los que son carcinógenicos, como el 1,3-

butadieno y el cloruro de vinilo, hasta los solventes químicos como el tolueno y el etilbenceno que a las concentraciones que se hallan en el aire ambiente pueden limitarse a tener efectos irritantes.

Los compuestos tóxicos del aire pueden existir en forma gaseosa o como partículas. Como ejemplos de compuestos tóxicos están el benceno, tolueno, xileno y etilbenceno. También existe un cierto número de compuestos tóxicos gaseosos que pueden no ser GOT, como el amoniaco y el cloro. Muchos de los compuestos tóxicos como partículas son metales pesados como el plomo, el cromo y el cadmio. El Apéndice B contiene un listado Federal de los EU, de 189 Contaminantes Peligrosos del Aire. Éste no es una lista exhaustiva de los compuestos tóxicos del aire. Para algunas aplicaciones de inventarios puede ser necesario considerar a otras sustancias como HAPs.

Lo ideal sería estimar las emisiones de estos compuestos usando datos de muestreos en la fuente o factores de emisión. Dos fuentes de factores de emisión son el *Factor Information Retrieval System* (FIRE) (Sistema de Recuperación de Información sobre Factores) (U.S. EPA, 1995) y la *California Air Toxics Emission Factor Database* (CATEF) (Base de Datos de Factores de Emisión de Compuestos Tóxicos del Aire de California (ARB, 1996) del *California Air Resources Board* (ARB) (Directorio de Recursos del Aire de California). Además se requiere hacer un juicio de ingeniería para determinar si un factor de emisión en particular es aplicable para una fuente dada. Cuando los factores de emisión de tóxicos no están disponibles, es necesario combinar las estimaciones de emisión de GOT o de partículas totales con los perfiles de especiación para estimar las emisiones de compuestos tóxicos individuales. Sin embargo, por lo general no se recomienda este enfoque debido a que los perfiles de especiación no se hacen con el fin de estimar las emisiones de compuestos individuales.

4.9 Gases con Efecto Invernadero

El efecto invernadero se presenta cuando la radiación de luz solar que entra queda atrapada por una combinación de gases activos respecto a la radiación (i. e., gases con efecto invernadero o simplemente, gases de invernadero). La energía luminosa del sol (radiación de longitud de onda corta) que pasa a través de la atmósfera de la tierra es absorbida por la superficie de la tierra y reflejada a la atmósfera como energía calorífica (radiación de longitud de onda larga). Entonces la energía calorífica es atrapada por la atmósfera creando una situación semejante a la que se presenta en un invernadero o en un automóvil cuando se suben las ventanilla. Muchos científicos creen que la emisión de estos gases (dióxido de carbono [CO_2], metano [CH_4], óxido nitroso [N_2O], clorofluorocarburos [CFCs] y otros) hacia la atmósfera puede aumentar el efecto invernadero y contribuir al calentamiento global. A continuación se describe cada uno de estos gases.

El bióxido de carbono (CO_2) es un gas incoloro e inodoro que existe naturalmente en la atmósfera de la tierra. También se emiten cantidades significativas por la combustión de combustibles fósiles. La segunda fuente más importante de emisiones globales de CO_2 ocurre por cambios en el uso del suelo y de los bosques. Los bosques y otra vegetación absorben CO_2 durante su crecimiento. Por lo tanto, la pérdida de área forestal (i. e., deforestación) está llevando a una reducción de la incorporación del CO_2 en años futuros. O, en otras palabras, a un aumento neto del CO_2 atmosférico. Los cultivos o las quemas y/o los desmontes con fines agrícolas también pueden aumentar la liberación o el almacenamiento natural de CO_2 de los suelos (IPCC, 1993).

El metano (CH_4) es el hidrocarburo gaseoso más abundante y estable en la atmósfera. La estimación más reciente de su tiempo de vida en la atmósfera es de 11 años (IPCC, 1993). Las reacciones químicas en las que participa dentro de la tropósfera pueden llevar a la producción de ozono* y la reacción con radicales hidroxilo (OH) en la estratósfera produce vapor de agua. Esto es importante debido a que tanto el ozono como el vapor de agua son gases de invernadero, al igual que el CO_2 que es el producto final de la oxidación del metano. Algunas fuentes antropogénicas de metano importantes son las operaciones en las minas de carbón, la producción de gas natural, los arrozales, la ganadería y la quema de biomasa. También se forma metano por la descomposición bacteriana de la materia orgánica en condiciones anaeróbicas (e.g., residuos animales, tratamiento de aguas negras domésticas y rellenos sanitarios.

El óxido nitroso (N_2O) es un importante gas de invernadero con una vida atmosférica de 110 - 168 años (WMO, 1992). Después de ser liberado es prácticamente inerte y rara vez participa en reacciones químicas en la tropósfera. También es la fuente principal de NO_x en la estratósfera, lo que está contribuyendo al agotamiento del ozono estratosférico. Más del 20 por ciento de las emisiones globales totales de N_2O y el 50 por ciento de las emisiones totales de N_2 pueden deberse a emisiones terrestres naturales (IPCC, 1993). La fuente antropogénica más importante de N_2O es el aumento del uso de fertilizantes nitrogenados. También se produce óxido nitroso en los suelos de manera natural por desnitrificación (i. e., la reducción del nitrito o del nitrato a nitrógeno gaseoso como N_2 o como óxido de nitrógeno) y por nitrificación (i. e., la oxidación del amoniaco a nitrato). Los fertilizantes nitrogenados comerciales constituyen una fuente adicional de nitrógeno aumentando así las emisiones de N_2O del suelo. Otras fuentes potencialmente significativas de óxido nitroso incluyen la combustión de combustibles fósiles, la quema de biomasa y la producción de ácido adípico para la industria del nylon. Recientemente ha estado aumentando la importancia de la combustión en fuentes móviles como fuente de emisiones de N_2O debido al uso de catalizadores de tres vías para reducir las emisiones de NO_x (De Soete, 1989).

Los clorofluorocarburos (CFCs) son cualesquiera de un gran número de sustancias artificiales compuestas por cloro, flúor y carbono. Entre algunos ejemplos están el diclorodifluorometano (CFC-12) y el triclorotrifluoroetano (CFC-113). Los CFCs son sumamente estables debido a su halogenación completa. Tampoco son inflamables y por lo general tampoco son tóxicos en dosis bajas. Sin embargo, han sido identificado como gases con efecto invernadero y también como sustancias agotadoras del ozono (ODS, por sus siglas en inglés). Debido a su potencial para agotar el ozono se ha detenido virtualmente toda la producción mundial de CFCs como se indica en el Protocolo de Montreal.

Los CFCs tienen puntos de ebullición apropiados para ser excelentes refrigerantes. Su baja tensión superficial y su baja viscosidad los hace ideales como solventes limpiadores. También tienen altas tasas de evaporación y no dejan residuos. También se usan como acarreadores inertes en los esterilizadores de óxido de etileno (EtO).

5.0 CATEGORÍAS DE FUENTE

La contaminación del aire proviene de una compleja mezcla de, literalmente, miles de fuentes que van desde las chimeneas industriales y vehículos de motor hasta el uso individual de limpiadores y pinturas domésticos. Incluso la vida animal y vegetal puede desempeñar un papel importante en el problema de la contaminación del aire. En general, para los propósitos de un inventario de emisiones las fuentes de emisión se agrupan en cuatro tipos diferentes:

- Fuentes puntuales
- Fuentes de área
- Vehículos automotores
- Fuentes naturales.

Esta sección presenta una descripción general de estos diferentes tipos de fuentes de emisión, explica el concepto de ajuste de fuentes puntuales y fuentes de área y presenta una lista de verificación de las categorías de fuente que deben ser incluidas (o cuando menos, consideradas) cualquier inventario de emisiones.

5.1 Fuentes Puntuales

El Volumen IV de esta serie de manuales, *Desarrollo de Inventarios de Fuentes Puntuales,* presenta información detallada sobre esta categoría de fuentes. Sin embargo, antes de comenzar a desarrollar un inventario de fuentes puntuales, deben tomarse dos importantes decisiones. Primero, se debe definir claramente lo que es una "fuente puntual" (i. e., debe establecerse una delimitación entre fuentes puntuales y de área). Segundo, se debe determinar el nivel de detalle deseado

5.1.1 Delimitación de Fuentes Puntuales y Fuentes de Área

La división de fuentes emisoras en puntuales y de área es arbitraria pero necesaria para permitir la recopilación eficiente de la información que se requiere para apoyar los programas de calidad del aire. Esta división tiene implicaciones importantes, tanto para el desarrollo de los programas regulatorios, como para el tipo de información necesaria para apoyarlos.

Es deseable contar con información detallada sobre cada “punto” en el que se descargan emisiones a la atmósfera. Aunque esto permitiría entender de forma detallada las características de cada fuente emisora, no existe manera práctica de recopilar dicha información. Si se tratan todas las plantas como fuentes puntuales se puede aumentar la exactitud del inventario pero se requerirán muchos más recursos para recopilar y mantener el inventario de fuentes puntuales. Un enfoque alternativo consiste en recopilar información en una base más simple agregando todas las fuentes que estén relacionadas (e. g., todos los automóviles, todas las panaderías) dentro de una sola “fuente de área”.

En México las fuentes puntuales se definen en el Artículo 6 del *Reglamento de la Ley General del Equilibrio Ecológico y la Protección al Ambiente en materia de Control y Prevención de la Contaminación del Aire* como toda instalación establecida en un solo lugar que tenga como propósito desarrollar procesos industriales o comerciales, de servicios o actividades que generen o puedan generar emisiones contaminantes a la atmósfera.

Como se indica en el Artículo 111 Bis de la *Ley General del Equilibrio Ecológico y la Protección al Ambiente* y en el Artículo 11 del *Reglamento de la Ley General del Equilibrio Ecológico y la Protección al Ambiente en materia de Control y Prevención de la Contaminación del Aire* las fuentes puntuales de jurisdicción federal incluyen a:

- Los siguientes sectores industriales: químico, petrolero y petroquímico, de pinturas y tintas, de automóviles, de la celulosa y el papel, del hierro y el acero, del vidrio, de la generación de electricidad, del asbesto, del cemento y la cal así como del tratamiento de residuos peligrosos;
- Todos las plantas, proyectos o actividades (industriales, comerciales o de servicios) realizados por entidades de la Administración Pública Federal;
- Las plantas localizadas en la zona adyacente al Distrito Federal y
- Las fuentes que afecten el equilibrio ecológico de un estado o país adyacente.

Estas plantas deben solicitar una licencia de operación a través de la Secretaría (SEMARNAP). Además, anualmente deben presentar estimaciones de sus emisiones y/o las mediciones en chimenea para la planta.

Algunas compañías que tienen un certificado de microindustria pueden estar exentas de los requerimientos de licencia y de certificado de operación para fuentes puntuales si sus actividades quedan exentas según el *Acuerdo por el que se Exceptúan del Trámite para la Obtención de la Licencia de Funcionamiento a las Fuentes Fijas consideradas como Empresas Microindustriales en los Términos de la Ley en la Materia Publicado el 17 de Mayo de 1990.*

Las fuentes puntuales también pueden ser especificadas de muchas otras maneras. Entre éstas se incluye la siguiente definición de fuentes puntuales (considerando a todas las otras fuentes como fuentes de área):

- Fuentes de un tipo dado (e. g., unidad de reformación catalítica fluidizada) o tanto por tipo como por tamaño (e. g., caldera con un consumo de calor >10,000 Btu/hr);
- Fuentes que emiten más de una cantidad especificada de emisiones determinada en alguna base consistente (e. g., calderas que emiten más de 100 toneladas anuales de NO_x);
- Cualquier fuente (independientemente del tipo, tamaño o emisiones) que se localice en una planta de un tipo dado (e. g., refinería de petróleo) o de un tipo y tamaño dados (e. g., fundición de acero con producción de acero superior a las 1,000 toneladas anuales) y
- Cualquier fuente (independientemente del tipo, tamaño o emisiones) que se localice en una planta con una cantidad de emisiones más grande que la especificada determinada en alguna base consistente.

Algunos ejemplos de bases consistentes para determinar la cantidad de las emisiones son:

- Emisiones reales (lo que realmente se emitió en un periodo de tiempo anterior);
- Emisiones permisibles (el máximo que puede ser emitido conforme a los límites regulatorios) y
- Emisiones potenciales (lo que se emitiría si se operara tiempo completo sin equipo de control).

Además estas definiciones pueden variar según la región regulatoria para tomar en cuenta los diferentes niveles de severidad del problema de la calidad del aire y/o lo estricto que sea el programa regulatorio. Por ejemplo, en los EU se ha establecido una base específica para las áreas que exceden varias normas de calidad del aire ambiente. Dependiendo de la severidad de las excedencias el corte de las emisiones de fuentes puntuales se coloca a un nivel diferente. Como resultado, las áreas con peor calidad del aire tienen el corte de emisiones de fuentes puntuales más bajo. Más aún, se ha estimulado el que cada estado inventaríe las fuentes por debajo de estos cortes en base individual. La decisión de establecer un corte más bajo depende de varios factores locales, por lo general, de los recursos disponibles para obtener y manejar los datos.

A menudo, en los programas ambientales de los EU se ha usado la última definición (i. e., umbrales de emisión a nivel de planta) basados en emisiones reales. Estas fuentes se han designado como “fuentes estacionarias” y están sujetas a regulaciones más estrictas que las fuentes que emiten menos. La Agencia de Protección Ambiental de los EU (USEPA) ha extendido esta definición regulatoria al terreno del manejo de datos. La USEPA requiere que las agencias estatales presenten los datos sobre las fuentes definidas desde el punto de vista regulatorio como fuentes estacionarias, como “fuentes puntuales”. Todos los datos sobre las plantas remanentes deben presentarse en forma agregada como “fuentes de área”.

A medida que el programa de inventarios de emisiones de México evolucione la definición establecida de fuente puntual puede modificarse para añadir las nuevas fuentes significativas que se vayan identificando o para eliminar las fuentes insignificantes. Una vez más, la meta es aumentar al máximo la exactitud global del inventario de emisiones completo (i. e., fuentes puntuales, de área, vehículos automotores y fuentes naturales) dentro de las limitaciones de los recursos disponible.

5.1.2 Nivel de Detalle

Por lo general, la información sobre fuentes puntuales se recopila por medio de encuesttas. Las fuentes puntuales se pueden inventariar a los siguientes tres niveles de detalle (que se ilustran en la Figura 5-1):

- Nivel de planta, que se refiere a una planta o una instalación que podría contener varias actividades emisoras de contaminantes;

- Nivel puntual o de chimenea en donde ocurren las emisiones al aire ambiente y

- Nivel de proceso, que representa las operaciones de la unidad de emisión en una categoría de fuente.

Siempre que sea posible, las emisiones deben inventariarse a nivel de proceso a fin de apoyar las actividades de calidad del aire tales como el desarrollo de regulaciones, el cumplimiento, rastreo y otorgamiento de permisos. Por ejemplo, para identificar los procesos o los dispositivos a los que podrían aplicarse las futuras regulaciones y luego estimar el impacto (i. e., costos y beneficios) de dichas regulaciones se tendrían que estimar las emisiones para cada proceso o dispositivo. Otra razón igualmente importante para recopilar datos a este nivel de detalle es que le da a la agencia la información requerida para verificar las estimaciones de las emisiones en toda la planta que fueron proporcionadas por los operadores de la instalación. Sin embargo, las limitaciones en los recursos pueden hacer que las emisiones se inventaríen a nivel de planta o a nivel puntual o de chimenea.

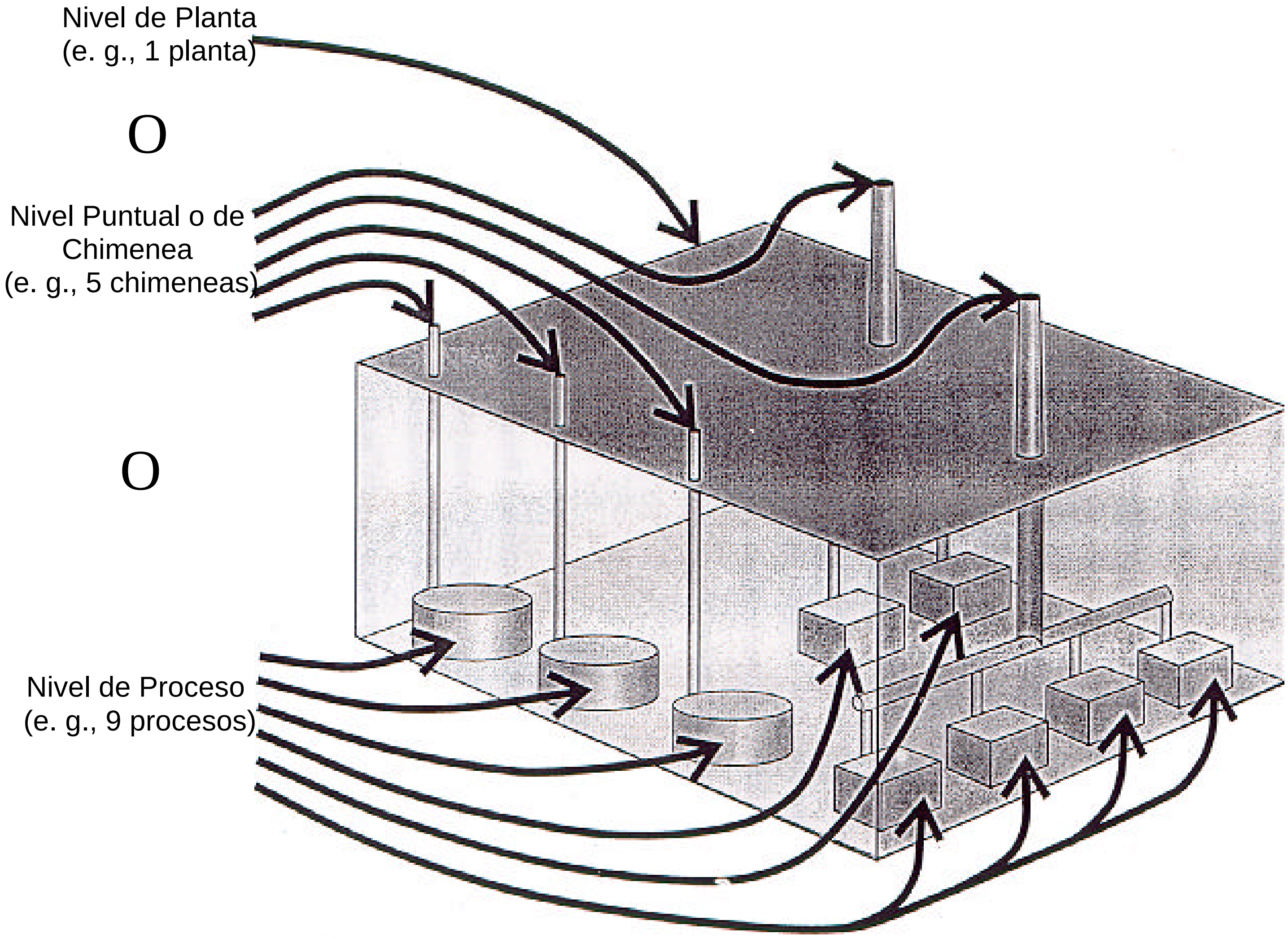


Figura 5.1 Diferentes Niveles de un Inventario de Fuentes Puntuales

5.2 Fuentes de Area

Las fuentes de área representan las emisiones de las fuentes que son demasiado numerosas y dispersas como para ser incluidas de manera eficiente en un inventario de fuentes puntuales. En conjunto, sin embargo, las fuentes de área son emisoras significativas de contaminantes del aire los que deben incluirse en un inventario de emisiones para asegurar que esté completo. Por ejemplo, con frecuencia las estaciones de servicio y las tintorerías se tratan como fuentes de área. Por lo general estas instalaciones no se incluyen en los inventarios de fuentes puntuales debido al enorme esfuerzo que se requeriría para recopilar los datos y estimar las emisiones de cada planta individual. Las fuentes móviles que no circulan por carreteras (e. g., equipo industrial, equipo de construcción, etc.) a menudo se incluyen en las fuentes de área estacionarias sobre todo debido a que los métodos usados para estimar las emisiones de fuentes de área y fuentes móviles que no circulan por carreteras son muy similares. En contraste, la metodología de inventario aplicada a los vehículos automotores es muy diferentes. En el Volumen V de esta serie de manuales, *Desarrollo de Inventarios de Fuentes de Área*, se puede encontrar información más detallada acerca de las fuentes de área. Los aspectos de las fuentes de área relacionados específicamente con el cálculo de emisiones, como la eficacia y la penetración de la regla también se discuten en el Volumen **III** de esta serie de manuales, *Técnicas Básicas de Estimación de Emisiones.*

En lugar de hacer distinción entre plantas individuales y dispositivos emisores como se hace en los inventarios de fuentes puntuales, los inventarios de fuentes de área agrupan a las emisiones de fuentes similares en *categorías*. Un inventario de fuentes de área generalmente consiste de las siguientes grandes categorías:

- Combustión en fuentes estacionarias;
- Fuentes móviles que no circulan por carreteras;
- Uso de solventes;
- Almacenamiento y transporte de productos del petróleo;
- Fuentes industriales y comerciales ligeras;
- Fuentes agrícolas;
- Fuentes de manejo de residuos y
- Fuentes de área diversas.

Cada una de estas categorías está comprende otras categorías de fuentes más específicas (i. e., el uso de solventes orgánicos incluye el uso comercial o doméstico de solventes, el lavado en seco y la limpieza de superficies) que se definen por procesos de emisión semejantes o por una similitud en los métodos para la mejor estimación de las emisiones. Un inventario de área completo puede contener 150 o más categorías de fuente individuales. En general, el lavado en seco está representado por dos o mas categorías de fuentes para tomar en cuenta los diferentes solventes que se usan (i . e., percloroetileno vs. solventes con base petróleo). De manera similar, el recubrimiento de superficies puede tener muchas categorías de fuente para tomar en cuenta las diferentes aplicaciones que existen (e. g., latas metálicas, monedas, maquinaria, muebles de madera, etc.).

Las emisiones de las categorías de fuente más grandes se producen por diversos mecanismos. La Tabla 5-1 presenta los diferentes mecanismos asociados con cada una de las grandes categorías de fuentes de área. También se incluyen ejemplos de categorías de fuentes específicas.

Tabla 5-1

Mecanismos de Emisión para Varias Categorías de Fuente de Área

Categoría de Fuente	Combustión	Evaporación	Perturbación Mecánica	Proceso Biológico
Uso de Combustible en Fuentes Estacionarias	✓ (Combustión Residencial)			
Fuentes Móviles que no Circulan por Carreteras	✓ (Equipo de Construcción)	✓ (Equipo Recreativo)		
Uso de Solventes		✓ (Desengrasado)		
Almacenamiento y Transporte de Productos de Petróleo		✓ (Distribución de Gasolina, Fugas de Gas LP)		
Fuentes Industriales y Comerciales Ligeras	✓ (Fabricación de Ladrillos)		✓ (Construcción de Edificios)	✓ (Panaderías)
Fuentes Agrícolas	✓ (Quemas Agrícolas)	✓ (Aplicación de Plaguicidas)	✓ (Cultivo Agrícola)	✓ (Desechuos Animales)
Fuentes de Manejo de Residuos	✓ (Incineración)	✓ (Plantas Públicas de Tratamiento)		
Fuentes de Area Diversas	✓ (Incendios silvestres)		✓ (Polvo de Caminos)	✓ (Amoníaco del Ganado)

5.3 Ajuste de Fuentes Puntuales y de Area

Cuando un inventario de fuentes puntuales y un inventario de fuentes de área incluyen emisiones del mismo proceso existe la posibilidad de hacer un doble conteo de las emisiones. En estas situaciones, cuando sea apropiado, la estimación de emisiones de las fuentes de área debe ajustarse hacia abajo. Ciertas categorías de fuentes de área, tales como el uso de solventes comercial y doméstico y el recubrimiento arquitectónico de superficies no requieren ningún ajuste por fuentes puntuales. Otras categorías, como la combustión y el uso de solventes pueden compartir procesos con las fuentes puntuales. Para evitar el doble conteo, la actividad en las fuentes puntuales se resta de la actividad total en las categorías de fuente puntuales y de fuentes de área combinadas. La siguiente ecuación muestra la actividad en fuentes de área resultante:

Actividad en Fuentes de Area = Actividad Total de la Categoría de Fuente – Suma de la Actividad en Fuentes Puntuales

Si la actividad en fuentes de área resultante es inferior a cero se deben revisar los datos de las fuentes puntuales para buscar errores y corregir los que se encuentren. Si la actividad en las fuentes de área sigue siendo inferior a cero se supone que es igual a cero y que sólo hay emisiones de las fuentes puntuales.

Por ejemplo, si las emisiones de fuentes de área se calculan usando el empleo, el número de empleados en las fuentes puntuales debe restarse del empleo total en la región del inventario para obtener el empleo en las fuentes de área. De manera semejante, si se usan estadísticas de venta de combustible para estimar su uso en la combustión industrial de área, entonces el combustible usado en las plantas consideradas fuentes puntuales debe restarse de las estadísticas globales de combustible. Otro ejemplo que ilustra el uso de solventes en las artes gráficas se presenta en la Figura 5-2.

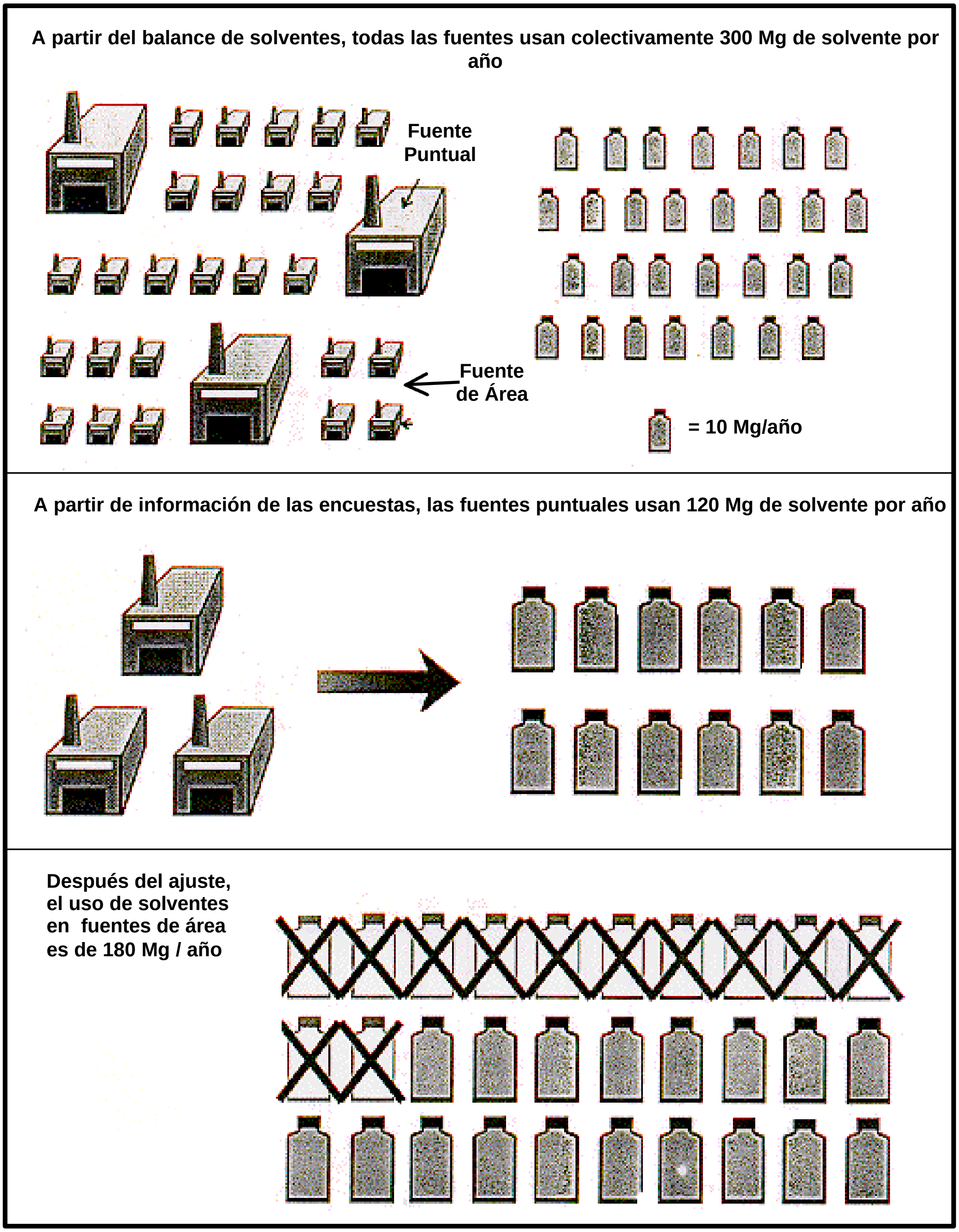


Figura 5-2. Ajuste Hipotético de Fuentes Puntuales y de Área para Solventes

En algunas ocasiones se hace un ajuste de las fuentes puntuales restando las emisiones de fuentes puntuales de las emisiones de todas las fuentes, si bien esto debe hacerse como último recurso. Si se usa este método, se deben emplear las emisiones no controladas (de las fuentes totales combinadas y de las fuentes puntuales). Cualquier ajuste por el control de emisiones que se necesite para las fuentes de área debe hacerse después del ajuste de las fuentes puntuales.

5.4 Vehículos Automotores

Los vehículos automotores que circulan por carreteras son aquellos como los automóviles, los camiones y autobuses diseñados para operar en carreteras públicas. En la mayor parte de las áreas urbanas los vehículos automotores contribuyen en gran medida a las emisiones de GOT, CO, NO_x, SO_x, partículas, compuestos tóxicos del aire y especies que reducen la visibilidad. Debido a la gran magnitud de sus emisiones y a las consideraciones especiales que se requieren para hacer estimaciones de dichas emisiones, los vehículos automotores se tratan separadamente de otras fuentes de área. En el Volumen VI de esta serie de manuales, *Desarrollo del Inventario de Vehículos Automotores* se puede hallar información más detallada sobre las fuentes vehiculares.

Las emisiones de vehículos automotores consisten de un gran número de contaminantes resultantes de varios procesos diferentes (ver Figura 5-3). Las emisiones más comúnmente considerados son las del escape, que resultan de la combustión y se emiten por el tubo de escape del vehículo y las que provienen de varios procesos de emisión evaporativa. Estos procesos, que generan sólo emisiones de GOT, incluyen:

- **Emisiones por remojo en caliente (hot soak)** – Emisiones que ocurren debido a la volatilización del combustible en el sistema de distribución después de apagar el motor. El calor residual de éste volatiliza el combustible.

- **Emisiones evaporativas durante la marcha** – Emisiones evaporativas provenientes de fugas del combustible, líquido o vapor, que ocurren cuando está operando el motor.

- **Emisiones diurnas** – Emisiones del tanque de combustible del vehículo debido a la mayor temperatura de la masa de líquido y a la presión de vapor. Estas emisiones resultan del aumento de la temperatura ambiente, de la entrada de calor desde el sistema de escape del vehículo o del calor reflejado desde la superficie de la carretera.

- **Emisiones evaporativas en reposo** – Emisiones evaporativas que no son las de remojo en caliente, las diurnas ni las debidas a la recarga del tanque. Estas emisiones se presentan cuando el motor no está en operación y se deben sobre todo a fugas de combustible y a la permeación de vapor a través de las líneas del combustible.

- **Emisiones evaporativas durante la recarga de combustible** – Emisiones evaporativas desplazadas desde el tanque de combustible durante la recarga. Aunque el vehículo es la fuente de las emisiones, éstas ocurren mientras el vehículo está en reposo y en lugares conocidos, como las gasolinerías. Por lo tanto, estas emisiones se tratan por lo general como una fuente de área y se presentan en el Volumen V de esta serie de manuales: *Desarrollo de Inventarios de Fuentes deÁrea*. Los factores de emisión de la recarga pueden estimarse usando el modelo MOBILE o bien obtenerse de otras fuentes, como el AP-42.

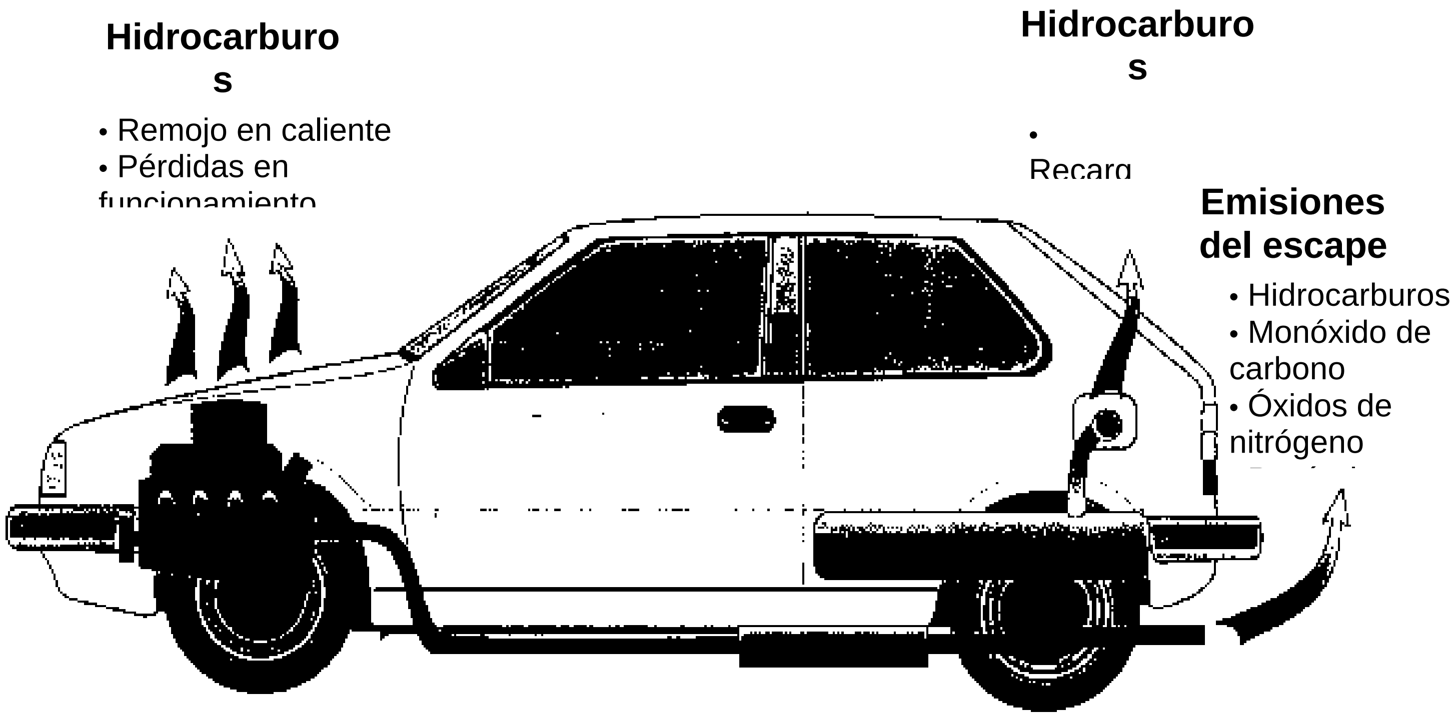


Figura 5-3. Procesos de Emisión en Vehículos Automotores

El interés por obtener estimaciones de la contribución de los vehículos automotores que circulan por carreteras a los inventarios regionales de emisiones en México ha ido en aumento, lo que ha llevado al desarrollo de inventarios de emisiones de vehículos automotores para la Ciudad de México, Monterrey, Ciudad Juárez, Guadalajara y Toluca (Espinosa, et al., 1996). Para tomar en cuenta las diferencias potenciales en las flotillas vehiculares y en los hábitos de manejo en México, el modelo MOBILE basado en datos de los EU ha sido modificado para las áreas metropolitanas de la Ciudad de México, Monterrey y Ciudad Juárez. El modelo MOBIL estima los factores de emisión de los vehículos automotores los que después deben combinarse con los datos de actividad apropiados. Se han hecho múltiples modificaciones al modelo MOBILE porque se sabe que la mezcla de flotillas vehiculares, combustibles usados y los hábitos y condiciones de manejo no son homogéneas en todo México. Por ejemplo, en las regiones fronterizas, la flotilla mexicana puede contener mas vehículos de los EU y se pueden usar mayores cantidades de combustibles también de los EU. Como otro ejemplo, la gran altitud de la Ciudad de México afecta el proceso de combustión y, por lo tanto, también las emisiones de los vehículos automotores.

5.5 Fuentes Naturales

Además de las actividades humanas, los fenómenos naturales y la vida, tanto animal como vegetal pueden desempeñar un papel importante en el problema de la contaminación del aire. En algunas áreas en las que las emisiones de fuentes naturales pueden ser significativas para el inventario global es importante comprender cual es su contribución dado que, por lo general, la instrumentación de estrategias de control no puede reducirlas con facilidad. A continuación se describen dos fuentes naturales de importancia que a menudo se consideran en los inventario de emisiones al aire.

Emisiones Biogénicas. Un gran número de investigadores han establecido que la vegetación (e. g., hierba, cultivos, arbustos, bosques, etc.) emiten cantidades significativas de hidrocarburos a la atmósfera. Varios estudios (e. g., Pierce et al., 1990; Robinson y Robbins, 1968) han demostrado que las emisiones biogénicas pueden compararse, o rebasar, las emisiones de hidrocarburos no metano (NMHC, por sus siglas en inglés) de fuentes antropogénicas en ciertas áreas.

Emisiones de Suelos. Como se mencionó antes en la exposición sobre gases con efecto invernadero en la Sección 4.9, el óxido nitroso (N_2O) es producido de manera natural en los suelos por desnitrificación (i. e., la reducción de nitritos o nitratos a nitrógeno gaseoso como N_2 ó NO_x) y por nitrificación (i. e., la oxidación de amoníaco a nitrato). Los fertilizantes nitrogenados comerciales constituyen una fuente adicional de nitrógeno, incrementando así las emisiones de N_2O del suelo. La tasa de emisiones de NO_x de los suelos también dependen de otras variables como el tipo de suelo, la humedad, la temperatura, la estación, el tipo de cultivo y otras prácticas agrícolas. Se estima que las emisiones de NO_x de los suelos representan hasta el 16 por ciento de la cantidad global de NO_x en la tropósfera y hasta el 8 por ciento de NO_x en América del Norte (U.S. EPA, 1993).

La erosión del viento es otro fenómeno natural que genera emisiones. Sin embargo, debido a que dichas emisiones se asocian por lo general con tierras alteradas a veces se les trata como fuentes de área. En la Sección 11.5 del Volumen V de esta serie de manuales, *Desarrollo de Inventarios de Fuentes de Area* se da información más detallada sobre las emisiones debidas a la erosión del viento.

Otras categorías más pequeñas de fuentes naturales incluyen a las termitas (CH_4), los relámpagos (NO_x) y los volcanes y alguna otra actividad geotérmica (SO_x). En el Volumen VII de esta serie de manuales, *Desarrollo de Inventarios de Fuentes Naturales* se puede encontrar información mas detallada obre las fuentes naturales se presenta

5.6 Lista Típica de Verificación de Categorías de Fuente

Las fuentes que se incluyen en el inventario deben jerarquizarse en base a su importancia dentro de éste. Los recursos deben asignarse, de preferencia, a las fuentes que son más importantes para satisfacer los usos finales del inventario. Las fuentes de alta prioridad incluyen a aquellas que se sabe que contribuyen de manera significativa a la contaminación del aire, que son fuente de contaminantes específicos seleccionados (e. g., PM_{10}) o que es muy probable que afecten la calidad del aire.

La Tabla 5-2 es una lista típica de verificación de las categorías de fuente que podrían incluirse en un inventario. Para cada categoría de fuente se presentan las principales emisiones esperadas por contaminante. **Cabe señalar que esta lista de verificación sólo debe usarse como una herramienta para iniciar el proceso de identificación de las categorías de fuente que se incluirán en un inventario. Es probable que las condiciones específicas de cada región lleven a añadir o a eliminar elementos de esta lista a fin de obtener un inventario completo**. Por ejemplo, las terminales de autobuses o de camiones, la manufactura de ladrillos a pequeña escala, los establecimientos de asados al carbón y los vendedores callejeros no son categorías de fuente que se inventaríen por lo general en los EU pero se han añadido a la lista de verificación como categorías potenciales para México.

Tabla 5-2
Ejemplo de una Lista de Verificación de las Categorías de Fuente de un Inventario y sus Principales Contaminantes

Categoría de Fuente	**Contaminantes del Inventario**															
	GOT	**GOR**	**CO**	**NO_x**	**SO_x**	**Partíc.**	**PM_{10}**	**$PM_{2.5}$**	**NH_3**	**CE**	**C org.**	**HAPs**	**CO_2**	**N_2O**	**CH_4**	**CFCs**
Fuentes Puntuales																
Planta Eléctrica	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Manufactura Química[a]	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓		✓		✓
Refinación de Petróleo[a]	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓				
Producción Primaria de Metales[a]	✓	✓			✓	✓	✓	✓				✓				
Producción Secundaria de Metales[a]	✓	✓				✓	✓	✓				✓				
Producción de Cemento[a]	✓	✓	✓	✓	✓	✓	✓	✓				✓				
Producción de Minerales Diversos[a]						✓	✓	✓		✓	✓	✓				
Industria de Vehículos Automotores[a]	✓	✓										✓				
Operaciones de Pulpa de Madera[a]	✓	✓			✓	✓	✓	✓		✓	✓	✓				
Producción de Petróleo y Gas[a]	✓	✓			✓							✓				
Impresión y Publicaciones	✓	✓										✓				
Recubrimiento de Superficies	✓	✓										✓				
Terminales a Granel	✓	✓										✓				
Minería y Explotación de Canteras[a]						✓	✓	✓				✓				
Manufactura de Productos de Madera[a]	✓	✓				✓	✓	✓				✓				
Producción de Azúcar[a]	✓	✓				✓	✓	✓				✓				
Tenerías y Acabados[a]	✓	✓										✓				
Producción de Vidrio[a]	✓	✓				✓	✓	✓				✓				
Producción de Partes de Hule y de Plástico [a]	✓	✓										✓				
Producción de Metal Fabricado[a]	✓	✓				✓	✓	✓				✓				
Productos Textiles[a]	✓	✓				✓	✓	✓				✓				
Rellenos Sanitarios	✓	✓	✓	✓								✓	✓		✓	
Incineradores Municipales	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Quema de Residuos al Aire Libre	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Plantas de Asfalto[a]	✓	✓				✓	✓	✓				✓				

Categoría de Fuente	**Contaminantes del Inventario**															
	GOT	**GOR**	**CO**	**NO_x**	**SO_x**	**Partíc.**	**PM_{10}**	**$PM_{2.5}$**	**NH_3**	**CE**	**C org.**	**HAPs**	**CO_2**	**N_2O**	**CH_4**	**CFCs**
Alimentos y Agricultura[a]	✓	✓				✓	✓	✓			✓	✓				
Combustión en Fuentes Puntuales	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	

Tabla 5-2 (Continuación)

Categoría de Fuente	**Contaminantes del Inventario**															
	GOT	**GOR**	**CO**	**NO_x**	**SO_x**	**Partíc.**	**PM_{10}**	**$PM_{2.5}$**	**NH_3**	**CE**	**C org.**	**HAPs**	**CO_2**	**N_2O**	**CH_4**	**CFCs**
Fuentes de Área																
Combustión Industrial, Comercial e Institucional	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Combustión Residencial (Combustibles Comerciales)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Combustión Residencial (Combustibles de Biomasa o Derivados de Residuos)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Locomotoras	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Embarcaciones Comerciales	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Aeronaves	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Otro Equipo Móvil que no circula por Carreteras (Construcción, Industrial, Recreativo, etc.).	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Cruces Fronterizos	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Terminales de Autobuses y de Camiones	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Recubrimiento de Superficies Industriales	✓	✓										✓				
Acabado de Carrocerías	✓	✓										✓				
Recubrimiento de Superficies Arquitectónicas	✓	✓										✓				
Pinturas de Tránsito	✓	✓										✓				
Limpieza de Superficies Industriales (Desengrasado)	✓	✓										✓				
Lavado en Seco	✓	✓										✓				
Artes Gráficas	✓	✓										✓				
Aplicación de Asfalto	✓	✓										✓				
Uso Comercial y Doméstico de Solventes	✓	✓										✓				
Distribución de Gasolina	✓	✓										✓				
Recarga de Combustible en Aviones	✓	✓										✓				
Distribución de Gas LP	✓	✓										✓				
Panaderías	✓	✓										✓				

Tabla 5-2 (Continuación)

Categoría de Fuente	**Contaminantes del Inventario**															
	GOT	**GOR**	**CO**	**NO_x**	**SO_x**	**Partíc.**	**PM_{10}**	**$PM_{2.5}$**	**NH_3**	**CE**	**C org.**	**HAPs**	**CO_2**	**N_2O**	**CH_4**	**CFCs**
Fuentes de Área (Continuación)																
Ladrilleras	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Actividades de Construcción						✓	✓	✓		✓	✓	✓				
Asados al Carbón	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Vendedores Callejeros	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Aplicación de Plaguicidas	✓	✓										✓				
Corrales de Engorda de Ganado						✓	✓	✓	✓			✓				
Quemas Agrícolas	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Aplicación de Fertilizantes									✓			✓		✓		
Desechos de Animales	✓	✓							✓			✓			✓	
Labranza Agrícola						✓	✓	✓		✓	✓	✓				
Incineración en Sitio	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Manejo de Residuos – Quema al Aire Libre	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Tratamiento de Aguas Residuales	✓	✓							✓			✓			✓	
Aguas Negras y Aguas Residuales en Canales Abiertos	✓	✓							✓			✓			✓	
Incendios Silvestres e Incendios Prescritos	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Incendios de Construcciones	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Polvo de Caminos Pavimentados						✓	✓	✓		✓	✓	✓				
Polvo de Caminos sin Pavimentar						✓	✓	✓		✓	✓	✓				
Erosión del Viento						✓	✓	✓		✓	✓	✓				
Emisiones Domésticas de Amoníaco									✓			✓				

Tabla 5-2 (Continuación)

Categoría de Fuente	Contaminantes del Inventario															
	GOT	GOR	CO	NO_x	SO_x	Partíc.	PM_{10}	$PM_{2.5}$	NH_3	CE	C org.	HAPs	CO_2	N_2O	CH_4	CFCs
Fuentes de Vehículos Automotores																
Vehículos de Gas de Trabajo Ligero (LDGV)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Camiones de Gas de Trabajo Ligero (LDGT)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Vehículos de Gas de Trabajo Pesado (HDGV)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Vehículos Diesel de Trabajo Ligero (LDDV)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Camiones Diesel de Trabajo Ligero (LDGT)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Vehículos Diesel de Trabajo Pesado (HDDV)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Motocicletas (MC)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Fuentes Naturales																
Hidrocarburos Biogénicos	✓	✓														
NO_x del Suelo				✓										✓		
Termitas															✓	
Rayos				✓												
Volcanes/Otras Fuentes Geotérmicas					✓	✓	✓	✓				✓				

[a] Sólo incluye las emisiones relacionadas con los procesos; la combustión en fuentes puntuales se trata como su propia subcategoría.

6.0 OTRAS CARACTERÍSTICAS DE UN INVENTARIO DE EMISIONES

Dos de las diez características de un inventario de emisiones (tipos de contaminantes y tipos de fuentes) se describieron en las Secciones 4.0 y 5.0. Las ocho características restantes se determinan sobre todo por el propósito establecido del inventario.

6.1 Año Base

El año base de un inventario identifica el año para el cual se estiman las emisiones y determina la posición del inventario en el tiempo. Esto da una marca fija para comparar los inventario previos y los subsecuentes. Es importante establecer un año base de manera que todas las estimaciones de emisiones tengan una base común y representen las actividades que ocurren durante el mismo periodo de tiempo.

Se puede usar cualquier año como base de un inventario pero en general, esto lo determina el propósito establecido del inventario. Por ejemplo, si se desea ver los efectos de las estrategias de control instrumentadas recientemente el año base será algún año previo a la instrumentación de dichas estrategias. Para haber una comparación de los niveles actuales de emisión con los niveles históricos se puede usar un año base en el pasado. El año base también podría determinado por varios requerimientos regulatorios. La razón principal para esto es que los inventario de emisiones de diferentes regiones se pueden comparar fácilmente entre sí y con las normas regulatorias. En otros casos, la disponibilidad de datos puede determinar cual es el año base de un inventario. Por ejemplo, podría desearse hacer un inventario para 1997 pero si las estadísticas que se van a usar como datos de actividad sólo se han recopilado hasta 1995 es probable que 1995 sea un mejor año base que 1997.

6.2 Características relacionadas con el tiempo

Hay dos características principales relacionadas con el tiempo que deben considerarse para cada inventario: el periodo de tiempo y la variabilidad temporal. Otras características menores pueden ser aplicables para algunos inventarios. El periodo de tiempo se refiere al lapso representado por el inventario. Las emisiones del inventario se presentarán en unidades de masa del contaminante por periodo de tiempo del inventario (e. g., kg de CO/año). Para muchos inventarios a gran escala, el periodo de tiempo será, por lo general, de un año. Sin embargo, en algunas aplicaciones especializadas se pueden requerir periodos más cortos (e. g., un día, un mes, la estación de ozono del verano, la estación calurosa, etc.).

La variabilidad temporal describe la variabilidad de las emisiones en el tiempo. Si las emisiones son constantes en el tiempo, esta variabilidad no es de gran interés. Sin embargo, la mayor parte de las emisiones cambian con el tiempo. Dependiendo de los requerimientos del inventario asociados con su propósito puede ser necesario describir las variaciones de las emisiones en base estacional, mensual o diaria. Incluso, algunos inventarios especializados pueden requerir emisiones en base horaria (o en periodos más cortos). Por ejemplo, las emisiones de los vehículos automotores que circulan por carreteras varían en diferentes periodos de tiempo debido a los diferentes niveles de actividad. Las emisiones vehiculares entre semana pueden ser mayores que en fines de semana debido a los elevados niveles de actividad vehicular asociados con el traslado hacia y desde el trabajo. Asimismo, como se muestra en la Figura 6-1, es probable que las emisiones en la mañana y en las primeras horas de la tarde sean más altas que las emisiones al mediodía o a la medianoche, debido a las horas pico caracterizadas por el gran número de viajes. n elevado tráfico de traslado. Debido a que la distribución temporal de la actividad vehicular presentada en la Figura 6-1 es específica para los EU, la actividad en México puede distribuirse de manera diferente. Dependiendo del propósito del inventario puede ser necesario considerar una o mas de estas variabilidades temporales.

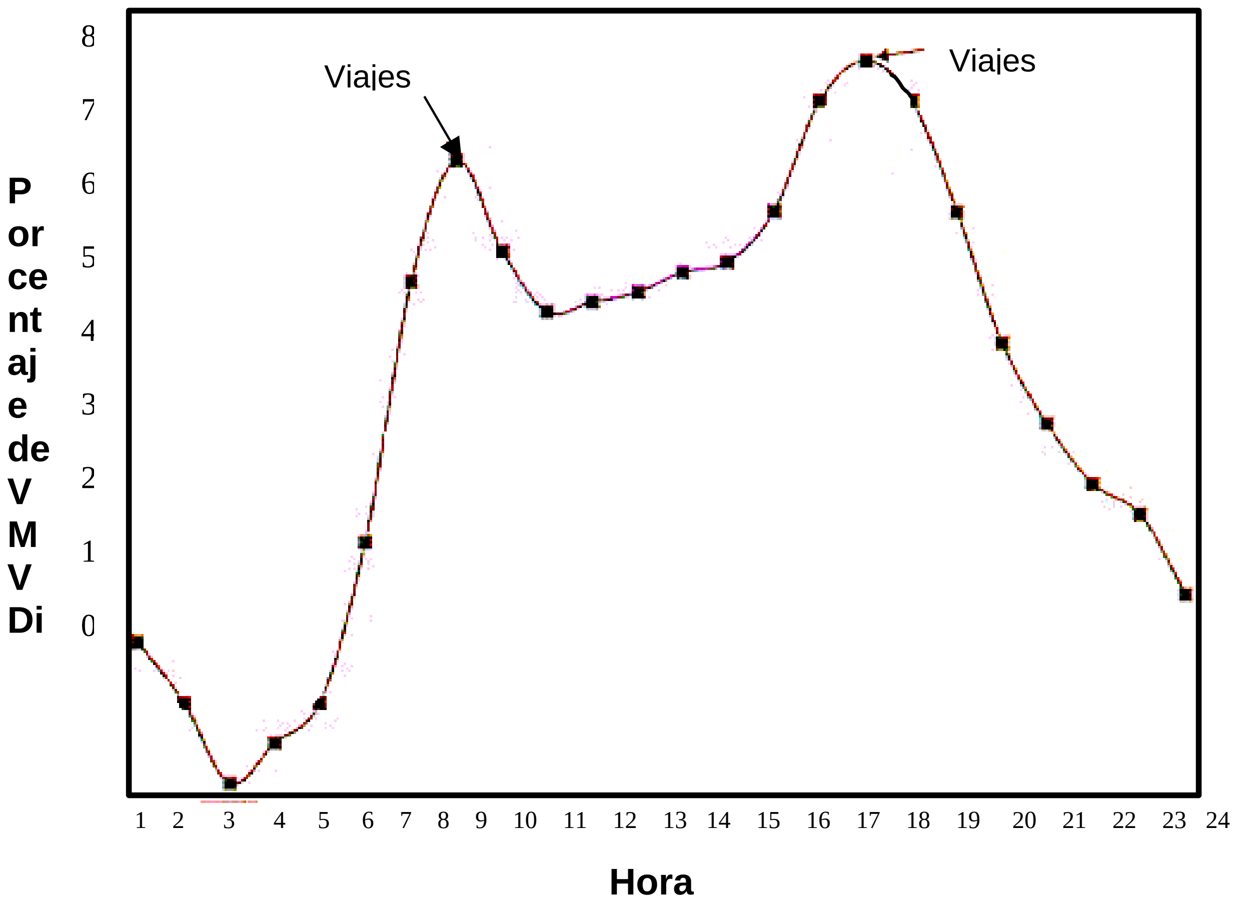


Figura 6-1. Distribución Temporal Hipotética de la Actividad de Vehículos Automotores en los Estados Unidos

6.3 Características Espaciales

En cualquier inventario hay dos características espaciales principales: el dominio del inventario y la resolución espacial. El dominio del inventario representa el área para la cual se van a inventariar las fuentes de contaminantes del aire. A veces este dominio se determina por el propósito del inventario. Con frecuencia, el dominio del inventario corresponde a las fronteras políticas, geográficas o las de las agencias responsables de la calidad del aire. Dependiendo de la aplicación del inventario, puede ser necesario tratar aquellas fuentes externas al dominio definido del inventario que, debido al transporte meteorológico, tengan influencia sobre la calidad del aire al interior del dominio. En la Figura 6-2 se presenta un dominio hipotético cuadrado que mide 25 km por lado.

La resolución espacial indica con que especificidad debe definirse la localización geográfica de las fuentes de contaminación. A veces los inventarios básicos dan solamente los totales de contaminantes para todo el dominio del inventario. Los inventario más complejos, en particular aquellos asociados con modelado de la calidad del aire, requieren con frecuencia una descripción más detallada de la distribución de las emisiones. En general la resolución de las fuentes de área, naturales y vehiculares dentro del dominio de un inventario se hace usando las celdas de una cuadrícula. El dominio de inventario que se presenta en la Figura 6-2 contiene 25 celdas de 5 km por lado. A menudo la exactitud deseada para la calidad del aire determina el tamaño de la celda. Sin embargo, en general, el tamaño de celda requerido también está relacionado con el tamaño del dominio. Los dominios grandes tienen celdas que por lo general miden varios kilómetros por lado, mientras que los dominios de inventario más pequeños pueden tener celdas de sólo unos cuantos cientos de metros por lado. En la Figura 6-2 se puede ver la siguiente distribución espacial de emisiones:

- Fuentes de Área de Población y Residenciales: Celdas A1 y A2;
- Fuentes de Área Agrícolas: Celdas B3, B4, C3, C4, D3 y D4;
- Fuentes Marinas: Celdas A3, A4, A5 y B5;
- Vehículos Automotores: Celdas A1, A2, B1, B2, C2, D2, D3, D4, E2, E4 y E5 y
- Fuentes Naturales Biogénicas: Celdas C5, D5, E1, E2, E3 y E4.

Para la mayor parte de tipos de inventarios, las fuentes puntuales necesitarán localizarse geográficamente ya sea usando coordenadas de longitud y latitud o coordenadas del Mercator Transverso Universal (UTM, por sus siglas en inglés). Para algunos inventarios complejos, la exactitud geográfica requerida para la ubicación de las fuentes puntuales puede ser de hasta ±10 metros. En la Figura 6-2 las tres fuentes puntuales ubicadas en las celdas B1, C1 y C2 requerirán coordenadas de localización detalladas.

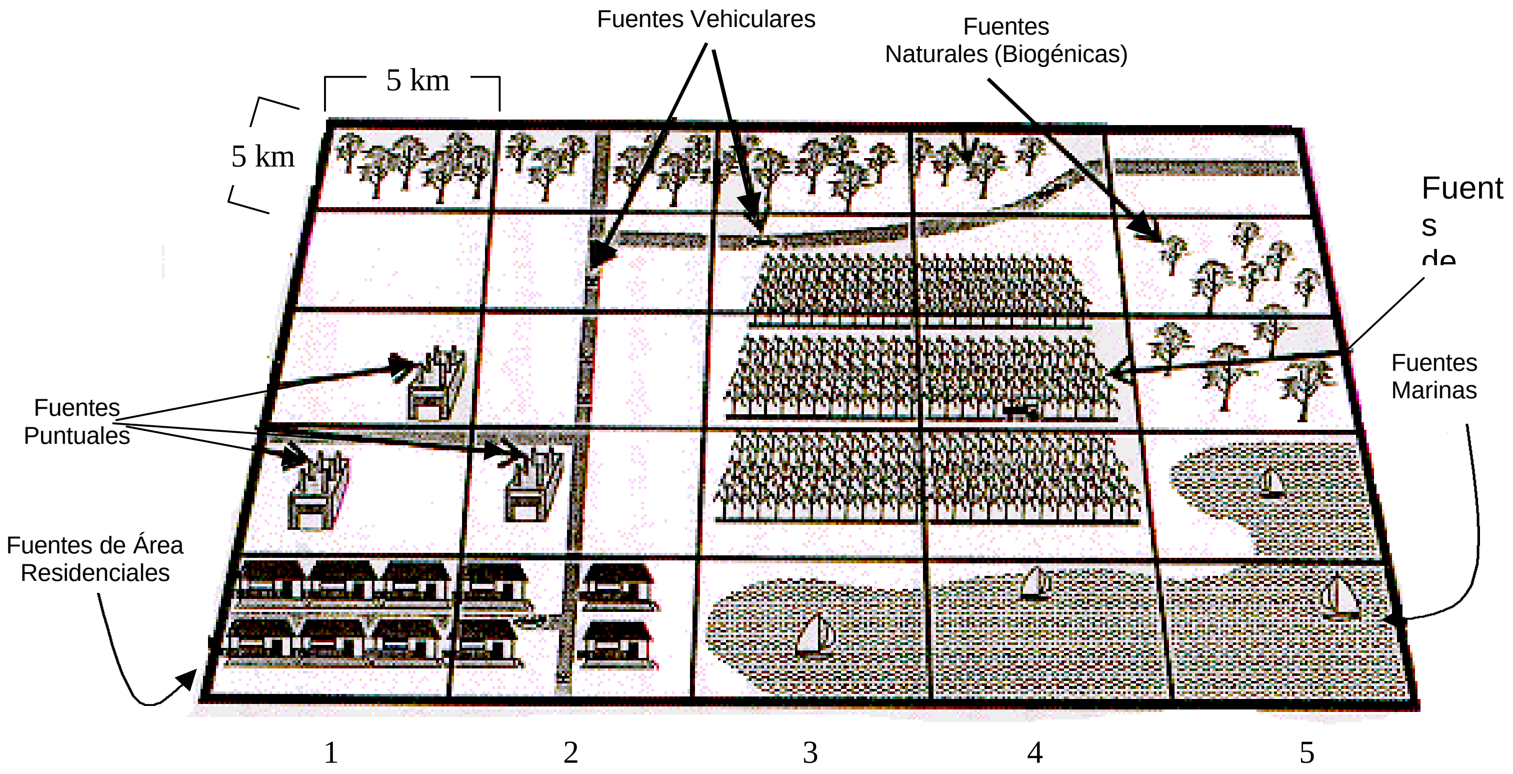


Figura 6-2. Dominio Hipotética de un Inventario y Distribución Espacial de Varios Tipos de Fuent

6.4 Resolución de Especies

La resolución de especies se refiere a la división de un contaminante del inventario (e. g., GOT, partículas, etc.) en sus componentes químicos individuales [e. g., tolueno, plomo, carbono elemental (CE), carbono orgánico (C org.), etc.] o en grupos específicos (e. g., parafinas, compuestos aromáticos, etc.). La necesidad de una resolución de especies, así como la metodología específica, están determinadas por el propósito del inventario. La resolución de especies se hace sobre todo usando perfiles de especiación que describen la fracción de cada especie química individual. Muchos inventarios no incluyen una resolución de especies detallada Otras aplicaciones especializadas sí las requieren. Estas aplicaciones incluyen los inventarios de compuestos tóxicos del aire, el modelado fotoquímico y el modelado del balance químico de masa usado para la atribución de fuentes.

Como ya se dijo en la Sección 4.8, los inventarios de compuestos tóxicos del aire buscan cuantificar la cantidad de contaminantes peligrosos del aire (HAPs, por sus siglas en inglés) que se emiten. Lo ideal sería usar factores de emisión para cada HAP individual. Aunque hay algunos factores de emisión de HAPs para fuentes de combustión y algunas otras, por lo general no existen. Como resultado es frecuente separar las especies de HAPs individuales de los GOT y las partículas usando perfiles de especiación. Como se mencionó en la Sección 4.8, éste no es el enfoque preferido para estimar las emisiones de HAPs .Si se usa, es frecuente que dé como resultado una sobreestimación de los HAPs. El enfoque se ilustra en la Figura 6-3.

En el modelado fotoquímico la especiación es necesaria debido a que las especies de hidrocarburos que se emiten tienen reactividades fotoquímicas diferentes. Las emisiones de hidrocarburos totales se calculan y después se especian en diferentes grupos de hidrocarburos. A fin de representar de manera adecuada las reacciones químicas que ocurren en la atmósfera, a cada grupo de especies se le asigna un nivel apropiado de reactividad fotoquímica.

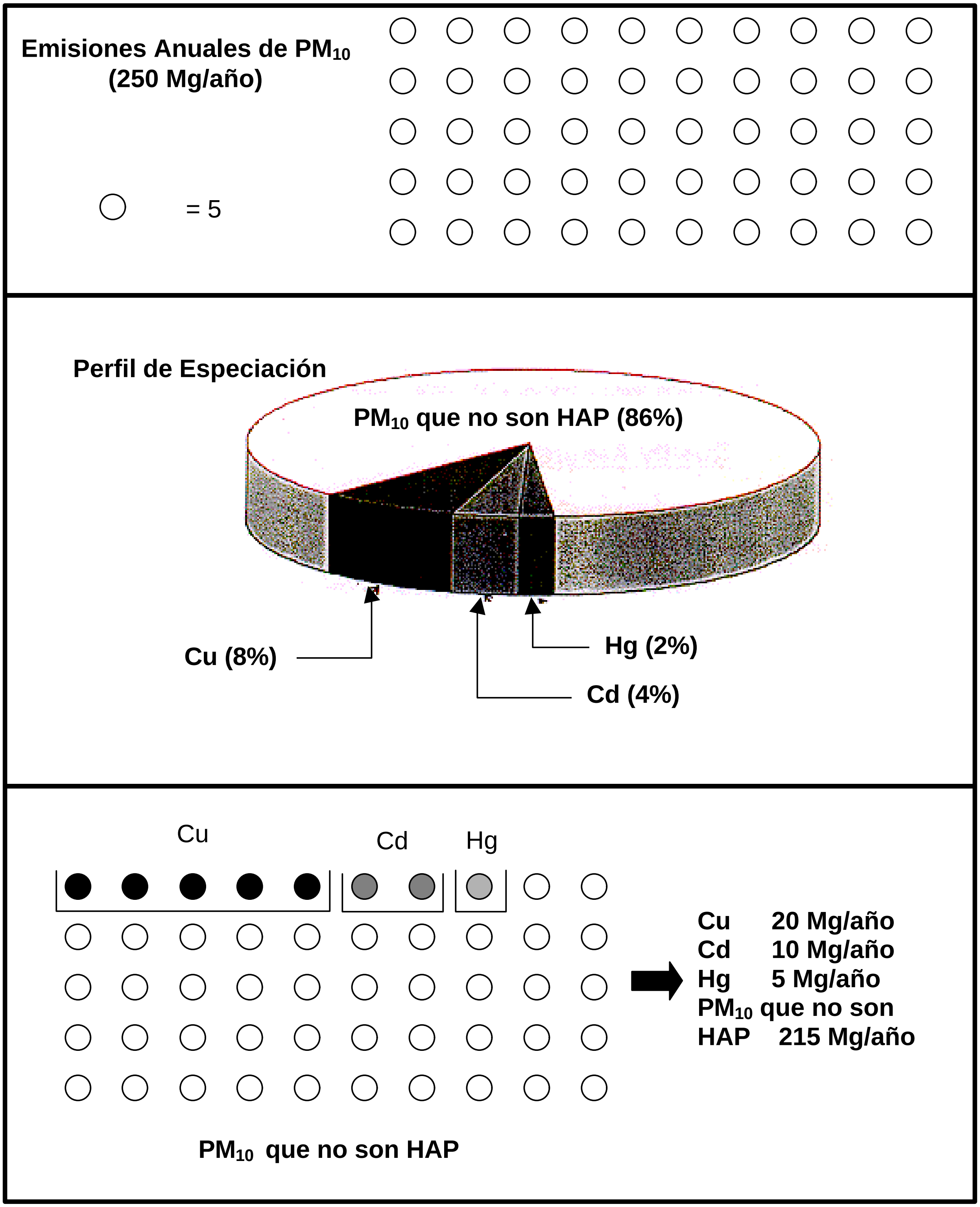


Figura 6-3. Especiación Hipotética de HAPs

Por último, la atribución de fuentes (o modelos de receptores) usando un balance químico de masa requiere una resolución de especies bastante detallada. La atribución de fuentes puede determinarse partiendo, al revés, de las concentraciones de GOT y de partículas medidas en un sitio de monitoreo usando cálculos computarizados de matrices de álgebra lineal. En este caso, la resolución de especies proporciona el contenido químico único (en general, de metales y de hidrocarburos) de las emisiones de cada tipo de fuente. Este contenido químico sirve como “huella digital” de la presencia de material de esa fuente en los datos de muestras ambientales en el receptor. Sin la resolución de especies, es imposible instrumentar esta aplicación. Se puede encontrar más información sobre la atribución de fuentes en algunos estudios recientes sobre el tema (Watson et al., 1984; Chow et al., 1992; Scheff et al., 1984).

6.5 Aseguramiento de la Calidad

El aseguramiento de la calidad (AC) es un elemento indispensable de cualquier inventario de emisiones. Sin importar el tipo de inventario de que se trate se necesita el AC. Sin embargo, la cantidad y enfoque del AC es variable y depende del propósito específico del inventario. Por ejemplo, un inventario detallado para modelado a gran escala por lo general requiere mucho más AC que un inventario de reporte a nivel planta. Además, si un tipo de fuente en particular ya ha sido identificado de manera preliminar como una gran fuente de contaminantes, se podrían dirigir más recursos de AC a este tipo de fuente que a otros que sean menores.

El AC debe llevarse a cabo durante todo el desarrollo del inventario y no como una ocurrencia de última hora. Algunos ejemplos de actividades de AC incluyen:

- El uso de una lista de verificación de las categorías de fuente (como la que se presenta en la Tabla 5-2) confirma que todas las categorías de fuente necesarias han sido incluidas en el inventario;

- Revisar los resultados de los muestreos y los datos de actividad buscando aquellos valores que estén fuera de lugar, antes de calcular las emisiones;

- Confirmar que todos los cálculos de emisión se han hecho de manera apropiada y

- Comparar los resultados del inventario con los de otros inventarios en regiones similares.

Hay también muchas otras actividades de AC no enlistadas anteriormente que pueden ayudar a garantizar un inventario de emisiones de alta calidad.

Aunque los resultados de un inventario pueden afectar la manera en que se lleve a cabo el AC durante el desarrollo del inventario, los recursos necesarios para el AC deben identificarse desde el principio. En la mayor medida posible, el tipo de AC (e. g., AC detallado línea por línea o AC de alto nivel) y las áreas que requieren mayor concentración de AC deben designarse al comienzo del inventario.

6.6 Manejo de Datos

Otra característica esencial de un.. inventario de emisiones es el manejo de datos requerido. Con el uso tan extendido de las computadoras y con el aumento en los requerimientos de datos, en la actualidad virtualmente todos los datos de un inventario se manejan de manera electrónica. Se debe analizar si el manejo de datos se hace usando una aplicación de tipo hoja de cálculo o una de base de datos. Las primeras tienden a ser más fáciles de usar pero las bases de datos son mucho más poderosas. El método de transferencia de la información relativa al inventario y de cualquier requerimiento de confidencialidad de los datos también debe establecerse al principio del proceso de desarrollo del inventario. El propósito del inventario ayudará a determinar el tipo de manejo de datos requerido. Por ejemplo, un inventario usado alimentar un modelo de calidad del aire puede requerir un manejo de datos diferente al manejo de datos para un inventario diseñado para el cumplimiento regulatorio. Por lo demás, los usos esperados para el inventario en el futuro también pueden influir en el tipo de manejo de datos seleccionado.

6.7 Proyecciones

Las proyecciones predicen un inventario para un año base, hacia delante o hacia atrás en el tiempo. El uso de las proyecciones se determina principalmente por el propósito del inventario. En muchos inventarios no se desarrollan emisiones proyectadas. Las proyecciones se usan sobre todo para rastrear las tendencias pasadas y futuras de las emisiones debido al crecimiento de la actividad y a las estrategias de control instrumentadas. También se usan las proyecciones en los análisis teóricos de diversas estrategias de control propuestas para futura instrumentación. Por ejemplo, las proyecciones podrían usarse para estimar las futuras emisiones de los vehículos automotores con base en el crecimiento esperado de la población. De manera semejante, las proyecciones se pueden usar para rastrear la reducción estimada en las emisiones debidas a la propuesta de introducción de pinturas reformuladas con menor contenido de solventes. Por lo general, las proyecciones de crecimiento de las emisiones se basan en las proyecciones de crecimiento de otros sustitutos (e. g., población, actividad económica, etc.). Las proyecciones de control, por otro lado, se basan a menudo en las reducciones estimadas por las estrategias de control. Las metodologías de proyección y los datos requeridos deben ser establecidos en las primeras etapas del proceso de desarrollo del inventario. La EPA ha publicado lineamientos relativos a la proyección de emisiones (U.S. EPA, 1991b).

6.8 Estimación de la Incertidumbre

La característica final de un inventario de emisiones es la estimación de la incertidumbre. Estas estimaciones constituyen una valiosa herramienta para evaluar la exactitud de un inventario de emisiones.

La incertidumbre puede estimarse cuantitativa o cualitativamente. Las estimaciones cuantitativas son poco frecuentes y existen varias razones. En primer lugar, no existe un método acordado para hacer estimaciones cuantitativas de la incertidumbre. Por otra parte, el cálculo de estimaciones cuantitativas de la incertidumbre puede ser un proceso muy complejo desde el punto de vista estadístico. Por último, a menudo se requiere un gran número de suposiciones para hacer estimaciones cuantitativas de la incertidumbre.

En general, cuando se hacen estimaciones de la incertidumbre éstas son de naturaleza mas bien cualitativa. Éstas pueden centrarse en las metodologías, en los datos de actividad, en los datos relacionados con las emisiones, en las suposiciones subyacentes o en otros componentes del desarrollo de inventarios. Por ejemplo, la suposición de que las emisiones de las operaciones de recubrimiento de superficies se limitan sólo a los solventes contenidos en el recubrimiento aplicado (sin considera los solventes de la preparación y/o de la limpieza de la superficie) ciertamente llevará a subestimar las emisiones de GOT en el inventario. De manera similar, la suposición de que todas las fuentes puntuales usan el mismo combustible y operan con el mismo calendario va a generar incertidumbre en el inventario, aunque no está claro si ésta resultaría en una sobre o en una subestimación. Aunque en las estimaciones cualitativas no se calcula estadísticamente la incertidumbre de un inventario de emisiones son valiosas debido a que señalan las debilidades potenciales en el inventario.

7.0 ITERACIÓN DEL PROCESO DE INVENTARIO

Los pasos técnicos para desarrollar un inventario de emisiones se mostraron antes en la Figura 2-1. Estos pasos comienzan con la identificación del propósito del inventario y terminan con la documentación de sus resultados. Es importante señalar que aún si todos los pasos en la Figura 2-1 se instrumentan apropiadamente durante el desarrollo del inventario, esto simplemente representa una iteración del desarrollo del inventario de emisiones. Por lo general se requieren múltiples iteraciones para desarrollar inventarios de emisiones de alta calidad. Este concepto de iteración se representa por los rompecabezas de la Figura 7-1. Los primeros inventarios se caracterizarán por la información faltante y por otras imperfecciones, pero la calidad de los inventarios subsecuentes actualizados mejorará gradualmente.

La meta final es desarrollar un inventario de emisiones que sea completo, exacto y que contabilice las emisiones de contaminantes del aire y los datos asociados de las fuentes dentro de un área geográfica dada en un intervalo de tiempo específico. Sin embargo, las limitaciones prácticas hacen necesario un enfoque iterativo para alcanzar este objetivo. El desarrollo de un inventario, llevado en forma sistemática e iterativa a lo largo del tiempo, reducirá la cantidad de incertidumbre y mejorará la calidad global del inventario de emisiones.

Un inventario de emisiones debe ser completo, lo que quiere decir que deben incluirse todas las fuentes de los contaminantes identificados del inventario. La limitación en los recursos puede reducir el número de fuentes inventariadas a un subconjunto de las fuentes totales existentes. De manera semejante, algunas fuentes de emisiones pueden ser ignoradas o pasadas por alto durante el proceso inicial de inventario. Las revisiones subsecuentes se usan para incluir las fuentes faltantes.

En la mayor medida posible, un inventario de emisiones también debe ser exacto. Los datos incorrectos o las suposiciones demasiado simplistas introducirán inexactitudes en el inventario. Estas inexactitudes pueden ser corregidas en las iteraciones de inventarios posteriores con información más completa o mejorada.

Finalmente, un inventario de emisiones debe representar las emisiones actuales. Algunas aplicaciones del inventario se actualizan cada año y requieren información corriente para ese año específico. Estos inventarios ser actualizarán anualmente para rastrear el incremento de emisiones debido al crecimiento en la actividad que las produce o la reducción debida a la instrumentación de diversas estrategias de control. Los datos y la información caducos deben ser actualizados en las iteraciones posteriores del inventario.

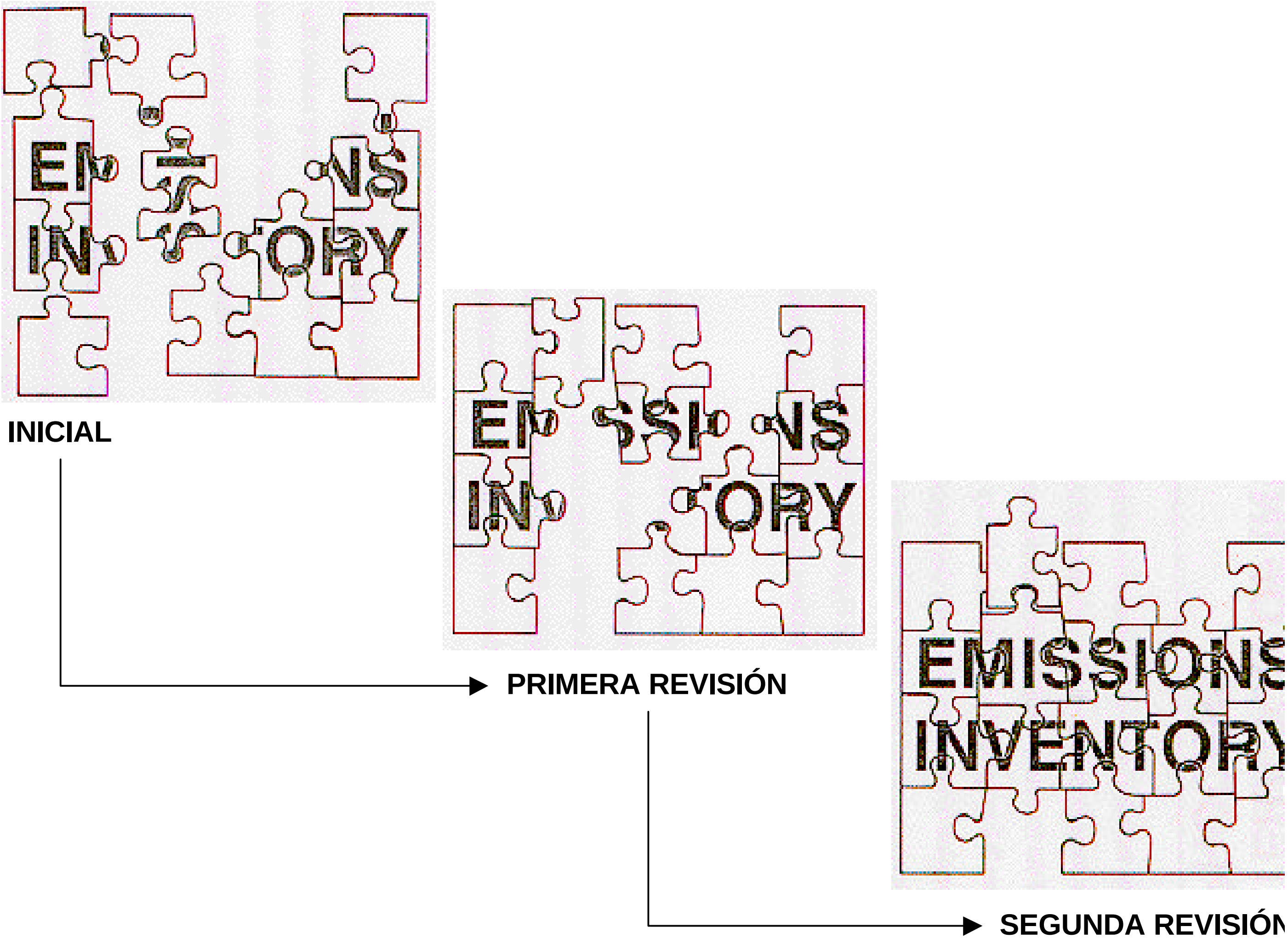


Figura 7-1. Iteraciones de un Inventario de Emisiones

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APENDICE A

HIDROCARBUROS NO REACTIVOS

Compuestos Fotoquímicamente No Reactivos. U.S. EPA

Sustancia Química	Sinónimo
metano	
etano	
cloruro de metileno	diclorometano
1,1,1-tricloroetano	metilcloroformo
1,1,2-tricloro 1,2,2-trifluoroetano	CFC–113
triclorofluorometano	CFC–11
diclorodifluorometano	CFC–12
clorodifluorometano	HCFC–22
trifluorometano	HFC–23
1,2-dicloro 1,1,2,2-tetrafluoroetano	CFC–114
cloropentafluoroetano	CFC–115
1,1,1-trifluoro 2,2-dicloroetano	HCFC–123
1,1,1,2-tetrafluoroetano	HFC–134a
1,1-dicloro 1-fluoroetano	HCFC–141b
1-cloro 1,1-difluoroetano	HCFC–142b
2-cloro 1,1,1,2-tetrafluoroetano	HCFC–124
pentafluoroetano	HFC–125
1,1,2,2-tetrafluoroetano	HFC–134
1,1,1-trifluoroetano	HFC–143a
1,1-difluoroetano	HFC–152a
paraclorobenzotrifluoruro	PCBTF
Xiloxanos completamente metilados cíclicos, ramificados o lineales	
acetona	
percloroetileno	tetracloroetileno
3,3-dicloro-1,1,1,2,2-pentafluoropropano	HCFC–225ca
1,3-dicloro-1,1,2,2,3-pentafluoropropano	HCFC–225cb
1,1,1,2,3,4,4,5,5,5-decafluoropentano	HFC–43–10mee
difluorometano	HFC–32
etilfluoruro	HFC–161
1,1,1,3,3,3-hexafluoropropano	HFC–236fa
1,1,2,2,3-pentafluoropropano	HFC–245ca
1,1,2,3,3-pentafluoropropano	HFC–245ea
1,1,1,2,3-pentafluoropropano	HFC–245eb
1,1,1,3,3-pentafluoropropano	HFC–245fa
1,1,1,2,3,3-hexafluoropropano	HFC–236ea
1,1,1,3,3-pentafluorobutano	HFC–365mfc
clorofluorometano	HCFC–31

U.S. EPA Photochemically Non-Reactive Compounds (Continued)

Compuestos Fotoquímicamente No Reactivos. U.S. EPA (Continuación)

Sustancia Química	Sinónimo
1-cloro 1-fluoroetano	HCFC–151a
1,2-dicloro 1,1,2-trifluoroetano	HCFC–123a
1,1,1,2,2,3,3,4,4-nonafluoro-4-metoxi-butano	$C_4F_9OCH_3$
2-(etoxidifluorometil) 1,1,1,2,3,3,3-heptafluoropropano	$(CF_3)_2CFCF_2OCH_3$
1-etoxi 1,1,2,2,3,3,4,4,4-nonafluorobutano	$C_4F_9OC_2H_5$
2-(etoxidifluorometil) 1,1,1,2,3,3,3-heptafluoropropano	$(CF_3)_2CFCF_2OC_2H_5$
compuestos perfluorocarburos que pertenezcan a estas clases:	
(i) alcanos completamente fluorados cíclicos, ramificados o lineales;	
(ii) Éteres completamente fluorados sin insaturaciones, cíclicos, ramificados o lineales;	
(iii) Aminas terciarias completamente fluoradas sin insaturaciones, cíclicas, ramificadas o lineales y	
(iv) Perfluorocarburos sin insaturaciones que contengan azufre y con enlaces azufre sólo a carbono y flúor.	

Fuente: Federal Register, Vol. 62, No. 164. Agosto 25, 1997. pp. 44900 – 44903.

APENDICE B

CONTAMINANTES PELIGROSOS DEL AIRE

Listado Federal de los Estados Unidos de Contaminantes Peligrosos del Aire (Tomado de la Ley del Aire Limpio – Sección 112(b))

Número CAS	Nombre Químico
75-07-0	Acetaldehído
60-35-5	Acetamida
75-05-8	Acetonitrilo
98-86-2	Acetofenona
53-96-3	2-Acetilaminofluoreno
107-02-8	Acroleína
79-06-1	Acrilamida
79-10-7	Acrílico, ácido
107-13-1	Acrilonitrilo
107-05-1	Alilo, cloruro
92-67-1	4-Aminobifenilo
62-53-3	Anilina
90-04-0	o-Anisidina
1332-21-4	Asbesto
71-43-2	Benceno (incluyendo el benceno de la gasolina)
92-87-5	Bencidina
98-07-7	Benzotricloruro
100-44-7	Bencilo, cloruro
92-52-4	Bifenilo
117-81-7	Bis(2-etihexil)ftalato (DEHP)
542-88-1	Bis(clorometil) éter
75-25-2	Bromoformo
106-99-0	1,3-Butadieno
156-62-7	Calcio, cinamida
105-60-2	Caprolactama
133-06-2	Captano
63-25-2	Carbarilo
75-15-0	Carbono, disulfuro
56-23-5	Carbono, tetracloruro
463-58-1	Carbonilo, sulfuro
120-80-9	Catecol
133-90-4	Clorambeno
57-74-9	Clordano
7647-01-0	Clorhídrico, ácido (sólo gas)
7782-50-5	Cloro
79-11-8	Cloroacético, ácido
532-27-4	2-Cloroacetofenona
108-90-7	Clorobenceno
510-15-6	Clorobencilato
67-66-3	Cloroformo

Listado Federal de los Estados Unidos de Contaminantes Peligrosos del Aire (Continuación)

Número CAS	Nombre Químico
107-30-2	Clorometil metil eter
126-99-8	Cloropreno
1319-77-3	Cresol / cresílico, ácido (mezcla de isómeros)
95-48-7	o-Cresol
108-39-4	m-Cresol
106-44-5	p-Cresol
98-82-8	Cumeno
94-75-7	2,4-D (incluyendo sales y ésteres)
72-55-9	DDE
334-88-3	Diazometano
132-64-9	Dibenzofurano
96-12-8	1,2-Dibromo-3-Cloropropano
84-74-2	Dibutilo, ftalato
106-46-7	1,4-Diclorobenceno
91-94-1	3,3'-Diclorobencidina
111-44-4	Dicloroetil éter (Bis[2-Cloroetil]éter)
542-75-6	1,3-Dicloropropeno
62-73-7	Diclorvos
111-42-2	Dietanolamina
121-69-7	N,N-Dimetilanilina
64-67-5	Dietilo, sulfato
119-90-4	3,3'-Dimetoxibencidina
60-11-7	4-Dimetilaminoazobenceno
119-93-7	3,3'-Dimetilbencidina
79-44-7	Dimetilcarbamoilo, cloruro
68-12-2	Dimetilformamida
57-14-7	1,1-Dimetilhidracina
131-11-3	Dimetilo, ftalato
77-78-1	Dimetilo, sulfato
N/A	4,6-Dinitro-o-cresol (incluyendo sales)
51-28-5	2,4-Dinitrofenol
121-14-2	2,4-Dinitrotolueno
123-91-1	1,4-Dioxano (1,4-Dietileno, oxido)
122-66-7	1,2-Difenilhidracina
106-89-8	Epiclorohidrina (l-cloro-2,3-epoxipropano)
106-88-7	1,2-Epoxibutano
100-42-5	Estireno
96-09-3	Estireno, óxido
140-88-5	Etil acrilato
100-41-4	Etil benceno
51-79-6	Etil carbamato (Uretano)

Listado Federal de los Estados Unidos de Contaminantes Peligrosos del Aire (Continuación)

Número CAS	Nombre Químico
75-00-3	Etil cloruro (Cloroetano)
106-93-4	Etileno, dibromuro (Dibromoetano)
107-06-2	Etileno, dicloruro (1,2-Dicloroetano)
107-21-1	Etilénglicol
151-56-4	Etilénimina (Aziridina)
75-21-8	Etileno, óxido
96-45-7	Etileno, tiourea
75-34-3	Etilideno, dicloruro (1,1-Dicloroetano)
106-50-3	p-Feniléndiamina
108-95-2	Fenol
7664-39-3	Fluorhídrico, ácido
50-00-0	Formaldehído
75-44-5	Fosgeno
7803-51-2	Fosfina
7723-14-0	Fósforo
85-44-9	Ftálico, anhidrido
76-44-8	Heptacloro
118-74-1	Hexaclorobenceno
87-68-3	Hexaclorobutadieno
77-47-4	Hexaclorociclopentadieno
67-72-1	Hexacloroetano
822-06-0	Hexametileno, diisocianato
680-31-9	Hexametilfósforamida
110-54-3	Hexano
302-01-2	Hidracina
123-31-9	Hidroquinona
78-59-1	Isoforona
N/A	Lindano (todos los isómeros)
108-31-6	Maleico, anhidrido
67-56-1	Metanol
72-43-5	Metoxicloro
74-83-9	Metilo, bromuro (Bromometano)
71-55-6	Metil cloroformo (1,1,1-Tricloroetano)
74-87-3	Metil cloruro (Clorometano)
78-93-3	Metil etil cetona (2-Butanona)
60-34-4	Metil hidracina
108-10-1	Metil isobutil cetona (Hexona)
624-83-9	Metil isocianato
80-62-6	Metil metacrilato
1634-04-4	Metil ter-butil éter
74-88-4	Metilo, yoduro (Yodometano)

Listado Federal de los Estados Unidos de Contaminantes Peligrosos del Aire (Continuación)

Número CAS	Nombre Químico
101-14-4	4,4'-Metilén bis (2-Cloroanilina)
75-09-2	Metileno, cloruro (Diclorometano)
101-68-8	4,4'-Metilén difenil diisocianato (MDI)
101-77-9	4,4'-Metiléndianilina
91-20-3	Naftaleno
98-95-3	Nitrobenceno
92-93-3	4-Nitrobifenilo
100-02-7	4-Nitrofenol
79-46-9	2-Nitropropano
684-93-5	N-Nitroso-N-metilurea
62-75-9	N-Nitrosodimetilamina
59-89-2	N-Nitrosomorfolina
56-38-2	Paratión
82-68-8	Pentacloronitrobenceno (Quintobenceno)
87-86-5	Pentaclorofenol
1336-36-3	Policlorados, bifenilos (Arocloros)
1120-71-4	1,3-Propano sultona
57-57-8	beta-Propiolactona
123-38-6	Propionaldehído
114-26-1	Propoxur (Baygon)
78-87-5	Propileno, dicloruro (1,2-Dicloropropano)
75-56-9	Propileno, óxido
75-55-8	1,2-Propilénimina (2-Metilaziridina)
91-22-5	Quinoleína
106-51-4	Quinona (p-Benzoquinona)
1746-01-6	2,3,7,8-Tetraclorodibenzo-p-dioxina
79-34-5	1,1,2,2-Tetracloroetano
127-18-4	Tetracloroetileno (Percloroetileno)
7550-45-0	Titanio, tetracloruro
108-88-3	Tolueno
95-80-7	Toluén-2,4-diamina
584-84-9	2,4- Toluén diisocianato
95-53-4	o-Toluidina
8001-35-2	Toxafeno (camfeno clorado)
120-82-1	1,2,4-Triclorobenceno
79-00-5	1,1,2-Tricloroetano
79-01-6	Tricloroetileno
95-95-4	2,4,5-Triclorofenol
88-06-2	2,4,6-Triclorofenol
121-44-8	Trietilamina
1582-09-8	Trifluoralina

Listado Federal de los Estados Unidos de Contaminantes Peligrosos del Aire (Continuación)

Número CAS	Nombre Químico
540-84-1	2,2,4-Trimetilpentano
108-05-4	Vinilo, acetato
593-60-2	Vinilo, bromuro
75-01-4	Vinilo, cloruro
75-35-4	Vinilideno, cloruro (1,1-Dicloroetileno)
1330-20-7	Xileno (mezcla de isómeros)
95-47-6	o-Xileno
108-38-3	m-Xileno
106-42-3	p-Xileno
N/A	Antimonio[a], compuestos[a]
N/A	Arsénico, compuestos[a] (inorgánicos, incluyendo arsina)
N/A	Berilio, compuestos[a]
N/A	Cadmio, compuestos[a]
N/A	Cianuro, compuestos[a,b]
N/A	Cobalto, compuestos[a]
N/A	Coque, emisiones de hornos de
N/A	Cromo, compuestos[a]
N/A	Fibras minerales finas[d]
N/A	Glicol éteres[c]
N/A	Manganeso, compuestos[a]
N/A	Materia Orgánica Policíclica[e]
N/A	Mercurio, compuestos[a]
N/A	Níquel, compuestos[a]
N/A	Plomo, compuestos[a]
N/A	Radionúclidos (incuyendo Radón)[f]
N/A	Selenio, compuestos[a]

[a] Para todos los incisos anteriores que contienen la palabra “compuestos” y también para los glicol éteres es aplicable lo siguiente: a menos que se indique otra cosa, en estos listados se incluye cualquier sustancia química única que contenga al compuesto o elemento químico nombrado (i. e., antimonio, arsénico, etc.), como parte de la infraestructura de esa sustancia.

[b] X'CN donde X = H' o cualquier otro grupo en el que pueda ocurrir una disociación formal. Por ejemplo, KCN ó $Ca(CN)_2$.

[c] Incluye los mono y di-éteres de etilenglicol, de dietilénglicol y de trietilénglicol $R\text{-}(OCH_2CH_2)n\text{-}OR'$, donde:

n = 1, 2 ó 3
R = grupos alquilo ó arilo
R' = R, H, o grupos que, cuando son removidos, producen éteres glicólicos con la estructura: R-(OCH2CH2)n-OH.
Los polímeros se excluyen de la categoría de glicoles.

[d] Incluyen las emisiones de fibras minerales de plantas que manufacturan o procesan fibras de vidrio, de roca o de escoria (u otras fibras derivadas de minerales) de diámetro promedio igual o inferior a 1 micrómetro.

[e] Incluye los hidrocarburos aromáticos policíclicos sustituidos y / o los no sustituidos y los compuestos aromáticos heterocíclicos con dos o más anillos fusionados de los cuales, uno al menos, tenga estructura bencenoide. La Materia Orgánica Policíclica es una mezcla de compuestos orgánicos que contienen uno o más de estos compuestos químicos aromáticos policíclicos. La Materia Orgánica Policíclica, por lo general, se forma o se emite durante algunos procesos térmicos entre los que están: (1) la combustión incompleta; (2) la pirólisis; (3) la volatilización, destilación o procesamiento de combustibles fósiles o bituminosos y (4) la destilación o procesamiento térmico de combustibles no fósiles.

[f] Un tipo de átomo que de manera espontánea sufre descomposición radiactiva.

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Diciembre18, 1997

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Asunto: Transmisión del *Manual de Fundamentos de los Inventarios de Emisiones* para el Proyecto de Metodología para Inventarios de Emisiones de México

Estimado John:

Anexa se encuentra una copia final del Volumen II (*Fundamentos de los Inventarios de Emisiones)* de los Manuales para el Programa del Inventario de Emisiones de México. Este es el quinto documento que hemos desarrollado dentro de nuestra serie de manuales para el inventario de emisiones. Adicionalmente, estamos entregando al INE una copia "master" impresa por un lado y archivos electrónicos (en Word 6.0) que contienen tanto el texto como las imágenes para facilitar los esfuerzos de reproducción y traducción. Los "enlaces" electrónicos serán desarrollados proóximamente.

En caso de cualquier pregunta o comentarios relacionados con el material anexo, comuníquese conmigo al (916) 857-7451 o con Marty Wolf al (916) 857-7468.

Atentamente

William R. Oliver
Gerente de Proyecto

Anexos

c: Victor Hugo Páramo, INE (cinco copias)
Comité Asesor Binacional
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MEXICO EMISSIONS INVENTORY PROGRAM MANUALS

VOLUME III - BASIC EMISSION ESTIMATING TECHNIQUES

Prepared for:

Western Governors' Association
Denver, Colorado

and

Binational Advisory Committee

Prepared by:

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May 17, 1996

PREFACE

Air pollution can negatively impact public health when present in the atmosphere in sufficient quantities. Most rural areas rarely experience air quality problems, while elevated concentrations of air pollution are commonly found in many urban environments. Recently, urbanization and industrial activity throughout Mexico has increased, resulting in air quality concerns for several regions.

Air pollution results from a complex mix of, literally, thousands of sources, from industrial smoke stacks and motor vehicles, to the individual use of grooming products, household cleaners, and paints. Even plant and animal life can play an important role in the air pollution problem. Due to the complex nature of air pollution, detailed regional plans are needed to identify the emission sources and to develop methods for reducing the health impact from exposure to air pollution. Examples of air quality planning activities include:

- Application of air quality models;
- Examination of the sources emitting air pollution for emissions control analysis, where necessary;
- Development of emission projections to examine possible changes in future air quality;
- Analysis of emission trends; and
- Analysis of emissions transport from one region to another.

Development of fundamentally sound emissions inventories is a key aspect for each of these air quality planning functions.

Developing emission estimates to meet air quality planning needs requires continual development and refinement; “one time” inventory efforts are not conducive to the air quality planning process. For lasting benefit, an *inventory program* must be implemented so that accurate emission estimates can be developed for all important geographic regions, refined over time, and effectively applied in the air quality planning and monitoring process. Therefore, a set of inventory manuals is being developed that can be used throughout the country to help coordinate the development of consistent emission estimates. These manuals are intended for use by local, state, and federal staff, as well as by industry and private consultants. The purpose of these manuals is to assist in implementing the inventory program and in maintaining that program over time so that emissions inventories can be developed in periodic cycles and continually improved.

The manuals cover inventory program elements such as estimating emissions, program planning, database management, emissions validation, and other important topics. Figure 1 shows the complete series of manuals that will be developed to support a comprehensive inventory program. The main purpose of each manual is summarized below.

Volume I—Emissions Inventory Program Planning. This manual addresses the important planning issues that must be considered in an air emissions inventory program. Program planning is discussed not as an “up-front” activity, but rather as an ongoing process to ensure the long-term growth and success of an emissions inventory program. *Key Topics*: program purpose, inventory end uses, regulatory requirements, coordination at federal/state/local levels, staff and data management requirements, identifying and selecting special studies.

Volume II—Emissions Inventory Fundamentals. This manual presents the basic fundamentals of emissions inventory development and discusses inventory elements that apply to multiple source types (e.g., point and area) to avoid the need for repetition in multiple volumes. *Key Topics*: applicable regulations, rule effectiveness, rule penetration, pollutant definitions (e.g., how to properly exclude nonreactive volatile compounds), point/area source delineation, point/area source reconciliation.

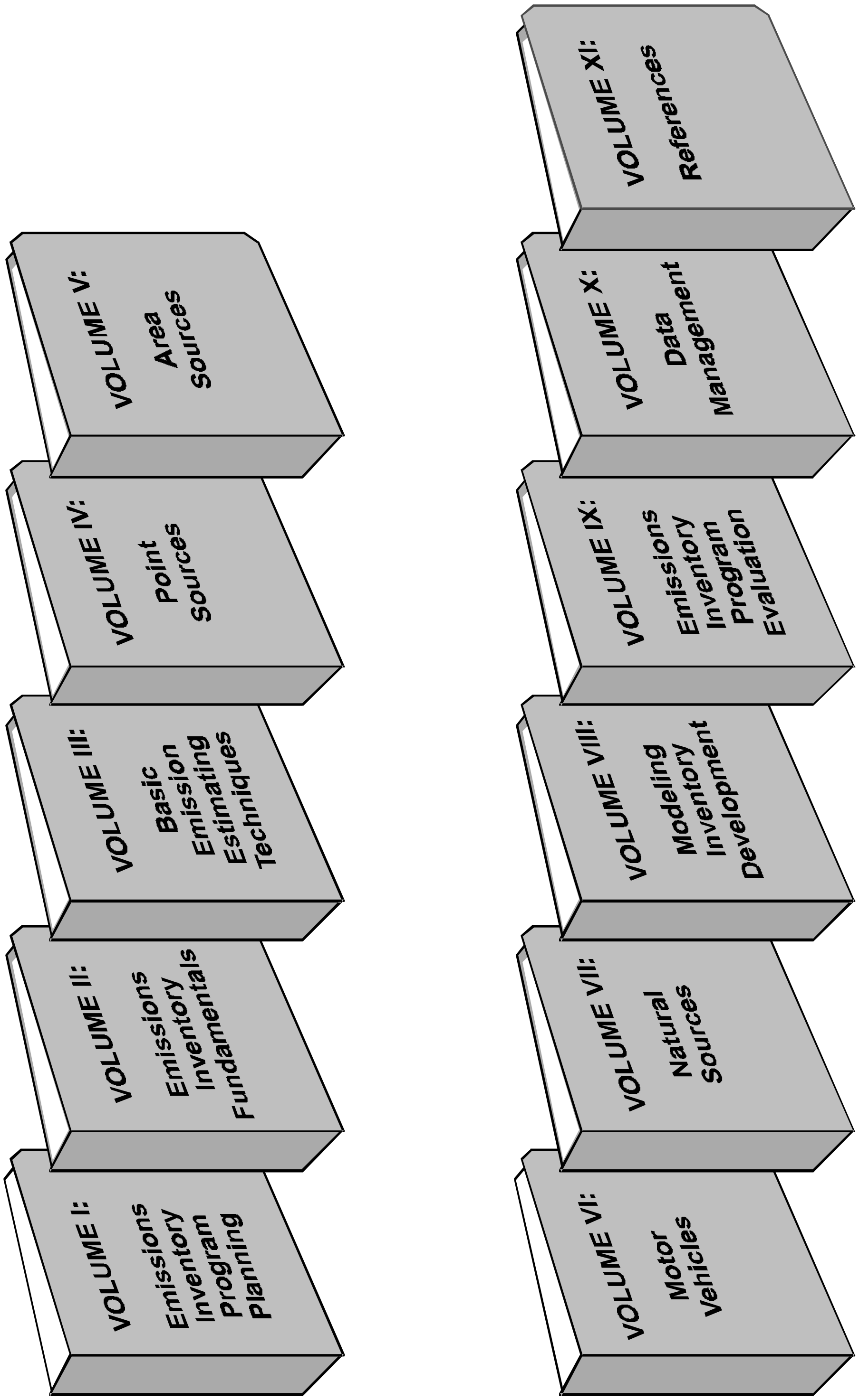

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Figure 1. Mexico Emissions Inventory Program Manuals

Volume III—Emissions Inventory Development: Basic Emission Estimating Techniques (EETs). This manual presents the basic EETs used to develop emission estimates, including examples and sample calculations. Inventory tools associated with each methodology are identified and included in Volume XI (References). *Key Topics*: source sampling, emissions models, surveying, emission factors, material balance, extrapolation.

Volume IV—Point Sources. This manual provides guidance for developing the point source emissions inventory. A cross-reference table is provided for each industry/device type combination (e.g., petroleum refining/combustion devices) with one or more of the basic EETs presented in Volume III. *Key Topics*: cross-reference table, stack parameters, control devices, design/process considerations, geographic differences and variability in Mexico, quality assurance/quality control (QA/QC), overlooked processes, data references, data collection forms.

Volume V—Area Sources (includes non-road mobile). This manual provides guidance for developing the area source emissions inventory. After the presentation of general area source information, a table is provided to cross-reference each area source category (e.g., asphalt application) with one or more of the basic EETs presented in Volume III. Then, source category-specific information is discussed for each source category defined in the table. *Key Topics*: area source categorization and definition, cross-reference table, control factors, geographic differences and variability in Mexico, QA/QC, data references, data collection forms (questionnaires).

Volume VI—Motor Vehicles. Because motor vehicles are inherently different from point and area sources, the available estimation methods and required data are also different. To estimate emissions from these complex sources, models are the preferred estimation tool. Many of these models utilize extensive test data applicable to a given country or region. This manual focuses primarily on the data development phase of estimating motor vehicle emissions. *Key Topics*: available estimation methods, primary/secondary/tertiary data and information, source categorization, emission factor sources, geographic variability within Mexico, QA/QC.

Volume VII—Natural Sources. This manual provides guidance for developing a natural source emissions inventory (i.e., biogenic volatile organic compounds [VOC] and soil oxides of nitrogen [NO_x]). In addition, this manual includes the theoretical aspects of emission calculations and discussion of specific models. *Key Topics*: source categorization and definition, emission mechanisms, basic emission algorithms, biomass determination, land use/land cover data development, temporal and meteorological adjustments, emission calculation approaches.

Volume VIII—Modeling Inventory Development. This manual provides guidance for developing inventory data for use in air quality models and addresses issues such as temporal allocation, spatial allocation, speciation, and projection of emission estimates. *Key Topics*: definition of modeling terms, seasonal adjustment, temporal allocation, spatial allocation, chemical speciation, projections (growth and control factors).

Volume IX—Emissions Inventory Program Evaluation. This manual consists of three parts: QA/QC, uncertainty analysis, and emissions verification. The QA/QC portion defines the overall QA/QC program and is written to complement source specific QA/QC procedures written into other manuals. The uncertainty analysis includes not only methods of assessing uncertainty in emission estimates, but also for assessing uncertainty in modeling values such as speciation profiles and emission projection factors. The emissions verification section describes various analyses that can be performed to examine the accuracy of the emission estimates. Examples include receptor modeling and trajectory analysis combined with specific data analysis techniques. *Key Topics*: description of concepts and definition of terms, inventory review protocol, completeness review, accuracy review, consistency review, recommended uncertainty EETs, applicable emission verification EETs.

Volume X—Data Management. This manual addresses the important needs associated with the data management element of the Mexico national emission inventory program. *Key Topics*: general-purpose data management systems and tools, specific-purpose software systems and tools, coding system, confidentiality, electronic submittal, frequency of updates, recordkeeping, Mexico-specific databases, reports.

Volume XI—References. This manual is a compendium of tools that can be used in emission inventory program development. Inventory tools referenced in the other manuals are included (i.e., hardcopy documents, electronic documents, and computer models).

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ACRONYMS

API	American Petroleum Institute
ASTM	American Society for Testing and Materials
BIF	boiler and industrial furnace
Btu	British thermal unit
CAA	Clean Air Act
CANACINTRA	The Nacional Cámara de la Industria de la Transformación
CEM	continuous emission monitor
CFR	Code of Federal Regulations
CMAP	Mexican Classification of Activities and Products
CO	carbon monoxide
CO_2	carbon dioxide
DDF	Department of the Federal District
dscfm	dry standard cubic feet per minute
dscm	dry standard cubic meter
EET	emission estimating techniques
FIRE	Factor Information Retrieval System
ft^3	cubic feet
GHG	greenhouse gas
gr/dscf	grains per dry standard cubic feet
HAP	hazardous air pollutant
HCl	hydrogen chloride

hr	hour
ID	identification
INE	National Institute of Ecology
INEGI	Instituto Nacional de Estadística, Geografía e Informática
IPCC	Intergovernmental Panel on Climate Change
Kb	kilobyte
kg	kilogram
kJ	kilojoule
km	kilometer
L	liter
LAEEM	Landfill Air Emissions and Estimation Model
lb	pound
LPG	liquefied petroleum gas
m^3	cubic meter
Mg	megagram (i.e., 10^6g = 1 metric tonne)
mg	milligram
NH_3	ammonia
NO_x	oxides of nitrogen
O_2	oxygen
OAQPS	Office of Air Quality Planning and Standards
OH	hydroxyl radicals
PM	particulate matter

PM_{10}	particulate matter of 10 microns
ppbv	parts per billion by volume
ppmv	parts per million by volume
psig	pounds per square inch - gauge
QA	quality assurance
QC	quality control
RO_2	peroxy radicals
SO_2	sulfur dioxide
SO_x	oxides of sulfur
THC	total hydrocarbons
ton	English ton (i.e., 2,000 lbs)
tonne	metric ton (i.e., 1,000 kg)
tpy	tons per year
TSDF	treatment, storage, and disposal facilities
TSP	total suspended particulate
U.S.	United States
U.S. EPA	United States Environmental Protection Agency
VOC	volatile organic compounds
WHO	World Health Organization

1.0 INTRODUCTION

This manual presents the basic EETs used to develop point and area source (including non-road mobile) emission estimates. The basic EETs presented here were identified by examining inventory methods currently used in Mexico, Europe, Asia, and the United States (U.S.). Inventory techniques developed by the World Health Organization (WHO) and techniques used to develop global-scale greenhouse gas (GHG) emissions inventories were also reviewed. The six different basic EETs identified are:

- Source Sampling: direct measurements of the pollutant concentration in a known volume of gas and of the stack gas flow rate. Most commonly used for combustion emission sources.
- Emissions Models: equations developed when emissions are not directly related to a single parameter that may use computers if a large number of complex calculations are involved. For example, the U.S. Environmental Protection Agency (U.S. EPA) TANKS program is a computer emissions model used to estimate emissions from storage tanks.
- Surveying: questionnaires designed to collect emissions data. Often used to collect point source data developed at the facility level or area source data from a representative sampling of sources from a given source category.
- Emission Factors: ratios that relate the quantity of a pollutant emitted to a single unit of activity. The activity may be process-based data (e.g., throughput, hours of operation, surface area) or census-based data (e.g., population, employment).
- Material Balance: using measurements of all but the air component of a process to determine the air emissions. Most commonly used for solvent evaporation sources where data are not available to support the other approaches.
- Extrapolation: scaling emissions from a given source to another source based on a scaling parameter known for both sources (e.g., production quantity, land area, number of employees).

In this manual, each of the basic EETs is explained and discussed in detail. In addition, sample calculations are provided to illustrate the implementation of each basic EET.

The basic EETs manual is intended to be used in conjunction with the Point and Area Source Manuals (i.e., Volumes IV and V, respectively). The Point and Area Source Manuals each contain a table that cross-references each point or area source category with one or more of the basic EETs which may be used to develop emission estimates. For example, for Electric Utilities/Combustion Emissions, the Point Source Manual cross-reference table refers the user to source sampling, emission factors, or material balance as the basic EETs to use to develop emission estimates for this source category. These basic methods are described in this basic EETs manual.

The remainder of this manual is organized as follows:

- Section 2.0 presents the basic emission estimating equation and defines and provides general guidance on information sources for each equation variable;
- Section 3.0 addresses source sampling;
- Section 4.0 presents emissions models (mechanistic and multivariate);
- Section 5.0 discusses surveying;
- Section 6.0 covers emission factors (process-based and census-based);
- Section 7.0 describes material balance calculations;
- Section 8.0 explains extrapolation;
- Appendix III-A contains sample calculations for emissions models;
- Appendix III-B contains information on how to obtain U.S. EPA air emission estimating tools; and
- Appendix III-C contains an example surveying form for sample point source questionnaire (i.e., INE’s Encuesta Industrial).

2.0 FUNDAMENTAL EMISSION ESTIMATING EQUATION

Developing an emissions inventory program for Mexico will require a combination of approaches. No single emissions inventory method can be used to estimate emissions for all emission source categories. Figure 2-1 depicts various approaches for estimating emissions that should be considered when analyzing the costs versus the quality of the results. In regions with serious environmental impacts from air pollution, more sophisticated and costly emission determination methods may be warranted, such as source sampling. Conversely, in regions with minimal environmental problems, a less expensive estimation method such as the use of emission factors may be acceptable.

The fundamental emission estimating equation is:

$$\mathbf{E = A \times EF \times [1 - (CE/100 \times RE \times RP)] \times T \times M\%} \qquad (2\text{-}1)$$

where:
E = Emission Rate
A = Activity Rate (e.g., throughput, population, etc.)
EF = Emission Factor (lb/activity rate unit)
CE = Control Efficiency (%)
RE = Rule Effectiveness
RP = Rule Penetration
T = Temporal Adjustment
M% = Mass% of pollutant

The accuracy of the emission estimate is dependent upon the relative accuracy of each of these individual components. Errors introduced into any one of these components will affect the final emission estimate.

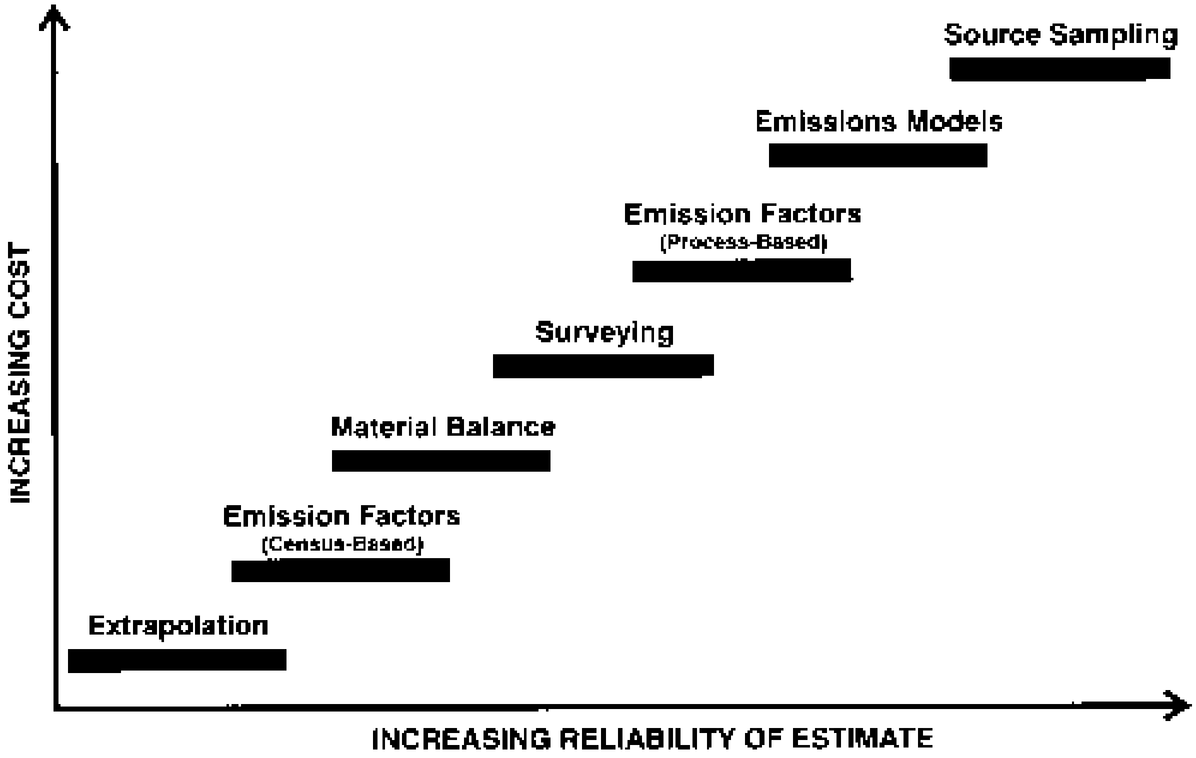


Figure 2-1. Emission Estimation Hierarchy

The information presented in this manual focuses on the first two components of the basic emission estimating equation: emission factor and activity rate. Control efficiencies are addressed more in the Point and Area Source Manuals (Volumes IV and V). Rule effectiveness and rule penetration are discussed further in the Emission Inventory Fundamentals Manual (Volume II). Temporal adjustment and pollutant mass percent (i.e., non-reactive compounds and speciation profiles) are explained in more detail in the Modeling Inventory Development Manual (Volume VIII). The rest of this section provides definitions for each component of the basic emission estimating equation and general guidance on where to find information for each one.

Activity Rate. Activity data are usually directly related to the emissive process. For industrial processes, activity data are generally reported as process weight rates (e.g., kg, ton, or L per month of material used or manufactured). Similarly, for fuel-burning equipment, activity data are reported as fuel consumption rates (e.g., tons, L, or m^3, or MJ per hour or per month). In many instances, conversion factors must be applied to convert reported consumption or production values to units that correspond to the emission factor throughput units (e.g., tons, barrels, etc.). In addition, if U.S. emission factors are used, conversions from standard to metric units may also be necessary. Point source activity data are usually process-based and will most likely be collected by facility personnel and reported in summary format to the agency (e.g., the industrial questionnaire). Area source activity data are often surrogates which are demonstrated or assumed to be correlated to the emissive process (e.g., number of employees). Area source activity data are usually collected by the agency from available census data (e.g., from the Instituto Nacional de Estadística, Geografía e Informática [INEGI]) or surveying of small facilities.

Emission Factor. An emission factor is a ratio that relates the quantity of a pollutant released to the atmosphere to a unit of activity. Emission factors are generally classified into two types: process-based and census-based. Process-based emission factors are commonly used to develop point source emission estimates, and are often combined with the activity data collected from a surveying or material balance approach. Census-based emission factors, on the other hand, are widely used to develop area source emission estimates. The most comprehensive source for U.S.-specific emission factors for criteria pollutants is *AP-42 Compilation of Air Pollutant Emission Factors* (U.S. EPA, 1995a). Also, the U.S. EPA's Factor Information Retrieval System (FIRE) database is a consolidation of emission factors for both criteria and toxic air pollutants.

Control Efficiency. The overall control efficiency is the product of the capture device efficiency and the control device efficiency. The capture device efficiency indicates the percentage of the emission stream that is taken into the control system, and the control device efficiency indicates the percentage of the air pollutant that is removed from the emission stream before release to the atmosphere. Control device efficiency data may be determined for specific equipment from source tests measuring pollutant concentrations before and after application of the control device, from literature values (e.g., *Volume IV—Point Sources, Table 4-1*) or from the manufacturer's design specification or guaranteed performance specification. The overall control efficiency may also need to be adjusted to reflect control device downtime during maintenance operations or upset conditions.

Rule Effectiveness. Emissions inventory experience has shown regulatory programs to be less than 100 percent effective for most source categories. Rule effectiveness reflects the ability of a regulatory program to achieve the required emissions reductions. The intent of this factor is to account for the fact that most emission control equipment does not achieve emission reductions at the designed rates at all times and under all conditions. Process upsets, control equipment malfunctions, operator errors, equipment maintenance, and other nonroutine operations are typical examples of times when control device performance is expected to be less than optimal. A default fraction of 0.80 (equal to 80 percent effectiveness) was established by the U.S. EPA to estimate rule effectiveness required in some regions; however, the limited accuracy of using a single default value for all source categories has been questioned and efforts continue to develop guidance for developing rule effectiveness factors for specific source types.

Rule Penetration. Rule penetration is the extent to which a regulation covers emissions from all sources within a source category. For example, a rule may be written such that only the larger surface coating facilities must comply with new control requirements. If area source emissions for all coating facilities are being estimated together as a single source category, then a rule penetration factor must be developed, since not all surface coating facilities will be subject to the rule, and therefore, not all surface coating emissions will be further controlled.

Temporal Adjustment. Most inventories traditionally estimate annual emissions. Hence, all procedures, emission factors, correction factors, and activity levels used in the inventory have been developed to represent annual average conditions. For certain air quality planning activities, temporal adjustments must be made to the annual emission estimates. For example, high photochemical ozone levels are generally associated with the warmer months of the year, while emissions from some sources vary seasonally. For air quality planning purposes, ozone precursor emissions should be determined during the months constituting the ozone season for ozone inventories. Peak ozone season for most areas of the U.S. is May through September. However, in Mexico City, the most critical ozone season is in the winter (i.e., from 15 November to 15 February). Regional air quality modeling efforts may require hourly emission rates. Default temporal profiles (i.e., hours/day, days/week, weeks/yr) are often used to develop hourly estimates from annual estimates.

Pollutant Mass Percent. In some instances, the pollutant or pollutant group defined by an emission factor is not the same as the pollutant or pollutant group defined for the emissions inventory. For example, several VOCs, are considered photochemically nonreactive by the U.S. EPA as defined in the Clean Air Act (CAA) and are not included in VOC emissions inventories in the U.S. (40 CFR 60, 1992). Many of the nonreactive compounds are halogenated VOCs, which find principal application as metal and fabric cleaners, refrigerants, and propellants in aerosol products. A major industrial category employing these halogenated compounds is degreasing. As another example, the vast majority of landfill emissions are methane, which is not considered a VOC. To the extent that emissions from these various processes are known to be comprised of nonreactive VOC, they may be excluded from the total hydrocarbon (THC) emissions inventories (e.g., the national point source emissions inventory data, SNIFF) for certain emission inventory purposes such as ozone modeling. Similarly, particulate matter (PM) profiles showing particle size distribution data can be used to determine the mass percent of total suspended particulate (TSP) emissions that should be included in an inventory of particulate matter with an aerodynamic diameter less than 10 microns (PM_{10}).

The pollutant mass percent may also be used to estimate emissions of a given chemical species. For example, speciation profiles may be used to obtain data on the beryllium percent of the total PM emissions from mining operations or the benzene percent of the total VOC emissions from a storage tank.

3.0 SOURCE SAMPLING

This section describes the use of source sampling data for estimating emissions from point sources. Examples are provided to illustrate the calculation of emissions from data collected during the source tests. Specific source sampling methods and data reduction procedures can be found in published source sampling reference methods (40 CFR 60, 1992).

Due to the technical complexities of source sampling, substantial time and equipment is involved to obtain accurate and valid emissions data for numerous pollutants from a source. Consequently, conducting source sampling at a facility can be very expensive. However, if properly applied, source sampling can provide a better estimate of emissions from a source than emission factors or material balances. The use of source sampling data reduces the number of assumptions regarding the applicability of generalized emission factors, air pollution control device efficiencies, equipment variations, or fuel characteristics that are applied to similar types of emission sources in order to estimate emission rates of pollutants.

3.1 General Information

The purpose of any source sampling program is to determine the pollutant concentration in a gas stream or the pollutant emission rate from a stack or process exhaust vent. By measuring the pollutant concentration in a known volume of gas and determining the stack gas flow rate, the pollutant mass emission rate can be calculated.

Source tests are integrated, short-term measurements that are typically conducted over 1 to 4 hours. In order to collect a representative sample, three source tests should be conducted at a stack or vent for each pollutant of concern under a defined operating condition. Variations in the process operation during sampling can add a large degree of variability to source sampling data. Therefore, key parameters of a process operation that can impact pollutant emissions from the source should be monitored during sample collection.

Collection of specific process data during the source tests is critical to correlating sampling results to process operation. For example, emissions will fluctuate as changes occur in the process (e.g., decreasing temperature of a combustion chamber may increase emissions of some pollutants). Collection of specific process data is also important to correlate emissions to process activity and to develop emission factors. For example, if 0.5 kg/hr NO_x is emitted during a 4 hour source test in which 400 liters of fuel were burned, then an emission factor of 0.005 kg of NO_x per liter of fuel can be determined. This source specific emission factor can then be used to estimate NO_x emissions from this source based on the amount of fuel burned.

Source sampling data should be used for emission estimation purposes only if the data were obtained under conditions that were representative of normal operating conditions at the process. Emission data determined from a source sampling event can be extrapolated to estimate annual emissions from a source if the process does not vary significantly in operation. If the process does vary significantly, then multiple source tests will need to be conducted to obtain representative emission results. If facility operation cannot be adequately characterized, then source sampling data should not be used to estimate emissions from the source.

The procedures for conducting source tests are described in various reference methods (e.g., U.S. EPA methods, boiler and industrial furnace (BIF) methods, etc.). Sampling methods that describe procedures for short-term sample collection are referred to as manual methods. These methods are usually specific for a source type (e.g., fossil fuel combustion sources, fuel gas streams at petroleum refineries, electric steam generators) and for a pollutant (e.g., particulate matter, hydrogen sulfide, lead) or class of compounds (e.g., dioxins, VOCs). The extractive sampling systems for these pollutants usually consist of an absorbing solution or media to capture the pollutant, a pump to pull the sample gas through the solution or media, and a dry gas meter to measure the sample gas volume. Since a different type of absorbing solution or media is used for the collection of different pollutants, source sampling for a variety of pollutants (e.g., metals, particulate matter, dioxins) is complex, labor intensive, and expensive. A schematic of a manual sampling system used to determine particulate matter emissions from a stationary source (known as a Method 5 sampling train) is shown in Figure 3-1.

An alternative to manual source sampling is continuous monitoring, which takes into account process variability over time. Instruments or continuous emission monitors (CEMs) are typically used to measure stack gas concentrations of nitrogen oxides (NO_x), carbon dioxide (CO_2), carbon monoxide (CO), sulfur dioxide (SO_2), and total hydrocarbons (THC). There are also commercially available CEMs to measure opacity, hydrogen chloride (HCl) and ammonia (NH_3). CEMs can either be permanently installed at a source to generate data 24-hours a day or they can be used for emissions monitoring during a defined source testing period (e.g., for 1 to 4 hours). A CEM system consists of a pump to withdraw the sample gas from the source, a series of instruments or analyzers to analyze the gas for a specific pollutant, and a data acquisition system to record the data over time. A schematic of a CEM system is shown in Figure 3-2.

3.2 Example Calculations Using Source Sampling Data

Following the completion of a source test, the sampling data (including pollutant concentration and exhaust gas volumetric flow rate) are usually presented in a report. Most source sampling reports summarize emissions for each pollutant by expressing them in terms of either:

- A mass loading or emission rate (mass of pollutant emitted per unit of time); or
- An emission factor (mass of pollutant emitted per unit of process activity).

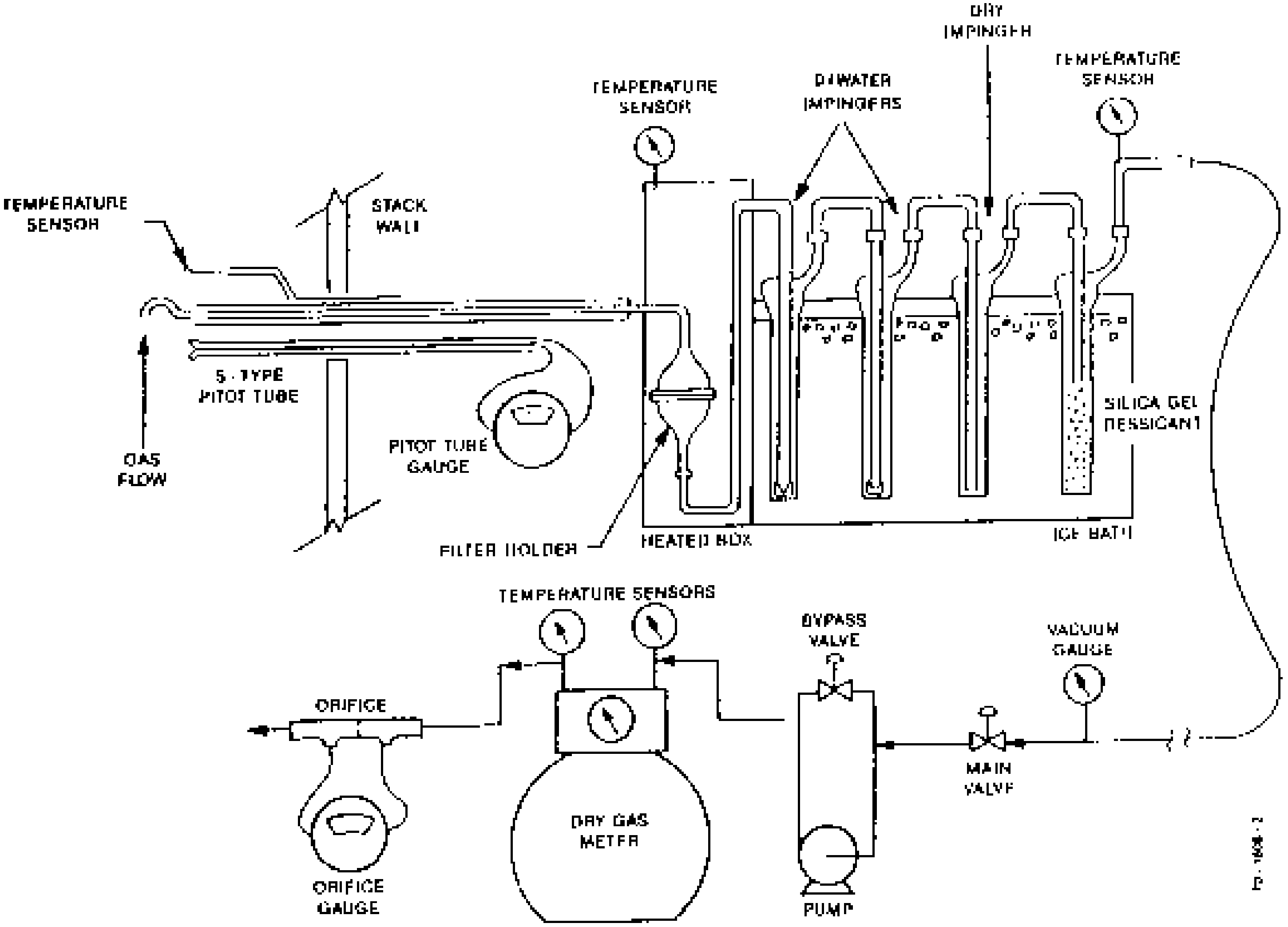


Figure 3-1. Sampling System for Particulate Matter (U.S. EPA Method 5 Sampling Train)

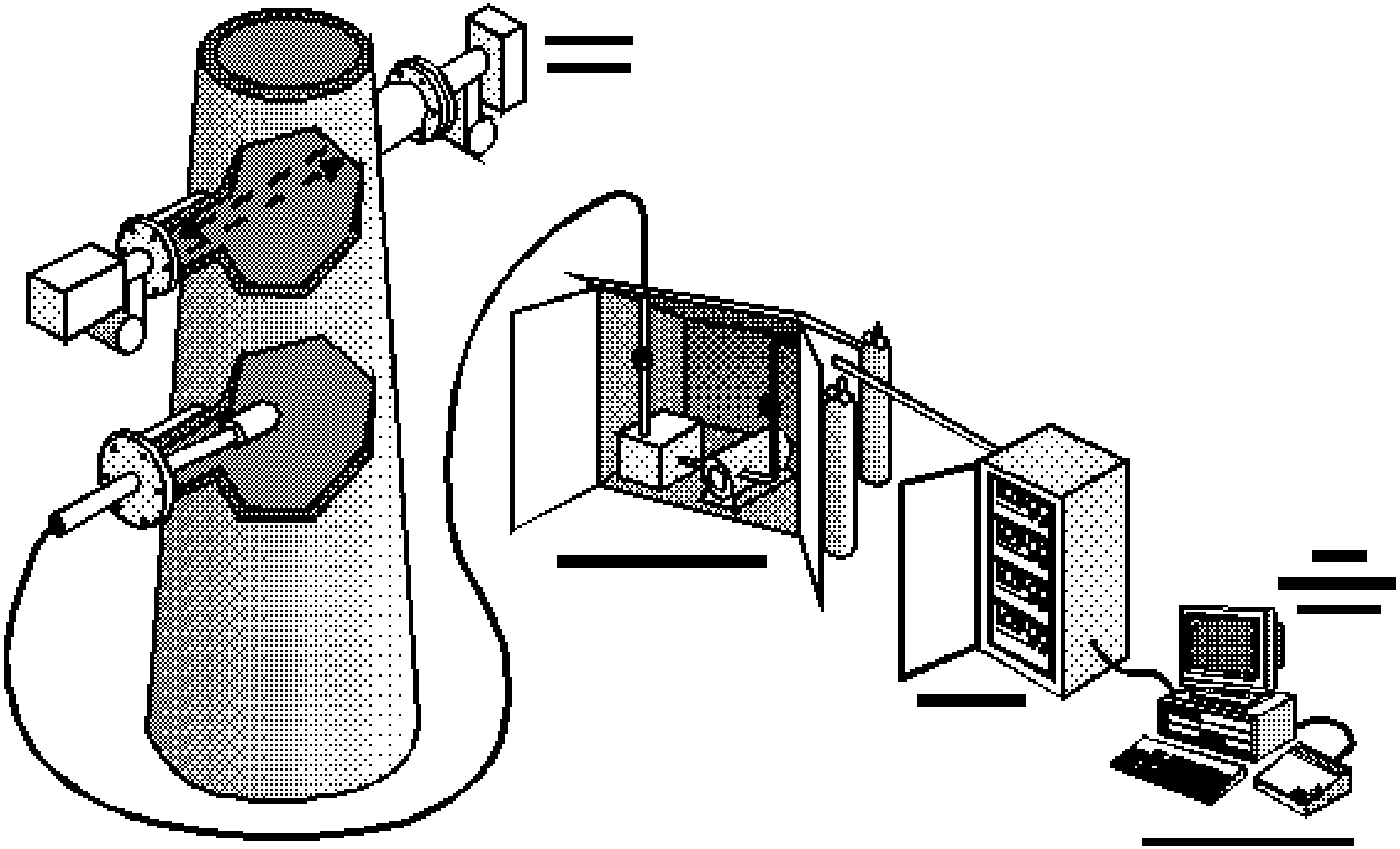


Figure 3-2. A continuous emission monitoring (CEM) system

The variables and symbols used for the calculations are listed in Table 3-1. The examples provided below show how to calculate mass emission rates or emission factors from source sampling data.

Given the following source specific data,

Example 3-1:

ΔV = 0.78 Normal cubic meters (Nm^3);

M_r = 5.5 milligrams (mg);

M_f = 9.5 mg;

Q = 34,170 Normal cubic meters per hour (Nm^3/hr);

T = 2,920 hours per year (hr/yr);

R = 118 million kilo Joules per hour (MMkJ/hr).

Calculate the exhaust gas particulate matter concentration, C_s, in units of milligrams per Normal cubic meter (mg/Nm^3):

Step 1

$$\mathbf{C_s = (M_r + M_f) / \Delta V} \tag{3-1}$$

$$= (5.5 \text{ mg} + 9.5 \text{ mg}) / 0.78 \text{ Nm}^3$$
$$= 19.2 \text{ mg/Nm}^3$$

Calculate the mass emission rate, MER, in kilograms per hour (kg/hr):

Table 3-1

List of Variables and Symbols for Emission Calculations

Variable	Symbols	Units
Gas sample volume	ΔV^a	Normal cubic meter [dry basis] (Nm^3)
Mass of particulate collected in the rinse sample	M_r	milligrams (mg)
Mass of particulate collected on the filter sample	M_f	mg
Exhaust gas volumetric flow rate at standard conditions	Q	Normal cubic meter per hour [dry basis] (Nm^3/hr)
Exhaust gas particulate matter concentration	C_s	milligrams per Normal cubic meter [dry basis] (mg/Nm^3)
Mass emission rate	MER	kilograms per hour (kg/hr)
Annual mass emission rate	MER_a	metric tons per year (metric ton/yr)
Annual hours of operation	T	hours per year (hr/yr)
Activity mass emission rate	MER_b	kilograms per million kilo Joule (kg/MMkJ)
Boiler heat input rate	R	MMkJ/hr
Pollutant concentration	C	parts per million by volume [dry basis] (ppmv).
Molecular weight of the pollutant	MW	gram per gram-mole (g/g-mole)
Molar volume	V	Volume occupied by one mole of ideal gas at standard temperature and pressure (0.024 m^3/g-mole at 20°C and 1 atmosphere)
Fuel factor from U.S. EPA Method 19	F_d^b	dry standard cubic meters per Joule at 0% oxygen [dry basis] (dscm/J)
Measured oxygen concentration	$O_2\%$	percent [dry basis]
Concentrations of hydrogen, carbon, sulfur, nitrogen, and oxygen	H, C, S, N, O	percent as determined by fuel analysis
Higher heating value of fuel	HHV	kilo Joule per kilogram (kJ/kg)

[a] Normal cubic meter is based on O°C and 760 mm Hg.

[b] standard cubic meter is based on 20°C and 760 mm Hg.

Step 2

$$\mathbf{MER = C_s \times Q/(10^6)} \qquad (3\text{-}2)$$

$$= 19.2 \text{ mg/Nm}^3 \times 34{,}170 \text{ Nm}^3\text{/hr/}(10^6 \text{ mg/kg}) = 0.66 \text{ kg/hr}$$

These data are expressed in typical units for particulate matter emissions. Results can also be expressed in other units such as milligrams per Normal cubic meter (dry basis) (mg/dscm) using standard conversion factors. Mass emission rates are often expressed on an annual basis (e.g., metric tons per year) as well. These estimates generally include an actual annual usage rate (i.e., hours per year), as most sources typically do not operate continuously throughout the entire year.

Assuming that the source discussed above operates 2,920 hr/yr, calculate the annual particulate matter mass emission rate (MER_a) in metric tons/yr:

Step 3

$$MER_a = MER \times T / 1{,}000 \qquad (3\text{-}3)$$

$$MER_a = 0.66 \text{ kg/hr} \times 2{,}920 \text{ hr/yr} / (1{,}000 \text{ kg/metric ton})$$

$$MER_a = 1.93 \text{ metric tons/yr}$$

Some emissions data are also expressed on a per unit of activity basis as an emission factor. These emission factors are typically expressed as a weight of pollutant emitted per unit of process activity. As an example, calculate the activity mass emission rate (MER_b) of particulate matter from a boiler with a heat input rate of 118 MMkJ/hr:

Step 4

$$MER_b = MER / R \qquad (3\text{-}4)$$

$$MER_b = 0.66 \text{ kg/hr} / (118 \text{ MMkJ/hr})$$

$$MER_b = 0.0056 \text{ kg/MMkJ}$$

Concentrations of pollutants that are present as a particulate or an aerosol (e.g., PM_{10}, lead, dioxins) are usually expressed in mass per units volume unit such as micrograms per Normal cubic meter. Concentrations of other pollutants that are present as a vapor (e.g., NO_x, SO_2, CO) are generally expressed in volume/volume units such as parts per million by volume (ppmv) or parts per billion (ppbv) units.

3.3 Example Calculations Using CEM Data

To determine SO_2, NO_x, THC, and/or CO emissions, a facility may install a CEM system which continuously measures pollutant concentrations (in ppmv). The CEM system is typically equipped with an oxygen (O_2) and/or CO_2 monitor; these gases are considered diluent gases (rather than pollutants) and they are monitored to serve as indicators of the exhaust gas flow rate and/or excess air flow. O_2 and CO_2 concentrations are typically reported in units of percent (by volume) since they are much higher than the levels of the other CEM gases noted (i.e., ppmv). Depending on the regulatory requirements and the type of source, these instruments may be either permanently installed to collect data continuously during unit operation or they may be used temporarily to collect data over a certain time period.

The CEM concentration data are generally transmitted from the instrument to a data logging system which is programmed to store the data and prepare reports in a site-specific format. The concentration data are often averaged for specific time intervals (e.g., 10-minute, 1-hour, 24-hour).

In addition to the concentration units, the emissions data are often reported in other units, such as mass emission rates (e.g., kg/hr), or emission factors (kg/process unit). In order to convert the concentration units to these other data forms, additional data are required. To convert the concentration data to mass rate data, the exhaust gas volumetric flow rate (e.g., in units of Normal cubic meters per hour) must be either measured or estimated. The source may be equipped with an exhaust gas flow rate monitor which will provide continuous flow rate data to the system or the flow rate may be measured using a pitot tube. It is also possible to estimate the flow rate based on empirical measurements, fuel rate measurements, diluent gas concentrations, or air intake measurements (e.g., fan speed, damper positions). To convert the emission data to emission rate units (e.g., kg/MMkJ of heat input or kg/metric ton of coal fired), the process unit rate (e.g., MMkJ/hr, heat input or tons per hour of coal fired) must be either measured or estimated.

Empirical fuel factors, referred to as F-factors, may also be used to convert fuel usage rate data to heat input or gas flow rates. F-factors are usually specific to a fuel type (e.g., natural gas, #2 fuel oil). Examples of F-factors that have been adopted by the U.S. EPA are presented in Method 19 (40 CFR 60, 1992).

The variables and symbols used in the following calculations are listed in Table 3-1.

Table 3-2 presents an example output from a CEM system, consisting of SO_2, NO_x, CO, O_2, and flow rate monitors, installed on an oil-fired boiler exhaust stack. The data in the table represent a “snapshot” of emissions from the boiler over a 60 minute period.

Table 3-2

Example CEM Output for a Boiler Burning Fuel Oil

Period	O_2 (%V)	SO_2 (ppmv)	NO_x (ppmv)	CO (ppmv)	Stack Gas Flow Rate (Nm^3/hr)
11:00	2.1	1,004.0	216.2	31.5	33,964
11:15	2.0	1,100.0	200.6	25.5	34,361
11:30	2.1	1,050.0	216.7	25.1	32,891
11:45	1.9	1,070.0	220.5	20.8	34,890
12:00	1.9	1,070.0	213.8	19.4	34,749
Average:	2.0	1,058.8	213.6	24.5	34,171

[a] Based on a fuel heating value of 41,828 kJ/kg (18,000 Btu/lb).

3.3.1 Calculating Hourly Emissions from Concentration Measurements

Although CEMs can report real-time hourly emissions automatically, it may be necessary to manually estimate a source’s annual emissions from hourly pollutant concentration data. This section describes how to calculate emissions from raw CEM concentration data.

Using the CEM data presented in Table 3-2, hourly SO_2 mass emissions for 11:00 can be calculated:

Example 3-2:

Step 1

$$\text{MER} = \frac{\text{C x MW x Q}}{(1{,}000 \text{ x V x } 10^6)} \qquad (3\text{-}5)$$

$$= \frac{1{,}004 \text{ ppmv x } 64 \text{ g/g-mole x } 33{,}964 \text{ Nm}^3\text{/hr}}{(1{,}000 \text{ g/kg x } 0.024 \text{ m}^3\text{/g-mole x } 10^6)}$$

$$= 90.9 \text{ kg/hr}$$

To calculate the average SO_2 mass emission rate for the entire sampling period:

Step 2

$$\text{MER}_{\text{ave}} = \frac{\text{C}_{\text{ave}} \text{ x MW x Q}_{\text{ave}}}{(1{,}000 \text{ x V x } 10^6)} \qquad (3\text{-}6)$$

$$= \frac{1{,}058.8 \text{ ppmv x } 64 \text{ g/g-mole x } 34{,}171 \text{ Nm}^3\text{/hr}}{(1{,}000 \text{ g/kg x } 0.024 \text{ m}^3\text{/g-mole x } 10^6)}$$

$$= 96.5 \text{ kg/hr}$$

Annual SO_2 emission can be calculated using equation 3-3, assuming the boiler operates 2,920 hours per year:

Step 3

$$\text{MER}_{\text{a}} = 96.5 \text{ kg/hr x } 2{,}920 \text{ hr/yr / } (1{,}000 \text{ kg/metric ton})$$

$$= 282 \text{ metric tons/yr}$$

Assuming the heat input of the boiler is 118 MMkJ/hr, the SO_2 activity emission rate can be calculated using equation 3-4:

Step 4

$$MER_b = 96.5 \text{ kg/hr} / (118 \text{ MMkJ/hr})$$

$$= 0.82 \text{ kg/MMkJ}$$

3.3.2 Calculating Stack Gas Flow Rate

When direct measurements of stack gas flow rates are not available, Q can be calculated using fuel factors (F-factors). The F-factor is the ratio of gas volume of the products of combustion to the heat content of the fuel and includes all components of combustion less water. This factor can be calculated from fuel ultimate analysis results using the following equation.

$$F_d = \frac{10^6 [3.64(\%H) + 1.53(\%C) + 0.57(\%S) + 0.14(\%N) - 0.46(\%O)]}{HHV} \qquad (3\text{-}7)$$

Fuel heating values are available in publications such as *Steam, Its Generation and Use* (Stultz and Kitto, 1992). The average F-factors are provided in U.S. EPA Reference Method 19 for different fuels and are shown in Table 3-3.

Using the CEM data in Table 3-2 and the F-factor for oil shown in Table 3-3, the stack gas flow rate of the boiler can be calculated.

Example 3-3:

$$Q = F_d \times \left(\frac{20.9\%}{20.9\% - O_2\%} \right) \times R \times 10^9 \qquad (3\text{-}8)$$

$$= 2.47 \times 10^{-7} \text{ dscm/J} \left(\frac{20.9\%}{20.9\% - 2\%} \right) \times 118 \text{ MMkJ/hr} \times 10^9 \text{ J/MMkJ}$$

$$= 32{,}230 \text{ dscm/hr}$$

Table 3-3

F_d Factors for Various Fuels[a]

Fuel Type	F_d	
	dscm/J[b]	**dscf/MMBtu**
Coal		
Anthracite[c]	2.71×10^{-7}	10,100
Bituminous[c]	2.62×10^{-7}	9,780
Lignite	2.65×10^{-7}	9,860
Oil[d]	2.47×10^{-7}	9,190
Gas		
Natural	2.34×10^{-7}	8,710
Propane	2.34×10^{-7}	8,710
Butane	2.34×10^{-7}	8,710
Wood	2.48×10^{-7}	9,240
Wood Bark	2.58×10^{-7}	9,600

[a] Determined at standard conditions: 20°C (68°F) and 760 mm Hg (29.92 in. Hg).

[b] dscm/J = dry standard cubic meters per Joule

[c] As classified according to ASTM Method D 388-77.

[d] Crude, residual, or distillate.

4.0 EMISSIONS MODELS

Many emission estimates are developed using an emission factor which assumes a linear relationship (i.e., an "emission factor") between the emission rate and a unit of activity (e.g., quantity of fuel consumed, production rate, population, employment, etc). For certain source categories, the functional relationship between emissions and multiple process and environmental variables are studied sufficiently to support the development of complex models. If these emissions models require complex calculations or large amounts of input data, they are likely to be computer-based.

While emissions models are designed to yield more accurate emission estimates than an emission factor approach, the accuracy of the emission estimate will always be dependent on the quality of the input data and the assumptions underlying the model. Therefore, before deciding to use a modeling approach for a given source type, it is important to compare the data needs of an emissions model with the data available. The data requirements for such models vary. To estimate emissions, one or many physical parameters may be needed from the source for which the model will be used.

Some emissions models developed in other countries may be used in Mexico. In these cases, it is especially important to consult the user's manuals for these models to identify any default values that are assumed in the absence of user-defined values, and to try and evaluate whether these default values are appropriate for use in Mexico. Also, it is important to check that the metric units of the available data are correctly converted to the standard/English units required, if U.S. models are used.

Emissions models may be classified into three types: adaptive, mechanistic, and multivariate. Adaptive models are based on software that integrates neural network, fuzzy logic, and chaotic systems into one software package (Collins and Terhune, 1994). During the setup stage, the software is trained with historic operating and emissions data. Operating parameters are then monitored and used by the software system (or "soft CEM") to predict emissions at a cost less than the application of a true CEM device. However, the purchase cost of adaptive software can still be quite expensive, approaching US$100,000. Therefore, adaptive models are not recommended for near-term inventory efforts in Mexico due to the high cost associated with implementation, and are not discussed any further in the Basic EETs Manual at this time. The rest of this section provides further description and examples of mechanistic and multivariate models.

4.1 Mechanistic Models

Mechanistic models are based on equations that have been developed using the fundamentals of chemistry, physics, and biology to describe the emission rate for a particular source type. Important VOC emitters for which a number of variables are needed to calculate emissions are petroleum product storage and handling operations (e.g., aboveground and underground storage tanks, tank car/tank truck loading, barge/ship loading, and gasoline dispensing at service stations).

The remainder of this section presents information on U.S. EPA models developed to estimate emissions from the following source categories:

- Storage Tanks;
- Petroleum Product Loading Operations;
- Landfills;
- Water and Wastewater Air Emissions Models; and
- Fugitive Dust.

For each source category, a brief summary of the emission model equations is presented, followed by a summary of the required data parameters and the recommended U.S. default values. Sample calculations for each model may be found in Appendix III-A. In cases where a computer model is available from the U.S. EPA, a brief description has been included.

For more information about U.S. EPA models and other air emission estimating tools:

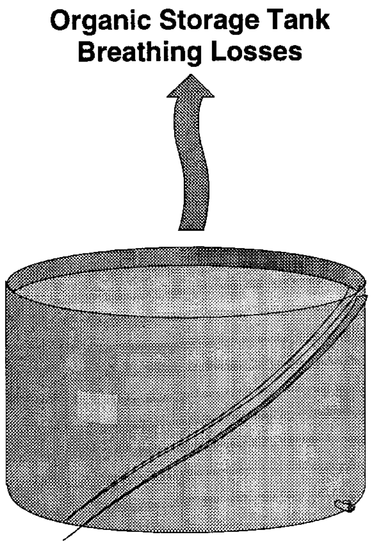
- CHIEF Bulletin Board System (BBS):
  95-919-541-5742 (dial in by modem)
- Info CHIEF Help Desk
  95-919-541-5285 (phone)
  95-919-541-5680 (fax)

Copies of many of the brochures distributed by the Info CHIEF Help Desk may be found in Appendix III-B.

4.1.1 Storage Tanks

The current U.S. EPA emission model equations for storage tanks are the best examples of mechanistic models. For example, the fixed roof storage tank model applies heat transfer and other principles to model breathing losses as shown in Figure 4-1.

The disadvantage of using the TANKS program or *AP-42* equations is that more resources are required to gather the input data and use the equations or program than using other approximations. If there is only a small amount of emissions, the extra effort may not be warranted. A compromise is to develop region-specific default emission factors using the *AP-42* equations or TANKS program that reflect average temperature, tank conditions, and chemical contents for the inventory region.



VOC emitted from vapor expansion and contraction due to changes in temperature and pressure.

Emissions = $f(V_V, W_V, \Delta P_V, P_{VA}, P_A, \Delta T_V, T_{LA})$

Where: V_V = vapor space volume of tank

W_V = vapor density of stored liquid

ΔP_V = daily vapor range of stored liquid

P_{VA} = vapor pressure at daily average liquid surface temperature

P_A = atmospheric pressure

ΔT_V = daily vapor temperature range of stored liquid

T_{LA} = daily average liquid surface temperature

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Figure 4-1. Example of Mechanistic Modeling

Fixed Roof Tanks

Emission Model Equations—The two significant types of emissions from fixed roof storage tanks are standing storage and working losses. Standing storage loss is the expulsion of vapor from a tank through vapor expansion and contraction, which are the results of changes in temperature and barometric pressure. This loss occurs without any liquid level change in the tank.

The combined loss from filling and emptying is called working loss. Evaporation during filling operations is a result of an increase in the liquid level in the tank. As the liquid level increase, the pressure inside the tank exceeds the relief pressure and vapors are expelled from the tank. Evaporative loss during emptying occurs when air drawn into the tank during liquid removal becomes saturated with organic vapor and expands, thus exceeding the capacity of the vapor space.

Fixed roof tank emissions vary as a function of vessel capacity, vapor pressure of the stored liquid, utilization rate of the tank, and atmospheric conditions at the tank location. The emission model equations are summarized below. The detailed equations may be found in *AP-42, Section 7.1* (U.S. EPA, 1995a). Required data parameters and U.S. default values are listed in Table 4-1.

Total emission losses from fixed roof tanks are defined as:

$$L_T = L_S + L_W \tag{4-1}$$

where: L_T = total losses, lb/yr;
L_S = standing storage losses, lb/yr; and
L_W = working losses, lb/yr.

Standing (breathing) loss:

$$L_S = 365\ V_V W_V K_E K_S \tag{4-2}$$

where: V_V = vapor space volume, ft^3;
W_V = vapor density, lb/ft^3;
K_E = vapor space expansion factor, dimensionless; and
K_S = vented vapor saturation factor, dimensionless.

Working loss:

$$L_W = 0.0010\ M_V P_{VA} Q K_N K_P \tag{4-3}$$

where: M_V = vapor molecular weight, lb/lb-mole;
P_{VA} = vapor pressure at daily average liquid temperature, psia;
Q = annual net throughput, bbl/yr;
K_N = turnover factor, dimensionless; and
K_P = working loss product factor, dimensionless.
(0.75 for crude oils, 1.0 for all other organic liquids)

Floating Roof Tanks

Emission Model Equations—Total emissions from floating roof tanks are the sum of withdrawal losses and standing storage losses. Withdrawal losses occur as the liquid level, and thus the floating roof, is lowered. Some liquid remains attached to the tank surface and is exposed to the atmosphere. Evaporative losses will occur until the tank is filled and the exposed surface, with the liquid, is covered again. In internal floating roof tanks with column-supported fixed roofs, some liquid also clings to the columns.

Table 4-1

Fixed Roof Tanks
Required Data Parameters and U.S. Default Values

Parameter Description	Variable	U.S. Default Value
Tank Diameter	D	
Tank Shell Height	H_S	
Tank Liquid Height	H_L	
Tank Cone Roof Slope	S_R	0.0625
Tank Dome Roof Radius	R_R	Tank Diameter (D)
Tank Capacity	V_{LX}	
Tank Paint Color	Used to determine	
Tank Paint Condition	Used to determine	
Tank Paint Solar Absorption		0.17 (i.e., white paint in good condition)
Tank breather vent pressure setting	P_{BP}	0.03 psig
Tank breather vent vacuum setting	P_{BV}	-0.03 psig
Material Throughput	Q	
Material Vapor Molecular Weight	M_V	Molecular weight values provided for selected petrochemicals.
Material Vapor Pressure at Average, Maximum, and Minimum Liquid Surface Temperatures	P_{VA}, P_{VX}, and P_{VN} at T_{LA}, T_{LX}, and T_{LN}	Vapor pressure values provided for selected petrochemicals. Vapor pressure correlations based on RVP and S available for crude oils and refined petroleum stocks.
Material Reid Vapor Pressure	RVP	Values provided for selected refined petroleum stocks.
Material Distillation Slope	S	Values provided for selected refined petroleum stocks.
Location Daily Maximum and Minimum Ambient Temperatures	T_{AX} and T_{AN}	Values provided for various U.S. locations.
Location Total Solar Insolation Factor	I	Values provided for various U.S. locations.

Standing storage losses from floating roof tanks include rim seal and roof fitting losses. Rim seal and roof fitting losses can occur through many complex mechanisms such as wind-induced loss, breathing loss from temperature and pressure changes, loss from permeation of the seal material or loss from a wicking effect of the liquid. For internal floating roof tanks, standing losses also may include deck seam losses to the extent that the seams may not be completely vapor tight.

The emission model equations are summarized below. The detailed equations and supporting data tables and figures may be found in *AP-42, Section 7.1* (U.S. EPA, February 1996). Required data parameter and U.S. default values are listed in Table 4-2.

Total emission losses from floating roof tanks are defined as:

$$\ldots\ldots\ldots\ldots \quad \mathbf{L_T = L_R + L_{WD} + L_F + L_D} \qquad (4\text{-}4)$$

where: L_T = total losses, lb/yr;

L_R = rim seal losses, lb/yr;

L_{WD} = withdrawal losses, lb/yr;

L_F = deck fitting losses, lb/yr; and

L_D = deck seam losses, lb/yr.

Rim seal loss (L_R):

$$(K_{Ra} + K_{Rb} \text{ x } v^{n}) \text{ x } \frac{P_{VA}/14.7}{[1 + (1 - P_{VA}/14.7)^{0.5}]^{2}} \text{ x } D \text{ x } M_v \qquad (4\text{-}5)$$

(Note: the v^n term is only used for external floating roof tanks.)

Withdrawal loss (L_{WD}):

$$\mathbf{L_{WD} = \frac{0.943 \text{ x } Q \text{ x } C \text{ x } W_L}{D} \text{ x } \left(1 + \frac{N_c \text{ x } F_c}{D}\right)} \qquad (4\text{-}6)$$

Deck fitting loss (L_F):

$$L_F = F_F \text{ x } \frac{P_{VA}/14.7}{[1 + (1 - P_{VA}/14.7)^{0.5}]^{2}} \text{ x } M_v \text{ x } K_c \qquad (4\text{-}7)$$

Deck seam loss (L_D):

$$_D = K_D \text{ x } S_D \text{ x } D^2 \text{ x } \frac{P_{VA}/14.7}{[1 + (1 - P_{VA}/14.7)^{0.5}]^2} \text{ x } M_v \text{ x } K \qquad (4\text{-}8)$$

where: K_{Ra} = zero windspeed rim seal loss factor, lb-mole/ft·yr

K_{Ra} = wind speed dependent rim seal loss factor, lb-mole/(mph)^n ft·yr

v = average wind speed at tank site, mph;

n = seal-related wind speed exponent;

P_{VA} = true vapor pressure at daily average surface temperature, psia;

D = tank diameter, ft;

M_v = vapor molecular weight of liquid, lb/lb-mol;

K_c = product factor (0.4 for crude oils, 1.0 for all other organic liquids);

Q = throughput, bbl/yr;

C = clingage factor, bbl/1000 ft^2;

W_L = density of liquid, lb/gal;

N_c = number of columns;

F_c = effective column diameter, ft; and

F_F = roof/deck fitting loss factor, lb-mol/yr;

K_D = deck seam loss per unit seam length factor, lb-mol/ft yr (0.34 for bolted, 0.0 for welded); and

S_D = deck seam length factor, ft/ft^2.

Table 4-2

Floating Roof Tanks
Required Data Parameters and U.S. Default Values

Parameter Description	Variable	U.S. Default Value
Tank Diameter	D	
Tank Number of Columns	N_C	Look-up table based on Tank Diameter (D).
Tank Effective Column Diameter	F_C	1.0 feet
Tank Shell Condition	Used to determine C (light rust, dense rust, gunite lining).	
Tank Clingage Factor	C	
Tank Location Wind Speed	v (also used to determine F_F)	Values provided for various U.S. locations.
Tank Construction (Welded or Riveted)	Used to determine K_{Ra}, K_{Rb}, and n	
Tank Deck Construction	Used to determine K_D (bolted or welded) and S_D (size of sheets or panels).	
Tank Deck Fitting Loss Factor	F_F	Can be calculated from tank-specific counts of number of deck fittings.
Tank Seal System (types of primary, secondary seals)	Used to determine K_{Ra}, K_{Rb}, and n	
Tank Seal Factors (and seal-related wind speed exponent)	K_{Ra}, K_{Rb}, n	For externals, use values for welded, average fit, mechanical shoe primary seal. For internals, use values for average fit, vapor-mounted primary seal only.
Tank Deck Seam Length Factor	S_D	Sd = 0.2 for bolted decks, 0.0 for welded decks.
Material Throughput	Q	
Material Vapor Molecular Weight	M_V	Molecular weight values provided for selected petrochemicals.
Material Vapor Pressure at Average Liquid Surface Temperature	P_{VA} at T_{LA}	Vapor pressure values provided for selected petrochemicals. Vapor pressure correlations based on RVP and S available for crude oils and refined petroleum stocks.

U.S. EPA Computer Model

The TANKS program is designed to estimate emissions of VOCs from storage tanks. The user provides specific information concerning the storage tank and its contents; the TANKS program then estimates the annual or seasonal emissions and produces a report. The emissions can be separated into breathing and working losses (U.S. EPA, 1996).

The TANKS program has a chemical database of over 100 organic liquids and meteorology (met.) data from over 250 cities in the U. S. The user may add new chemicals and cities (with met. data) to their version of the database. The tank styles addressed in the program include vertical and horizontal fixed roof tanks, and internal and external floating roof tanks. The tank contents can consist of single or multiple liquid components.

TANKS Version 3.0 is currently available. The emission estimating equations that form the basis of the TANKS 3.0 software program were developed by the American Petroleum Institute (API). The API retains the copyright to these equations but has granted permission for the nonexclusive, noncommercial distribution of this material to governmental and regulatory agencies. The API, however, reserves the rights regarding all commercial duplication and distribution of its material. Therefore, the TANKS program is available for public use, but the program cannot be sold without written permission from the API.

The TANKS 3.0 program is written in FoxPro2.5,™ a dBase-compatible language, and is distributed by the U.S. EPA through the CHIEF BBS or through the mail on diskette. TANKS 3.0 may require revisions and modifications to ensure consistency with U.S. EPA emission calculations methodology. The U.S. EPA welcomes feedback on the program from users to identify limitations and to suggest changes to be incorporated in future versions of TANKS.

4.1.2 Petroleum Product Loading Operations

Loading losses are the primary source of evaporative emissions of petroleum products from rail tank car, tank truck, and marine vessels. Loading losses occur as organic vapors in “empty” cargo tanks are displaced to the atmosphere by the liquid being loaded into the tanks.

Emission Model Equations—The emission model equation is presented below. More detailed information may be found in *AP-42, Section 4.4* (U.S. EPA, 1995a). Required data parameters and U.S. default values are listed in Table 4-3.

$$\mathbf{E = Q \times EF} \qquad (4\text{-}9)$$

where:
E = average annual mass emission rate, lb/yr;
Q = volume loaded, Mgal/yr; and
EF = emission factor, lb/Mgal.

$$\mathbf{= 12.46 \times \frac{S \times P \times M_v}{T}} \qquad (4\text{-}10)$$

where:
S = a saturation factor (based on fill method and service);
P = true vapor pressure of liquid loaded, psia;
M_V = molecular weight of vapors, lb/lb-mol; and
T = temperature of bulk liquid loaded, °R.

U.S. EPA Computer Model

Due to the simplicity of this model equation, no computer model is currently available.

Table 4-3

Loading Operations
Required Data Parameters and U.S. Default Values

Parameter Description	Variable	U.S. Default Value
Loading Fill Method	Used to determine S (splash or submerged).	
Loading Service	Used to determine S (clean, dedicated normal, or dedicated vapor balance).	
Material Throughput	Q	
Material Saturation Factor	S	Look-up table based on fill method and service.
Material Vapor Molecular Weight	M_V	Molecular weight values provided for selected petrochemicals in *AP-42, Section 7.1*.
Material Vapor Pressure at Average Liquid Surface Temperature	P	Vapor pressure values provided for selected petrochemicals in *AP-42, Section 7.1*. Vapor pressure correlations based on RVP and S available for crude oils and refined petroleum stocks.
Material Bulk Loading Temperature	T	

4.1.3 Landfills

Methane and carbon dioxide (CO_2) are the primary constituents of landfill gas, and are produced by microorganisms within the landfill under anaerobic conditions. Though toxic pollutant concentrations are typically very small, because landfill gas emission volumes can be very large, landfills are often included in air toxics emission inventories. The rate of emissions from a landfill is governed by gas production and transport mechanisms. Production mechanisms involve the production of the emission constituent in its vapor phase through vaporization, biological decomposition, or chemical reaction. Transport mechanisms involve the transportation of a volatile constituent in its vapor phase to the surface on the landfill, through the air boundary layer above the landfill, and into the atmosphere.

Emission Model Equations

Uncontrolled methane emissions may be estimated for individual landfill by using the theoretical first-order kinetic model of methane production developed by the U.S. EPA. The emission model equation is presented below. More detailed information may be found in *AP-42, Section 2.7* (U.S. EPA, 1995a). Required data parameters and U.S. default values are listed in Table 4-4.

$$\mathbf{Q_{CH4} = L_o \times R \times (e^{-kc} - e^{-kt})} \qquad (4\text{-}11)$$

where:

Q_{CH4} = methane generation rate at time t, m^3/yr;
L_o = methane generation potential, m^3CH_4/Mg refuse;
R = average annual refuse acceptance rate during active life, Mg/yr;
e = base log, unitless;
k = methane generation rate constant, yr^{-1};
c = time since landfill closure, yrs ($c = 0$ for active landfills); and
t = time since the initial refuse placement, yrs.

Table 4-4

Landfills
Required Data Parameters and U.S. Default Values

Parameter Description	Variable	U.S. Default Value
Methane generation potential	L_o	8120 m^3CH_4/Mg refuse. Based on 80th percentile of the literature value range (i.e., 200-9540 m^3CH_4/Mg refuse).
Average annual refuse acceptance rate during active life	R	
Methane generation rate constant	k	0.02 yr^{-1}. Based on the New Source Performance Standard (NSPS) default value.
Time since landfill closure	c	
Time since the initial refuse placement	t	

U.S. EPA Computer Model

The Landfill Air Emissions and Estimation Model (LAEEM) is a computer program specifically designed to monitor the emissions from landfills. The system allows the user to enter specific information regarding the characteristics and capacity of an individual landfill and to project the emissions of methane, CO, nonmethane organic compounds, and individual hazardous air pollutants (HAPs) over time using the Scholl Canyon decay model for landfill gas production estimation. The Scholl Canyon Model is a first-order decay equation that uses site-specific characteristics for estimating the gas generation rate. In the absence of site-specific data, the program provides conservative default values as presented in Table 4-4. The user also may tailor decay rate characteristics on an individual basis. An integrated decay rate constant calculator is provided for landfills that may be operating a gas recovery system to allow more accurate assessments of decay attributes. Outputs may be reviewed in either tabular or graphical forms. A help system is also provided with information on the model operation as well as details on assumptions and defaults used by the system.

The model is IBM™-PC compatible, requires at least 512 kilobytes (Kb) of memory, and can be used with a monochrome or color graphics adaptor. Reading the user's guide before using the model is recommended.

4.1.4 Waste and Wastewater Air Emissions Models

The U.S. EPA's Office of Air Quality Planning and Standards (OAQPS) has developed air emission models for hazardous waste treatment, storage, and disposal facilities (TSDF).

VOCs in surface impoundments, land treatment facilities, landfills, wastepiles, or wastewater collection and treatment systems can escape to the environment from waste and wastewater through a variety of pathways. To allow reasonable estimates of organic compounds disappearance, one must know which pathways predominate for a given chemical, type of waste site, and set of meteorological conditions. Table 4-5 summarizes the relative importance of the nine pathways for the emissions models developed for the various hazardous waste emission sources (U.S. EPA, 1994).

Emission Model Equations

A pathway is considered to be any process that removes VOCs from a site. The removal may be physical (as in volatilization of a solvent from a surface impoundment) or chemical (as in oxidation of an alcohol in a wastewater treatment plant). Pathways may be considered as rate processes, with rate often strongly dependent on concentration of the disappearing species and temperature of the system.

Each pathway is briefly defined below. However, the emission model equations developed to describe these pathways are very complex. Detailed discussion of the emission

Table 4-5

Pathways for Hazardous Waste Area Emission Sources[a]

Pathway	Surface Impoundments	Wastewater Treatment Plants		Land Treatment	Landfill
		Aerated	Non-aerated		
Volatilization	I	I	I	I	I
Biodegradation	I	I	I	I	S
Photodecomposition	S	N	N	N	N
Hydrolysis	S	S	S	N	N
Oxidation/reduction	N	N	N	N	N
Adsorption	N	S	S	N	N
Hydroxyl radical reaction	N	N	N	N	N
Migration[b]	N	N	N	N	N
Runoff[b]	N	N	N	N	N

I = Important
S = Secondary
N = Negligible or not applicable

[a] Individual chemicals in a given site type may have dominant pathways different from the ones shown here.

[b] Water migration and runoff are considered to have negligible effects on ground and surface water in a properly sited, operated, and maintained RCRA permitted hazardous waste treatment, storage, and disposal facility.

Sources: U.S. EPA, 1994.

model equations and sample calculations for each pathway may be found in the document *Air Emissions Models For Waste and Wastewater (EPA-453/R-94-080A)* (U.S. EPA, 1994), available from the CHIEF bulletin board.

- **Volatilization** occurs when molecules of a dissolved substance escape to an adjacent gas phase.

- **Adsorption** takes place when molecules of a dissolved chemical (in a liquid-solid system) become physically attached to elements of the solid phase. Chemical bonding may also occur (chemisorption).

- **Migration** occurs when chemicals applied to soils are transported through the soils to groundwater.

- **Runoff** occurs when chemicals at or near the soil may be washed away by rain.

- **Biological decomposition** takes place when microbes break down organic compounds for metabolic processes.

- **Photochemical decomposition** may occur when a chemical absorbs light and react (direct photolysis) or the chemical reacts because of light absorption by surrounding elements (indirect photolysis).

- **Hydrolysis** occurs when a chemical reacts with water.

- **Oxidation/reduction** is another pathway. Organic compounds in aquatic systems may be oxidized by oxygen (particularly as single oxygen, $^1O_2$) or other oxidants such as hydroxyl radicals (OH) and peroxy radicals (RO_2). In anaerobic environments, reduction reactions may take place.

- **Hydroxyl radical reactions** may occur through addition of a hydroxyl radical, abstraction of a hydrogen atom, or both.

Required Data Parameters

Different data parameters required for each waste and wastewater emissions model. Table 4-6 provide some examples of the data parameters needed to support these emission models.

Table 4-6

Waste and Wastewater Models
Example Required Data Parameters

Parameter	Units
Ratio of the area of waste to area of air flow in drain	dimensionless
Fraction of entering organic lost to atmosphere	dimensionless
Partition coefficient	mol fraction gas per mol fraction liquid
Length of collection conduit	m
Length of drain	m
Underflow rate	m^3/s
Diameter of drain	m
Radius of underflow conduit	m
Depth of liquid in underflow	m
Wind velocity	m/s
Relative humidity	percent
Collection system temperature	deg.C
Cross-sectional area of vent holes	cm^2
Height of manhole cover above surface	m

U.S. EPA Computer Model

CHEMDAT8—CHEMDAT8 is a Lotus 123® spreadsheet prepared by the U.S. EPA's Emissions Standard Division that includes analytical models for estimating VOCs from TSDF processes. The original models include disposal impoundments, closed landfills, land treatment facilities, and aeration and nonaeration impoundment processes. Predicted emissions can be viewed on the screen or printed. A graphical presentation of the relationships between emission prediction and vapor pressure and between emission prediction and the partition coefficient is also available. The resulting scatter diagrams can be printed via PrintGraph®, another Lotus® program.

The models in CHEMDAT8 can be applied to other types of TSDF processes besides those contained in the original design. The nonaerated impoundment model in CHEMDAT8 can estimate emissions from storage surface impoundments and open-top wastewater treatment tanks. The CHEMDAT8 model for predicting emissions from surface treatment impoundments and aerated wastewater treatment tanks is the aerated impoundment model. The land treatment model in CHEMDAT8 can estimate emissions from land treatment soil, open landfills, and wastepiles. Emissions from an oil film surface in a land treatment facility or an oil film on surface impoundments can be predicted via the oil film model in CHEMDAT8. When a CHEMDAT8 model is not available to predict emissions, the equations shown in the reports that provide the background to the model can be used to perform hand calculations of emissions.

This eighth version of the CHEMDAT spreadsheet contains several major operational modifications. In CHEMDAT8, the user can select a subset of target compounds for investigation. The user can also specify which TSDF processes are to be considered during a session. These two selections improve the efficiency of CHEMDAT8 relative to some of the earlier versions by minimizing storage requirements as well as actual loading and execution time.

Default input parameters in the CHEMDAT8 diskette demonstrate sample calculations. However, the input parameters can be changed to reflect different TSDF characteristics and then recalculate emissions under these modified conditions. Furthermore, the list of 60 compounds currently in CHEMDAT8 can be augmented by an additional 700 chemicals. Procedures for introducing data for additional compounds into CHEMDAT8 are described in the supporting documentation report.

WATER8

WATER8 is a menu-driven computer program that is intended for estimating emissions from wastewater treatment systems only. WATER8 uses some of the same models found in CHEMDAT8, but has data for a total of 800 compounds. The WATER8 program also has graphic enhancements to aid the user in visualizing the system being modeled.

4.1.5 Fugitive Dust

Significant atmospheric dust arises from the mechanical disturbance of granular material exposed to the air. Dust generated from these open sources is termed “fugitive”, because it is not discharged to the atmosphere in a confined flow stream. Common sources of fugitive dust include paved and unpaved roads, agricultural tilling operations, aggregate storage piles, and heavy construction operations. The dust-generation process is caused by pulverization and abrasion of surface materials by application of mechanical force through implements (i.e., wheels, blades, etc.) and by entrainment of dust particles by the action of turbulent air currents, such as wind erosion of an exposed surface by wind speeds greater than 19 km/hr (12 miles/hr).

Various emission model equations have been developed by U.S. EPA to estimate emissions from these fugitive dust sources. More detailed information may be found in *AP-42, Section 13.2* (U.S. EPA, 1995a).

Emission Model Equations—Example emission model equations are presented below. More detailed information may be found in *AP-42, Section 13.2.1* (U.S. EPA, 1995a). Required data parameters and U.S. default values are listed in Table 4-7.

Unpaved Roads

$$\mathbf{E = VKT \times EF} \qquad (4\text{-}12)$$

where: E = average annual mass emission rate, kg/yr;
VKT = vehicle kilometers traveled, VKT/yr;
EF = emission factor, kg/VKT.

$$= k(1.7)\left(\frac{s}{12}\right)\left(\frac{S}{48}\right)\left(\frac{W}{2.7}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{365-p}{365}\right)\ \text{(kg/VI} \qquad (4\text{-}13)$$

where: k = particle size multiplier, dimensionless;
s = silt content of road surface material, %;
S = mean vehicle speed, km/hr;
W = mean vehicle weight, Mg;
w = mean number of wheels;
p = number of days with a least 0.254 mm (0.01 in.) of precipitation per year.

Paved Roads

$$\mathbf{E = VKT \times EF} \qquad (4\text{-}14)$$

where: E = average annual mass emission rate, g/yr;
VKT = vehicle kilometers traveled, VKT/yr;
EF = emissions factor, g/VKT.

$$EF = k\left(\frac{sL}{2}\right)^{0.65}\left(\frac{W}{3}\right)^{1.5} \qquad (4\text{-}15)$$

where: k = base emission factor for particle size range (g/VKT)
sL = road surface silt loading (g/m^2)
W = average weight (tons) of the vehicles traveling the road

Heavy Construction Operations

$$E = A \times T \times EF \qquad (4\text{-}16)$$

where:
E = average annual mass emission rate, Mg/yr
A = construction area, hectares
T = construction time, months
EF = emission factor
= 2.69 Mg/hectare/month

Aggregate Handling and Storage Piles

$$E = Q \times EF \qquad (4\text{-}17)$$

where:
E = average annual mass emission rate, kg/yr
Q = quantity of material transferred, Mg/yr
EF = emission factor, kg/Mg

$$EF = k(0.0016)\,\frac{\left(\frac{U}{2.2}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}} \qquad (4\text{-}18)$$

where:
k = particle size multiplier, dimensionless
U = mean wind speed, m/s
M = material moisture content, %

Industrial Wind Erosion

$$E = A \times EF \qquad (4\text{-}19)$$

where:
E = average annual mass emission rate, g/yr
A = area of surface material subject to disturbance, m^2
EF = emission factor, $g/m^2/yr$

$$EF = k \sum_{i=1}^{N} P_i \qquad (4\text{-}20)$$

where:
k = particle size multiplier, dimensionless
N = number of disturbances per year
P_i = erosion potential corresponding to the fastest mile of wind for the ith period between disturbances g/m^2

Table 4-7

Fugitive Dust
Required Data Parameters and U.S. Default Values

Parameter Description	Variable	U.S. Default Value
Particle size for which emissions are to be estimated	Used to determine k	
Particle size multiplier	k	
Silt content of road surface material	s	Table of default values presented by industry and road use/surface material.
Mean vehicle speed	S	Range of test condition values was 21-64 km/hr.
Mean vehicle weight	W	Range of test condition values was 2.7-142 Mg.
Mean number of wheels	w	Range of test condition values was 4-13 wheels.
Number of days with at least 0.254 mm (0.01 in.) of rain per year	p	Regional data provided for the U.S.
Road surface silt loading	sL	Table of values presented by U.S. State and City.
Surface material area	A	
Construction time	T	
Quantity of material transferred	Q	
Mean wind speed	U	
Material moisture content	M	Table of values presented by industry and surface material.
Number of disturbances per year	N	
Erosion potential function	P_i	

U.S. EPA Computer Model

In 1990, the U.S. EPA developed two programs to help estimate fugitive dust emissions from mechanical disturbances (i.e., unpaved roads, paved roads, materials handling, agricultural tilling, and construction/demolition) and wind erosion. These computer programs are based on the material presented in the document, *Control of Open Fugitive Dust Sources* (U.S. EPA, 1988). The Help feature provides definitions for terms with which the user might not be familiar. In addition, for certain variables, typical or suggested default values are given. For example, the number of days with significant rainfall is given for over 175 U.S. cities and the mean annual wind speed is provided for over 120 U.S. cities.

The fugitive dust programs are distributed by the U.S. EPA through the CHIEF BBS or through the mail on diskette. For further information, the reader is referred to *The User's Manual for the* PM_{10} *Open Fugitive Dust Source Computer Model Package* (U.S. EPA, 1990).

Because these programs have not been updated since 1990, they are not as user-friendly as more recently developed software. In many cases, it would probably be more efficient for users to develop their own spreadsheets with the emission model equations.

As another option, the PART5 mobile model may be used to estimate fugitive dust emissions from paved and unpaved roads.

4.2 Multivariate Emissions Models

A multivariate emissions model is a hybrid methodology that combines various traditional inventory approaches and site-specific information within an extrapolation framework. As its name suggests, a multivariate emissions model expresses emission estimates in terms of a set of variables that help characterize the system being modeled. This approach is particularly well-suited for regions that have limited records and statistics to apply traditional inventory techniques. The fundamental concept is to develop emission estimates based on land use/land cover characteristics. For example, agricultural, residential, commercial, and industrial geographic sites all have different emission characteristics. These emissions differences can be characterized using different variables that describe emissions activity of land use/land cover type.

Although the use of multivariate models will likely have higher initial costs than other inventory methods due to the model development step, the ease of application and possible reduction in future inventory maintenance costs make this a very attractive approach. Another significant advantage of multivariate models is that they are based on local data. This allows the effects of local conditions to be included in the emissions estimates. Some possible source types in Mexico that could be estimated with a multivariate emissions model include construction activities, agricultural activities, and solvent use. The general approach for developing a multivariate emissions model is outlined in section 4.2.1 and a conceptual example is provided in section 4.2.2.

4.2.1 Developing a Multivariate Emissions Model

The first step in developing a multivariate emissions model is the identification of the variables that characterize the overall system that the model is intended to cover. These variables will differ from system to system. Using agricultural activities as an example, these variables could be a type of crop (orchards, row vegetables, etc.), acreage, or harvested quantity. For construction activities, these variables could be a type of construction (building, road, railway, etc.), construction size, or construction cost. Each one of these variables can be used to describe the magnitude of emissions from these sources. For example, construction of two kilometers of road would generate more particulate emissions than construction of one kilometer of road.

The second step of multivariate model development is the determination of which emission source types should be included in the model. For agricultural activities, this would likely be defined as agricultural tilling, harvesting, and equipment exhaust emissions. For construction activities, this could be much more complex and could include earth moving, materials handling, equipment exhaust, and other emission source types. The total number of emission source types covered in the model is ultimately determined by the emission activities of the system that is being characterized.

After defining the source types to include in the multivariate model, the next step is the development of the emissions data to be used in the model. Emissions from each source type at a single site (construction, agricultural, etc.) are estimated using methods from the literature (i.e. empirical equations) and site-specific data. In order to create a statistically robust multivariate model, it is necessary to repeat this estimation for a number of other sites.

Total estimated emissions from each geographical site would then be plotted versus each of the variables identified as characterizing the entire system. Sites that differ considerably from representative sites may produce significantly higher or lower emissions estimates that could adversely affect the statistical analysis. These data points may be considered "outliers" and excluded from further analysis. From these plotted data, a "best-fit" emission rate for each site variable can be statistically determined (i.e., kg of PM_{10}/acre of tomatoes, kg of PM_{10}/US$ of building construction, etc.). Statistical analysis is then used to assess the imprecision of each best-fit emission factor and to quantify the uncertainty of the emissions estimates. From this analysis, the most statistically accurate relationship is selected. It is likely that this relationship will be a simple linear relationship, but it is possible that it might be exponential, logarithmic, or piecewise (i.e., construction costs less than US $10 million might have one best-fit relationship, while those with a cost greater than US $10 million might have a different one).

After the determination of the most appropriate best-fit relationship, regional emissions can be estimated by inserting regional data into the model.

4.2.2 Example Multivariate Model - Construction Activities

Construction activities are a widely distributed area source and can be a significant source of particulate matter (PM_{10}). Because construction activities are so widespread, it is usually not feasible to estimate emissions from each individual construction site. This makes construction activities an ideal candidate for multivariate models. The following example conceptually illustrates the development of a multivariate emissions model. Actual multivariate models must be derived using the steps outlined below.

Identification of System Variables. There are several variables related to construction activities that characterize the overall system (PM_{10} emissions). Some of the more basic system variables include:

- Construction type (buildings, roads, railway, etc.);
- Construction size (building area, excavation volume, amount of concrete poured, etc.);
- Project value; and
- Number of construction workers.

Other variables might be applicable for certain special types of construction activities.

Determination of Emission Source Types. Construction activities generate PM_{10} emissions from a number emission sources such as:

- Demolition and debris removal;
- Excavation and other earth moving;
- Vehicle and equipment exhaust;
- Materials handling; and
- Reentrained dust.

Development of Emissions Data. Emissions for a single construction site are estimated by aggregating calculated emissions from each of the source types as shown in the following equation:

$$\mathbf{E_{tot} = (x_{d,c,e,m,r})(y_{d,c,e,m,r})} \tag{4-21}$$

where: E_{tot} = total site emissions;
x = activity rate;
y = emission factor;
d = demolition and debris removal;
c = excavation and other earth moving;
e = vehicle and equipment exhaust;
m = materials handling; and
r = reentrained dust.

Table 4-8 lists the site-specific activity rates (x_i) and empirical emission factors (y_i) needed to estimate construction emissions. The site-specific parameters contained within the empirical emission factors are also included.

Plotting Emissions Data. After obtaining site-wide PM_{10} emissions totals (E_{tot}) for several different building construction sites, these totals would then be plotted against construction site area, construction project value, number of construction workers, and any other relevant system variables. Hypothetical data for six sites (labeled E_1 through E_6) are plotted in Figure 4-2.

Statistical Analysis of Plotted Data. The next step is to statistically determine the "best-fit" relationship among the different data plots. For the hypothetical data plotted in Figure 4-2, it is assumed that the "best-fit" relationship is a simple linear regression that intercepts the y-intercept at the origin (i.e., no construction activity will result in no PM_{10} emissions).

In this hypothetical example, comparison of the resultant R^2 values indicates that the strongest statistical relationship exists between PM_{10} emissions and construction area. In

Table 4-8

Activity Rates and Emission Factor Parameters Needed to Estimate Construction Emissions

Emission Source Type	Activity Rate (x_i)	Emission Factor (y_i)	Required Site-Specific Parameters
Demolition/ debris removal (d)	Amount of demolition material (Mg)	kg PM_{10}/Mg demolition material[a]	Wind speed (m/s) Demolition material moisture content (%)
Excavation/ earth moving (c)	Vehicle VKT	kg PM_{10}/VKT[a]	Equipment type
Vehicle/ equipment exhaust (e)	Hours of operation	g PM_{10}/hour of operation[b]	Equipment type Fuel type Rated horsepower Operating load
Materials handling (m)	Amount of handled material (Mg)	kg PM_{10}/Mg handled material[a]	Wind speed (m/s) Storage pile moisture content (%)
Reentrained dust (r)	Vehicle VKT	kg PM_{10}/VKT[a]	Silt content (%) Vehicle speed (km/hr) Vehicle weight (Mg) Mean number of vehicle wheels (-) Precipitation (Number of days with $\geq$ 0.254 mm precipitation per year)

[a] Empirical equations for demolition/debris removal, excavation/earth moving, materials handling, and reentrained dust can be found in *Fugitive Dust Background Document and Technical Information Document for Best Available Control Measures* (U.S. EPA, 1992)

[b] Emission factors (g/hp-hr) for different equipment types can be found in *Nonroad Engine and Vehicle Emission Study Report* (U.S. EPA, 1991a). Mexico-specific emission factors might need to be developed.

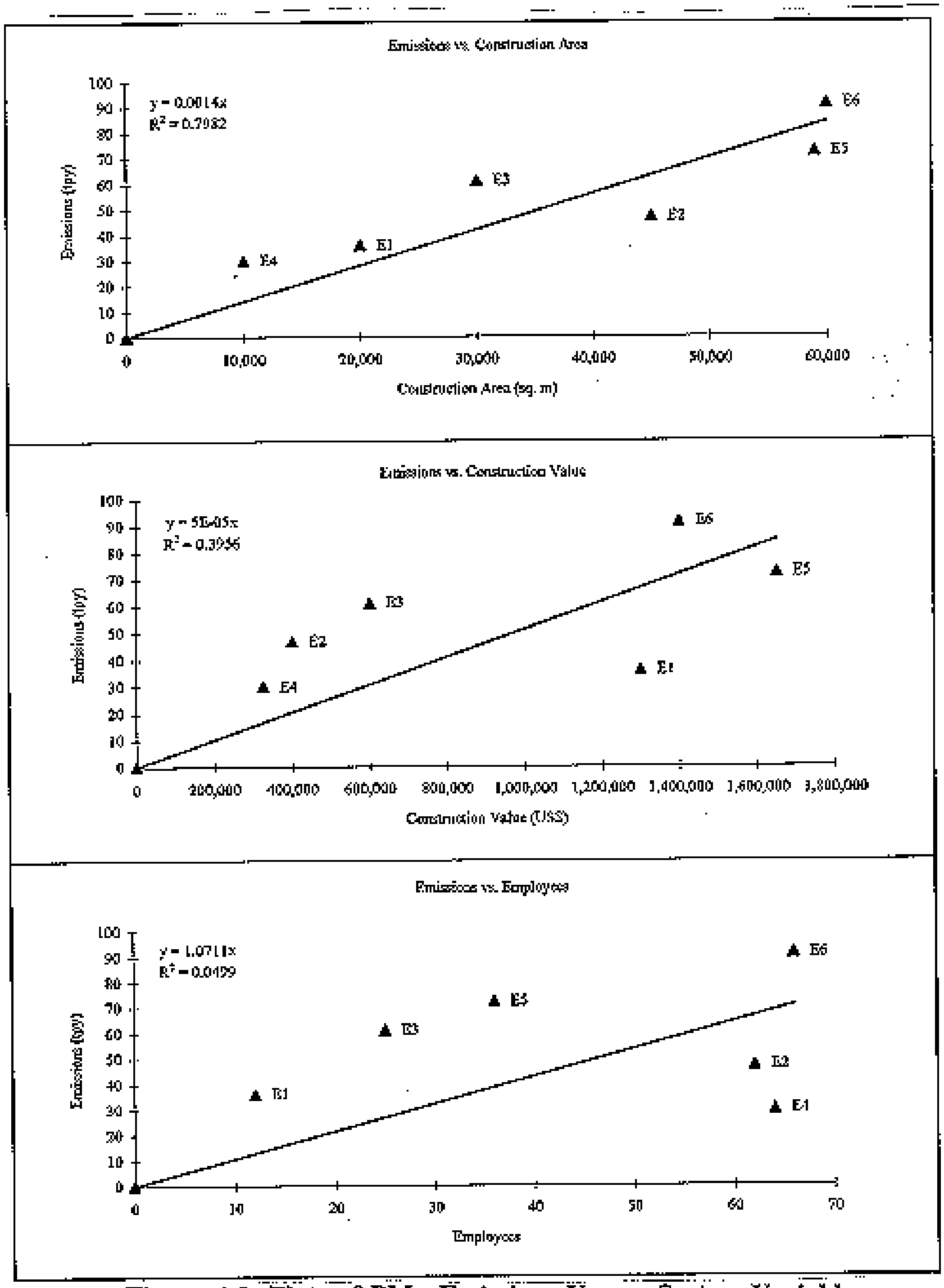

Figure 4-2. Plots of PM_{10} Emissions Versus System Variables

actual situations, emissions likely will not be dependent on one system variable; rather, they will probably be dependent on several system variables.

Calculation of Regional Emissions. Now that the “best-fit” relationship between PM_{10} emissions and construction area has been established as being statistically valid, the application of this relationship to calculate region-wide emissions is quite straightforward. As can be seen in the Figure 4-2 plot of emissions versus construction area, the equation that determines the linear regression is:

$$\text{Total } PM_{10} \text{ Emissions (tpy)} = 0.0014 \times \text{Construction Area } (m^2)$$

If the total hypothetical regional construction area is 2,600,000 m^2, then the regional PM_{10} construction emissions are:

$$0.0014 \times (2{,}600{,}000 \; m^2) = 3{,}640 \text{ tpy } PM_{10}$$

5.0 SURVEYING

A survey questionnaire is the technique commonly used to gather point source emissions inventory data (Figure 5-1). The questionnaire should be sent to each facility and request information about the characteristics of each emitting device at the facility. Using a questionnaire to gather point source emissions data in Mexico is not new; the National Institute of Ecology (INE) has been gathering point source data with this technique for several years. A copy of the national point source questionnaire is shown in Appendix III-B.

A survey approach can also be used to gather information needed to calculate area source estimates or used to develop region-specific emission factors for the development of certain area source emission estimates. Figure 5-2 illustrates the process for area sources.

Conducting a survey consists of several steps. For either a survey of point or area sources, the first step is to determine an appropriate sample size and to identify the facilities/subcategories and process differences within the surveyed source category. Next, mailing lists must be prepared; questionnaires must be designed, assembled, and mailed or delivered; data-handling procedures must be prepared and organized; and response-receiving systems must be established. Considerable thought and planning must be dedicated to the design of a new questionnaire or the modification of an existing one. The success rate of a surveying effort is largely dependent on whether the survey is backed by a regulatory agency and also the conciseness, ease of use, and generality of the questionnaire. In addition the questionnaire responses must be subjected to thorough QA/QC reviews to eliminate invalid data (e.g., supersonic stack exit gas velocities). The cost of a surveying effort is a function of the completeness and specificity of the questionnaire, the extent of the target audience, and the thoroughness of the QA/QC follow-on activities.

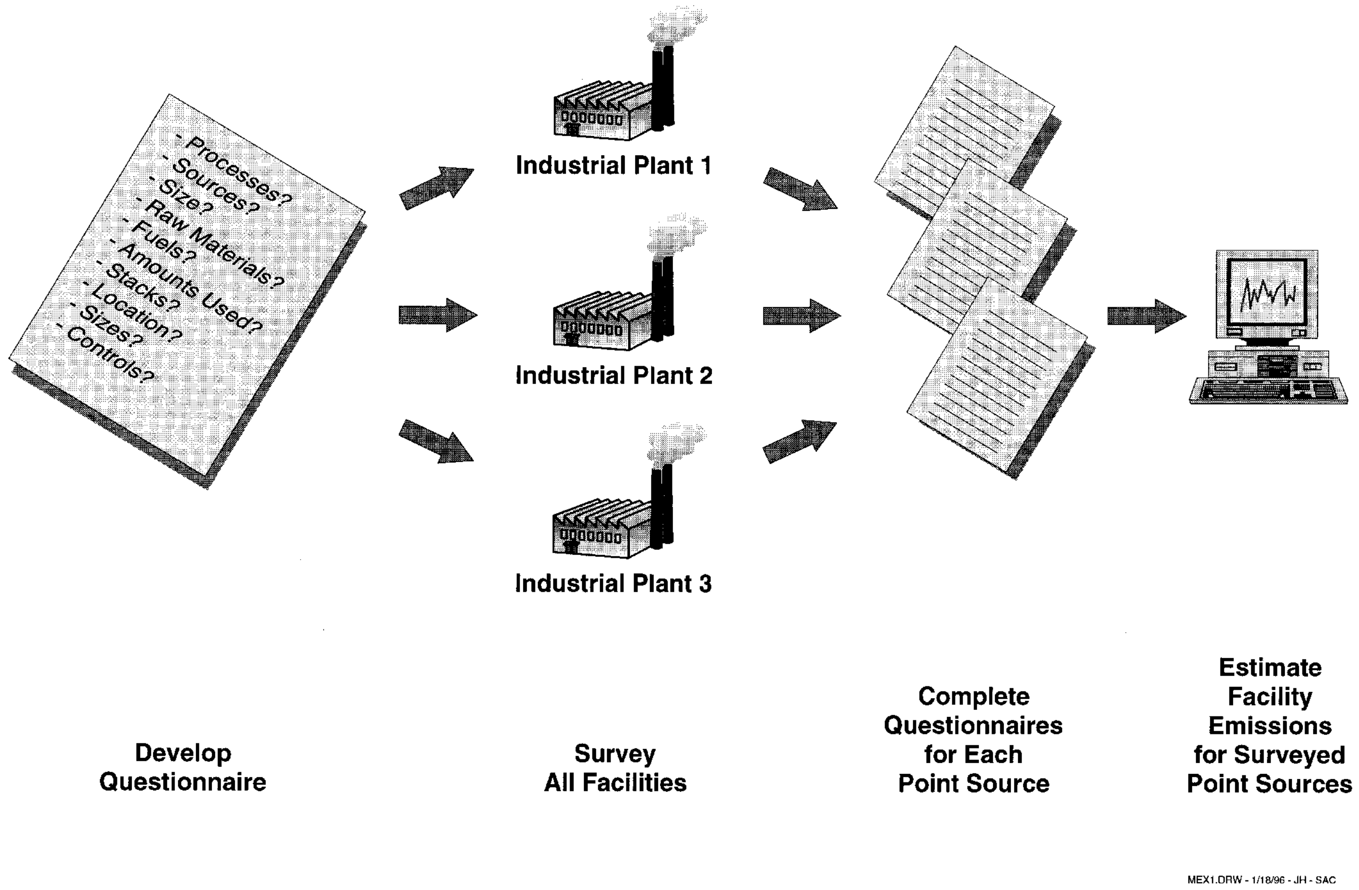

Figure 5-1. Example of Point Source Surveying

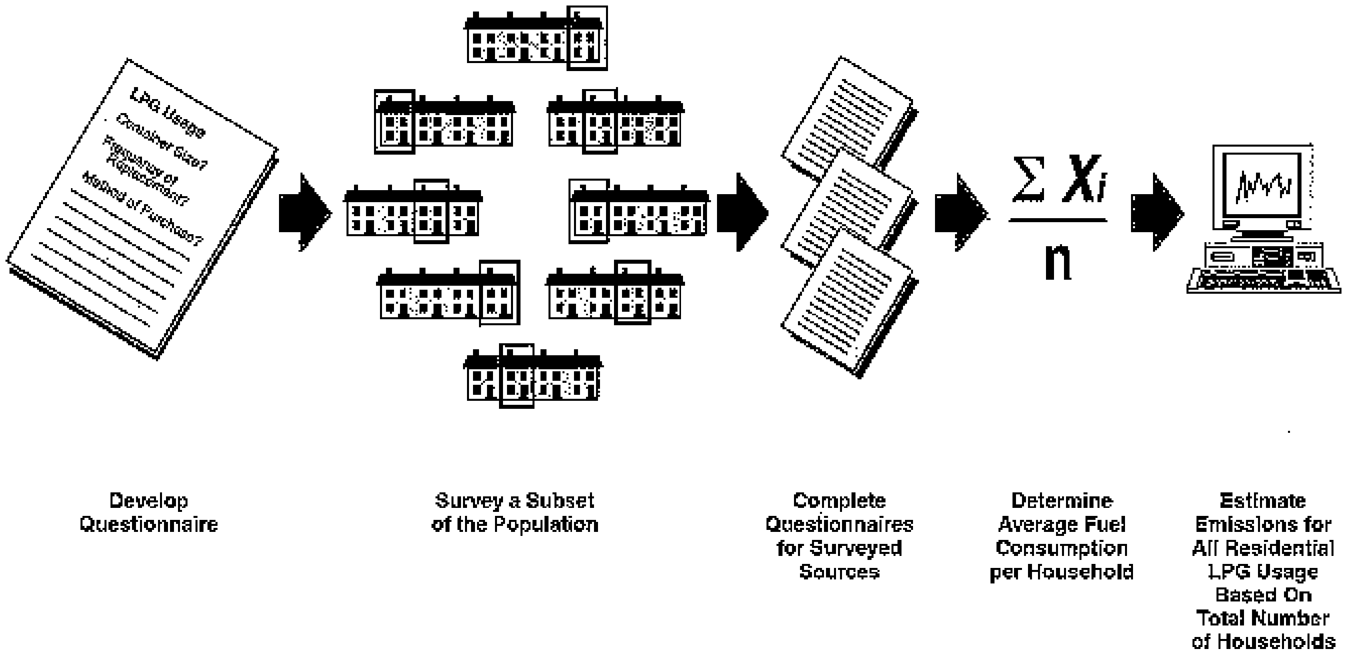

Figure 5-2. Example of Area Source Surveying

The material presented in the remainder of this section is intended to introduce the reader to the concept of surveying and provide background information on the techniques used to conduct a successful survey. These techniques are applicable to both point and area sources. For more information about the use of specific questionnaires, see the document entitled *Development of Questionnaires for Various Emission Inventory Uses* (Holman and Collins, 1979).

5.1 Initial Planning

Although not complicated, there are several important considerations to keep in mind while planning and conducting a survey effort. This section summarizes the most important considerations, which are applicable to both point and area sources alike. The key to a good survey effort is adequate planning. Important points to consider during the initial planning phase for both point and area source surveys are:

- Historically, paper copies of questionnaires have been sent to individual facilities. Another approach is to use computer media (floppy disks or electronic transmission) instead of paper to return or update questionnaire responses to the agency. This technique can also include the use of standardized computer forms or software so that data submitted to the agency is in a format easily handled by agency personnel. This technique has not been used in Mexico, but other regions have found several benefits from this approach. If properly designed the electronic questionnaire can be easier to complete and minimizes data entry and QA reviews.

- Compile distribution lists from a number of different sources, using several sources and cross checking those sources.

- Secure any administrative clearances needed under federal or state rules to conduct a survey of the private sector.

- Explain the reasons for the survey during the initial contact phase, whether it is by phone or mail.

- Consider who should contact the survey recipient. Response rates for industry surveys may be higher if the state or federal agency, not a contractor, contacts the survey recipient.

- The survey process takes several steps including identifying the correct recipient. To identify the correct recipient at a facility, arrange convenient times for an interview and actually talk to the recipient and answer the survey questions. For example the steps might be:

- Contact the facility by letter or by phone to inform them about the survey, and set up a convenient time for answering questions. Be certain that the person contacted is able to answer the survey questions.
- Send the survey questions to the recipient.
- Place a second call to interview the recipient about the survey questions.

Once the facilities have been identified and the questionnaire(s) developed, surveying point sources is straightforward. Several important items for planning an area source survey are summarized below.

- Investigate and subdivide the source category if necessary. Many area source categories, such as degreasing and surface coating consist of different processes used by many different industries. Uses of particular processes can vary widely from one industry to the next. Stratify the population of sources if necessary (see Section 5.3).
- Design the survey for a reasonable point in the product distribution process. In the case of many solvent use categories, a survey could be sent to either manufacturers, distributors, retailers, or users, but the most practical choice might be just manufacturers or just distributors.
- Consider future needs in survey form planning; plan ahead if possible. For example, the survey may collect data/information for emission calculations. As part of the air quality planning process, emission projections are also anticipated. Therefore, consider collecting emissions projection information at the same time the basic data are collected.
- For area sources, plan how the information gathered through the survey will be scaled up for the entire inventory region, since the survey design will probably cover only a sample of all sources and it is unlikely that the survey will have a 100 percent response rate. Identify a reasonable surrogate activity, if necessary, and plan on collecting that information in the survey (see Section 5.4).
- When data collection is based on sites identified by their Mexican Classification of Activities and Products (CMAP) Code, and the source

category process may or may not take place at every site with that CMAP Code, refine the distribution list by identifying the sites that do use the process;

  - For instance, industrial surface coating is typically associated with a number of CMAP Codes, but not all of the facilities under a particular CMAP Code may have surface coating operations.
  - Calling a facility before sending the survey can make the distribution more efficient. It will also identify the proportion of facilities in an CMAP Code that do or do not use a process, which is useful for scaling up area source survey data.

5.2 Facility Identification

A necessary step in the survey is the preparation of a contact list that tabulates the name, address, and general process category (e.g., wood products manufacture) of each facility that could be surveyed. The purpose of the contact list is to identify the individual facilities that will be surveyed. The size of the resulting contact list gives an agency an indication of the numbers and types of sources that can effectively be considered in the survey within resource limitations. In this regard, the contact list can be used to help an agency determine whether the resources allocated for the compilation effort will be sufficient, and provide the basic information needed to develop a sampling subset. The correct number of samples (returned and correctly completed questionnaires) must be determined based on statistically sound sampling techniques, the priority given to the category, and the resources available.

The contact list should be compiled from a variety of information sources, including:

- Listings of air emission sources included in existing emissions inventory is a good starting point.
- Listings of water pollution sources and hazardous waste generators may be used to identify potential sources in various CMAPs.

- Air pollution control agency files may provide valuable information on the location and types of sources in the region of concern. These files can also be used later to cross-check certain information supplied on questionnaires.

- Other government agency files maintained by labor departments and tax departments frequently aid in the preparation of the mailing list. Such files will include various state industrial directories in which companies are listed alphabetically by CMAP Code and municipality.

- Local industrial directories may provide a current list of the sources that operate in the inventory region. These are often organized by CMAP code and may provide employment data. For example, facility listings along the border can be obtained from the Maquiladora Association.

- National publications can be used when available. However, the information in them may be older and less accurate than local primary references.

The mailing list should be organized to facilitate the necessary mailing and follow-up activities. A logical order in which to list companies is by state or municipality, then by CMAP Code, and finally, alphabetically. Ordering the list in this manner will increase the efficiency of all subsequent data-handling tasks and will allow a quicker QC check of the list.

5.3 Sample Selection

For area sources, developing the surveying plan will entail decisions regarding the selection (or sampling) of facilities to include in the survey effort. Depending on the objectives of the survey effort, different sampling techniques can be used. Table 5-1 lists several different sample selection techniques that can be used. For the development of area source emission estimates, typically either random sampling or random stratified sample selection techniques will be typically used. If the population of sources is small enough, the entire population can be selected. If the population is large and it’s not possible to survey every facility, then a subset of the population must be selected. Careful consideration must be given to sample selection so that the survey results remain unbiased. A thorough discussion of the statistical procedures for selecting samples is beyond the scope of this section. The reader is referred to more detailed

Table 5-1

Types of Survey Sampling Methods

Method	Description	Conditions When the Sampling Design is Useful[a]
Haphazard sampling	“Any sampling location will do” Take samples at convenient locations or times. Can lead to biased estimates.	A very homogeneous population over time and space is essential if unbiased estimates of population parameters are needed. This method of selection is *not* recommended due to difficulty in verifying this assumption.
Judgement sampling	Subjective selection by an individual. Select samples that appear to be “representative” of average conditions. Can lead to biased estimates. Accuracy is difficult to measure.	The target population should be clearly defined, homogeneous, and completely assessable so that sample selection bias is not a problem. Conversely, specific samples are selected for their unique value and interest rather than for making inferences to a wider population.
Simple random sampling	Each population unit has an equal chance of being selected for measurement. Selection of one unit does not influence selection of other units.	The simplest random sampling design. Other designs below will frequently give more accurate estimates of means if the population contains trends or patterns of emission rates.
Stratified random sampling	Divide target population into nonoverlapping parts. Sampling locations are selected from each stratum by simple random sampling.	Useful when a heterogeneous population can be broken down into parts that are internally homogeneous. For example, solvent usage might be stratified according to the end product produced.
Multi-stage sampling	Divide target population into primary units. Select a set of primary units using simple random sampling. Randomly subsample each of the selected primary units. Example: collect soil samples (primary units) at random, then select one or more aliquots at random from each subsample.	Needed when measurements are made on subsamples of the field sample. This technique has limited applicability to emissions inventory development.
Cluster sampling	Clusters of individual units chosen at random. All units in chosen clusters are measured.	Useful when population units cluster together (schools of fish, clumps of plants, etc.) and every unit in each randomly selected cluster can be measured. This techniques has limited applicability to emissions inventory development.

Table 5-1

Types of Survey Sampling Methods

Method	Description	Conditions When the Sampling Design is Useful[a]
Systematic sampling	Take measurements at locations and/or times according to a spatial or temporal pattern. For example: at equidistant intervals along a line or on a grid pattern.	Usually the method of choice when estimating trends or patterns of emissions over space. Also useful for estimating the mean when trends and patterns are not present or they are known a priori or when strictly random methods are impractical.
Double sampling	If data using one measurement technique has a strong linear relationship to data obtained with less expense or effort using another measurement technique, more samples can be taken using the less expensive method. The linear relationship between the two techniques is then applied to estimate the mean for the more expensive method.	Useful when there is a strong linear relationship between the variable of interest and a less expensive or more easily measured variable.
Search sampling	Used to geographically locate pollution sources or to find “hot spots” of elevated contamination.	Useful when historical information, site knowledge, or prior samples indicate where the object of the search may be found. This technique has limited applicability to emissions inventory development. This approach, however, could be used to develop information that would describe the spatial characteristics of emissions in relationship to a specific parameter (for example, lawn and garden equipment use versus household income).

[a] Gilbert, 1987.

discussions on this subject such as the text books *Sampling Techniques* (Cochran, 1977) and *Statistical Methods for Environmental Pollution Monitoring* (Gilbert, 1987).

The concept of a stratified random sampling approach can be very useful for developing area source emissions estimates, as well as developing data for use in multivariate emissions models. In this technique, the population of N units is divided into subpopulations N_1, N_2,...,N_L units. These subpopulations, or strata, are nonoverlapping, and together they comprise the entire population. When the strata have been determined, a sample is drawn from each, with drawings made independently in different strata. The sample sizes are denoted by n_1, n_2,...n_L, respectively. From an emissions inventory perspective, the primary reason for conducting this type of sampling approach is to divide a heterogeneous population into subsets, each of which is more likely to be internally homogeneous. A conceptual example is provided below.

Example 5-1

Most urban areas with a diversified economy contain numerous, small manufacturing facilities which may be using solvents, primarily through coating, degreasing, or wipe cleaning operations. Many of these facilities will not be included in the point source inventory and will be comprised of numerous, diverse manufacturing operations (e.g., wood products manufacture and coating; plastics coating; miscellaneous metal parts manufacture and coating; etc). Due to the large number of operations and their differences in raw material and production characteristics, it is necessary to develop a survey approach that will accurately collect information that can be statistically extrapolated to the entire population of non-point source facilities. A stratified random survey can be used to solve this problem.

The first stratum might divide the facilities into groups based on two digit CMAP code so that like facilities are grouped together (i.e., facilities manufacturing like materials are likely to have similar emission characteristics). A second stratum might be considered necessary to distinguish between large and smaller facilities to prevent biases resulting from the different rates of material usage that could occur because of facility operating efficiency. Once the survey is completed and emissions have been calculated, the emissions data can be correlated with the strata used to define the subpopulations, in this case two digit CMAP and number of employees.

5.4 Determination of Sample Size

The number of surveys that are mailed out will be dependent upon available resources and initial goals established for the accuracy of the results. This subsection provides a brief overview of the statistical procedures for selecting an appropriate sample size given a specified accuracy goal. For a more through explanation of the following material, please consult a standard text book on statistics.

For many area source surveys, the goal is to establish an average value for a particular set of parameters that can be used to estimate emissions for the entire population of sources. For example, the average amount of coating material may be determined, or the average amount of liquefied petroleum gas (LPG) used per household. In general, the "error" or uncertainty in the mean value developed from the survey results can be minimized by sampling more and more sources. The uncertainty in the mean value (x) can be stated as follows:

$$\mathbf{x} = \pm \quad \mathbf{A} \tag{5-1}$$

where: = The sample standard deviation
A = t statistic divided by the number of samples (t/√n).

The t statistic varies with sample size and desired level of confidence. As more samples are taken, the level of uncertainty in the average value decreases. However, a point of diminishing returns is quickly reached as the number of samples approaches 20. Figure 5-3 illustrates this concept by plotting A (i.e., t/√n) versus number of samples taken. This particular plot is for a 90% confidence level.

If desired, a more rigorous approach to determining the appropriate sample size can be determined by specifying the amount of acceptable error. Establishing the sample size based on acceptable error requires an iterative approach that begins with an initial survey. Assuming a 50% response rate, limit the initial survey to approximately 40 questionnaires so that

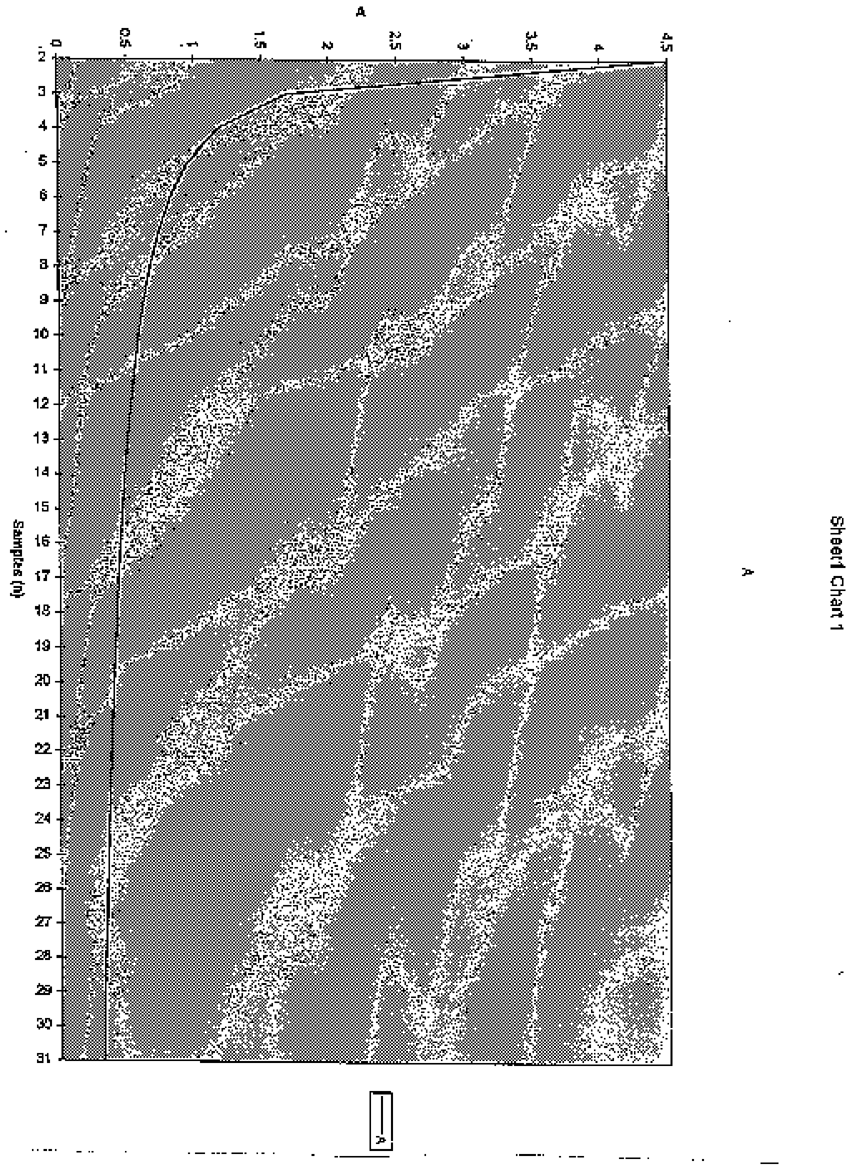

Figure 5-3. Influence of Sample Size on Uncertainty

about 20 responses are received. From the results of the initial survey, a specific sample size can be estimated based the survey error goals:

$$n = \left(\frac{Z_{/2}}{e} \right)^2 \qquad (5\text{-}2)$$

Where:
n = sample size
= standard deviation of the population
e = limit of error (usually in the range of 5 to 10 percent of the value of the mean)
= confidence level
$Z_{/2}$ = index derived from the normal curve which corresponds to the desired confidence level:

percent	$Z_{/2}$
90	1.65
95	1.96
99	2.58
99.7	3.00

A simple example illustrating this concept is presented below for a hypothetical survey applied to residential LPG usage.

Example 5-2

Assume that no more than a 10% error at the 90% confidence level is desired for a survey of residential LPG usage. From the hypothetical survey, the average LPG usage determined from the initial questionnaires is 1,000 liters with a standard deviation of 400 liters. Using these data in equation 5-2, the number of needed samples is:

$$n = \left(\frac{1.65 \ x \ 400}{0.10 \ x \ 1{,}000} \right)^2$$

$$= 44 \text{ samples}$$

5.5 Limiting the Size of the Mail Survey

If more sources are identified on the mailing list than can be realistically handled with available resources, an agency should screen the mailing list in some manner to reduce the number of facilities to be sent questionnaires. This can be done in a number of ways.

In many instances, the number of employees in a company will be known, and an estimate of the emissions potential can be made by applying emissions per employee factors where available. This will provide a rough estimate of the emissions potential of those facilities, which can then be used to select a sample of facilities that represent a range of emissions to receive the questionnaire. Another way to reduce the mailing list is to contact the intended recipients of the survey by telephone before mailing the survey. These brief contacts with plant managers or other appropriate employees will indicate whether the pollutant emitting process takes place at the facility. If the process is not used at the facility, this response can be recorded and no further contact with the facility is necessary thus reducing the number of surveys that are sent out.

5.6 Designing the Questionnaires

A questionnaire should be prepared for each source category that is surveyed. These questionnaires can use industry-specific terminology that is familiar to those working in a particular industry, which will enhance communication, reduce confusion, and increase inventory accuracy. It may also be productive to first work with a small focus group of sources in the industry to refine and “test market” the questionnaire. Input from knowledgeable industrial personnel will help to eliminate ambiguity in responses and misunderstandings about the goals of the survey. Although a survey questionnaire that is tailored to a particular industry or process has many advantages, there are also several disadvantages. One disadvantage is that designing many industry-specific questionnaires can require significant resources. Second, the returned questionnaires will have different data storage requirements because of the variations in format for different industries.

Developing a questionnaire involves identifying and writing the appropriate questions, establishing a suitable format, and developing a cover letter and instructions for filling out the questionnaire. The basic rule is to design the questionnaire for the person who will be asked to complete it. An agency should consider that the person who will complete the questionnaire may not have the benefit of a technical background in air pollution, engineering, or physical sciences. Hence, questionnaires and instructions should not be designed to require specialized technical training to be understood. Each question should be self-explanatory or accompanied by clear directions. All necessary information should be solicited on the questionnaire, thus avoiding later requests for additional data. Any additional data needed for subsequent application of a dispersion or photochemical model should also be collected at this time.

The format of the questionnaire should be as simple and functional as possible. When data handling is to be done by computer, time will be saved if the questionnaire format is designed such that the data entry personnel can readily enter the information directly from each questionnaire. If computerized data reporting is encouraged, agency time may be saved on data entry. The questionnaire should be well-spaced for easy readability and should have sufficient space for complete written responses. The questionnaire should be as short as possible; lengthy questionnaires are intimidating. Also, shorter questionnaires reduce postal costs.

The ultimate use of the data should always be considered when determining the information to request on the questionnaire. For point sources, process information should also be requested, in addition to emission rates and general source information such as location, ownership, and nature of business. An effort should be made to request activity level data for the appropriate inventory year and inventory season. If data for the appropriate time period cannot be obtained, questions should be included that will collect the information needed to derive temporal adjustment factors as accurately as possible. Control device information is also helpful for determining potential reductions in emissions from applying various control strategies.

Finally, any information that is needed to make corrected or adjusted emissions estimates should be solicited. For example, because emissions from petroleum product storage and handling operations are dependent on a number of variables, including temperature, tank conditions, and product vapor pressure, the questionnaire should include requests for appropriate values for these variables. If seasonal adjustments are considered, special emphasis should be given to variables such as activity levels, temperature, and wind speed that cause seasonal variations in emissions.

Each questionnaire should be accompanied by a cover letter stating the purpose of the inventory and citing any statutes that require a response from the recipient. Cooperation in filling out and returning the questionnaire should be respectfully requested. In addition, each questionnaire should be accompanied by a set of general procedures and instructions telling the recipient how the questionnaire should be completed and the date it should be returned to the agency. In lieu of a specific reply date, a specific number of calendar or working days in which to respond can be indicated. In this manner, delays in mailouts will not require changing the reply date.

If a more general questionnaire is sent out, the instructions should carefully explain that the questionnaire has been designed for a variety of operations and that some questions or sections of the questionnaire may not apply to a particular facility. In all cases, a contact name, telephone number, and mailing address should be supplied in case a recipient has questions. The cover letter and instructions can be combined in some cases, but this should only be done when the instructions are brief.

5.7 Mailing and Tracking the Questionnaires

After the final mailing list has been compiled and the appropriate questionnaire packages are assembled (including mailing label, cover letter, instructions, questionnaires, and self-addressed stamped envelope), an agency should proceed with the mailout activities. The mailing of the questionnaires can be performed in two ways. The first method is by registered mail, which serves to inform the agency when a questionnaire is received by the company. This does not guarantee that the company will return the form, but the response rate will probably be somewhat greater than if the questionnaires are sent by first-class mail. However, the slight increase in response may not justify the added expense of sending every company a registered letter. As a compromise, registered mail may be used to contact only larger sources.

The second method is to send the questionnaires by conventional first class mail. This method has proven to be effective if the mailing address includes the name of the plant manager or if "ATTENTION PLANT MANAGER" is printed on the outside of the envelope. This directs the envelope to the proper supervisory personnel and reduces the chances of the questionnaire package being discarded. It is highly recommended that a stamped envelope be included with each questionnaire because the questionnaire is then more likely to be returned.

Incorrect mailing addresses are a large part of unreturned questionnaires; therefore, the extra effort applied to obtaining correct addresses will be rewarded. Also, it is important to distinguish between facility physical location and mailing address. Identifying the mailing address can have a critical effect on the questionnaire response rate.

Responses may begin arriving within a few days after mailing. Many of the early returns may be from companies that are not sources of emissions. Also, some of the questionnaires will be returned to an agency by the postal service because either the establishments are out of business or the company is no longer at the indicated mailing address. New addresses for companies that have moved can be obtained by calling the establishments, looking up their addresses in the telephone book, or contacting an appropriate state or local agency, such as the tax or labor departments.

A simple computer program can be helpful in mailing and logging in the questionnaires. Such a program should be designed to produce a number of duplicate mailing labels for each source sent a questionnaire. One label is attached to the outside of the envelope containing the questionnaire materials. A second label is attached to the cover letter or instruction sheet of the questionnaire. This facilitates the identification of the questionnaires as they are returned, as well as name and mailing address corrections. Additional mailing labels may be used for other administrative purposes or to recontact those sources whose responses are inadequate. Information for an example label is shown below:

Example 5-3

0000 (CMAP Code)
0000 (Plant Number)

INDIVIDUAL'S NAME and TITLE (or PLANT MANAGER)
COMPANY NAME
STREET
MUNICIPALITY, STATE, ZIP CODE

As shown above in the example label, it may be helpful to print the CMAP code and the assigned facility identification number on the upper right corner of the labels. The identification (ID) number can be used to group records of all correspondence with one company. If the study area is large, a municipality identification number may also be included on the mailing label. Be careful to separate the internal coding information from the address so that the Post Office does not confuse these items with the address.

It is important to develop a tracking system to determine the status of each facet of the mail survey. Such a tracking system should tell an agency: (1) to which companies questionnaires were mailed; (2) the dates the questionnaires were mailed and returned; (3) corrected name, address, and CMAP information; (4) information on the type of the source; (5) whether recontacting is necessary; and (6) the status of the follow-up contact effort. Tracking can be accomplished manually through the use of worksheets or through the use of a simple computer program. A computer printout of the mailing list can be formatted for use as a tracking worksheet.

As soon as the questionnaires are returned, some useful analyses can be performed. One activity that can help enhance the timely completion of the mail survey, as well as assist in estimating the amount of resources that will be subsequently needed in the inventory effort, is to classify each response in one of the five categories listed below:

P = point source
A = area source

N = no emissions (non-source)
C = closed/out of business
R = recontact for reclassification

In addition, an agency can begin performing emissions calculations for sources that have responded, and the resulting source and emissions information can begin to be loaded into the inventory files. All responses should then be filed by CMAP code, source category, geographic location, alphabetical order, or any other criteria that provide orderly access for additional analysis.

5.8 Recontacting

The agency may have to recontact a company if it does not return the questionnaire or if the response provided is inadequate. If a company does not return the questionnaire as requested, a more formal letter citing statutory reporting requirements for completing the questionnaire should be sent via registered mail. When the number of companies to be recontacted is small, the information can be obtained through telephone contacts or plant visits.

Recontacting activities should begin two to four weeks after the questionnaires are mailed. Telephone calls are advantageous when recontacting companies in that direct verbal communication is involved and additional mailing costs can be avoided. A second follow-up mailing may be necessary if a large number of companies must be recontacted. In either case, recontact should be completed 8 to 12 weeks after the first mailing.

5.9 Accessing Agency Air Pollution Files

An agency may have special files or databases that can be accessed for use in emissions inventory development. These files may include permit files, compliance files, or emissions statements. Permits are typically required for construction, startup, modifications, and continuing operation of an emissions source. Permit applications generally include enough information about a potential source to describe the nature of the source and to estimate the magnitude of emissions that will result from its operations. Some permits also include source test data.

Some agencies may also maintain a compliance file, which records the agency's interaction with each source on enforcement matters. For example, a compliance file might contain a list of air pollution regulations applicable to a given source, a history of contacts made with that source on enforcement matters, and an agreed-upon schedule for the source to effect some sort of control measures.

5.10 Scaling Up the Survey Results

A properly designed area source survey effort will also include a mechanism for "scaling up" the survey results. By the nature of the source type, it may not be possible to survey the universe of sources covered by the category. The method for scaling the results will depend on the type of source that is included in the survey effort. Two examples are provided below.

In the simplest sense, the survey results could be scaled up by applying the average material usage (or emissions) determined from the survey effort to the population of sources. From an emissions perspective, this approach assumes that the population of sources is size independent. For example, a survey of residential LPG usage could be performed to more precisely estimate the amount of this fuel consumed on a residential level. Surveying each home is not practical; therefore, a subset of population would be surveyed and the results scaled to the entire population. For this hypothetical example, the average amount of LPG used per household would be determined through the survey with the average value applied to the total number of households in the region. A simple example follows:

Example 5-4:

Based on a survey of a subset of the households using LPG, the average annual use of LPG is 1,000 liters/yr. Available census data indicate that there are 500,000 households in the region and that 90% of them use LPG as a residential fuel. Estimate the total NO_x emissions from household use of LPG in the region.

$$Q_{LPG} = 1{,}000 \text{ liters/household/yr} \times 500{,}000 \text{ households} \times 90\%$$
$$= 450 \text{ million liters/yr}$$

$$EF_{NOx} = 1.7 \text{ kg/1,000 liters} \qquad \text{(AP-42, Section 1.5)}$$

$$E_{NOx} = Q_{LPG} \times EF_{NOx}$$
$$= (450 \times 10^6 \text{ liter/yr}) \times (1.7 \text{ kg/1,000 liters})$$
$$= 765{,}000 \text{ kg } NO_x\text{/yr}$$

If the material usage is expected to vary by source size, then a more complex approach is required. For example, the amount of coating material used in wood coating operations will vary based on the production level of the facility. The survey design must include questions that collect sufficient information that can be used to scale the results to other facilities that were not included in the survey effort. These data can consist of such things as the number of employees, or economic parameters such as the value of goods or services produced. The key is to think ahead and identify appropriate parameters that can be used to scale the inventory results to other sources. A simple example follows:

Example 5-5:

Based on a survey of a subset of the facilities manufacturing wood products, the average coating usage per employee is 30 liters/yr. The total number of employees in the region involved in wood products manufacturing is 1,050 based on data from CANACINTRA. Additionally, the survey results indicate that the average coating has a density of 1.4 kg/liter and is 45% VOC by weight. Estimate the total VOC emissions from wood products manufacturing in the region.

$$Q = 30 \text{ liter/employee/yr} \times 1{,}050 \text{ employees}$$
$$= 31{,}500 \text{ liter/yr}$$

$$EF_{VOC} = 1.4 \text{ kg/liter} \times 45\%$$
$$= 0.63 \text{ kg/liter}$$

$$E_{VOC} = Q \times EF_{VOC}$$
$$= 31{,}500 \text{ liter/yr} \times 0.63 \text{ kg/liter}$$
$$= 19{,}845 \text{ kg VOC/yr}$$

6.0 EMISSION FACTORS

Emission factors are commonly used to calculate emissions when site-specific stack monitoring data are unavailable. An emission factor is a ratio that relates the quantity of a pollutant released to the atmosphere to a unit of activity. Emission factors can generally be classified into two types: process-based and census-based. Process-based emission factors are commonly used to develop point source emission estimates, and are often combined with the activity data collected from a surveying or material balance approach. Census-based emission factors, on the other hand, are widely used to develop area source emission estimates (see Figure 6-1).

6.1 Process-Based Emission Factors

Various source sampling programs have been conducted to measure emission rates from certain devices or processes known to be air emission sources. Since source testing of every individual emission source is often not required or economically feasible, the source test results from "representative sources" are used to develop process-based emission factors for similar device types or processes. These process-based emission factors are expressed in the general form of mass of pollutant emitted/process unit. Some common process units are energy input, material throughput, production units, operating schedule, or number of devices, or device characteristic (e.g., lb/MMBtu, lb/gal, lb/batch, lb/hr, lb/flanges or lb/sq ft [surface area]).

The most comprehensive source for U.S.-specific process-based emission factors is *AP-42 Compilation of Air Pollutant Emission Factors* (U.S. EPA, January 1995a). The primary reference for toxic air pollutant emission factors is the FIRE data system (U.S. EPA, 1995b).

Non-U.S.-specific emission factors for various source aggregates are available from the *Rapid Source Inventory Techniques* guidance document developed for the WHO (Economopoulos, 1993) and various GHG inventory guidance documents (Intergovernmental Panel on Climate Change [IPCC], 1993a and b).

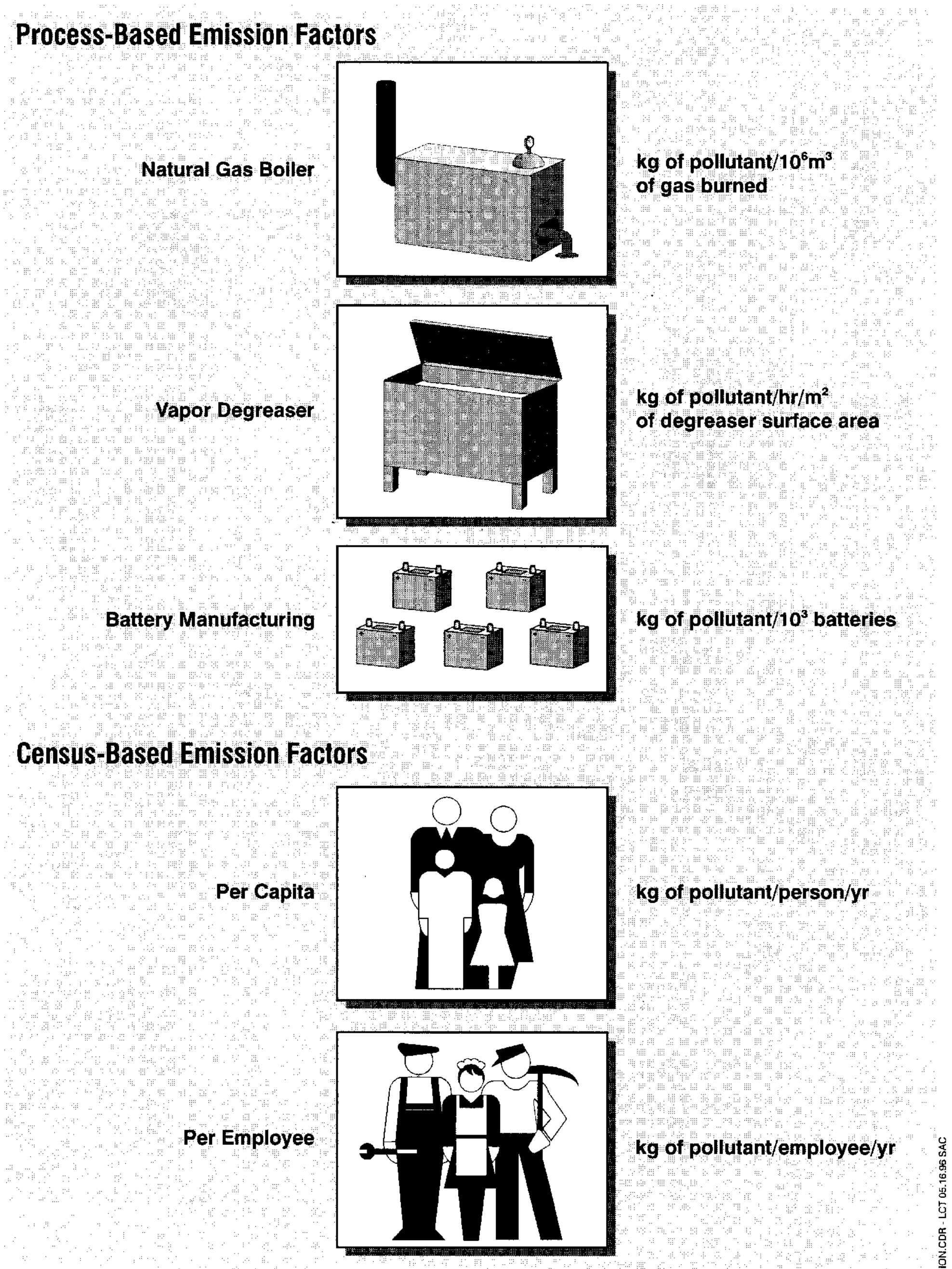

Figure 6-1. Examples of Emission Factors

Below are a few sample calculations of emission estimates developed using process-based emission factors. Volume IV - Point Sources provides more detailed guidance on developing point source emission estimates.

Example 6-1:

Calculate the annual NO_x emissions from an uncontrolled utility boiler (> 100 million Btu/hr heat input) burning natural gas. The annual throughput of natural gas is 50 million cubic meters.

EF_{NOX} = $8800 \text{ kg}/10^6\text{m}^3$ (From AP-42, Table 1.4-2)
Q_{fuel} = $50\ 10^6\text{m}^3/\text{yr}$

E_{NOX} = $EF_{NOX} \times Q_{fuel}$
= 8800×50
= 440,000 kg/yr

Example 6-2:

Calculate the annual VOC emissions from an uncontrolled open-top vapor degreaser. The solvent used is 100 percent VOC. The degreaser has a surface area of 5 cubic meters and operates 8 hours/day, 5 days/week, 52 weeks/year.

EF_{VOC} = 0.7 kg/hr/m^2 (From AP-42, Table 4.6-2)
A = 5 m^2
T_{hours} = 8 hrs/day x 5 days/wk x 52 wks/yr
= 2080 hrs/yr

E_{VOC} = $EF_{VOC} \times A \times T_{hours}$
= $0.7 \times 5 \times 2080$
= 7,280 kg/yr

Example 6-3:

Calculate the PM emissions from the grid casting step of the production of lead acid storage batteries. Twenty thousand batteries are produced each month.

EF_{PM} = 1.42 kg/10^3 batteries (From AP-42, Table 7.15-1)
$Q_{product}$ = 20,000 batteries/month x 12 months/yr
= 240,000 batteries/yr
E_{PM} = EF_{PM} x $Q_{product}$
= 1.42 x 240
= 341 kg/yr

6.2 Census-Based Emission Factors

Sources in certain area source categories are difficult to inventory by any of the previously discussed methodologies. The use of census-based emission factors is an efficient method for dispersed and numerous emission source types that cannot be readily characterized by a knowledge of process rates, fuel consumption rates, and/or material feed rates. Compared to the other emission estimating techniques, the use of census-based emission factors is the most “user-friendly” and cost-effective choice, since census data are readily available in most emission inventory regions. In Mexico, population and housing data, and employment data by economic sector and municipality are available in printed and electronic format from the INEGI.

The disadvantage of using existing census-based emission factors is that most of them were developed in the U.S. or Europe and may not account for the socioeconomic conditions and control practices in Mexico. The Department of the Federal District (DDF) has begun to develop Mexico-specific census-based emission factors. For example, the U.S. per capita emission factor for consumer solvents is 6.3 pounds/person/year (i.e., 2.86 kilograms/person/year). For the Mexico City area source inventory, DDF has recently reduced the aerosol contribution from 0.36 kg/person/yr to 0.05 kg/person/yr, thus adjusting the overall consumer solvents per capita emission factor to 2.55 kilograms/person/yr.

Also, it is important to remember that census-based emission factors are more accurate when applied to the entire region for which the emission factor was developed than when applied to smaller regions. For example, the Mexico-specific per capita emission factor for aerosols developed by DDF is an “average” emission factor for the entire country (i.e., it was based on national population and aerosol usage data). The accuracy of this emission factor decreases as it is applied to smaller regions. For example, if the per-capita consumption of aerosols in Xochimilco is higher than the national average, then use of the “average” emission factor will result in an underestimation of emissions for Xochimilco).

Per-employee emission factors are generally more accurate than per capita emission factors, since higher levels of employment reflect economic growth and, more specifically, tend to reflect rises in pollution-generating activity levels. However, care should be taken to eliminate employment data that are associated with non-manufacturing (e.g., administrative and clerical) jobs, whenever possible, since they are not likely to contribute significantly to pollution-generating activity levels. At a minimum, an effort should be made to eliminate employment data associated with company locations that are administrative offices rather than production plants.

6.2.1 Per Capita Emission Factors

Solvent evaporation from consumer and commercial products such as waxes, aerosol products, and window cleaners cannot be routinely determined for many local sources by the local agency. In addition, it would probably be impossible to develop a survey that would yield such information. Using per capita factors assumes that emissions in a given area can be reasonably associated with population. This assumption is valid over broad areas for certain activities such as dry cleaning, architectural surface coatings, small degreasing operations, and solvent evaporation from household and commercial products.

Per capita emission factors should not be developed and used indiscriminately for sources whose emissions do not correlate well with population. For example, large, concentrated industries, such as petrochemical facilities, should not be inventoried using per capita emission factors.

U.S.-specific per capita emission factors for various activities are available from several sources including the U.S. EPA's FIRE emission factor database, *AP-42 Compilation of Air Pollutant Emission Factors*, and *Procedures for the Preparation of Emission Inventories for Carbon Monoxide and Precursors of Ozone*, (U.S. EPA, 1991b).

Below is a sample calculation of an emissions estimate developed using per capita emission factors. Volume V - Area Sources provides more detailed guidance on developing area source emission estimates.

Example 6-4:

Calculate the 1990 VOC emissions from consumer aerosol usage in Xochimilco (D.F.). Assume that aerosols are 69% VOC. The 1990 population was estimated to be 642,753 people.

EF_{VOC} = 0.046 kg/person/yr x 69% VOC (From DDF, 1995)
= 0.032 kg/person/yr
$P_{Xochimilco}$ = 642,753 people

E_{VOC} = $EF_{VOC} \times P_{Xochimilco}$
= 0.032 x 642,753
= 20,568 kg/yr

6.2.2 Per-employee Emission Factors

This approach uses employment rather than population as the surrogate activity level indicator. Per-employee emission factors are usually used to estimate emissions for those source categories for which a CMAPP has been assigned and for which employment data (typically by CMAP) are available at the local level. Generally, this involves manufacturing the appropriate CMAP categories. In most cases, a large fraction of VOC emissions within CMAP will be covered by point source procedures, so the per-employee emission factor approach can be considered a secondary procedure to cover emissions from sources that are below the point source cutoff level. Point source reconciliation is discussed in more detail in the Area Sources Manual (Volume V).

The following sample calculation presents an emissions estimate developed using per capita emission factors. The Area Sources Manual (Volume V) provides more detailed guidance on developing area source emission estimates.

Example 6-5:

Calculate the annual VOC emissions from commercial dry cleaners in Mexico City (D.F.) for the area source inventory. Assume the dry cleaning solvents are 100% VOC. Assume that employment records for Mexico City show that there are 3,000 employees in the appropriate CMAP. Assume that 1,000 of these employees work at facilities that are included in the point source emissions inventory.

EF_{VOC} = 2,937 kg/employee/yr (EPA-450/4-91-016)
$E_{dry\ clean}$ = 3,000 total employees - 1,000 point source employees
= 2,000 area source employees

$$E_{VOC} = EF_{VOC} \times E_{dry\ clean}$$
$$= 2{,}937 \times 2{,}000$$
$$= 5{,}874{,}000 \text{ kg/yr}$$

7.0 MATERIAL BALANCE

The material balance (also known as a mass balance) is a method commonly used for estimating emissions from many source categories. The material balance method can be used where source test data, emission factors, or other developed methods are not available. In fact, for some sources, a material balance is the only practical method to estimate emissions accurately. For example, source testing of low-level, intermittent, or fugitive VOC exhaust streams can be very difficult and costly in many instances.

Use of a material balance involves the examination of a process to determine if emissions can be estimated solely on knowledge of specific operating parameters and material compositions. Although the material balance is a valuable tool in estimating emissions from many sources, its use requires that a measure of the material being “balanced” be known at each point throughout the process. The material balance is most appropriate to use in cases where accurate measurements can be made of all but the air emission component. If such knowledge is not available, and is therefore, assumed, serious errors may result.

In the VOC emissions inventory, a material balance is generally used to estimate emission from solvent evaporation sources. This technique is equally applicable to both point and area sources. Point sources may use a material balance approach at the device or facility level, whereas area sources may use a material balance approach at the regional or national level.

Figure 7-1 illustrates a few examples of using a material balance approach for point sources. The simplest method of material balance is to assume that all solvent consumed by a source process evaporates during that process. For instance, it is reasonable to assume that during many surface coating operations, all of the solvent in the coating evaporates to the atmosphere during the drying process. In such cases, emissions are simply equal to the amount of solvent applied in the surface coating (and added thinners) as a function of time. As another example, consider a dry cleaning plant that uses Stoddard solvent as the cleaning agent. To estimate emissions, the agency needs only to elicit from each plant the amount of solvent

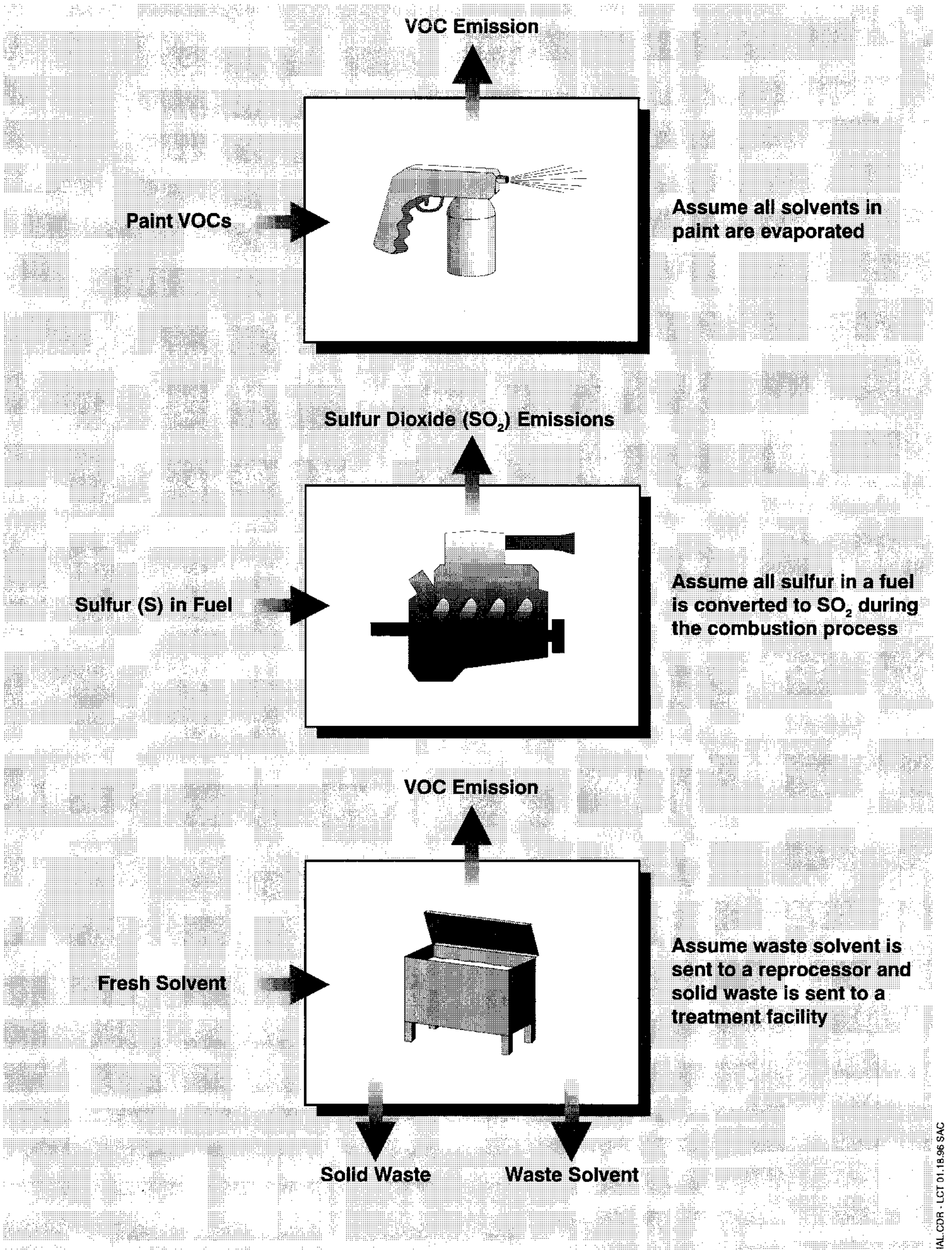

Figure 7-1. Examples of Material Balance

purchased during the time interval of concern, because the emissions are assumed equal to the quantity of solvent purchased.

The assumption that makeup solvent equals emissions also holds in certain more complicated situation. If a nondestructive control device such as a condenser or adsorber is employed, this assumption is valid to the extent that the captured solvent is returned to the process. Similarly, if waste solvent reclamation is practiced by a plant, by distillation or “boildown,” this assumption will be applicable. Both of these practices simply reduce the makeup solvent requirements of an operation, and therefore, the quantity of solvent lost to the atmosphere.

Available test methods are published through the American Society for Testing and Materials (ASTM) and have focused on providing information on material balance and gravimetric determinations for various industrial processes (ASTM, Volumes 06.01 and 15.05). The use of a mass or material balance to determine total emissions from a process is usually simple and affordable. Total VOC emitted from a batch paint mixing process, for example, would be calculated as follows (according to ASTM Method D 2369):

$$\mathbf{VOC_{in}\ (lb/gal) - VOC_{mixed\ paint}\ (lb/gal) = VOC_{emitted}\ (lb/gal)} \qquad (7\text{-}1)$$

As another example, fuel analysis can be used to predict emissions based on application of conservation laws. The presence of certain elements in fuels may be used to predict their presence in emission streams. This includes toxic elements such as metals found in coal as well as other elements such as sulfur which may be converted to other compounds during the combustion process.

The basic equation used in fuel analysis emission calculations is:

$$E = Q_f \text{ x Pollutant concentration in fuel x } \left(\frac{MW_p}{MW_f} \right) \qquad (7\text{-}2)$$

Where:
Q_f = Throughput of the fuel, mass rate (e.g., kg/hr)
MW_p = Molecular weight of pollutant emitted (lb/lb-mole)
MW_f = Molecular weight of pollutant in fuel (lb/lb-mole)

For instance, SO_2 emissions from oil combustion can be calculated based on the concentration of sulfur in the oil. This approach assumes complete conversion of sulfur to SO_2. Therefore, for every pound of sulfur (MW = 32 g) burned, two pounds of SO_2 (MW = 64 g) are emitted.

Example 7-1:

Calculate the hourly SO_x emissions (reported as SO_2) from an internal combustion engine burning diesel fuel, based on the fuel analysis data (i.e., sulfur content). The fuel throughput is estimated to be 150 liters/hr. The density of diesel is 0.85 kg/liter (7.1 lb/gal). The sulfur content of the diesel is 0.05% by mass.

Q_{fuel} = 150 liters/hr x 0.85 kg/liter
= 127.5 kg/hr
C_S = 0.05/100
= 0.0005
E_{SO2} = Q_{fuel} x C_S x (MW_p /MW_f)
= 127.5 x 0.0005 x (64/32)
= 0.13 kg/hr

In the above examples, the material balance is simplified, because of the assumption that all of the material being balanced is emitted to the atmosphere. Situations exist where this assumption is not always reasonable. For example, if a destructive control device such as an afterburner, incinerator, or catalytic oxidation unit is employed on the process exhaust, any VOC emissions will be either destroyed or so altered, that one could not reasonably assume, without testing the exhaust downstream of the device, the characteristics and quantities of any remaining VOC material. As another example, degreasing emissions will not equal solvent consumption if the waste solvent is sold to a commercial reprocessor. In such a situation, emissions will be the difference of solvent consumed and solvent in the waste sent to the reprocessor. As still another example, some fraction of the diluent used to liquify cutback asphalt is believed to be retained in the pavement rather than evaporating after application.

Example 7-2:

Calculate monthly VOC emissions from a vapor degreaser. Each month, 100 liters of solvent is added at the beginning of the month. During the month, an additional 20 liters are added to replenish losses. At the end of the month, 100 liters of waste solvent is sent to a recycler and 0.2 kg of solid waste is collected for disposal. The solvent is 100% VOC. The waste solvent is 98% VOC. The solid waste is 5% VOC. The solvent density is 1.5 kg/liter.

$$
\begin{aligned}
Q_{solvent} &= (100 \text{ liters/month} + 20 \text{ liters/month}) \times 1.5 \text{ kg/liter} \\
&= 180 \text{ kg/month} \\
Q_{waste} &= (100 \text{ liters/month} \times 1.5 \text{ kg/liter} \times 98\% \text{ VOC}) + \\
&\quad (0.2 \text{ kg/month} \times 5\% \text{ VOC}) \\
&= 147 \text{ kg/month} + 0.01 \text{ kg/month} \\
&= 147 \text{ kg/month}
\end{aligned}
$$

$$
\begin{aligned}
E_{VOC} &= Q_{solvent} - Q_{waste} \\
&= 180 - 147 \\
&= 33 \text{ kg/month}
\end{aligned}
$$

The above example shows that, in some cases, assuming total evaporation of all consumed solvent would result in an overestimation of emissions. Therefore, material balances can also be used in conjunction with process-based emission factors (see Section 6.1) to estimate emissions, such as those based on the difference between the raw material and the product when the emission factor for a process is per unit of material consumed.

For example, material balances could be performed for area source emission calculations involving fuel manufacture, distribution, and consumption (see Figure 7-2). A material balance for fuel distribution and consumption was recently applied in the United States

(De Luchi, 1993). A national material balance for solvents for surface coating materials may also be the best method for estimating VOC emissions from these source categories or pesticide application.

Several other situations can complicate the material balance. First, not all of the solvent losses from certain operations such as dry cleaning or degreasing occur at the plant site. Instead, significant quantities of solvent may be evaporated from the waste solvent disposal site, unless the waste solvent is incinerated or disposed of in a manner that precludes subsequent evaporation to the atmosphere. Generally, one can assume that much of the solvent sent to disposal sites will evaporate. The agency should determine whether some solvent associated with various operations evaporates a the point of disposal rather than at the point of use, since these losses may occur outside of the area covered by the inventory.

Material balances cannot be employed in some evaporation processes because the amount of material lost is too small to be determined accurately by conventional measurement procedures. As an example, applying material balances to petroleum product storage tanks is not generally feasible, because the breathing and working losses are too small relative to the total average capacity or throughput to be determined readily from changes in the amount of material stored in each tank. In these cases, AP-42 emission equations (i.e., models), developed by special procedures, should be applied.

In summary, with the exception of a few source types such as fuel and solvent use examples presented above, a material balance approach is not recommended as the primary method for estimating emissions. Rather, material balances may be more widely used as a top-down method to evaluate the reasonableness of emission estimates generated using other techniques.

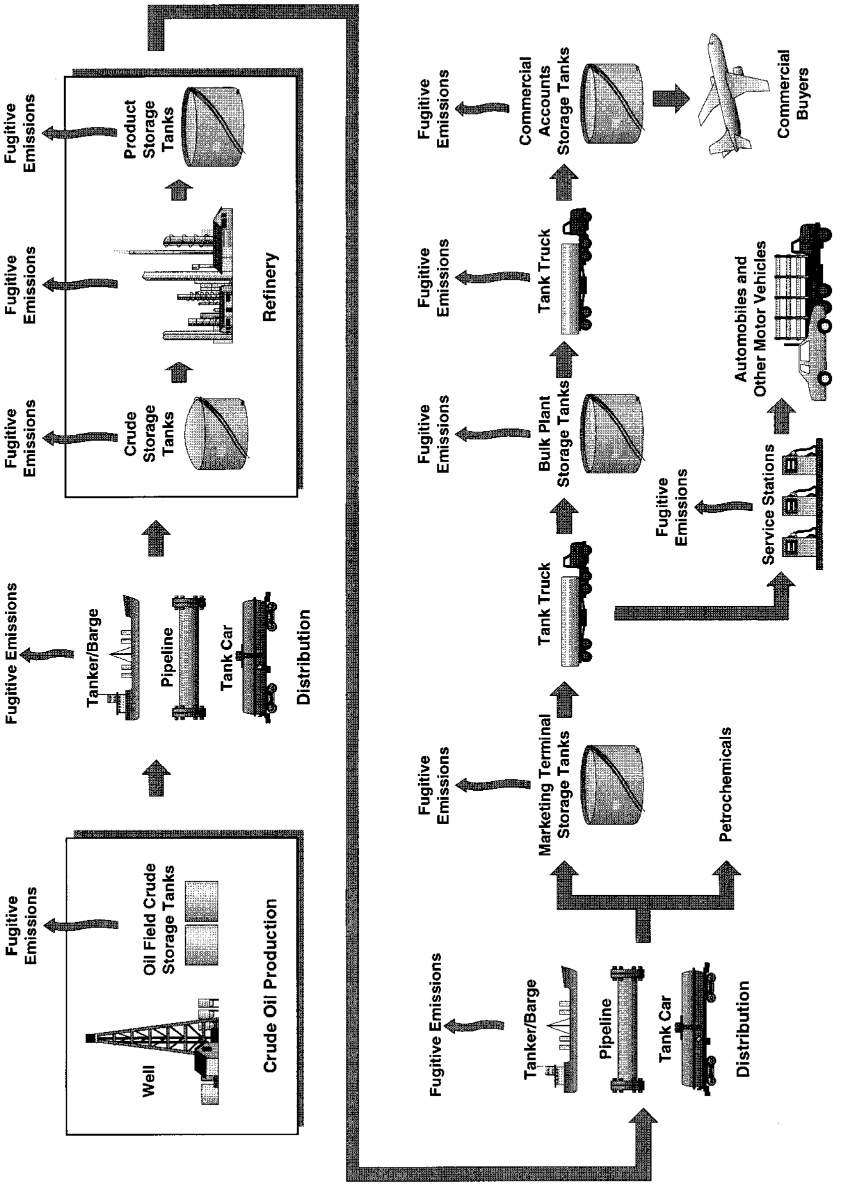

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Figure 7-2. Example of Material Balance Highlighting Fugitive Emissions

8.0 EXTRAPOLATION

Extrapolation techniques can be used to calculate emissions directly and to verify the emission estimates calculated using another approach. Figure 8-1 illustrates the general concept of emissions extrapolation. Extrapolation of emissions from one geographic region to another is generally considered the least desirable approach for emissions estimation. Such an approach may not properly account for important differences between two regions and may propagate biases from one inventory to another.

When combined in a modeling framework, however, extrapolation will be a practical and cost effective approach to develop emission estimates for regions where there is insufficient information to support more rigorous emissions estimating methodologies. The rest of this section presents some examples of how an extrapolation approach may be used to develop emission estimates.

First, emissions data from one type of process or one facility may be extrapolated to similar source types or facilities. This type of extrapolation would be used to develop point source emission estimates.

In other cases, if it can be argued that the socioeconomic conditions between two or more geographical regions are comparable, then the available area source emissions data for one region can be extrapolated to the remaining regions based on population/employment data. Emissions inventories compiled in the U.S. and in Europe can be used in this manner. Within Mexico, emissions inventories that have been compiled for Mexico City and that are being developed for other areas (e.g., Monterrey metropolitan area) may be used as a basis for QA and/or development of portions of the emissions inventories for other regions.

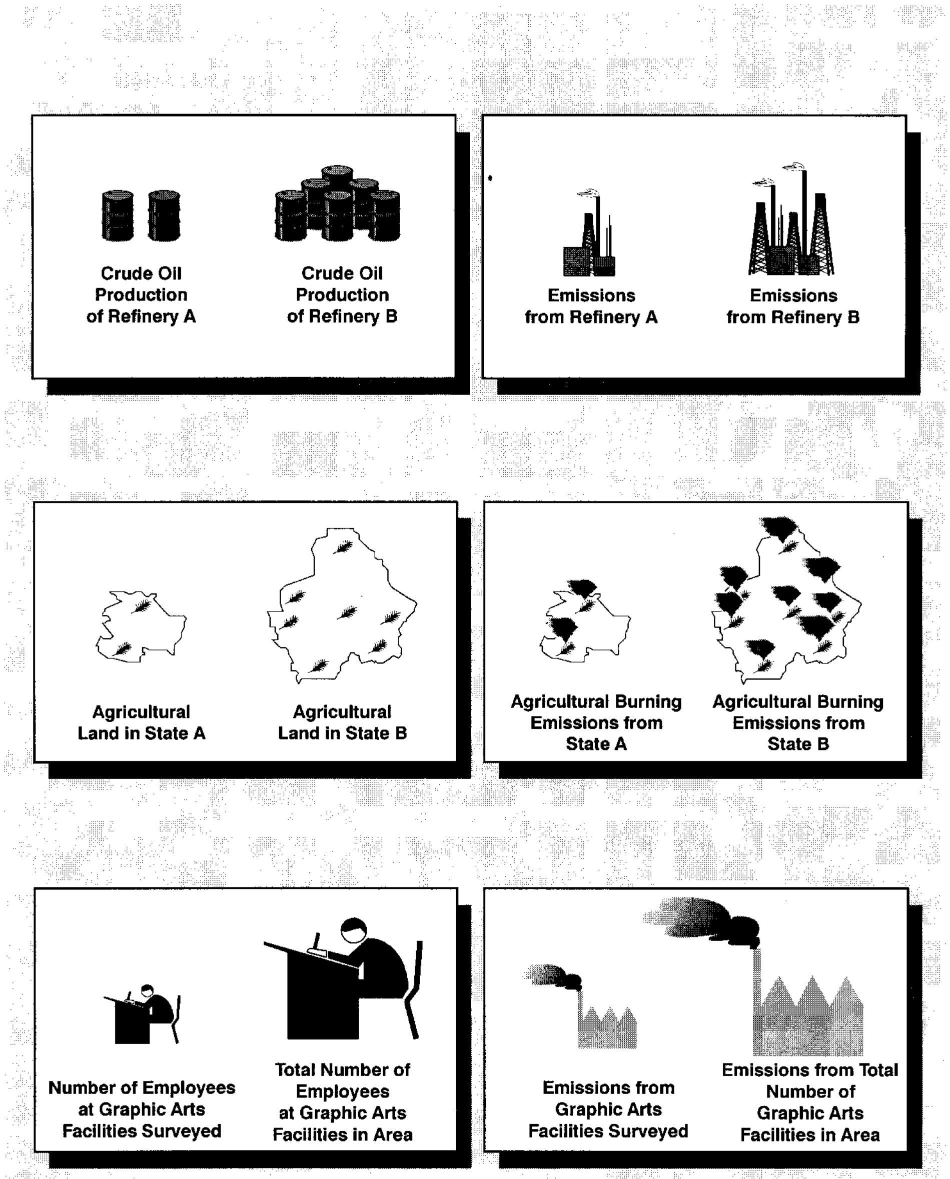

Figure 8-1. Examples of Extrapolation

Example 8-1:

Based on detailed emissions calculations for Refinery A, the total annual VOC emissions are estimated to be 100 tonnes (metric). The company has just purchased a smaller facility, Refinery B, which processes one-half as much crude oil as Refinery A. For a meeting tomorrow, the company president wants an estimate of the total cost that will be associated with permit fees for VOC emissions. Since there is no time for detailed emissions calculations for Refinery B, estimate the VOC emissions by extrapolating from Refinery A based on the refinery capacities (i.e., the amount of crude oil processed).

$$
\begin{aligned}
E_{VOCb} &= E_{VOCa} \text{ x } P_{CRUDEb}/P_{CRUDEa} \\
&= 100 \text{ tonnes/yr x } 1/2 \\
&= 50 \text{ tonnes/yr}
\end{aligned}
$$

Example 8-2:

Based on a surveying effort, the total annual VOC emissions from agricultural burning in State A are estimated to be 50 tonnes (metric). Resources are not available to fund a similar surveying effort in State B. Since the agricultural conditions are very similar in State B emissions (e.g., similar crops, agricultural methods, climate, etc.), estimate the VOC emissions by extrapolating from State A based on the area of agricultural land in each state. Land use maps show 400,000 m^2 of agricultural land in State A and 50,000 m^2 of agricultural land in State B.

$$
\begin{aligned}
E_{VOCb} &= E_{VOCa} \text{ x } A_{AGb}/P_{AGa} \\
&= 50 \text{ tonnes/yr x } 50{,}000/400{,}000 \\
&= 6.25 \text{ tonnes/yr}
\end{aligned}
$$

This approach can also be used when the agency surveys only a fraction of the area sources within a given category. In this case, employment is used as an indicator to "scale up" the inventory to account collectively for emission sources and emissions in the area source inventory. Parameters other than employment, such as sales data or number of facilities, can be used to develop emission estimates. However, employment is generally the most readily available parameter. Scaling up emission estimates is also discussed in Section 5.0 of this manual.

Example 8-3:

A surveying effort is conducted to collect VOC emission estimates from small graphic arts facilities in Coyoacan to use in the area source inventory for Mexico City. Due to resource constraints, the questionnaire is only sent to some facilities in Coyoacan, and not all the facilities that are included in the survey mailing list actually return the questionnaire. The total annual VOC emissions reported on the questionnaires is 100 tonnes (metric). Since resources are not available to survey each small graphic arts facility, estimate the VOC emissions for Coyoacan by extrapolating (i.e., scaling up) the collected VOC emissions based on employment. Available employment records show that 500 people in Coyoacan work in the graphic arts industry and the questionnaires show that a total of 125 people work at the facilities completing the survey forms.

$$\begin{aligned} E_{VOCcoy} &= E_{VOCsur} \text{ x } P_{coy}/P_{sur} \\ &= 100 \text{ tonnes/yr x } 500/125 \\ &= 400 \text{ tonnes/yr} \end{aligned}$$

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APPENDIX III-A

SAMPLE CALCULATIONS FOR EMISSIONS MODELS

Sample Calculation—Fugitive Dust

$$M = VKT \times EF \tag{4-12}$$

where:

M = average annual mass emission rate, kg/yr;
VKT = vehicle kilometers traveled, VKT/yr;
EF = emission factor, kg/VKT.

$$EF = k(1.7)\left(\frac{s}{12}\right)\left(\frac{S}{48}\right)\left(\frac{W}{2.7}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{365-p}{365}\right) \text{ (kg/VKT)} \tag{4-13}$$

$$EF = k(5.9)\left(\frac{s}{12}\right)\left(\frac{S}{30}\right)\left(\frac{W}{3}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{365-p}{365}\right) \text{ (lb/VMT)} \tag{4-14}$$

where:

EF = emission factor;
k = particle size multiplier (dimensionless);
s = silt content of road surface material (%);
S = mean vehicle speed, km/hr (mph);
W = mean vehicle weight, Mg (ton);
w = mean number of wheels;
p = number of days with a least 0.254 mm (0.01 in.) of precipitation per year.

Calculate annual PM_{10} emissions (i.e., using an aerodynamic particle size multiplier of 0.36) from rural dirt roads with an average silt content of 12 percent. Assume the mean vehicle weight is 4 Mg, the mean vehicle speed is 25 km/hr, and the mean number of wheels is four. Also, the mean number of days with greater than 0.254 mm precipitation is 40 and the vehicle kilometers traveled is 3,650,000 km/yr.

$$EF = (0.36)\ (1.7)\left(\frac{12}{12}\right)\left(\frac{25}{48}\right)\left(\frac{4}{2.7}\right)^{0.7}\left(\frac{4}{4}\right)^{0.5}\left(\frac{365-40}{365}\right)$$

$$= 0.3737 \text{ kg/VKT}$$

$$M = (3{,}650{,}000) \times (0.3737)$$

$$= 1{,}364{,}000 \text{ kg } PM_{10}\text{/yr}$$

Sample Calculation—Landfills

$$Q_{CH4} = L_o \text{ x } R \text{ x } (e^{-kc} - e^{-kt}) \qquad (4\text{-}11)$$

where:
Q_{CH4} = methane generation rate at time t, m^3/yr;
L_o = methane generation potential, $m^3 CH_4$/Mg refuse;
R = average annual refuse acceptance rate during active life, Mg/yr;
e = base log, unitless;
k = methane generation rate constant, yr^{-1};
c = time since landfill closure, yrs (c=0 for active landfills); and
t = time since the initial refuse placement, yrs.

Calculate annual methane emissions from an active landfill that has been open for 15 years and has accepted refuse at an average rate of 10,000 Mg/yr. Assume a methane generation potential of 125 m^3/Mg and a methane generation rate constant of 0.02/yr

$$Q_{CH4} = (125 \text{ m}^3 \text{ Mg}) \text{ x } (10{,}000 \text{ Mg/yr}) \text{ x } (e^{-(0.02/yr)\ (0\ yr)}\ e^{-(0.02/yr)\ (15\ yr)})$$

$$= 125 \text{ x } 10{,}000 \text{ x } (1 - 0.7408)$$

$$= 324{,}000 \text{ m}^3 \text{ CH}_4\text{/yr}$$

Sample Calculation—Fugitive Dust

Sample Calculation—Landfills

Sample Calculation—Storage Tanks

Sample Calculation—Petroleum Products Loading

Sample Calculation—Waste & Wastewater

APPENDIX III-B

HOW TO OBTAIN
U.S. EPA AIR EMISSION ESTIMATING TOOLS

APPENDIX III-C

SAMPLE POINT SOURCE QUESTIONNAIRE (I.E., INE'S ENCUESTA INDUSTRIAL)

Manuales del Programa de Inventarios de Emisiones de México

Volumen III - Técnicas Básicas de Estimación de Emisiones

Elaborado para:

La Asociación de Gobernadores del Oeste
y El Comité Asesor Binacional

Enero, 1996

DCN 96-670-017-01
RCN 670-017-20-04

MANUALES DEL PROGRAMA DE INVENTARIOS DE EMISIONES DE MEXICO

VOLUMEN III - TECNICAS BASICAS DE ESTIMACION DE EMISIONES

Elaborado para:

La Asociación de Gobernadores del Oeste
Denver, Colorado

y

El Comité Asesor Binacional

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Mayo 17, 1996

PREFACIO

La contaminación del aire puede tener impactos negativos sobre la salud pública cuando su concentración en la atmósfera alcanza niveles significativos. En la mayor parte de las áreas rurales los problemas de calidad del aire se dejan sentir sólo en raras ocasiones mientras que con frecuencia en muchos ambientes urbanos se registran elevadas concentraciones de contaminantes. Durante los años recientes, México ha tenido un gran crecimiento en la urbanización y en la actividad industrial lo que ha generado serias preocupaciones acerca de la calidad del aire en diversas regiones del País.

La contaminación del aire resulta de una compleja mezcla de, literalmente, miles de fuentes, que van desde las chimeneas industriales y los vehículos automotores, hasta el uso individual de productos de aseo, limpiadores domésticos y pinturas. Incluso la vida animal y vegetal puede desempeñar un papel importante en el problema de la contaminación del aire. Debido a la compleja naturaleza de la contaminación del aire se requieren planes regionales detallados para identificar las fuentes de emisión así como el desarrollo de métodos para reducir el impacto sobre la salud ocasionado por la exposición a los contaminantes. Entre algunos ejemplos de las actividades de planeación de la calidad del aire están:

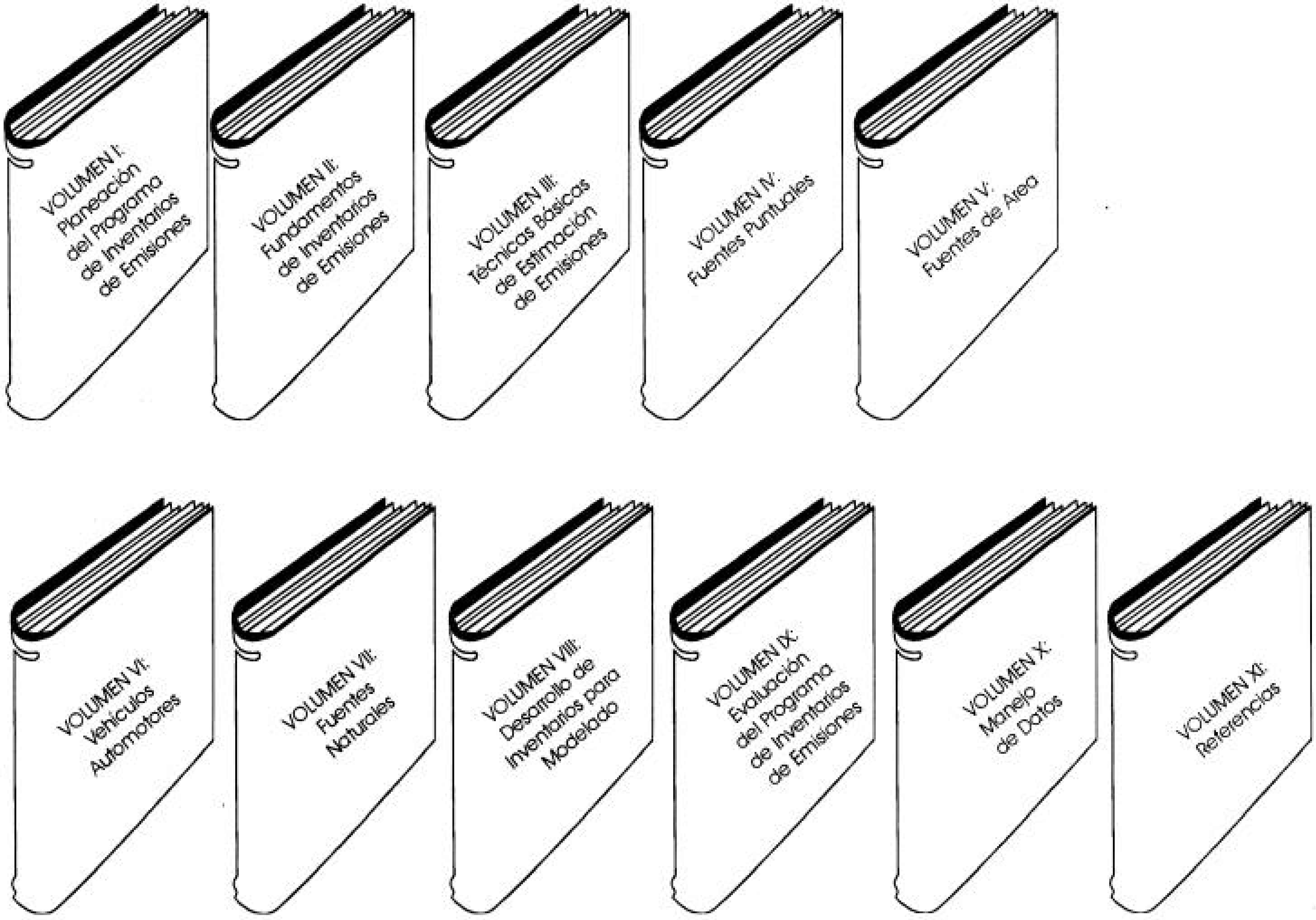
- la aplicación de modelos de calidad del aire
- el examen de las fuentes emisoras de contaminantes para analizar el control de emisiones cuando así se requiere
- el desarrollo de proyecciones de las emisiones para examinar posibles cambios en la futura calidad del aire

- el análisis de las tendencias de emisión y
- el análisis del transporte de las emisiones de una región a otra.

El desarrollo de inventarios de emisión básicamente correctos es un aspecto clave en cada una de estas funciones de planeación de la calidad del aire.

El cálculo de estimaciones de emisión que cumplan con las necesidades de planeación de la calidad del aire requiere de un desarrollo y refinamiento continuos. Los esfuerzos para hacer inventarios “de una sola vez” no son adecuados para el proceso de planeación de la calidad del aire. Para obtener un beneficio duradero debe implantarse un *programa de inventarios* de manera que puedan desarrollarse estimaciones exactas de las emisiones para todas las regiones geográficas de importancia que puedan refinarse con el paso del tiempo y que puedan aplicarse efectivamente en el proceso de planeación y monitoreo de la calidad del aire. De esta manera, se está desarrollando un conjunto de manuales de inventarios que puedan usarse en todo el País para ayudar a coordinar el desarrollo de estimaciones de emisiones consistentes. Estos manuales son para uso de autoridades locales, estatales y federales, así como para uso de consultores privados y de la industria. El propósito de estos manuales es ayudar en el proceso de implantación del programa de inventarios y en su mantenimiento a lo largo del tiempo de manera que los inventarios de emisiones se puedan desarrollar en ciclos periódicos mejorándolos continuamente.

Los manuales abarcan elementos del programa de inventarios tales como la estimación de emisiones, la planeación del programa, manejo de bases de datos, validación de emisiones y otros temas de importancia. La Figura 1 muestra la serie completa de manuales que serán desarrollados para apoyar un programa de inventarios de largo alcance. A continuación se resume el propósito principal de cada manual.



Manuales del Programa de Inventarios de Emisiones de México

Volumen I - Planeación del Programa de Inventarios de Emisiones. Este manual presenta los aspectos de planeación que deben ser considerados en un programa de inventario de emisiones al aire. La planeación del programa no se presenta como una actividad “terminal”, sino más bien como un proceso continuo para asegurar el crecimiento en el largo plazo y el éxito del programa de inventarios. *Temas Clave:* propósito del programa; usos finales del inventario; requerimientos regulatorios; coordinación en los niveles federal, estatal y local; requerimientos de personal y de manejo de datos; identificación y selección de estudios especiales.

Volumen II - Fundamentos de Inventarios de Emisiones. Este manual presenta los fundamentos básicos para la preparación de inventarios de emisiones y presenta los elementos que son aplicables a los diversos tipos de fuentes (e. g., puntuales y de área) para evitar la necesidad de que sean repetidos en cada volumen. *Temas Clave*: regulaciones aplicables; efectividad de la regla; penetración de la regla; definiciones sobre contaminantes (e. g., cómo excluir de manera adecuada los compuestos volátiles no reactivos); definición de fuentes puntuales y de área; reconciliación de fuentes puntuales y de área.

Volumen III - Preparación de Inventarios de Emisiones: Técnicas Básicas de Estimación de Emisiones (TEEs). Este documento presenta las TEEs básicas utilizadas para hacer estimaciones de emisiones, incluyendo ejemplos y cálculos como muestra se identifican las herramientas para inventarios asociadas con cada metodología y se incluyen en el Volumen XI (Referencias). *Temas Clave*: muestreo en la fuente, modelos de emisiones, encuestas, factores de emisión, balance de materiales y extrapolación.

Volumen IV - Fuentes Puntuales. Este manual proporciona guías para elaborar inventarios de emisiones de fuentes puntuales. Incluye una tabla de referencias cruzadas para cada combinación de industria y tipo de dispositivo (e. g., refinación de petróleo y dispositivos de combustión) con una o más de las TEEs presentadas en el Volumen III. *Temas Clave:* tabla de referencias cruzadas; parámetros de chimenea; dispositivos de control; consideraciones de diseño y de proceso; diferencias geográficas y variabilidad en México; aseguramiento y control de calidad (AC/CC); procesos pasados por alto; referencias de datos y formas para recopilación de datos.

Volumen V - Fuentes de Area (incluyendo fuentes móviles que no circulan por carreteras). Este manual contiene los lineamientos para el desarrollo de inventarios de emisiones de fuentes de área. Después de presentar información general sobre las fuentes de área, se da una tabla para hacer las referencias cruzadas de cada categoría de fuente de área (e. g., aplicación de asfalto) con una o más de las TEEs básicas que se presentan en el Volumen III. Posteriormente, se comenta la información específica para cada categoría de fuente definida en la tabla. *Temas Clave:* categorización y definición de fuentes de área; tabla de referencias cruzadas; factores de control; diferencias geográficas y variabilidad en México; AC/CC; referencias de datos; formas para recopilación de datos (cuestionarios).

Volumen VI - Vehículos Automotores. Debido a que los vehículos automotores son intrínsecamente diferentes a las fuentes puntuales y a las de área, tanto los métodos de estimación disponibles como los datos requeridos son también diferentes. Para estimar las emisiones de estas complejas fuentes los modelos son las herramientas preferidas. Muchos de estos modelos utilizan datos de pruebas extensivas aplicables a un país o a una región determinados. Este manual se enfoca principalmente en la fase de desarrollo de datos para la estimación de emisiones de vehículos automotores. *Temas Clave:* métodos de estimación disponibles; datos e información primarios, secundarios y terciarios; categorización de fuentes; fuentes de factores de emisión; variabilidad geográfica dentro de México, AC/CC.

Volumen VII - Fuentes Naturales. Este manual da lineamientos para el desarrollo de inventarios de emisiones de fuentes naturales (e. g., compuestos orgánicos volátiles biogénicos [COV] y óxidos de nitrógeno [NO_x]) en suelos. Además, incluye los aspectos teóricos de los cálculos de emisiones y la discusión de modelos específicos. *Temas*

Clave: categorización y definición de fuentes; mecanismos de emisión; algoritmos básicos de emisión; determinación de biomasa; desarrollo de datos de uso y cobertura del suelo; ajustes temporales y meteorológicos; enfoques para el cálculo de emisiones.

Volumen VIII - Desarrollo de Inventarios para Modelado. Este manual proporciona los lineamientos para el desarrollo de datos de inventarios que serán utilizados en modelos de calidad del aire y trata aspectos tales como la localización temporal y espacial, la especiación y la proyección de estimaciones de emisiones. *Temas Clave:* definición de términos de modelado; ajuste estacional; localización temporal y espacial; especiación química y proyecciones (crecimiento y factores de control).

Volumen IX - Evaluación del Programa Inventarios de Emisiones. Este manual consta de tres partes: AC y CC, análisis de incertidumbre y verificación de emisiones. La parte de AC y CC define el programa global de aseguramiento y control de calidad y se ha escrito para complementar los procedimientos de AC y CC para fuentes específicas que se presentan en otros manuales. El análisis de incertidumbre no sólo incluye métodos para evaluar la incertidumbre en las estimaciones de emisiones, sino también para evaluar la incertidumbre en los valores de modelado tales como los perfiles de especiación y los factores de proyección de emisiones. La sección de verificación de emisiones describe varios análisis que se pueden hacer para examinar la exactitud de las estimaciones de emisiones. Los ejemplos incluyen modelos de receptores y análisis de trayectoria combinados con técnicas específicas de el análisis de datos. *Temas Clave:* descripción de conceptos y definición de términos; protocolo de revisión de inventarios; revisiones de integridad, exactitud y consistencia; TEEs de incertidumbre recomendadas y TEEs aplicables de verificación de emisiones.

Volumen X - Manejo de Datos. Este manual trata de las necesidades importantes asociadas con el elemento de manejo de datos del programa nacional de inventarios de emisiones de México. *Temas Clave:* sistemas y herramientas de manejo de datos con propósitos generales; sistemas y herramientas de software de propósitos específicos; sistemas de codificación; confidencialidad; presentación electrónica; frecuencia de actualizaciones, mantenimiento de registros; bases de datos específicas de México y reportes.

Volumen XI - Referencias. Este manual es un compendio de las herramientas que pueden utilizarse en el desarrollo de un programa de inventarios de emisiones. Se incluyen las herramientas citadas para hacer inventarios en los otros manuales (e. g., documentos impresos y electrónicos, así como modelos de computadora).

CONTENIDO

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APENDICE III-A: MUESTRA DE CALCULOS PARA MODELOS DE EMISIONES

APENDICE III-B: COMO OBTENER LAS HERRAMIENTAS PARA ESTIMAR EMISIONES AL AIRE DE LA U.S. EPA

APENDICE III-C: MUESTRA DE CUESTIONARIO PARA FUENTES PUNTUALES (I. E., ENCUESTA INDUSTRIAL DEL INE)

FIGURAS Y TABLAS

Figuras **Pág.**

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ACRONIMOS

AC	Aseguramiento de Calidad
API	American Petroleum Institute *(Instituto Americano del Petróleo)*
ASTM	American Society for Testing and Materials *(Sociedad Americana de Pruebas y Materiales)*
BIF	boiler and industrial furnace *(caldera y horno industrial)*
Btu	British Thermal unit (*Unidad Térmica Británica)*
CAA	Clean Air Act *(Ley del Aire Limpio)*
CANACINTRA	Cámara Nacional de la Industria de Transformación
CC	Control de Calidad
CFR	Code of Federal Regulations *(Código de Regulaciones Federales)*
CMAP	Clasificación Mexicana de Actividades y Productos
CO	Monóxido de carbono
CO_2	Dióxido de Carbono
COVs	Compuestos orgánicos volátiles
DDF	Departamento del Distrito Federal
dscfm	dry standard cubic feet per minute *(Pie cúbico estándar seco por minuto)*
dscm	dry standard cubic meter *(Metro cúbico estándar seco)*
FIRE	Factor Information Retrieval System *(Sistema de Recuperación de Información sobre factores)*
ft^3	pie cúbico
GHG	greenhouse gas *(gas con efecto invernadero)*

gr/dscf	granos por pie cúbico seco estándar
HAP	hazardous air pollutant *(contaminante atmosférico peligroso)*
HCl	ácido clorhídrico
HCT	Hidrocarburos totales
hr	hora
ID	identificación
INE	Instituto Nacional de Ecología
INEGI	Instituto Nacional de Estadística, Geografía e Informática
IPCC	Intergovernmental Panel on Climate Change *(Panel Intergubernamental para el Cambio Climático)*
Kb	kilobyte
kg	kilogramo
kJ	kilojoule
km	kilómetro
L	litro
LAEEM	Landfill Air Emissions and Estimation Model *(Modelo de Emisiones al Aire y estimación de Rellenos Sanitarios)*
lb	libra
LPG	gas licuado de petróleo
m^3	metro cúbico
MCE	Monitor Continuo de Emisiones
Mg	megagramo (i.e., 10^6 g = 1 tonelada métrica)
mg	miligramo
NH_3	amoniaco
NO_x	óxidos de nitrógeno
O_2	oxígeno

OAQPS	Office of Air Quality Planning and Standards *(Oficina de Planeación y Estándares de la Calidad del Aire)*
OH	Radicales hidroxilo
OMS	Organización Mundial de la Salud
PM	partículas
PM_{10}	partículas de diámetro inferior o igual a 10 micrómetros
ppbv	partes por billón en volumen
ppmv	partes por millón por volumen (aquí, 1 billón =10^9
psig	libras por pulgada cuadrada - presión manométrica
PST	partículas suspendidas totales
RO_2	radicales peroxi
SO_2	dióxido de azufre
SO_x	óxidos de azufre
TEE	Técnica de Estimación de Emisiones
THC	Total hydrocarbons *(hidrocarburos totales)*
ton	tonelada inglesa (i. e., 2,000 lbs)
tonne	tonelada métrica (i. e., 1,000 kg)
tpa	toneladas por año

TSDF	treatment, storage and disposal facilities *(instalaciones, para tratamiento, almacenamiento y disposición)*
U.S. EPA	United States Environmental Protection Agency *(Agencia de Protección Ambiental de EU)*

1.0 INTRODUCCION

Este manual presenta las técnicas básicas de estimación de emisiones (TEEs) que se usan para hacer estimaciones de emisiones de fuentes puntuales y de área (incluyendo las fuentes móviles que no circulan por carreteras). Las TEEs básicas que se presentan aquí se identificaron al examinar los métodos para hacer inventarios que actualmente se utilizan en México, Europa, Asia y EU. También se revisaron las técnicas desarrolladas por la Organización Mundial de la Salud (OMS) y aquéllas que se emplean para calcular inventarios de emisiones de gases con efecto invernadero a escala global. Las seis diferentes TEEs básicas identificadas son:

- Muestreo en la Fuente: son mediciones directas de la concentración de contaminantes en un volumen conocido de gas y de la tasa de flujo del gas en la chimenea. Son utilizadas con mayor frecuencia para fuentes de emisiones de combustión.

- Modelos de Emisión: son ecuaciones desarrolladas cuando las emisiones no se relacionan directamente con un solo parámetro. Se pueden usar computadoras en el caso de que se tenga un gran número de cálculos complejos. Por ejemplo, el programa TANKS de la U.S. Environmental Protection Agency (U.S. EPA) es un modelo de emisiones computarizado que se usa para estimar emisiones de tanques de almacenamiento.

- Encuestas: son cuestionarios diseñados para recopilar datos de emisiones. A menudo son utilizados para recopilar datos de fuentes puntuales desarrollados a nivel de establecimiento o bien datos de fuentes de área de un muestreo representativo de fuentes dentro de una categoría dada.

- Factores de Emisión: son relaciones entre la cantidad de un contaminante emitido y una sola unidad de actividad. La actividad puede, consistir en datos basados en procesos (e. g., producción, horas de operación, área superficial) o en datos basados en censos (e. g., población, número de empleados).

- Balance de Materiales: se usan mediciones de todos los componentes, de un proceso, excepto el aire para determinar las emisiones al aire. Es utilizado con mayor frecuencia para fuentes de evaporación de solventes cuando no hay datos disponibles para apoyar los otros enfoques.

- Extrapolación: consiste en el escalamiento de las emisiones de una fuente dada a otra con base en un parámetro de escalamiento conocido para ambas fuentes (e. g., cantidad de producción, área del terreno, número de empleados).

En este manual se explica y comenta con detalle cada una de las TEEs básicas. Además se presentan muestras de cálculos para ilustrar la instrumentación de cada TEE básica.

El manual de TEEs básicas está hecho para utilizarse en conjunto con los manuales de Fuentes Puntuales y Fuentes de Area (volúmenes IV y V, respectivamente. Cada uno de éstos contiene una tabla que con referencias cruzadas entre cada categoría de fuente puntual o de área con una o más de las TEEs básicas que pueden usarse para calcular estimaciones de emisiones. Por ejemplo, para las emisiones de combustión de las plantas generadoras de energía eléctrica, la tabla de referencias cruzadas del Manual de Fuentes Puntuales muestra al usuario que el muestreo en la fuente, los factores de emisión o el balance de materiales son las TEEs básicas que se usan para desarrollar estimaciones de emisiones para esta categoría de fuente. Estos métodos básicos se describen en este manual de TEEs básicas.

El resto de este manual está organizado de la siguiente manera:

- Sección 2.0: presenta la ecuación básica para la estimación de emisiones y define y proporciona una guía general sobre las fuentes de información para cada variable de la ecuación
- Sección 3.0: trata el muestreo en la fuente
- Sección 4.0: presenta los modelos de emisión (mecanísticos y de variable múltiple)
- Sección 5.0: comenta la encuesta
- Sección 6.0: cubre los factores de emisión (basados en procesos y basados en censos)
- Sección 7.0: describe los cálculos de balances de materiales
- Sección 8.0: explica la extrapolación
- Apéndice III-A: contiene muestras de cálculos para modelos de emisiones
- Apéndice III-B: contiene información acerca de la manera de obtener las herramientas de estimación de emisiones al aire de la U.S. EPA
- Apéndice III-C: contiene un ejemplo de la forma de encuesta para un cuestionario de una fuente puntual (i. e., Encuesta Industrial del INE).

2.0 ECUACION FUNDAMENTAL PARA LA ESTIMACION DE EMISIONES

El desarrollo de un programa de inventario de emisiones para México requerirá de una combinación de enfoques. No existe ningún método único que pueda usarse para estimar las emisiones de todas las categorías de fuente. La Figura 2-1 ilustra varios enfoques que deberían tomarse en cuenta para estimar emisiones cuando se analizan los costos en relación con la calidad de los resultados. En regiones con serios impactos ambientales ocasionados por la contaminación del aire se pueden asegurar métodos más elaborados y costosos, por ejemplo muestreo en la fuente para determinar las emisiones. Por el contrario, en aquellas regiones que tienen problemas ambientales mínimos, el uso de métodos de estimación menos costosos, como el de los factores de emisión, puede ser aceptable.

La ecuación fundamental para estimar emisiones es:

$$E = A \times EF \times [1 - (CE/100 \times RE \times RP)] \times T \times M\% \qquad (2\text{-}1)$$

donde:
E = Tasa de Emisión
A = Tasa de Actividad (e.g., producción, población, etc.)
EF = Factor de Emisión (lb/unidad de tasa de actividad)
CE = Eficiencia de Control (%)
RE = Efectividad de la Regla
RP = Penetración de la Regla
T = Ajuste Temporal
M% = Masa porcentual de Contaminante

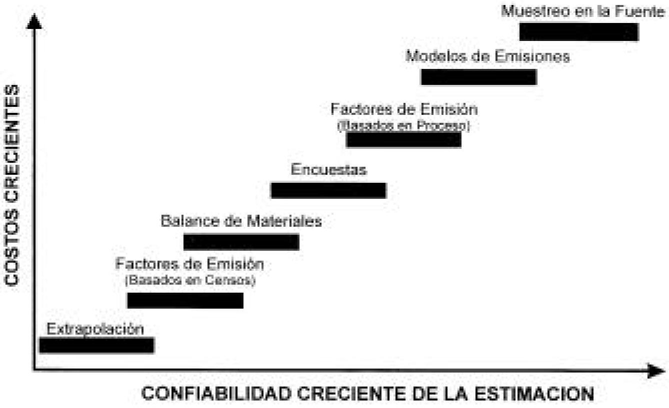


Figura 2-1. Jerarquía de la Estimación de Emisiones

La exactitud de la estimación de emisiones depende de la exactitud relativa de cada uno de estos componentes individuales. Si se introducen errores en cualquiera de ellos se afectará la estimación final de las emisiones.

La información presentada en este manual se enfoca en los dos primeros componentes de la ecuación básica para estimar emisiones: Los factores de emisión y las tasas de actividad. Las eficiencias de control se tratan con mayor detalle en los Manuales de Fuentes Puntuales y Fuentes de Area (Volúmenes IV y V, respectivamente). La efectividad y la penetración de la regla se ven con más profundidad en el Manual de Fundamentos de Inventarios de Emisiones (Volumen II). El ajuste temporal y la masa porcentual de contaminante (i. e., compuestos no reactivos y perfiles de especiación) se explican con más detalles en el Manual para el Desarrollo de Inventarios para Modelado (Volumen VIII). El resto de esta sección presenta las definiciones de cada componente de la ecuación básica para estimar emisiones y guías generales acerca de dónde encontrar información sobre cada uno.

Tasas de Actividad. En general, los datos de actividad se relacionan con los procesos emisores. En los procesos industriales, los datos de actividad por lo general están dados como tasas del proceso en peso (e. g., kg, ton ó L mensuales de material utilizado o manufacturado). De manera semejante, para el equipo en que se quema combustible, los datos se dan como tasas de consumo de combustible (e. g., tons, L ó m^3, ó MJ por hora o por mes). En muchos casos se deben aplicar factores de conversión para transformar los valores de consumo o de producción reportados en unidades que correspondan a las unidades de producción del factor de emisión (e.g., tons, barriles, etc.). Además, si se utilizan factores de emisión de Estados Unidos, también puede necesitarse hacer conversiones de unidades estándar a métricas. Por lo general, los datos de actividad para fuentes puntuales se basan en procesos, y es muy probable que sean recopilados por el personal de la planta y se reporten a la Agencia en un formato resumido (e. g., el cuestionario industrial). Con frecuencia, los datos de actividad para fuentes de área a menudo son sustitutos que se demuestra o se asume que están correlacionados con el proceso emisor (e. g., número de empleados). Los datos de actividad para fuentes de área son recopilados, en general, por la agencia a partir de los datos disponibles de censos (e. g., del Instituto Nacional de Estadística, Geografía e Informática [INEGI]), o haciendo encuestas en plantas pequeñas.

Factores de Emisión. Un factor de emisión es una relación entre la cantidad de contaminante emitido a la atmósfera y una unidad de actividad. En general, los factores de emisión se clasifican en dos tipos: los basados en procesos y los basados en censos. Por lo común los primeros se usan para hacer estimaciones de las emisiones de fuentes puntuales, y a menudo se combinan con los datos de actividad recopilados con encuestas o con balances de materiales. Por otra parte, los factores de emisión basados en censos, se usan mucho para hacer estimaciones de las emisiones de fuentes de área. La fuente más completa de factores de emisión específicos para los E.U., para los contaminantes criterio es la publicación *AP-42 Compilation of Air Pollutant Emission Factors* (U.S. EPA, 1995a). [AP-42 Recopilación de Factores de Emisión de Contaminantes del Aire *(U.S. EPA, 1995a.]* Asimismo, el documento Factor Information Retrieval System (FIRE) (Sistema de Recuperación de Información sobre Factores de la EPA) es una reunión de factores de emisión de contaminantes del aire, tanto criterio como tóxicos.

Eficiencia de Control. La eficiencia global de control es el producto de la eficiencia del dispositivo de captura por la eficiencia del dispositivo de control. La eficiencia del dispositivo de captura indica el porcentaje de la corriente de emisión que es llevado al sistema de control y la eficiencia del dispositivo de control indica el porcentaje de contaminante atmosférico que es removido de la corriente de emisión antes de liberarla a la atmósfera. Los datos de la eficiencia del dispositivo de control pueden ser determinados para un equipo específico a partir de muestreos en la fuente midiendo las concentraciones del contaminante antes y después de la aplicación del dispositivo de control; a partir de datos

bibliográficos (e. g., *Volumen IV—Fuentes Puntuales, Tabla 4-1*) o a partir de las especificaciones de diseño del fabricante o de la especificación del desempeño garantizado. La eficiencia global de control también puede requerir de ajustes para reflejar el tiempo de paro del equipo de control durante las operaciones de mantenimiento o cuando hay perturbaciones.

Efectividad de la Regla. La experiencia con los inventarios de emisión ha revelado que los programas regulatorios tienen una efectividad menor al 100 por ciento para la mayor parte de las categorías de fuente. La efectividad de la regla refleja la capacidad de un programa regulatorio para lograr las reducciones requeridas en las emisiones. El propósito de este factor es tomar en cuenta el hecho de que la mayor parte de los dispositivos de control no logran reducir las emisiones hasta las tasas planeadas en todo momento y en todas las condiciones. Las perturbaciones en el proceso, las fallas en el funcionamiento del equipo de control, los errores del operador, el mantenimiento del equipo y otras operaciones no rutinarias son ejemplos típicos de ocasiones en que es de esperarse que el desempeño del dispositivo de control sea inferior al óptimo. Una fracción por omisión del 0.80 (igual a una efectividad del 80 por ciento) fue establecida por la EPA para estimar la efectividad de la regla requerida en algunas regiones; sin embargo, la limitada exactitud de utilizar un solo valor por omisión para todas las categorías de fuente ha sido cuestionada y se sigue trabajando para definir los lineamientos para desarrollar factores de efectividad de la regla para cada tipo específico de fuente.

Penetración de la Regla. La penetración de la regla es el grado en el que una regulación abarca las emisiones de todas las fuentes dentro de una categoría. Por ejemplo, se puede hacer una regla que indique que sólo las fábricas de pinturas más grandes deben cumplir con los nuevos requerimientos de control. Si las emisiones de fuentes de área de todas las fábricas de pinturas se estiman en conjunto como una sola categoría de fuente, entonces se debe desarrollar un factor de penetración de la regla, ya que no todas las fábricas esarán sujetas a la regla y, por lo tanto, no todas las emisiones de pintura deberán tener más control.

Ajuste Temporal. Tradicionalmente, la mayor parte de los inventarios estiman emisiones anuales. Por lo tanto, todos los procedimientos, factores de emisión y de corrección, así como los niveles de actividad utilizados en el inventario han sido desarrollados para representar condiciones anuales promedio. Para determinadas actividades de planeación de la calidad del aire deben hacerse ajustes temporales a las estimaciones anuales de emisiones. Por ejemplo, con frecuencia, los altos niveles de ozono son asociados con los meses más cálidos del año, mientras que las emisiones de algunas fuentes varían de manera estacional. Para los propósitos de planeación de la calidad del aire, en los inventarios de ozono las emisiones de precursores de este contaminante deberían ser determinadas durante los meses que constituyen la temporada de ozono para sus inventarios. La temporada pico del ozono en la mayor parte de las áreas de EU va de mayo a septiembre. Sin embargo, en la Ciudad de México, la estación más crítica se presenta en el invierno (i. e., del 15 de noviembre al 15 de febrero). Los trabajos de modelado de la calidad del aire a nivel regional pueden requerir tasas de emisión horarias. Los perfiles temporales por omisión (i. e., horas/día, días/semana, semanas/año) se utilizan con frecuencia para desarrollar estimaciones horarias a partir de estimaciones anuales.

Porcentaje de Masa del Contaminante. En algunos casos, el contaminante o grupo de contaminantes definido por un factor de emisión no es el mismo que el definido para el inventario de emisiones. Por ejemplo, varios compuestos orgánicos volátiles (COVs) son considerados fotoquímicamente no reactivos por la EPA, conforme a la *Clean Air Act* (CAA) (Ley de Aire Limpio), y no se incluyen en los inventarios de emisiones de COVs en los EU (40 CFR 60, 1992). Muchos de los compuestos no reactivos son COVs halogenados que tienen su principal aplicación como limpiadores de metales y de telas, refrigerantes y propelentes de productos en aerosol. Una importante categoría industrial que utiliza estos compuestos halogenados es la de desengrasado. En otro ejemplo, la gran mayoría de las emisiones de rellenos sanitarios son de metano, que no se considera un COV. Dado que, hasta

donde se sabe, las emisiones de estos diversos procesos están constituídas por COVs no reactivos, podrían ser excluidas de los inventarios de emisiones de hidrocarburos totales (HCT) (e.g., los datos del inventario nacional de emisiones de fuentes puntuales, SNIFF) para algunos propósitos de los inventarios de emisiones, tales como el modelado de ozono. De manera similar, los perfiles de partículas (MP) que muestran datos sobre la distribución del tamaño de partícula, pueden ser utilizados para determinar el porcentaje de masa de las emisiones de partículas suspendidas totales (PST) que deberían incluírse en un inventario de partículas de diámetro aerodinámico inferior a 10 micrómetros (PM_{10}).

El porcentaje de masa del contaminante también puede utilizarse para estimar las emisiones de una especie química determinada. Por ejemplo, los perfiles de especiación pueden usarse para obtener datos sobre el porcentaje de berilio en las emisiones de partículas totales de las operaciones de extracción, o el porcentaje de benceno en las emisiones de COVs totales de un tanque de almacenamiento.

3.0 MUESTREO EN LA FUENTE

Esta sección describe el uso de los datos de muestreo en la fuente para estimar emisiones de fuentes puntuales. Se presentan ejemplos para ilustrar el cálculo de las emisiones a partir de los datos recopilados durante los muestreos. Se pueden hallar métodos específicos de muestreo en la fuente y procedimientos para reducción de datos en los métodos de referencia publicados (40 CFR 60, 1992).

Debido a la complejidad técnica del muestreo en la fuente se requiere de tiempo y equipo para obtener datos de emisiones que sean exactos y válidos para numerosos contaminantes de una fuente. En consecuencia, el costo de realizar un muestreo de este tipo en una planta puede ser muy alto. Sin embargo, si se aplica correctamente, este método puede proporcionar una mejor estimación de las emisiones de una fuente que los factores de emisión o los balances de materiales. El uso de datos de muestreo en la fuente reduce el número de suposiciones relacionadas con la aplicabilidad de factores de emisión generalizados, las eficiencias del equipo de control de contaminación del aire, las variaciones del equipo, o las características del combustible que son aplicadas a tipos similares de fuentes de emisión para estimar las tasas de emisión de los contaminantes.

2.1 Información General

El propósito de cualquier programa de muestreo en la fuente es determinar la concentración del contaminante en una corriente de gas ó la tasa de emisión del contaminante de una chimenea o del escape de un proceso. Midiendo la concentración del contaminante en un volumen conocido de gas y determinando la tasa de flujo del gas en una chimenea es posible calcular la tasa de emisión en masa del contaminante.

Los muestreos en la fuente se integran con mediciones de corto plazo que, por lo general, se realizan tiempos de una a cuatro horas. Para recolectar una muestra representativa deben hacerse tres muestreos en una chimenea o en un escape para cada contaminante de interés condiciones de operación definidas. Las variaciones en la operación del proceso durante el muestreo pueden añadir un alto grado de variabilidad en los datos de muestreo. Por lo tanto, los parámetros clave de la operación de un proceso que pueden afectar las emisiones de contaminantes de la fuente deben ser monitoreados durante la toma de muestras.

La recopilación de datos específicos del proceso durante los muestreos es crítica para correlacionar los resultados del muestreo con la operación del proceso. Por ejemplo, las emisiones fluctúan cuando ocurren cambios en el proceso (e.g. la disminución de la temperatura de una cámara de combustión puede aumentar las emisiones de algunos contaminantes). La recopilación de datos específicos del proceso también es importante para correlacionar las emisiones con la actividad del proceso y para desarrollar factores de emisión. Por ejemplo, si se emiten 0.5 kg/hr de NO_x durante un muestreo en la fuente de cuatro horas en el cual se quemaron 400 litros de combustible, es posible determinar un factor de emisión de 0.005 kg de NO_x por litro de combustible. Entonces este factor de emisión específico puede ser usado para estimar las emisiones de NO_x de esta fuente, basándose en la cantidad de combustible quemado.

Los datos de muestreo en fuente deben usarse para estimar emisiones sólo si los datos se obtuvieron en condiciones representativas de la operación normal del proceso. Los datos de emisión determinados a partir de un muestreo en la fuente pueden extrapolarse para estimar las emisiones anuales de una fuente si la operación del proceso no varía de manera significativa. Si el proceso si tiene variaciones considerables será necesario hacer varios muestreos para obtener resultados representativos. Si la operación de la planta no puede ser caracterizada de manera adecuada los datos del muestreo en la fuente no deben usarse para estimar las emisiones.

Los procedimientos para hacer los muestreos en la fuente se encuentran en diversos métodos de referencia (e. g., métodos de la EPA, métodos para calderas y hornos industriales [BIF, por sus siglas en inglés], etc.). Los métodos de muestreo que describen procedimientos para tomas de muestra en tiempos cortos se conocen como métodos manuales. Éstos, en general, son específicos para un tipo de fuente (e.g., fuentes de combustión con combustibles fósiles, corrientes de gas combustible en refinerías de petróleo y generadores eléctricos de vapor) y para un contaminante (e. g., partículas, ácido sulfhídrico, plomo) o para una clase de compuestos (e. g., dioxinas, COVs). Los sistemas de muestreos por extracción para estos contaminantes consisten, por lo general, de una solución o un medio absorbente para capturar el contaminante, una bomba para jalar la muestra de gas a través de la solución o del medio, y un medidor de gas seco para medir el volumen de la muestra gaseosa. Debido a que se utilizan diferentes tipos de solución o de medio para absorber los diferentes contaminantes, el muestreo en la fuente para varios contaminantes (e. g., metales, partículas, dioxinas) es complejo, de mucho trabajo y costoso. En la Figura 3-1, se muestra esquema de un sistema manual de muestreo utilizado para determinar las emisiones de partículas de una fuente estacionaria (conocido como tren de muestreo del Método 5).

Una alternativa para el muestreo manual en la fuente es el monitoreo continuo, que toma en cuenta la variabilidad del proceso con el tiempo. Para medir las concentraciones de óxidos de nitrógeno (NO_x), dióxido de carbono (CO_2), monóxido de carbono (CO), dióxido de azufre (SO_2) e hidrocarburos totales (HCT). Por lo general se utilizan instrumentos o monitores continuos de emisiones (MCEs). También hay MCEs comerciales disponibles para medir opacidad, ácido clorhídrico (HCl) y amoniaco (NH_3). Los MCEs pueden instalarse en la fuente de manera permanente para generar datos las 24 horas del día, o pueden usarse para el monitoreo de las emisiones durante un periodo definido de muestreo en la fuente (e. g., de 1 a 4 horas). Un sistema MCE consiste de una bomba para extraer la muestra gaseosa de la fuente, de una serie de instrumentos o de analizadores para analizar un contaminante específico en el gas y de un sistema de adquisición de datos para registrar la información con el tiempo. En la Figura 3-2 se muestra el esquema de un sistema MCE.

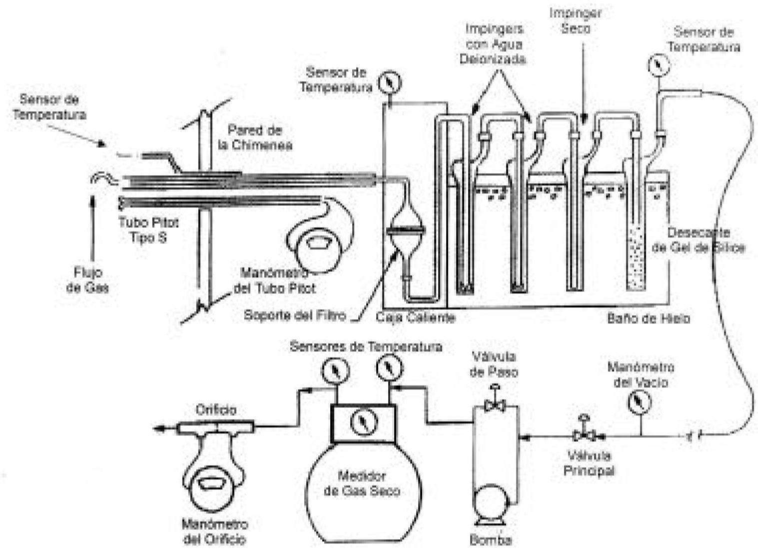


Figura 3-1. Sistema de Muestreo para Partículas (Tren de Muestreo Método 5 de la EPA)

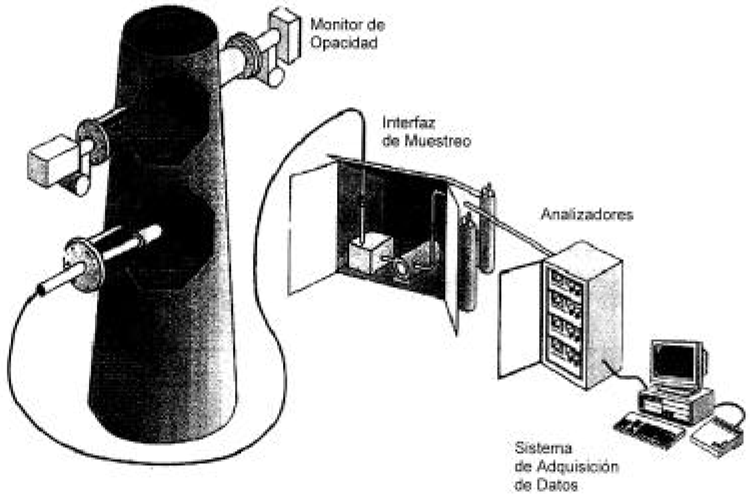


Figura 3-2 Sistema de Monitoreo Continuo de Emisiones (MCE)

2.2 Ejemplo de Cálculos en que se usan Datos de Muestreo en la Fuente

En general, después de que se ha concluido un muestreo, los datos (incluyendo las concentraciones del contaminante y la tasa de flujo volumétrico del gas de escape) son presentados en un informe. La mayor parte de los reportes de muestreo en la fuente resumen las emisiones de cada contaminante expresándolas en cualquiera de los siguientes términos:

- Una tasa de carga de masa o una tasa de emisión (masa de contaminante emitida por unidad de tiempo) ó
- Un factor de emisión (masa de contaminante emitida por unidad de actividad del proceso).

Las variables y símbolos utilizados para los cálculos se enlistan en la Tabla 3-1. Los ejemplos que se proporcionan a continuación muestran la manera de calcular tasas de emisión en masa, o factores de emisión, a partir de datos de muestreo en la fuente.

Tabla 3-1

Lista de Variables y Símbolos para los Cálculos de Emisión

Variable	Símbolo	Unidades
Volumen de la muestra de gas	ΔV^a	metro cúbico normal [base seca] (Nm^3)
Masa de partículas recolectadas en la muestra de enjuague	M_r	miligramos (mg)
Masa de partículas recolectadas en la muestra del filtro	M_f	mg
Tasa de flujo volumétrico del gas de escape en condiciones estándar	Q	metro cúbico normal por hora [base seca] (Nm^3/hr)
Concentración de partículas en el gas de escape	C_s	miligramos por metro cúbico normal[base seca] (mg/Nm^3)
Tasa de emisión en masa	TEM	kilogramos por hora (kg/hr)
Tasa anual de emisión en masa	TEM_a	toneladas métricas por año (metric ton/año)
Horas de operación por año	T	Horas por año (hr/año)

Tabla 3-1 (Continuación)

Lista de Variables y Símbolos para los Cálculos de Emisión

Variable	Símbolo	Unidades
Tasa de emisión en masa por actividad	TEM_b	kilogramos por millón de kjoule (kg/MkJ)
Tasa de consumo de calor de la caldera	R	MkJ/hr
Concentración del contaminante	C	Partes por millón en volumen [base seca] (ppmv).
Peso molecular del contaminante	PM	Gramo por gramo-mol (g/g-mol)
Volumen molar	V	Volumen ocupado por un mol de gas ideal a presión y temperatura estándar (0.024 m^3/g-mol a 20°C y 1 atmósfera)
Factor de combustible del Método 19 de la EPA	F_d^b	Metros cúbicos estándar secos por joule a 0% de oxígeno [base seca] (dscm/J)
Concentración medida de oxígeno	O_2%	Porciento [base seca]
Concentraciones de hidrógeno, carbono, azufre, nitrógeno y oxígeno	H, C, S, N, O	Porcentaje determinado por el análisis de combustible
Poder calorífico superior del combustible	PCS	kjoule por kilogramo (kJ/kg)

[a] El metro cúbico normal está dado a: 0°C y 760 mm Hg.

[b] El metro cúbico estándar está dado a: 20°C y 760 mm Hg.

Dados los siguientes datos específicos para una fuente:

Ejemplo 3-1:

ΔV = 0.78 metros cúbicos normales (Nm^3)

M_r = 5.5 miligramos (mg)

M_f = 9.5 mg

Q = 34,170 metros cúbicos normales por hora (Nm^3/hr);

T = 2,920 horas por año (hr/año)

R = 118 millones de kjoules por hora (MkJ/hr).

Calcular la concentración de partículas en el gas de escape en unidades de miligramos por metro cúbico normal (mg/Nm^3):

Paso 1

(3-1)

$$C_s = (M_r + M_f) / \Delta V$$

$$= (5.5\ mg + 9.5\ mg) / 0.78\ Nm^3$$

$$= 19.2\ mg/Nm^3$$

Calcular la tasa de emisión en masa, TEM, en kilogramos por hora (kg/hr):

Paso 2

(3-2)

$$TEM = C_s \times Q/(10^6)$$

$$= 19.2\ mg/Nm^3 \times 34{,}170\ Nm^3/hr/(10^6\ mg/kg) = 0.66\ kg/hr$$

Estos datos se expresan en unidades típicas para las emisiones de partículas. Los resultados también pueden expresarse en otras unidades tales como miligramos por metro cúbico normal (base seca) (mg/Nm^3 seco), utilizando factores de conversión estándar. Con frecuencia, las tasas de emisión en masa se expresan en base anual (e. g., toneladas métricas por año). Estas estimaciones generalmente incluyen una tasa anual de uso real (i. e., horas por año) dado que la mayor parte de las fuentes no operan de manera continua durante todo el año.

Asumiendo que la fuente presentada antes opera 2,920 hr/año, calcular la tasa anual de emisión de partículas (TEM_a) en toneladas métricas/año:

Paso 3

(3-3)

$$TEM_a = TEM \times T / 1{,}000$$

$$TEM_a = 0.66 \text{ kg/hr} \times 2{,}920 \text{ hr/año}/ (1{,}000 \text{ kg/tonelada métrica})$$

$$TEM_a = 1.93 \text{ toneladas métricas/año}$$

Algunos datos de emisión se expresan también por unidad de actividad como un factor de emisión. Estos factores de emisión se expresan a menudo como el peso del contaminante emitido por unidad de actividad del proceso. Como ejemplo, calcular la tasa de emisión en masa de la actividad (TEM_b) de partículas de una caldera con una tasa de consumo de calor de 118 MMkJ/hr:

Paso 4

(3-4)

$$TEM_b = TEM / R$$

$$TEM_b = 0.66 \text{ kg/hr} / (118 \text{ MMkJ/hr})$$

$$TEM_b = 0.0056 \text{ kg/MMkJ}$$

Las concentraciones de contaminantes que están presentes como partícula o un aerosol (e.g., PM_{10}, plomo, dioxinas) en general son expresadas en masa por unidades de volumen tales como microgramos por metro cúbico normal. Las concentraciones de otros contaminantes que están presentes como un vapor (e.g., NO_x, SO_2, CO) se expresan por lo general en unidades de volumen/volumen tales como partes por millón por volumen (ppmv), o partes por billón (ppbv).

2.3 Ejemplo de Cálculos Utilizando Datos de MCE

Para determinar las emisiones de SO_2, NO_x, HCT, y/o CO, una planta se puede instalar un sistema de MCE que mida de manera continua las concentraciones de contaminantes (en ppmv). El sistema de MCE a menudo está equipado con un monitor de oxígeno (O_2) y/o uno de CO_2. Estos gases se consideran como gases diluyentes (más que contaminantes), y se monitorean para que sirvan como indicadores de la tasa de flujo de escape los gases de escape y/o del flujo de aire en exceso. En general, las concentraciones de O_2 y CO_2 se reportan en unidades de porcentaje (en volumen) dado que son mucho más altas que los niveles de los otros gases monitoreados (i. e., ppmv). Dependiendo de los requerimientos regulatorios y del tipo de fuente, los instrumentos se pueden instalar de forma permanente para recoger datos de manera continua durante la operación de la unidad, o pueden ser utilizados temporalmente para recolectar datos durante un periodo de tiempo determinado.

Los datos de concentraciones de MCE son transmitidos por lo general del instrumento al sistema de registro de datos, que está programado para almacenarlos y elaborar reportes en un formato específico. A menudo los datos de concentración se promedian en intervalos específicos de tiempo (e. g., 10 minutos, 1 hora, 24 horas).

Además de las unidades de concentración, los datos de las emisiones se reportan con frecuencia en otras unidades, tales como tasas de emisión en masa (e. g., kg/hr), o como factores de emisión (kg/unidad de proceso). Para convertir las unidades de concentración en estas otras formas de datos se requieren datos adicionales. Para convertir los datos de concentración en datos de tasa en masa, la tasa de flujo volumétrico del gas de escape (i. e., en unidades de metros cúbicos normales por hora) debe ser medida o estimada. La fuente puede estar equipada con un monitor de tasa de flujo del gas de escape que proporciona datos continuos de la tasa de flujo al sistema; o bien la tasa de flujo puede ser medida utilizando un tubo pitot. También es posible estimar la tasa de flujo con base en mediciones empíricas, en mediciones de la tasa de combustible, en las concentraciones del gas diluyente o en mediciones del aire de admisión (e. g., velocidad del ventilador, posiciones de la compuerta de tiro). Para convertir los datos de emisión en unidades de tasa de emisión (e. g., kg/MMkJ de consumo de calor o kg/tonelada métrica de carbón alimentado), la tasa de unidad de proceso (e.g., kg/MMkJ de consumo de calor o toneladas por hora carbón alimentado) debe ser medida o estimada.

También se pueden usar factores empíricos del combustible, conocidos como factores F, para convertir los datos de tasa de uso de combustible en tasas de consumo de calor o de flujo de gas. Por lo común, los factores F son específicos para un tipo de combustible (e. g., gas natural, combustóleo #2). Algunos ejemplos de factores F que han sido adoptados por la EPA se presentan en el Método 19 (40 CFR 60, 1992).

Las variables y los símbolos usados en los siguientes cálculos se enlistan en la Tabla 3-1. La Tabla 3-2 presenta un ejemplo de los resultados obtenidos en un sistema de MCE, que consta de monitores de SO_2, NO_x, CO, O_2 y de tasa de flujo, instalados en una chimenea de escape de una caldera alimentada con petróleo. Los datos en la tabla representan una “instantánea” de las emisiones de la caldera durante un periodo de 60 minutos.

Tabla 3-2

Ejemplo de Resultados de un MCE para una Caldera que Quema Petróleo

Periodo	O_2 (%V)	SO_2 (ppmv)	NO_x (ppmv)	CO (ppmv)	Tasa de Flujo de Gas en la Chimenea (Nm^3/hr)
11:00	2.1	1,004.0	216.2	31.5	33,964
11:15	2.0	1,100.0	200.6	25.5	34,361
11:30	2.1	1,050.0	216.7	25.1	32,891
11:45	1.9	1,070.0	220.5	20.8	34,890
12:00	1.9	1,070.0	213.8	19.4	34,749
Promedio:	2.0	1,058.8	213.6	24.5	34,171

[a] Basado en un valor calorífico del combustible de 41,828 kJ/kg (18,000 Btu/lb).

2.3.1 Cálculo de emisiones horarias, a partir de mediciones de concentración

Aunque los MCEs pueden reportar emisiones horarias en tiempo real de manera automática, puede ser necesario estimar de forma manual las emisiones anuales de una fuente a partir de datos horarios de concentración de contaminantes. Esta sección describe la manera de calcular emisiones a partir de datos crudos de concentración de un MCE.

Utilizando los datos de un MCE presentados en la Tabla 3-2, es posible calcular las emisiones horarias en masa de SO_2 para las 11:00:

$$TEM_a = \frac{C \ x \ PM \ x \ Q}{(1{,}000 \ x \ V \ x \ 10^6)} \tag{3-5}$$

$$= \frac{1{,}004 \text{ ppmv x } 64 \text{ g/g-mol x } 33{,}964 \text{ Nm}^3\text{/hr}}{(1000 \text{ g/kg x } 0.024 \text{ m}^3\text{/g-mol x } 10^6)}$$

$$= 90.9 \text{ kg/hr}$$

Para calcular la tasa promedio de emisión de masa de SO_2 para todo el periodo de muestreo:

$$TEM_{prom} = \frac{C_{prom} \ x \ MW_{prom} \ x \ Q_{prom}}{(1{,}000 \ x \ V \ x \ 10^6)} \tag{3-6}$$

$$= \frac{1{,}058.8 \text{ ppmv x } 64 \text{ g/g-mol x } 34{,}171 \text{ Nm}^3\text{/hr}}{(1000 \text{ g/kg x } 0.024 \text{ m}^3\text{/g-mol x } 10^6)}$$

$$= 96.5 \text{ kg/hr}$$

Las emisiones anuales de SO_2 pueden ser calculadas utilizando la ecuación 3-3, y asumiendo que la caldera opera durante 2,920 horas anuales.

$$TEM_a = 96.5 \text{ kg/hr x } 2{,}920 \text{ hr/año / } (1{,}000 \text{ kg/tonelada métrica})$$
$$= 282 \text{ toneladas métricas/año}$$

Suponiendo que el consumo de calor de la caldera es de 118 MMkJ/hr, la tasa de emisión de actividad de SO_2 puede ser calculada utilizando la ecuación 3-4:

$$TEM_b = 96.5 \text{ kg/hr / } (118 \text{ MMkJ/hr})$$
$$= 0.82 \text{ kg/MMkJ}$$

2.3.2 Cálculo de la tasa de flujo del gas en la chimenea

Cuando no se dispone de mediciones directas de las tasas de flujo del gas en la chimenea, Q puede calcularse utilizando factores del combustible (factores F). El factor F es la relación del volumen gaseoso de los productos de combustión con el contenido de calor del combustible e incluye todos los componentes de la combustión excepto el agua. Este factor puede ser calculado a partir de los resultados de un análisis elemental del combustible utilizando la siguiente ecuación:

$$F_d = \frac{10^6 [3.64(\%H) + 1.53(\%C) + 0.57(\%S) + 0.14(\%N) - 0.46(\%O)]}{HHV} \qquad (3\text{-}7)$$

Los valores caloríficos de los combustibles están disponibles en publicaciones tales como *Steam, Its Generation and Use* (Stultz and Kitto, 1992). Los factores F promedio están en el Método de Referencia 19 de la EPA para diferentes combustibles y se presentan en la Tabla 3-3.

Utilizando los datos del MCE en la Tabla 3-2 y el factor F para petróleo de la Tabla 3-3 es posible calcular la tasa de flujo del gas en la chimenea de la caldera.

Ejemplo 3-3:

$$Q = F_d \text{ x } \frac{20.9\%}{20.9\% - O_2\%} \text{ x } R \text{ x } 10^9$$

$$= 2.47 \text{ x } 10^{-7} \text{ dscm/J } \frac{20.9\%}{20.9\% - O_2} \text{ x } 118 \text{ MMkJ/hr x } 10^9 \text{ J/MMkJ}$$

$$= 32{,}230 \text{ dscm/hr}$$

Tabla 3-3

Factores F_d para Diversos Combustibles[a]

Tipo de Combustible	**F_d**	
	dscm/J[b]	**dscf/MMBtu**
Carbón:		
Antracita[c]	2.71×10^{-7}	10,100
Bituminouso[c]	2.62×10^{-7}	9,780
Lignito	2.65×10^{-7}	9,860
Petróleo[d]	2.47×10^{-7}	9,190
Gas:		
Natural	2.34×10^{-7}	8,710
Propano	2.34×10^{-7}	8,710
Butano	2.34×10^{-7}	8,710
Madera	2.48×10^{-7}	9,240
Cortezas de Madera	2.58×10^{-7}	9,600

[a] Determinado en condiciones estándar: 20°C (68°F) y 760 mm Hg (29.92 in. Hg).
[b] dscm/J = metros cúbicos estándar secos por Joule
[c] Clasificado de acuerdo con el ASTM Método D 388-77.
[d] Crudo, residual o destilado.

4.0 MODELOS DE EMISIONES

Muchas estimaciones de emisiones se desarrollan utilizando un factor de emisión que supone una relación lineal (i. e., un “factor de emisión”) entre la tasa de emisión y una unidad de actividad (e. g., cantidad de combustible consumido, tasa de producción, población, empleo, etc.). Para ciertas categorías de fuente la relación funcional entre las emisiones, los procesos múltiples y las variables ambientales se estudia suficientemente para soportar el desarrollo de modelos complejos. Si estos modelos de emisión requieren cálculos complejos o grandes volúmenes de datos para alimentarlos, es probable que se basen en computadoras.

Si bien los modelos están diseñados para producir estimaciones más exactas que las obtenidas con factores de emisión, la exactitud de la estimación siempre dependerá de la calidad de los datos con que se alimente el modelo y de las suposiciones en que se base. Por lo tanto, antes de decidir utilizar un modelo como la alternativa para un tipo específico de fuente es importante comparar las necesidades del modelo de emisión con los datos disponibles. Los requerimientos de datos son variables. Para estimar emisiones pueden requerirse uno o varios parámetros físicos de la fuente para la cual se usará el modelo.

Algunos modelos de emisiones desarrollados en otros países pueden aplicarse en México. En estos casos es muy importante consultar los manuales del usuario para identificar cualesquier valores por omisión que sean asumidos en ausencia de valores definidos por el usuario, y tratar de evaluarlos si estos valores son adecuados para usarse en México. Asimismo, es importante revisar que la conversión de la unidades métricas de los datos disponibles a las unidades estándar inglesas requeridas sea correcta si se están aplicando modelos de los EU.

Los modelos de emisión pueden clasificarse en tres tipos: adaptativos, mecanísticos y de variable múltiple. Los primeros están basados en un paquete de cómputo que integra redes neurales, lógica confusa (“fuzzy”) y sistemas caóticos en un solo paquete (Collins and Terhune, 1994). Durante la etapa inicial se carga el programa como los datos históricos de operación y los de emisiones. Los parámetros de operación se monitorean entonces y son utilizados por el sistema del programa (o “softMCE) para predecir las emisiones a un costo menor que el de la aplicación de un equipo real de MCE. Sin embargo, el precio de un programa adaptativo todavía puede ser bastante elevado, cercano a los 100,000 dólares. Por lo tanto, estos modelos no se recomiendan para los trabajos de inventarios en el corto plazo en México debido a los altos costos asociados con su instrumentación y por lo pronto no se tratan ya en el Manual de TEEs Básicas. En el resto de esta sección se dan más descripciones y algunos ejemplos de modelos mecanísticos y de variables múltiples.

4.1 Modelos Mecanísticos

Los modelos mecanísticos se basan en ecuaciones que han sido desarrolladas utilizando fundamentos de Química, Física y Biología para describir la tasa de emisión de un tipo de fuente en particular. Entre los emisores importantes de COVs que requieren muchas variables para calcular las emisiones se encuentran las operaciones de almacenamiento y manejo de derivados del petróleo (e. g., tanques de almacenamiento superficiales y subterráneos; carga de carros-tanque, pipas y buques-tanque; y carga de gasolina en las estaciones de servicio).

En el resto de esta sección se presenta información sobre los modelos de la EPA que se han desarrollado para estimar las emisiones de las siguientes categorías de fuente:

- Tanques de almacenamiento
- Operaciones de carga de derivados del petróleo

- Rellenos sanitarios
- Modelos de emisiones al aire de agua y aguas residuales
- Polvos fugitivos.

Para cada categoría de fuente se presenta un breve resumen de las ecuaciones del modelo de emisión, seguida por un resumen de los datos y parámetros requeridos, así como los valores por omisión recomendados en los EU. Se pueden hallar ejemplos de los cálculos para cada modelo en el Apéndice III-A. En los casos en que existe un modelo para computadora que esté disponible se incluye una breve descripción.

Para mayor información acerca de los modelos de la EPA y otras herramientas de estimación de emisiones al aire, comunicarse al:

- CHIEF Bulletin Board System (BBS):
  95-919-541-5742 (marcar por módem)
- Info CHIEF Help Desk
  95-919-541-5285 (teléfono)
  95-919-541-5680 (fax)

En el Apéndice III-B se pueden hallar copias de los folletos distribuidos por la oficina de asistencia de Info CHIEF (Info CHIEF Help Desk).

4.1.1 Tanques de Almacenamiento

Las ecuaciones actuales de modelos de emisión de la EPA para tanques de almacenamiento constituyen los mejores ejemplos de modelos mecanísticos. Por ejemplo, en el modelo de tanque de almacenamiento de techo fijo se aplican los principios de transferencia de calor y otros a las pérdidas por respiración en el modelo, como se muestra en la Figura 4-1.

La desventaja de usar el programa TANKS o las ecuaciones del *AP-42,* es que se requieren más recursos para reunir los datos de entrada y para utilizar las ecuaciones o el programa, que si se usaran otras aproximaciones. Si sólo existe una pequeña cantidad de emisiones puede que no valga la pena el esfuerzo extra. Existe el compromiso de desarrollar factores de emisión por omisión específicos para cada región, utilizando las ecuaciones del *AP-42* o el programa TANKS, que reflejen la temperatura promedio, las condiciones de los tanques y los contenidos de sustancias químicas para la región del inventario.

Pérdidas por Respiración en un Tanque de Almacenamiento de Sustancias Orgánicas

COVs emitidos por la expansión y contracción del vapor debidas a cambios en la temperatura y presión

Emisiones = $f(V_V, W_V, DP_V, P_{VA}, DT_V, T_{LA})$

donde:

V_V = volumen del espacio de vapor en el tanque

W_V = densidad de vapor del líquido almacenado

ΔP_V = intervalo diario de vapor del líquido almacenado

P_{VA} = presión de vapor a la temperatura diaria promedio de la superficie del líquido

P_A = presión atmosférica

ΔT_V = intervalo diario de la temperatura del vapor del líquido almacenado

T_{LA} = temperatura promedio diaria de la superficie del líquido

Figura 4-1. Ejemplo de Modelado Mecanístico

Tanques de Techo Fijo

Ecuaciones de un Modelo de Emisiones - Los dos tipos de emisiones más significativas de los tanques de almacenamiento de techo fijo son las pérdidas en reposo y las pérdidas en operación. Las primeras consisten en la expulsión de vapor del tanque debidas a la expansión y la contracción del vapor, que son resultado de los cambios en la temperatura y en la presión barométrica. Estas pérdidas se presentan sin ningún cambio en el nivel del tanque.

La pérdida combinada por el llenado y el vaciado se conoce como pérdida en operación. La evaporación durante las operaciones de llenado es resultado de un aumento en el nivel del líquido en el tanque. A medida que el nivel del líquido aumenta, la presión dentro del tanque rebasa la presión de alivio y se expulsan vapores del tanque. La pérdida evaporativa durante el vaciado del líquido se presenta cuando el aire arrastrado hacia el tanque durante la remoción del líquido se satura con vapores orgánicos y se expande, excediendo así la capacidad del espacio de vapor.

Las emisiones de los tanques de techo fijo varían en función de la capacidad del contenedor, la presión de vapor del líquido almacenado, la tasa de utilización del tanque y las condiciones atmosféricas el lugar donde se encuentra el tanque. A continuación se resumen las ecuaciones del modelo de emisión. Las ecuaciones detalladas pueden encontrarse en el *AP-42, Sección 7.1* (U.S. EPA, 1995a). Los parámetros requeridos y los valores por omisión para los EU se presentan en la Tabla 4-1.

Las pérdidas totales de emisión en los tanques de techo fijo son definidas como:

(4-1)

$$\mathbf{L_T = L_S + L_W}$$

donde:

L_T=pérdidas totales, lb/año
L_S=pérdidas en el almacenamiento en reposo, lb/año
L_W=pérdidas en operación, lb/año.

Pérdidas en reposo (respiración):

(4-2)

$$\mathbf{L_S = 365\ V_V W_V K_E K_S}$$

donde:

V_V = volumen del espacio de vapor, ft^3
W_V= densidad del vapor, lb/ft^3
K_E = factor de expansión del espacio del vapor, adimensional
K_S = factor de saturación del vapor venteado, adimensional.

Pérdida en Operación:

(4-3)

$$\mathbf{L_W = 0.0010\ M_V P_{VA} Q K_N K_P}$$

donde:

M_V = peso molecular del vapor, lb/lb-mol
P_{VA}= presión del vapor a la temperatura promedio diaria del líquido, $lb/pulg^2$ absoluta
Q = producción neta anual, bbl/año
K_N = factor de producción, adimensional
K_P = factor de pérdida de producto en la operación, adimensional.
(0.75 para petróleos crudos, 1.0 para los demás líquidos orgánicos)

Tabla 4-1

Tanques de Techo Fijo
Parámetros Requeridos y Valores Estadounidenses por Omisión

Descripción del Parámetro	Variable	Valor por Omisión para EU
Diámetro del tanque	D	
Altura de la envolvente del tanque	H_S	
Altura del líquido en el tanque	H_L	
Pendiente del techo cónico del tanque	S_R	0.0625
Radio del techo de domo del tanque	R_R	Diámetro del Tanque (D)
Capacidad del tanque	V_{LX}	
Color de la pintura del tanque	Se utiliza para determinar α	
Condición de la pintura del tanque	Se utiliza para determinar α	
Absorción solar de la pintura del tanque	α	0.17 (i. e., pintura blanca en buenas condiciones)
Arreglo de la presión en el respiradero del tanque	P_{BP}	0.03 psig
Arreglo del vacío en el respiradero del tanque	P_{BV}	-0.03 psig
Gasto del Material	Q	
Peso molecular del vapor del material	M_V	Se dan los valores del peso molecular para productos petroquímicos selectos
Presión de vapor del material a las temperaturas promedio máxima y mínima de la superficie del líquido	P_{VA}, P_{VX}, y P_{VN} a T_{LA}, T_{LX}, y T_{LN}	Se dan los valores de la presión de vapor productos petroquímicos selectos. Las correlaciones de la presión de vapor basadas en la RVP y S están disponibles para petróleos crudos y productos refinados de petróleo.
Presión de vapor Reid del material	RVP	Valores proporcionados para productos refinados de petróleo selectos
Pendiente de destilación del material	S	Valores proporcionados para productos refinados de petróleo selectos
Temperaturas ambiente locales diarias, máxima y mínima	T_{AX} y T_{AN}	Valores proporcionados para diversas localidades de EU
Factor de insolación total en la localidad	I	Valores proporcionados para diversas localidades de EU

Tanques de Techo Flotante

Ecuaciones del Modelo de Emisiones - Las emisiones totales de los tanques de techo flotante son la suma de las pérdidas al extraer material y las pérdidas en el almacenamiento en reposo. Las pérdidas por extracción ocurren cuando baja el nivel del líquido y, por lo tanto, baja el nivel del techo flotante. Algo del líquido queda adherido a la superficie del tanque y es expuesto a la atmósfera. Existen pérdidas evaporativas hasta que el tanque esté lleno y la superficie expuesta quede cubierta nuevamente con el líquido. En los tanques de techo flotante interno, con techos fijos soportados por columnas, algún líquido también se cuelga de éstas.

Las pérdidas en el almacenamiento en reposo de estos tanques incluyen las pérdidas en la orilla del sello y las del ajuste del techo. Todas éstas pueden presentarse a través de muchos mecanismos complejos tales como la pérdida inducida por el viento; la pérdida por respiración debida a cambios de temperatura y presión; la pérdida por la permeación del material del sello; o la pérdida por el efecto de capilaridad del líquido. Para los tanques de techo flotante interno, las pérdidas en reposo también pueden incluir aquellas ocasionadas por las juntas en la plataforma, al grado en que éstas no sean completamente herméticas.

A continuación se resumen las ecuaciones del modelo de emisiones. Las ecuaciones detalladas, las tablas de datos de apoyo y las figuras pueden encontrarse en el *AP-42, Sección 7.1* (U.S. EPA, Febrero 1996). Los datos de los parámetros requeridos y los valores por omisión para los EU se presentan en la Tabla 4-2.

Las pérdidas totales por emisión de los tanques con techo flotante se definen como:

(4-4)

$$L_T = L_R + L_{WD} + L_F + L_D$$

donde:

L_T = pérdidas totales, lb/año;
L_R = pérdidas en la orilla del sello, lb/año;
L_{WD} = pérdidas al extraer material del tanque, lb/año;
L_F = pérdidas en el ajuste de la plataforma, lb/año
L_D = pérdidas en la junta de la plataforma, lb/año.

Pérdidas en la orilla del sello (L_R):

(4-5)

$$L_r = (K_{Ra} + K_{Rb} \times v^n) \times \frac{P_{VA}/14.7}{[1 + (1 - P_{va}/14.7)^{0.5}]^2} \times D \times M_V \times K_C$$

(Nota: el término v^n se usa solamente para los tanques con techo flotante externo).

Pérdidas al extraer material del tanque (L_{WD}):

(4-6)

$$L_{WD} = \frac{0.943 \times Q \times C \times W_L}{D} \times \left(1 + \frac{N_C \times F_C}{D}\right)$$

Pérdida en el ajuste de la plataforma (L_F):

(4-7)

$$L_F = F_F \times \frac{P_{VA}/14.7}{[1 + (1 - P_{va}/14.7)^{0.5}]^2} \times M_V \times K_C$$

Pérdida en la junta de la plataforma (L_D):

(4-8)

$$L_D = (K_D + S_D \times D^2) \times \frac{P_{VA}/14.7}{[1 + (1 - P_{va}/14.7)^{0.5}]^2} \times M_V \times K_C$$

donde:

K_{Ra} = factor de pérdida en la orilla del sello a velocidad del viento igual a cero, lb-mol/pie·año
K_{Ra} = factor de pérdida en la orilla del sello dependiente de la velocidad del viento, lb-mol/(mph)^n pie·año
v = velocidad promedio del viento en el sitio del tanque, mph;
n = exponente de la velocidad del viento relacionado con el sello
P_{VA}= presión de vapor verdadera a la temperatura diaria promedio de la superficie, psia
D= diámetro del tanque, ft
M_v= peso molecular del vapor del líquido, lb/lb-mol
K_c= factor del producto (0.4 para aceites crudos, 1.0 para todos los demás líquidos orgánicos)

Q= producción, bbl/año;
C= factor de adherencia, bbl/1000 ft^2;
W_L= densidad del líquido, lb/gal;
N_c= número de columnas
F_c= diámetro efectivo de la columna, ft
F_F= factor de pérdida del ajuste entre el techo y la plataforma, lb-mol/año
K_D= factor de pérdida en la junta de la plataforma por unidad de longitud de la junta, lb-mol/ft año (0.34 para junta atornillada, 0.0 para junta soldada)
S_D= factor de longitud de la junta de la plataforma, ft/ft^2.

Tabla 4-2
Tanques con Techo Flotante
Parámetros Requeridos y Valores por Omisión para los EU

Descripción del Parámetro	Variable	Valor Estadounidense por Omisión
Diámetro del tanque	D	
Número de columnas del tanque	N_C	Ver tabla basada en el diámetro del tanque (D).
Diámetro efectivo de la columna del tanque	F_C	1.0 pie
Condición de la envolvente del tanque	Se usa para determinar C (herrumbre ligera, herrumbre densa, recubrimiento de mortero lanzado)	
Factor de adherencia del tanque	C	
Velocidad del viento el lugar donde se halla el tanque	v (también se usa para determinar F_F)	Se dan valores para varios lugares de EU
Construcción del tanque (soldado o remachado)	Se usa para determinar K_{Ra}, K_{Rb}, y n	
Construcción de la plataforma del tanque	Utilizado para determinar K_D (soldado o atornillado) y S_D (tamaño de las láminas o páneles)	
Factor de pérdida en el ajuste de la plataforma del tanque	F_F	Se puede calcular contando el número de uniones de la plataforma de un tanque específico
Sistema de sellado del tanque (tipos de sellos primarios o secundarios)	Se usan para determinar K_{Ra}, K_{Rb}, y n	

Tabla 4-2

Tanques con Techo Flotante
Parámetros Requeridos y Valores por Omisión para los EU

Descripción del Parámetro	Variable	Valor Estadounidense por Omisión
Factores del sello del tanque (y exponente de velocidad del viento relacionado con el sello)	K_{Ra}, K_{Rb}, n	Para los techos externos, usar valores para soldado, ajuste promedio, sello primario del pilote. Para internos, usar valores para ajuste promedio y sellos primarios montados en vapor, solamente.
Factor de longitud de la unión de la plataforma del tanque	S_D	Sd=0.2 para plataformas remachadas, 0.0 para plataformas soldadas
Producción de material	Q	
Peso molecular del vapor del material	M_V	Se dan valores del peso molecular para productos petroquímicos selectos
Presión de vapor del material a la temperatura promedio de la superficie del líquido	P_{VA} a T_{LA}	Se dan valores de la presión de vapor para productos petroquímicos selectos. Las correlaciones de la presión de vapor están basadas en la RVP y S disponibles para petróleos crudos y productos refinados de petróleo
Densidad del líquido del material	W_L	Se dan valores para productos petroquímicos selectos

Modelo de la EPA para Computadora

El programa TANKS está diseñado para estimar las emisiones de COVs de tanques de almacenamiento. El usuario da la información específica sobre el tanque y su contenido, y el programa estima las emisiones anuales o estacionales y genera un reporte. Las emisiones se pueden dividir en pérdidas de respiración y pérdidas por operación (U.S. EPA, 1996).

El programa TANKS tiene una base de datos sobre productos químicos para más de 100 líquidos orgánicos, y datos meteorológicos de más de 250 ciudades en EU. El usuario puede añadir nuevas sustancias y ciudades (con datos meteorológicos) a su propia versión de la base de datos. Los estilos de tanque presentados en el programa incluyen tanques de techo fijo, tanto verticales como horizontales, y tanques de techo flotante tanto interno como externo. El tanque puede contener uno o múltiples componentes líquidos.

Ya está disponible la versión 3.0 del programa. Las ecuaciones para estimar emisiones que forman la base del software fueron desarrolladas por el American Petroleum Institute (API) *(Instituto Americano del Petróleo)*. El API conserva el derecho de autor de estas ecuaciones, pero dio el permiso para la distribución no exclusiva y no comercial de este material para las agencias gubernamentales y regulatorias. Sin embargo, se reserva los derechos con respecto a toda duplicación y distribución comercial de su material. Por lo tanto, el programa TANKS está disponible para uso público, pero no puede ser vendido sin el permiso del API por escrito.

El TANKS 3.0 se escribió en FoxPro2.5™, un lenguaje compatible con d-Base, y es distribuido por la EPA a través del CHIEF BBS, o por vía postal en diskettes. El programa TANKS 3.0 puede requerir revisiones y modificaciones para asegurar su consistencia con la metodología para el cálculo de emisiones de la EPA. Este organismo da la bienvenida a la retroalimentación de los usuarios para el programa, para identificar las limitaciones y sugerir cambios que se incorporen en las futuras versiones del TANKS.

4.1.2 Operaciones de Carga de Productos Derivados del Petróleo 4.1.2 Petroleum Product Loading Operations4.1.2 Petroleum Product Loading Operations4.1.2 Petroleum Product Loading Operations

donde:
S = factor de saturación (basado en el método de llenado y de servicio)
P = presión de vapor verdadera del líquido cargado, psia;
M_V = peso molecular de los vapores, lb/lb-mol
T = temperatura de la masa de líquido cargado, °R.

Las pérdidas en la carga son la fuente más importante de emisiones evaporativas de derivados del petróleo de carros-tanque, pipas y buques-tanque. Las pérdidas en la carga se presentan cuando los vapores orgánicos en los tanques de carga "vacíos" son desplazados a la atmósfera por el líquido que está siendo introducido.

Ecuaciones del Modelo de Emisión - A continuación se presentan la ecuaciones del modelo de emisión. Es posible encontrar información más detallada en el *AP-42, Sección 4.4* (U.S. EPA, 1995a). Los parámetros requeridos y los valores por omisión para EU se presentan en la Tabla 4-3.

Tabla 4-3

Operaciones de Carga
Parámetros Requeridos y Valores por Omisión para EU

Descripción del Parámetro	Variable	Valor por Omisión para EU
Método de llenado	Se usa para determinar S (salpicado o sumergido)	
Servicio de carga	Se usa para determinar S (limpio, normal dedicado o con balance de vapor dedicado)	
Producción de material	Q	

Factor de saturación del material	S	Ver tabla basada en el método de llenado y de servicio

Tabla 4-3 (Continuación)

Operaciones de Carga
Parámetros Requeridos y Valores por Omisión para EU

Descripción del Parámetro	Variable	Valor Estadounidense por Omisión
Peso molecular del vapor del material	M_V	En el AP-42, Sección 7.1 se dan pesos moleculares para productos petroquímicos selectos.
Presión de vapor del material a la temperatura promedio de la superficie del líquido	P	En el AP-42, Sección 7.1 se dan valores de presiones de vapor para petroquímicos selectos. También están disponibles correlaciones de la presión de vapor con base en RVP y S están disponibles para petróleos crudos y productos refinados de petróleo.
Temperatura de la masa del material durante la carga	T	

Modelo de Computadora de la EPA

Dada la simplicidad de la ecuación de este modelo, actualmente no hay disponible ningún modelo de computadora.

4.1.3 Rellenos Sanitarios

Los componentes principales del gas de los rellenos sanitarios son el metano y el dióxido de carbono (CO_2), y son producidos por microorganismos dentro del relleno en condiciones anaerobias. Aunque las concentraciones de contaminantes tóxicos son muy pequeñas, por lo general los volúmenes de las emisiones de gases en los rellenos sanitarios pueden ser muy grandes, por lo que a menudo se les incluye en los inventarios de emisiones tóxicas al aire. La tasa de emisiones de un relleno sanitario está determinada por los mecanismos de producción de gas y los de transporte. Los primeros incluyen la producción del componente de la emisión en su fase vapor, a través de la vaporización, descomposición biológica o reacción química. Los mecanismos de transporte incluyen el transporte de un componente volátil en su fase vapor a la superficie del relleno sanitario, el transporte a través de la capa de aire sobre el relleno y hacia dentro de la atmósfera.

Ecuaciones del Modelo de Emisión

En un relleno sanitario en particular, se pueden estimar las emisiones no controladas de metano utilizando el modelo cinético teórico de primer orden de producción de metano desarrollado por la EPA, mismo que se presenta a continuación. Se puede hallar información más detallada en el *AP-42, Sección 2.7* (U.S. EPA, 1995a). Los parámetros requeridos y los valores por omisión para EU se presentan en la Tabla 4-4.

$$Q_{CH4} = L_o \times R \times (e^{-kc} - e^{-kt}) \tag{4-11}$$

donde:

Q_{CH4} = tasa de generación de metano en el tiempo t, m^3/año
L_o = potencial de generación de metano, m^3CH_4/Mg de residuos
R = tasa promedio anual de aceptación de desperdicios durante la vida activa, Mg/año
e = base de los logaritmos naturales, adimensional
k = constante de la tasa de generación de metano, año^{-1}
c = tiempo transcurrido desde el cierre del relleno, años (c=0 para rellenos activos)
t = tiempo transcurrido desde la colocación inicial de residuos, años.

Tabla 4-4

Rellenos Sanitarios
Parámetros Requeridos y Valores por Omisión para EU

Descripción del Parámetro	Variable	Valor por Omisión para EU
Potencial de generación de metano	L_o	8120 m^3CH_4/Mg residuos. Basado en el percentil 80 del intervalo de valores de la literatura (i.e., 200-9540 m^3CH_4/Mg desperdicios)
Tasa anual promedio de aceptación de residuos durante la vida activa	R	
Constante de la tasa de generación de metano	k	0.02 $año^{-1}$. Basado en el valor por omisión de la Norma de Desempeño de Fuentes Nuevas (*New Source Performance Standard,* NSPS).
Tiempo transcurrido desde el cierre del relleno	c	
Tiempo transcurrido desde la colocación inicial de residuos	t	

Modelo para Computadora de la EPA

El Modelo de Emisiones al Aire de Rellenos Sanitarios y Estimación (LAEEM, por sus siglas en inglés) es un programa de computadora diseñado específicamente para monitorear las emisiones en estos sitios. El sistema permite al usuario introducir información específica sobre las características y capacidad de un relleno sanitario individual, y proyectar las emisiones de metano, CO, compuestos orgánicos no metano, y contaminantes peligrosos del aire individuales (CPAs) con el tiempo, utilizando el modelo de decaimiento de Scholl Canyon para la estimación de la producción de gas de rellenos sanitarios. Este modelo es una ecuación de decaimiento de primer orden que usa las características específicas del sitio para estimar la tasa de generación de gas. En ausencia de datos específicos del sitio, el programa proporciona valores conservadores por omisión, los cuales se presentan en la Tabla 4-4. El usuario también puede diseñar las características de la tasa de decaimiento en base individual. Se proporciona un calculador integrado de la constante de la tasa de decaimiento para los rellenos sanitarios que puedan estar operando un sistema de recuperación de gas para permitir una evaluación más exacta de los atributos del decaimiento. Los resultados se pueden revisar de forma tabular o gráfica. También se incluye un sistema de ayuda con información sobre la operación del modelo, así como detalles sobre las suposiciones y valores por omisión que utiliza el sistema.

El modelo es compatible con IBM™-PC y requiere cuando menos 512 kilobytes (Kb) de memoria, y puede ser utilizado con un adaptador de gráficos monocromático o de color. Se recomienda leer el manual del usuario antes de utilizarlo.

4.1.4 Modelos de Emisiones de Residuos y Aguas Residuales al Aire

La Oficina de Planeación de la Calidad del Aire y Estándares (OAQPS, por sus siglas en inglés) de la EPA ha desarrollado modelos de emisiones al aire para las plantas dedicadas al tratamiento, almacenamiento y disposición de residuos peligrosos (ETADs).

Los COVs en represas superficiales, plantas de tratamiento de suelos, rellenos sanitarios, pilas de residuos, o sistemas de recolección y tratamiento de aguas residuales, pueden escapar al ambiente desde los residuos y aguas residuales a través de una gran variedad de trayectorias. Para poder estimar de manera razonable la desaparición de compuestos orgánicos, se debe saber qué trayectorias predominan para una sustancia dada, cuál es el tipo de sitio y se debe tener un conjunto de condiciones meteorológicas. La Tabla 4-5 resume la importancia relativa de nueve rutas para los modelos de emisión desarrollados para las diversas fuentes de emisión de residuos peligrosos (U.S. EPA, 1994).

Tabla 4-5

Rutas para las Fuentes de Area de Emisiones de Residuos Peligrosos[a]

Ruta	Embalses Superficiales	Plantas de Tratamiento de Aguas Residuales		Tratamiento de Suelos	Relleno Sanitario
		Aereadas	**No Aereadas**		
Volatilización	I	I	I	I	I
Biodegradación	I	I	I	I	S
Fotodescomposición	S	D	D	D	D
Hidrólisis	S	S	S	D	D
Oxidación y reducción	D	D	D	D	D
Adsorción	D	S	S	D	D
Reacción de radical hidroxilo	D	D	D	D	D
Migración[b]	D	D	D	D	D
Escurrimiento[b]	D	D	D	D	D

I = Importante
S = Secundario
D = Despreciable o no aplicable

[a] Algunos compuestos individuales en un tipo de sitio determinado pueden tener rutas dominantes diferentes a las que se muestran aquí.

[b] Se considera que la migración de agua y los escurrimientos tienen efectos despreciables sobre el suelo y sobre las agua superficiales en una planta autorizada para el manejo de residuos peligrosos, que esté localizada, operada y mantenida de manera adecuada.

Fuente: U.S. EPA, 1994.

Ecuaciones del Modelo de Emisión

Se considera que una ruta es cualquier proceso que remueva los VOCs de un sitio. Esta remoción puede ser física (e. g., la volatilización de un solvente de un embalse superficial), o química (e. g., la oxidación de un alcohol en una planta de tratamiento de aguas residuales). Las rutas pueden ser consideradas como procesos donde la tasa, con frecuencia, es altamente dependiente de la concentración de la especie que desaparece y la temperatura del sistema.

A continuación se define brevemente cada una de las rutas. Sin embargo, las ecuaciones del modelo de emisión desarrolladas para describir estas trayectorias son sumamente complejas. Una discusión detallada de estas ecuaciones, así como ejemplos de cálculos para cada ruta pueden encontrarse en el documento *Air Emissions Models For Waste and Wastewater (EPA-453/R-94-080A)* (U.S. EPA, 1994), disponible en el la oficina del CHIEF.

- **Volatilización:** se presenta cuando las moléculas de una sustancia disuelta escapan a una fase gaseosa adyacente.

- **Adsorción:** tiene lugar cuando las moléculas de una sustancia disuelta (en un sistema líquido-sólido) se adhieren físicamente a los elementos de la fase sólida. También puede haber enlace químico (quimisorción)

- **Migración:** ocurre cuando las sustancias aplicadas a los suelos son transportadas a través de éstos hacia el agua subterránea.

- **Escurrimiento:** se presenta cuando las sustancias químicas en el suelo o cerca de él pueden ser deslavadas por la lluvia.

- **Descomposición biológica:** tiene lugar cuando los microbios fraccionan los compuestos orgánicos para sus procesos metabólicos.

- **Descomposición fotoquímica:** puede ocurrir cuando una sustancia química absorbe luz y reacciona (fotólisis directa), o cuando la sustancia reacciona debido a que los elementos que la rodean absorben la luz (fotólisis indirecta).

- **Oxidación y reducción:** los compuestos orgánicos que se encuentran en los sistemas acuáticos pueden ser oxidados por el oxígeno (sobre todo como un solo oxígeno, O_2) u otros oxidantes tales como los radicales hidroxilo (OH) y los radicales peroxi (RO_2). En medios anaeróbicos pueden presentarse reacciones de reducción.
- **Hidrólisis:** se presenta cuando una sustancia reacciona con el agua.

- **Reacciones de radical hidroxilo:** éstas puede ocurrir por la adición de un radical hidroxilo, por la sustracción de un átomo de hidrógeno, o por ambos mecanismos.

Parámetros requeridos

Para cada modelo de emisiones de residuos y de aguas residuales se requieren diferentes parámetros. La Tabla 4-6 proporciona algunos ejemplos de los datos necesarios para soportar estos modelos de emisión.

Tabla 4-6

Modelos de Residuos y de Aguas Residuales

Parámetros Requeridos

Parámetro	Unidades
Relación entre el área del residuo y el área del flujo de aire en el drenaje	Adimensional
Fracción de compuestos orgánicos que entran y se pierden en la atmósfera	Adimensional
Coeficiente de reparto	Fracción molar de gas por fracción molar de líquido
Longitud del conducto de recolección	m
Longitud del drenaje	m
Tasa de la corriente subálvea	m^3/s
Diámetro del drenaje	m
Radio del conducto de la corriente subálvea	m
Profundidad del líquido en la corriente subálvea	m
Velocidad del viento	m/s
Humedad relativa	Porcentaje
Temperatura del sistema de recolección	ºC
Area transversal de los orificios de venteo	cm^2
Altura de la cubierta de la boca de acceso sobre la superficie	m

Modelo para Computadora de la EPA

CHEMDAT8—CHEMDAT8 es una hoja de cálculo Lotus 123® elaborada por la División de Normas de Emisión de la EPA que incluye modelos analíticos para la estimación de COVs en procesos de plantas, etc. El modelo original incluye embalses de disposición, rellenos sanitarios cerrados, plantas de tratamiento de suelos y procesos de aereación y no aereación en estanques. Las emisiones previstas se pueden ser ver en pantalla o imprimirse. También está disponible una presentación gráfica de las relaciones entre la predicción de las emisiones, tanto con la presión de vapor, como con el coeficiente de reparto. Los diagramas de dispersión resultantes pueden imprimirse con PrintGraph®, que es otro programa de Lotus®.

Los modelos en CHEMDAT8 pueden aplicarse en otros tipos de proceso de tratamiento, etc., además de los contenidos en el diseño original. El modelo de estanque no aereado puede estimar las emisiones de estanques superficiales de almacenamiento y de tanques abiertos de tratamiento de aguas residuales. El modelo de CHEMDAT8 para predecir emisiones de estanques superficiales de tratamiento y tanques de tratamiento de aguas residuales es el modelo de estanque aereado. El modelo de tratamiento de suelos de CHEMDAT8 puede estimar las emisiones de suelos de tratamiento terrestre, tiraderos de cielo abierto y de pilas de residuos. Las emisiones de la superficie de una película de aceite en una planta de tratamiento de suelos, o de una película de aceite en estanques superficiales pueden predecirse con el modelo de película de aceite de CHEMDAT8. Cuando no está disponible un modelo de CHEMDAT8 para predecir emisiones, se pueden hacer cálculos manuales de las emisiones usando las ecuaciones mostradas en los reportes, mismas que constituyen los antecedentes del modelo.

Esta octava versión de la hoja de cálculo CHEMDAT contiene varias modificaciones operativas importantes. Con CHEMDAT8 el usuario puede seleccionar como blanco un subconjunto de compuestos para investigación. También puede especificar qué procesos de las plantas de tratamiento, etc., se deben considerar durante una sesión. Estas dos selecciones mejoran la eficiencia del programa con relación a algunas de las primeras versiones, haciendo mínimos los requerimientos de almacenamiento, así como el tiempo real de carga y ejecución.

Los parámetros de entrada por omisión en el disquete de CHEMDAT8 demuestran algunos cálculos como ejemplo. Sin embargo, los parámetros de entrada pueden cambiarse para reflejar diferentes características de las plantas y, después recalcular las emisiones conforme a estas condiciones modificadas. Más aún, la lista de 60 compuestos que ya están en el CHEMDAT8 puede incrementarse hasta casi 700 sustancias. Los procedimientos para introducir los datos de compuestos adicionales en el CHEMDAT8 se describen en el reporte de apoyo.

WATER8

WATER8 es un programa de computadora manejado con menús, que tiene el objetivo de estimar emisiones solamente de sistemas de tratamiento de aguas residuales. WATER8 usa algunos de los mismos modelos que se encuentran en CHEMDAT8, pero contiene datos para un total de 800 compuestos. Este programa también tiene mejoras gráficas para ayudar al usuario a visualizar el sistema que está siendo modelado.

4.1.5 Polvos Fugitivos

El polvo atmosférico significativo surge de perturbaciones mecánicas del material granulado expuesto al aire. El polvo generado por estas fuentes abiertas se denomina “fugitivo” debido a que no se descarga a la atmósfera en una corriente de flujo confinado. Las fuentes de polvos fugitivos más comunes incluyen caminos pavimentados y no pavimentados, operaciones agrícolas, pilas de almacenamiento de agregados y operaciones de construcción pesada. La generación del polvo se debe a la pulverización y abrasión de los materiales de la superficie al aplicar una fuerza mecánica a través de diversos implementos (i. e., ruedas, cuchillas, etc.), y por el arrastre de partículas de polvo por la acción de corrientes turbulentas de aire, tales como la erosión eólica de una superficie expuesta a vientos con velocidades superiores a los 19 km/hr (12 millas/hr).

La EPA ha desarrollado varias ecuaciones de modelos de emisión, para estimar las emisiones de estas fuentes de polvos fugitivos. Puede encontrarse información más detallada en el *AP-42, Sección 13.2* (U.S. EPA, 1995a).

Ecuaciones del Modelo de Emisión - A continuación se presentan ejemplos de ecuaciones del modelo de emisión. Información más detallada puede encontrarse en el *AP-42, Sección 13.2.1* (U.S. EPA, 1995a). Los datos de los parámetros requeridos y los valores por omisión para los EU se presentan en la Tabla 4-7.

Caminos Sin Pavimentar

$$\mathbf{E = VKT \times EF} \tag{4-12}$$

donde:

E = tasa de emisión promedio anual como masa, kg/año
VKT = kilómetros recorridos por el vehículo, VKT/año
EF = factor de emisión, kg/VKT

$$\mathbf{EF = k\,(1.7)\left(\frac{s}{12}\right)\left(\frac{S}{24}\right)\left(\frac{W}{2.7}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{365-p}{365}\right)\ (kg/VKT)} \tag{4-13}$$

donde:

k = multiplicador del tamaño de partícula, adimensional
s = contenido de sedimentos del material de recubrimiento del camino, %
S = velocidad promedio del vehículo, km/hr
W = peso medio del vehículo, Mg
w = numero medio de ruedas
p = número de días al año con una precipitación mínima de 0.254 mm (0.01 in).

Caminos Pavimentados

$$E = VKT \times EF \qquad (4\text{-}14)$$

donde: E = tasa de emisión anual promedio en masa, g/año;

VKT = vehículo kilómetros recorridos, VKT/año;

EF = factor de emisión, g/VKT.

$$EF = k\left(\frac{SL}{2}\right)^{0.65}\left(\frac{W}{3}\right)^{1.5} \qquad (4\text{-}15)$$

donde: k = factor de emisión de base para el intervalo de tamaño de partícula (g/VKT)

sL = carga de sedimentos de la superficie del camino (g/m^2)

W = peso promedio (tons) de los vehículos que transitan por el camino

Operaciones de Construcción Pesada

$$E = A \times T \times EF \qquad (4\text{-}16)$$

donde: E = tasa de emisión anual promedio en masa, Mg/año

A = área en construcción, hectáreas

T = tiempo de construcción, meses

EF = factor de emisión = 2.69 Mg/hectárea/mes

Manejo de Agregados y Pilas de Almacenamiento

(4-17)

$$E = Q \times EF$$

donde: E = tasa de emisión anual promedio en masa, kg/año
Q = cantidad de material transferido, Mg/año
EF = factor de emisión, kg/Mg

(4-18)

$$EF = k(0.0016)\ \frac{\left(\frac{U}{2.2}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}}$$

donde:
k = multiplicador del tamaño de partícula, adimensional
U = velocidad media del viento, m/s
M = contenido de humedad del material, %

Erosión Eólica Industrial

(4-19)

$$E = A \times EF$$

donde: E = tasa de emisión anual promedio de masa, g/año
A = área de la superficie del material sujeto a la perturbación, m^2
EF = factor de emisión, g/m^2/año

(4-20)

$$EF = k \sum_{i=1}^{N} P_i$$

donde:
k = multiplicador del tamaño de partícula, adimensional
N = número de perturbaciones por año
P_i = potencial de erosión correspondiente a la milla más rápida de viento para el periodo (i)ésimo entre perturbaciones g/m^2

Tabla 4-7

Polvos Fugitivos
Parámetros Requeridos y Valores por Omisión para EU

Descripción del Parámetro	Variable	Valor por Omisión para EU
Tamaño de partícula para el que se estimarán las emisiones	Se usa para determinar k	
Multiplicador del tamaño de partícula	k	
Contenido de sedimento del material de la superficie del camino	s	Tabla de valores por omisión presentada industria y por el uso del camino y material de la superficie
Velocidad media del vehículo	S	Intervalo de valores en condiciones de prueba: 21-64 km/hr.
Peso medio del vehículo	W	Intervalo de valores en condiciones de prueba: 2.7-142 Mg.
Número medio de ruedas	w	Intervalo de valores en condiciones de prueba 4-13 ruedas
Número de días por año con precipitación mínima de 0.254 mm (0.01 in)	p	Se dan datos regionales para EU
Carga de sedimentos en la superficie del camino	sL	Se presenta tabla de valores por estado y ciudad de EU
Area superficial del material	A	
Tiempo de construcción	T	
Cantidad de material transferido	Q	
Velocidad media del viento	U	
Contenido de humedad del material	M	Se presenta tabla de valores presentados por industria y material de la superficie
Número de perturbaciones por año	N	
Función del potencial de erosión	P_i	

Modelo para Computadora de la EPA

En 1990, la EPA desarrolló dos programas para ayudar a estimar las emisiones de polvos fugitivos causados por las perturbaciones mecánicas (i. e., caminos pavimentados y no pavimentados, manejo de materiales, actividades agrícola, y construcción y demolición), y por erosión eólica. Estos programas para computadora se basan en el material presentado en el documento *Control of Open Fugitive Dust Sources* (Control de Fuentes Abiertas de Polvos Fugitivos) (U.S. EPA, 1988). La sección de ayuda da definiciones para los términos con los cuales el usuario pudiera no estar familiarizado. Además, se dan valores por omisión, típicos o sugeridos para ciertas variables. Por ejemplo, el número de días con precipitación pluvial significativa para más de 175 ciudades de EU, así como la velocidad media anual del viento para más de 120 ciudades de EU.

La EPA distribuye los programas para polvos fugitivos a través del CHIEF BBS o en disquete por correo. Para mayor información, puede leerse *The User's Manual for the PM_{10} Open Fugitive Dust Source Computer Model Package* (Manual del Usuario del Modelo de Computadora para PM_{10} de Fuentes Abiertas de Polvos Fugitivos) (U.S. EPA, 1990).

Debido a que estos programas no han sido actualizados desde 1990, no son tan amigables con el usuario como el software desarrollado más recientemente. En muchos casos, probablemente sería más eficiente que los usuarios desarrollaran sus propias hojas de cálculo con las ecuaciones del modelo de emisiones. Como otra opción puede usarse el modelo PART5 para fuentes móviles para estimar las emisiones de polvos fugitivos de caminos pavimentados y sin pavimentar.

4.2 Modelos de Emisiones de Variable Múltiple

Un modelo de emisiones de variable múltiple es una metodología híbrida que combina varios enfoques tradicionales de inventarios con información específica del sitio dentro de un marco de extrapolación. Como su nombre sugiere, un modelo de variable múltiple expresa las estimaciones de las emisiones en términos de un conjunto de variables que ayudan a caracterizar el sistema que se modela. Este enfoque es adecuado en particular, para las regiones que tienen registros y estadísticas que resultan limitados para la aplicación de otras técnicas tradicionales de inventario. El concepto fundamental está en el desarrollo de estimaciones de emisión basadas en las características del uso y cobertura del suelo. Por ejemplo, los lugares agrícolas, residenciales, comerciales e industriales tienen diferentes características, en sus emisiones. Estas diferencias pueden ser caracterizadas utilizando diversas variables que describan la actividad que produce emisiones para cada tipo de y de cobertura del suelo.

Aunque es probable que el uso de modelos de variable múltiple tenga costos iniciales más elevados que el de otros métodos de inventario debido al paso correspondiente al desarrollo del modelo mismo, la facilidad de aplicación y la posible reducción de costos de mantenimiento del inventario en el futuro lo hacen una opción atractiva. Otra ventaja significativa de los modelos de variable múltiple es que se basan en datos locales. Esto permite que los efectos de las condiciones locales sean incluidos en las estimaciones de las emisiones. Entre los posibles tipos de fuente que podrían ser evaluados con estos modelos en México se encuentran las actividades de construcción las agrícolas, así como el uso de solventes. El enfoque general para desarrollar un modelo de variable múltiple de emisiones se describe en la sección 4.2.1, y se presenta un ejemplo conceptual en la sección 4.2.2.

4.2.1 Desarrollo de un Modelo de Emisiones de Variable Múltiple de Emisiones

El primer paso en el desarrollo de un modelo de emisiones de variable múltiple es la identificación de las variables que caracterizan el sistema global que se pretende cubrir. Estas variables diferirán de un sistema a otro. Usando las actividades agrícolas como ejemplo, estas variables podrían ser un tipo de cultivo (legumbres, hortalizas, etc.), superficie cultivada o tamaño de la cosecha. Para las actividades de construcción, las variables podrían ser el tipo de construcción (edificios, carreteras, vías de ferrocarril, etc.), el tamaño de la misma o su costo. Cada una de estas variables puede usarse para describir la magnitud de las emisiones de estas fuentes. Por ejemplo, la construcción de dos kilómetros de carretera generaría más emisiones de partículas que la construcción de un kilómetro.

El segundo paso del desarrollo de un modelo de variable múltiple es la determinación de qué tipos de fuentes emisoras deben incluirse en el modelo. Para las actividades agrícolas, esto podría definirse como las del cultivo, la cosecha y las emisiones de los escapes del equipo. En el caso de las actividades de construcción, esto podría ser mucho más complejo e incluir el movimiento de tierras, el manejo de materiales, los escapes de los equipos y otros tipos de fuentes de emisión. A la larga, el número total de tipos de fuentes de emisión cubiertos en el modelo está determinado por las actividades emisoras del sistema que se está caracterizando.

Después de definir los tipos de fuente que serán incluidos en el modelo de variable múltiple, el siguiente paso consiste en desarrollar los datos de emisiones que se usarán. Las emisiones de cada tipo de fuente en un solo sitio (de construcción, agrícola, etc.), se estiman utilizando métodos bibliográficos (i .e., ecuaciones empíricas), y datos específicos del sitio. Para crear un modelo de variable múltiple que sea coherente desde el punto de vista estadístico, es necesario repetir esta estimación para varios otros sitios.

Después, las emisiones totales estimadas para cada sitio geográfico se graficarían contra cada una de las variables que caracterizan el sistema completo. Los sitios que difieran de manera considerable de los sitios representativos pueden producir estimaciones significativamente más altas o más bajas que podrían afectar negativamente el análisis estadístico. Estos datos puntuales deben ser considerados como "extremosos" y ser excluidos de análisis posteriores. A partir de estos datos graficados se puede determinar estadísticamente una tasa de emisión correspondiente al "mejor ajuste" para cada variable del sitio (i. e., kg de PM_{10}/acre de tomates, kg de PM_{10}/US$ de construcción de edificios, etc.). Luego se usa análisis estadístico para evaluar la imprecisión de cada factor de emisión correspondiente al mejor ajuste y para cuantificar la incertidumbre de las estimaciones de emisiones. A partir de este análisis se selecciona la relación más exacta desde el punto de vista estadístico. Es probable que esta sea una relación lineal simple pero también es posible que sea exponencial, logarítmica o segmentada (i. e., los costos de construcción menores a 10 millones de dólares podrían tener una relación de mejor ajuste, mientras que aquellos con un costo mayor a 10 millones, podrían tener otra diferente).

Después de determinar la relación más apropiada de mejor ajuste, las emisiones regionales pueden ser estimadas insertando datos regionales en el modelo.

4.2.2 Ejemplo de un Modelo de Variable Múltiple - Actividades de Construcción

Las actividades de construcción son una fuente de área muy distribuida y pueden ser una fuente significativa de partículas (PM_{10}). Debido a que las actividades de construcción están tan difundidas, por lo general no es factible estimar las emisiones de cada sitio de construcción individual. Esto hace que estas actividades sean candidatos ideales para los modelos de variable múltiple. El siguiente ejemplo ilustra, de manera conceptual, el desarrollo de un modelo de emisiones de variable múltiple. Los modelos reales de variable múltiple deben derivarse siguiendo los pasos que se describen a continuación.

Identificación de las Variables del Sistema. Existen diversas variables relacionadas con las actividades de construcción que caracterizan al sistema completo (emisiones PM_{10}). Entre las variables más básicas del sistema se incluyen:

- Tipo de construcción (edificios, carreteras, vías de ferrocarril, etc.)
- Tamaño de la construcción (área del edificio, volumen de excavación, cantidad de concreto vaciado, etc.)
- Valor del proyecto y
- Número de trabajadores en la construcción.

Puede haber otras variables aplicables para algunos tipos especiales de actividades de construcción.

Determinación de los Tipos de Fuentes Emisoras. Las actividades de construcción generan emisiones de PM_{10} a partir de varias como:

- Demolición y remoción de escombros
- Excavación y otros movimientos de tierras
- Escapes de vehículos y equipo
- Manejo de materiales y
- Polvo rearrastrado.

Desarrollo de los Datos de Emisiones. Las emisiones para un sitio con una sola construcción se estiman sumando las emisiones calculadas de cada uno de los tipos de fuente, como se muestra en la siguiente ecuación:

$$\mathbf{E_{tot} = \sum(x_{d.c.e.m.r})(y_{d.c.e.m.r})} \qquad (4\text{-}21)$$

donde:
E_{tot} = emisiones totales en el sitio;
x = tasa de actividad;
y = factor de emisión;
d = demolición y remoción de escombros;
c = excavación y otros movimientos de tierras;
e = escapes de los vehículos y equipos;
m = manejo de materiales y
r = polvo rearrastredo

En la Tabla 4-8 se enlistan tasas de actividad específicas del sitio (x_i) y factores de emisión empíricos (y_i) necesarios para estimar las emisiones de la construcción. También se incluyen los parámetros específicos del sitio contenidos dentro de los factores de emisión empíricos.

Tabla 4-8

Tasas de Actividad y Parámetros de los Factores de Emisión que se necesitan para Estimar las Emisiones de la Construcción

Tipo de Fuente de Emisión	Tasa de Actividad (x_i)	Factor de Emisión (y_i)	Parámetros Específicos de Sitio que se requieren
Demolición y remoción de escombros (d)	Cantidad de material de demolición (Mg)	kg PM_{10}/Mg de material de demolición[a]	Velocidad del viento (m/s) Contenido de humedad en el material de demolición (%)
Excavación y movimientos de tierras (c)	VKT vehículo	kg PM_{10}/VKT[a]	Tipo de equipo
Escapes de vehículos y equipos (e)	Horas de operación	g PM_{10}/hora de operación[b]	Tipo de equipo Tipo de combustible Potencia nominal Carga de operación
Manejo de	Cantidad de	kg PM_{10}/Mg de	Velocidad del viento (m/s)

materiales (m)	material manejado (Mg)	material manejado[a]	Contenido de humedad en las pilas de almacenamiento (%)

Tabla 4-8 (Continuación)

Tasas de Actividad y Parámetros del Factor de Emisión Necesarios para Estimar las Emisiones de la Construcción

Tipo de Fuente de Emisión	Tasa de Actividad (x_i)	Factor de Emisión (y_i)	Parámetros Específicos de Sitio que se requieren
Polvo rearrastrado (r)	VKT vehículo	kg PM_{10}/VKT[a]	Contenido de sedimentos (%) Velocidad del vehículo (km/hr) Peso del vehículo (Mg) Numero medio de ruedas del vehículo (-) Precipitación (número de días por año con precipitación ≥ 0.254 mm)

[a] Las ecuaciones empíricas para la demolición y remoción de escombros, excavación y movimiento de tierras, manejo de materiales y polvo rearrastrado pueden encontrarse en *Fugitive Dust Background Document and Technical Information Document for Best Available Control Measures* (U.S. EPA, 1992)

[b] Los factores de emisión (g/hp-hr) para diferentes tipos de equipos pueden encontrarse en *Nonroad Engine and Vehicle Emission Study Report* (U.S. EPA, 1991a). Podría ser necesario que se desarrollaran factores de emisión específicos para México.

Graficación de los Datos de Emisiones. Después de obtener las emisiones totales de PM_{10} para todo el sitio (E_{tot}) para varios sitios diferentes de construcción de edificios, los totales se graficarían contra el área de construcción del sitio, el valor del proyecto de construcción, el número de trabajadores y cualesquier otra variable relevante del sistema. En la Figura 4-2 se grafican datos hipotéticos para seis sitios (con los literales E_1 hasta E_6).

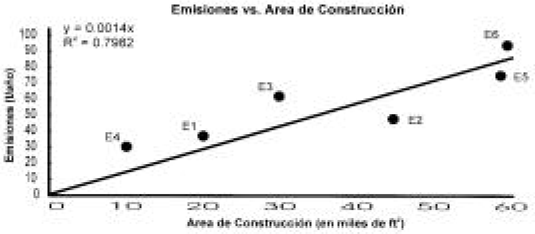
Análisis Estadístico de los Datos Graficados. El siguiente paso es determinar estadísticamente la relación de "mejor ajuste", entre las diferentes gráficas de datos. Para los datos hipotéticos graficados en la Figura 4-2 se asume que la relación del "mejor ajuste" es una regresión lineal simple que interseca el eje de las ordenadas en el origen (i. e., sin construcción no hay emisiones de PM_{10}). En este ejemplo hipotético la comparación de los valores de R^2 resultantes indican que la relación estadística más fuerte está entre las emisiones de PM_{10} y el área de construcción. En situaciones reales es probable que las emisiones no sean dependientes de una sola variable del sistema sino que dependan de varias.

Cálculo de las Emisiones Regionales. Una vez que se ha establecido que la relación de mejor ajuste entre las emisiones de PM_{10} y el área de construcción es estadísticamente válida la aplicación de esta relación para calcular las emisiones en toda la región es bastante directa. Como se puede ver en la graficación de emisiones contra el área de construcción de la Figura 4-2, la ecuación que determina la regresión lineal es:

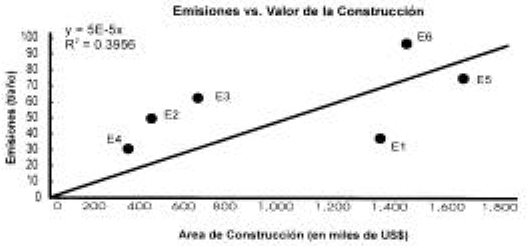
$$\text{Emisiones Totales de } PM_{10} \text{ (ton/año)} = 0.0014 \times \text{Area de Construcció } (m^2)$$

Si el área total hipotética de construcción a nivel regional es de 2,600,000 m^2 entonces las emisiones regionales de PM_{10} de la construcción son:

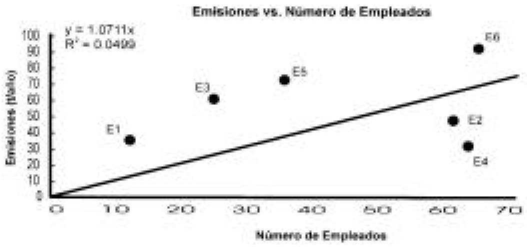
$$0.0014 \times (2{,}6000{,}000 \text{ } m^2) = 3640 \text{ ton/año de } PM_{10}$$



Emisiones vs. Area de Construcción



Emisiones vs. Valor de la Construcción



Emisiones vs. Número de Empleados

5.0 ENCUESTAS

Una encuesta es la técnica que se usa por lo común para recabar datos para los inventarios de emisiones de fuentes puntuales (Figura 5-1). El cuestionario debe enviarse a cada planta solicitando información acerca de las características de cada uno de sus dispositivos emisores. El uso de un cuestionario para reunir datos de emisiones de fuentes puntuales no es nuevo en México. El Instituto Nacional de Ecología (INE) ha estado recabando datos de fuentes puntuales con esta técnica por varios años. En el Apéndice III-B se muestra una copia del cuestionario nacional de fuentes puntuales

También se puede usar el método de encuesta para reunir la información necesaria para calcular las estimaciones de fuentes de área o para desarrollar factores de emisión específicos para una región que sirvan para hacer ciertas estimaciones de emisiones de fuentes de área. La Figura 5-2 ilustra el proceso para fuentes de área.

La realización de una encuesta consta de varios pasos. Ya sea para una encuesta de fuentes puntuales o de área, el primer paso es determinar un tamaño adecuado de muestra e identificar las plantas y subcategorías, así como las diferencias en los procesos dentro de la categoría de fuentes encuestada. A continuación, se deben preparar las listas de distribución por correo. Se deben diseñar los cuestionarios, ordenarlos, y enviarlos por correo o entregarlos personalmente. Se deben preparar y organizar los procedimientos para el manejo de datos y se deben establecer sistemas para la recepción de las respuestas. Se requiere un considerable esfuerzo mental y de planeación para diseñar un nuevo cuestionario o para modificar alguno ya existente. El grado de éxito de una encuesta depende mucho de si ésta se encuentra apoyada por una agencia regulatoria y también de qué tan concisa es, de su facilidad de uso y de lo general del cuestionario.

Además, las respuestas deben sujetarse a profundas revisiones para el aseguramiento y control de calidad (AC/CC) para eliminar los datos inválidos (e. g., velocidades supersónicas del gas a la salida de la chimenea). El costo de una encuesta está en función de qué tan completos y específicos sean los cuestionarios, del tamaño de la audiencia blanco y de la profundidad de las actividades de seguimiento para el control y aseguramiento de calidad.

El material presentado en el resto de esta sección tiene como objetivo introducir al lector al concepto de encuesta, y brindar información sobre los antecedentes de las técnicas utilizadas para conducir una encuesta exitosa. Estas técnicas son aplicables tanto a fuentes puntuales como de área. Para mayor información acerca del uso de cuestionarios específicos referirse al documento intitulado *Development of Questionnaires for Various Emission Inventory Uses* (Holman and Collins, 1979).

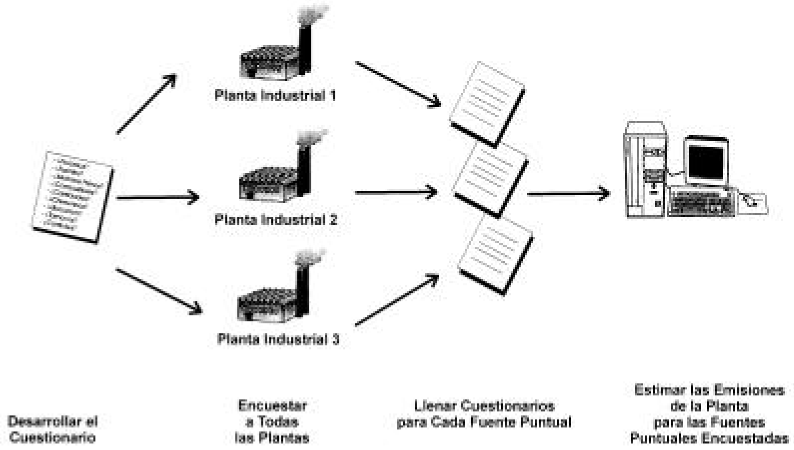


Figura 5-1. Ejemplo de una Encuesta de Fuente Puntual

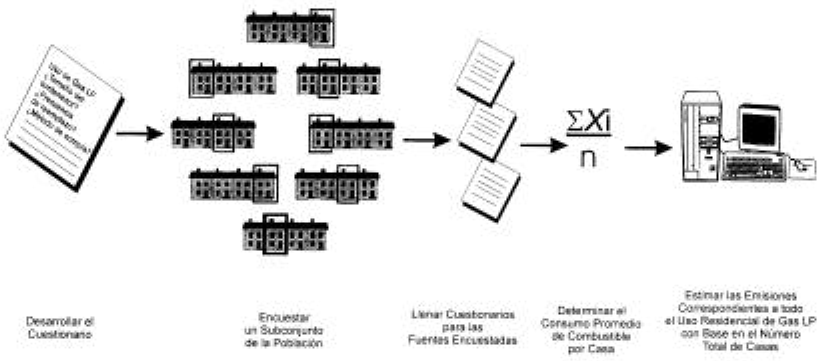


Figura 5-2. Ejemplo de Encuesta de Fuentes de Area

5.1 Planeación Inicial

Si bien no son complicadas existen varias consideraciones importantes que es necesario tener en mente cuando se planea y se conduce una encuesta. En esta sección se resumen las consideraciones más relevantes que son aplicables tanto a las fuentes puntuales como a las de área. La clave de una buena encuesta es una planeación adecuada. Algunos puntos importantes que deben ser considerados durante la fase inicial de planeación, tanto para encuestas de fuentes puntuales como para encuestas de área son:

- Siempre se han enviado copias de los cuestionarios impresas en a las plantas individuales. Otra opción es utilizar medios computarizados (discos o transmisión electrónica) en lugar de papel para devolver o actualizar las respuestas del cuestionario a la agencia. Esta técnica también puede incluir el uso de formas estandarizadas de computadora o software, de manera que los datos presentados a la agencia se encuentren en un formato que sea manejado fácilmente por su personal. Esta técnica no ha sido utilizada en México pero otras regiones han encontrado varios beneficios en ella. Si está diseñado adecuadamente el cuestionario electrónico puede ser mucho más sencillo de llenar y reduce a un mínimo la captura de datos, y las revisiones de Aseguramiento de Calidad.

- Recopilar las listas de distribución de diversas fuentes, utilizando otras fuentes diferentes y verificarlas en forma cruzada.

- Contar con todas las autorizaciones administrativas que se necesiten conforme a las regulaciones federales o estatales para hacer una encuesta del sector privado.

- Explicar las razones para la encuesta durante la fase inicial de contacto, ya sea por teléfono o por correo.

- Considerar quién debe hacer el contacto con el receptor de la encuesta. Las tasas de respuesta para las encuestas industriales pueden ser más elevadas si la agencia estatal o federal, y no un contratista, se pone en contacto con el receptor.

- El proceso de encuesta consta de varios pasos que incluyen la identificación del receptor correcto dentro de la planta. Para ello, se debe arreglar una entrevista a las horas más convenientes, se debe hablar directamente con el receptor y responder a las preguntas sobre la encuesta. Por ejemplo, los pasos a seguir serían:
    - Establecer contacto con la planta por carta o por teléfono para informarles acerca de la encuesta y acordar un horario adecuado para responder las preguntas. Asegurarse de que la persona contactada tenga la capacidad para responder las preguntas de la encuesta.
    - Enviar las preguntas de la encuesta al receptor
    - Hacer una segunda llamada para entrevistar al receptor acerca de las preguntas de la encuesta.

Una vez que se han identificado las plantas y se han desarrollado el o los cuestionarios, la encuesta de fuentes puntuales ya es directa. A continuación se resumen varios aspectos importantes para planear una encuesta de fuentes de área:

- Investigar y, si es necesario, subdividir la categoría de fuentes. Muchas categorías de fuentes de área, tales como el desengrasado y la pintura consisten de diversos procesos que son utilizados por muchas industrias diferentes. Los usos de procesos particulares pueden variar mucho de una industria a otra. Se puede estratificar la población de fuentes si es necesario (ver Sección 5.3).
- Diseñar la encuesta para un punto razonable dentro del proceso de distribución del producto. En el caso de muchas categorías de uso de solventes se podría enviar una encuesta ya sea a los fabricantes, a los distribuidores, a los minoristas o a los usuarios, pero la decisión más práctica podría enviarla sólo a los fabricantes o sólo a los distribuidores.
- Considerar las necesidades futuras en la planeación de la forma de encuesta. Planear por adelantado, si es posible. Por ejemplo, el cuestionario puede recopilar datos o información para los cálculos de emisiones. Como parte del proceso de planeación de la calidad del aire las proyecciones de emisiones también se anticipan. Por lo tanto, se debe reunir información sobre las proyecciones de emisiones al mismo tiempo que se recaban los datos básicos.
- Para las fuentes de área, se debe planear la manera en que la información reunida a través de la encuesta será escalada para hacer el inventario de toda la región dado que es probable que el diseño de la encuesta cubra sólo una muestra de todas las fuentes y es poco factible que se tenga una tasa de respuesta del 100 por ciento. Identificar una actividad sustituta razonable, de ser necesario, y planear la recopilación de dicha información en la encuesta (ver Sección 5.4).
- Cuando la recopilación de los datos se basa en sitios identificados por el código

CMAP, (Clasificación Mexicana de Actividades y Productos) y el proceso de categoría de la fuente pueda o no llevarse a cabo en todos los sitios con ese código CMAP, se debe refinar la lista de distribución identificando los sitios que sí utilizan el proceso:

- Por ejemplo, la pintura industrial por lo general está asociada con varios códigos CMAP pero es probable que no todas las plantas dentro en un código particular tengan operaciones de pintura.

- Si se habla a una planta antes de enviar la encuesta la distribución puede ser más eficiente. Esto también servirá para identificar la proporción de plantas en un código CMAP que utilizan o no un proceso, lo que es útil para el escalamiento de los datos de la encuesta de fuentes de área.

5.2 Identificación de Plantas

Un paso necesario en la encuesta es la elaboración de una lista de contactos en forma de tabla con el nombre, dirección y categoría general del proceso (e. g., manufactura de productos de madera) de cada planta que podría encuestarse. El propósito de la lista de contactos es identificar las plantas individuales que serán encuestados. El tamaño de la lista resultante proporciona a la agencia una indicación de los números y tipos de fuentes que pueden ser considerados de manera efectiva en la encuesta dentro de las acciones de los recursos. A este respecto, la lista de contactos puede ser utilizada para ayudar a una agencia a determinar si los recursos asignados a la tarea de recopilación serán suficientes y para proporcionar la información básica necesaria para desarrollar un subconjunto de muestreo. El número correcto de muestras (cuestionarios devueltos y llenados de manera correcta), debe determinarse basándose en técnicas de muestreo racionales estadísticamente desde el punto de vista en la prioridad dada a la categoría y en los recursos disponibles.

La lista de contactos debería ser recopilada a partir de una variedad de fuentes de información, que incluyen:

- Los listados de fuentes de emisiones al aire incluidas en los inventarios de emisiones existentes constituyen un buen punto de partida.
- Los listados de fuentes de contaminación del agua y de generadores de residuos peligrosos pueden ser utilizados para identificar las fuentes potenciales en varias CMAPs.
- Los archivos de la agencia de control de la contaminación del aire pueden proporcionar información valiosa acerca de la ubicación y tipos de fuentes en la región de interés. Estos archivos también pueden ser utilizados después para la verificación cruzada de cierta información proporcionada en los cuestionarios.
- Los archivos de otras agencias gubernamentales mantenidos por los departamentos laborales y fiscales ayudan con frecuencia en la elaboración de la lista de distribución. Dichos archivos incluyen varios directorios industriales estatales en los que las empresas están organizadas por orden alfabético por código CMAP y por municipio.

- Los directorios industriales locales pueden proporcionar una lista actual de las fuentes que operan en la región del inventario. Estos a menudo están organizados por código CMAP y pueden dar datos de empleo. Por ejemplo, los listados de plantas a lo largo de la frontera pueden obtenerse de la Asociación de Maquiladoras.

- Se pueden usar publicaciones nacionales, cuando estén disponibles. Sin embargo, la información que contienen puede ser más antigua y menos exacta que las referencias locales primarias.

La lista de correo debe ser organizada para facilitar las actividades de distribución y seguimiento. Un orden lógico para enlistar a las empresas sería por estado o por municipio, luego por código CMAP y finalmente por orden alfabético. Al ordenar la lista en esta forma se incrementa la eficiencia de todas las actividades subsecuentes de manejo de datos y permite que la revisión de control de calidad sea más rápida.

5.3 Selección de Muestras

Para las fuentes de área, el desarrollo del plan de encuesta implicará tomar decisiones relacionadas con la selección (o muestreo) de las plantas que se van a incluir en la encuesta. Dependiendo de los objetivos de ésta, se pueden utilizar diferentes técnicas de muestreo. Algunas de estas técnicas se presentan en la Tabla 5-1. Para el desarrollo de estimaciones de las emisiones de fuentes de área, en general, se pueden usar técnicas de muestreo aleatorio o de selección por muestreo aleatorio estratificado. Si la población de fuentes es suficientemente pequeña, se puede seleccionar la población completa. Si la población es grande y no es posible encuestar cada planta debe seleccionarse un subconjunto de la población. Se debe dar especial atención a la selección de la muestra para que los resultados de la encuesta se mantengan sin sesgos. Una discusión profunda de procedimientos estadísticos para seleccionar muestras queda fuera del alcance de esta sección. El lector debe referirse a exposiciones más detalladas sobre este tema, tales como los libros de texto *Sampling Techniques* (Cochran, 1977) y *Statistical Methods for Environmental Pollution Monitoring* (Gilbert, 1987).

El concepto de un enfoque de muestreo aleatorio estratificado puede ser sumamente útil para el desarrollo de estimaciones de emisiones de fuentes de área, así como para la generación de datos que puedan usarse en modelos de emisiones de variable múltiple. En esta técnica, la población de N unidades se divide en $N_1, N_2,...,N_L$ unidades de subpoblaciones. Estas subpoblaciones, o estratos, no se traslapan y en conjunto abarcan la población entera. Cuando los estratos han sido determinados se retira una muestra de cada uno de ellos con extracciones realizadas de manera independiente en diferentes estratos. Los tamaños de muestra son denominados $n_1, n_2,...n_L$, respectivamente. Desde el punto de vista de un inventario de emisiones, la razón principal para conducir este tipo de enfoque para el muestreo es dividir una población heterogénea en subconjuntos, cada uno de los cuales tiene mayor posibilidad de ser internamente homogéneo. A continuación se presenta un ejemplo conceptual

Ejemplo 5-1

La mayor parte de las áreas urbanas con una economía diversificada contienen numerosas fábricas pequeñas que pueden estar utilizando solventes, principalmente para aplicar pintura, desengrasar o para operaciones de limpieza. Muchos de estos establecimientos no estarán incluidos en el inventario de fuentes puntuales y comprenderán numerosas y diversas operaciones de manufactura (e. g., fabricación y pintura de productos de madera; pintura de plásticos; fabricación y pintura de partes metálicas variadas, etc.). Debido al gran número de operaciones y a sus diferencias en las características de materias primas y producción, es necesario desarrollar una encuesta que recopile exactamente la información que puede ser extrapolada estadísticamente a la población entera de plantas con fuentes no puntuales. Para resolver este problema se puede usar una encuesta aleatoria estratificada.

En el primer estrato se podrían dividir las plantas en grupos en base a un código CMAP de dos dígitos de manera que los establecimientos semejantes queden en el mismo grupo (i. e., es probable que las plantas que fabrican materiales parecidos tengan emisiones con características semejantes). En un segundo estrato se podría considerar necesario distinguir las fábricas grandes de las pequeñas, para evitar los sesgos resultantes de las diferentes tasas de uso de material que podrían ocurrir debido a la eficiencia en la operación de la fábrica. Una vez que la encuesta esté terminada y que las emisiones hayan sido calculadas, los datos de emisiones pueden ser correlacionados con los estratos utilizados para definir las subpoblaciones, en este caso, el código CMAP de dos dígitos y el número de empleados

.

Tabla 5-1

Tipos de Métodos para el Muestreo en Encuestas

Método	Descripción	Condiciones en las que el Diseño del Muestreo es Util[a]
Muestreo *Haphazard*	"Cualquier ubicación de muestreo sirve". Se toman las muestras en sitios o tiempos convenientes. Puede conducir a estimaciones sesgadas.	Una población muy homogénea en el tiempo y el espacio es esencial si se necesitan estimaciones no sesgadas de los parámetros. Este método de selección *no* es recomendado, debido a la dificultad para verificar esta suposición.
Muestreo Basado en el Juicio	Selección subjetiva hecha por un individuo. Selecciona muestras que parecen ser "representativas" de las condiciones promedio. Puede llevar a estimaciones sesgadas. La exactitud es difícil de medir.	La población blanco debe ser definida con claridad, debe ser homogénea y completamente evaluable, de manera tal que el sesgo de la selección de muestra no sea un problema. Por el contrario, las muestras específicas se seleccionan por su valor único e interés más que por sus inferencias con una población más amplia.
Muestreo Aleatorio Simple	Cada unidad de población tiene la misma oportunidad de ser seleccionada para medición. La selección de una unidad no tiene influencia sobre la selección de otras unidades.	Es el diseño de muestreo aleatorio más simple. Otros diseños que se describen a continuación con frecuencia arrojarán estimaciones más exactas de las medias si la población tiene tendencias o patrones de tasas de emisión.
Muestreo Aleatorio Estratificado	Divide la población blanco en partes que no se traslapan. Los sitios de muestreo de cada estrato son seleccionados por un muestreo aleatorio simple.	Es útil cuando una población heterogénea puede ser desglosada en partes que son internamente homogéneas. Por ejemplo, el uso de solventes podría ser estratificado de acuerdo con el producto final elaborado.
Muestreo Multi-Etapas	Divide la población blanco en unidades primarias. Selecciona un conjunto de unidades primarias utilizando un muestreo aleatorio simple. Hace submuestreos aleatorios de cada una de las	Es necesario cuando las mediciones se hacen en submuestras de la muestra de campo. La aplicación de esta técnica es limitada para el desarrollo de inventarios de emisiones.

Método	**Descripción**	**Condiciones en las que el Diseño del Muestreo es Util**[a]
	unidades primarias seleccionadas. Ejemplo: recolección de muestras de suelo (unidades primarias) al azar, luego seleccionar una o más alícuotas aleatorias de cada submuestra.	

Tabla 5-1 (Contiuación)

Tipos de Métodos para el Muestreo en Encuestas

Método	Descripción	Condiciones en las que el Diseño del Muestreo es Util[a]
Muestreo de Agrupamiento	Grupos de unidades individuales seleccionadas al azar. Todas las unidades en los grupos seleccionados son medidas.	Es útil cuando las unidades poblacionales se agrupan (cardúmenes, manchones de plantas, etc.), y cada unidad en cada grupo seleccionado aleatoriamente pueden ser medidas. La aplicación de esta técnica es limitada para el desarrollo de inventarios de emisiones.
Muestreo Sistemático	Toma medidas en sitios y/o tiempos, de acuerdo con un patrón espacial o temporal. Por ejemplo, a intervalos equidistantes a lo largo de una línea o en un patrón de rejilla.	Por lo general es el método elegido cuando se estiman tendencias o patrones de emisiones en el espacio. También es útil para estimar la media cuando no hay tendencias ni patrones o éstos se conocen *a priori*, o cuando los métodos estrictamente aleatorios son imprácticos.
Muestreo Doble	Si los datos obtenidos usando una técnica de medición tienen una fuerte relación lineal con los datos obtenidos con menor gasto o esfuerzo utilizando otra técnica se pueden tomar más muestras usando el método más barato. La relación lineal entre las dos técnicas se aplican entonces para estimar la media para el método más caro.	Es útil cuando existe una fuerte relación lineal entre la variable de interés y una variable menos cara o cuya medición sea más fácil.
Muestreo de Búsqueda	Se usa para localizar geográficamente fuentes de contaminación o para encontrar "puntos rojos" de alta contaminación.	Es útil cuando la información histórica, el conocimiento del sitio o las muestras previas indican donde es posible encontrar al objeto de la búsqueda. La aplicación de esta técnica es limitada para el desarrollo de inventarios de emisiones. Sin embargo, el enfoque puede usarse para desarrollar información que describiría las características espaciales de las emisiones en relación con un parámetro específico (por ejemplo, el uso de

Método	Descripción	Condiciones en las que el Diseño del Muestreo es Util[a]
		equipo para podar y de jardinería contra el ingreso doméstico).

[a] Gilbert, 1987.

5.4 Determinación del Tamaño de Muestra

El número de encuestas que se envían depende de los recursos disponibles y de las metas iniciales establecidas para la exactitud de los resultados. Esta subsección proporciona una breve vista general de los procedimientos estadísticos para seleccionar un tamaño de muestra adecuado dada una meta de exactitud especificada. Para una explicación más profunda del material que se presenta a continuación, por favor consulte un libro estándar de texto sobre estadística.

Para muchas encuestas de fuentes de área la meta es establecer un valor promedio para un conjunto particular de parámetros que pueda usarse para estimar las emisiones de toda la población de fuentes. Por ejemplo, puede determinarse la cantidad promedio de pintura, o la cantidad promedio de gas LP que se utiliza por casa. En general, el "error" o incertidumbre en el valor promedio calculado a partir de los resultados de la encuesta puede hacerse mínimo si se muestrean muchas más fuentes. La incertidumbre en el valor promedio (x) puede expresarse como sigue:

$$\bar{x} = \pm \sigma A \qquad (5\text{-}1)$$

donde:
σ = Desviación estándar de la muestra
A = t estadístico dividido entre el número de muestras ($t/\sqrt{n}$).

El valor estadístico t varía con el tamaño de muestra y con el nivel de confianza deseado. Mientras más muestras se tomen el nivel de incertidumbre en el valor promedio disminuye. Sin embargo, se alcanza un punto de vueltas decrecientes cuando el número de muestras se acerca a 20. La Figura 5-3 ilustra este concepto graficando A (i.e., $t/\sqrt{n}$) contra el número de muestras tomadas. Esta gráfica particular es para un nivel de confianza del 90%.

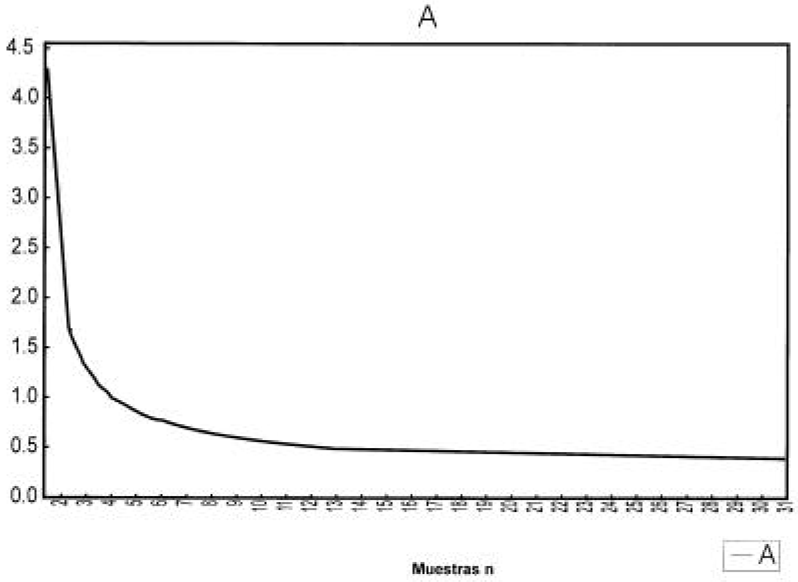


Figura 5-3. Influencia del Tamaño de la Muestra sobre la Incertidumbre

Si se desea, se puede determinar un enfoque más riguroso para calcular el tamaño adecuado de la muestra especificando la cantidad de error aceptable. Para establecer el tamaño de muestra en base al error aceptable se requiere un enfoque interativo que comienza con una encuesta inicial. Suponiendo una tasa de respuesta del 50 por ciento, se limita la encuesta inicial a aproximadamente 40 cuestionarios de modo que se reciban alrededor de 20 respuestas. A partir de los resultados de la encuesta inicial se puede estimar un tamaño específico de muestra en base a las metas de error de la encuesta:

$$\mathbf{n = \frac{(Z_{\alpha/2}\sigma)^2}{e}} \qquad (5\text{-}2)$$

Donde: n = tamaño de la muestra

σ = desviación estándar de la población

e = límite del error (generalmente dentro del intervalo del 5 al 10 por ciento del valor de la media)

∝ = nivel de confianza

$Z_{\propto/2}$ = índice derivado de la curva normal que corresponde al nivel de confianza deseado

∝ por ciento	$Z_{\propto/2}$
90.0	1.65
95.0	1.96
99.0	2.58
99.7	3.00

A continuación se presenta un ejemplo sencillo para ilustrar este concepto, para una encuesta hipotética aplicada al uso residencial de gas LP.

Ejemplo 5-2

Suponer que se desea un error no mayor del 10% en el nivel de confianza del 90% para una encuesta del uso residencial de gas LP. A partir de la encuesta hipotética, el uso promedio de gas LP determinado a partir de los cuestionarios iniciales es de 1,000 litros con una desviación estándar de 400 litros. Utilizando estos datos en la ecuación 5-2 el número de muestras necesarias es de:

$$n = \left[\frac{1.65 \text{ x } 400}{0.10 \text{ x } 1000}\right]^2$$

$$= 44 \text{ muestras}$$

5.5 Limitación del Tamaño de la Encuesta por Correo

Si en la lista de distribución por correo se identifican más fuentes de las que en realidad pueden manejarse con los recursos disponibles la agencia debe tamizarla de alguna manera para reducir el número de plantas a las que se enviarán cuestionarios. Esto puede hacerse de varias maneras.

En muchos casos se conoce el número de empleados en una empresa y puede hacerse una estimación del potencial de emisiones aplicando factores de emisión por empleado cuando estén disponibles. Esto dará una estimación gruesa del potencial de emisiones de esas plantas, que luego se puede usar para seleccionar una muestra de plantas que represente un intervalo de emisiones para recibir el cuestionario. Otra manera de reducir la lista de distribución es comunicarse por teléfono con los receptores potenciales de la encuesta antes de enviarla por correo. Estos breves contactos con los gerentes de planta o con otros empleados apropiados indicarán si el proceso emisor de contaminantes efectivamente se lleva a cabo en la planta. Si el proceso no se usa en la planta, la respuesta se puede registrar y no es necesario hacer ningún contacto posterior lo que reducirá el número de encuestas que se manden.

5.6 Diseño de los Cuestionarios

Se debe elaborar un cuestionario para cada categoría de fuente encuestada. En estos cuestionarios se puede usar terminología específica de una industria en particular que resulte familiar para aquellos que ahí trabajan. Esto fortalece la comunicación, reduce la confusión y aumenta la exactitud del inventario. También puede ser productivo trabajar primero con un pequeño grupo focal de fuentes en la industria para refinar y hacer una “prueba de mercado” al cuestionario. Las aportaciones de personal capaz de en la industria ayudarán a eliminar ambigüedad en las respuestas y malentendidos respecto a las metas de la encuesta.

Aunque un cuestionario hecho a la medida para una industria o proceso en particular tiene muchas ventajas también presenta varios inconvenientes. El primero es que el diseño de muchos cuestionarios específicos por industria puede requerir recursos significativos. En segundo lugar, los cuestionarios que sean devueltos tendrán diferentes requerimientos para el almacenamiento de datos debido a las variaciones de formato para las diferentes industrias.

El desarrollo de un cuestionario implica identificar y redactar las preguntas correctas, establecer un formato adecuado y hacer la portada y las instrucciones para el llenado. La regla básica es diseñar el cuestionario para la persona a quien se le solicitará que lo responda. Una agencia debe considerar que la persona que llenará el cuestionario puede no contar con los conocimientos técnicos en contaminación del aire, ingeniería o ciencias físicas. Por lo tanto, ni los cuestionarios ni las instrucciones deben diseñarse de manera tal que su comprensión requiera una capacitación técnica especializada. Cada pregunta debe explicarse por sí misma acompañarse con instrucciones precisas. Toda la información necesaria debe solicitarse en el cuestionario, evitando así solicitudes posteriores de datos adicionales. Cualesquier datos necesarios para la posterior aplicación de un modelo fotoquímico o de dispersión también deben recopilarse en este momento.

El formato del cuestionario debe ser lo más sencillo y funcional posible. Cuando el manejo de los datos se haga por computadora se ahorrará tiempo si el formato está diseñado de tal manera que el personal responsable de la administración de datos pueda introducir la información directamente de cada cuestionario. Si se está promoviendo un reporte computarizado de datos la agencia puede ahorrar tiempo en la captura. El cuestionario debe estar bien espaciado para facilitar su lectura y debe dejar espacio suficiente para las respuestas escritas. El cuestionario debe ser lo más corto posible dado que los cuestionarios largos intimidan. Además, los cuestionarios cortos reducen los costos de envío.

Siempre debe tomarse en cuenta cual será el uso final de los datos cuando se determine la información que se va a pedir en el cuestionario. Para las fuentes puntuales, también debe pedirse información del proceso además de las tasas de emisión y otra información general de la fuente como ubicación, propiedad y naturaleza del negocio. Debe hacerse un esfuerzo para solicitar los datos del nivel de actividad para el año y la estación del inventario. Si no es posible obtener los datos para el periodo adecuado se deben incluir preguntas para recopilar la información necesaria para calcular factores de ajuste temporal de la manera más exacta posible. La información sobre los dispositivos de control también es útil para determinar las reducciones potenciales en las emisiones al aplicar diversas estrategias de control.

Finalmente, se debe solicitar cualquier información que se necesite para hacer estimaciones de emisión corregidas o ajustadas. Por ejemplo, debido a que las emisiones de las operaciones de almacenamiento y manejo de productos derivados del petróleo dependen de numerosos variables que incluyen la temperatura, las condiciones del tanque y la presión de vapor del producto, el cuestionario debe incluir la solicitud para poner los valores apropiados de estas variables. Si se considera hacer ajustes estacionales, debe darse un énfasis especial a variables como niveles de actividad, temperatura y velocidad del viento las que pudieran ocasionar variaciones estacionales en las emisiones.

Cada cuestionario debe ser acompañado por una carta en la que se establezca el propósito del inventario y en la que cite cualesquier estatutos que requieran respuesta por parte del receptor. Se debe solicitar de manera respetuosa, la cooperación del receptor del cuestionario para su llenado y devolución. Además, cada cuestionario debe acompañarse de un conjunto de procedimientos e instrucciones generales que indiquen al receptor la forma en que debe ser llenado, así como la fecha en que debe ser devuelto a la agencia. En lugar de establecer una fecha específica se puede indicar un número específico de días naturales o hábiles para responder. De esta manera, los retrasos en el correo no implicarán cambios en la fecha de respuesta.

Si se envía un cuestionario más general, las instrucciones deben explicar claramente que éste ha sido diseñado para una gran variedad de operaciones y que algunas preguntas o secciones pueden no ser aplicables a una planta particular. En todos los casos, se debe dar el nombre de un contacto, su número telefónico y dirección en caso de que algún receptor tenga preguntas. Algunas veces es posible combinar la carta-portada y las instrucciones, pero esto sólo debe hacerse cuando las instrucciones sean breves.

5.7 Envío y Rastreo de los Cuestionarios

Después de que la lista final de distribución ha sido recopilada y que se han armado los paquetes apropiados de cuestionarios (incluyendo etiqueta, carta-portada, instrucciones, cuestionarios y sobre con porte pagado) la agencia podría iniciar los envíos. El envío de los cuestionarios puede hacerse de dos maneras: la primera es a través de correo certificado, lo que sirve para que la agencia sepa cuando se recibió el cuestionario. Esto no garantiza que la empresa devolverá la forma, pero es probable que la tasa de respuesta sea algo más alta que si los cuestionarios fueran enviados por correo de primera clase. Sin embargo, es posible que el pequeño incremento en la respuesta no justifique el gasto extra de enviar una carta certificada a cada empresa. Como término medio se puede usar correo certificado solamente para contactar las grandes fuentes.

El segundo método consiste en enviar los cuestionarios por correo de primera clase convencional. Se ha comprobado que este método es efectivo si la dirección incluye el nombre del gerente de planta, o si escribe “ATENCION GERENTE DE PLANTA” en el sobre. Esto dirige el paquete al personal de supervisión adecuado y reduce las posibilidades de que sea desechado. Es muy recomendable incluir un sobre con porte pagado con cada cuestionario porque así es más probable que sea devuelto.

Los errores en las direcciones constituyen una gran proporción de los cuestionarios que no son regresados. Por lo tanto, el esfuerzo extra aplicado para obtener las direcciones correctas será recompensado. Asimismo, es importante distinguir entre la ubicación física de una planta y su dirección postal. La identificación de la dirección postal puede tener un efecto crítico en la tasa de respuesta del cuestionario.

Las respuestas pueden comenzar a llegar pocos días después del envío. Muchos de los retornos tempranos pueden venir de empresas que no son fuentes de emisiones. También, algunos otros cuestionarios serán devueltos a la entidad por el correo debido a que las fábricas ya no están en funcionamiento, o la empresa ya no está en la dirección indicada. Las nuevas direcciones de las empresas que se han mudado pueden obtenerse llamando a los establecimientos, buscándolas en los directorios telefónicos, o a través de las agencias estatales o locales pertinentes, tales como las oficinas fiscales o las laborales.

Un programa de computadora sencillo puede ser útil para enviar y registrar los cuestionarios. Este programa podría ser diseñado para producir etiquetas de correo por duplicado para cada fuente a la que se envía un cuestionario. Una etiqueta es adherida al sobre que contiene los materiales del cuestionario y la segunda se anexa a la carta-portada o a la hoja de instrucciones del cuestionario. Esto facilita la identificación de los cuestionarios a medida que son devueltos, así como las correcciones en el nombre y dirección. Las etiquetas postales adicionales se pueden utilizar para otros propósitos administrativos o para volver a hacer contacto con las fuentes cuyas respuestas sean inadecuadas. A continuación se muestra un ejemplo de la información de una etiqueta.

Ejemplo 5-3

0000 (Código CMAP)
0000 (Planta Número)

NOMBRE DEL INDIVIDUO Y TITULO (GERENTE DE PLANTA)
NOMBRE DE LA EMPRESA
CALLE
MUNICIPIO, ESTADO, CP

Como se muestra en el ejemplo de etiqueta, puede ser útil imprimir el código CMAP y el número de identificación asignado a la planta en la esquina superior derecha. El número de identificación (ID) puede utilizarse para agrupar los registros de toda la correspondencia con una empresa. Si el área de estudio es grande, el número de identificación del municipio también puede incluirse en la etiqueta. Debe tenerse cuidado de separar la información de codificación interna de la dirección, de manera que la oficina postal no la confunda con la dirección.

Es importante desarrollar un sistema de rastreo para determinar el estado de cada etapa de la encuesta por correo. Dicho sistema le dirá a la agencia: (1) a qué empresas enviaron cuestionarios; (2) las fechas en que los cuestionarios fueron enviados y devueltos; (3) nombre, dirección e información CMAP corregidos; (4) información sobre el tipo de fuente; (5) si un segundo contacto es necesario y (6) el estado del contacto de seguimiento. El rastreo puede hacerse manualmente con hojas de cálculo o usando un programa sencillo de computadora. Una impresión de computadora de la lista de distribución puede formatearse para usarla como hoja de rastreo.

Tan pronto como los cuestionarios son devueltos se pueden hacer algunos análisis útiles. Una actividad que puede ayudar a terminar la encuesta a tiempo, así como ayudar a estimar los recursos que serán necesarios después para hacer el inventario es la clasificación de cada respuesta en una de las cinco categorías enlistadas a continuación:

P = Fuentes puntuales
A = Fuentes de área
N = No hay emisiones (no hay fuente)
C = Cerrado/clausurado
R = Volverá hacer el contacto para reclasificación.

Además, la agencia puede comenzar a hacer los cálculos de emisiones para las fuentes que han respondido y la información resultante de fuentes y emisiones puede empezar a ser cargada en los archivos del inventario. Entonces, todas las respuestas deben ser archivadas por código CMAP, categoría de fuente, ubicación geográfica, orden alfabético o por cualquier otro criterio que dé un acceso ordenado para cualquier análisis adicional.

5.8 Renovación de Contactos

La agencia puede requerir hacer contacto nuevamente con la empresa si ésta no devuelve el cuestionario o si la respuesta proporcionada no es la adecuada. En el primer caso, debe enviarse una carta más formal, por correo certificado, donde se citen los requerimientos estatutarios de reporte para el llenado del cuestionario. Cuando el número de empresas que se deben volver a contactar es pequeño la información puede obtenerse por teléfono o haciendo visitas a las plantas.

La renovación de contactos debe comenzar dos o cuatro semanas después de que los cuestionarios han sido enviados. Las llamadas telefónicas son ventajosas porque se trata de comunicación verbal se pueden evitar costos postales adicionales. Sería necesario enviar una segunda carta de seguimiento. Si el número de empresas que deben volverse a contactar es grande. En cualquier caso, el segundo contacto debe hacerse entre 8 y 12 semanas después del primer envío.

5.9 Acceso a los Archivos de Contaminación del Aire de la Agencia

En la agencia puede haber archivos especiales o bases de datos que se pueden usar para hacer el inventario de emisiones. Entre estos archivos puede licencias, datos sobre cumplimiento o informes de emisiones. En general, se requieren licencias para la construcción, arranque, modificaciones y operación continua de una fuente emisora. Las solicitudes de licencia normalmente incluyen información suficiente acerca de una fuente potencial para describir su naturaleza y estimar la magnitud de las emisiones que resultarán de sus operaciones. Algunas licencias también incluyen datos de muestreos en la fuente.

Algunas agencias pueden también guardar un archivo de cumplimiento en el que se registra la interacción de la agencia con cada fuente en lo relativo la aplicación de regulaciones. Por ejemplo, un archivo de cumplimiento podría contener una lista de las regulaciones de contaminación del aire aplicables a una fuente dada, el historial de los contactos hechos con dicha fuente sobre aplicación de la legislación y un calendario acordado con la fuente para efectuar algún tipo de medidas de control.

5.10 Escalamiento de los Resultados de la Encuesta

Una encuesta de fuentes de área diseñado de manera adecuada también deberá incluir un mecanismo para "escalar" los resultados. Por la naturaleza del tipo de fuente puede no ser posible encuestar el universo de fuentes cubiertas por la categoría. El método para escalar los resultados dependerá del tipo de fuente que se incluya en la encuesta. A continuación se presentan dos ejemplos:

De una manera sencilla, los resultados de la encuesta pueden ser escalados aplicando el uso promedio de material (o de emisiones) determinado a partir de la encuesta a toda la población de fuentes. Desde una perspectiva de emisiones, este enfoque asume que la población de fuentes es independiente del tamaño. Por ejemplo se podría hacer una encuesta de uso residencial de gas LP para estimar de manera más precisa la cantidad de este combustible que se consuma a nivel residencial. No es práctico hacer una encuesta casa por casa por lo que podría encuestarse un subconjunto de la población y escalar los resultados a la población completa. Para este ejemplo hipotético, la cantidad promedio de gas LP utilizado por casa determinaría a través de la encuesta aplicando el valor promedio al número total de casas en la región. A continuación se presenta un ejemplo simple:

Ejemplo 5-4:

Con base en una encuesta de un subconjunto de casas que utilizan gas LP el uso anual promedio de gas LP es de 1,000 litros/año. Datos disponibles de censos indican que hay 500,000 casas en la región y que el 90% de ellas usan gas LP como combustible doméstico. Estimar las emisiones totales de NO_x provenientes del uso doméstico de gas LP en la región.

Q_{LPG} = 1,000 litros/casa/año x 500,000 casas x 90%
= 450 millones de litros/año

(AP-42, Sección 1.5)

FE_{NOx} = 1.7 kg/1,000 litros
E_{NOx} = Q_{LPG} x FE_{NOx}
= (450 x 10^6 litro/año) x (1.7 kg/1,000 litros)
= 765,000 kg NO_x/año.

Si se espera que el uso del material varíe dependiendo del tamaño de la fuente se requiere un enfoque más complejo. Por ejemplo, la cantidad de material utilizado en las operaciones de pintura de madera variará en base al nivel de producción del establecimiento. El diseño de la encuesta debe incluir preguntas que recopilen información suficiente para que se pueda usar para escalar los resultados a otras plantas que no se hayan incluido en la encuesta. Estos datos pueden ser, por ejemplo, el número de empleados, o parámetros económicos tales como el valor de los bienes o servicios producidos. La clave es pensar por adelantado e identificar los parámetros adecuados que se pueden usar para escalar los resultados del inventario a otras fuentes. A continuación se presenta un ejemplo sencillo:

Ejemplo 5-5:

Con base en la encuesta de un subconjunto de plantas en que se fabrican productos de madera, el uso promedio de pintura por empleado es de 30 litros/año. Él número total de empleados relacionados con la manufactura de productos de madera en la región es de 1,050, con base en datos de CANACINTRA. Adicionalmente, los resultados de la encuesta indican que la pintura promedio tiene una densidad de 1.4 kg/litro y un contenido de COVs del 45%, por peso. Estimar las emisiones de COVs totales de la manufactura de productos de madera en la región

Q = 30 litros/empleado/año x 1,050 empleados
= 31,500 litro/año

FE_{cov} = 1.4 kg/litro x 45%
= 0.63 kg/litro

E_{cov} = Q x EF_{cov}
= 31,500 litro/año x 0.63 kg/litro
= 19,845 kg COV/año

6.0 FACTORES DE EMISION

Los factores de emisión se usan a menudo para calcular las emisiones

cuando los datos de monitoreo de chimeneas específicos del sitio no están disponibles. Un factor de emisión es una relación entre la cantidad de contaminante emitido a la atmósfera con una unidad de actividad. Los factores de emisión, en general, se pueden clasificar en dos tipos: los basados en procesos y los basados en censos. Por lo general, los primeros se usan para desarrollar estimaciones de emisiones de fuentes puntuales y a menudo se combinan con los datos de actividad recopilados de una encuesta o de un balance de materiales. Los factores de emisión basados en censos, por otro lado, se usan mucho para hacer estimaciones de emisiones de fuentes de área (ver Figura 6-1).

5.1 Factores de Emisión Basados en Procesos

Se han realizado varios programas de muestreo de fuentes para medir las tasas de emisión de ciertos dispositivos o procesos que se sabe que son fuentes de emisiones al aire. Puesto que con frecuencia no se requiere ni es económicamente factible hacer un muestreo en cada fuente emisora, los resultados de muestreos de “fuentes representativas” se usan para desarrollar factores de emisión basados en procesos, para dispositivos o procesos similares. Estos factores se expresan en la forma general de masa de contaminante emitido por unidad de proceso. Entre las unidades de proceso más comunes se encuentran el consumo de energía, el rendimiento de materiales, las unidades de producción, el calendario de operación, o el número de dispositivos ó las características de éstos. (e. g., lb/MMBtu, lb/gal, lb/lote, lb/hr ó lb/pie^2 [área superficial]).

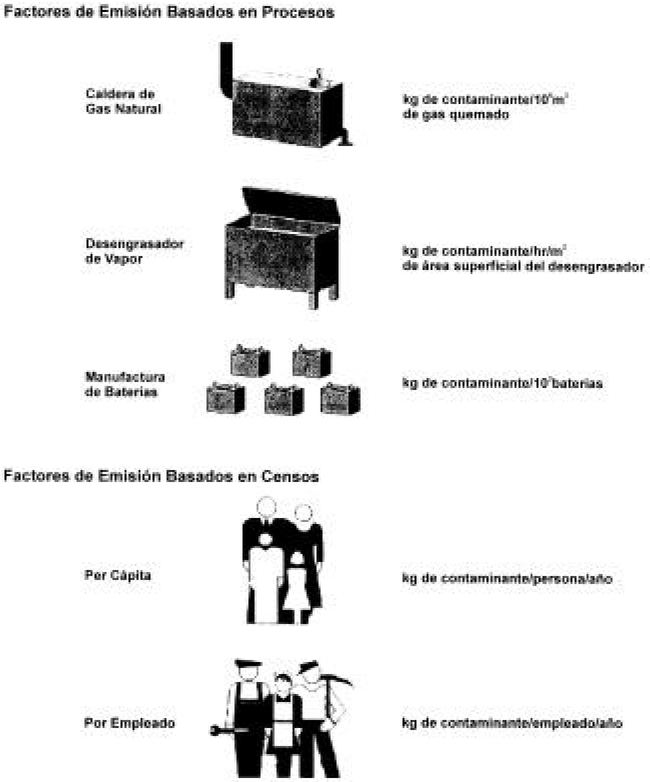


Figura 6-1. Ejemplos de Factores de Emisión

La fuente de consulta más extensa para factores de emisión basados en procesos, específicos para los Estados Unidos, es el documento *AP-42 Compilation of Air Pollutant Emission Factors* (U.S. EPA, January 1995a). La referencia principal para factores de emisión de contaminantes tóxicos del aire es el sistema de datos FIRE (U.S. EPA, 1995b).

En el documento de guía Rapid Source Inventory Technique preparado para la OMS (WHO) (Economopoulos, 1993) se encuentran factores de emisión no específicos para los Estados Unidos para diversos conjuntos de fuentes. Este tipo de factores también se hallan en documentos de guía para inventarios de gases de invernadero (Intergovernmental Panel on Climate Change [IPCC], 1993a y b).

A continuación se presentan algunos ejemplos de cálculos para estimaciones de emisiones utilizando factores de emisión basados en procesos. El Volumen IV - Fuentes Puntuales proporciona una guía más detallada sobre el desarrollo de estimaciones de emisiones para estas fuentes.

Ejemplo 6-1:

Calcular las emisiones anuales de NO_x de una caldera sin control en una planta termoeléctrica de (consumo de calor>100 millones de Btu/hr) que quema gas natural. El consumo anual de gas natural es de 50 millones de metros cúbicos.

FE_{NOX} = 8800 kg/10^6 m^3 (Del/ AP-42, Tabla 1.4-2)

$Q_{comb.}$ = 50 $10^6 m^3$/año

E_{NOX} = FE_{NOX} x $Q_{comb.}$

= 8800 x 50

= 440,000 kg/año

Ejemplo 6-2:

Calcular las emisiones anuales de COVs de un desengrasador de vapor sin tapa y sin control. El solvente usado es 100% COV. El desengrasador tiene un área superficial de 5 metros cuadrados y opera 8 horas/día, 5 días/semana, 52 semanas/año.

FE_{COV} = 0.7 kg/hr/m^2 (Del AP-42, Tabla 4.6-2)

A = 5 m^2

T_{horas} = 8 hrs/día x 5 días/sem x 52 sem/año

= 2080 hrs/año

E_{COV} = FE_{cov} x A x T_{horas}

= 0.7 x 5 x 2080

= 7,280 kg/año

Ejemplo 6-3

Calcular las emisiones de partículas del proceso de fundición de rejillas en la producción de baterías de plomo ácidas. Cada mes se producen veinte mil baterías.

$FE_{part.}$ = 1.42 kg/10^3 baterías (Del AP-42, Tabla 7.15-1)

$Q_{product}$ = 20,000 baterías/mes x 12 meses/año
= 240,000 baterías/ año
$E_{part.}$ = $FE_{part.}$ x $Q_{producto}$
= 1.42 x 240
= 341 kg/año

5.2 Factores de Emisión Basados en Censos

Las fuentes de área en ciertas categorías son difíciles de inventariar usando cualquiera de las metodologías antes presentadas. El uso de factores de emisión basados en censos es un método eficiente para tipos de fuentes emisoras dispersas y numerosas que no se pueden caracterizar rápidamente conociendo las tasas de proceso, de consumo de combustible y/o de alimentación de materiales. Comparadas con otras técnicas de estimación de emisiones el uso de factores de emisión basados en censos es la opción más “amigable” y más costo-efectiva dado que los datos de censos ya están disponibles en la mayor parte de las regiones donde se hacen inventarios de emisiones. En México, los datos de población y vivienda y los datos de empleo por sector económico y municipio están disponibles, en formato impreso y electrónico, a través del INEGI.

La desventaja de usar factores de emisión existentes basados en censos es que la mayor parte de ellos fueron desarrollados en EU o en Europa y es posible que no representen las condiciones socioeconómicas y las prácticas de control en México. El Departamento del Distrito Federal (DDF) ha comenzado a desarrollar factores de emisión basados en el censo que son específicos para México. Por ejemplo, en EU el factor de emisión per cápita para solventes comerciales es de 6.3 libras/persona/año (i. e., 2.86 kilogramos/persona/año). Para el inventario de fuentes de área de la Ciudad de México, el DDF ha reducido recientemente la contribución de los aerosoles de 0.36 kg/persona/año a 0.05 kg/persona/año, ajustando así el factor global de emisión general de solventes comerciales per cápita a 2.55 kg/persona/año.

Asimismo, es importante recordar que los factores de emisión basados en censos son más exactos cuando se aplican a toda la región para la que el factor de emisión fue desarrollado que cuando se aplica a regiones más pequeñas. Por ejemplo, el factor específico de emisión de aerosoles per cápita desarrollado para México por el DDF es un factor de emisión "promedio" para todo el país (i. e., se basó en los datos nacionales de población y uso de aerosoles). La exactitud de este factor de emisión disminuye en la medida en que se aplica a regiones más pequeñas. Por ejemplo, si el consumo de aerosoles per cápita en Xochimilco es más alto que el promedio nacional, el uso del factor de emisión "promedio" dará como resultado una subestimación de las emisiones para Xochimilco).

En general, los factores de emisión por empleado son más exactos que los factores de emisión per cápita dado que los niveles de empleo más altos reflejan un crecimiento económico y más específicamente, tienden a reflejar aumentos en los niveles de la actividad generadora de contaminación. Sin embargo, se debe tener cuidado de eliminar los datos de empleo asociados con trabajos que no son de manufactura (e. g., administrativos y clericales), dado que no es probable que contribuyan de manera significativa a los niveles de actividades generadoras de contaminación. Como mínimo, se debe hacer un esfuerzo para eliminar los datos de empleo asociados con los locales de la empresa que sean oficinas administrativas más que plantas de producción.

5.2.1 Factores de Emisión Per Cápita

La evaporación de solventes de los productos comerciales y de consumo tales como ceras, productos en aerosol y limpiadores de ventanas no puede ser determinada de manera rutinaria para muchas fuentes locales por la agencia del lugar. Además, probablemente sería imposible hacer una encuesta que arrojara este tipo de información. A utilizar factores per cápita se supone que las emisiones en un área dada pueden asociarse con la población de manera razonable. Esta suposición es válida en áreas extensas para ciertas actividades como tintorerías, pintura de superficies arquitectónicas, pequeñas operaciones de desengrasado y evaporación de solventes de productos domésticos y comerciales.

Los factores de emisión per cápita no se deben desarrollar ni utilizar de manera indiscriminada para aquellas fuentes cuyas emisiones no se correlacionan bien con la población. Por ejemplo, las industrias grandes y concentradas como son las plantas petroquímicas, no deben inventariarse usando factores de emisión per cápita.

Se pueden hallar factores de emisión per cápita específicos para los EU para diversas actividades en numerosas fuentes, incluyendo la base de datos de factores de emisión FIRE de la EPA, en el *AP-42 Compilation of Air Pollutant Emission Factors* y en *Procedures for the Preparation of Emission Inventories for Carbon Monoxide and Precursors of Ozone,* (U.S. EPA, 1991b).

A continuación se presenta un ejemplo del cálculo de una estimación de emisiones desarrollado utilizando factores de emisión per cápita. El Volumen V - Fuentes de Area proporciona una guía más detallada para el desarrollo de estimaciones de emisión de fuentes de área.

Ejemplo 6-4:

Calcular las emisiones de COVs en 1990 del uso doméstico de aerosoles en Xochimilco (DF). Suponer que el contenido de COVs en los aerosoles es del 69%. En 1990 la población se estimó en 642,753 habitantes.

$$FE_{COV} = 0.046 \text{ kg/persona/año} \times 69\% \text{ VOC} \quad \text{(Del DDF, 1995)}$$
$$= 0.032 \text{ kg/persona/año}$$
$$P_{Xochimilco} = 642{,}753 \text{ habitantes}$$

$$E_{COV} = EF_{VOC} \times P_{Xochimilco}$$
$$= 0.032 \times 642{,}753$$
$$= 20{,}568 \text{ kg/año}$$

5.2.2 Factores de Emisión por Empleado

Este enfoque utiliza los datos de empleo más que los de población como indicador del nivel de la actividad sustituta. En general, los factores de emisión por empleado se usan para estimar las emisiones de aquellas categorías de fuente a las que se ha asignado una clave CMAP y para las que existen datos de empleo disponibles a nivel local (en general, por CMAP). Con frecuencia, esto representa el desarrollo de las categorías CMAP apropiadas. En la mayor parte de los casos, una gran fracción de las emisiones de COVs dentro de un CMAP se calculan usando los procedimientos de fuentes puntuales, por lo que, el enfoque de factores de emisión por empleado puede ser considerado como un procedimiento secundario para cubrir las emisiones de fuentes que están por debajo del límite inferior de corte para fuentes puntuales. La reconciliación con las fuentes puntuales se presenta con más detalle en el Manual de Fuentes de Area (Volumen V).

El siguiente ejemplo de cálculo presenta una estimación de emisiones desarrollada usando factores de emisión per cápita. El Manual de Fuentes de Area (Volumen V) proporciona una guía más detallada para hacer estimaciones de emisiones de fuentes de área.

Ejemplo 6-5:
Calcular las emisiones anuales de COVs de tintorerías comerciales en la Ciudad de México (DF) para el inventario de fuentes de área. Suponer que los solventes para el lavado en seco son 100% COVs. Suponer que los registros de empleo para la Ciudad de México muestran que existen 3,000 empleados en el código CMAP apropiado. Suponer que 1,000 de estos empleados trabajan en establecimientos que están incluidos en el inventario de emisiones de fuentes puntuales

FE_{COVs} = 2,937 kg/empleado/año (EPA-450/4-91-016)
Etintorerías = 3,000 empleados totales - 1,000 empleados de fuentes puntuales
= 2,000 empleados de fuente de área
E_{COV} = $FE_{COV} \times E_{tintorerías}$
= 2,937 x 2,000
= 5,874,000 kg/año

7.0 BALANCE DE MATERIALES

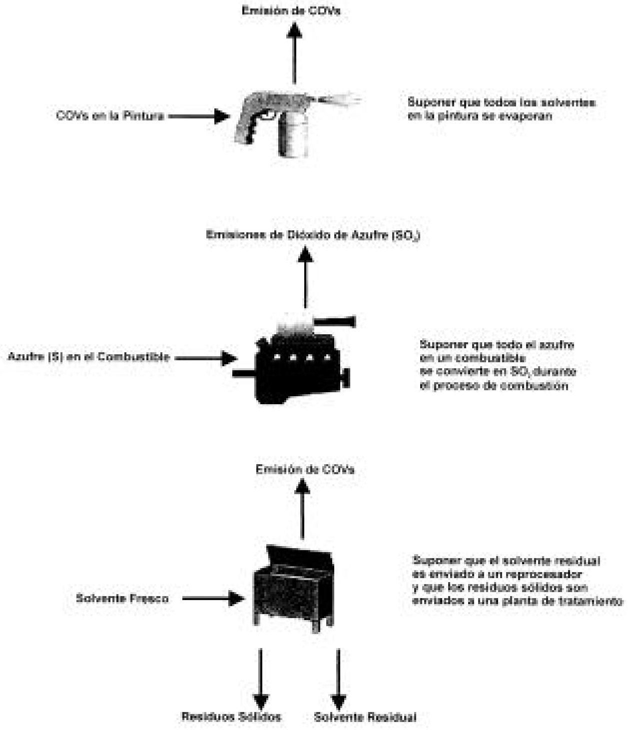
El balance de materiales (también conocido como balance de masa), es un método utilizado comúnmente para estimar las emisiones de muchas categorías de fuentes. El método de balance de materiales puede usarse en los casos en que no hay datos disponibles de muestreos en la fuente, factores de emisión u otros métodos desarrollados. De hecho, para algunas fuentes, un balance de materiales es el único método práctico para estimar las emisiones con exactitud. Por ejemplo, en muchos casos el muestreo en la fuente de emisiones de COVs de bajo nivel, intermitentes o fugitivas puede ser muy difícil y costoso.

El uso de un balance de materiales implica el análisis de un proceso para determinar si las emisiones pueden ser estimadas solamente con el conocimiento de los parámetros específicos de operación y de las composiciones de los materiales. Si bien el balance de materiales es una herramienta valiosa para estimar las emisiones de muchas fuentes su aplicación requiere que se conozca alguna medida del material que está siendo “balanceado” en cada punto a lo largo del proceso. El uso del balance de materiales es muy adecuado en los casos en que pueden hacerse mediciones exactas de todos los componentes, excepto las emisiones al aire. Si no se cuenta con esta información y, por lo tanto debe suponerse, se podrían generar serios errores.

En el inventario de emisiones de COVs, se usa por lo general un balance de materiales generalmente para estimar las emisiones de las fuentes de emisión de evaporación de solventes. Esta técnica es aplicable de igual manera tanto para las fuentes puntuales como para las de área. En las fuentes puntuales se puede usar a nivel de dispositivo o de planta, mientras que en el caso de las fuentes de área el balance de materiales podría aplicarse a nivel regional o nacional.

La Figura 7-1 ilustra algunos ejemplos del uso de balance de materiales para fuentes puntuales. El método más simple de balance de materiales es suponer que todo el solvente consumido por un proceso se evapora durante éste. Por ejemplo, es razonable suponer que durante muchas operaciones de pintura de superficies todo el solvente en la pintura se evapora a la atmósfera durante el proceso de secado. En tales casos, las emisiones simplemente son iguales a la cantidad de solvente aplicado en la pintura (y en los adelgazadores añadidos) como una función del tiempo. Como otro ejemplo, considerar una tintorería que usa solvente Stoddard como agente para lavar. Para estimar las emisiones, la agencia sólo necesita deducir la cantidad de solvente adquirido en cada planta durante el intervalo de tiempo de interés, porque se supone que las emisiones son iguales a la cantidad de solvente comprado.

La suposición de que el solvente de reemplazo es igual a las emisiones también se mantiene en algunas situaciones más complicadas. Si se emplea un dispositivo de control no destructivo como un condensador o un adsorbedor, esta suposición es válida en la medida que el solvente capturado sea regresado al proceso. De manera similar, esta suposición será aplicable si en la planta se practica la recuperación de solvente residual ya sea por destilación o por reducción o sequedad. Ambas prácticas reducen los requerimientos de solvente de reemplazo en una operación y, por lo tanto, la cantidad de solvente que se pierde hacia la atmósfera.



Suponer que todos los solventes
en la pintura se evaporan

Suponer que todo el azufre
en un combustible
se convierte en SO_2 durante
el proceso de combustión

Suponer que el solvente residual
es enviado a un reprocesador
y que los residuos sólidos son
enviados a una planta de tratamiento

Figura 7-1. Ejemplos de Balance de Materiales

Los métodos de prueba que están disponibles son publicados a través de la *American Society for Testing and Materials* (ASTM) (Sociedad Americana para Pruebas y Materiales) y se han enfocado en proporcionar información sobre balance de materiales y determinaciones gravimétricas para varios procesos industriales (ASTM, Volúmenes 06.01 y 15.05). En general, el uso de un balance de masa o de materiales para determinar las emisiones totales de un proceso es sencillo y costeable. Los COVs totales emitidos de un proceso de mezclado de pintura por lotes por ejemplo, se calcularía como se muestra a continuación (de acuerdo con el Método D 2369, de la ASTM):

$$\mathbf{COV_{que\ entra}\ (lb/gal) - COV_{pintura\ mezclada}\ (lb/gal) = COV_{emitidos}\ (lb/gal)} \qquad (7\text{-}1)$$

Como otro ejemplo, el análisis del combustible puede usarse para predecir las emisiones con base en la aplicación de las leyes de conservación. La presencia de ciertos elementos en los combustibles puede usarse para predecir su presencia en las corrientes de emisión. Esto incluye elementos tóxicos tales como los metales que se encuentran en el carbón así como otros elementos como el azufre que puede ser convertido en otros compuestos durante el proceso de combustión.

La ecuación básica que se usa en los cálculos de emisiones a partir del análisis de combustible es:

$$\mathbf{E = Q_{comb.} \times \text{Concentración del contaminante en el combustible} \left[\times \frac{(MW_{ce})}{MW_{cc}} \right]} \qquad (7\text{-}2)$$

Donde:

$Q_{comb.}$ = Consumo de combustible, tasa de masa (e.g., kg/hr)

MW_{ce} = Peso molecular del contaminante emitido (lb/lb-mole)

MW_{cc} = Peso molecular del contaminante en el combustible (lb/lb-mole)

Por ejemplo, las emisiones de SO_2 de la combustión de un combustóleo pueden calcularse basándose en la concentración de azufre en el combustóleo. En este enfoque se supone una conversión completa del azufre a SO_2. Por lo tanto, por cada libra de azufre (PM = 32 g) quemado se emiten dos libras de SO_2 (PM= 64 g).

Ejemplo 7-1:

Calcular las emisiones de SO_x por hora (reportado como SO_2) de una máquina de combustión interna que quema combustible diesel, con base en los datos del análisis del combustible (i. e., el contenido de azufre). El consumo estimado de combustible es de 150 litros/hr. La densidad del diesel es de 0.85 kg/litro (7.1 lb/gal). El contenido de azufre el diesel es 0.05% en masa.

$Q_{comb.}$ = 150 litros/hr x 0.85 kg/litro
= 127.5 kg/hr
C_S = 0.05/100
= 0.0005
E_{SO2} = $Q_{comb.} \times C_S \times (MW_p / MW_f)$
= 127.5 x 0.0005 x (64/32)
= 0.13 kg/hr

En los ejemplos anteriores el balance de materiales se simplifica porque se supone que todo el material que se está balanceando es emitido a la atmósfera. Existen situaciones en las que esta suposición no siempre es razonable. Por ejemplo, si se usa un dispositivo de control destructivo, como un postquemador, un incinerador o una unidad de oxidación catalítica en el escape del proceso, cualquier emisión de COVs será destruida o alterada de modo que no sería posible suponer las características y cantidades de COVs que queden, sin analizar la corriente que sale del dispositivo. Como otro ejemplo, las emisiones del desengrasado no son iguales al consumo de solvente si el solvente residual es vendido a un reciclador comercial. En esta situación las emisiones serán la diferencia entre el solvente consumido y el solvente enviado a reprocesamiento. En un ejemplo más, se cree que alguna fracción del diluyente usado para licuar asfalto rebajado es retenida en el pavimento y no se evapora después de la aplicación.

$$\begin{aligned}
Q_{solvente} &= (100 \text{ litros/mes} + 20 \text{ litros/mes}) \times 1.5 \text{ kg/litro} \\
&= 180 \text{ kg/mes} \\
Q_{residual} &= (100 \text{ litros/mes} \times 1.5 \text{ kg/litro} \times 98\% \text{ VOC}) + \\
&\quad (0.2 \text{ kg/mes} \times 5\% \text{ VOC}) \\
&= 147 \text{ kg/mes} + 0.01 \text{ kg/mes} \\
&= 147 \text{ kg/mes} \\
\\
E_{COV} &= Q_{solvente} - Q_{residual} \\
&= 180 - 147 \\
&= 33 \text{ kg/mes}
\end{aligned}$$

El ejemplo anterior muestra que, en algunos casos el suponer la evaporación total de todo el solvente consumido resultaría en una sobrestimación de las emisiones. Por lo tanto, los balances de materiales también pueden usarse junto con factores de emisión basados en el proceso (ver Sección 6.1) para estimar las emisiones. Estos balances serían como aquellos que se basan en la diferencia entre la materia prima y el producto cuando el factor de emisión para un proceso está dado por unidad de material consumido.

Por ejemplo, se puede hacer balances de materiales para calcular las emisiones de fuentes de área que incluyan la manufactura, distribución y consumo de combustibles (ver Figura 7-2). Recientemente se aplicó en EU un balance de materiales para la distribución y consumo de combustibles (De Luchi, 1993). Un balance de materiales a nivel nacional para solventes en pinturas podría ser también el mejor método para estimar las emisiones de COVs de esta categoría de fuentes o de la aplicación de plaguicidas.

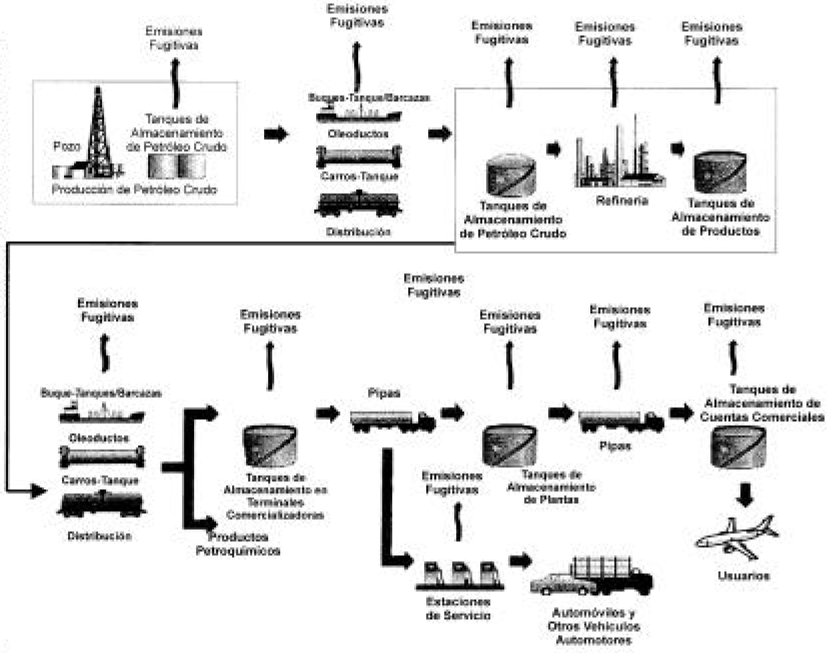


Figura 7-2. Ejemplo de Balance de Materiales Resaltando las Emisiones Fugitivas

Hay otras situaciones que pueden complicar el balance de materiales. En primer lugar, no todas las pérdidas de solventes de ciertas operaciones como el lavado en seco o el desengrasado, se dan en el sitio de la planta. En cambio se pueden evaporar, cantidades significativas de solventes en el sitio de disposición del solvente residual, a menos que sea incinerado o dispuesto en una manera que impida la subsecuente evaporación a la atmósfera. En general, se puede suponer que gran parte del solvente enviado a sitios de disposición se evaporará. La agencia debe determinar si una parte del solvente asociado con varias operaciones se evapora en el punto de disposición más que en el punto de uso, ya que estas pérdidas pueden presentarse fuera del área cubierta por el inventario.

No se pueden emplear balances de materiales en algunos procesos de evaporación debido a que la cantidad de material perdido es demasiado pequeña para ser determinada con exactitud usando los procedimientos de medición convencionales. Por ejemplo, la aplicación de balances de materiales a los tanques de almacenamiento de productos del petróleo no es factible, por lo general debido a que las pérdidas por respiración y por operación son demasiado pequeñas con respecto a la capacidad total promedio o a la producción para ser determinadas a partir de los cambios en la cantidad de material almacenado en cada tanque. En estos casos, deben aplicarse las ecuaciones de emisión del AP-42 (i. e., modelos) desarrolladas por procedimientos especiales.

En resumen, con excepción de algunos tipos de fuente tales como los ejemplos de uso de combustibles y de solventes presentados anteriormente, no se recomienda un enfoque de balance de materiales como el método principal para la estimación de emisiones. El balance de materiales debe ser utilizado más bien como un método de “arriba hacia abajo” para evaluar qué tan razonables son las estimaciones de emisión generados al usar otras técnicas.

8.0 EXTRAPOLACION

Las técnicas de extrapolación pueden usarse para calcular emisiones directamente y para verificar las estimaciones de emisiones calculadas con otros métodos. La Figura 8-1 ilustra el concepto general de la extrapolación de emisiones. En general, la extrapolación de emisiones de una región geográfica a otra se considera como el enfoque menos deseable para la estimación de emisiones. Este enfoque puede no tomar en cuenta de manera apropiada algunas diferencias importantes entre dos regiones y puede propagar los sesgos de un inventario a otro.

Sin embargo, cuando se combina con un marco de modelado, la extrapolación es un enfoque práctico y costo-efectivo para desarrollar estimaciones de emisiones para aquellas regiones en las que la información no es suficiente para soportar metodologías de estimación más rigurosas. El resto de esta sección presenta algunos ejemplos sobre la manera en que la extrapolación puede usarse para desarrollar estimaciones de emisiones.

En primer lugar, los datos de emisiones de un tipo de proceso o de planta, pueden ser extrapolados a tipos de fuente o de planta similares. Este tipo de extrapolación se usaría para hacer estimaciones de emisiones de fuentes puntuales.

En otros casos si se puede argumentar que las condiciones socioeconómicas entre dos o más regiones geográficas son comparables los datos disponibles de emisiones de fuentes de área para una región pueden ser extrapolados a las demás regiones basándose en datos de población y de empleo. Los inventarios de emisiones generados en EU y en Europa pueden usarse de esta manera. En México, los inventarios de emisiones que se han generado para la Ciudad de México y que se están desarrollando para otras zonas (e. g., el área metropolitana de Monterrey) se pueden usar como base para el aseguramiento de calidad y/o para desarrollar partes de los inventarios de emisiones de otras regiones.

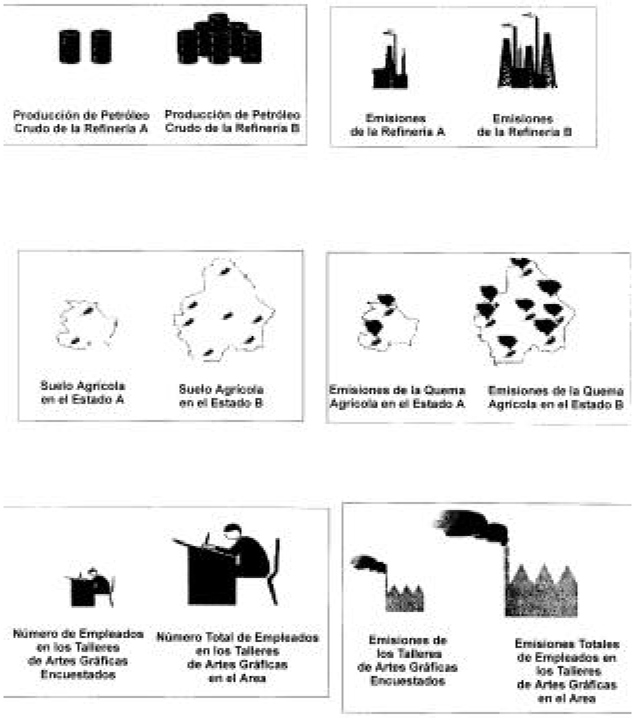


Figura 8-1. Ejemplos de Extrapolación

Ejemplo 8-1:

Con base en los cálculos detallados de emisiones para la Refinería A se estima que las emisiones anuales totales de COVs son de 100 toneladas (métricas). La compañía acaba de adquirir una planta más pequeña, la Refinería B, que procesa el equivalente a la mitad del petróleo crudo de la Refinería A. Para la reunión de mañana, el presidente de la compañía desea una estimación del costo total asociado con las emisiones permitidas de COVs. Puesto que no hay tiempo para hacer cálculos detallados de emisiones para la Refinería B, estimar las emisiones de COVs extrapolando los datos de la Refinería A con base en las capacidades de las refinerías (i. e., la cantidad de petróleo crudo procesado).

$$\begin{aligned} E_{COVb} &= E_{COVa} \text{ x } P_{CRUDOb}/P_{CRUDOa} \\ &= 100 \text{ toneladas/año x } ½ \\ &= 50 \text{ toneladas/año} \end{aligned}$$

Ejemplo 8-2

Basándose en una encuesta se estima que las emisiones totales anuales de COVs de la quema agrícola en el Estado A son de 50 toneladas (métricas). No hay recursos para financiar una encuesta similar en el Estado B. Puesto que las condiciones agrícolas son muy semejantes en el Estado B (e. g. similares cultivos, métodos agrícolas, etc.), estimar las emisiones de COVs extrapolando los datos del Estado A, con base en la superficie del suelo agrícola en cada estado. Los mapas de uso de suelo muestran 400,000 m^2 de suelos agrícolas en el Estado A, y 50,000 m^2 en el Estado B.

$$\begin{aligned} E_{COVb} &= E_{COVa} \text{ x } A_{SAb}/P_{SAa} \\ &= 50 \text{ toneladas/año x } 50{,}000/400{,}000 \\ &= 6.25 \text{ toneladas/año} \end{aligned}$$

Este enfoque también puede usarse cuando la agencia encuesta solamente una fracción de las fuentes de área dentro de una categoría dada. En este caso se usa el empleo como indicador para “escalar” el inventario para contabilizar de manera colectiva las fuentes de emisión y las emisiones en el inventario de fuentes de área. Para calcular estimaciones de emisiones se pueden usar otros parámetros distintos al empleo, tales como los datos de ventas o el número de plantas. Sin embargo, el empleo es por lo general el parámetro más fácilmente disponible. El escalamiento de las estimaciones de emisiones se presenta también en la sección 5.0 de este manual.

Ejemplo 8-3

Se está realizando una encuesta para recopilar las estimaciones de emisiones de COVs de pequeños talleres de artes gráficas en Coyoacán para usarlos en el inventario de fuentes de área de la Ciudad de México. Debido a las limitaciones en los recursos, el cuestionario fue enviado solamente a algunos de los talleres en Coyoacán y no todos los que están incluidos en la lista de distribución devolvieron el cuestionario. Las emisiones totales anuales de COVs reportadas en los cuestionarios son de 100 toneladas (métricas). Dado que no existen recursos para encuestar a cada pequeño taller de artes gráficas, estimar las emisiones de COVs en Coyoacán extrapolando (i. e., escalando) las emisiones de COVs recopiladas con base en el empleo. Los registros de empleo disponibles muestran que 500 personas en Coyoacán trabajan en la industria de las artes gráficas y los cuestionarios muestran que un total de 125 personas trabajan en los talleres que llenaron las formas de la encuesta.

$$
\begin{aligned}
E_{COVcov} &= E_{COVsur} \text{ x } P_{cov}/P_{sur} \\
&= 100 \text{ toneladas/año x } 500/125 \\
&= 400 \text{ toneladas/año}
\end{aligned}
$$

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APENDICE III - A
EJEMPLOS DE LOS CALCULOS PARA LOS MODELOS DE EMISIONES

Ejemplo de Cálculos - Polvos Fugitivos

$$M = VKT \times EF \qquad (4\text{-}12)$$

donde:
M = tasa promedio anual de emisión en masa, kg/año;
VKT = kilómetros recorridos por los vehículos VKT/año;
FE = factor de emisión, kg/VKT.

$$FE = k\ (1.7) \left(\frac{s}{12}\right) \left(\frac{S}{24}\right) \left(\frac{W}{2.7}\right)^{0.7} \left(\frac{w}{4}\right)^{0.5} \left(\frac{365-p}{365}\right)\ (kg/VKT) \qquad (4\text{-}13)$$

$$FE = k\ (5.9) \left(\frac{s}{12}\right) \left(\frac{S}{24}\right) \left(\frac{W}{2.7}\right)^{0.7} \left(\frac{w}{4}\right)^{0.5} \left(\frac{365-p}{365}\right)\ (lb/VKT) \qquad (4\text{-}14)$$

donde:
FE = factor de emisión
k = multiplicador del tamaño de partícula (adimensional)
s = contenido de sedimentos en el material de recubrimiento de los caminos (%);
S = velocidad media del vehículo, km/hr (mph);
W = peso medio del vehículo, Mg (ton);
w = número medio de ruedas
p = número de días al año con una precipitación mínima de 0.254 mm (0.01 in.).

Calcular las emisiones anuales de PM_{10} (i. e., utilizando un multiplicador de tamaño aerodinámico de partícula de 0.36) a partir de caminos rurales de terracería con un contenido promedio de sedimentos de 12 por ciento. Suponer que el peso medio del vehículo es de 4 Mg, la velocidad media del vehículo es de 25 km/hr y el número medio de ruedas es cuatro. Asimismo, el número medio de días al año con una precipitación superior a 0.254 mm es de 40, y el número de kilómetros recorridos por los vehículos es de 3,650,000 km/año.

$$FE = 0.36\ (1.7) \left(\frac{12}{12}\right) \left(\frac{25}{24}\right) \left(\frac{4}{2.7}\right)^{0.7} \left(\frac{4}{4}\right)^{0.5} \left(\frac{365-40}{365}\right)$$

$$= 0.3737\ kg/VKT$$

$$M = (3{,}650{,}000) \times (0.3737)$$

$$= 1{,}364{,}000\ kg\ PM_{10}/año$$

Ejemplo de Cálculos -—Rellenos Sanitarios

$$\mathbf{Q_{CH4} = L_o \times R \times (e^{-kc} - e^{-kt})} \tag{4-11}$$

donde: Q_{CH4} = tasa de generación de metano en el tiempo t, m^3/año;

L_o = potencial de generación de metano, $m^3 CH_4$/Mg desperdicios;

R = tasa promedio anual de aceptación de desperdicios durante la vida activa, Mg/año;

e = base de logaritmos naturales, sin unidades;

k = constante de la tasa de generación de metano, año^{-1};

c = tiempo transcurrido desde el cierre del relleno, años (c=0 para rellenos activos) y

t = tiempo transcurrido desde la colocación inicial de desperdicios, años.

Calcular las emisiones anuales de metano de un relleno sanitario activo que ha estado abierto durante 15 años y que ha aceptado desperdicios a una tasa promedio de 10,000 Mg/año. Suponer un potencial de generación de metano de 125 m^3/Mg y una constante de la tasa de generación de metano de 0.02/año

$$Q_{CH4} = (125\ m^3\ Mg) \times (10{,}000\ Mg/año) \times (e^{-(0.02/año)\ (0\ año)}\ e^{-(0.02/año)\ (15\ año})$$

$$= 125 \times 10{,}000 \times (1 - 0.7408)$$

$$= 324{,}000\ m^3\ CH_4/año$$

Ejemplo de Cálculos-—Polvos Fugitivos

Ejemplo de Cálculos -—Rellenos Sanitarios

Ejemplo de Cálculo -—Tanques de Almacenamiento

Ejemplo de Cálculo -—Carga de Productos Derivados del Petróleo

Ejemplo de Cálculo -—Residuos y Aguas Residuales

APENDICE III-B

COMO OBTENER LAS HERRAMIENTAS DE ESTIMACION DE LAS EMISIONES AL AIRE DE LA EPA

APENDICE III-C

EJEMPLO DEL CUESTIONARIO DE FUENTES PUNTUALES (I. E., ENCUESTA INDUSTRIAL del INE)

670-017-20-04
Mayo 17, 1996

John T. Leary
Gerente de Proyecto
Asociación de Gobernadores del Oeste
600 17th Street
Suite 1705, South Tower
Denver, CO 80202

Asunto: Entrega de la versión final del Manual de Técnicas Básicas para la Estimación de Emisiones para el Proyecto de Metodología para el Inventario de Emisiones de México.

Estimado John:

Anexa se encuentra una copia final del Volumen III de los Manuales para el Programa del Inventario de Emisiones de México, *Técnicas Básicas para la Estimación de Emisiones.* Hemos decidido elaborar los manuales en carpetas de tres anillos para facilitar la acualización de las secciones individuales en la medida en que el programa del inventario de emisiones de México sea desarrollado y refinado. Adicionalmente, estamos entregando al INE un “master” impreso por un lado y una versión electrónica (MS Word 6.0) de este documento para facilitar cualesquier esfuerzos posteriores de reproducción y traducción.

Estamos sumamente satisfechos por haber producido el primer volumen de una serie de manuales para el programa del inventario de emisiones, mismo que consideramos será de gran utilidad para México y ayudará a alcanzar los objetivos de transferencia de tecnología establecidos para este proyecto. Actualmente estamos iniciando los esfuerzos para terminar el Manual de Fuentes Puntuales y seguir avanzando en los borradores de los manuales para Fuentes de Area y Vehículos Automotores.

En caso de que existieran dudas o comentarios acerca del material que se anexa por favor comuníquese conmigo al (916) 857-7467.

Atentamente

Ronald J. Dickson
Ingeniero Senior

cc: Víctor Hugo Páramo, INE (cinco copias)
Comité Asesor Binacional
José Ortega, Corporación Radian
Jim Yarbrough, U.S. EPA Región VI
Archivo del Proyecto.

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Dr. John R. Holmes, State of California Air Resources Board
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Dr. Victor Hugo Páramo, Instituto Nacional de Ecología
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Mr. Carl Snow, Texas Natural Resource Conservation Commission

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MEXICO EMISSIONS INVENTORY PROGRAM MANUALS

VOLUME IV - POINT SOURCE INVENTORY DEVELOPMENT

Prepared for:

Western Governors' Association
Denver, Colorado

and

Binational Advisory Committee

Prepared by:

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10389 Old Placerville Road
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August 15, 1996

PREFACE

Air pollution can negatively impact public health when present in the atmosphere in sufficient quantities. Most rural areas rarely experience air quality problems, while elevated concentrations of air pollution are commonly found in many urban environments. Recently, urbanization and industrial activity throughout Mexico has increased, resulting in air quality concerns for several regions.

Air pollution results from a complex mix of, literally, thousands of sources, from industrial smoke stacks and motor vehicles, to the individual use of grooming products, household cleaners, and paints. Even plant and animal life can play an important role in the air pollution problem. Due to the complex nature of air pollution, detailed regional plans are needed to identify the emission sources and to develop methods for reducing the health impact from exposure to air pollution. Examples of air quality planning activities include:

- Application of air quality models;
- Examination of the sources emitting air pollution for emissions control analysis, where necessary;
- Development of emission projections to examine possible changes in future air quality;
- Analysis of emission trends; and
- Analysis of emissions transport from one region to another.

Development of fundamentally sound emissions inventories is a key aspect for each of these air quality planning functions.

Developing emission estimates to meet air quality planning needs requires continual development and refinement; “one time” inventory efforts are not conducive to the air quality planning process. For lasting benefit, an *inventory program* must be implemented so that accurate emission estimates can be developed for all important geographic regions, refined over time, and effectively applied in the air quality planning and monitoring process. Therefore, a set of inventory manuals is being developed that can be used throughout the country to help coordinate the development of consistent emission estimates. These manuals are intended for use by local, state, and federal staff, as well as by industry and private consultants. The purpose of these manuals is to assist in implementing the inventory program and in maintaining that program over time so that emissions inventories can be developed in periodic cycles and continually improved.

The manuals cover inventory program elements such as estimating emissions, program planning, database management, emissions validation, and other important topics. Figure 1 shows the complete series of manuals that will be developed to support a comprehensive inventory program. The main purpose of each manual is summarized below.

Volume I—Emissions Inventory Program Planning. This manual addresses the important planning issues that must be considered in an air emissions inventory program. Program planning is discussed not as an “up-front” activity, but rather as an ongoing process to ensure the long-term growth and success of an emissions inventory program. *Key Topics*: program purpose, inventory end uses, regulatory requirements, coordination at federal/state/local levels, staff and data management requirements, identifying and selecting special studies.

Volume II—Emissions Inventory Fundamentals. This manual presents the basic fundamentals of emissions inventory development and discusses inventory elements that apply to multiple source types (e.g., point and area) to avoid the need for repetition in multiple volumes. *Key Topics*: applicable regulations, rule effectiveness, rule penetration, pollutant

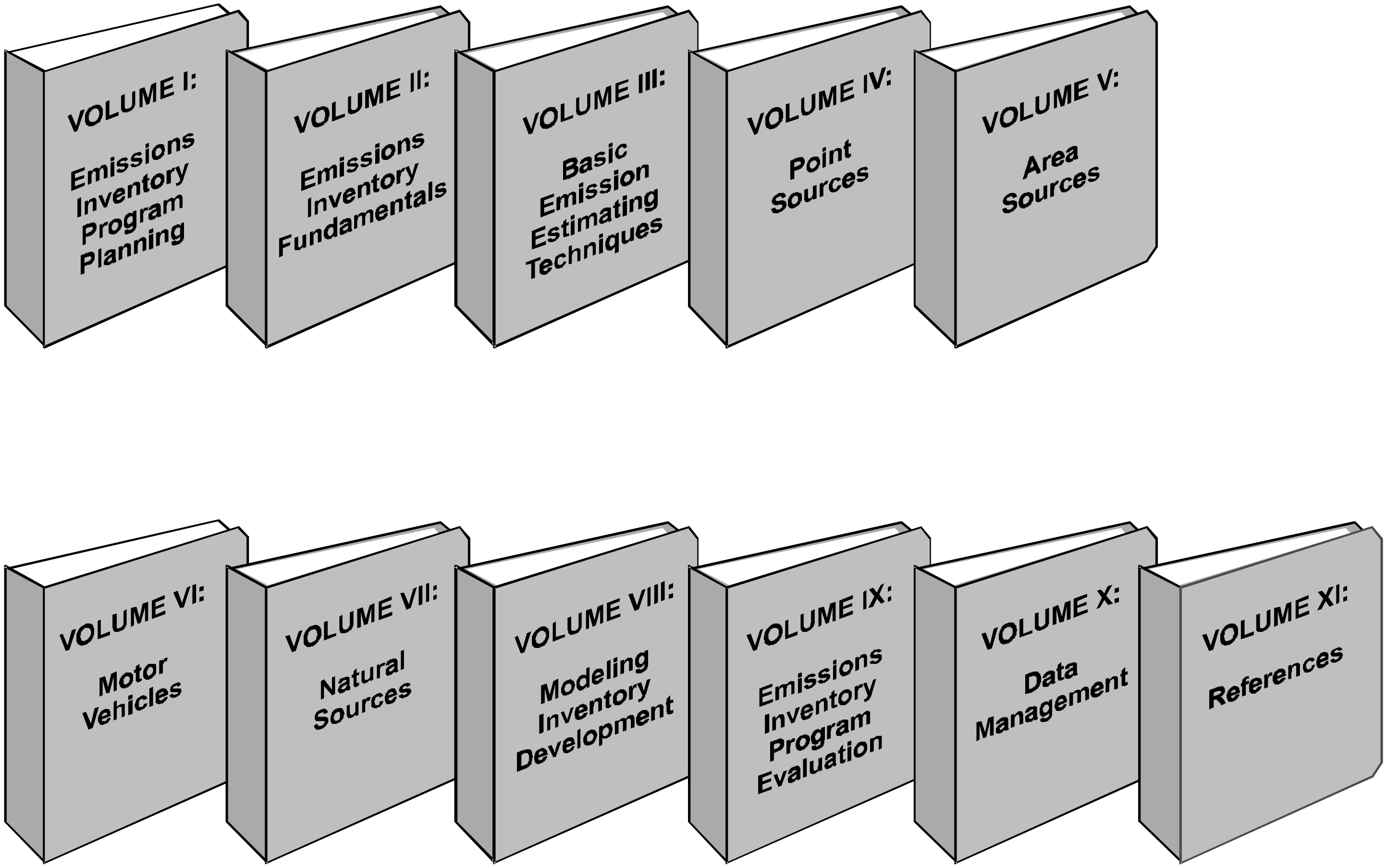

Figure 1. Mexico Emissions Inventory Program Manuals

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Figure 1

definitions (e.g., how to properly exclude nonreactive volatile compounds), point/area source delineation, point/area source reconciliation.

Volume III—Emissions Inventory Development: Basic Emission Estimating Techniques (EETs). This manual presents the basic EETs used to develop emission estimates, including examples and sample calculations. Inventory tools associated with each methodology are identified and included in Volume XI (References). *Key Topics*: source sampling, emissions models, surveying, emission factors, material balance, extrapolation.

Volume IV—Point Sources. This manual provides guidance for developing the point source emissions inventory. A cross-reference table is provided for each industry/device type combination (e.g., petroleum refining/combustion devices) with one or more of the basic EETs presented in Volume III. *Key Topics*: cross-reference table, stack parameters, control devices, design/process considerations, geographic differences and variability in Mexico, quality assurance/quality control (QA/QC), overlooked processes, data references, data collection forms.

Volume V—Area Sources (includes non-road mobile). This manual provides guidance for developing the area source emissions inventory. After the presentation of general area source information, a table is provided to cross-reference each area source category (e.g., asphalt application) with one or more of the basic EETs presented in Volume III. Then, source category-specific information is discussed for each source category defined in the table. *Key Topics*: area source categorization and definition, cross-reference table, control factors, geographic differences and variability in Mexico, QA/QC, data references, data collection forms (questionnaires).

Volume VI—Motor Vehicles. Because motor vehicles are inherently different from point and area sources, the available estimation methods and required data are also different. To estimate emissions from these complex sources, models are the preferred estimation tool. Many of these models utilize extensive test data applicable to a given country or region. This manual focuses primarily on the data development phase of estimating motor vehicle emissions. *Key Topics*: available estimation methods, primary/secondary/tertiary data and information, source categorization, emission factor sources, geographic variability within Mexico, QA/QC.

Volume VII—Natural Sources. This manual provides guidance for developing a natural source emissions inventory (i.e., biogenic volatile organic compounds [VOC] and soil oxides of nitrogen [NO_x]). In addition, this manual includes the theoretical aspects of emission calculations and discussion of specific models. *Key Topics*: source categorization and definition, emission mechanisms, basic emission algorithms, biomass determination, land use/land cover data development, temporal and meteorological adjustments, emission calculation approaches.

Volume VIII—Modeling Inventory Development. This manual provides guidance for developing inventory data for use in air quality models and addresses issues such as temporal allocation, spatial allocation, speciation, and projection of emission estimates. *Key Topics*: definition of modeling terms, seasonal adjustment, temporal allocation, spatial allocation, chemical speciation, projections (growth and control factors).

Volume IX—Emissions Inventory Program Evaluation. This manual consists of three parts: QA/QC, uncertainty analysis, and emissions verification. The QA/QC portion defines the overall QA/QC program and is written to complement source specific QA/QC procedures written into other manuals. The uncertainty analysis includes not only methods of assessing uncertainty in emission estimates, but also for assessing uncertainty in modeling values such as speciation profiles and emission projection factors. The emissions verification section describes various analyses that can be performed to examine the accuracy of the emission estimates. Examples include receptor modeling and trajectory analysis combined with specific data analysis techniques. *Key Topics*: description of concepts and definition of terms, inventory review protocol, completeness review, accuracy review, consistency review, recommended uncertainty EETs, applicable emission verification EETs.

Volume X—Data Management. This manual addresses the important needs associated with the data management element of the Mexico national emission inventory program. *Key Topics*: general-purpose data management systems and tools, specific-purpose software systems and tools, coding system, confidentiality, electronic submittal, frequency of updates, recordkeeping, Mexico-specific databases, reports.

Volume XI—References. This manual is a compendium of tools that can be used in emission inventory program development. Inventory tools referenced in the other manuals are included (i.e., hardcopy documents, electronic documents, and computer models).

CONTENTS

APPENDIX IV-A: INE'S POINT SOURCE INVENTORY DEVELOPMENT PROCESS
APPENDIX IV-B: MISCELLANEOUS DATA AND CONVERSION FACTORS
APPENDIX IV-C: EXCERPT FROM THE *1995 PROTOCOL FOR EQUIPMENT LEAK EMISSION ESTIMATES*
APPENDIX IV-D: EXAMPLE QUALITY CONTROL CHECKLIST
APPENDIX IV-E: SOURCE CLASSIFICATION CODES LIST
APPENDIX IV-F: THE NATIONAL INSTITUTE OF ECOLOGY POINT SOURCE QUESTIONNAIRES
APPENDIX IV-G: DEVICE LEVEL DATA COLLECTION FORMS

FIGURES AND TABLES

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ACRONYMS

BBS	bulletin board system
Btu	British thermal unit
CAD	computer aided design
CD	control device
CEM	continuous emissions monitor
CHIEF	Clearing House for Inventories and Emission Factors
CO	carbon monoxide
dscfm	dry standard cubic feet per minute
dscm	dry standard cubic meter
DQI	data quality indicator
DQO	data quality objective
EET	emissions estimating techniques
EIIP	Emission Inventory Improvement Program
EP	emission point
ESP	electrostatic precipitators
EU	emission unit
FGR	flue gas recirculation
FIRE	Factor Information Retrieval System
GPS	global positioning system
hr	hour

INE	National Institute of Ecology
INEGI	Instituto Nacional de Estadística, Geografía e Informática
kg	kilogram
km	kilometer
L	liter
lb	pound
LEVD	Low Emission Vapor Degreaser
LPG	liquefied petroleum gas
m^3	cubic meter
Mg	megagram (i.e., 10^6g = 1 metric tonne)
mg	milligram
MW	molecular weight
NH_3	ammonia
NO_x	oxides of nitrogen
O_2	oxygen
OFA	overfire air
PM	particulate matter
PM_{10}	particulate matter of less than 10 microns
ppbv	parts per billion by volume
ppmv	parts per million by volume
psig	pounds per square inch - gauge
QA	quality assurance

QC	quality control
SNIFF	National Information System of Point Sources
SO_2	sulfur dioxide
SO_3	sulfur trioxide
SO_x	oxides of sulfur
SCC	Source Classification Code
ton	English ton (i.e., 2,000 lbs)
tonne	metric ton (i.e., 1,000 kg)
TSDF	treatment, storage, and disposal facility
UNAM	National Meteorological and Atmospheric Science Center at the National University
U.S.	United States
U.S. EPA	United States Environmental Protection Agency
UTM	universal transverse mercator
VOC	volatile organic compound

1.0 INTRODUCTION

Article 17 from the *Regulation of the General Law for the Ecological Equilibrium and Environmental Protection on Air Pollution Control and Prevention (Reglamento de la Ley General de Equilibrio Ecológico y la Protección al Ambiente en Materia de Prevención y Control de la Contaminación de la Atmósfera)* states that “entities responsible for the stationary sources of federal jurisdiction must present an inventory including their polluting emissions into the atmosphere.” Article 112 from the *General Law for the Ecological Equilibrium and Environmental Protection (Reglamento de la Ley General de Equilibrio Ecológico y la Protección al Ambiente)* establishes that county and state governments must create and continuously update the emissions inventory, as well as prevent and control atmospheric pollution in their jurisdiction, including area, anthropogenic and other emission sources.

A series of documents is being prepared that will establish standard procedures for the preparation of point, area, mobile, and natural source emission inventories. The purpose of these documents is to provide cost-effective, reliable methods for developing inventories and improving the quality of emissions data collected and reported. These documents will also provide guidance on how to collect complete and accurate information on process technologies and air pollution control methods. The use of these standardized procedures will promote consistency in these activities among the emissions inventory reporting groups.

The emissions inventory procedures presented in this volume are specific to point sources. Point sources include facilities, plants, or activities for which individual source records are maintained in the inventory database. Volume IV is intended to familiarize the industrial sector and the federal, state, and municipal agencies with the basic concepts involved in preparing a point source emissions inventory. Volume III, *Basic Emission Estimating*

Techniques, provides an introduction to air pollutant emission estimation techniques and presents detailed examples to aid the reader in actual emission calculations.

Figure 1-1 illustrates the general point source development process and cross references these activities to the appropriate sections of this document. The National Institute of Ecology's (INE) point source inventory development process, included as Appendix IV-A, shows that INE sometimes may accept responsibility for the emission calculations if they are not provided or well-documented by the facilities.

The remainder of this manual is organized as follows:

- Section 2.0 covers two important issues that must be addressed before getting started: the definition of a "point source" and the level of detail of the inventory.
- Section 3.0 includes brief descriptions of basic methodologies recommended for estimating emissions from point sources. Pollutant and emission source information is also included to assist the reader in selecting an appropriate technique for estimating point source emissions. Appendix IV-B provides useful conversion factors.
- Section 4.0 describes design and process considerations that could influence emissions (e.g., fuel characteristics or operating parameters) and also presents some point sources that are typically overlooked during inventory development. Appendix IV-C provides information about procedures and approaches for estimating emissions from fugitive component equipment leaks.
- Section 5.0 presents typical control device types and efficiencies.
- Section 6.0 describes the importance of reporting accurate stack parameter information within the inventory for use in developing modeling inventories.

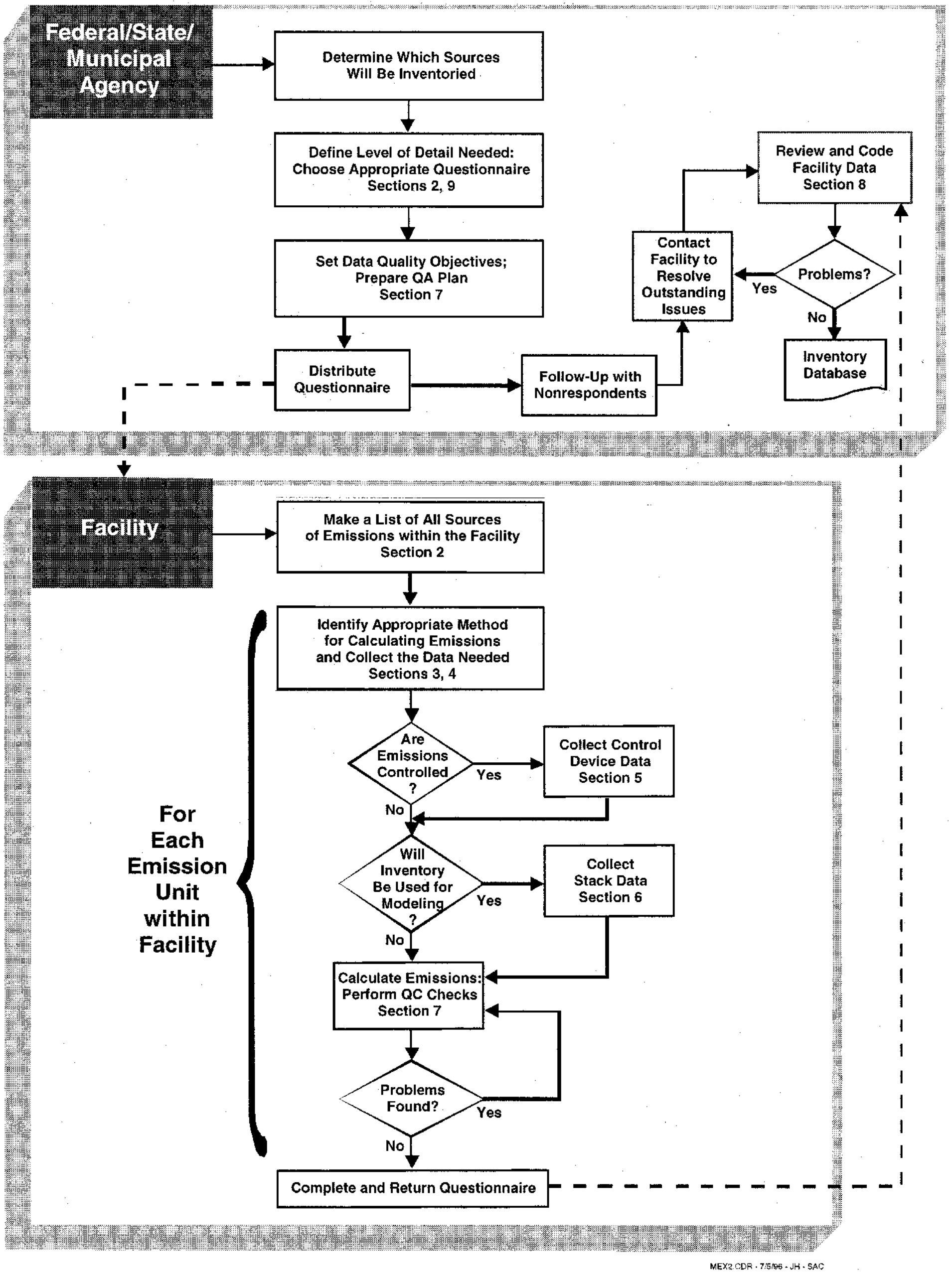

Figure 1-1. Point Source Inventory Development Process

- Section 7.0 discusses quality assurance/quality control (QA/QC) procedures. Data Quality Objectives (DQOs) for inventories are discussed as well as the methods for achieving these goals. An example QC checklist to aid the inventory preparer is included in Appendix IV-D.

- Section 8.0 describes available data coding procedures that should be used in the inventory to ensure that the data are reportable, manageable, and retrievable. Appendix IV-E provides a list and descriptions of source classification codes.

- Section 9.0 explains data collection procedures. INE’s existing industrial questionnaire and source-specific example data collection forms are included in Appendices IV-F and IV-G.

- Section 10.0 lists the references used to develop this document.

2.0 GETTING STARTED

The primary purpose of an air emissions inventory is to provide information to allow federal, state, and municipal air pollution control agencies to plan emissions control strategies and to manage air quality. The emissions inventory over time can be an indicator of changes in the air quality. Inventory areas are generally defined by political boundaries (e.g., municipalities and state boundaries).

Before beginning to develop a point source inventory, two important decisions must be made. First, a "point source" must be clearly defined (i.e., a point/area source delineation must be established). Second, the desired level of detail must be determined.

2.1 Point Source Definition

The division of sources of emissions into "point" and "area" sources is arbitrary but necessary to allow for the efficient collection of information needed to support air quality programs. This division has important implications for both the development of regulatory programs and the amount and type of information needed to support those programs.

Detailed information on every "point" at which emissions are discharged to the atmosphere is desirable. While this would allow a detailed understanding of the characteristics of each such point, there is no practical way that such information can be collected. An alternative approach is to collect information on a much simpler basis by aggregating related sources (e.g., all automobiles, all bakeries) into a single "area source." The definition of point/area sources that specifies this division is thus a tradeoff between the needs of regulatory programs and the resources available to support the data requirements of those programs.

Treating all facilities as point sources may increase the accuracy of the inventory, but will require substantially more resources to compile and maintain the point source inventory.

In Mexico, point sources are defined in Article 6 of the *General Law for the Ecological Equilibrium and Environmental Protection* as any facility that is established in one place only, with the purpose of developing industrial or commercial processes, service works, or activities that generate or can generate air pollutant emissions.

"Fuente fija. Es toda instalación establecida en un solo lugar, que tenga como finalidad desarrollar operaciones o procesos industriales, comerciales, de servicios o actividades que generen o puedan generar emisiones contaminantes a la atmósfera."

As indicated in Article 11 of the *Regulation of the General Law for the Ecological Equilibrium and Environmental Protection on Air Pollution Control and Prevention* and Article 29 of the *General Law for the Ecological Equilibrium and Environmental Protection*, all sources of Federal jurisdiction are point sources. Sources of Federal jurisdiction include:

- All facilities, projects, or activities (industrial, commercial, or service) conducted by Federal Public Administration entities;
- Government controlled industries;
- Facilities located in the Federal District adjoining zone;
- Certain private industries (i.e., asbestos, chemical, petrochemical, iron and steel, paper, sugar, drink and beverage, cement, automobile, and electricity generation and transmission); and

- Sources affecting the ecological equilibrium in an adjoining state or country.

These facilities must solicit a permit to operate through the Secretary (SEMARNAP). In addition, they must annually submit emission estimates for the facility.

Certain companies that have a microindustry certificate may be exempt from the licensing and operating certificate requirements for point sources if their activities are exempted in the *Agreement by which Point sources considered to be Small Businesses (microindustries) in Terms of the Law of the matter Published 17 May 1990 are Exempted from the Requirement of obtaining an Operating License (el Acuerdo por el que se Exceptúan del Trámite para la Obtención de la Licencia de Funcionamiento, a las Fuentes Fijas consideradas como Empresas Microindustriales en los Términos de la Ley en la materia publicado el 17 de Mayo de 1990).*

Point sources could be specified in a number of other ways. These include defining a point source as follows (with all other sources included as area):

- Source of a given type (e.g., Fluidized Catalytic Cracking unit) or type <u>and</u> size (e.g., boiler with heat input > 10,000 British thermal unit [Btu]/hr);
- Source that emits more than a specific amount of emissions determined on some consistent basis;
- Every source (regardless of type, size or emissions) that is located in a facility of a given type (e.g., petroleum refinery) or type <u>and</u> size (e.g., steel foundry with steel production more than 1,000 tons/year); and
- Every source (regardless of type, size or emissions) that is located in a facility with more than a specified amount of emissions determined on some consistent basis.

Examples of a consistent basis for determining the amount of emissions includes actual (what was actually emitted in some prior time period), allowable (the maximum that could be emitted under regulatory limits), and potential (what would be emitted if operated full time without control equipment). In addition, these definitions can vary by regulatory region to account for different levels of severity of the air quality problem and/or the stringency of the regulatory program.

As an example, a specific basis has been set in the United States for areas that exceed the ozone and carbon monoxide ambient standards. In these areas, if a facility emits more than 100 tons per year of oxides of nitrogen (NO_x) or carbon monoxide (CO), or 10 tons per year of volatile organic compound (VOC), it must be included in the point source inventory. Individual states are encouraged to inventory sources below these cutoffs on an individual point basis. The decision to set a lower cutoff depends on a number of local factors, usually available resources to obtain and manage the data.

Environmental programs in the United States have often used the last definition (i.e., facility-wide emission thresholds) based on potential emissions. These sources are regulatorily defined as “stationary sources” and are subject to more stringent regulations than sources that emit less. The United States Environmental Protection Agency (U.S. EPA) has carried this regulatory definition into the realm of data management. U.S. EPA requires that state agencies submit data on the regulatory-defined stationary sources as “point sources,” all data on the remaining facilities must be submitted in aggregated form as “area sources.”

As the Mexico emissions inventory program evolves, the point source definition may be modified to add new significant sources that are identified or to eliminate insignificant sources. Again, the goal is to maximize the overall accuracy of the comprehensive emissions inventory (i.e., point, area, motor vehicle, and nature sources) within the allotted amount of resources available.

2.2 Level of Detail

Information on point sources is usually gathered by surveys. An example of point source surveying is shown in Figure 2-1. Point sources can be inventoried at the following three levels of detail (which are illustrated in Figure 2-2):

- Plant level, which denotes a plant or facility that could contain several pollutant-emitting activities;
- Point/stack level, where emissions to the ambient air occur; and
- Process/segment level, representing the emission unit operations of a source category.

The specific issues pertaining to each level are listed below. Whenever possible, emissions should be inventoried at the process/segment level in order to be able to support air quality activities such as regulation, compliance, and permitting. For example, identifying the processes and devices to which a future regulation might apply and then estimating the impact (i.e., costs and benefits) of that regulation would typically require estimating emissions for each process/device.

Another equally important reason for collecting data at this level of detail is that it provides the agency with the information required to verify the emissions estimates provided by the facility operators.

2.2.1 Plant Level

In a plant-level survey, the following issues apply:

- Each plant within the area should be identified and assigned a unique plant identification number (Refer to Section 8.0 of this document for information on assigning plant identification numbers);

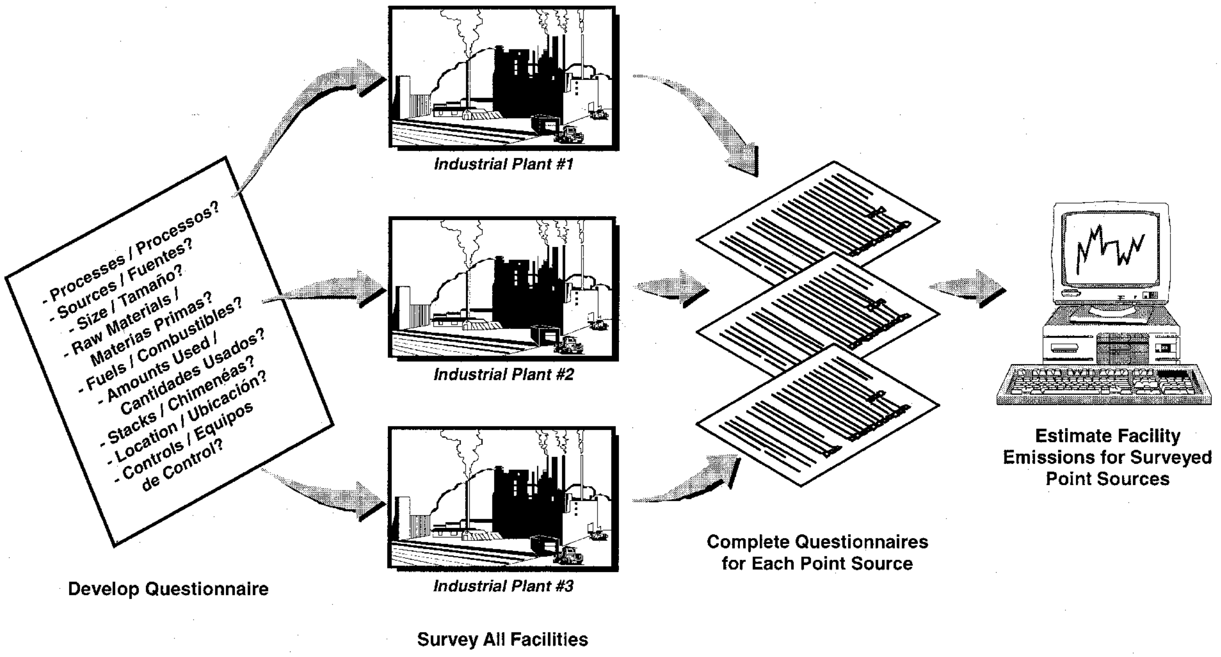

Figure 2-1. Example of Point Source Surveying

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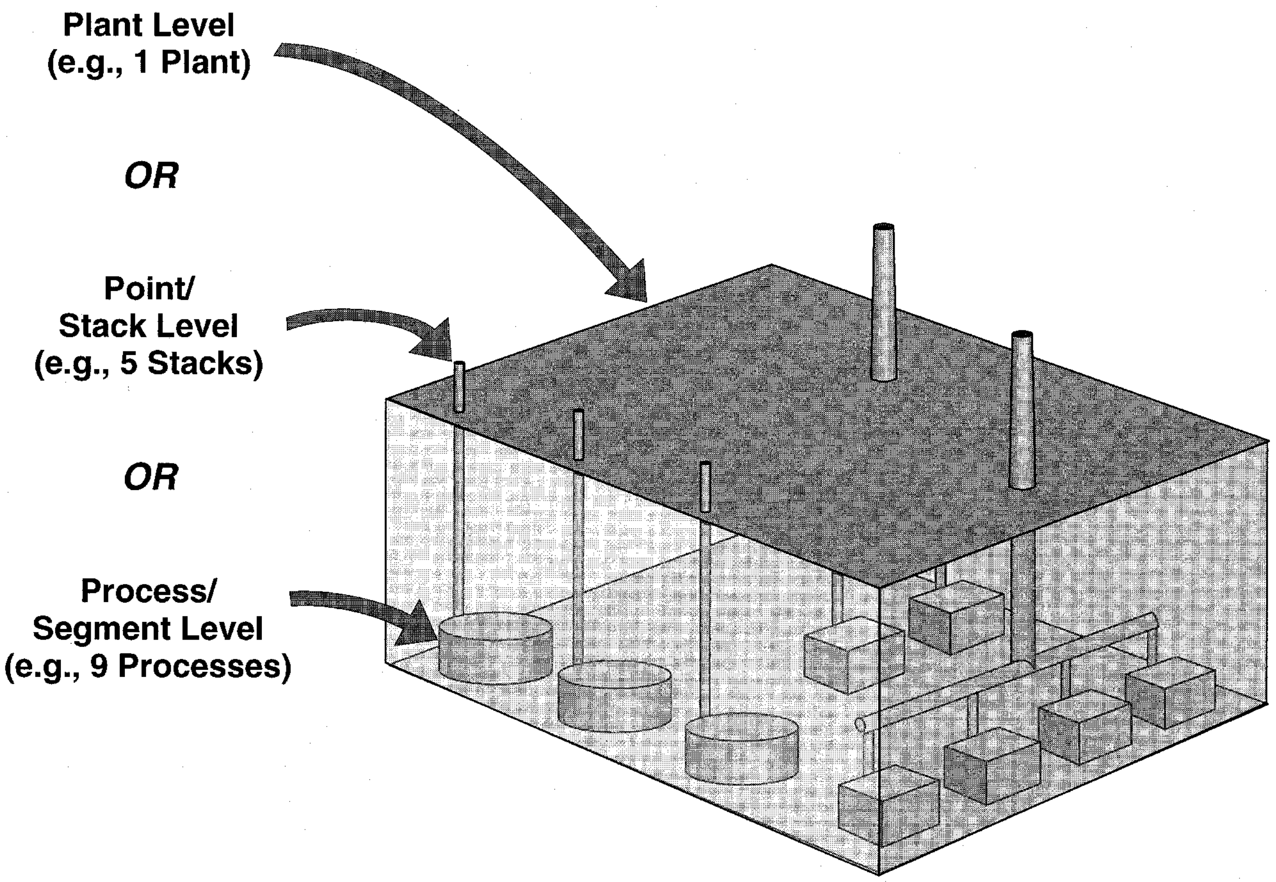

Figure 2-2. Different Point Source Inventory Levels

- The plant should be further identified by geographic descriptors such as state, municipality, street and/or mailing address, and universal transverse mercator (UTM) map coordinates, or latitude/longitude (see Section 6.1); and

- A plant contact should be identified to facilitate communication and interaction with the plant.

2.2.2 Point/Stack Level

In a point/stack-level survey, the following issues apply:

- Each stack, vent, or other point of emission should be identified as an emission point within a plant;

- Each stack, vent or other point of emission should receive a unique identification number within the inventory (see Chapter 8.0 of this document); and

- The following information should be recorded for each emission point in a comprehensive inventory, as well as for modeling programs:

    - Location (latitude/longitude or UTM coordinates; see Section 6.1 of this document);

    - Height of the emission point (see Section 6.2 of this document);

    - Diameter of the emission point (see Section 6.3 of this document);

    - Emission rate;

    - Gas exit temperature (see Section 6.4 of this document); and

    - Gas exit velocity (see Section 6.5 of this document) or volumetric flow rate (see Section 6.6 of this document) from the emission point.

2.2.3 Process/Segment Level

A plant may include various processes or operations. The information necessary to establish an inventory at this level includes the following:

- Process identification information;
- Process level data (e.g., raw materials, process streams, and products properties);
- Operating rate data, including actual, maximum, and design operating rate or capacity;
- Fuel use and properties data (ash, sulfur, trace elements, heat content, etc.);
- Identification of all air pollution control equipment and their associated collection and control efficiencies (measured or design);
- Identification of the estimation method or reference used to develop each emissions estimate; and
- Final products information.

3.0 RECOMMENDED EMISSIONS ESTIMATION TECHNIQUES

This section presents a brief overview of the primary emission estimating techniques (EETs) applicable to point sources:

- Emission factors;
- Source tests;
- Material balance; and
- Emissions models.

For a more detailed description of these methods, please refer to Volume III: *Basic Emission Estimating Techniques*.

Following these descriptions, an Emission Estimation Technique Cross-Reference Table shows which EETs are recommended for the types of point sources commonly associated with various industrial sectors. Appendix IV-B of this manual contains conversion factors which may be useful when performing air emission calculations.

3.1 Emission Factors

An emission factor is a ratio that relates the quantity of pollutant released to the atmosphere to the activity level associated with the release of that pollutant. The activity level may be a production rate or a quantity of fuel burned, for example. If the emission factor and the corresponding activity level for a process are known, an estimate of the emissions can be produced. The use of emission factors is straightforward when the relationship between process data and emissions is direct and relatively uncomplicated. It should be noted that the use of facility-specific emission factors is preferred over the use of industry-averaged data. However, depending upon available resources, obtaining facility-specific data may not be cost effective. Figure 3-1 illustrates examples of emission factor units and applications.

One of the primary references for criteria pollutant emission factors for industrial sources is *AP-42*, which also contains emission factors for a limited number of toxic organic and inorganic pollutants (U.S. EPA, 1995a). An electronic database of emission factors can be found in the Factor Information Retrieval (FIRE) System, which contains the same criteria pollutant emission factors as *AP-42* (U.S. EPA, 1995b). In addition, toxic pollutant emission factors are presented for many source types. The FIRE system is available in electronic format from the Clearinghouse for Inventories and Emission Factors (CHIEF) Bulletin Board System (BBS), 95-919-541-5742. The FIRE system as well as *AP-42* may also be obtained from the Air CHIEF CD-ROM which can be requested through the Info CHIEF telephone line, 95-919-541-5285.

In order to calculate emissions using factors, various inputs to the estimation algorithm are required:

- Activity information for the process as specified by the relevant emission factor;
- Emission factors to translate activity information into uncontrolled or controlled emission estimates; and
- Capture and control device efficiencies if using an uncontrolled emission factor (“controlled” emission factors already take this into account).

The basic emission estimation algorithm for using an uncontrolled emission factor when a control device is in place is:

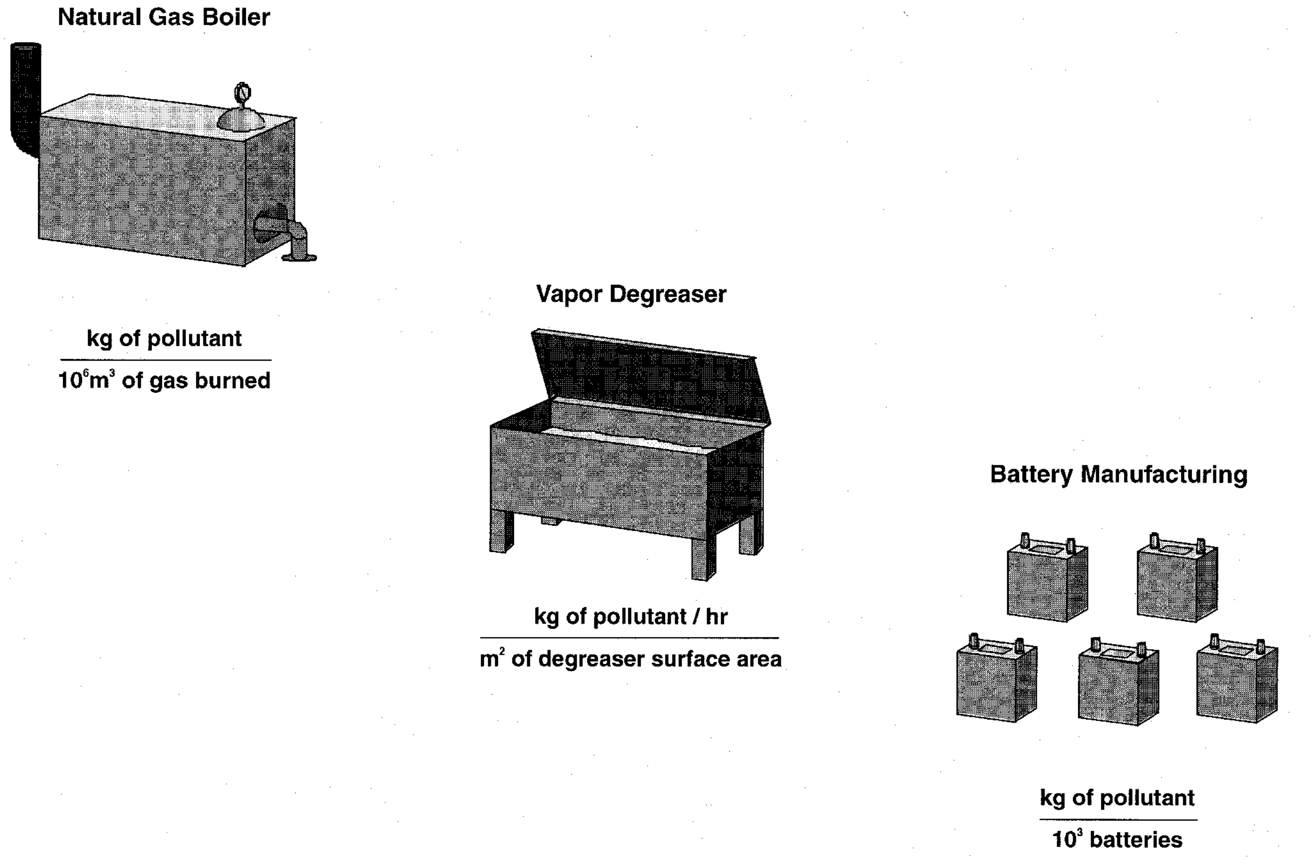

Figure 3-1. Examples of Emission Factor Units and Applications

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$$\mathbf{E = A \times EF \times (1 - ER/100)} \qquad (3\text{-}1)$$

where:

E = emission estimate for source (at the process level)
A = activity level (such as throughput or material produced)
EF = "uncontrolled" emission factor (such as lb of pollutant emitted/ton of material processed)
ER = overall emission reduction efficiency, expressed in percent; equal to the capture device efficiency multiplied by the control device efficiency. If no control device present, ER = 0.

If the emission factor was developed with a control device in place, the emission factor already incorporates the control system effectiveness term (1-ER/100); therefore, the form of the algorithm is:

$$\mathbf{E = A \times EF} \qquad (3\text{-}2)$$

where:

E = emission estimate for source (at the process level)
A = activity level (such as throughput or material produced)
EF = controlled emission factor (such as kilogram of pollutant emitted/Mg of material processed)

Equation 3-2 is also used when no control device is in place and the emission factor was developed from data generated from an uncontrolled system as shown in the following example:

Example 3-1:

Calculate the annual non-methane VOC emissions from a paint manufacturing facility that produced 200 Mg (metric tonnes) of paint in a year.

A_{paint} = 200 Mg/yr (From AP-42, Section 6.4)

EF_{VOC} = 15 kg/Mg

$$\begin{aligned} E_{VOC} &= A_{paint} \times EF_{VOC} \\ &= 200 \times 15 \\ &= 3{,}000 \text{ kg/yr} \end{aligned}$$

Emission Factors - Issues to Consider

- Emissions calculated using emission factors for a given process are likely to differ from that facility’s actual emissions because the estimate is less precise than source test measurements.

- The use of emission factors will produce higher emissions estimates than are actual for some sources and lower for others.

- Emission factors are often based on limited data, and may not truly represent the facility of interest.

- If emission factors are used to predict emissions from new or proposed sources, users should review the latest literature and technology to determine if such sources would likely exhibit emissions characteristics different from those of typical existing sources.

- In order to calculate emissions using emission factors, the following information is required:

  - Activity information for the process as specified by the relevant emission factor;

  - Emission factors to translate activity information into controlled or uncontrolled emission estimates; and

  - Capture device and control device efficiencies to provide the basis for estimating emissions to the atmosphere after passage through the control devices(s) if using an uncontrolled emission factor.

- The accuracy of the emission estimate is equally dependent upon the relative accuracy of each of these individual components. Errors introduced into any one of these components will affect the final emission estimate.

3.2 Source Tests

The source test is a common method of estimating process emissions. Source tests are short-term emission measurements taken at a stack or vent. Due to the substantial time and equipment involved, a source test requires more resources than an emission factor or material balance emission estimate. A source test measures pollutant concentration in the emission stream and the emission stream air flow rate.

The definition of source testing can be extended to include the use of continuous emissions monitors (CEM). This technology continuously removes a sample from the stack and analyses it for compounds of interest using the same principles as routine stack sampling. If CEM equipment are being used at a facility, the resulting data should be used to the greatest extent possible to prepare unit-specific emission estimates. The remainder of this section focuses on the use of traditional, short-term source test results to develop emission estimates.

Most source test reports summarize emissions for each pollutant by expressing them in terms of: (1) a mass loading rate (mass of pollutant emitted per unit of time); (2) an emission factor (mass of pollutant emitted per unit of process activity); or (3) a flue gas concentration (mass or number of moles of pollutant per some weight or volume of flue gas). Generally, when a mass loading rate or flue gas concentration is provided, the resulting emissions can easily be calculated with knowledge of operating parameters, as in the example below (U.S. EPA, 1993a):

Example 3-2:

A single-line paper coating plant has been subjected to an emission test for volatile organic compound (VOC) emissions. Since the coating solvent is primarily toluene, the emission concentrations were measured as toluene. The data averaged for three test runs are as follows:

Stack flow rate (Q_S) = 283 m^3/min
Emission concentration (C_e) = 96 ppm (as toluene)

Other information needed to complete the calculations include:
Plant operation = 16 hour/day, 312 days/year
Molecular weight of toluene (MW) = 92 g/gmole
Unit conversion factor (k) = 2.53 x 10^{-3}gmole-min/hr-ppm-m^3

The emission calculation begins with determination of the average mass loading rate (M_O):

M_O = $(k)(MW)(C_e)(Q_S)$
= $(2.53 \times 10^{-3})(92)(96)(283)$
= 6,324 g/hr
= 6.32 kg/hr

Total annual emissions = (6.32 kg/hr) (16 hr/day) (312 day/yr)
= 3.2 x 10^4 kg/yr

Note:

$$\left(\frac{1}{10^6}\right)\left(\frac{60\ \text{min}}{\text{hr}}\right)\left(\frac{\text{lb mole}}{379\ \text{ft}^3}\right)\left(\frac{35.31\ \text{ft}^3}{\text{m}^3}\right)\left(\frac{453.6\ \text{gmol}}{\text{lb mol}}\right) = 2.53 \text{ x } 10^{-3}$$

Sometimes, source test results may not be provided in the format that must be reported. The following examples show some of the data conversions that may be required.

Example 3-3: ppmv to kg/hr calculation

Given: Oxides of nitrogen (NO_x) measured at 100 parts-per-million volume (ppmv) in stack gas
Stack flow of 500 cubic meters (m^3) per minute

Required: kg/hr NO_x emitted in stack gas

Data: NO_x molecular weight (MW) = 46
Molar volume = 24.13 ℓ/kgmol @ 20°C
= 0.024 m^3/kgmol

$$\left(\frac{100\ \text{kgmol}\ NO_x}{10^6\ \text{kgmol}}\right)\left(\frac{46\ \text{kg}\ NO_x}{\text{kgmol}\ NO_x}\right)\left(\frac{\text{kgmol air}}{0.024\ m^3\ \text{air}}\right)\left(\frac{60\ \text{x}\ 500\ m^3\ \text{air}}{\text{hour}}\right) = 5{,}750\ \text{kg/hr}\ NO_x$$

Note: When computing mass emissions of NO_x, use the molecular weight of NO_2 (MW = 46) in the calculation. This is the standard convention, even though most NO_x is actually emitted from combustion sources as NO.

Example 3-4: Temperature correction: actual m^3/min to standard m^3/min (stack gas flow rate correction)

Given: Stack gas exit velocity measured at 10 m/s
Stack diameter = 0.8 m
Stack temperature = 80°C

Required: Stack gas flow in standard m^3/min (20°C reference temperature)

Conversion:

$$\text{Flow}_{20°C} = \left(\text{Flow}_{x°C}\right)\left(\frac{20°C + 273.15}{X°C + 273.15}\right)$$

$$\left(10\ \frac{m}{s}\right)\left(\pi\ \frac{(0.8)^2}{4}\ m^2\right)\left(\frac{60\ s}{\text{min}}\right)\left(\frac{293.15\ K}{353.15\ K}\right) = 250\ \text{standard}\ m^3/\text{min}$$

Note: For elevated temperature stack gas flows, it is generally necessary to correct for <u>both</u> temperature and water content (see Example 3-5).

Example 3-5: Water Vapor correction: actual m^3/min to dry standard m^3/min (stack gas flow rate correction)

Given: Wet stack gas flow rate from Example 3-4 = 250 standard m^3/min
Stack gas water vapor content = 2.1% (volume)

Required: Dry stack gas flow (dry standard m^3/min)

Conversion:

$$\text{Flow}_{\text{dry}} = \text{Flow}_{\text{wet}}\,[100\% - \%\ H_2O]$$

$$250 \text{ standard } m^3/\text{min } [1 - 0.021] = 245 \text{ dry standard } m^3/\text{min}$$

Example 3-6: Oxygen in flue gas correction (pollutant concentration correction)

Given: Particulate in stack gas = 20 mg/dry standard m^3 (dscm)
NO_x concentration in stack gas = 48 ppmv
Stack gas oxygen concentration = 4% (vol)

Required: Stack gas particulate and NO_x concentrations corrected to 7% oxygen.

Conversion:

$$\text{Conc}_{7\%} = \text{Conc}_{x\%}\left(\frac{21\% - 7\%}{21\% - X\%}\right)$$

$$\frac{20 \text{ mg PM}}{\text{dscm}}\left(\frac{21\% - 7\%}{21\% - 4\%}\right) = \frac{16.5 \text{ mg}}{\text{dscm}} \text{ PM @ } 7\%\ O_2$$

$$48 \text{ ppmv } NO_x\left(\frac{21\% - 7\%}{21\% - 4\%}\right) = 40 \text{ ppmv } NO_x \text{ @ } 7\%\ O_2$$

Source Tests - Issues to Consider

- Source tests typically provide better emission estimates than emission factors or material balances, if correctly applied.
- Source test data should be used for emission estimation purposes only if the data were obtained under conditions which are representative of operating conditions normally encountered at the source in question.
- Emission data from a one-time source test can be extrapolated to estimate annual emissions if the process stream does not vary and if the process is operated uniformly. If variability exists, multiple tests must be conducted, with knowledge of the process variation.
- If facility operation and test methods employed during the source test cannot be adequately characterized, the source test data should not be used.
- If a source test is used to estimate emissions for a process, test data gathered on-site for that process is generally preferred.
- The second choice is to use test data from similar equipment and processes on-site, or to use pooled source tests (tests taken from various similar facilities and averaged together) or test data taken from available literature.
- The reliability of the data may be affected by factors such as the number of tests conducted and the test methodology used.

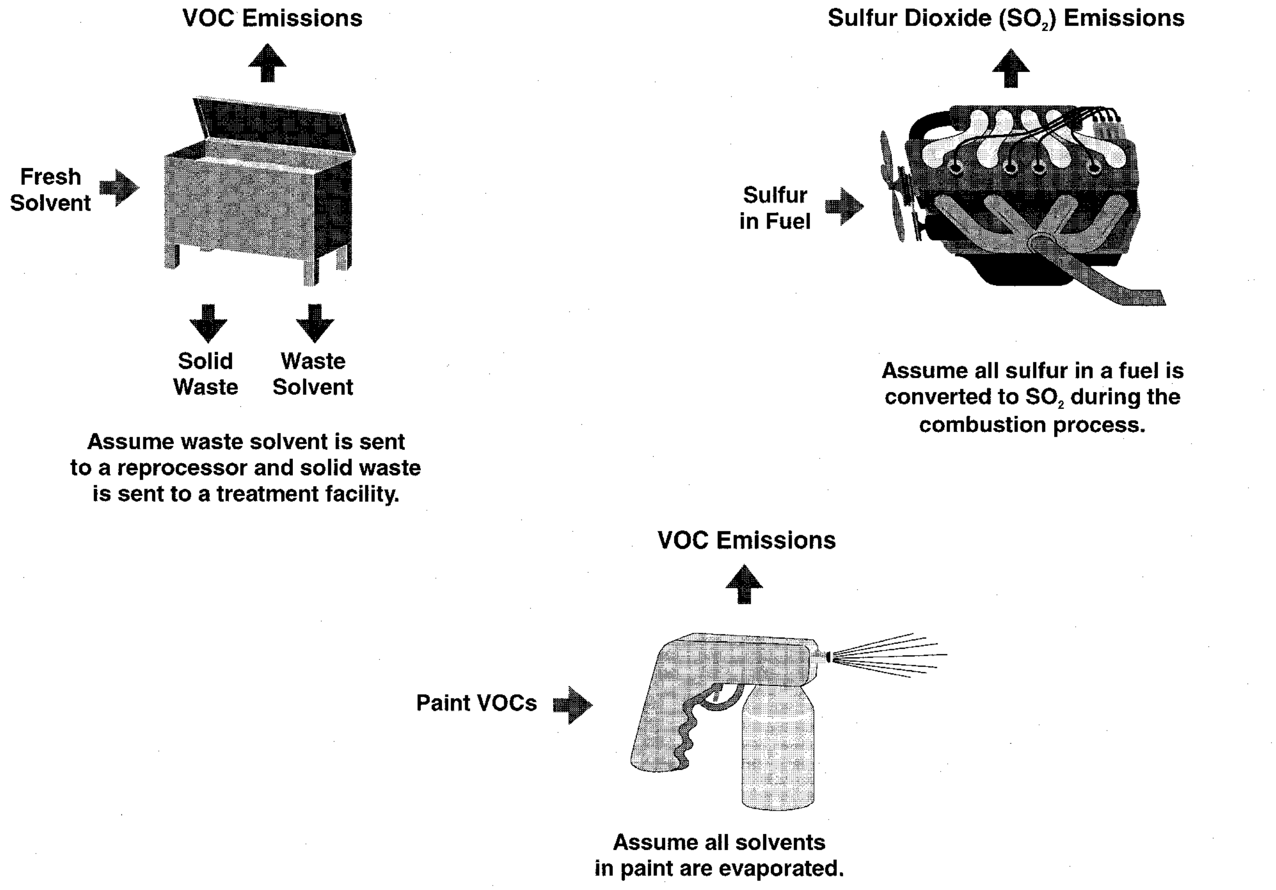
3.3 Material Balance

The material balance (also known as a mass balance) is a method commonly used for estimating emissions from many source categories. The basic assumption in the material balance method is that emissions are equal to the difference between the amount of material entering and exiting a process (allowing for fugitive losses, amount remaining in the final product, losses to wastewater, etc.). The material balance method can be used where source test data, emission factors, or other developed methods are not available. The material balance is most appropriate to use in cases where accurate measurements can be made of all but the air emission component, or when the emission estimate will be used for screening purposes if reasonable assumptions can be made about the fate of the compounds.

The use of a mass or material balance to determine total emissions from a process is usually simple and affordable. VOC emissions from solvent use (such as a coating operation) are often calculated using a material balance approach. In this case, the solvent sent to solid or hazardous waste disposal should be subtracted from total consumed:

$$\mathbf{Solvent_{total\ used}\ (liter) - Solvent_{waste}\ (liter) = Solvent_{emitted}\ (liter)} \qquad (3\text{-}3)$$

In the example above, the mass VOC/volume is multiplied by the volume of material used to give VOC emissions. Figure 3-2 illustrates examples of material balance.



Assume waste solvent is sent to a reprocessor and solid waste is sent to a treatment facility.

Assume all sulfur in a fuel is converted to SO_2 during the combustion process.

Assume all solvents in paint are evaporated.

Figure 3-2. Examples of Material Balances

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Example 3-7:

Calculate annual PM emissions from a surface coating operation that uses 1,800 liters/yr of coatings. The average density of the coatings is 1.2 kg/liter and the average solids content is 35% by mass. The coating transfer efficiency is 40% and the control device efficiency is 95%.

$$\begin{aligned} PM_{in} &= (1{,}800 \text{ liters/yr}) \times (1.2 \text{ kg/liter}) \times (35\% \text{ PM}) \\ &= 756 \text{ kg/yr} \end{aligned}$$

$$\begin{aligned} PM_{surface} &= 756 \text{ kg/yr} \times 40\% \\ &= 302 \text{ kg/yr} \end{aligned}$$

$$\begin{aligned} PM_{uncontrolled} &= PM_{in} - PM_{surface} \\ &= 756 - 302 \\ &= 454 \text{ kg/yr} \end{aligned}$$

$$\begin{aligned} PM_{controlled} &= 454 \text{ kg/yr} \times 95\% \\ &= 431 \text{ kg/yr} \end{aligned}$$

$$\begin{aligned} E_{PM} &= PM_{in} - PM_{surface} - PM_{control} \\ &= 756 - 302 - 431 \\ &= 23 \text{ kg/yr} \end{aligned}$$

<u>Material Balance - Issues to Consider</u>

- The material balance method should not be used for processes where material is reacted to form products or the material otherwise undergoes significant chemical change unless the process is well-characterized.

- Because the emissions are estimated to be the difference between the material input and the known material output, a small percentage error in estimating the input or output can result in a large percentage error in the emission estimate. Therefore, material balances may be inappropriate when considering a small difference (i.e., loss) between two rather large input and output values.

3.4 Emissions Models

A more complex method, an emissions model, is used to estimate emissions when emissions are not directly related to any one parameter. Models usually are computer-based so that a large number of equations and interactions can be easily calculated. The data requirements for models vary but in most cases at least one physical parameter is needed from the source for which the model will be used to estimate emissions. Examples of models available are the TANKS3 and WATER8 models which are used to calculate VOC emissions from storage tanks and wastewater collection and treatment, respectively (EPA, 1993c and EPA, 1994). These models are available free of charge through the CHIEF BBS, 95-919-541-5742. For more detailed information on emissions models, refer to Section 4.1 of Volume III: *Basic Emission Estimating Techniques*.

Emissions Models - Issues to Consider

- Models generally require more data than emission factors.
- The data needed will be dependent upon the particular emission source as well as the model. Emission models for wastewater treatment operations, for example, may require wastewater flow rate, pollutant concentration, and temperature, while emission models for storage tanks may require tank capacity, dimensions, throughput, and vapor pressure.
- The accuracy of the emission estimate is dependent upon the accuracy of the individual components entered.

3.5 Emission Estimation Cross-Reference Table

Table 3-1 (located at the end of this section) recommends emission estimation techniques for several industrial categories and their emissions sources. Many facilities (e.g., chemical manufacturers) have numerous types of air pollutant emission sources including production processes, combustion devices, equipment leaks, storage tanks, and solvent usage as described below:

- Process emissions from facilities are those that directly result from production or manufacturing processes. The magnitude and type of process emissions vary with the type of production;
- Generators, boilers, and incinerators are common sources of gaseous and particulate emissions from combustion;
- Fugitive VOC emissions may be emitted from leaking production equipment including pump seals, valves, flanges, other connections, and open ended lines;
- Storage tanks may generate fugitive VOC emissions during transfer operations or during daily temperature changes; and
- Solvent usage for equipment or parts cleaning (i.e., degreasing) is another common source of fugitive VOC emissions.

Air pollutant emissions from the various emission sources at a facility may be estimated by different methods. The methods available for estimating emissions are dependent on the particular emission source. The selection of an estimation technique from the available methods requires consideration of the availability of data. If more data are needed to use a particular method, the costs have to be weighed against the desired quality of the emission estimate. Where risks of adverse environmental effects are high, more sophisticated and costly emission estimation methodologies such as source tests may be necessary. Conversely, where risks are low, less expensive estimation methods such as emission factors and emission models may be acceptable.

The rankings of methods in Table 3-1 are based on the industry, the magnitude of emissions, and the cost and quality of the emission estimate for specific combinations of emission sources and pollutants. A rank of “1" indicates that a method is the most preferred estimation technique. If a method does not have a ranking, then it is not available for that particular emission source and pollutant.

How to Use Table 3-1

- Identify the emission sources at your facility.
- Using Table 3-1, identify the EET for each emission source.
- If possible, use the most preferred EET to estimate emissions from a given source (ranked number 1).
- Review the corresponding subsection of Section 3.1 and the *Basic EET* manual (Volume III) to determine the data needed to use the preferred EET.
- If data and resources are not available to use the preferred EET, then use the next best technique (ranked 2 or 3 in Table 3-1) to estimate emissions.

Table 3-1

Recommended Emission Estimating Techniques for Source Categories

Source Category	Emission Source	Pollutant(s)	Estimation Techniques[a]				Comments
			Emission Factor	Source Tests	Material Balance	Emission Models	
Electric Utility	Combustion	CO	2	1			
		NO_x	2	1			
		SO_x	3	1	2[b]		
		VOC	2	1			
		PM	2	1			
		NH_3[c]	2	1			
Chemical Manufacturing	Process	VOC	2	1			
		NH_3	2	1			
	Combustion	CO	2	1			
		NO_x	2	1			
		SO_x	3	1	2[b]		
		VOC	2	1			
		PM	2	1			
		NH_3[c]	2	1			
	Equipment Leaks	VOC	1	2			
	Storage Tanks	VOC			2	1	
	Wastewater Treatment	VOC	2		3	1	
	Solvent Usage	VOC			1		

Table 3-1

Continued

Source Category	Emission Source	Pollutant(s)	Estimation Techniques[a]				Comments
			Emission Factor	Source Tests	Material Balance	Emission Models	
Petroleum Refining	Process	VOC	2	1			
	Combustion	CO	2	1			
		NO_x	2	1			
		SO_x	3	1	2[b]		
		VOC	2	1			
		PM	2	1			
		NH_3[c]	2	1			
	Equipment Leaks	VOC	1	2			
	Storage Tanks	VOC			2	1	
	Wastewater Treatment	VOC	2		3	1	
	Solvent Usage	VOC			1		Solvents used for equipment maintenance.
Primary Metal Production	Process (non-combustion)	VOC	2	1			
		SO_x	3	1	2[b]		
		PM	2	1			
	Combustion	CO	2	1			
		NO_x	2	1			
		SO_x	3	1	2[b]		
		VOC	2	1			
		PM	2	1			
		NH_3[c]	2	1			
	Fugitive Dust	PM	1				Storage piles, haul roads, etc.

Table 3-1

(Continued)

Source Category	Emission Source	Pollutant(s)	Estimation Techniques[a]				Comments
			Emission Factor	Source Tests	Material Balance	Emission Models	
Secondary Metal	Process (non-combustion)	VOC	2	1			Includes charging, refining, and casting.
		PM	2	1			
	Combustion	CO	2	1			Emissions may be generated from charge materials in addition to combustion fuels.
		NO_x	2	1			
		SO_x	3	1	2[b]		
		VOC	2	1			
		PM	2	1			
		NH_3[c]	2	1			
	Fugitive Dust	PM	1				Storage piles, haul roads, etc.

Table 3-1

(Continued)

Source Category	Emission Source	Pollutant(s)	Estimation Techniques[a]				Comments
			Emission Factor	Source Tests	Material Balance	Emission Models	
Cement Production	Combustion	CO	2	1			
		SO_x	3	1	2[b]		
		VOC	2	1			
		PM	2	1			
		NH_3[c]	2	1			
	Fugitive	PM	1				Storage piles and driving surfaces dust.
	Process	PM	2	1			Dryer operations.
Miscellaneous Mineral Products (e.g., lime and aggregate kilns)	Process	PM	2	1			Crushing and grinding operations.
	Combustion	CO	2	1			
		NO_x	2	1			
		SO_x	3	1	2[b]		
		VOC	2	1			
		PM	2	1			
	Combustion	NH_3[c]	2	1			
	Fugitive	PM	1				Storage piles and driving surfaces dust.

Table 3-1

(Continued)

Source Category	Emission Source	Pollutant(s)	Estimation Techniques[a]				Comments
			Emission Factor	Source Tests	Material Balance	Emission Models	
Automotive Industry	Process	VOC	2	1			
	Combustion	CO	2	1			
		NO_x	2	1			
		SO_x	3	1	2[b]		
		VOC	2	1			
		PM	2	1			
		NH_3[c]	2	1			
	Solvent Usage	VOC			1		Cleaning operations.
Wood Pulping Operations	Process	VOC	2	1			Digesters, evaporators, oxidation towers, etc.
		SO_x	2	1			
		PM	2	1			
	Combustion	CO	2	1			
		NO_x	2	1			
		SO_x	2	1	3[b]		
		VOC	2	1			
		PM	2	1			
		NH_3[c]	2	1			

Table 3-1

(Continued)

Source Category	Emission Source	Pollutant(s)	Estimation Techniques[a]				Comments
			Emission Factor	Source Tests	Material Balance	Emission Models	
Oil and Gas Production	Process	VOC	2	1			
	Fugitive (including equipment leaks)	VOC	1	2			Pipeline valves and seals and other fugitive.
	Combustion	CO	2	1			
		NO_x	2	1			
		SO_x	3	1	2[b]		
		VOC	2	1			
		PM	2	1			
		NH_3[c]	2	1			
	Storage Tanks	VOC			2	1	
Printing and Publishing	Process	VOC	2	1	3		
	Fugitive	VOC			1		Equipment cleaning.
Surface Coating	Process	VOC	2	3	1		Use mass balance if no VOC control device.
		PM	1				
	Degreasing	VOC	2		1		
	Fugitive	VOC			1		Equipment cleaning.
Bulk Fuel Terminals	Loading	VOC	1		2		Mass balance used for VOC from spills.
	Storage Tanks	VOC	2			1	
	Equipment Leaks	VOC	1	2			

Table 3-1

(Continued)

Source Category	Emission Source	Pollutant(s)	Estimation Techniques[a]				Comments
			Emission Factor	Source Tests	Material Balance	Emission Models	
Mining and Quarrying	Process	PM	1				
	Fugitive	PM	1				Storage piles and road surface dust.
Wood Products Manufacture	Process	VOC	2		1		
		PM	1	2			
	Combustion	CO	2	1			
		NO_x	2	1			
		SO_x	2	1	3[b]		
		VOC	2	1			
		PM	2	1			
		NH_3[c]	2	1			
	Storage Tanks	VOC				1	
Sugar Production	Process	PM	1				
	Combustion	CO	2	1			
		NO_x	2	1			
		SO_x	2	1	3[b]		
		VOC	2	1			
		PM	2	1			
		NH_3[c]	2	1			
	Fugitive	VOC			1		

Table 3-1

(Continued)

Source Category	Emission Source	Pollutant(s)	Estimation Techniques[a]				Comments
			Emission Factor	Source Tests	Material Balance	Emission Models	
Tanning and Leather Finishing	Process	VOC			1		
	Combustion	CO	2	1			
		NO_x	2	1			
		SO_x	2	1	3[b]		
		VOC	2	1			
		PM	2	1			
		NH_3[c]	2	1			
Glass Production	Melting Furnace	CO	2	1			Includes combustion emissions.
		NO_x	2	1			
		SO_x	2	1			
		VOC	2	1			
		PM	2	1			
		NH_3[c]	2	1			
	Process	PM	2	1			Raw material blending and transport.
		VOC	2	1			Forming and finishing.

Table 3-1

(Continued)

Source Category	Emission Source	Pollutant(s)	Estimation Techniques[a]				Comments
			Emission Factor	Source Tests	Material Balance	Emission Models	
Rubber and Plastic Parts	Process	VOC	2	1			
	Combustion	CO	2	1			
		NO_x	2	1			
		SO_x	2	1	3[b]		
		VOC	2	1			
		PM	2	1			
		NH_3[c]	2	1			
Fabricated Metal Products	Process	PM	2	1			
	Combustion	CO	2	1			
		NO_x	2	1			
		SO_x	2	1	3[b]		
		VOC	2	1			
		PM	2	1			
		NH_3[c]	2	1			
Textile Products	Process	VOC	2	1	3		VOC from finishing operations.
		PM	2	1			Lint from mechanical operations.
	Combustion	CO	2	1			
		NO_x	2	1			
		SO_x	2	1	3[b]		
		VOC	2	1			
		PM	2	1			
		NH_3[c]	2	1			

Table 3-1

(Continued)

Source Category	Emission Source	Pollutant(s)	Estimation Techniques[a]				Comments
			Emission Factor	Source Tests	Material Balance	Emission Models	
Solid Waste Disposal	Landfill Gas	VOC				1	
	Municipal Waste Combustors	CO	2	1			
		NO_x	2	1			
		SO_x	2	1			
		VOC	2	1			
		PM	2	1			
		NH_3[c]	2	1			
	Open Burning Dump	CO	1				
		NO_x	1				
		SO_x	1				
		VOC	1				
		PM	1				
		NH_3	1				
Miscellaneous Industrial Activities and Processes	Process Emissions	CO	2	1	3		The emissions estimation method selected will be dependent on the particular industry. Generally, source tests provide the most accurate estimates; however, other methods may be more practical.
		NO_x	2	1	3		
		SO_x	2	1	3		

Table 3-1

(Continued)

Source Category	Emission Source	Pollutant(s)	Estimation Techniques[a]				Comments
			Emission Factor	Source Tests	Material Balance	Emission Models	
Miscellaneous Industrial Activities and Processes (Cont.)	Process Emissions	VOC	2	1	3		
		PM	2	1	3		
	Combustion Emissions	CO	2	1			
		NO_x	2	1			
		SO_x	2	1	3[b]		
		VOC	2	1			
		PM	2	1			
		NH_3[c]	2	1			
	Fugitive	VOC			1		Solvent cleaning is a common VOC source.
Government Facilities	Combustion	CO	2	1			Typically includes space heating, as well as combustion for process operations.
		NO_x	2	1			
		SO_x	2	1	3[b]		
		VOC	2	1			
		PM	2	1			
		NH_3[c]	2	1			
	Fugitive	VOC			1		Typically includes solvent cleaning.

Table 3-1

(Continued)

Source Category	Emission Source	Pollutant(s)	Estimation Techniques[a]				Comments
			Emission Factor	Source Tests	Material Balance	Emission Models	
Food and Agriculture	Process	VOC	1	2			Includes alfalfa dehydration, grain elevators, beer production, etc.
		PM	1	2			
	Combustion Emissions	CO	2	1			
		NO_x	2	1			
		SO_x	2	1	3[b]		
		VOC	2	1			
		PM	2	1			
		NH_3	2	1			
Asphalt Plants	Process	PM	2	1			Aggregate handling operations.
	Combustion Emissions	CO	2	1			
		NO_x	2	1			
		SO_x	2	1	3[b]		
		VOC	2	1			
		PM	2	1			
		NH_3	2	1			

[a] Emission estimation techniques are discussed briefly in Section 2.1 and in detail in *Volume III: Basic Emissions Estimating Techniques*. The numeric values indicate the order of preference that should be considered when selecting an estimation technique, number 1 being the most preferred.

[b] Based on fuel sulfur analysis from supplier.

[c] Ammonia slip from SCR used as a NO_x control method.

CO = carbon monoxide
NH_3 = ammonia
NO_x = oxides of nitrogen
PM = particulate matter
SO_x = oxides of sulfur
VOC = volatile organic compound

4.0 SPECIAL CONSIDERATIONS INFLUENCING EMISSIONS

Variability in processes, equipment, and raw materials used within the inventory region can lead to variability in emissions. In addition, some emission sources are frequently overlooked and inadvertantly excluded from inventory efforts. These two special considerations affecting point source inventory development are addressed below.

4.1 Design and Process Variability

Many factors can influence emissions. This section presents some of the factors that may vary from device to device or from region to region. **The inventory developer should be aware of these factors and should try to collect device-specific or region-specific data whenever possible.**

4.1.1 Combustion Characteristics

Combustion products from fuel burning can include partially oxidized hydrocarbons, carbon monoxide (CO), sulfur dioxide (SO_2), sulfur trioxide (SO_3), oxides of nitrogen (NO_x), acids such as hydrochloric acid, organohalides, and particulates. The generation of combustion products is strongly influenced by fuel type, furnace type, firing configuration, and boiler operating conditions. Although a detailed discussion on boiler operations is not presented here, some general observations are included to assist in understanding the relative impact of various boilers and fuel types on air emissions.

Fuel Properties: The four primary classifications of coal are lignite, anthracite, bituminous, and subbitumimous. Fuel is ranked based on standard methods referred to as “proximate” and “ultimate” analyses. Proximate analyses report fuel composition in broad categories such as moisture content and ash content. Ultimate analyses provide an estimate of the carbon, hydrogen, sulfur, oxygen, nitrogen, and water content of the fuel. An ultimate analysis is used to compute combustion air requirements and can be used to calculate fuel factors (F_d) for determining exhaust flow rates. Generally, boiler size, firing configuration, and operation has little effect on the percent conversion of fuel sulfur to sulfur oxides, so fuel analysis is typically a valid means of predicting emissions of sulfur oxides. Example 4-1 shows how fuel analysis can be used to estimate SO_2 emissions.

Example 4-1:

This example shows how SO_2 emissions can be calculated from oil combustion based on fuel analysis data.

Emissions of SO_2 may be calculated using the following equation:

$$E = Q_f \text{ x Pollutant concentration in fuel x } (MW_p/MW_f)$$

where:

E = Emissions
Q_f = Fuel Flow rate
MW_p = Molecular weight of pollutant emitted (g/gmole)
MW_f = Molecular weight of pollutant fuel (g/gmole)

For this example:

Q_f = 2.09×10^4 kg/hr
Percent sulfur (%S) in fuel = 1.17
MW of SO_2 = 64
MW of Sulfur(S) = 32
E_{SO2} = Q_f x Pollutant concentration in fuel x (MW_p/MW_f)
= $(2.09 \times 10^4)(1.17/100)(64/32)$
= 489.3 kg/hr

In addition, the Norma Mexicana (Mexican Official Standard) NOM-086-ECOL-1994 defines the environmental protection specifications for liquid and gaseous fossil fuels used in stationary and mobile sources (SEMARNAP, 1994). Specifications for natural gas and petroleum products such as gasoline, diesel, fuel oil, and liquified petroleum gas (LPG) being used in the various geographical regions are defined in this standard. Fuel specifications have been defined for critical zones, such as Mexico City, Guadalajara, and Monterrey Metropolitan zones and North Boundary zone.

Table 4-1 presents a list of fuel types, their applicability based on geographical regions, and the fuel specification reference in NOM-086-ECOL-1994 where detailed information on fuel characteristics (including sulfur content, Reid vapor pressure, ash content, etc.) can be found. The specifications defined in NOM-086-ECOL-1994 can be used to develop emission estimates if more specific information on fuel properties cannot be obtained from PEMEX or government agencies.

Operating Conditions: By contrast, NO_x formation is highly dependent on boiler conditions, especially temperature and air/fuel ratios near the burner. NO_x formation is produced by two mechanisms: 1) conversion of fuel-bound nitrogen and 2) oxidation of molecular nitrogen from combustion air (referred to as thermal NO_x formation). Thermal NO_x formation is highly temperature dependent and becomes rapid as temperatures exceed 1,649°C (Buonicore, 1992). Lower operating temperatures result in decreased thermal NO_x production. Shorter residence time also lowers thermal NO_x generated by oil- and coal-fired boilers. Nitrogen oxide emissions from the tangential-fired oil boilers are typically lower than those from horizontally opposed units. Many boilers employ combustion modifications to reduce NO_x emissions. These include staged combustion, off-stoichiometric firing, flue gas recirculation (FGR), and low-NO_x burners with overfire air (OFA). These control strategies can reduce NO_x emissions by 5 or 50 percent (Buonicore, 1992).

Table 4-1

Applicability by Geographical Regions and Specification Reference in NOM-086-ECOL-1994 for Fuel Types

Fuel	Fuel Specification Table Number in NOM-086-ECOL-1994	Applicability by Geographical Regions
Gasoline (Magna Sin)	Table 1	Country-wide, except Mexico City Metropolitan Zone (ZMCM-Zona Metropolitana de la Ciudad de Mexico) and North Boundary Zone (ZFN-Zona Fronteriza Norte) through 1997[a]
Gasoline (Magna Sin Zona Fronteriza Norte)	Table 2 and Annex 1, 2, and 3 of Table 2	North Boundary Zone Distribution influence area of the following marketing terminals: • Ciudad Juárez and Tijuana • West Zone (including Cananea, Ciudad Obregon, Guaymas, Hermosillo, Magdalena and Nogales in Sonora, and Ensenada, Rosarito and Mexicali in Baja California • North Zone (including Avalos and Monclova in Coahuila; and Nuevo Laredo and Reynosa in Tamaulipas.
Gasoline (Magna Sin Zonas Metropolitanas)	Table 3	Mexico City Metropolitan Zone through 1997. In 1998, Mexico City, Guadalajara, and Monterrey Metropolitan Zones.
Gasoline (Nova Plus)	Table 4	Country-wide, except Mexico City Metropolitan Zone through 1997[b]
Gasoline (Nova Plus-Zonas Metropolitanas)	Table 5	Mexico City Metropolitan Zone through 1997. In 1998, Mexico City, Guadalajara, and Monterrey Metropolitan Zones.

Table 4-1

(Continued)

Fuel	Fuel Specification Table Number in NOM-086-ECOL-1994	Applicability by Geographical Regions
Diesel (Diesel Sin)	Table 6	Mexico City, Guadalajara, and Monterrey Metropolitan Zones.
Low Sulfur Diesel (Diesel Desulfurado)	Table 7	Country-wide
Diesel (Diesel Industrial)	Table 8	Country-wide. Exclusively for use in open-flame flares
Fuel Oil (Gasoleo Industrial)	Table 9	Country-wide, except Mexico City Metropolitan Zone. Not available after December 31, 1997. Exclusively for use in open-flame combustion.
Heavy Fuel Oil (Combustóleo Pesado)	Table 10	Country-wide
Natural Gas (Gas Natural)	Table 11	Country-wide
Liquefied Petroleum Gas-LPG (Gas LP)	Table 12	Country-wide
Aviation gasoline (Turbosina) or Aviation turbine fuel	Table 13	Country-wide

[a] In 1998, applicable country-wide except Metropolitan zones of Mexico City, Guadalajara, and Monterrey, and ZFN.

[b] In 1998, applicable country-wide except Metropolitan zones of Mexico City, Guadalajara, and Monterrey.

4.1.2 Raw Materials

In addition to the effects that fuel properties can have on emission estimates, physical and chemical properties of other raw materials used by a point source may also influence emissions. For example, the material density is often used to convert the volume of material used to a mass of material used. As another example, the material VOC content (i.e., g/L) is often used to estimate emissions from surface coating operations.

The physical and chemical properties of some raw materials may vary throughout Mexico. For instance, the “maquiladora” industry, principally located in the northern border zone, began in the 1960's as part of a plan to bring international industrial facilities to Mexico. The plan allowed foreign companies to bring equipment, components, and raw materials into Mexico without paying tariff barriers. Therefore, many of the raw materials used by the maquiladoras may be imported and may be different from the raw materials used in other regions of Mexico.

4.1.3 Operating Practices

Operating practices may vary in different regions of Mexico and potentially impact the development of emission estimates. For example, many of the technologies, production standards, and operating practices of the maquiladoras are imported and reflect foreign industrial practices. In general, the foreign industrial plants are more automated, whereas Mexican industry traditionally tends to use more manual processes and is often more artisan based. These differences may result in different emission estimates. For example, automated surface coating equipment generally can apply a thinner and more even layer of paint with less overspray than if manual, hand-held paint spray equipment are used.

4.1.4 Age of Equipment

In Mexico, the manufacturing sector is comprised of a small number of large national consortia and foreign companies (2,481 in 1992) and a large number of micro (101, 226), small (20,734), and medium (3,338) companies. In general, the large manufacturing facilities have implemented clean and competitive production processes and use modern equipment. On the other hand, the smaller companies operate with older equipment and technologies and are considered to be high energy-consumers that may be significant polluters, despite their smaller size.

The age of equipment can influence the development of emission estimates in a couple of ways. First, newer equipment may employ a newer technology that was designed to reduce emissions. For example, recently designed Low Emission Vapor Degreasers (LEVDs) use new technologies such as full vacuum or sealed degreasing chambers to significantly reduce emissions compared to a conventional, open-top degreaser. Second, the age of equipment should be considered when selecting an emission factor for an emission source. In order for the emission factor to be applicable, the age of the equipment inventoried should be similar to the age of equipment tested to develop the emission factor.

4.1.5 Meteorological and Climatological Data

Meteorological and climatological information are needed when estimating emissions from certain emission sources. For example, parameters such as annual average ambient temperature and wind speed are required by the emission estimating equations for storage tanks. As another example, the quantity of fuel combusted for heating or air-conditioning purposes will generally vary based on climate.

Region-specific climatological information should be obtained from reports developed by the National Institute of Statistics, Geography and Computer Science (INEGI) or by the National Meteorological and Atmospheric Science Center at the National University (UNAM).

4.2 Typically Overlooked Emission Sources

Some processes that routinely emit atmospheric pollutants are often overlooked in emissions inventories. Inventory preparers should be aware of these processes and should include emissions from the following sources:

- In-process fuel-fired equipment;
- Fugitive components;
- Control devices;
- Miscellaneous solvent use;
- On-site vehicles
- Process additives
- Storage piles; and
- Material handling.

The responsibility for properly recording this information is given to the emissions inventory preparer. Examples of the typically overlooked processes and ambiguities about equipment classifications are discussed below.

4.2.1 In-Process Fuel-Fired Equipment

Many industrial processes use fuel-fired equipment or indirect-fired equipment as part of a given manufacturing process. For example, cement kilns use fuel-fired dryers to dry the product. Another example of in-process fuel use is natural gas-fired dryers for coating operations. **Emissions from in-process fuel use are estimated using the same techniques used to estimate emissions from combustion sources and should be included in the inventory**.

4.2.2 Fugitive Emission Sources

There are several potential sources of equipment leak emissions associated with the oil and gas, petroleum refining, and petroleum product distribution industries. Components such as pumps, valves, pressure relief valves, flanges, agitators, and compressors are potential sources that can leak due to seal failure. Fugitive component emissions occur from process equipment whenever the liquid or gas stream leaks. These emissions generally occur randomly and are difficult to predict. In addition, these emissions may be intermittent and vary in intensity over time. Therefore, measurements of equipment leak emissions actually represent a “snapshot” of the leaking process. Other sources, such as open-ended lines, and sampling connections may leak to the atmosphere for reasons other than faulty seals. The majority of data collected in the United States for estimating equipment leak emissions has been from the synthetic organic chemical manufacturing industry, petroleum refineries, petroleum marketing terminals, gas processing plants, and oil and gas production facilities for total organic compounds and non-methane organic compounds.

The *Protocol for Equipment Leak Emission Estimates* document (U.S. EPA, 1995c) is a good reference for information about procedures and approaches for estimating emissions from equipment leaks. Available approaches for estimating emissions from equipment leaks range from the simple (multiplying equipment counts by average emission factors) to the complex (developing unit-specific correlations of mass emission rates and screening values). Several pages of this document which describe the average emission factor approach and the screening ranges approach are presented as Appendix IV-C.**

In addition to equipment leaks from fugitive components, there are other miscellaneous fugitive emissions that may or may not be regularly identified as a “point source” associated with a given process or industry. Emission inventory specialists use published lists to begin a point source list which is further developed based on personal observations. Examples of fugitive process emissions that may be added include metallurgical fumes from welding or soldering, particulate emissions from metal-working operations, or ammonia emissions from reproduction (e.g., blueprinting) services.

The inventory development must diligently search for fugitive sources of emissions and include them in the inventory to prevent the underestimation of emissions.

4.2.3 Control Devices

Care must be taken when accounting for the influence that control devices have on emissions. Though control devices are generally used to reduce emissions, it may be possible that they are also emission sources. The best example is the use of selective reduction to control combustion emissions. Selective reduction is used to control NO_x emissions, but may result in ammonia emissions due to “ammonia slip,” that is, excess ammonia that is unreacted and that is directly released.

4.2.4 Miscellaneous Solvent Usage

Solvents are often used to spot clean pieces of equipment prior to surface coating or other manufacturing processes. In addition to degreasing vats where the components are actually submerged into the solvent, solvent cleaners may be applied by hand using small brushes or rags. **Emissions occur when these solvents evaporate and should be quantified using the material balance technique. These emissions should be included in the emissions inventory**.

4.2.5 On-site Vehicle Emissions

Large industrial complexes may have vehicle fleets used on-site to transport materials, products, or personnel within a facility. The vehicles themselves are sources of combustion related pollutants - NO_x and CO in particular. Also, if the roads used within the facility are not paved, particulate matter may be stirred up from the road surface. **The regulatory agency should decide if on-site vehicle emissions should be included in the point source inventory. Emissions from this source are usually estimated using emission factors**.

4.2.6 Process Additives

Any chemicals added to a production or control process have the potential to be emitted. Examples of these types of sources include ammonia injected into flue gas to control NO_x and catalysts used in chemical reaction processes. **Emissions from these processes are estimated using source tests, emission factors, or material balance techniques and should be included in the inventory**.

4.2.7 Storage Piles

Storage piles may be a source of particulate matter emissions if not properly covered and otherwise controlled. Materials typically found in storage piles include coal at power plants, rocks at concrete and/or asphalt production facilities, and other materials stored in bulk. **These sources have the potential to generate significant PM emissions and should be included in the emissions inventory. PM emissions from these sources are estimated using emission factors or models**.

4.2.8 Materials Handling

Materials transported via truck or rail which are not covered may also produce particulate matter emissions. Within a facility, materials such as coal may be transported via conveyor belts or pneumatic transport systems which result in fugitive particulate emissions. **As with storage piles, emissions from these sources are usually estimated using emission factors or models and should be included in any emissions inventory**.

5.0 AIR POLLUTION CONTROL DEVICES

To properly estimate emissions, the effectiveness of an existing control device must be applied in the emission calculations. Control devices for reducing particulate and volatile organic compound (VOC) emissions generally employ physical collection or combustion processes. Sulfur oxides and nitrogen oxides are more often controlled by chemical transformation. Control devices for carbon monoxide are typically not used by stationary sources. Ammonia emissions may be controlled by physical, combustion, or chemical processes. A basic description of the techniques typically used by industry to control particulate matter of less than 10 microns (PM_{10}), VOCs, sulfur dioxide (SO_2), oxides of nitrogen (NO_x), and hazardous air pollutants can be found in the *Control Technologies for Hazardous Air Pollutants Handbook* (U.S. EPA, 1991).

5.1 Control Effectiveness

The control device efficiency is the percentage of the air pollutant that is removed from the emission stream before release to the atmosphere. In addition to control device efficiency, emissions will be determined by capture efficiency of a system. The capture efficiency indicates the percentage of the emission stream that is taken into the control system. Overall control effectiveness is a product of the capture device efficiency and the control device efficiency. Consequently, estimates of efficiencies for capture devices and control devices are needed for accurate emissions estimates.

Example 5-1:

If you have a highly efficient afterburner (to reduce VOC emissions) that achieves 99% destruction, and the capture system achieves 80% capture efficiency, then the total VOC reduction efficiency is only 79.2%.

Control Effectiveness = control device efficiency (%) x capture efficiency (%)
= 99/100 x 80/100
= 79.2%

5.1.1 Capture Efficiency

The capture efficiency is defined as the fraction of pollutant emitted from the processing point that is actually gathered by baffles, hoods, or other capturing devices, and routed to the control device. Capture efficiency can be estimated by tests preformed at the facility for which emissions are being estimated. Often, capture device efficiency is estimated on the basis of tests performed on similar equipment at other facilities. Alternatively, capture efficiency can be estimated from manufacturer's specifications or literature values. In the absence of capture efficiency data, estimates may be based on engineering judgement (e.g., all of the pollutants from an enclosed emission source are ducted to the control device).

5.1.2 Control Device Efficiency

Three different ways to determine control device efficiency are presented below in order of preference.

Source Test: Control device efficiency may be determined for specific equipment and operating conditions by source tests measuring pollutant concentrations before and after application of the control device.

However, because of possible variation in control device operation with process, control device malfunction, and deterioration over time, the measurement is subject to the potential limitations of all source tests.

Manufacturer Specification: A second method of obtaining a control efficiency is to use the manufacturer's design specification or guaranteed performance specification.

However, the design collection efficiency reported by manufacturers is the efficiency obtainable under optimum conditions and may not represent actual conditions. In addition, a control device may be improperly sized for effective control of the process under consideration. Some assessment of design efficiency will be required to adjust for these source conditions.

Literature Values: When test data or manufacturer's specifications are not available for estimating control efficiency of a specific control device, literature values may be used. Table 5-1 lists control devices commonly used at stationary point sources, applicable pollutants controlled, and their typical control efficiencies.

While Table 5-1 may be used for rough estimates of control device efficiencies, control efficiency will be affected by the specific operating conditions. Consequently, control efficiency estimates may not be precisely applicable to specific control devices. Knowledge of the process and engineering judgement must be used in addition to the estimate.

Control device efficiency estimates will also need to be adjusted for downtime or control device condition (e.g., degradation of fabric filter bags). If control devices are shut down periodically for maintenance or by upset conditions, the emissions released in a given hour may far exceed those released in the controlled mode over many hours of operation. Failure to

Table 5-1

Typical Control Devices and Control Efficiencies (%)[a]

Device/Technique	**Pollutant**			
	Particulate Matter	**VOC**	**SO_x**	**NO_x**
Cyclone	80-90+			
Fabric Filter	80-99+			
Electrostatic Precipitator	95-99+			
Scrubber	80-95	--	80-98	--[b]
Absorption		90-99	--	--[b]
Adsorption		50-99	--[b]	--[b]
Condensation	--	50-95		
Thermal Incineration	--	95-99+		
Catalytic Incineration		95-99+		--
Selective Catalytic Reduction				40-90
Selective Noncatalytic Reduction				40-60

Sources: Emission Inventory Improvement Program (EIIP), July 1995a and Nevers, 1995.

[a] Efficiencies are estimates only. Specific knowledge of the actual process and device is required for a more accurate efficiency estimate.

[b] Experimental control technique.

-- = Data not available.
SO_x = oxides of sulfur
NO_x = oxides of nitrogen
VOC = volatile organic compound

account for excess emissions resulting from downtime and deteriorated efficiency can be a large source of error in an emission estimate.

5.2 Control Device Descriptions

Brief descriptions of some common control devices and techniques are presented in this section. Further detail can be found in *Air Pollution Control, A Design Approach* (Cooper and Alley, 1994). For additional information on control device advantages/disadvantages, cost, consult *Control Technologies for Hazardous Air Pollutants* (U.S. EPA, June 1991), *OAQPS Control Cost Manual* (U.S. EPA, 1990), and *Air Pollution Engineering Manual* (Buonicore 1992).

5.2.1 Cyclone

The cyclone (also known as a “mechanical collector”) is a particulate control device that uses gravity, inertia, and impaction to remove particles from a ducted stream. Large diameter cyclones are often used as primary cleaners to remove the bulk of heavier particles before from an air stream before entering a secondary cleaner (EIIP, 1995b).

5.2.2 Fabric Filter

Fabric filter systems (often called baghouses) filter particles through filtering elements (bags). Particles are caught on the surface of the bags, while the cleaned air stream passes through. Fabric filters can achieve the highest particulate collection efficiency of all particulate control devices (EIIP, 1995b).

5.2.3 Electrostatic Precipitator

Electrostatic precipitators (ESPs) are used to control particulate emissions. ESPs employ electrical forces to remove particles from the gas stream onto collecting plates. The accumulated particles are then knocked or washed off the plates and into collecting hoppers (EIIP, 1995b).

5.2.4 Scrubber

Scrubbers are used to remove particulate matter and sulfur oxides. Wet scrubbers utilize water to remove particles by direct contact from an air stream. Sulfur oxides may be controlled with alkaline liquids in wet or dry scrubbers.

5.2.5 Absorption

Absorption is an operation in which components of a gas mixture are transferred into a liquid. This process can be physical, when the absorbed compound simply dissolves in the solvent, or chemical, when a reaction occurs (U.S. EPA, 1991). In a majority of pollution control applications, the liquid is water and the process is sometimes referred to as scrubbing or washing (Cooper, 1994). The type of equipment most often used for gas/liquid contact operations is the packed tower. The gas stream enters the bottom of the column and passes upward through a wetted packed bed. The liquid enters the top of the column and is uniformly distributed over the column packing. Mass transfer from the gas to the liquid phase occurs across the gas-liquid interface provided by the wetted surface of the tower packing (Cooper, 1994).

5.2.6 Adsorption

An adsorber system controls VOC by selectively adsorbing the compounds on a surface, or bed, that is typically carbon. Adsorbed VOC are removed from the carbon bed in the process of desorption by heating the carbon, typically using steam, or by reducing the pressure of the system. These systems include fixed beds and moving beds, which are also known as fluidized beds. Some fluidized systems have also been designed for SO_2 adsorption (Nevers, 1995; U.S. EPA, 1991; Cooper, 1994).

5.2.7 Condensation

Condensation is a separation technique in which VOC are separated from a gas through saturation followed by a phase change to a liquid. Two techniques may be used to produce the VOC phase change: (1) increase the system pressure at a given temperature; or (2) reduce the system temperature at a constant pressure. The two most common types of condensers used are surface and contact condensers (U.S. EPA, 1991).

5.2.8 Incineration

Thermal incineration is a widely used control technique that oxidizes VOC at high temperatures. These devices are capable of high control efficiencies (e.g., greater than 99 percent VOC destruction). Catalysts may be used to help oxidize the VOC in catalytic incinerator systems (U.S. EPA, 1991).

5.2.9 Selective Reduction

Selective catalytic reduction is an add-on technology that controls nitrogen oxides by reacting them catalytically with ammonia to form nitrogen and water. Selective noncatalytic reduction technologies use a reducing agent to reduce the nitrogen oxides to nitrogen and water (EIIP, 1995a; EIIP, 1995b).

6.0 STACK PARAMETERS

Stack data are needed if the inventory is being used for air quality modeling. This includes the obvious smokestacks or chimneys, as well as less obvious vents, pipes, or other openings that exhaust air pollutants. Depending on the model and the modeling objective, stacks may be treated individually or may be grouped. The remainder of this chapter discusses the stack parameters. See *Screening Procedures for Estimating the Air Quality Impact of Stationary Sources, Revised* for more discussion on the requirements for modeling inventories (U.S. EPA, 1992).

The stack parameters usually required for modeling are:

- Location;
- Height;
- Diameter;
- Temperature;
- Velocity; and/or
- Volumetric flow rate.

In a large facility, compiling parameters for all stacks may pose a significant data collection challenge. It is often possible to treat groups of similar stacks as a single stack.

6.1 Stack Location

The location of each stack is identified by geographic coordinates such as latitude and longitude, or universal transverse mercator (UTM) coordinates. For dispersion modeling, the stack locations should be accurate to within 10 meters. For regional modeling, less accuracy may be tolerable. The stack locations can be determined by several different methods which are briefly described below.

6.1.1 Global Positioning System (GPS)

A GPS can be used to determine a location very accurately. Numerous GPS satellites currently in orbit around the earth function as known reference points; they broadcast satellite identity, position, and time. By making distance measurements to four or more satellites, the location of a GPS receiver on the ground can be determined using trilateration.

A good GPS is costly, with survey grade GPS receivers ranging from U.S. $10,000 to $30,000. A survey grade GPS receiver has a 1 cm to 1 meter accuracy depending on whether an FM receiver is used for differential correction or post-processing is performed from a base station fixed over a known point. Accuracy also depends on the occupation times over a location to be surveyed (10 minutes to 1 hour for cm accuracy).

Resource grade GPS receivers cost U.S. $600-4,000 and have a 1 to 10 meter accuracy. Recreational grade receivers cost U.S. $200-600 with 100 meter accuracy. The accuracy of these two grades of GPS receivers may not be adequate for certain point source inventory efforts with a small inventory domain or where micro-analysis is needed.

6.1.2 Survey Data/CAD Maps

If the site has been surveyed, the locations of specific stacks can sometimes be determined from the survey maps or computer aided design (CAD) files. At least two benchmarks must be located within the surveyed area; however, the more benchmarks within the area, the more accurate the stack can be located. The survey locations are then calibrated according to the benchmarks. The Instituto Nacional de Estadística, Geografía e Informática

(INEGI) [National Institute of Statistics, Geography and Computer Science] standards and procedures should be followed for identifying benchmarks.

6.1.3 Topographic Maps

The least accurate method for locating stacks is to use a topographic map to locate the plant. If the plant has more than one stack, it is unlikely that this method can be used to accurately locate each individual stack. However, this level of detail is generally not required for large-scale, regional modeling (see discussion in 6.1, above, on dealing with groups of stacks).

6.2 Stack Height

The stack height is measured from the ground. The most common inventory error for this parameter is in measuring the height above the roof rather than above ground. Three methods of determining stack height are described briefly below.

6.2.1 Clinometer

A clinometer is a simple device that can be used to measure the height of an object. The distance from the person taking the measurement to the base of the stack is also needed to complete the calculations. Accuracy varies and primarily depends on:

- How accurate the measurement to the base is; and
- Precision of the clinometer.

Figure 6-1 illustrates the use of a clinometer. In this figure, the stack is located at the edge of the building, so measurement of the distance to the base is not obstructed. If the stack is positioned near the middle of the building, it may be more accurate to measure building

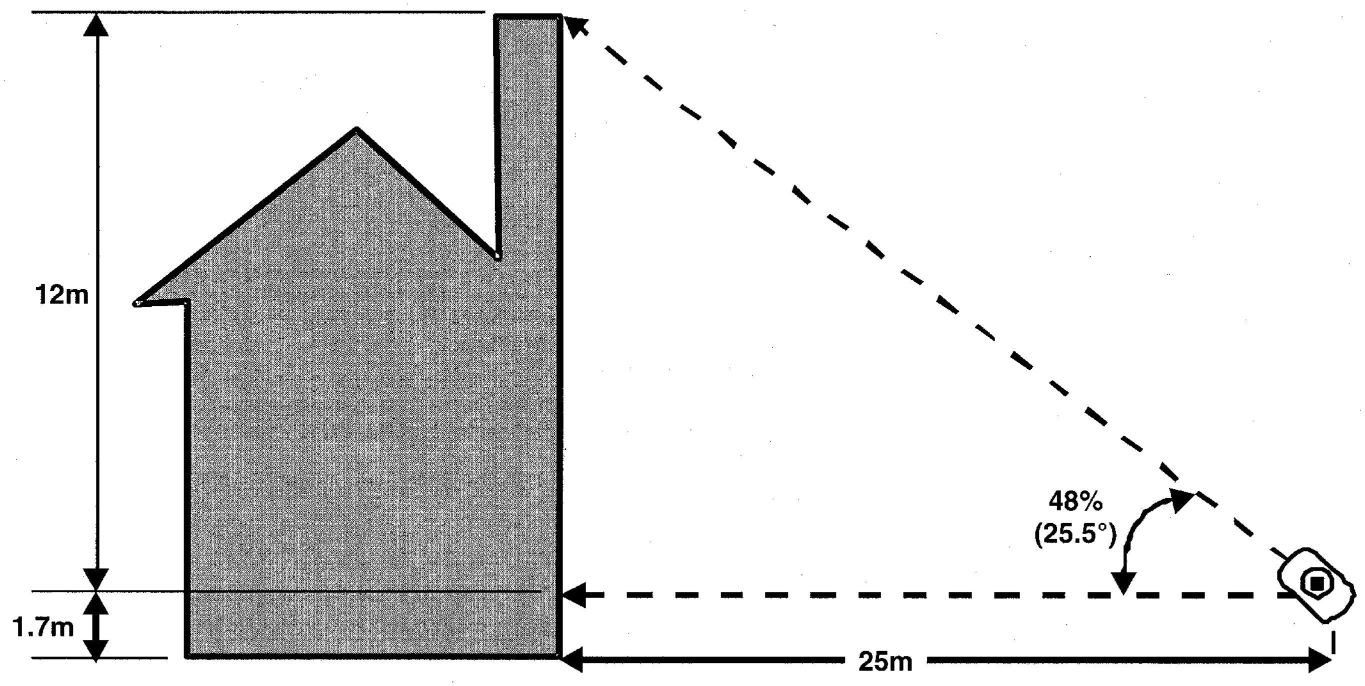

Figure 6-1. Using a Clinometer to Measure Stack Height

height and stack height above the roof (using a clinometer) and add the two measurements together.

The clinometer reading is given as a percentage of the distance to the base. In the example shown in Figure 6-1, the stack height (from eye-level) is:

$$\mathbf{48/100 \times 25 = 12.0\ m} \tag{6-1}$$

The eye's height from the ground (1.7 m) is added to give a total height of 13.7 m.

6.2.2 Direct Measurement

If the stack is not too tall, the measurement can be made directly. Generally, it is easiest to drop a measuring tape from the roof to the ground to measure building height; then the height of the stack from the roof to the top of the stack is measured. The total height is equal to the sum of these two measurements.

6.2.3 Architectural/Engineering Drawings

If blue prints or other building schematics are available, the stack heights may be taken directly from them. However, verify the height (using one of the other two methods or by estimation) if possible.

6.3 Stack Diameter

The exit diameter or inner diameter of the stack are the parameters of interest. The inner diameter should be measured directly. If blueprints or drawings are used, verify the reasonableness of the values shown. This is a very important variable because it affects the exit velocity calculation and should, therefore, be measured as accurately as possible.

If the stack is not round, the diameter is calculated from the area of the stack. For example, the area (A) of a rectangular vent is calculated by measuring the length of the two (unequal) sides, and multiplying them together. The area of a circle is πr^2 (where r is the radius or 1/2 of the diameter). The effective diameter (d) therefore, is calculated as:

$$\mathbf{d = 2 \times \sqrt{A/\pi}} \tag{6-2}$$

6.4 Temperature

The temperature of the gases at the point where they leave the stack is another important variable. In most models, the exit temperature affects the height of the plume rise. This value should be measured just inside the top of the stack.

Remember that if the stack is very tall, the gases will cool significantly as they rise. Most exit temperatures for some specific processes fall within a typical range but temperatures outside those ranges are also possible. For example, wet scrubbers (or other controls) may significantly reduce temperatures from combustion processes.

6.5 Exit Velocity

This is the exit velocity of the stack gases. It is usually calculated from the stack diameter and volumetric flow rate as follows:

$$\textbf{Exit velocity (m/s)} = \frac{\textbf{flow rate (m}^3\textbf{/s)}}{\textbf{area of stack (m}^2\textbf{)}} \tag{6-3}$$

The area of the stack is calculated using the stack diameter at the point of exit (see Section 6.3 above).

6.6 Volumetric Flow Rate

The volumetric flow rate is the volume of gases exiting a stack or other emission point per unit of time (e.g., m^3/s).

The flow rate is not used directly for modeling. However, it is more commonly available (i.e., measured or in manufacturers' specifications for exhaust fans) than is exit velocity. Therefore, the actual volumetric flow rate is typically used to calculate velocity (see Section 6.5). If the flow rate has been converted to a standard (or sometimes expressed as "normal" flow rate), it should be converted back to actual flow.

7.0 QUALITY ASSURANCE/ QUALITY CONTROL

Quality assurance activities are essential to the development of comprehensive, high-quality emission inventories for any purpose. The development of a reasonable and comprehensive emissions inventory requires the implementation of quality assurance/quality control (QA/QC) procedures throughout the entire inventory process. For more information on QA/QC, uncertainty, and emissions verification, see Emission Inventory Improvement Program (EIIP) Volume VI: *Quality Assurance Procedures for the Emission Inventory Improvement Program*, external draft (EIIP, 1995c).

Quality assurance is an integrated system of activities involving planning, QC, quality assessment, reporting, and quality improvements which are designed to help ensure that the inventory meets the data quality goals or objectives established prior to developing the inventory. Quality control is the overall system of routine technical activities that are designed to measure and control the quality of the inventory as it is being developed. The main objective of QA/QC for emissions inventories is the development of accurate, useful, and reliable data.

Figure 7-1 shows the basic steps involved in INE's point source inventory QA/QC procedures. The INE auditor randomly selects a facility to QA/QC from a strategic set of industrial sectors. The auditor obtains a copy of the industrial questionnaire (Encuesta Industrial) that the facility submitted to INE and performs a "general revision". This general revision consists of reviewing the submitted data for completeness and reasonableness. After that, the auditor makes a list of the SNIFF codes that the auditor thinks should be assigned to the data submitted on the questionnaire. Then, the SNIFF codes assigned by the auditor are compared with the codes that INE's coders actually assigned when they entered the questionnaire data into the SNIFF data files, and modifications are made, if necessary.

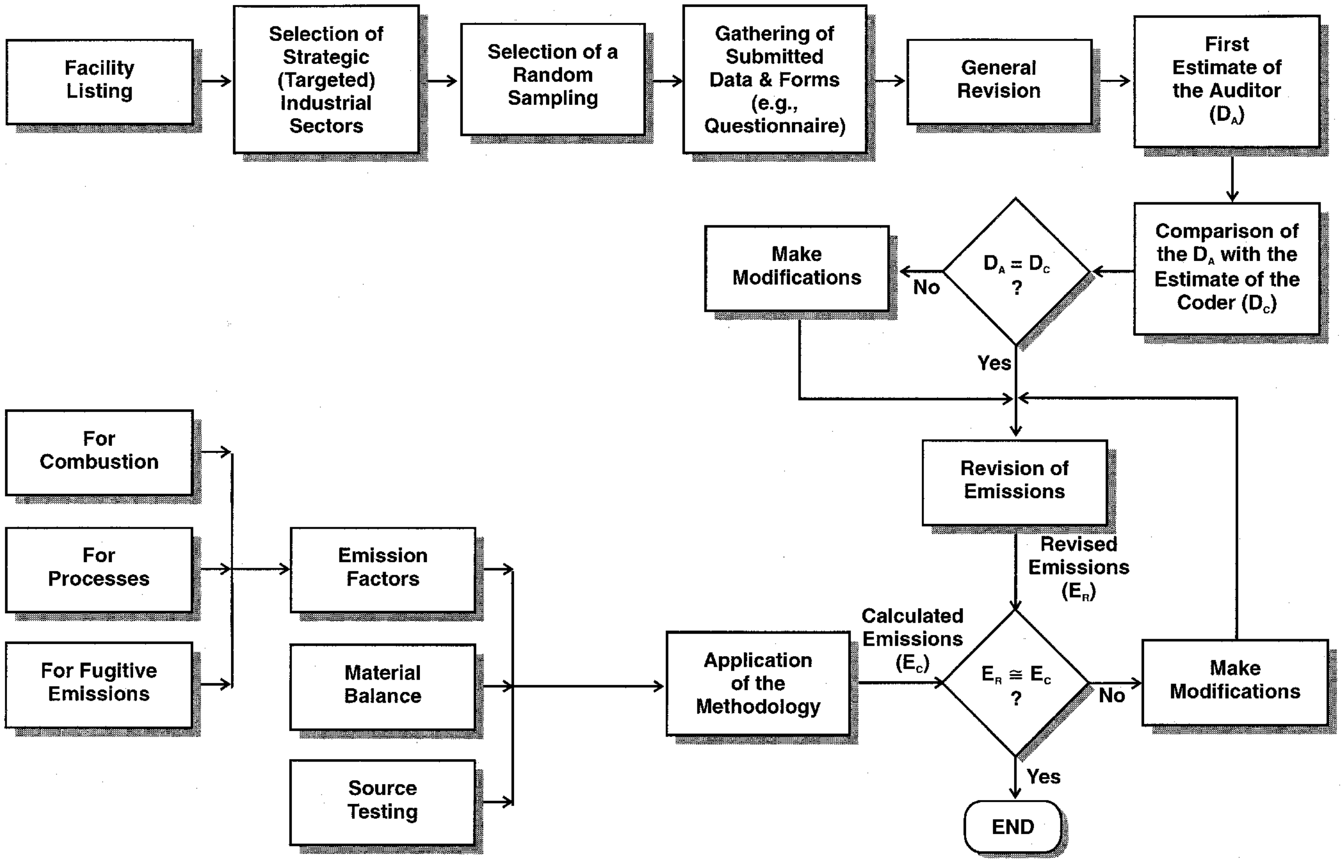

Figure 7-1. INE's Point Source Inventory QA/QC Procedures

Next, the auditor looks at the “revised emissions” reported by the facility on the questionnaire and compares them to emissions calculated using a standard methodology. For example, a facility might submit an emissions estimate based on source test data on the questionnaire. This estimate might be compared to an emission estimate developed by the auditor based on the fuel usage and emission factors from AP-42. If the results from these two approaches are reasonably consistent, then the QA/QC procedure is complete. If not, then more QA/QC activities (e.g., follow-up call to facility, auditor review of source test results) must be performed until the auditor is satisfied that the emission estimate submitted to SNIFF is reasonable.

An example QC checklist for stationary point sources is included in Appendix IV-D. This checklist, designed for an inventory of ozone precursors, includes questions concerning completeness, use of approved methods, and reasonableness.

7.1 Statement of Data Quality Objectives

The first step in planning any inventory is to define the purpose and intended use of the inventory. This information will, in turn, be used to determine the data quality objectives (DQOs) for the inventory as well as the QA/QC requirements.

DQOs are statements of the level of uncertainty a decision maker is willing to accept. Their purpose is to ensure that the final data will be sufficient for its intended use. DQO statements must identify the end use or intended purpose of the data and the level of uncertainty anticipated in the emissions estimates.

It is very important to recognize that DQOs are method-specific; they are based on what is possible for a given methodology and the quality of the data available. The inventory preparers should look at the historical data. What problems have they had in the past that limited inventory quality? Can these problems be overcome for this effort? If this inventory is for a source or region that has never been inventoried, information and experiences from similar efforts should be studied.

DQOs should be planned in advance and written down. A complete DQO statement should address:

- Accuracy (or uncertainty) of emission estimates;
- Completeness;
- Representativeness; and
- Comparability.

Despite the best intentions of inventory preparers, the development effort is often constrained by schedules, resource limitations, and lack of data. The DQOs for the inventory should be realistic and need to account for any factors that will limit inventory quality. The important thing is that some thought be given in advance to the desired quality of the product.

Table 7-1 lists six important quality goals for inventories and gives general methods for achieving these goals.

7.2 Data Quality Indicators

Having determined the DQOs, the next, and often more difficult, step is to identify the data quality indicators (DQIs) that will be used to measure the progress towards each DQO. Quantitative measures (such as confidence limits, numerical ranking systems, or letter grades) are preferable. However, implementing these is also more difficult. An alternative is to use qualitative DQIs, which may simply be a critical discussion of the inventory’s strengths and limitations. Ultimately, the appropriate QA/QC will depend upon the methods employed for the inventory. See Section 7.3 for method specific QA/QC guidance.

Table 7-1

Methods for Achieving Emissions Inventory Data Quality Objectives

Data Quality Objectives	Methods
Ensure correct implementation of INE guidance.	• Review inventory documentation, comparing actual procedures used to those required.
Where INE guidance was not used or unavailable, assess bias by evaluating the reasonableness of the approach used.	• Technical review of approach used. • Compare with results from other methods.
Ensure accuracy of input data.	• Check accuracy of transcription of data. • Check any conversion factors used. • Assess reasonableness of assumptions used to calculate input data. • Verify that the data source was current and the best available.
Ensure accuracy of calculations.	• Reconstruct a representative sample (or all) by hand.
Assess comparability and representativeness of inventory.	• Compare emissions to those from similar inventories. • Cross-check activity data by comparing it to surrogates.
Assess completeness of inventory.	• Compare list of source categories or emission points to those listed in INE guidance. • Cross-check against other published inventories, business directories, etc.

7.3 QA/QC Procedures for Specific Emission Estimation Methods

The following sections contain detailed descriptions of QA/QC procedures for specific emission estimation techniques including source tests, emission factors, material balance, and emission models.

7.3.1 Source Tests

Thorough descriptions of stack sampling procedures, source sampling tools and equipment, identification and handling of samples, laboratory analysis, use of the sampling data, and preparation of reports are available in several references, such as the *Guidelines for Assessing and Reporting Data Quality for Environmental Measurements* (U.S. EPA, 1983) or *Quality Assurance Handbook for Air Pollution Measurement Systems: Volume III. Stationary Source Specific Methods* (U.S. EPA, 1984). These documents also contain a detailed discussion on the accuracy calculations required and interpretations of data, specific criteria for unacceptable data, and indications that a system is out-of-control. In addition to referencing the QA Handbook, a QA Plan should be developed by the team conducting the test prior to each specific field test.

A systems audit should be conducted on-site as a qualitative review of the various aspects of a total sampling and/or analytical system to assess its overall effectiveness. The systems audit should represent an objective evaluation of each system with respect to strengths, weaknesses, and potential problem areas. The audit provides an evaluation of the adequacy of the overall measurement system(s) to provide data of known quality which are sufficient, in terms of quantity and quality, to meet the program objectives.

The acceptance criteria and limits and values for each control parameter associated with manual sampling methods, such as dry gas meter calibration and leak rates, are summarized in Table 7-2. QA/QC procedures associated with CEMs (e.g., multi-point

Table 7-2

Summary of Manual Sampling Methods Acceptance Criteria and Control Limits

Parameter or Criteria	Control Limit and Values
Isokinetics TSP	100 ± 10%
Isokinetics PM_{10}	100 ± 20%
DP_{50} Calculated Cut Size	9 - 11 μg
Final Leak Rate (after each port)	$\leq$0.02 acfm or 4% of sampling rate, whichever is less
Dry Gas Meter Calibration	Post average factor ( ) agree ± 5% of pre-factor
Individual Correction Factors (Y_i)	Agree within 2% of average factor
Average Correction Factor	1.00 ± 1%
Intermediate Dry Gas Meter	Calibrated every 6 months against standard
Analytical Balance (Top Loader)	0.1 g of National Bureau of Standards Class S Weights
Filter Constant Weight	Two weighings agree ± 0.5 mg

Source: EIIP, Volume VI, Table 9-2.

calibration of instruments, zeroing of instruments, calculation of drift, etc.) are contained in the specific reference methods (40 CFR, Part 60, Appendix A).

7.3.1.1 Error Analyses

The purpose of an error analysis is to identify the sources of error, to evaluate the relative magnitude of each error component in the results, and ultimately to minimize error by focusing on QA/QC efforts where they will have the most impact.

The emission rates of a particular pollutant are the product of stack gas and sampling measurements such as concentration (g/dscm) and emission rate (kg/hr) data. The magnitude of error in a concentration or emission rate caused by a measurement error can be calculated. Relative error can be defined as:

$$\textbf{Relative Error} = \textbf{(Observed - True)/True} \times \textbf{100} \qquad (7\text{-}1)$$

Table 7-3 illustrates how errors in stack gas measurements can affect the final concentrations and emission values. The resulting errors in concentrations and emission rates are caused from a hypothetical +10 percent isolated measurement error in various stack gas and sampling measurements. The following sections show in more detail how a measurement error can affect the parameter being measured during stack sampling.

7.3.1.2 Flow versus Stack Diameter

The following equation calculates the error in stack gas flow rate caused by a measurement error in stack diameter:

Table 7-3

Sensitivity of Emissions Test Results to Hypothetical Errors in Manual Measurements

Measurement	Error Caused by +10% Error in Measurement	
	Concentration Error[a] (%)	**Emission Rate Error[b] (%)**
D_s, Stack Diameter (meters)	0	21.0
p, Velocity Pressure (in H_2O)	0	4.9
P_{static}, Static Pressure (in H_2O)	0	0.03
P_{bar}, Barometric Pressure (in Hg)	-9.0	-3.8
T_s, Stack Temperature (°F)	0	-1.8
T_m, Meter Temperature (°F)	1.6	1.5
O_2, Oxygen Measurement (%V)	0	-0.03
CO_2, Carbon Dioxide Measurement (%V)	0	-0.3
H_2O, Water Entrainment (g)	0	-0.9
V, Meter Volume (m^3)	-9.1	-8.3
H, Meter Pressure (in H_2O)	-0.05	-0.04
Y, Meter Calibration	-9.1	-8.3
Pollutant Analysis (μg)	10.0	10.0

[a] Concentration of pollutant in stack gas. For example, a 10% error in the measured stack diameter has no affect on the reported concentration.

[b] Rate of emissions in mass per unit time or activity. For example, a 10% error in the measured stack diameter results in a 21% error in the estimated emission rate.

Source: EIIP, Volume VI, Table 9-4.

$$\mathbf{E_R = (2E_M + E_M^2)} \qquad (7\text{-}2)$$

where:

E_R = the resulting flow rate error (fraction)
E_M = the diameter measurement error (fraction)

For example, if E_M = 10%, then

$$E_R = (2 \times 0.1 + 0.1^2)$$

7.3.1.3 Flow versus Velocity Pressure

The following equation calculates the error in stack gas flow rate caused by a measurement error in velocity pressure:

$$\mathbf{E_R} = \sqrt{\mathbf{(1 + E_M)}} - \mathbf{1} \qquad (7\text{-}3)$$

For example, if E_M = 10%, then

$$E_R = \sqrt{(1 + 0.1)} - 1$$
$$= 0.049 \qquad 4.9\%$$

Therefore, a 10 percent error in velocity pressure measurement results in a 4.9 percent error in flow measurement.

7.3.2 Emission Factors

Data used to develop emission factors available in *AP-42* or the Factor Information Retrieval System (FIRE) system, for example, are obtained from source tests, material balance studies, and engineering estimates. The data are acquired through technical papers and reports, actual test results and reports, and personal communication.

Each emission factor published in *AP-42* or FIRE receives a quality rating, which serves as an assessment of the confidence the generator of that value places in the accuracy of the emission factor. When using existing emission factors, the user should be familiar with the criteria for assigning data quality ratings and emission factor ratings as described in the document *Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections* (U.S. EPA, 1993b). The inventory preparer should review the data and emission factor ratings associated with the major sources in the inventory. If emission estimates for a major source have been developed using data or emission factors with a low rating, further attempts should be made to obtain site-specific or region-specific data.

The criteria for assigning the data quality ratings to source tests are as follows:

- A-rated test(s) was performed by a sound methodology and reported in enough detail for adequate validation. These tests are not necessarily U.S. EPA reference test methods, although such reference methods are certainly to be used as a guide;
- B-rated test(s) was performed by a generally sound methodology but lacked enough detail for adequate validation;
- C-rated test(s) was based on a nonvalidated or draft methodology or lacked a significant amount of background data; and
- D-rated test(s) was based on a generally unacceptable method but may provide an order-of-magnitude value for the source.

Once the data quality ratings for the source tests are assigned, these ratings along with the number of source tests available for a given emission point are evaluated. Because of the almost impossible task of assigning a meaningful confidence limit to industry-specific variables (*e.g.*, sample size versus sample population, industry and facility variability, method of measurement), the use of a statistical confidence interval for establishing a representative emission factor for each source category is usually not practical. Therefore, some subjective quality rating is necessary. The following emission factor quality ratings are used for the emission factors found in *AP-42*, FIRE, or any U.S. EPA published document:

A - Excellent - The emission factor was developed only from A-rated test data taken from many randomly chosen facilities in the industry population. The source category is specific enough to minimize variability within the source category population.

B - Above Average - The emission factor was developed only from A-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As with the A-rating, the source category is specific enough to minimize variability within the source category population.

C - Average - The emission factor was developed only from A- and B-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As with the A-rating, the source category is specific enough to minimize variability within the source category population.

D - Below Average - The emission factor was developed only from A- and B-rated test data from a small number of facilities, and there may be reason to suspect that these facilities do not represent a random sample of the industry. There also may be evidence of variability within the source category population.

E - Poor - The emission factor was developed from C- and D-rated test data, and there may be reason to suspect that the facilities tested do not represent a random sample of the industry. There also may be evidence of variability within the source category population.

U - Unrated or Unratable - The emission factor was developed from suspect data with no supporting documentation to accurately apply an "A" through "E" rating. A "U" rating may be applied in the following circumstances (FIRE):

U1 - Mass Balance (for example, estimating air emissions based on raw material input, product recovery efficiency, and percent control).

U2 - Source test deficiencies (such as inadequate quality assurance/quality control, questionable source test methods, only one source test).

U3 - Technology transfer.

U4 - Engineering judgement.

U5 - Lack of supporting documentation.

7.3.3 Material Balance

If a mass balance method is used to estimate emissions, the preparer should:

- Ensure that all assumptions made are reasonable;
- Ensure that all end points and pathways are identified and quantified;
- Ensure that all data are accurate (consumption, etc.); and
- Check that the emissions are reasonable (compared to the previous years results or other reference points).

7.3.4 Emission Models

If a model is used to estimate emissions, the preparer should:

- Verify the accuracy of input data;

- Verify that all software used has been quality assured;

- Where possible, model results should be verified with a manual calculation, otherwise, results should be compared to results from an alternative method; and

- Check that the emissions results are reasonable (compared to the previous years results or other reference points).

8.0 DATA CODING PROCEDURES

Data coding is an integral part of an emissions inventory. Using unique codes for inventory data will ensure that the data are properly maintained and retrievable. For example, each facility should be assigned a unique identification number (see Section 8.2). In order to track inventories for review or update, the information must be coded in a unique way as to allow for easy retrieval.

Also, in order to share or transfer data to other users, the information must be in a consistent and recognizable format. All agency inventory activities should be coordinated so that submittal and update procedures flow smoothly for each inventory. A useful data coding system should allow for the following:

- Identification of the type of data included; and
- Storage and retrieval of specific data.

8.1 Facility Identification Codes

In order to track and update a facility's inventory, a unique facility identification code should be assigned to each plant. Suggestions for assigning these codes are as follows:

- Use a predetermined number of characters in the code (such as one letter, followed by four numbers);
- Keep the facility identification code short (less data entry time and less likelihood of data entry errors); and
- The use of a letter within the code significantly increases the number of unique combinations you can have.

Within a facility, each emission unit (EU), emission point (EP), and control device (CD) should be identified with a unique code such as EU1, EP1, EP2, and CD1, CD2, and so on.

8.2 SNIFF Data Coding Procedures

Currently, information gathered through the INE's industrial questionnaire is integrated in the National Information System of Point Sources (SNIFF) database. The parameters, quantity of codes, and number of informational fields available in SNIFF are identified in Table 8-1.

The codes used for data entered into SNIFF were specifically developed by INE for the Emissions Inventory Program and are contained in internal INE code catalogs. Data coding and entry are usually performed by the INE personnel. In order to obtain a copy of the code catalog, you must submit a request to the INE's Subdirectorate of Emissions Inventory.

As the inventory process in Mexico becomes further developed and the electronic reporting and storing of data becomes more sophisticated, a more precise and descriptive method for identifying industrial activity will be required. For example, the Source Classification Code (SCC) system, described in Section 8.3, introduces an expanded concept of applying unique identification codes to individual processes.

8.3 Source Classification Codes (SCCs)

Many databases use SCC codes to link emissions data to specific technology types. Each SCC represents a unique process or function within a source category that is logically associated with a point of air pollution emissions. With an appropriate SCC, a process can be accurately identified for retrieval purposes.

Table 8-1

Identifying Features of the SNIFF Code System

Parameter	Approximate Number of Codes	Number of Fields
Location	by district, state and municipality	3
Activity of the company (industrial sector)	450[a]	1
Process type	396	1 (only the principal process)
Machinery and equipment	350	5 (one for each process phase)
Raw materials	2,000	6
Products	22,000	7
Fuels	13	1
Fuel Units	28	1
Pollutants	100[b]	5
Control devices	170	10 (2 for each process phase)
Control device capacity	22	1

[a] The classification system that is used by SNIFF to identify industrial activities has 7 digits. The first 2 digits correspond to the level of severity or potential for air pollution from a given industrial branch (01 for the group of the largest emittors, 02 for the next largest emittors, and 03 for the minor emittors or those that are considered to be area sources). The following 2 digits identify the industrial branch or sector (0101 for electric utility plants, 0102 for petroleum refineries and petrochemical plants, 0103 for chemical processes, etc.), and the last 3 digits correspond to the subsector within the industrial branch (0103002 for fabrication of ammonia and its derivatives, 0102004 for fabrication of nitric acid, etc.).

[b] Only criteria pollutants are reported.

The SCCs are divided into four levels of identification: Levels I, II, III, and IV, consisting of 1, 2, 3, and 2 digits, respectively. Level I identifies the category of the process with a one digit number as shown in Table 8-2. The second level (II) of identification is a 2-digit code that signifies the major industry group. For example, Industrial Processes (Level I, code 3) are subdivided into chemical manufacturing (3-01), food/agricultural (3-02), primary metals (3-03), etc. The third level, a 3-digit number, indicates the major product, raw material, fuel, or piece of equipment. The fourth level of classification, a 2-digit number, identifies different operations at the point source. As an example, the assignment of an SCC for an electric utility burning pulverized bituminous coal in a wet bottom furnace is shown in Figure 8-1.

In some cases, “General” appears as a fourth-level SCC process description. This indicates that the process or series of processes have been identified and simplified into a “black box” or group of activities rather than a complex assortment of related emissions sources. Normally, “General” SCCs are replaced by more specific SCCs when more detailed information about the process becomes available.

The term “Other Not Classified” is a fourth-level SCC process description that can be used to represent activities that exist but for which no specific SCC has been defined. These “Other Not Classified” SCCs are usually represented by codes ending in “99". If these codes are used, then the emissions inventory specialist is strongly urged to enter into a comment field an appropriate entry that more fully describes the emissions discharged.

A complete numerical listing of SCCs is available for downloading from the Clearinghouse for Inventories and Emission Factors (CHIEF) bulletin board system (BBS) 95-919-541-5742 (which is a modem access line) and from the Factor Information Retrieval (FIRE) System database. A hardcopy of the SCC listing is included in Appendix IV-E of this document.

Table 8-2

Level I SCC Categories

Level I Values	Process Category	Category Description
1	External Combustion Sources	Boilers and space heaters
2	Internal Combustion Sources	Turbines and reciprocating engines
3	Industrial Processes	All industrial processes other than evaporation sources, and combustion for steam or power, and disposal of solid waste
4	Evaporation Sources	Surface coating operations, petroleum storage, and printing operations
5	Solid Waste Disposal	Incineration of wastes, wastewater treatment, landfills, treatment, storage, and disposal facility (TSDF) processes

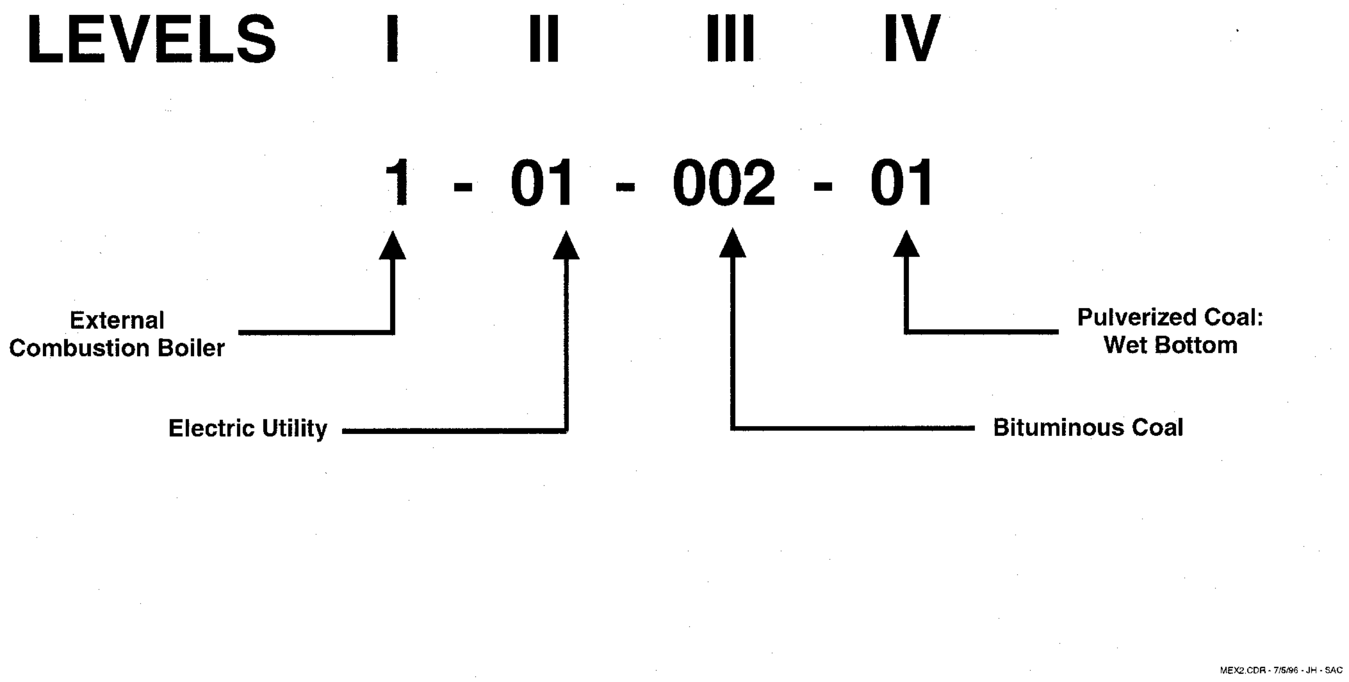

Figure 8-1. SCC for Electric Utility Burning Pulverized Bituminous Coal in a Wet Bottom Furnace

9.0 DATA COLLECTION

Data collection should be done efficiently to obtain the information required to calculate emissions. Using data collection forms or questionnaires are the most efficient means of gathering information. Once completed, the forms themselves may be kept as background documentation for emissions inventory development. Data collection forms may be generic enough to be used at any facility, or may be developed individually for each industry or device type. A detailed discussion for surveying facilities is presented in Section 5 of Volume III: *Basic Emission Estimating Techniques*.

9.1 General Questionnaire

A general questionnaire is merely a collection of process-specific questionnaires. It is best used if the mailing list is long, if the agency is unfamiliar with many of the sources on the list, or if agency resources are limited.

Developing a questionnaire involves the following:

- Establish a suitable format and make it as simple and functional as possible;
- Identify and write the appropriate questions;
- Develop a cover letter and instructions for filling out the questionnaire;
- Design the questionnaire for the person who will be asked to complete it; consider the technical background and experience level of the person who will complete the questionnaire;
- Design the questionnaire to be understood by persons without specialized technical training;
- Space the questions for readability with sufficient area for complete responses;

- Make the questionnaire as short as possible; lengthy questionnaires can be intimidating;
- Use terminology that will be familiar to the recipient;
- Ensure that each question is self-explanatory or accompanied by clear directions;
- Solicit all necessary information on the questionnaire, thus avoiding later requests for additional data;
- Consider the ultimate use of the data when determining the information to request on the questionnaire;
- Collect any additional data needed for subsequent application of a photochemical model at this time;
- Request process information in addition to general source information such as location, ownership, and nature of business;
- Obtain appropriate activity levels (such as indicators of production and fuel consumption) for each type of source; and
- Obtain control device information to estimate controlled emissions and to determine potential reductions in emissions for applying various control strategies.

In accordance with Article 17 of the *Regulation in Matters of the Prevention and Control of Atmospheric Pollution*, those responsible for the point sources under federal jurisdiction that emit odors, gases, solid particulates or liquids to the atmosphere should present an inventory of their containment emissions to the atmosphere. INE has developed two point source questionnaires to collect this information. The data that are obtained from the industrial questionnaire (Formato LF-CO) and the microindustry questionnaire (Formato IE-MI) are integrated in the SNIFF database (see Section 8.2). Appendix IV-F contains these questionnaires.

9.2 Industry-specific Questionnaire

Ideally, a questionnaire sent to any facility would be industry-specific and would only address information pertaining to the industry of interest. If sufficient resources are available to design an industry-specific questionnaire, it may be advantageous to do so. Advantages and disadvantages to using industry-specific questionnaires are listed below:

Advantages

- Questionnaires are generally shorter because questions not applicable to the particular industry are not included; and
- Can use industry-specific terminology that is familiar to those working in a particular industry which enhances communication, reduces confusion and increases inventory accuracy.

Disadvantages

- The design of many industry-specific questionnaires can require significant resources;
- The returned questionnaires must be processed individually because of the variations in format for different industries; and
- Industry-specific questionnaires may be incorrectly sent to some sources because of limited prior knowledge of the operations at these sources.

9.3 Device Level Data Collection Forms

Appendix IV-G contains examples of device specific data collection forms for surface coating operations, boilers, and fugitive equipment leaks. These forms may be distributed blank, or may be filled in by the regulatory agency using previously gathered information about the source. This approach is appropriate for periodic (monthly, annual, etc.) updates of a source’s emissions inventory.

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APPENDIX IV-A

INE'S POINT SOURCE INVENTORY DEVELOPMENT PROCESS

APPENDIX IV-B

MISCELLANEOUS DATA AND CONVERSION FACTORS

SOME USEFUL WEIGHTS AND MEASURES

Unit Of Measure	Equivalent	
grain	0.002	ounces
gram	0.04	ounces
ounce	28.35	grams
kilogram	2.21	pounds
pound	0.45	kilograms
pound (troy)	12	ounces
ton (short)	2000	pounds
ton (long)	2240	pounds
ton (metric)	2200	pounds
ton (shipping)	40	feet^3
centimeter	0.39	inches
inch	2.54	centimeters
foot	30.48	centimeters
meter	1.09	yards
yard	0.91	meters
mile	1.61	kilometers
centimeter^2	0.16	inches^2
inch^2	6.45	centimeters^2
foot^2	0.09	meters^2
meter^2	1.2	yards^2
yard^2	0.84	meters^2
mile^2	2.59	kilometers^2
centimeter^3	0.061	inches^3
inch^3	16.39	centimeters^3
foot^3	283.17	centimeters^3
foot^3	1728	inches^3

SOME USEFUL WEIGHTS AND MEASURES (cont.)

Unit Of Measure	Equivalent	
$meter^3$	1.31	$yards^3$
$yard^3$	0.77	$meters^3$
cord	128	$feet^3$
cord	4	$meters^3$
peck	8	quarts
bushel (dry)	4	pecks
bushel	2150.4	$inches^3$
gallon (U. S.)	231	$inches^3$
barrel	31.5	gallons
hogshead	2	barrels
township	36	$miles^2$
hectare	2.5	acres

MISCELLANEOUS DATA

One cubic foot of anthracite coal weighs about 53 pounds.

One cubic foot of bituminous coal weighs from 47 to 50 pounds.

One ton of coal is equivalent to two cords of wood for steam purposes.

A gallon of water (U. S. Standard) weighs 8.33 pounds and contains 231 cubic inches.

There are 9 square feet of heating surface to each square foot of grate surface.

A cubic foot of water contains 7.5 gallons and 1728 cubic inches, and weighs 62.5 lbs.

Each nominal horsepower of a boiler requires 30 to 35 pounds of water per hour.

A horsepower is equivalent to raising 33,000 pounds one foot per minute, or 550 pounds one foot per second.

To find the pressure in pounds per square inch of a column of water, multiply the height of the column in feet by 0.434.

TYPICAL PARAMETERS OF VARIOUS FUELS[a]

Type Of Fuel	Heating Value		Sulfur % (by weight)	Ash % (by weight)
	kcal	Btu		
Solid Fuels				
Bituminous Coal	7,200/kg	13,000/lb	0.6-5.4	4-20
Anthracite Coal	6,810/kg	12,300/lb	0.5-1.0	7.0-16.0
Lignite (@ 35% moisture)	3,990/kg	7,200/lb	0.7	6.2
Wood (@ 40% moisture)	2,880/kg	5,200/lb	N	1-3
Bagasse (@ 50% moisture)	2,220/kg	4,000/lb	N	1-2
Bark (@ 50% moisture)	2,492/kg	4,500/lb	N	1-3[b]
Coke, Byproduct	7,380/kg	13,300/lb	0.5-1.0	0.5-5.0
Liquid Fuels				
Residual Oil	$9.98 \times 10^6/m^3$	150,000/gal	0.5-4.0	0.05-0.1
Distillate Oil	$9.30 \times 10^6/m^3$	140,000/gal	0.2-1.0	N
Diesel	$9.12 \times 10^6/m^3$	137,000/gal	0.4	N
Gasoline	$8.62 \times 10^6/m^3$	130,000/gal	0.03-0.04	N
Kerosene	$8.32 \times 10^6/m^3$	135,000/gal	0.02-0.05	N
Liquid Petroleum Gas	$6.25 \times 10^6/m^3$	94,000/gal	N	N
Gaseous Fuels				
Natural Gas	$9,341/m^3$	1,050/SCF	N	N
Coke Oven Gas	$5,249/m^3$	590/SCF	0.5-2.0	N
Blast Furnace Gas	$890/m^3$	100/SCF	N	N

[a] N = negligible.
[b] Ash content may be considerably higher when sand, dirt, etc., are present.

THERMAL EQUIVALENTS FOR VARIOUS FUELS

Type Of Fuel	kcal	Btu (gross)
Solid fuels		
Bituminous coal	(5.8 to 7.8) x 10^6/Mg	(21.0 to 28.0) x 10^6/ton
Anthracite coal	7.03 x 10^6/Mg	25.3 x 10^6/ton
Lignite	4.45 x 10^6/Mg	16.0 x 10^6/ton
Wood	1.47 x 10^6/m^3	21.0 x 10^6/cord
Liquid fuels		
Residual fuel oil	10 x 10^3/liter	6.3 x 10^6/bbl
Distillate fuel oil	9.35 x 10^3/liter	5.9 x 10^6/bbl
Gaseous fuels		
Natural gas	9,350/m^3	1,050/ft^3
Liquefied petroleum gas		
Butane	6,480/liter	97,400/gal
Propane	6,030/liter	90,500/gal

WEIGHTS OF SELECTED SUBSTANCES

Type Of Substance	g/liter	lb/gal
Asphalt	1030	8.57
Butane, liquid at 60°F	579	4.84
Crude oil	850	7.08
Distillate oil	845	7.05
Gasoline	739	6.17
Propane, liquid at 60°F	507	4.24
Residual oil	944	7.88
Water	1000	8.4

DENSITIES OF SELECTED SUBSTANCES

Substance	Density	
Fuels		
Crude Oil	874 kg/m^3	7.3 lb/gal
Residual Oil	944 kg/m^3	7.88 lb/gal
Distillate Oil	845 kg/m^3	7.05 lb/gal
Gasoline	739 kg/m^3	6.17 lb/gal
Natural Gas	673 kg/m^3	1 lb/23.8 ft^3
Butane	579 kg/m^3	4.84 lb/gal (liquid)
Propane	507 kg/m^3	4.24 lb/gal (liquid)
Wood (Air dried)		
Elm	561 kg/m^3	35 lb/ft^3
Fir, Douglas	513 kg/m^3	32 lb/ft^3
Fir, Balsam	400 kg/m^3	25 lb/ft^3
Hemlock	465 kg/m^3	29 lb/ft^3
Hickory	769 kg/m^3	48 lb/ft^3
Maple, Sugar	689 kg/m^3	43 lb/ft^3
Maple, White	529 kg/m^3	33 lb/ft^3
Oak, Red	673 kg/m^3	42 lb/ft^3
Oak, White	769 kg/m^3	48 lb/ft^3
Pine, Southern	641 kg/m^3	40 lb/ft^3
Agricultural Products		
Corn	25.4 kg/bu	56 lb/bu
Milo	25.4 kg/bu	56 lb/bu
Oats	14.5 kg/bu	32 lb/bu
Barley	21.8 kg/bu	48 lb/bu
Wheat	27.2 kg/bu	60 lb/bu
Cotton	226 kg/bale	500 lb/bale
Mineral Products		
Brick	2.95 kg/brick	6.5 lb/brick
Cement	170 kg/bbl	375 lb/bbl

DENSITIES OF SELECTED SUBSTANCES (cont.)

Substance	Density	
Cement	1483 kg/m^3	2500 lb/yd^3
Concrete	2373 kg/m^3	4000 lb/yd^3
Glass, Common	2595 kg/m^3	162 lb/ft^3
Gravel, Dry Packed	1600 - 1920 kg/m^3	100 - 120 lb/ft^3
Gravel, Wet	2020 kg/m^3	126 lb/ft^3
Gypsum, Calcined	880 - 960 kg/m^3	55 - 60 lb/ft^3
Lime, Pebble	850 - 1025 kg/m^3	53 - 64 lb/ft^3
Sand, Gravel (Dry, loose)	1440 - 1680 kg/m^3	90 - 105 lb/ft^3

CONVERSION FACTORS

The table of conversion factors on the following pages contains factors for converting English to metric units and metric to English units as well as factors to manipulate units within the same system. The factors are arranged alphabetically by unit within the following property groups.

-Area
-Density
-Energy
-Force
-Length
-Mass
-Pressure
-Velocity
-Volume
-Volumetric Rate

To convert a number from one unit to another:

1. Locate the unit in which the number is currently expressed in the left-hand column of the table;

2. Find the desired unit in the center column; and

3. Multiply the number by the corresponding conversion factor in the right-hand column.

CONVERSION FACTORS[a]

To Convert From	To	Multiply By
Area		
Acres	Sq feet	4.356×10^{4}
Acres	Sq kilometers	4.0469×10^{-3}
Acres	Sq meters	4.0469×10^{3}
Acres	Sq miles (statute)	1.5625×10^{-3}
Acres	Sq yards	4.84×10^{3}
Sq feet	Acres	2.2957×10^{-5}
Sq feet	Sq cm	929.03
Sq feet	Sq inches	144.0
Sq feet	Sq meters	0.092903
Sq feet	Sq miles	3.587×10^{-8}
Sq feet	Sq yards	0.111111
Sq inches	Sq feet	6.9444×10^{-3}
Sq inches	Sq meters	6.4516×10^{-4}
Sq inches	Sq mm	645.16
Sq kilometers	Acres	247.1
Sq kilometers	Sq feet	1.0764×10^{7}
Sq kilometers	Sq meters	1.0×10^{6}
Sq kilometers	Sq miles	0.386102
Sq kilometers	Sq yards	1.196×10^{6}
Sq meters	Sq cm	1.0×10^{4}
Sq meters	Sq feet	10.764
Sq meters	Sq inches	1.55×10^{3}
Sq meters	Sq kilometers	1.0×10^{-6}
Sq meters	Sq miles	3.861×10^{-7}
Sq meters	Sq mm	1.0×10^{6}
Sq meters	Sq yards	1.196
Sq miles	Acres	640.0
Sq miles	Sq feet	2.7878×10^{7}
Sq miles	Sq kilometers	2.590

CONVERSION FACTORS (cont.)[a]

To Convert From	To	Multiply By
Sq miles	Sq meters	2.59×10^{6}
Sq miles	Sq yards	3.0976×10^{6}
Sq yards	Acres	2.0661×10^{-4}
Sq yards	Sq cm	8.3613×10^{3}
Sq yards	Sq ft	9.0
Sq yards	Sq inches	1.296×10^{3}
Sq yards	Sq meters	0.83613
Sq yards	Sq miles	3.2283×10^{-7}
Density		
Dynes/cu cm	Grams/cu cm	1.0197×10^{-3}
Grains/cu foot	Grams/cu meter	2.28835
Grams/cu cm	Dynes/cu cm	980.665
Grams/cu cm	Grains/milliliter	15.433
Grams/cu cm	Grams/milliliter	1.0
Grams/cu cm	Pounds/cu inch	1.162
Grams/cu cm	Pounds/cu foot	62.428
Grams/cu cm	Pounds/cu inch	0.036127
Grams/cu cm	Pounds/gal (Brit.)	10.022
Grams/cu cm	Pounds/gal (U. S., dry)	9.7111
Grams/cu cm	Pounds/gal (U. S., liq.)	8.3454
Grams/cu meter	Grains/cu foot	0.4370
Grams/liter	Pounds/gal (U. S.)	8.345×10^{-3}
Kilograms/cu meter	Grams/cu cm	0.001
Kilograms/cu meter	Pounds/cu ft	0.0624
Kilograms/cu meter	Pounds/cu in	3.613×10^{-5}
Pounds/cu foot	Grams/cu cm	0.016018
Pounds/cu foot	kg/cu meter	16.018
Pounds/cu inch	Grams/cu cm	27.68
Pounds/cu inch	Grams/liter	27.681
Pounds/cu inch	kg/cu meter	2.768×10^{4}

CONVERSION FACTORS (cont.)[a]

To Convert From	To	Multiply By
Pounds/gal (U. S., liq.)	Grams/cu cm	0.1198
Pounds/gal (U. S., liq.)	Pounds/cu ft	7.4805
Energy		
Btu	Cal. gm (IST.)	251.83
Btu	Ergs	1.05435×10^{10}
Btu	Foot-pounds	777.65
Btu	Hp-hours	3.9275×10^{-4}
Btu	Joules (Int.)	1054.2
Btu	kg-meters	107.51
Btu	Kw-hours (Int.)	2.9283×10^{-4}
Btu/hr	Cal. kg/hr	0.252
Btu/hr	Ergs/sec	2.929×10^{6}
Btu/hr	Foot-pounds/hr	777.65
Btu/hr	Horsepower (mechanical)	3.9275×10^{-4}
Btu/hr	Horsepower (boiler)	2.9856×10^{-5}
Btu/hr	Horsepower (electric)	3.926×10^{-4}
Btu/hr	Horsepower (metric)	3.982×10^{-4}
Btu/hr	Kilowatts	2.929×10^{-4}
Btu/lb	Foot-pounds/lb	777.65
Btu/lb	Hp-hr/lb	3.9275×10^{-4}
Btu/lb	Joules/gram	2.3244
Calories, kg (mean)	Btu (IST.)	3.9714
Calories, kg (mean)	Ergs	4.190×10^{10}
Calories, kg (mean)	Foot-pounds	3.0904×10^{3}
Calories, kg (mean)	Hp-hours	1.561×10^{-3}
Calories, kg (mean)	Joules	4.190×10^{3}
Calories, kg (mean)	kg-meters	427.26
Calories, kg (mean)	kW-hours (Int.)	1.1637×10^{-3}
Ergs	Btu	9.4845×10^{-11}
Ergs	Foot-poundals	2.373×10^{-6}

CONVERSION FACTORS (cont.)[a]

To Convert From	To	Multiply By
Ergs	Foot-pounds	7.3756×10^{-8}
Ergs	Joules (Int.)	9.99835×10^{-8}
Ergs	kW-hours	2.7778×10^{-14}
Ergs	kg-meters	1.0197×10^{-8}
Foot-pounds	Btu (IST.)	1.2851×10^{-3}
Foot-pounds	Cal. kg (IST.)	3.2384×10^{-4}
Foot-pounds	Ergs	1.3558×10^{7}
Foot-pounds	Foot-poundals	32.174
Foot-pounds	Hp-hours	5.0505×10^{-7}
Foot-pounds	Joules	1.3558
Foot-pounds	kg-meters	0.138255
Foot-pounds	kW-hours (Int.)	3.76554×10^{-7}
Foot-pounds	Newton-meters	1.3558
Foot-pounds/hr	Btu/min	2.1432×10^{-5}
Foot-pounds/hr	Ergs/min	2.2597×10^{5}
Foot-pounds/hr	Horsepower (mechanical)	5.0505×10^{-7}
Foot-pounds/hr	Horsepower (metric)	5.121×10^{-7}
Foot-pounds/hr	Kilowatts	3.766×10^{-7}
Horsepower (mechanical)	Btu (mean)/hr	2.5425×10^{3}
Horsepower (mechanical)	Ergs/sec	7.457×10^{9}
Horsepower (mechanical)	Foot-pounds/hr	1.980×10^{6}
Horsepower (mechanical)	Horsepower (boiler)	0.07602
Horsepower (mechanical)	Horsepower (electric)	0.9996
Horsepower (mechanical)	Horsepower (metric)	1.0139
Horsepower (mechanical)	Joules/sec	745.70
Horsepower (mechanical)	Kilowatts (Int.)	0.74558
Horsepower (boiler)	Btu (mean)/hr	3.3446×10^{4}
Horsepower (boiler)	Ergs/sec	9.8095×10^{10}
Horsepower (boiler)	Foot-pounds/min	4.341×10^{5}
Horsepower (boiler)	Horsepower (mechanical)	13.155

CONVERSION FACTORS (cont.)[a]

To Convert From	To	Multiply By
Horsepower (boiler)	Horsepower (electric)	13.15
Horsepower (boiler)	Horsepower (metric)	13.337
Horsepower (boiler)	Joules/sec	9.8095×10^3
Horsepower (boiler)	Kilowatts	9.8095
Horsepower (electric)	Btu (mean)/hr	2.5435×10^3
Horsepower (electric)	Cal. kg/hr	641.87
Horsepower (electric)	Ergs/sec	7.46×10^9
Horsepower (electric)	Foot-pounds/min	3.3013×10^4
Horsepower (electric)	Horsepower (boiler)	0.07605
Horsepower (electric)	Horsepower (metric)	1.0143
Horsepower (electric)	Joules/sec	746.0
Horsepower (electric)	Kilowatts	0.746
Horsepower (metric)	Btu (mean)/hr	2.5077×10^3
Horsepower (metric)	Ergs/sec	7.355×10^9
Horsepower (metric)	Foot-pounds/min	3.255×10^4
Horsepower (metric)	Horsepower (mechanical)	0.98632
Horsepower (metric)	Horsepower (boiler)	0.07498
Horsepower (metric)	Horsepower (electric)	0.9859
Horsepower (metric)	kg-meters/sec	75.0
Horsepower (metric)	Kilowatts	0.7355
Horsepower-hours	Btu (mean)	2.5425×10^3
Horsepower-hours	Foot-pounds	1.98×10^6
Horsepower-hours	Joules	2.6845×10^6
Horsepower-hours	kg-meters	2.73745×10^5
Horsepower-hours	kW-hours	0.7457
Joules (Int.)	Btu (IST.)	9.4799×10^{-4}
Joules (Int.)	Ergs	1.0002×10^7
Joules (Int.)	Foot-poundals	12.734
Joules (Int.)	Foot-pounds	0.73768
Joules (Int.)	kW-hours	2.778×10^{-7}

CONVERSION FACTORS (cont.)[a]

To Convert From	To	Multiply By
Joules (Int.)/sec	Btu (mean)/min	0.05683
Joules (Int.)/sec	Cal. kg/min	0.01434
Joules (Int.)/sec	Horsepower	1.341×10^{-3}
Kilogram-meters	Btu (mean)	9.2878×10^{-3}
Kilogram-meters	Cal. kg (mean)	2.3405×10^{-3}
Kilogram-meters	Ergs	9.80665×10^{7}
Kilogram-meters	Foot-poundals	232.715
Kilogram-meters	Foot-pounds	7.233
Kilogram-meters	Hp-hours	3.653×10^{-6}
Kilogram-meters	Joules (Int.)	9.805
Kilogram-meters	kW-hours	2.724×10^{-6}
Kilogram-meters/sec	Watts	9.80665
Kilowatts (Int.)	Btu (IST.)/hr	3.413×10^{3}
Kilowatts (Int.)	Cal. kg (IST.)/hr	860.0
Kilowatts (Int.)	Ergs/sec	1.0002×10^{10}
Kilowatts (Int.)	Foot-poundals/min	1.424×10^{6}
Kilowatts (Int.)	Foot-pounds/min	4.4261×10^{4}
Kilowatts (Int.)	Horsepower (mechanical)	1.341
Kilowatts (Int.)	Horsepower (boiler)	0.10196
Kilowatts (Int.)	Horsepower (electric)	1.3407
Kilowatts (Int.)	Horsepower (metric)	1.3599
Kilowatts (Int.)	Joules (Int.)/hr	3.6×10^{6}
Kilowatts (Int.)	kg-meters/hr	3.6716×10^{5}
Kilowatt-hours (Int.)	Btu (mean)	3.41×10^{3}
Kilowatt-hours (Int.)	Foot-pounds	2.6557×10^{6}
Kilowatt-hours (Int.)	Hp-hours	1.341
Kilowatt-hours (Int.)	Joules (Int.)	3.6×10^{6}
Kilowatt-hours (Int.)	kg-meters	3.6716×10^{5}
Newton-meters	Gram-cm	1.01972×10^{4}
Newton-meters	kg-meters	0.101972

CONVERSION FACTORS (cont.)[a]

To Convert From	To	Multiply By
Newton-meters	Pound-feet	0.73756
Force		
Dynes	Newtons	1.0×10^{-5}
Dynes	Poundals	7.233×10^{-5}
Dynes	Pounds	2.248×10^{-6}
Newtons	Dynes	1.0×10^{-5}
Newtons	Pounds (avdp.)	0.22481
Poundals	Dynes	1.383×10^{4}
Poundals	Newtons	0.1383
Poundals	Pounds (avdp.)	0.03108
Pounds (avdp.)	Dynes	4.448×10^{5}
Pounds (avdp.)	Newtons	4.448
Pounds (avdp.)	Poundals	32.174
Length		
Feet	Centimeters	30.48
Feet	Inches	12
Feet	Kilometers	3.048×10^{-4}
Feet	Meters	0.3048
Feet	Miles (statute)	1.894×10^{-4}
Inches	Centimeters	2.540
Inches	Feet	0.08333
Inches	Kilometers	2.54×10^{-5}
Inches	Meters	0.0254
Kilometers	Feet	3.2808×10^{3}
Kilometers	Meters	1000
Kilometers	Miles (statute)	0.62137
Kilometers	Yards	1.0936×10^{3}
Meters	Feet	3.2808
Meters	Inches	39.370
Micrometers	Angstrom units	1.0×10^{4}

CONVERSION FACTORS (cont.)[a]

To Convert From	To	Multiply By
Micrometers	Centimeters	1.0×10^{-3}
Micrometers	Feet	3.2808×10^{-6}
Micrometers	Inches	3.9370×10^{-5}
Micrometers	Meters	1.0×10^{-6}
Micrometers	Millimeters	0.001
Micrometers	Nanometers	1000
Miles (statute)	Feet	5280
Miles (statute)	Kilometers	1.6093
Miles (statute)	Meters	1.6093×10^{3}
Miles (statute)	Yards	1760
Millimeters	Angstrom units	1.0×10^{7}
Millimeters	Centimeters	0.1
Millimeters	Inches	0.03937
Millimeters	Meters	0.001
Millimeters	Micrometers	1000
Millimeters	Mils	39.37
Nanometers	Angstrom units	10
Nanometers	Centimeters	1.0×10^{-7}
Nanometers	Inches	3.937×10^{-8}
Nanometers	Micrometers	0.001
Nanometers	Millimeters	1.0×10^{-6}
Yards	Centimeters	91.44
Yards	Meters	0.9144
Mass		
Grains	Grams	0.064799
Grains	Milligrams	64.799
Grains	Pounds (apoth. or troy)	1.7361×10^{-4}
Grains	Pounds (avdp.)	1.4286×10^{-4}
Grains	Tons (metric)	6.4799×10^{-8}
Grams	Dynes	980.67

CONVERSION FACTORS (cont.)[a]

To Convert From	To	Multiply By
Grams	Grains	15.432
Grams	Kilograms	0.001
Grams	Micrograms	1×10^{6}
Grams	Pounds (avdp.)	2.205×10^{-3}
Grams	Tons, metric (megagrams)	1×10^{-6}
Kilograms	Grains	1.5432×10^{4}
Kilograms	Poundals	70.932
Kilograms	Pounds (apoth. or troy)	2.679
Kilograms	Pounds (avdp.)	2.2046
Kilograms	Tons (long)	9.842×10^{-4}
Kilograms	Tons (metric)	0.001
Kilograms	Tons (short)	1.1023×10^{-3}
Megagrams	Tons (metric)	1.0
Milligrams	Grains	0.01543
Milligrams	Grams	1.0×10^{-3}
Milligrams	Ounces (apoth. or troy)	3.215×10^{-5}
Milligrams	Ounces (avdp.)	3.527×10^{-5}
Milligrams	Pounds (apoth. or troy)	2.679×10^{-6}
Milligrams	Pounds (avdp.)	2.2046×10^{-6}
Ounces (apoth. or troy)	Grains	480
Ounces (apoth. or troy)	Grams	31.103
Ounces (apoth. or troy)	Ounces (avdp.)	1.097
Ounces (avdp.)	Grains	437.5
Ounces (avdp.)	Grams	28.350
Ounces (avdp.)	Ounces (apoth. or troy)	0.9115
Ounces (avdp.)	Pounds (apoth. or troy)	0.075955
Ounces (avdp.)	Pounds (avdp.)	0.0625
Pounds (avdp.)	Poundals	32.174
Pounds (avdp.)	Pounds (apoth. or troy)	1.2153
Pounds (avdp.)	Tons (long)	4.4643×10^{-4}

CONVERSION FACTORS (cont.)[a]

To Convert From	To	Multiply By
Pounds (avdp.)	Tons (metric)	4.5359×10^{-4}
Pounds (avdp.)	Tons (short)	5.0×10^{-4}
Pounds (avdp.)	Grains	7000
Pounds (avdp.)	Grams	453.59
Pounds (avdp.)	Ounces (apoth. or troy)	14.583
Pounds (avdp.)	Ounces (avdp.)	16
Tons (long)	Kilograms	1.016×10^{3}
Tons (long)	Pounds (apoth. or troy)	2.722×10^{3}
Tons (long)	Pounds (avdp.)	2.240×10^{3}
Tons (long)	Tons (metric)	1.016
Tons (long)	Tons (short)	1.12
Tons (metric)	Grams	1.0×10^{6}
Tons (metric)	Megagrams	1.0
Tons (metric)	Pounds (apoth. or troy)	2.6792×10^{3}
Tons (metric)	Pounds (avdp.)	2.2046×10^{3}
Tons (metric)	Tons (long)	0.9842
Tons (metric)	Tons (short)	1.1023
Tons (short)	Kilograms	907.18
Tons (short)	Pounds (apoth. or troy)	2.4301×10^{3}
Tons (short)	Pounds (avdp.)	2000
Tons (short)	Tons (long)	0.8929
Tons (short)	Tons (metric)	0.9072
Pressure		
Atmospheres	cm of H_2O (4°C)	1.033×10^{3}
Atmospheres	Ft of H_2O (39.2°F)	33.8995
Atmospheres	In. of Hg (32°F)	29.9213
Atmospheres	kg/sq cm	1.033
Atmospheres	mm of Hg (0°C)	760
Atmospheres	Pounds/sq inch	14.696
Inches of Hg (60°F)	Atmospheres	0.03333

CONVERSION FACTORS (cont.)[a]

To Convert From	To	Multiply By
Inches of Hg (60°F)	Grams/sq cm	34.434
Inches of Hg (60°F)	mm of Hg (60°F)	25.4
Inches of Hg (60°F)	Pounds/sq ft	70.527
Inches of H_2O (4°C)	Atmospheres	2.458×10^{-3}
Inches of H_2O (4°C)	In. of Hg (32°F)	0.07355
Inches of H_2O (4°C)	kg/sq meter	25.399
Inches of H_2O (4°C)	Pounds/sq ft	5.2022
Inches of H_2O (4°C)	Pounds/sq inch	0.036126
Kilograms/sq cm	Atmospheres	0.96784
Kilograms/sq cm	cm of Hg (0°C)	73.556
Kilograms/sq cm	Ft of H_2O (39.2°F)	32.809
Kilograms/sq cm	In. of Hg (32°F)	28.959
Kilograms/sq cm	Pounds/sq inch	14.223
Millimeters of Hg (0°C)	Atmospheres	1.3158×10^{-3}
Millimeters of Hg (0°C)	Grams/sq cm	1.3595
Millimeters of Hg (0°C)	Pounds/sq inch	0.019337
Pounds/sq inch	Atmospheres	0.06805
Pounds/sq inch	cm of Hg (0°C)	5.1715
Pounds/sq inch	cm of H_2O (4°C)	70.309
Pounds/sq inch	In. of Hg (32°F)	2.036
Pounds/sq inch	In. of H_2O (39.2°F)	27.681
Pounds/sq inch	kg/sq cm	0.07031
Pounds/sq inch	mm of Hg (0°C)	51.715
Velocity		
Centimeters/sec	Feet/min	1.9685
Centimeters/sec	Feet/sec	0.0328
Centimeters/sec	Kilometers/hr	0.036
Centimeters/sec	Meters/min	0.6
Centimeters/sec	Miles/hr	0.02237

CONVERSION FACTORS (cont.)[a]

To Convert From	To	Multiply By
Feet/minute	cm/sec	0.508
Feet/minute	Kilometers/hr	0.01829
Feet/minute	Meters/min	0.3048
Feet/minute	Meters/sec	5.08×10^{-3}
Feet/minute	Miles/hr	0.01136
Feet/sec	cm/sec	30.48
Feet/sec	Kilometers/hr	1.0973
Feet/sec	Meters/min	18.288
Feet/sec	Miles/hr	0.6818
Kilometers/hr	cm/sec	27.778
Kilometers/hr	Feet/hr	3.2808×10^{3}
Kilometers/hr	Feet/min	54.681
Kilometers/hr	Meters/sec	0.27778
Kilometers/hr	Miles (statute)/hr	0.62137
Meters/min	cm/sec	1.6667
Meters/min	Feet/min	3.2808
Meters/min	Feet/sec	0.05468
Meters/min	Kilometers/hr	0.06
Miles/hr	cm/sec	44.704
Miles/hr	Feet/hr	5280
Miles/hr	Feet/min	88
Miles/hr	Feet/sec	1.4667
Miles/hr	Kilometers/hr	1.6093
Miles/hr	Meters/min	26.822
Volume		
Barrels (petroleum, U. S.)	Cu feet	5.6146
Barrels (petroleum, U. S.)	Gallons (U. S.)	42
Barrels (petroleum, U. S.)	Liters	158.98
Barrels (U. S., liq.)	Cu feet	4.2109
Barrels (U. S., liq.)	Cu inches	7.2765×10^{3}

CONVERSION FACTORS (cont.)[a]

To Convert From	To	Multiply By
Barrels (U. S., liq.)	Cu meters	0.1192
Barrels (U. S., liq.)	Gallons (U. S., liq.)	31.5
Barrels (U. S., liq.)	Liters	119.24
Cubic centimeters	Cu feet	3.5315×10^{-5}
Cubic centimeters	Cu inches	0.06102
Cubic centimeters	Cu meters	1.0×10^{-6}
Cubic centimeters	Cu yards	1.308×10^{-6}
Cubic centimeters	Gallons (U. S., liq.)	2.642×10^{-4}
Cubic centimeters	Quarts (U. S., liq.)	1.0567×10^{-3}
Cubic feet	Cu centimeters	2.8317×10^{4}
Cubic feet	Cu meters	0.028317
Cubic feet	Gallons (U. S., liq.)	7.4805
Cubic feet	Liters	28.317
Cubic inches	Cu cm	16.387
Cubic inches	Cu feet	5.787×10^{-4}
Cubic inches	Cu meters	1.6387×10^{-5}
Cubic inches	Cu yards	2.1433×10^{-5}
Cubic inches	Gallons (U. S., liq.)	4.329×10^{-3}
Cubic inches	Liters	0.01639
Cubic inches	Quarts (U. S., liq.)	0.01732
Cubic meters	Barrels (U. S., liq.)	8.3864
Cubic meters	Cu cm	1.0×10^{6}
Cubic meters	Cu feet	35.315
Cubic meters	Cu inches	6.1024×10^{4}
Cubic meters	Cu yards	1.308
Cubic meters	Gallons (U. S., liq.)	264.17
Cubic meters	Liters	1000
Cubic yards	Bushels (Brit.)	21.022
Cubic yards	Bushels (U. S.)	21.696
Cubic yards	Cu cm	7.6455×10^{5}

CONVERSION FACTORS (cont.)[a]

To Convert From	To	Multiply By
Cubic yards	Cu feet	27
Cubic yards	Cu inches	4.6656×10^{4}
Cubic yards	Cu meters	0.76455
Cubic yards	Gallons	168.18
Cubic yards	Gallons	173.57
Cubic yards	Gallons	201.97
Cubic yards	Liters	764.55
Cubic yards	Quarts	672.71
Cubic yards	Quarts	694.28
Cubic yards	Quarts	807.90
Gallons (U. S., liq.)	Barrels (U. S., liq.)	0.03175
Gallons (U. S., liq.)	Barrels (petroleum, U. S.)	0.02381
Gallons (U. S., liq.)	Bushels (U. S.)	0.10742
Gallons (U. S., liq.)	Cu centimeters	3.7854×10^{3}
Gallons (U. S., liq.)	Cu feet	0.13368
Gallons (U. S., liq.)	Cu inches	231
Gallons (U. S., liq.)	Cu meters	3.7854×10^{-3}
Gallons (U. S., liq.)	Cu yards	4.951×10^{-3}
Gallons (U. S., liq.)	Gallons (wine)	1.0
Gallons (U. S., liq.)	Liters	3.7854
Gallons (U. S., liq.)	Ounces (U. S., fluid)	128.0
Gallons (U. S., liq.)	Pints (U. S., liq.)	8.0
Gallons (U. S., liq.)	Quarts (U. S., liq.)	4.0
Liters	Cu centimeters	1000
Liters	Cu feet	0.035315
Liters	Cu inches	61.024
Liters	Cu meters	0.001
Liters	Gallons (U. S., liq.)	0.2642
Liters	Ounces (U. S., fluid)	33.814

CONVERSION FACTORS (cont.)[a]

To Convert From	To	Multiply By
Volumetric Rate		
Cu ft/min	Cu cm/sec	471.95
Cu ft/min	Cu ft /hr	60. 0
Cu ft/min	Gal (U. S.)/min	7.4805
Cu ft/min	Liters/sec	0.47193
Cu meters/min	Gal (U. S.)/min	264.17
Cu meters/min	Liters/min	999.97
Gallons (U. S.)/hr	Cu ft/hr	0.13368
Gallons (U. S.)/hr	Cu meters/min	6.309×10^{-5}
Gallons (U. S.)/hr	Cu yd/min	8.2519×10^{-5}
Gallons (U. S.)/hr	Liters/hr	3.7854
Liters/min	Cu ft/min	0.0353
Liters/min	Gal (U. S., liq.)/min	0.2642

[a] Where appropriate, the conversion factors appearing in this table have been rounded to four to six significant figures for ease in use. The accuracy of these numbers is considered suitable for use with emissions data; if a more accurate number is required, tables containing exact factors should be consulted.

CONVERSION FACTORS FOR COMMON AIR POLLUTION MEASUREMENTS

AIRBORNE PARTICULATE MATTER

To Convert From	To	Multiply By
Milligrams/cu m	Grams/cu ft	283.2×10^{-6}
	Grams/cu m	0.001
	Micrograms/cu m	1000.0
	Micrograms/cu ft	28.32
	Pounds/1000 cu ft	62.43×10^{-6}
Grams/cu ft	Milligrams/cu m	35.3145×10^{3}
	Grams/cu m	35.314
	Micrograms/cu m	35.314×10^{6}
	Micrograms/cu ft	1.0×10^{6}
	Pounds/1000 cu ft	2.2046
Grams/cu m	Milligrams/cu m	1000.0
	Grams/cu ft	0.02832
	Micrograms/cu m	1.0×10^{6}
	Micrograms/cu ft	28.317×10^{3}
	Pounds/1000 cu ft	0.06243
Micrograms/cu m	Milligrams/cu m	0.001
	Grams/cu ft	28.317×10^{-9}
	Grams/cu m	1.0×10^{-6}
	Micrograms/cu ft	0.02832
	Pounds/1000 cu ft	62.43×10^{-9}
Micrograms/cu ft	Milligrams/cu m	35.314×10^{-3}
	Grams/cu ft	1.0×10^{-6}
	Grams/cu m	35.314×10^{-6}
	Micrograms/cu m	35.314
	Pounds/1000 cu ft	2.2046×10^{-6}
Pounds/1000 cu ft	Milligrams/cu m	16.018×10^{3}
	Grams/cu ft	0.35314
	Micrograms/cu m	16.018×10^{6}
	Grams/cu m	16.018
	Micrograms/cu ft	353.14×10^{3}

CONVERSION FACTORS FOR COMMON AIR POLLUTION MEASUREMENTS (cont.).

SAMPLING PRESSURE

To Convert From	To	Multiply By
Millimeters of mercury (0°C)	Inches of water (60°F)	0.5358
Inches of mercury (0°C)	Inches of water (60°F)	13.609
	Millimeters of mercury (0°C)	1.8663
Inches of water (60°F)	Inches of mercury (0°C)	73.48×10^{-3}

CONVERSION FACTORS FOR COMMON AIR POLLUTION MEASUREMENTS (cont.).

ATMOSPHERIC GASES

To Convert From	To	Multiply By
Milligrams/cu m	Micrograms/cu m	1000.0
	Micrograms/liter	1.0
	ppm by volume (20°C)	24.04/M
	ppm by weight	0.8347
	Pounds/cu ft	62.43×10^{-9}
Micrograms/cu m	Milligrams/cu m	0.001
	Micrograms/liter	0.001
	ppm by volume (20°C)	0.02404/M
	ppm by weight	834.7×10^{-6}
	Pounds/cu ft	62.43×10^{-12}
Micrograms/liter	Milligrams/cu m	1.0
	Micrograms/cu m	1000.0
	ppm by volume (20°C)	24.04/M
	ppm by weight	0.8347
	Pounds/cu ft	62.43×10^{-9}
ppm by volume (20°C)	Milligrams/cu m	M/24.04
	Micrograms/cu m	M/0.02404
	Micrograms/liter	M/24.04
	ppm by weight	M/28.8
	Pounds/cu ft	$M/385.1 \times 10^{6}$
ppm by weight	Milligrams/cu m	1.198
	Micrograms/cu m	1.198×10^{-3}
	Micrograms/liter	1.198
	ppm by volume (20°C)	28.8/M
	Pounds/cu ft	7.48×10^{-6}
Pounds/cu ft	Milligrams/cu m	16.018×10^{6}
	Micrograms/cu m	16.018×10^{9}
	Micrograms/liter	16.018×10^{6}
	ppm by volume (20°C)	$385.1 \times 10^{6}/M$
	ppm by weight	133.7×10^{3}

M = Molecular weight of gas.

CONVERSION FACTORS FOR COMMON AIR POLLUTION MEASUREMENTS (cont.).

VELOCITY

To Convert From	To	Multiply By
Meters/sec	Kilometers/hr	3.6
	Feet/sec	3.281
	Miles/hr	2.237
Kilometers/hr	Meters/sec	0.2778
	Feet/sec	0.9113
	Miles/hr	0.6214
Feet/sec	Meters/sec	0.3048
	Kilometers/hr	1.09728
	Miles/hr	0.6818
Miles/hr	Meters/sec	0.4470
	Kilometers/hr	1.6093
	Feet/sec	1.4667

ATMOSPHERIC PRESSURE

To Convert From	To	Multiply By
Atmospheres	Millimeters of mercury	760.0
	Inches of mercury	29.92
	Millibars	1013.2
Millimeters of mercury	Atmospheres	1.316×10^{-3}
	Inches of mercury	39.37×10^{-3}
	Millibars	1.333
Inches of mercury	Atmospheres	0.03333
	Millimeters of mercury	25.4005
	Millibars	33.35
Millibars	Atmospheres	0.00987
	Millimeters of mercury	0.75
	Inches of mercury	0.30

CONVERSION FACTORS FOR COMMON AIR POLLUTION MEASUREMENTS (cont.).

VOLUME EMISSIONS

To Convert From	To	Multiply By
Cubic m/min	Cubic ft/min	35.314
Cubic ft/min	Cubic m/min	0.0283

BOILER CONVERSION FACTORS

1 Megawatt = 10.5 x 10^6 BTU/hr
(8 to 14 x 10^6 BTU/hr)

1 Megawatt = 8 x 10^3 lb steam/hr
(6 to 11 x 10^3 lb steam/hr)

1 BHP = 34.5 lb steam/hr

1 BHP = 45 x 10^3 BTU/hr
(40 to 50 x 10^3 BTU/hr)

1 lb steam/hr = 1.4 x 10^3 BTU/hr
(1.2 to 1.7 x 10^3 BTU/hr)

NOTES: In the relationships,

Megawatt is the net electric power production of a steam electric power plant.

BHP is boiler horsepower.

Lb steam/hr is the steam production rate of the boiler.

BTU/hr is the heat input rate to the boiler (based on the gross or high heating value of the fuel burned).

For less efficient (generally older and/or smaller) boiler operations, use the higher values expressed. For more efficient operations (generally newer and/or larger), use the lower vlaues.

VOLUME	cu. in.	ml.	liters	ounces (U. S. fl.)	gallons (U. S.)	barrels (U. S.)	cu. ft.
Cubic inches	....	16.3868	.0163868	0.5541	4.3290x10^{-3}	1.37429x10^{-4}	5.78704x10^{-4}
Milliliters	0.061024	....	0.001	0.03381	2.6418x10^{-4}	8.387x10^{-6}	3.5316x10^{-5}
Liters	61.024	1000	....	33.8147	0.26418	8.387x10^{-3}	0.035316
Ounces (U. S. fl.)	1.80469	29.5729	0.029573	....	7.8125x10^{-3}	2.48x10^{-4}	1.0443x10^{-3}
Gallons (U. S.)*..	231	3785.3	3.7853	128	....	0.031746	0.13368
Barrels (U. S.)...	7276.5	1.1924x10^5	119.2369	4032.0	31.5	....	4.2109
Cubic feet	1728	2.8316x10^4	28.316	957.568	7.481	0.23743	....

[1] U. S. gallon of water at 16.7°C (62°F) weighs 3.780 kg. or 8.337 pounds (avoir.)

MASS	grams	kilograms	ounces (avoir.)	pounds (avoir.)	grains	tons (U. S.)	milligrams
Grams	....	0.001	3.527x10^{-2}	2.205x10^{-3}	15.432	1.102x10^{-6}	1000
Kilograms	1000	....	35.274	2.2046	15432	1.102x10^{-3}	1x10^6
Ounces (avoir.)...	28.350	0.028350	....	0.0625	437.5	3.125x10^{-5}	2.8350x10^4
Pounds (avoir.)*..	453.59	0.45359	16.0	....	7000	5.0x10^{-4}	4.5359x10^5
Grains	0.06480	6.480x10^{-5}	2.286x10^{-3}	1.429x10^{-4}	....	7.142x10^{-8}	64.799
Tons (U. S.)	9.072x10^5	907.19	3.200x10^4	2000	1.4x10^7	....	9.0718x10^8
Milligrams	0.001	1x10^{-6}	3.527x10^{-5}	2.205x10^{-6}	0.015432	1.102x10^{-9}	....

*Mass of 27.692 cubic inches water weighed in air at 4.0°C, 760 mm mercury pressure.

WORK AND ENERGY	g. cal.	kg. cal.	ergs	Joules	BTU	ft. lb.	kg. meters	L-Atm	HP Hours	ft. poundals	KWH	WH
Gram Calories (mean)...........	....	0.001	$4.186x10^{7}$	4.186	$3.9680x10^{-3}$	3.0874	0.42685	0.041311	$1.5593x10^{-6}$	99.334	$1.1628x10^{-6}$	$1.1628x10^{-3}$
Kilogram Calories.	1000	....	$4.186x10^{10}$	4186	3.9680	3087.4	426.85	41.311	$1.5593x10^{-3}$	99334	$1.1628x10^{-3}$	1.1628
Ergs	$2.3889x10^{-8}$	$2.3889x10^{-11}$	....	$1x10^{-7}$	$9.4805x10^{-11}$	$7.3756x10^{-8}$	$1.0197x10^{-8}$	$9.8689x10^{-10}$	$3.7251x10^{-14}$	$2.3730x10^{-6}$	$2.7778x10^{-14}$	$2.7778x10^{-11}$
Joules	0.23889	$2.3889x10^{-4}$	$1x10^{7}$	....	$9.4805x10^{-4}$	0.73756	0.10197	$9.8689x10^{-3}$	$3.7251x10^{-7}$	23.730	$2.7778x10^{-7}$	$2.7778x10^{-4}$
BTU (mean)	251.98	0.25198	$1.0548x10^{10}$	1054.8	....	777.98	107.56	10.409	$3.9292x10^{-4}$	$2.5030x10^{4}$	$2.930x10^{-4}$	0.2930
Foot Pounds	0.32389	$3.2389x10^{-4}$	$1.35582x10^{7}$	1.3558	$1.2854x10^{-3}$	....	0.13825	0.013381	$5.0505x10^{-7}$	32.174	$3.7662x10^{-7}$	$3.7662x10^{-4}$
Kilogram meters ..	2.3427	$2.3427x10^{-3}$	$9.8066x10^{7}$	9.8066	$9.2967x10^{-3}$	7.2330	....	0.096781	$3.6529x10^{-6}$	232.71	$2.7241x10^{-6}$	$2.7241x10^{-3}$
Liter Atmospheres (normal)	24.206	$2.4206x10^{-2}$	$1.0133x10^{9}$	101.328	0.09606	74.735	10.333	....	$3.7745x10^{-5}$	2404.5	$2.8164x10^{-5}$	$2.8164x10^{-2}$
Horsepower Hours .	$6.4130x10^{5}$	641.30	$2.6845x10^{13}$	$2.6845x10^{6}$	2454.0	$1.9800x10^{6}$	$2.7374x10^{5}$	26494	....	$6.3705x10^{7}$	0.7457	745.7
Foot poundals	0.010067	$10.067x10^{-6}$	$4.21402x10^{5}$	0.04214	$3.9952x10^{-5}$	0.031081	$4.2972x10^{-3}$	$4.1558x10^{-4}$	$1.5697x10^{-8}$	....	$1.17055x10^{-8}$	$1.17055x10^{-5}$
Kilowatt Hours ...	$8.6001x10^{5}$	860.01	$3.6000x10^{13}$	$3.6000x10^{6}$	3413.0	$2.6552x10^{6}$	$3.6709x10^{-5}$	$3.5529x10^{6}$	1.3440	$8.5430x10^{7}$	....	1000
Watt Hours	860.01	0.86001	$3.6000x10^{10}$	3600	3.4130	2655.3	367.09	$3.5529x10^{3}$	$1.3410x10^{-3}$	$8.5430x10^{1}$	0.001	....

[illegible]

CONVERSION FACTORS FOR VARIOUS SUBSTANCES[a]

Type Of Substance	Conversion Factors
Fuel	
Oil	1 bbl = 159 liters (42 gal)
Natural gas	1 therm = 100,000 Btu (approx.25000 kcal)
Gaseous Pollutants	
O_3	1 ppm, volume = 1960μg/m^3
NO_2	1 ppm, volume = 1880μg/m^3
SO_2	1 ppm, volume = 2610μg/m^3
H_2S	1 ppm, volume = 1390 μg/m^3
CO	1 ppm, volume = 1.14 mg/m^3
HC (as methane)	1 ppm, volume = 0.654 mg/m^3
Agricultural products	
Corn	1 bu = 25.4 kg = 56 lb
Milo	1 bu = 25.4 kg = 56 lb
Oats	1 bu = 14.5 kg = 32 lb
Barley	1 bu = 21.8 kg = 48 lb
Wheat	1 bu = 27.2 kg = 60 lb
Cotton	1 bale = 226 kg = 500 lb
Mineral products	
Brick	1 brick = 2.95 kg = 6.5 lb
Cement	1 bbl = 170 kg = 375 lb
Cement	1 yd^3 = 1130 kg = 2500 lb
Concrete	1 yd^3 = 1820 kg = 4000 lb
Mobile sources, fuel efficiency	
Motor vehicles	1.0 mi/gal = 0.426 km/liter
Waterborne vessels	1.0 gal/naut mi = 2.05 liters/km
Miscellaneous liquids	
Beer	1 bbl = 31.5 gal
Paint	1 gal = 4.5 to 6.82 kg = 10 to 15 lb
Varnish	1 gal = 3.18 kg = 7 lb
Whiskey	1 bbl = 190 liters = 50.2 gal
Water	1 gal = 3.81 kg = 8.3 lb

[a] Many of the conversion factors in this table represent average values and approximations and some of the values vary with temperature and pressure. These conversion factors should, however, be sufficiently accurate for general field use.

APPENDIX IV-C

EXCERPT FROM THE *1995 PROTOCOL FOR EQUIPMENT LEAK EMISSION ESTIMATES*

APPENDIX IV-D

EXAMPLE QUALITY CONTROL CHECKLIST

APPENDIX IV-E

SOURCE CLASSIFICATION CODES LIST

APPENDIX IV-F

THE NATIONAL INSTITUTE OF ECOLOGY POINT SOURCE QUESTIONNAIRES

APPENDIX IV-G

DEVICE LEVEL DATA COLLECTION FORMS

Example QC Checklist

Completeness Checks - Point Sources	**Yes**	**No**	**Comments**
Have all applicable VOC point sources been included in the inventory?			
Have process, point, and segment level data been provided for all VOC point sources?			
Have all process, point, and segment level documentation data been provided for NO_X and CO sources been provided?			
Is the Annual Emission Inventory signed by the proper authority who will take legal responsibility for the accuracy of the information verified in the report to the state?			
Is the following information provided in the report (to the regulatory agency) and is it accurate: source addresses, contact information, and industrial process classification code(s)?			
Procedures Checks			
Have you made a copy of the inventory and report you are mailing to the regulatory agency?			
Does the inventory documentation describe the methodology used (i.e., survey, plant inspections, continuous emissions monitoring data, fuel analysis data, air quality modeling data, material balance, and permit files) to develop the point source inventory listing?			
Does the point source inventory documentation include the contact person(s) for referring questions?			
Select a subset that represents at least 10 percent of the listed point sources and determine if the following data are compiled and presented for each source. *Note: Identify in the comment column the record number of those plants that were checked.*			

Example QC Checklist (Continued)

Procedures Checks (Continued)	**Yes**	**No**	**Comments**
• Plant name and location (including latitude, longitude, and zip code)			
• Operating schedule			
• Applicable regulations			
• UTM zone			
• Pollutant code or CAS number			
• Stack ID (for point pollutant data)			
• Emission limitations (only if subject to INE regulation)			
• Compliance year (only if subject to INE Regulation)			
• Daily process rate and units			
• Control equipment type			
• Control efficiency			
• Emissions estimation method			
• Emission factors			
Reasonableness Checks			
If point source VOC emissions are attributed to the synthetic organic chemical manufacturing industry (SOCMI), are fugitive leaks also quantified? *Note: Fugitive equipment leak emissions should be 1 to 10 times larger than emissions from vents, reactors, etc.*			
Are the following data elements within the ranges listed below for general point sources data?			

Example QC Checklist (Continued)

Reasonableness Checks (Continued)	**Yes**	**No**	**Comments**
• Hours per day ≤24			
• Days per week ≤7			
• Hours per year = hours x days			
• Seasonal throughputs 0 - 100			
• Boiler capacity 80 - 120 percent of hourly maximum rate x fuel heat content			
• Is percent space heat for winter greater than summer			
• Are the following data elements within the ranges listed below for point pollutant data?			
• Stack height >50 Feet			
• Stack diameter .5 >30 Feet			
• Plume height >200 Feet			
• Temperature of exit gases 60 >2,000°F			
• Temperature of exit gases with wet scrubber >250°F			
• Temperature of exit gases without wet scrubber >250°F			
• Exhaust gas flow rate equal to capacity x temperature			
• Exhaust gas velocity			
Are the following data elements within the ranges listed below for general segment data?			
• Process hourly rate units < 10 percent of >125 percent x maximum design capacity.			
• For control devices, is the control efficiency between 0 - 100 percent?			

Example Data Collection Form Instructions- Surface Coating Operations

1. This form may be used as a work sheet to aid the plant engineer in collecting the information necessary to calculate emissions from each surface coating operation. The information requested on the form relates to the different methods for quantifying emissions. This form may also be used by the regulatory agency to assist in area wide inventory preparation.

2. The completed forms should be maintained in a reference file by the plant engineer with other supporting documentation.

3. If the information requested is unknown, write "unknown" in the blank. If the information requested does not apply to a particular unit or process, write "NA" in the blank.

4. If hourly or monthly material use information is not available, enter the information in another unit (quarterly or yearly). Be sure to indicate the unit of measure on the form.

5. Use the comments field on the form to record all useful information that will allow your work to be reviewed and reconstructed.

6. Collect all Material Safety Data Sheets (MSDSs) for all materials containing potential air contaminants that are used at the facility.

7. For each material used, determine maximum hourly usage rates and annual usage rates.

8. The plant engineer should maintain all material usage information and MSDSs in a reference file.

Example Data Collection Form - Surface Coating Operations

GENERAL INFORMATION

Facility/Plant Name:

Facility Description:

Location:

County:

City:

State:

Plant Geographical coordinates:
Latitude:______________________________
Longitude:____________________________
UTM Zone:____________________________
UTM Easting: _____________________
UTM Northing:________________________

Contact Name:

Title:

Telephone Number:

Unit ID Number:

Permit Number:

Example Data Collection Form - Surface Coating Operations

EQUIPMENT AND PROCESS INFORMATION	**COMMENTS**
Name or description of equipment:	
Make:	
Model:	
Rated capacity of equipment:	
Type of Operation:	
surface coater:	
dryer:	
printing press:	
other:	
Type of equipment for this operation:	
dip coater:	
letter press:	
other:	
Application/Dryer evaporation split (%):	
Typical use:	
hours/days:	
days/week:	
weeks/year:	
Seasonal Variations (%):	

January: February: March:

April: May: June:

July: August: September:

October: November: December:

Example Data Collection Form - Surface Coating Operations

W4444444444444444444444444444444444444444444U

MATERIAL INFORMATION

W44444444444444444444444444444444444444444444

MATERIAL COMPOSITION

S))

Name of Material:

S))

VOC Content (lb/gal or wt.%):

S))

Solids Content (wt.%):

S))

Density of Material:

S))

Composition (lb_x/lb material) * 100%:

- name of component ____________

- wt.% of component ____________

W44444444444444444444444444444444444444444444

MATERIAL USAGE

S))

Hourly throughput:

S))

Monthly throughput:

S))

Annual throughput:

S))

Maximum throughput:

W44444444444444444444444444444444444444444444

SURFACE COATING OPERATIONS

S))

Type of Coating (ink, primer, paint, etc.):

S))

Substrate Coated (wood, metal, etc.):

S))

Mixture Name (for multi-part coatings):

S))

Brand/Product Name (for each part of coating mixture):

S))

Mix Ratio for Coating Mixtures:

S))

% VOC Evaporated as Fugitive:

S))

Particulate Emission Factor:

S))

- Reference:

W44444444444444444444444444444444444444444444

Worksheet A
Solvent Description

Solvent Composition	**Annual Usage (gal/yr)**	**Percent of Total Solvents Listed**	**Molecular Weight (lb/lb_{mole})**	**Liquid Density (lb/gal)**
Total				
Solvent Molecular Weight (weighted average), (M_i)			lb/lb_{mole}	
Solvent Liquid Density (weighted average), (d_i)			lb/lb_{mole}	

$$Y = \sum_{i=1}^{n} (x_i \quad y_i)$$

where:

Y = Weighted average molecular weight (M_i) or liquid density (d_i)
y_i = Molecular weight (M_i) or liquid density (d_i) for VOC_i
x_i = Fraction of total solvent for VOC_i
n = Number of VOC species in the solvent(s)

Worksheet B
Spray Booths

Annual Hours of Operation of this Booth:

EXHAUST GAS STREAM CHARACTERISTICS

Flow Rate (acfm)		Exhaust Stack			Building Height (ft)	Abatement Device Particulate Loading (lb/hr)	
Design Maximum	Average Expected	Temperature °F	Height (ft)	Diameter (ft)		Inlet	Outlet

TYPE OF COATING AND MAXIMUM RATE OF USE

Type	Max. Rate of Use (lb/hr)	Max. Rate of Use (ton/yr)	Volatile Portion (%weight)
Lacquer			
Varnish			
Enamel			
Metal Primer			
Metal Spray			
Resin			
Sealer			
Shellac			
Stain			
Zinc Chromate			
Epoxy			
Polyurethane			
Other			

SOLVENT COMPOSITION AND RATE OF USE (INCLUDE THAT SUPPLIED WITH COATING)

Chemical Composition of Volatiles & wt. (%)	Max. Rate of Use (lb/hr)	Max. Rate of Use (ton/yr)

TYPE OF PM ABATEMENT DEVICE

G Spray Chamber (water use gal/hr) ________________

G Dry Filter Pads (total number in all layers) __________

(size) ____

G Water Curtain (water use gal/hr) ________________

G Other (explain) ____________________________

G Manufacturer's Rating for PM Control Efficiency __________

TYPE OF VOC ABATEMENT DEVICE

Type ____

Rated Control Efficiency ______________________________

Worksheet B

(Continued)

METHOD OF SPRAYING	DESCRIPTION OF ITEMS TO BE COATED (SHAPE AND SIZE)
G Air Atomization **G** Airless Electrostatic **G** Disc **G** Airless **G** Air-Atomized **G** Other ________________________	

Example Data Collection Form Instructions - Boilers

1. This form may be used as a work sheet to aid the plant engineer in collecting the information necessary to calculate emissions from boilers. The information requested on the form relates to the different methods for quantifying emissions. This form may also be used by the regulatory agency to assist in area wide inventory preparation.

2. The completed forms should be maintained in a reference file by the plant engineer with other supporting documentation.

3. The information identified on these forms is needed to generate a complete emissions inventory. If the information requested does not apply to a particular boiler, write "NA" in the blank.

4. If rated capacity is not documented in MMBtu/hr, please enter the capacity in lb/hr steam produced, or other appropriate units of measure.

5. If hourly or monthly fuel use information is not available, enter the information in another unit (quarterly or yearly). Be sure to indicate on the form, what the unit of measure is.

6. Use the comments field on the form to record all useful information that will allow your work to be reviewed and reconstructed.

Example Data Collection Form - Boilers

GENERAL INFORMATION

Facility/Plant Name:

Facility Description:
Utility ___________________
Commercial ___________________
Industrial ___________________

Location:

County:

City:

State:

Plant Geographical coordinates:
Latitude:______________________________
Longitude:_____________________________
UTM Zone:____________________________
UTM Easting: ______________________
UTM Northing:________________________

Contact Name:

Title:

Telephone Number:

Unit ID Number:

Permit Number:

Example Data Collection Form - Boilers

SOURCE INFORMATION	**COMMENTS**

Unit ID:

Manufacturer:

Date Installed:

Rated Capacity (units):

Maximum Heat Input (units):

Fuel Type:

Operating Schedule:

Hours/Day:

Days/Week:

Weeks/Year:

FUEL USE[a]:

Year:

Maximum Hourly Fuel Use (units):

Monthly Fuel Use (units):

January:	July:
February:	August:
March:	September:
April:	October:
May:	November:
June:	December:

Total Annual Fuel Use (units):

---

[a] This form should be completed for each fuel type used.

Example Data Collection Form - Boilers

FIRING CONFIGURATION (Check the appropriate type)

Tangential Fired ☐ Horizontally Fired ☐ Vertically Fired ☐ Pulverized Coal Fired ☐

Dry Bottom ☐ Wet Bottom ☐

Cylone Furnace ☐

Spreader Stoker ☐ Uncontrolled ☐ Controlled ☐

Overfeed Stoker ☐ Uncontrolled ☐ Controlled ☐

Underfired Stoker ☐ Uncontrolled ☐ Controlled ☐

Handfired Units ☐

POLLUTION CONTROL EQUIPMENT (Enter control efficiency and source of information):

ESP:

Baghouse:

Wet Scrubber:

Dry Scrubber:

Spray Dryer:

Cyclone:

Other:

Example Data Collection Form - Boilers

FUEL ANALYSIS:	**COMMENTS**
Sulfur Content (S):	
Ash Content:	
Nitrogen Content (N):	
Lead Content (Pb):	
Mercury (Hg):	
Others:	
Higher Heating Value (HHV in Btu/lb):	
Reference (Attach Analysis if Available):	
STACK INFORMATION:	
Stack ID:	
Unit ID:	
Stack (Release) Height (feet):	
Stack Diameter (inch):	
Stack Gas Temperature (°F):	
Stack Gas Velocity (ft/sec):	
Stack Gas Flow Rate (ascf/min):	
Do Other Sources Share This Stack (Y/N)?: (If yes, include Unit IDs for each).	
Site-specific Stack Sampling Report Available (Y/N)?:	
Reference (Include Full Citation of Test Reports Used):	

Example Data Collection Form
Instructions-Equipment Leak Fugitives

1. This form may be used as a worksheet to aid in collecting the information/data necessary to estimate HAP and VOC emissions from equipment leaks.

2. The form is divided into five sections: General Information; Stream Composition Data; Equipment Counts; Screening Data; and Equipment Leaks Controls.

3. Some of the sections require entry on a stream basis; for these, a separate copy of the section will need to be made for each stream in the process unit.

4. For the stream composition data section, weight percents may not need to be provided for constituents present in concentrations less than 1.0 weight percent.

5. For the stream composition data section, in the row labelled "OTHER", identify total weight percent of all constituents not previously listed. The total weight percent of constituents labelled as "OTHER" must not exceed 10 percent. Total weight percent of all constituents in the stream must equal 100 percent.

6. For the screening data section, complete the information/data for each screened stream.

7. For the equipment count section, complete the questions and table for each stream in the facility.

8. For the equipment count section, the Leak Detection and Repair (LDAR) trigger concentration refers to the concentration level that the component is considered to be leaking.

9. For the equipment count section, enter the control parameters for each component type in the stream. Provide the percent of the total equipment type in the stream that has the controls listed in Table III-1.

10. For the equipment count section, if other controls are used, specify what they are in the space left of the slash. Specify the percent of each component type in the stream that use the other control in the space to the right of the slash.

11. For the equipment count section, indicate any secondary control devices to which the closed vent system transports the process fluid.

Example Data Collection Form -
Fugitive Emissions from Equipment Leaks

GENERAL INFORMATION
Process Unit Capacity (lb/yr)
Portable VOC Monitoring Instrument Used[a]
Calibration Gas of Monitoring Instrument[a]

STREAM COMPOSITION DATA						
CAS Number	Chemical Name	Concentration (wt%)				
		Stream 1	Stream 2	Stream 3	Stream 4	Stream 5
--	OTHER					
--	Total HAP					
--	Total VOC					
--	Source[b]					
Amount of Time Fluid in Stream (hr/yr)						

[a] Collect information if screening data has been gathered at the process unit.

[b] EJ = Engineering judgement; TD = Test data; LV = Literature values.

Example Data Collection Form -
Fugitive Emissions from Equipment Leaks

EQUIPMENT COUNTS					
Component	Service	Count Source[b]	Stream 1	Stream 2	Stream 3
Valves	gas/vapor				
	light liquid				
	heavy liquid				
Connectors	all				
Pumps	light liquid				
	heavy liquid				
Compressor	gas/vapor				
Open Lines	all				
Sample Connections	all				
Pressure Relief Valve	gas/vapor				

[a] Do not include equipment in vacuum service.

[b] D = Design specifications; I = Inspection and maintenance tags; C = Actual count; and R = Ratio, if ratio specify (i.e., 25 valves per pump).

Example Data Collection Form - Fugitive Emissions from Equipment Leaks

SCREENING DATA	
Stream ID:	Component Type:
Date Components Screened:	Total Number of Components Screened
Component ID	Screening Value (ppmv)

Example Data Collection Form -
Fugitive Emissions from Equipment Leaks

EQUIPMENT LEAKS CONTROLS

Stream ID:

Is the equipment in this stream subject to a LDAR program? (Yes/No)

Type of Monitoring System[a]:

	Leak Detection and Repair Parameters				Control Parameters				
Equipment	Quantity in Program	LDAR Trigger Conc.	Monitoring Frequency	Response Time[b]	Percent with Control A[c]	Percent with Control B[c]	Percent with Control C[c]	Other	Closed-Vent Secondary Control
Valves							NA	/	
Pumps								/	
Compressors							NA	/	
Connectors						NA	NA	/	
Open-ended lines							NA	/	
Sampling Connections	NA	NA	NA	NA				/	
Pressure Relief Valves							NA	/	

NA = Not applicable.

[a] V = Visual; P = Portable; F = Fixed point; If other, please specify.

[b] IM = Immediately; D = 1 day; D3 = 3 days; W = 1 week; W2 = 2 weeks; and M = 1 month.

[c] See Table III-1 (Controls by Equipment Type).

Table IV-1
Controls By Equipment Type

Control Option	Equipment	Controls
A	All	Closed vent system
B	Valves Pumps Compressors Open-ended lines Sampling Connections PRV's	Sealless Dual mechanical seal with barrier fluid[a] Mechanical seals with barrier fluid[a] Capped, plugged, blind-flagged *In-situ* sampling Rupture disk
C	Pumps Sampling connections	Sealless Closed loop sampling

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RCN 670-017-21-04

MANUALES DEL PROGRAMA DE INVENTARIOS DE EMISIONES DE MEXICO

VOLUMEN IV - DESARROLLO DEL INVENTARIO DE FUENTES PUNTUALES

Elaborado para:

La Asociación de Gobernadores del Oeste
Denver, Colorado

y

El Comité Asesor Binacional

Elaborado por:

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Agosto 15, 1996

PREFACIO

La contaminación del aire puede tener impactos negativos sobre la salud pública cuando su concentración en la atmósfera alcanza niveles significativos. En la mayor parte de las áreas rurales los problemas de calidad del aire se dejan sentir sólo en raras ocasiones mientras que muchos ambientes urbanos con frecuencia registran elevadas concentraciones de contaminantes. Durante los últimos años, México ha tenido un gran crecimiento en la urbanización y en la actividad industrial, lo que ha generado serias preocupaciones acerca de la calidad del aire en diversas regiones del país.

La contaminación del aire resulta de una compleja mezcla de, literalmente, miles de fuentes, que van desde las chimeneas industriales y los vehículos automotores, hasta el uso individual de productos de aseo, limpiadores domésticos y pinturas; incluso la vida animal y vegetal puede desempeñar un papel importante en el problema. Debido a la compleja naturaleza de la contaminación del aire se requieren planes regionales detallados para identificar las fuentes de emisión, así como el desarrollo de métodos para reducir el impacto sobre la salud ocasionado por la exposición a los contaminantes. Entre algunos ejemplos de las actividades de gestión de la calidad del aire se encuentran:

- La aplicación de modelos de calidad del aire
- El examen de las fuentes emisoras de contaminantes para analizar el control de emisiones, cuando así se requiere
- El desarrollo de proyecciones de las emisiones para examinar posibles cambios en la futura calidad del aire

- El análisis de las tendencias de emisión
- El análisis del transporte de las emisiones de una región a otra.

El desarrollo de inventarios de emisión bien fundamentados es un aspecto clave en cada una de estas funciones de gestión de la calidad del aire.

El cálculo de estimaciones de emisión que cumplan con las necesidades de la gestión de la calidad del aire requiere de un desarrollo y refinamiento continuos; los esfuerzos de inventarios “de un solo paso” no son adecuados para el proceso de gestión de la calidad del aire. Para obtener un beneficio de larga duración debe instrumentarse un *programa de inventarios,* de manera que sea posible el desarrollo de estimaciones exactas de las emisiones para todas las regiones geográficas de importancia, que tengan la capacidad de ser refinadas con el paso del tiempo y que puedan aplicarse efectivamente en el proceso de gestión y monitoreo de la calidad del aire. De esta manera, se está desarrollando un conjunto de manuales de inventarios que puedan ser aplicados en todo el país para ayudar a coordinar el desarrollo de estimaciones de emisiones consistentes. Estos manuales han sido diseñados para ser utilizados por las autoridades locales, estatales y federales, así como por consultores privados e industriales. El propósito de estos manuales es ayudar en el proceso de instrumentación del programa de inventarios y en su mantenimiento a lo largo del tiempo, de manera tal que los inventarios de emisiones se puedan desarrollar en ciclos periódicos mejorándolos continuamente.

Los manuales abarcan elementos del programa de inventarios tales como la estimación de emisiones, la planeación del programa, manejo de bases de datos, validación de emisiones y otros temas de importancia. La Figura 1 muestra la serie completa de manuales que serán desarrollados para apoyar un programa de inventarios de largo alcance. A continuación se resume el propósito principal de cada manual.

Figura 1. Manuales del Programa de Inventarios de Emisiones de México

Volumen I - Planeación del Programa de Inventarios de Emisiones. Este manual presenta los aspectos de gestión que deben ser considerados en un programa de inventario de emisiones al aire. La planeación del programa no se presenta como una actividad “terminal”, sino más bien como un proceso continuo para asegurar el crecimiento en el largo plazo y el éxito del programa de inventarios. *Temas Clave:* propósito del programa; usos finales del inventario; requerimientos regulatorios; coordinación en los niveles federal, estatal y local; requerimientos de personal y de manejo de datos; identificación y selección de estudios especiales.

Volumen II - Fundamentos de Inventarios de Emisiones. Este manual presenta los fundamentos básicos para el desarrollo de inventarios de emisiones, así como los elementos que son aplicables a los diversos tipos de fuentes (e. g., puntuales y de área), para evitar la necesidad de que sean repetidos en cada volumen. *Temas Clave*: regulaciones aplicables; efectividad de la regla; penetración de la regla; definiciones sobre contaminantes (e. g., cómo excluir de manera adecuada los compuestos volátiles no reactivos); definición de fuentes puntuales y de área; reconciliación de fuentes puntuales y de área.

Volumen III - Técnicas Básicas de Estimación de Emisiones (TEEs). Este documento presenta las TEEs básicas utilizadas para hacer estimaciones de emisiones, incluyendo ejemplos y cálculos como muestra. Por otro lado se identifican las herramientas para inventarios asociadas con cada metodología y se incluyen en el Volumen XI (Referencias). *Temas Clave*: muestreo en la fuente, modelos de emisiones, encuestas, factores de emisión, balance de materiales y extrapolación.

Volumen IV - Fuentes Puntuales. Este manual proporciona guías para elaborar inventarios de emisiones de fuentes puntuales. Incluye una tabla de referencias cruzadas para cada combinación de industria y tipo de dispositivo (e. g., refinación de petróleo y dispositivos de combustión), con una o más de las TEEs presentadas en el Volumen III. *Temas Clave:* tabla de referencias cruzadas; parámetros de chimenea; dispositivos de control; consideraciones de diseño y de proceso; diferencias geográficas y variabilidad en México; aseguramiento y control de calidad (AC/CC); procesos omitidos; referencias de datos y formas para recopilación de datos.

Volumen V - Fuentes de Area (incluyendo fuentes móviles que no circulan por carreteras). Este manual contiene los lineamientos para el desarrollo de inventarios de emisiones de fuentes de área. Además de presentar información general sobre las fuentes de área, se proporciona una tabla de referencias cruzadas entre cada categoría de fuente de área (e. g., aplicación de asfalto) con una o más de las TEEs básicas incluidas en el Volumen III. Posteriormente, se discute la información específica para cada categoría de fuente definida en la tabla. *Temas Clave:* categorización y definición de fuentes de área; tabla de referencias cruzadas; factores de control; diferencias geográficas y variabilidad en México; AC/CC; referencias de datos; formas para recopilación de datos (cuestionarios).

Volumen VI - Vehículos Automotores. Debido a que los vehículos automotores son intrínsecamente diferentes a las fuentes puntuales y a las de área, tanto los métodos de estimación disponibles como los datos requeridos son también diferentes. Los modelos han sido las herramientas preferidas para estimar las emisiones de estas complejas fuentes. Muchos de estos modelos utilizan datos de pruebas extensivas aplicables a un país o a una región determinados. Este manual se enfoca principalmente en la fase de desarrollo de datos para la estimación de emisiones de vehículos automotores. *Temas Clave:* métodos de estimación disponibles; datos e información primarios, secundarios y terciarios; clasificación de fuentes; fuentes de factores de emisión; variabilidad geográfica dentro de México, AC/CC.

Volumen VII - Fuentes Naturales. Este manual proporciona los lineamientos para el desarrollo de inventarios de emisiones de fuentes naturales (e. g., compuestos orgánicos volátiles biogénicos [COVs] y óxidos de nitrógeno [NO_x]) en suelos. Además, incluye los aspectos teóricos de los cálculos de emisiones y la discusión de modelos específicos. *Temas Clave:* clasificación y definición de fuentes; mecanismos de emisión; algoritmos básicos de emisión; determinación de biomasa; desarrollo de datos de uso y cobertura del suelo; ajustes temporales y meteorológicos; enfoques para el cálculo de emisiones.

Volumen VIII - Desarrollo de Inventarios para Modelado. Este manual proporciona los lineamientos para el desarrollo de datos de inventarios que serán utilizados en modelos de calidad del aire, y trata aspectos tales como la localización temporal y espacial, la especiación y la proyección de estimaciones de emisiones. *Temas Clave:* definición de términos de modelado; ajuste estacional; localización temporal y espacial; especiación química y proyecciones (factores de crecimiento y control).

Volumen IX - Evaluación del Programa de Inventarios de Emisiones. Este manual consta de tres partes: AC y CC, análisis de incertidumbre y verificación de emisiones. La parte de AC y CC define el programa global de aseguramiento y control de calidad, y ha sido escrito para complementar los procedimientos de AC y CC para fuentes específicas que se presentan en otros manuales. El análisis de incertidumbre no sólo incluye métodos para evaluar la incertidumbre en las estimaciones de emisiones, sino también para evaluar la incertidumbre en los valores de modelado tales como los perfiles de especiación y los factores de proyección de emisiones. La sección de verificación de emisiones describe varios análisis para evaluar la exactitud de las estimaciones. Los ejemplos incluyen modelos de receptores y análisis de trayectoria, combinados con técnicas específicas para el análisis de datos. *Temas Clave:* descripción de conceptos y definición de términos; protocolo de revisión de inventarios; evaluación de integridad, exactitud y consistencia; TEEs de incertidumbre recomendadas, y metodología aplicable para la verificación de emisiones.

Volumen X - Manejo de Datos. Este manual trata de las necesidades asociadas con los aspectos del manejo de datos del programa nacional de inventarios de emisiones de México. *Temas Clave:* sistemas y herramientas generales para el manejo de datos; sistemas y herramientas de software específicos; sistemas de codificación; confidencialidad; presentación electrónica; frecuencia de actualizaciones, mantenimiento de registros; bases de datos específicas de México y reportes.

Volumen XI - Referencias. Este manual es un compendio de las herramientas que pueden utilizarse en el desarrollo de un programa de inventarios de emisiones. Se incluyen las herramientas citadas para hacer inventarios en los otros manuales (e. g., documentos impresos y electrónicos, así como modelos de computadora).

CONTENIDO

Sección **Pág.**

FIGURAS Y TABLAS

ACRONIMOS

AC	Aseguramiento de calidad
BBS	Bulletin board system *(Sistema del Tablero de Boletín)*
Btu	Unidad térmica británica
CAD	*Computer aided design* (diseño auxiliado por computadora)
CC	Control de calidad
CCF	Código de Clasificación de Fuentes
CHIEF	Clearing House for Inventories and Emission Factors *(Centro de Información para Inventarios y Factores de Emisión)*
CO	Monóxido de carbono
COV	Compuesto orgánico volátil
DQI	Data quality indicator *(indicador de calidad de los datos)*
DQO	Data quality objective *(objetivo de calidad de los datos)*
dscfm	dry standard cubic feet per minute *(pie cubico estándar seco por minuto)*
dscm	dry standard cubic meter *(metro cúbico estándar seco)*
EC	Equipo de control
EIIP	Emission Inventory Improvement Program *(Programa de Mejoramiento del Inventario de Emisiones)*
ESP	Precipitadores electrostáticos
EU	Estados Unidos

FGR	Flue gas recirculation *(recirculación de gases de combustión)*
FIRE	Factor Information Retrieval System *(Sistema de Recuperación de Información de Factores)*
GPS	Global Positioning System *(Sistema de Posicionamiento Global)*
hr	Hora
INE	Instituto Nacional de Ecología
INEGI	Instituto Nacional de Estadística, Geografía e Informática
kg	Kilogramo
km	Kilometro
l	Litro
lb	Libra
LEVD	Low Emission Vapor Degreaser *(Desengrasador de Vapor de Baja Emisión)*
LPG	Gas licuado
m^3	Metro cúbico
MCE	Monitoreo continuo de emisiones
Mg	Megagramo (i.e., 10^6 g = 1 tonelada métrica)
mg	Miligramo
MP	Partículas
NH_3	Amoniaco
NO_x	Oxidos de nitrógeno
O_2	Oxígeno
OFA	overfire air *(aire de sobrefuego)*
PE	Punto de emisión
PM	Peso molecular
PM_{10}	Partículas de diámetro inferior o igual a 10 micrómetros

ppbv	Partes por billón por volumen
ppmv	Partes por millón por volumen
psig	Libras por pulgada cuadrada - presión manométrica
SNIFF	Sistema Nacional de Información de Fuentes Fijas
SO_2	Dióxido de azufre
SO_3	Trióxido de azufre
SO_x	Oxidos de azufre
TEEs	Técnicas de estimación de emisiones
ton	Tonelada inglesa (i. e., 2,000 lb)
tonne	Tonelada métrica (i. e., 1,000 kg)
TSDF	treatment, storage, and disposal facility (*establecimiento para tratamiento, almacenamiento y disposición)*
U.S. EPA	*United States Environmental Protection Agency* (Agencia de Protección Ambiental de Estados Unidos)
UE	Unidad de emisión
UNAM	Instituto de Meteorología y Ciencias de la Atmósfera de la Universidad Nacional Autónoma de México
UTM	Mercator universal transverso

1.0. INTRODUCCION

El Artículo 17 del Reglamento de la Ley General de Equilibrio Ecológico y Protección al Ambiente en Materia de Prevención y Control de la Contaminación de la Atmósfera establece que “las entidades responsables de las fuentes puntuales de jurisdicción federal deben presentar un inventario que incluya sus emisiones contaminantes a la atmósfera”. Por su parte, el Artículo 112 de la Ley General de Equilibrio Ecológico y Protección al Ambiente, determina que los gobiernos, a nivel federal y estatal, deben crear y actualizar de manera continua el inventario de emisiones, así como prevenir y controlar la contaminación atmosférica en sus jurisdicciones, incluyendo las fuentes de emisiones de área, antropogénicas y de otros tipos.

Actualmente se está elaborando una serie de documentos que definirán los procedimientos estándar para el desarrollo de inventarios de emisiones de fuentes puntuales, de área, móviles y naturales; cuyo objetivo es proporcionar métodos costo-efectivos y confiables para elaborar inventarios e incrementar la calidad de la información que es recopilada y reportada. Por otro lado, los documentos también tienen la finalidad de constituir una guía para obtener información completa y precisa sobre las tecnologías de proceso y métodos de control de la contaminación. La aplicación de una metodología estandarizada fortalecerá la consistencia de dichas actividades entre los grupos que deberán reportar al inventario de emisiones.

Los procedimientos para elaborar un inventario de emisiones que se presentan en este volumen son específicos para fuentes puntuales, entre las que se incluyen los establecimientos, plantas o actividades para las que se tienen registros individuales de fuente en la base de datos del inventario. El volumen IV pretende familiarizar al sector industrial y a las entidades federales, estatales y municipales con los conceptos fundamentales necesarios para desarrollar un inventario de emisiones de fuentes puntuales. El volumen III, *Técnicas Básicas de Estimación de Emisiones*, presenta una introducción a la metodología para la estimación de emisiones contaminantes, e incluye ejemplos detallados que ayudarán al lector a hacer cálculos de emisiones reales.

La Figura 1.1., ilustra el proceso general de desarrollo de inventarios de fuentes puntuales, y correlaciona sus actividades con las secciones correspondientes de este documento.

El proceso para el desarrollo del inventario de fuentes puntuales del Instituto Nacional de Ecología (INE), incluido como Apéndice IV-A, muestra que en algunos casos el INE podría asumir la responsabilidad sobre los cálculos de las emisiones si éstos no fueran proporcionados o bien fundamentados por los establecimientos.

El presente manual está organizado de la siguiente manera:

- La Sección 2.0 cubre dos importantes aspectos que deben ser tratados antes de entrar en materia: la definición de “fuente puntual” y la determinación del grado de detalle del inventario.
- La Sección 3.0 incluye una breve descripción de las metodologías básicas recomendadas para estimar las emisiones contaminantes de fuentes puntuales. Adicionalmente presenta información sobre las fuentes de emisión, con el objetivo de ayudar al lector en la selección de una técnica de estimación apropiada. El Apéndice IV-B contiene un listado de los factores de conversión más comunes.

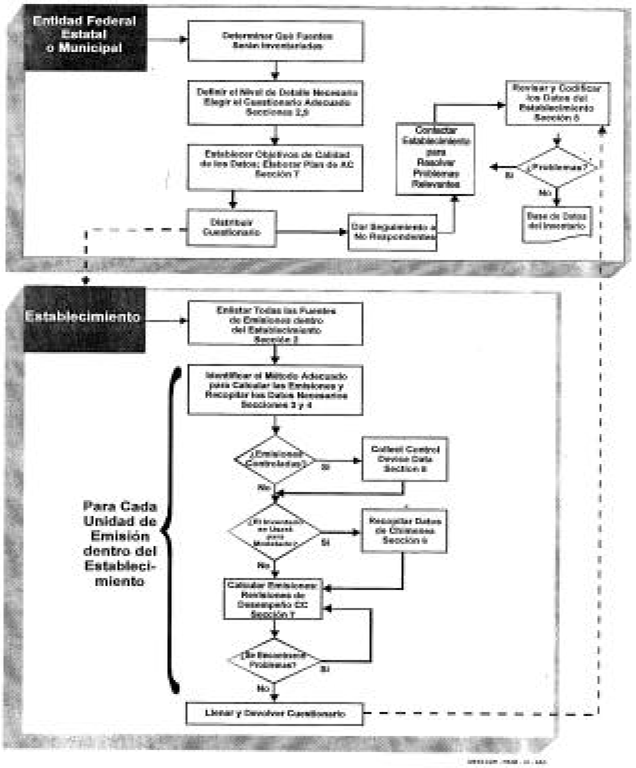


Figura 1-1. Proceso de Desarrollo del Inventario de Fuentes Puntuales

- La Sección 4.0 describe los aspectos de diseño y proceso que podrían tener influencia en las emisiones (e. g., características de los combustibles o parámetros de operación), y también presenta algunas fuentes puntuales que normalmente son omitidas durante el desarrollo de inventarios. El Apéndice IV-C contiene información sobre los procedimientos y enfoques para estimar las emisiones del componente fugitivo de las fugas del equipo.

- La Sección 5.0 presenta algunos ejemplos de equipos de control típicos y analiza su eficiencia.

- La Sección 6.0 describe la importancia de reportar información precisa sobre los parámetros de chimenea dentro del inventario, para ser utilizada en el desarrollo de inventarios de modelado.

- La Sección 7.0 analiza los procedimientos de aseguramiento y control de calidad (AC/CC). Adicionalmente, discute tanto los Objetivos de Calidad de Datos (DQO´s) para los inventarios, como los métodos para lograrlos. El Apéndice IV-D incluye un ejemplo de una lista de revisión de control de calidad para apoyar al desarrollador del inventario.

- La Sección 8.0 describe los procedimientos disponibles para la codificación de datos, que deben ser utilizados en el inventario con el objetivo de asegurar que la información sean reportable, manejable y recuperable. El Apéndice IV:E proporciona una lista y descripción de los códigos para la clasificación de fuentes.

- La Sección 9.0 explica los procedimientos para la recopilación de datos. Los Apéndices IV-F y IV-G contienen el cuestionario industrial vigente del INE, y ejemplos de las formas para la recopilación de datos específicas para cada tipo de fuente, respectivamente.

- La sección 10.0 enlista las referencias y utilizadas para la elaboración de este documento.

2.0. ARRANQUE

El objetivo fundamental de un inventario de emisiones atmosféricas es organizar la información que permita a las entidades federal, estatales y municipales la planeación de estrategias para el control de emisiones, y la administración de la gestión de la calidad del aire. En el largo plazo, un inventario de emisiones puede ser un indicador de los cambios en la calidad del aire y, en general, las áreas de un inventario son definidas por los límites políticos (i. e., límites estatales o municipales).

Antes de iniciar el desarrollo de un inventario de fuentes puntuales es necesario tomar dos decisiones importantes: la primera consiste en definir claramente qué será considerado como "fuente puntual"; y la segunda, en determinar el nivel de detalle deseado.

2.1. Definición de Fuente Puntual

La división de las fuentes de emisión en "puntuales" y "de área" es arbitraria, pero se considera fundamental para la eficiente recopilación de la información que sustentará los programas de gestión de la calidad del aire. Esta división tiene implicaciones importantes tanto para el desarrollo de programas normativos, como para la determinación del volumen y tipo de información que serán necesarios para apoyar dichos programas.

El contar con información detallada sobre cada "punto" en el que las emisiones son descargadas a la atmósfera, sería sumamente deseable, dado que permitiría un entendimiento preciso de cada fuente; sin embargo, no existe una manera práctica en la que dicha información pudiera ser recopilada. Un enfoque alternativo consiste en agrupar las fuentes relacionadas (e. g., todos los automóviles o todas las panaderías) en una sola "fuente de área". La definición de las fuentes puntuales o de área que establece esta división es, entonces, un balance entre las necesidades de los programas normativos y los recursos disponibles para respaldar los requerimientos de los datos de estos programas.

Manejar a todos los establecimientos como fuentes puntuales podría incrementar la precisión, pero demandaría muchos más recursos para compilar y mantener el inventario.

En México, las fuentes puntuales son definidas en el Artículo 6 de la Ley General de Equilibrio Ecológico y Protección al Ambiente como "cualquier instalación emplazada en un solo sitio con el propósito de ejecutar operaciones o procesos industriales, comerciales o de servicios, o actividades que generen o puedan generar emisiones contaminantes a la atmósfera".

Conforme a lo estipulado en el Artículo 11 del Reglamento de la Ley General de Equilibrio Ecológico y Protección al Ambiente en Materia de Control y Prevención de la Contaminación del Aire; y en el Artículo 29 de la Ley General de Equilibrio Ecológico y Protección al Ambiente, todas las fuentes de jurisdicción federal son puntuales, e incluyen a:

- Todos los establecimientos, proyectos o actividades (industriales, comerciales o de servicios) que sean manejados por entidades de la Administración Pública Federal
- Las industrias controladas por el gobierno
- Los establecimientos ubicados en el Distrito Federal
- Determinadas industrias privadas (i. e., asbesto, química, petroquímica, siderúrgica, papelera, azucarera, de bebidas, cementera y automotriz, así como de generación y transmisión de electricidad)
- Las fuentes que afectan el equilibrio ecológico en un estado o país vecino.

Estos establecimientos deben solicitar una licencia de operación a la Secretaría de Medio Ambiente, Recursos Naturales y Pesca (SEMARNAP). Adicionalmente, deben presentar estimados de emisiones anuales.

Algunas empresas clasificadas como microindustrias pueden estar exentas de los requerimientos de licencia y certificado de operación de las fuentes puntuales, si sus actividades se incluyen en el "Acuerdo por el que se Exceptúan del Trámite para la Obtención de la Licencia de Funcionamiento, a las Fuentes Puntuales Consideradas como Empresas Microindustriales en los Términos de la Ley en la Materia", publicado el 17 de mayo de 1990.

Entre las diversas definiciones de fuente puntual es posible incluir las siguientes (todas las demás son consideradas como fuentes de área):

- Fuente de tipo determinado (e. g., unidad trituradora catalítica fluidizada), o de tipo **y** tamaño determinado (e. g., caldera con demanda de calor superior a 10,000 Btu/hr)
- Fuente con un volumen de emisiones superior a una cantidad específica determinada en alguna base consistente
- Cualquier fuente (independiente del tipo, tamaño o emisiones) que esté ubicada en una instalación de un tipo determinado (e. g., refinería de petróleo), o de un tipo **y** tamaño determinado (e. g., fundición de acero con una producción superior a mil toneladas anuales)
- Cualquier fuente (independiente del tipo, tamaño o emisiones) que esté ubicada en una instalación que emita más de cierta cantidad específica determinada en alguna base consistente.

Los ejemplos de una base consistente para determinar el volumen de emisiones incluyen el criterio real (lo que fue realmente emitido en un período de tiempo anterior), lo permisible (el máximo que puede ser emitido de acuerdo con los límites normativos), y lo potencial (lo que sería emitido si se operara tiempo completo sin ningún equipo de control).

Por otro lado, estas definiciones pueden variar de acuerdo con la región normativa para responder a los diferentes niveles de severidad tanto del problema de la calidad del aire, como de los programas regulatorios en cada región.

Por ejemplo, en EU se ha establecido un criterio específico para áreas que exceden las normas de concentración para el ozono o monóxido de carbono. En estas áreas, si una planta emite más de 100 toneladas anuales de óxidos de nitrógeno (NO_x) o monóxido de carbono (CO), o 10 toneladas anuales de compuestos orgánicos volátiles (COVs), debe ser incluida en el inventario de emisiones de fuentes puntuales. A los estados se les incentiva para generar inventarios que incluyan fuentes cuyas emisiones están por debajo de los niveles nacionales. La decisión para establecer niveles menores depende de numerosos factores locales, así como de los recursos disponibles para obtener y manejar los datos.

Los programas ambientales en los EU han usado frecuentemente la última definición (es decir, los umbrales de emisión a nivel de establecimiento), basada en emisiones potenciales. En la normatividad, estas fuentes se definen como “fuentes estacionarias” y están sujetas a regulaciones más estrictas que las que aplican a las fuentes con emisiones menores. La Agencia de Protección Ambiental (EPA, por sus siglas en inglés) de EU, ha llevado esta definición regulatoria al manejo mismo de la información. La EPA solicita a las entidades estatales que incluyan información sobre las fuentes que la regulación define como estacionarias en el capítulo de fuentes puntuales, y toda la derivada de las instalaciones restantes en el de fuentes “de área”.

En la medida en que el programa para el inventario de emisiones de México evoluciona, la definición de fuentes puntuales puede ser modificada para incluir fuentes con emisiones significativas o eliminar las que son insignificantes. El objetivo es maximizar la precisión general del extenso inventario de emisiones (i. e., fuentes puntuales, de área, vehículos automotores y naturales) dentro de los limitados recursos disponibles.

2.2. Nivel de Detalle

En general, la información sobre las fuentes puntuales es recopilada a través de inspecciones. La Figura 2-1 presenta un ejemplo del proceso de inspección. Las fuentes puntuales pueden ser inventariadas en los siguientes tres niveles de detalle, mismos que se ilustran en la Figura 2-2:

- A nivel de planta, en el que pueden incluirse diversas actividades emisoras
- A nivel de punto de emisión o chimenea
- A nivel de proceso o segmento, que representa las operaciones de la unidad de emisión de una categoría de fuentes.

Las características específicas de cada uno de estos niveles son discutidas en la siguiente sección.

Siempre que sea posible, las emisiones deben ser inventariadas en el nivel de proceso o segmento para respaldar las actividades de gestión de la calidad del aire, tales como la regulación, cumplimiento y autorización. Por ejemplo, la identificación del tipo de proceso y equipo a los que una regulación futura pudiera aplicar, y la posterior evaluación de su impacto (costos y beneficios), en general requerirían la estimación de las emisiones de cada proceso o equipo.

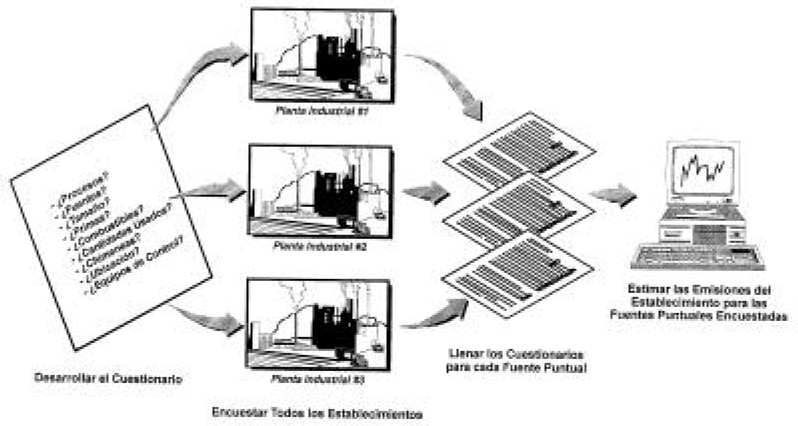


Figura 2-1. Ejemplo de Una Encuesta de Fuentes Puntuales

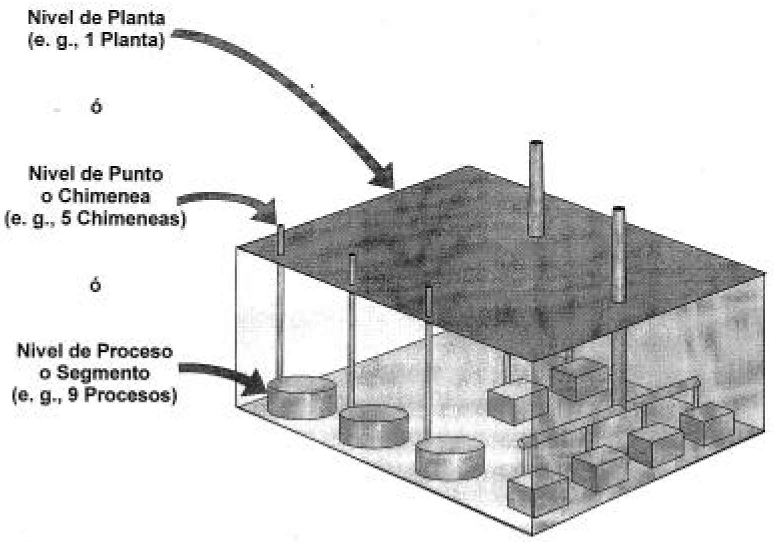


Figura 2-2 Diferentes Niveles del Inventario de Fuentes Puntuales

Otra razón igualmente importante para trabajar en este nivel de detalle es que la entidad cuente con la información requerida para verificar los estimados de emisiones proporcionados por los operadores del establecimiento.

2.2.1. A Nivel de Planta

En una inspección a nivel de planta, deben observarse los siguientes aspectos:

- Cada planta dentro del área debe ser identificada, y debe asignársele un número de identificación único (ver Sección 8.0 para mayor información sobre la asignación de números de identificación a las plantas)
- La planta debe identificarse más detalladamente con referencias geográficas, tales como estado, municipio, calle y/o dirección postal, las coordenadas del transverso universal de mercator (UTM), o la latitud y longitud (ver Sección 6.1)
- Debe identificarse un contacto en la planta para facilitar la comunicación e interacción.

2.2.2. A Nivel de Punto de Emisión o Chimenea

En las inspecciones a nivel de punto de emisión o chimenea, es importante que se observen los siguientes aspectos:

- Cada chimenea, respiradero o cualquier otro punto de emisión debe ser identificado como “punto de emisión” dentro de la planta;
- Cada chimenea, respiradero o punto de emisión debe recibir un número de identificación único dentro del inventario (ver Sección 8.0)

- La siguiente información de cada punto de emisión debe ser registrada tanto para un inventario completo, como para programas de modelado:
    - Localización (latitud y longitud o coordenadas UTM; ver Sección 6.1)
    - Altura del punto de emisión (ver Sección 6.2)
    - Diámetro del punto de emisión (ver Sección 6.3)
    - Tasa de emisiones
    - Temperatura de salida de los gases (ver Sección 6.4)
    - Velocidad de salida de los gases (ver Sección 6.5) o tasa de flujo volumétrico en el punto de emisión.

2.2.3. A Nivel de Proceso o Segmento

Una planta puede estar integrada por varios procesos u operaciones. La información necesaria para elaborar un inventario a este nivel incluye:

- Información de identificación del proceso

- Datos sobre cada nivel del proceso (e, g., materias primas, corrientes de proceso y características de los productos)

- Datos sobre la tasa de operación, incluyendo la capacidad utilizada real, máxima y de diseño

- Uso características de los combustibles (cenizas, azufre, elementos traza, contenido calorífico, etc.)

- Identificación del equipo de control de la contaminación del aire y su nivel de eficiencia de captura y control asociado (medido o diseñado);

- Identificación del método de estimación o referencia aplicado para calcular el cada estimación de emisiones

- Información sobre productos finales.

3.0. TECNICAS DE ESTIMACION DE EMISIONES RECOMENDADAS

Esta sección presenta una breve revisión de las principales técnicas para la estimación de emisiones (TEEs) aplicables a las fuentes puntuales:

- Factores de emisión
- Pruebas de fuente
- Balance de materiales
- Modelos de emisiones.

Para un análisis más detallado de estos métodos, referirse al Volumen III: *Técnicas Básicas de Estimación de Emisiones*.

Posterior a las descripciones, una Tabla de Referencia Cruzada de las Técnicas de Estimación de Emisiones muestra qué técnicas de estimación se recomiendan para los tipos de fuentes puntuales más comunes. El Apéndice IV-B de este manual contiene una lista de factores de conversión que pueden ser de utilidad en el momento de realizar cálculos de emisiones al aire.

3.1. Factores de Emisión

Un factor de emisión es una relación entre la cantidad de contaminantes emitidos a la atmósfera con el nivel de actividad asociado con dicha emisión. El nivel de actividad puede ser, por ejemplo, una tasa de producción o la cantidad de combustible consumido. Si se conoce el factor de emisión y el nivel de actividad correspondiente, es posible hace una estimación de las emisiones. El uso de factores de emisión es directo cuando la relación entre la información del proceso y las emisiones es directa y relativamente simple. Debe mencionarse que el uso de factores de emisión específicos para un establecimiento es preferible al uso de los factores promedio para todo un sector industrial. Sin embargo, dependiendo de los recursos disponibles la obtención de datos específicos para un establecimiento puede no ser costo-efectivo. La Figura 3-1 ilustra algunos ejemplos de aplicación de los factores de emisión.

Una de las principales referencias sobre los factores de emisión para contaminantes criterio es *AP-42*, que también contiene factores de emisión para un número limitado de contaminantes tóxicos orgánicos e inorgánicos (U.S. EPA, 1995a). Una base de datos electrónica de los factores de emisión puede encontrarse en el Sistema de Recuperación de Información sobre Factores (*Factor Information Retrieval System - FIRE*), que contiene los mismos factores de emisión para contaminantes criterio que el *AP-42* (U.S. EPA, 1995b), así como algunos factores de emisión para contaminantes tóxicos para diversos tipos de fuentes. El sistema FIRE está disponible en formato electrónico en el Sistema de Boletineo (*Bulletin Board System - BBS*) de la Cámara de Compensación para Inventarios y Factores de Emisión (*Clearinghouse for Inventories and Emission Factors - CHIEF*), cuyo número telefónico es (001) (919) 541-5742. El sistema FIRE, así como el *AP-42*, están disponibles en el CD-ROM Air CHIEF, que puede ser solicitado al teléfono (001) (919) 541-5285.

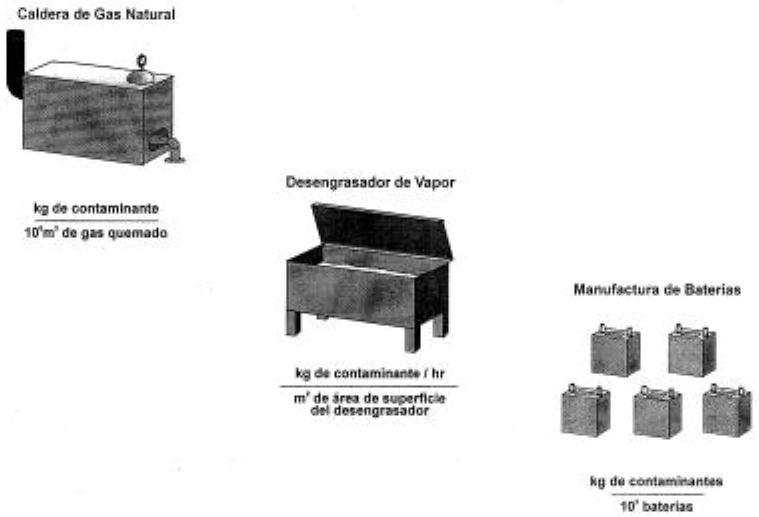


Figura 3-1. Ejemplos de Unidades del Factor de Emisión y Aplicaciones

Para efectuar el cálculo de emisiones utilizando factores, el algorítmo de estimación se requiere de varios componentes:

- Información de actividad para el proceso, tal y como se especifique en el factor de emisión pertinente
- Factores de emisión para traducir la información de actividad en estimados de emisiones controladas o no controladas
- Valor de la eficiencia de los equipos de captura y control cuando se aplica un factor de emisiones no controladas (los factores de emisiones "controladas" lo incluyen por definición).

El algoritmo básico para la estimación de emisiones aplicando un factor de emisiones no controladas cuando un equipo de control está instalado es:

$$E = A \times EF \times (1 - ER/100) \tag{3-1}$$

donde:

E = Estimado de emisión para la fuente (a nivel de proceso)
A = Nivel de actividad (por ejemplo, material producido)
EF = Factor de emisiones no controladas (por ejemplo lb de contaminantes emitidas / ton de material procesado)
ER = Eficiencia general en la reducción de emisiones totales, expresada en porcentaje; que es igual a la eficiencia del equipo de captura multiplicada por la eficiencia del equipo de control. Si no hay un equipo de control, ER = 0

Si el factor de emisión fue desarrollado considerando la operación de un equipo de control, entonces incorpora el término de efectividad del sistema de control (1-ER/100); por lo tanto, la forma del algoritmo es:

(3-2)

$$E = A \times EF$$

donde:

E = Estimado de emisión para la fuente (a nivel de proceso)
A = Nivel de actividad (por ejemplo material producido)
EF = Factor de emisiones controladas (por ejemplo, kg. de contaminantes emitidos / Mg. de material procesado)

La ecuación 3-2 también es aplicada cuando no existe un equipo de control en operación y el factor de emisión ha sido desarrollado a partir de la información generada en un sistema no controlado, tal y como se muestra en el siguiente ejemplo:

Ejemplo 3-1

Calcular las emisiones anuales de compuestos orgánicos volátiles (COVs) diferentes al metano, provenientes de una fábrica de pinturas que produce 200 toneladas métricas de pintura al año.

$A_{pintura}$ = 200 Mg/año (Tomado del AP-42, Sección 6.4)
EF_{VOC} = 15 kg/Mg
E_{COV} = $A_{pintura}$ x EF_{COV}
= 200 x 15
= 3,000 kg/año

Factores de Emisión - Aspectos a ser Considerados

- Las emisiones calculadas utilizando factores de emisión para un proceso dado, tienden a diferir de las emisiones reales de un establecimiento, dado que los estimados son menos precisos que las mediciones en pruebas de fuente.
- El uso de factores de emisión arrojará estimados superiores a los valores reales para algunas fuentes, pero inferiores para otras.
- Con frecuencia, los factores de emisión se basan en información limitada y es posible que no representen a las emisiones reales con fidelidad.
- Si los factores de emisión son utilizados para proyectar las emisiones de fuentes nuevas o propuestas, los responsables del cálculo deben revisar la literatura y tecnología más reciente para determinar si tales fuentes tendrían características que las diferencien de las fuentes típicas.
- Para calcular las emisiones usando factores de emisión se requieren los siguientes datos:
  - Información de actividad para el proceso, tal y como se especifique en el factor de emisión pertinente
  - Factores de emisión para traducir la información de actividad en estimados de emisiones controladas o no controladas
  - Valor de la eficiencia de los equipos de captura y control, para constituir las bases para estimar las emisiones ala atmósfera después de que éstas han pasado a través del equipo o equipos de control, si se está aplicando un factor de emisiones no controladas.
- La precisión de los estimados de emisiones depende de la precisión relativa de cada uno de sus componentes individuales. Los errores en que se incurra en alguna de las partes afectarán el estimado de emisiones final.

3.2. Pruebas de Fuente

El análisis de fuente es un método común para estimar emisiones de proceso y arrojan medidas de emisión en el corto plazo, tomadas en las chimeneas o respiraderos. Debido a la magnitud del tiempo y equipo requeridos, una prueba de fuente requiere más recursos que una estimación basada en factores de emisión o balance de materiales. Sin embargo, cabe señalar que la prueba de fuente evalúa tanto las concentraciones de contaminantes en la corriente de emisiones, como la tasa de flujo de aire de la corriente de emisiones

La definición de pruebas de fuente puede ampliarse para incluir el uso de monitores continuos de emisiones (MCEs). Esta tecnología hace muestreos continuos en la chimenea y analiza los compuestos de interés, aplicando los mismos principios que en el muestreo rutinario. Si el equipo MCE es empleado en un establecimiento, los datos resultantes deben ser utilizados, en la medida de lo posible, para generar estimados de emisión de una unidad específica. El resto de esta sección se enfoca en el uso de los resultados de las pruebas de fuente para el cálculo de estimados de emisiones.

La mayor parte de los reportes pruebas de fuente agrupan las emisiones de cada contaminante expresándolas en términos de: (1) la tasa de carga de masa (masa de contaminantes emitida por unidad de tiempo); (2) un factor de emisiones (masa de contaminantes emitida por unidad de proceso); o (3) concentración de los gases de combustión (masa o número de moles de contaminantes por unidad de peso o volumen del flujo de gas). Generalmente, cuando se cuenta con una tasa de carga de masa o concentración de flujo de gas, las emisiones resultantes pueden ser calculadas fácilmente si se conocen ciertos parámetros de operación, tal y como se muestra en el siguiente ejemplo (U.S. EPA, 1993a):

Ejemplo 3-2

Una planta papelera con una sola línea de producción ha sido sujeta a una prueba de emisiones para compuestos orgánicos volátiles (COVs). Dado que el solvente utilizado es principalmente tolueno, las emisiones fueron medidas como tolueno. Los datos promedio de tres pruebas realizadas son los siguientes:

Tasa de flujo de la chimenea (Q_s) = 283 m^3/min
Concentraciones de las emisiones (C_e) = 96 ppm (de tolueno)

Otros datos necesarios para completar el cálculo incluyen:

Operación de la planta = 16 horas/día, 312 días/año
Peso molecular del tolueno (MW) = 92 g/gmole
Factor de conversión de unidades (k) = 2.53×10^{-3} gmole-min/hr-ppm-m^3

El cálculo de las emisiones comienza con la determinación de la tasa de descarga promedio (M_o):

$$\begin{aligned} M_o &= (k)(MW)(C_e)(Q_s) \\ &= (2.53 \times 10^{-3})(92)(96)(283) \\ &= 6{,}324 \text{ g/hr} \\ &= 6.32 \text{ kg/hr} \end{aligned}$$

$$\begin{aligned} \text{Emisiones totales anuales} &= (6.32 \text{ kg/hr})\ (16 \text{ hr/día})\ (312 \text{ días/año}) \\ &= 3.2 \times 10^4 \text{ kg/año} \end{aligned}$$

Nota: $\left[\frac{1}{10^6}\right]\left[\frac{60\ \text{min}}{\text{hr}}\right]\left[\frac{\text{lb mole}}{379\ \text{ft}^3}\right]\left[\frac{35.31\ \text{ft}^3}{\text{m}^3}\right]\left[\frac{453.6\ \text{gmol}}{\text{lb mol}}\right] = 2.53 \times 10^{-3}$

En algunas ocasiones, los resultados de las pruebas de fuente no son entregados en el formato en que deben ser reportados. Los siguientes ejemplos muestran algunas de las conversiones de datos que pueden ser necesarias.

Ejemplo 3-3: Conversión de ppmv a kg/hr

Dados: Oxidos de nitrógeno (NO_x) medidos en 100 partes por millón en volumen (ppmv) en los gases de la chimenea
Flujo de escape de 500 metros cúbicos (m^3) por minuto

Requeridos: kg/hr de NO_x emitidos en gases de escape

Datos: Peso molecular (MW) del NO_x = 46
Volumen de moles = 24.13 l / kgmol @ 20°C
= 0.024 m^3/kgmol

$$\left[\frac{100\ \text{kgmol NO}_x}{10^6\ \text{kgmol}}\right]\left[\frac{46\ \text{kg NO}_x}{\text{kgmol NO}_x}\right]\left[\frac{\text{kgmol aire}}{\begin{array}{c}\text{NO}_x\\ 0.024\ \text{m}^3\ \text{aire}\end{array}}\right]\left[\frac{60 \times 500\ \text{m3 aire}}{\text{hora}}\right] = 5{,}750\ \text{kg/hr}$$

Nota: Cuando se mide la masa de emisiones de NO_x, debe usarse el peso molecular de NO_2 (MW = 46) en el cálculo. Esta es una convención estándar, aún cuando la mayor parte de NO_x es emitido desde las fuentes de combustión como NO.

Ejemplo 3-4: Corrección de temperatura: de m^3/min reales a m^3/min estándar (corrección del flujo de gases de escape)

Dados: Velocidad de salida de gases de chimenea medidos a 10 m/s
Diámetro de la chimenea = 0.8 m
Temperatura de la chimenea = 80°C

Requeridos: Flujo de los gases de escape en medida estándar m^3/min (con temperatura de referencia de 20°C)

Conversión:

$$\text{Flujo}_{20oC} = (\text{Flujo } x^oC)\left[\frac{20^oC + 273.15}{X^oC + 273.15}\right]$$

$$m^3/min \left[\frac{10\ m}{s}\right]\left[\frac{\pi\ (0.8)^2}{4}\ m^2\right]\left[\frac{60s}{min}\right]\left[\frac{293.15\ K}{353.15\ K}\right] = 250 \text{ unidades estándar}$$

Nota: Para flujos de gas de escape con temperaturas elevadas, en general es necesario corregir tanto la temperatura como el contenido de agua (ver ejemplo 3-5).

Ejemplo 3-5: Corrección por Vapor de Agua: de m^3/min reales a m^3 estándar con condiciones secas / min (corrección de la tasa de flujo de gases de escape de chimenea)

Dados: La tasa de flujo de gases de escape húmedos del ejemplo 3-4 = 250 m^3 estándar / min
Contenido de vapor de agua de los gases de chimenea = 2.1 % (volumen)

Requeridos: Flujo de gases de chimenea en condiciones secas (m^3 estándar secos /min)

Conversión:

$$\text{Flujo}_{\text{seco}} = \text{Flujo}_{\text{húmedo}}\ [100\% - \%\ H_2O]$$

$$250\ m^3 \text{ estándar / min } [1 - 0.021] = 245\ m^3 \text{ estándar secos / min}$$

Ejemplo 3-6: Oxígeno en la corrección de gases de flujo (corrección de concentraciones contaminantes)

Dados: Partículas en gases de chimenea = 20 mg/m^3 estándar seco (dscm)
Concentraciones de NOx en gases de chimenea = 48 ppmv
Concentraciones de oxígeno en gases de chimenea = 4 % (vol)

Requeridos: Partículas de gases en chimenea y concentraciones de NOx corregidas con 7 % de oxígeno.

Conversión:

$$\text{Conc}_{7\%} = \text{Conc}_{x\%} \left[\frac{21\% - 7\ \%}{21\ \% - X\ \%}\right]$$

$$\frac{20 \text{ mg PM}}{\text{dscm}} \left[\frac{21\ \% - 7\ \%}{21\ \% - 4\ \%}\right. = \frac{16.5 \text{ mg}}{\text{dscm}} \text{ PM @ } 7\ O_2$$

$$48 \text{ ppmv } NO_x \left[\frac{21\ \% - 7\ \%}{21\ \% - 4\ \%}\right] = 40 \text{ ppmv } NO_x \text{ @ } 7\ \%\ O_2$$

Análisis de Fuente - Aspectos a ser Considerados

- En general, cuando son aplicadas correctamente, las pruebas de fuente proporcionan mejores estimados de emisión que el uso de factores de emisión o balance de materiales.

- Los datos de las pruebas de fuente pueden ser utilizados para propósitos de estimación de emisiones solamente si fueron obtenidos en condiciones que sean representativas de las condiciones de operación normales en la fuente en cuestión.

- Los datos de emisiones de una sola prueba de fuente pueden ser extrapolados para estimar las emisiones anuales si la corriente de proceso no varía, y si el proceso opera de manera uniforme. Si existe variabilidad será necesario realizar múltiples pruebas, con base en los conocimientos de la variación.

- Si las operaciones en un establecimiento y los métodos empleados durante la prueba de fuente no pueden ser caracterizados adecuadamente, entonces no debe utilizarse la información generada en dichas pruebas.

- Si se usa una prueba de fuente para estimar las emisiones de un proceso, se prefiere la información compilada con observaciones en sitio para dicho proceso.

- La segunda opción es utilizar datos de pruebas en equipos y procesos similares, datos promedio de diversos establecimientos similares o datos basados en la literatura.

- La confiabilidad de la información puede verse afectada por factores tales como el número de pruebas conducidas y la metodología utilizada.

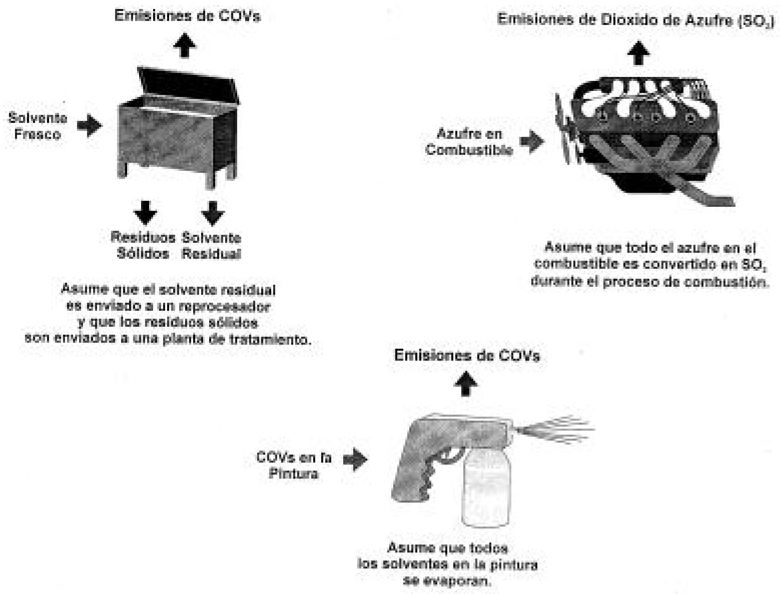
3.3. Balance de Materiales

El balance de materiales (también conocido como balance de masa) es un método comúnmente utilizado para estimar las emisiones de diversas categorías de fuentes. El supuesto básico es que las emisiones son iguales a la diferencia entre la cantidad de materiales que entra y que sale de un proceso (considerando pérdidas fugitivas, cantidad que permanece en el producto final, pérdidas en aguas residuales, etc.). El método de balance de materiales puede ser utilizado cuando no hay datos disponibles de pruebas de fuente, factores de emisión u otros métodos desarrollados. El balance de materiales es más apropiado cuando pueden hacerse mediciones precisas sobre todos los componentes de un proceso, exceptuando el de emisiones al aire, o cuando el estimado de emisión será utilizado con propósitos de selección, siempre que sea posible hacer supuestos razonables acerca del destino de los compuestos.

En general, el uso del balance de materiales o de masa para determinar las emisiones totales de un proceso es sencillo y poco costoso. Las emisiones de COVs derivadas de procesos donde se usan solventes (tales como las operaciones de recubrimiento) son calculadas normalmente utilizando el enfoque de balance de materiales. En este caso, los solventes enviados para la disposición de residuos sólidos o peligrosos deben sustraerse del total consumido:

$$\textbf{Solvente}_{\textbf{total usado}}\ \textbf{(litro)} - \textbf{Solvente}_{\textbf{desechado}}\ \textbf{(litro)} = \textbf{Solvente}_{\textbf{emitido}}\ \textbf{(litro)} \tag{3-3}$$

En el ejemplo anterior, la masa COVs/volumen es multiplicada por el volumen de material usado para generar emisiones de COVs. La Figura 3-2 ilustra algunos ejemplos de balance de materiales.



Asume que el solvente residual
es enviado a un reprocesador
y que los residuos sólidos
son enviados a una planta de tratamiento.

Asume que todo el azufre en el
combustible es convertido en SO_2
durante el proceso de combustión.

Asume que todos
los solventes en la pintura
se evaporan.

Figura 3-2. Ejemplos de Balance de Materiales

Ejemplo 3-7

Calcular las emisiones anuales de partículas (PM) de una operación de recubrimiento de una superficie, utilizando 1,800 litros/año de recubrimiento. La densidad promedio del recubrimiento es de 1.2 kg/litro, y el promedio de sólidos de 35% en masa. La eficiencia de transferencia del revestimiento es de 40%, y la eficiencia del equipo de control es 95%.

$$PM_{dentro} = (1{,}800 \text{ litros/año}) \times (1.2 \text{ kg/litro}) \times (35\ \%\ PM)$$
$$= 756 \text{ kg/año}$$

$$PM_{superficie} = 756 \text{ kg/año} \times 40\ \%$$
$$= 302 \text{ kg/año}$$

$$PM_{no\ controlado} = PM_{dentro} - PM_{superficie}$$
$$= 756 - 302$$
$$= 454 \text{ kg/año}$$

$$PM_{controlado} = 454 \text{ kg/año} \times 95\ \%$$
$$= 431 \text{ kg/año}$$

$$E_{PM} = PM_{dentro} - PM_{superficie} - PM_{controlado}$$
$$= 756 - 302 - 431$$
$$= 23 \text{ kg/año}$$

Balance de Materiales - Aspectos a Ser Considerados

- El método del balance de materiales no debe ser utilizado en procesos en los que el material reacciona para elaborar los productos, o en los que sufre cualquier otro cambio químico significativo, a menos que dichos procesos estén bien caracterizados.

- Debido a que las emisiones son estimadas para constituir la diferencia entre el material que entre y el material conocido que sale, un pequeño error porcentual en la estimación de la entrada o salida puede generar un gran error porcentual en el estimado de la emisión. Por lo tanto, los balances de materiales pueden ser inapropiados cuando se analiza una pequeña diferencia (i. e., pérdida), entre dos valores de entrada o salida relativamente grandes.

3.4. Modelos de Emisión

Un método más complejo, el de modelos de emisión, es utilizado para hacer estimaciones cuando las emisiones no están relacionadas directamente con ningún parámetro. Los modelos, en general, están basados en computadoras, de manera tal que un gran número de ecuaciones e interacciones pueden ser ejecutadas con facilidad. Los requerimientos de datos para los modelos son variables, pero en la mayoría de los casos, se necesita cuando menos un parámetro físico de la fuente en la cual el modelo será aplicado para estimar las emisiones. Los ejemplos de los modelos disponibles son el TANKS3 y el WATER8, que son utilizados para calcular las emisiones de COVs de los tanques de almacenamiento y las operaciones de recolección y tratamiento de aguas residuales, respectivamente (EPA, 1993c y EPA, 1994). Estos modelos están disponibles sin costo alguno a través del CHIEF BBS, (001) (919) 541-5742. Para información más detallada sobre los modelos de emisión, favor de referirse a la Sección 4.1 del Volumen III: *Técnicas Básicas de Estimación de Emisiones*.

Modelos de Emisiones - Aspectos a Ser Considerados

- Los modelos requieren generalmente más datos que los factores de emisión.

- Los datos necesarios dependerán tanto de la fuente particular de emisiones como del modelo seleccionado. Los modelos de emisión para operaciones de tratamiento de aguas residuales, por ejemplo, podrían requerir tasas de flujo de las aguas, concentración de contaminantes y temperatura; mientras que los modelos de emisión para tanques de almacenamiento requieren datos sobre la capacidad del tanque, dimensiones, y presión de vapor.

- La exactitud de los estimados de emisiones depende de la precisión de los componentes individuales utilizados.

3.5. Tabla de Referencia Cruzada para la Estimación de Emisiones

La Tabla 3-1 contiene las técnicas de estimación de emisiones más adecuadas para las distintas categorías industriales y sus fuentes de emisión. Numerosos establecimientos (e. g., manufacturadores químicos) tienen diversos tipos de fuentes de emisión de contaminantes al aire, por ejemplo sus procesos de producción, equipos de combustión, fallas de equipo, tanques de almacenamiento y uso de solventes, tal y como se describe a continuación:

- Las emisiones de proceso de los establecimientos son aquellas que resultan directamente de los procesos de manufactura o producción. La magnitud y tipo de emisiones de proceso varía de acuerdo con el tipo de producción
- Los generadores, calderas e incineradores son fuentes comunes de emisiones de gases y partículas derivadas de la combustión
- Las emisiones fugitivas de compuestos orgánicos volátiles pueden proceder de equipos de producción con fugas en sus sellos, válvulas, bordes, conexiones y líneas abiertas
- Los tanques de almacenamiento pueden generar emisiones fugitivas de COVs durante las operaciones de transferencia o por los cambios diarios de temperatura
- El uso de solventes para limpiar el equipo o sus partes (e. g., desengrasado) es otra fuente común de emisiones fugitivas de COVs.

Las emisiones de contaminantes al aire desde varias fuentes en un establecimiento pueden ser estimadas con diferentes métodos, que dependen de la fuente particular de la que provengan. La selección de una técnica de estimación requiere el análisis de la información disponible. Si la aplicación de un método particular requiriera mayor información, es necesario ponderar los costos contra la calidad deseada de los estimados de emisiones. Cuando los riesgos de efectos ambientales adversos sean altos, las metodologías de estimación más costosas y sofisticadas, tales como pruebas de fuente, pueden ser necesarias. En el caso contrario, es decir, cuando los riesgos sean bajos, los métodos de estimación menos costosos, tales como factores y modelos de emisión pueden ser aceptables.

La jerarquización de los métodos listados en la Tabla 3-1 se basan en tipo de industria y magnitud de las emisiones, así como en el costo y calidad de los estimados de emisión para combinaciones específicas de contaminantes y fuentes. La calificación de “1” indica que un método es la técnica de estimación más conveniente. Si un método no tiene calificación alguna, quiere decir que no está disponible para la fuente particular de emisiones y el tipo de contaminante referidos.

Cómo Utilizar la Tabla 3-1

- Identificar la fuente de emisión en el establecimiento en cuestión.

- Utilizando la Tabla 3-1, identificar la Técnica de Estimación de Emisiones (TEE) para cada fuente.

- Si es factible, utilizar la TEE más conveniente (con calificación 1) para estimar las emisiones de una fuente dada.

- Revisar la subsección correspondiente de la Sección 3.1. y el Volimen IV: *Técnicas Básicas de Estimación de Emisiones* para determinar la que es información es necesaria para utilizar la TEE más conveniente.

- Si no se cuenta con la información o los recursos para utilizar la técnica más conveniente, debe utilizarse la segunda mejor opción (con calificación de 2 o 3 en la Tabla 3-1) para estimar las emisiones.

Tabla 3-1

Técnicas de Estimación de Emisiones Recomendadas para las Diversas Categorías de Fuente

Categoría de Fuente	**Fuente de Emisión**	**Contaminante**	**Técnicas de Estimación**[a]				**Comentarios**
			Factor de Emisión	**Pruebas de Fuente**	**Balance de Material**	**Modelos de Emisión**	
Planta Generadora de Electricidad	Combustión	CO	2	1			
		NO_x	2	1			
		SO_x	3	1	2[b]		
		COVs	2	1			
		PM	2	1			
		NH_3[c]	2	1			
Manufactura Química	Proceso	COVs	2	1			
		NH_3	2	1			
	Combustión	CO	2	1			
		NO_x	2	1			
		SO_x	3	1	2[b]		
		COVs	2	1			
		PM	2	1			
		NH_3[c]	2	1			

Tabla 3-1

(Continuación)

Categoría de Fuente	**Fuente de Emisión**	**Contaminante**	**Técnicas de Estimación**[a]				**Comentarios**
			Factor de Emisión	**Pruebas de Fuente**	**Balance de Material**	**Modelos de Emisión**	
	Fugas de Equipo	COVs	1	2			
	Tanques de Almacenamiento	COVs			2	1	
	Tratamiento de Aguas Residuales	COVs	2		3	1	
	Uso de Solventes	COVs			1		
Refinación de Petróleo	Proceso	COVs	2	1			
	Combustión	CO	2	1			
		NO_x	2	1			
		SO_x	3	1	2[b]		
		COVs	2	1			
		PM	2	1			
		NH_3[c]	2	1			
	Fugas de Equipo	COVs	1	2			
	Tanques de Almacenamiento	COVs			2	1	

Tabla 3-1

(Continuación)

Categoría de Fuente	**Fuente de Emisión**	**Contaminante**	**Técnicas de Estimación**[a]				**Comentarios**
			Factor de Emisión	**Pruebas de Fuente**	**Balance de Material**	**Modelos de Emisión**	
	Tratamiento de Aguas Residuales	COVs	2		3	1	
	Uso de Solventes	COVs			1		Solventes utilizados para el mantenimiento del equipo.
Siderurgia Básica	Proceso (no combustión)	COVs	2	1			
		SO_x	3	1	2[b]		
		PM	2	1			
	Combustión	CO	2	1			
		NO_x	2	1			
		SO_x	3	1	2[b]		
		COVs	2	1			
		PM	2	1			
		NH_3[c]	2	1			
	Polvos Fugitivos	PM	1				Pilas de almacenamiento, caminos de transporte, etc.

Tabla 3-1

(Continuación)

Categoría de Fuente	Fuente de Emisión	Contaminante	Técnicas de Estimación[a]				Comentarios
			Factor de Emisión	Pruebas de Fuente	Balance de Material	Modelos de Emisión	
Siderurgia Secundaria	Proceso (no combustión)	COVs	2	1			Incluye carga, refinado y fundición.
		PM	2	1			
	Combustión	CO	2	1			Las emisiones pueden generarse de la carga de materiales, además del quemado de combustibles.
		NO_x	2	1			
		SO_x	3	1	2[b]		
		COVs	2	1			
		PM	2	1			
		NH_3[c]	2	1			
	Polvos Fugitivos	PM	1				Pilas de almacenamiento, caminos de transporte, etc.
Producción de Cemento	Combustión	CO	2	1			
		SO_x	3	1	2[b]		
		COVs	2	1			

Tabla 3-1

(Continuación)

Categoría de Fuente	Fuente de Emisión	Contaminante	Técnicas de Estimación[a]				Comentarios
			Factor de Emisión	Pruebas de Fuente	Balance de Material	Modelos de Emisión	
	Combustión	PM	2	1			
		NH_3[c]	2	1			
	Fugitivos	PM	1				Pilas de almacenamiento y polvos de las superficies de manejo.
	Proceso	PM	2	1			Operaciones del secador.
Productos Minerales Misceláneos (e. g., cal y agregados de hornos de calcinación)	Proceso	PM	2	1			Operaciones del fraccionamiento y molienda.
	Combustión	CO	2	1			
		NO_x	2	1			
		SO_x	3	1	2[b]		
		COVs	2	1			
		PM	2	1			
	Combustión	NH_3[c]	2	1			

Tabla 3-1

(Continuación)

Categoría de Fuente	Fuente de Emisión	Contaminante	Técnicas de Estimación[a]				Comentarios
			Factor de Emisión	Pruebas de Fuente	Balance de Material	Modelos de Emisión	
	Fugitivos	PM	1				Pilas de almacenamiento y polvos de las superficies de manejo.
Industria Automotriz	Proceso	COVs	2	1			
	Combustión	CO	2	1			
		NO_x	2	1			
		SO_x	3	1	2[b]		
		COVs	2	1			
		PM	2	1			
		NH_3[c]	2	1			
	Uso de Solventes	COVs			1		Operaciones de limpieza.
Operaciones de Pulpa de Madera	Proceso	COVs	2	1			Digestores, evaporadores, torres de oxidación, etc.
		SO_x	2	1			
		PM	2	1			
	Combustión	CO	2	1			
		NO_x	2	1			

Tabla 3-1

(Continuación)

Categoría de Fuente	**Fuente de Emisión**	**Contaminante**	**Técnicas de Estimación**[a]				**Comentarios**
			Factor de Emisión	**Pruebas de Fuente**	**Balance de Material**	**Modelos de Emisión**	
		SO_x	2	1	3[b]		
		COVs	2	1			
		PM	2	1			
		NH_3[c]	2	1			
Producción de Gas y Petróleo	Proceso	COVs	2	1			
	Fugitivos (incluyendo fugas de equipo)	COVs	1	2			Válvulas y sellos de las tuberías y otras fugitivas.
	Combustión	CO	2	1			
		NO_x	2	1			
		SO_x	3	1	2[b]		
		COVs	2	1			
		PM	2	1			
		NH_3[c]	2	1			

Tabla 3-1

(Continuación)

Categoría de Fuente	Fuente de Emisión	Contaminante	Técnicas de Estimación[a]				Comentarios
			Factor de Emisión	Pruebas de Fuente	Balance de Material	Modelos de Emisión	
	Tanques de Almacenamiento	COVs			2	1	
Editorial e Impresión	Proceso	COVs	2	1	3		
	Fugitivos	COVs			1		Limpieza del equipo.
Recubrimiento de Superficies	Proceso	COVs	2	3	1		Usar balance de masa si no existe equipo de control de COVs.
		PM	1				
	Desengrasado	COVs	2		1		
	Fugitivos	COVs			1		Limpieza del equipo
Terminales de Combustible a Granel	Carga	COVs	1		2		Balance de masa para COVs de derrames.
	Tanques de Almacenamiento	COVs	2			1	
	Fugas de Equipo	COVs	1	2			

Tabla 3-1

(Continuación)

Categoría de Fuente	Fuente de Emisión	Contaminante	Técnicas de Estimación[a]				Comentarios
			Factor de Emisión	Pruebas de Fuente	Balance de Material	Modelos de Emisión	
Mineria y Explotación de Canteras	Proceso	PM	1				
	Fugitivos	PM	1				Pilas de almacenamiento y polvos de las superficies de manejo.
Manufactura de Productos de Madera	Proceso	COVs	2		1		
		PM	1	2			
	Combustión	CO	2	1			
		NO_x	2	1			
		SO_x	2	1	3[b]		
		COVs	2	1			
		PM	2	1			
		NH_3[c]	2	1			
	Tanques de Almacenamiento	COVs				1	

Tabla 3-1

(Continuación)

Categoría de Fuente	**Fuente de Emisión**	**Contaminante**	**Técnicas de Estimación**[a]				**Comentarios**
			Factor de Emisión	**Pruebas de Fuente**	**Balance de Material**	**Modelos de Emisión**	
Producción de Azúcar	Proceso	PM	1				
	Combustión	CO	2	1			
		NO_x	2	1			
		SO_x	2	1	3[b]		
		COVs	2	1			
		PM	2	1			
		NH_3[c]	2	1			
	Fugitivos	COVs			1		
Tenería y Acabado de Pieles	Proceso	COVs			1		
	Combustión	CO	2	1			
		NO_x	2	1			
		SO_x	2	1	3[b]		
		COVs	2	1			
		PM	2	1			
		NH_3[c]	2	1			

Tabla 3-1

(Continuación)

Categoría de Fuente	Fuente de Emisión	Contaminante	Técnicas de Estimación[a]				Comentarios
			Factor de Emisión	Pruebas de Fuente	Balance de Material	Modelos de Emisión	
Producción de Vidrio	Horno de Fundición	CO	2	1			Incluye emisiones de la combustión.
		NO_x	2	1			
		SO_x	2	1			
		COVs	2	1			
		PM	2	1			
		NH_3[c]	2	1			
	Proceso	PM	2	1			Mezcla y transporte de materias primas.
		COVs	2	1			Formado y acabado.
Partes de Hule y Plástico	Proceso	COVs	2	1			
	Combustión	CO	2	1			
		NO_x	2	1			
		SO_x	2	1	3[b]		
		COVs	2	1			
		PM	2	1			
		NH_3[c]	2	1			

Tabla 3-1

(Continuación)

Categoría de Fuente	Fuente de Emisión	Contaminante	Técnicas de Estimación[a]				Comentarios
			Factor de Emisión	Pruebas de Fuente	Balance de Material	Modelos de Emisión	
Productos Metálicos Elaborados	Proceso	PM	2	1			
	Combustión	CO	2	1			
		NO_x	2	1			
		SO_x	2	1	3[b]		
		COVs	2	1			
		PM	2	1			
		NH_3[c]	2	1			
Productos Textiles	Proceso	COVs	2	1	3		COVs de las operaciones de acabado.
		PM	2	1			Tamo de las operaciones mecánicas.
	Combustión	CO	2	1			
		NO_x	2	1			
		SO_x	2	1	3[b]		
		COVs	2	1			
		PM	2	1			
		NH_3[c]	2	1			

Tabla 3-1

(Continuación)

Categoría de Fuente	Fuente de Emisión	Contaminante	Técnicas de Estimación[a]				Comentarios
			Factor de Emisión	Pruebas de Fuente	Balance de Material	Modelos de Emisión	
Disposición de Residuos Sólidos	Gas de Rellenos Sanitarios	COVs				1	
	Combustores de Residuos Municipales	CO	2	1			
		NO_x	2	1			
		SO_x	2	1			
		COVs	2	1			
		PM	2	1			
		NH_3[c]	2	1			
	Incineración en Tiraderos a Cielo Abierto	CO	1				
		NO_x	1				
		SO_x	1				
		COVs	1				
		PM	1				
		NH_3	1				

Tabla 3-1

(Continuación)

Categoría de Fuente	Fuente de Emisión	Contaminante	Técnicas de Estimación[a]				Comentarios
			Factor de Emisión	Pruebas de Fuente	Balance de Material	Modelos de Emisión	
Actividades y Procesos Industriales Misceláneos	Emisiones del Proceso	CO	2	1	3		El método de estimación de emisiones seleccionado dependerá de la industria particular. En general, las pruebas de fuente proporcionan los estimados más precisos; sin embargo, otros métodos pueden ser más prácticos.
		NO_x	2	1	3		
		SO_x	2	1	3		
		COVs	2	1	3		
		PM	2	1	3		
	Emisiones de la Combustión	CO	2	1			
		NO_x	2	1			
		SO_x	2	1	3[b]		
		COVs	2	1			
		PM	2	1			
		NH_3[c]	2	1			

Tabla 3-1

(Continuación)

Categoría de Fuente	**Fuente de Emisión**	**Contaminante**	**Técnicas de Estimación**[a]				**Comentarios**
			Factor de Emisión	**Pruebas de Fuente**	**Balance de Material**	**Modelos de Emisión**	
	Fugitivos	COVs			1		La limpieza de solventes es una fuente común de COVs.
Establecimientos Gubernamentales	Combustión	CO	2	1			Típicamente incluye el calentamiento del espacio, así como la combustión de las operaciones del proceso.
		NO_x	2	1			
		SO_x	2	1	3[b]		
		COVs	2	1			
		PM	2	1			
		NH_3[c]	2	1			
	Fugitivos	COVs			1		Típicamente incluye la limpieza de solventes.
Alimentos y Agricultura	Proceso	COVs	1	2			Incluye la deshidratación de alfalfa, los elevadores de grano, la producción de cerveza, etc.
		PM	1	2			
	Emisiones de la Combustión	CO	2	1			
		NO_x	2	1			

Tabla 3-1

(Continuación)

Categoría de Fuente	Fuente de Emisión	Contaminante	Técnicas de Estimación[a]				Comentarios
			Factor de Emisión	Pruebas de Fuente	Balance de Material	Modelos de Emisión	
		SO_x	2	1	3[b]		
		COVs	2	1			
		PM	2	1			
		NH_3	2	1			
Plantas de Asfalto	Proceso	PM	2	1			Agrega las operaciones de manejo.
	Emisiones de la Combustión	CO	2	1			
		NO_x	2	1			
		SO_x	2	1	3[b]		
		COVs	2	1			
		PM	2	1			
		NH_3	2	1			

[a] Las técnicas de estimación de emisiones son discutidas brevemente en la Sección 2.1 de este documento; y en detalle en el Volúmen III: *Técnicas Básicas para la Estimación de Emisiones.* Los valores numéricos indican el orden de preferencia que debe ser considerado al seleccionar una técnica de estimación, siendo el número 1 la más preferida.

[b] Basado en el ánalisis de azufre del proveedor.

[c] El amoniaco se desprende del SCR utilizado como método de control de NO_x.

CO = monóxido de carbono; NH_3= amoniaco; NO_x = óxidos de nitrógeno; PM = partículas; SO_x = óxidos de azufre; COVs = compuestos orgánicos volátiles.

4.0. CONSIDERACIONES ESPECIALES QUE AFECTAN LAS EMISIONES

Los factores tales como la variabilidad en los procesos, equipo y materias primas utilizados dentro de la región donde se el inventario es realizado, pueden conducir a variaciones en las emisiones. Por otro lado, algunas fuentes de emisión normalmente son pasadas por alto y omitidas sin quererlo de los inventarios. Estas dos situaciones especiales, que afectan el desarrollo de inventarios para fuentes puntuales, son discutidos a continuación.

4.1. Variabilidad por Diseño o Proceso

Muchos factores pueden influenciar las emisiones. Esta sección presenta algunos de los factores que pueden variar de un equipo a otro o de una región a otra. **El responsable del desarrollo del inventario debe estar al pendiente de estos factores y debe, en lo posible, recopilar información específica para el equipo o para la región.**

4.1.1. Características de la Combustión

Los productos de la combustión derivados del consumo de combustibles pueden incluir hidrocarbonos parcialmente oxidados, monóxido de carbono (CO), dióxido de azufre (SO_2), trióxido de azufre (SO_3), óxidos de nitrógeno (NO_x), ácidos como el ácido hidroclórico, organohálidos y partículas. La generación de los productos de la combustión está fuertemente influenciada por tipo de combustible y de horno, la configuración del incinerador y las condiciones de operación de la caldera. Si bien aquí no se presenta una descripción detallada de las operaciones de una caldera, sí se incluyen algunas observaciones generales para ayudar en el entendimiento de los impactos relativos de varios tipos de calderas y combustibles.

Propiedades de los Combustibles: Las cuatro clasificaciones primarias del carbón son lignito, antracita, bituminoso y sub-bituminoso. El combustible está clasificado con base en métodos estándar referidos como análisis “aproximado” y “último”. El primero revela la composición del combustible para ciertos parámetros tales como el contenido de humedad y de ceniza. El análisis último proporciona un estimado del contenido de carbón, hidrógeno, azufre, oxígeno, nitrógeno y agua en un combustible. Este análisis se utiliza para medir los requerimientos de combustión en términos de aire, y puede ser aplicado para calcular factores de combustible (F_d) para determinar las tasas de flujo del escape. En general, el tamaño de la caldera, la configuración del incinerador y la operación, tienen muy poco efecto sobre el porcentaje de conversión de azufre del combustible en óxidos de azufre, por lo que es relativamente fácil proyectar las emisiones de óxidos de azufre mediante el análisis del combustible. El ejemplo 4-1 muestra la manera en que el análisis de combustibles puede ser utilizado para estimar emisiones de SO_2.

Ejemplo 4-1:

Este ejemplo muestra cómo pueden calcularse las emisiones de SO_2 partiendo de la combustión de aceite basada en los datos del análisis de combustibles.

Las emisiones de SO_2 pueden ser calculadas utilizando la siguiente ecuación:

$$E = Q_f \times \text{Concentraciones de contaminantes en combustibles} \times (MW_p/MW_f)$$

donde:

E = Emisiones
Qf = Tasa de Flujo de Combustible
MW_p = Peso molecular del contaminante emitido (g/gmole)
MW_f = Peso molecular del combustible contaminante (g/gmole)

Para este ejemplo:

Q_r = 2.09×10^4 kg/hr
Porcentaje de azufre en combustible (%S) = 1.17
MW del SO_2 = 64
MW del Azufre (S) = 32
ESO_2 = Q_f x concentración de contaminante en combustible x (MW_p/MW_f)
= $(2.09 \times 10^4)(1.17 / 100)(64/32)$

= 489.3 kg/hr

Por otra parte, la Norma Oficial Mexicana NOM-086-ECOL-1994 define las especificaciones de protección ambiental para los combustibles fósiles líquidos y gaseosos usados en fuentes estacionarias y móviles (SEMARNAP, 1994). Esta norma define las especificaciones para gas natural y productos derivados del petróleo, tales como gasolina, diesel, aceite y gas licuado (LPG), que son usados en varias regiones geográficas. Asimismo, se han establecido especificaciones para combustibles en zonas críticas, entre las que se incluyen las zonas metropolitanas de la Ciudad de México, Guadalajara y Monterrey, y la Zona Fronteriza Norte.

La Tabla 4-1 presenta una lista de tipos de combustible, su aplicación de acuerdo con la región geográfica, y la referencia en la NOM-086-ECOL-1994 en la que se puede encontrar información detallada sobre las características de cada combustible (contenido de azufre, presión de vapor Reid, contenido de ceniza, etc.).Las especificaciones de la NOM-086-ECOL-1994 pueden ser utilizadas para desarrollar estimados de emisión cuando no es posible obtener información más específica sobre las propiedades de los combustibles de Pemex u otra entidad gubernamental.

Condiciones de Operación: En contraste, la formación de NO_x es depende en gran medida de las condiciones de la caldera, especialmente de la temperatura y la relación aire/combustible cerca de los quemadores. Los NO_x son producidos por dos mecanismos: 1) la conversión del nitrógeno que salta del combustible; y 2) la oxidación del nitrógeno molecular del aire en combustión, referido como formación termal de NO_x, que es altamente dependiente de la temperatura, y se incrementa si la temperatura excede 1,649°C (Buonicore, 1992). Si la temperatura de operación es menor, también lo es producción termal de NO_x. Un tiempo de residencia menor también reduce el NO_x termal generado por calderas de aceite o carbón. Las emisiones de óxido de nitrógeno de una caldera de aceite tangencial son típicamente menores de las que resultan de unidades horizontalmente opuestas. Muchas calderas tienen modificaciones de combustión para reducir las emisiones de NOx, entre las que se incluye la combustión de etapa (stage combustion), calentamiento *off-stoichiometric*, recirculación de gases de combustión (FRG, por sus siglas en inglés), y quemadores de bajo NO_x con aire de sobrecalentamiento (OFA). Estas estrategias de control pueden reducir las emisiones de NO_x entre el 5 y 50 por ciento (Buonicore, 1992).

Tabla 4-1

Capacidad de Aplicación por Regiones Geográficas y Referencia de Especificación en la NOM-086-ECOL-1994 Para los Diversos Tipos de Combustible

Combustible	Número de la Tabla de Especificación del Combustible en la NOM-086-ECOL-1994	Capacidad de Aplicación por Regiones Geográficas
Gasolina (Magna Sin)	Tabla 1	En todo el país, excepto, la Zona Metropolitana de la Ciudad de México (ZMCM) y la Zona Fronteriza Norte (ZFN) durante 1997[a]
Gasolina (Magna Sin Zona Fronteriza Norte)	Tabla 2 y Anexo 1, 2, y 3 de la Tabla 2	ZFN. Area de influencia en la distribución de las siguientes terminales de comercialización: • Ciudad Juárez y Tijuana • Zona Oeste (incluyendo Cananea, Ciudad Obregón, Guaymas, Hermosillo, Magdalena y Nogales en Sonora; Ensenada, Rosarito y Mexicali en Baja California • Zona Norte (incluyendo Avalos y Monclova en Coahuila; Nuevo Laredo y Reynosa en Tamaulipas.
Gasolina (Magna Sin - Zonas Metropolitanas)	Tabla 3	ZMCM durante 1997. En 1998, las Zonas Metropolitanas de la Ciudad de México, Guadalajara y Monterrey.

Tabla 4-1

(Continuación)

Combustible	Número de la Tabla de Especificación del Combustible en la NOM-086-ECOL-1994	Capacidad de Aplicación por Regiones Geográficas
Gasolina (Nova Plus)	Tabla 4	A nivel nacional, excepto la ZMCM durante 1997[b]
Gasolina (Nova Plus-Zonas Metropolitanas)	Tabla 5	ZMCM durante 1997. En 1998, las Zonas Metropolitanas de la Ciudad de México, Guadalajara y Monterrey.
Diesel Sin	Tabla 6	Zonas Metropolitanas de la Ciudad de México, Guadalajara y Monterrey.
Diesel Desulfurado	Tabla 7	A nivel nacional.
Diesel Industrial	Tabla 8	A nivel nacional. Exclusivo para uso en conos de flama abierta.
Gasoleo Industrial	Tabla 9	A nivel nacional, excepto la ZMCM. No disponible después del 31 de diciembre de 1997. Exclusivo para uso en combustión de flama abierta.
Combustóleo Pesado	Tabla 10	A nivel nacional.
Gas Natural	Tabla 11	A nivel nacional.
Gas LP	Tabla 12	A nivel nacional.
Turbosina o gasavión	Tabla 13	A nivel nacional.

[a] En 1998, aplicable a nivel nacional, excepto en las ZM de México, Guadalajara, Monterrey y la ZFN.

[b] En 1998, aplicable a nivel nacional, excepto en las ZM de México, Guadalajara, Monterrey

4.1.2. Materias Primas

Además de los efectos que las propiedades de los combustibles pueden tener en los estimados de emisión, las propiedades físicas y químicas de otras materias primas usadas por una fuente puntual también pueden influenciar las emisiones. Por ejemplo, la densidad del material es aplicada con frecuencia para convertir el volumen de material usado en la masa de material usado. Como ejemplo adicional, el contenido material de compuestos orgánicos volátiles (COVs) (i. e., g/L) es a menudo utilizado para estimar las emisiones de una operación de recubrimiento de superficies.

Las propiedades físicas y químicas de algunas materias primas pueden variar a lo largo del país. Por ejemplo, la industria maquiladora, localizada principalmente en la zona fronteriza del norte, comenzó a operar en 1960 como parte de un plan para ubicar establecimientos industriales internacionales en México. El plan permitió que numerosas empresas extranjeras trajeran equipo, componentes y materias primas al país sin estar sujetos a barreras arancelarias. Por consiguiente, muchas de las materias primas usadas por las maquiladoras pueden ser importadas y pueden diferir de las materias primas empleadas en otras partes de México.

4.1.3. Prácticas de Operación

Las prácticas de operación pueden variar en diferentes regiones de México y tener un impacto potencial en el desarrollo de las estimaciones de emisión. Muchas de las tecnologías, estándares de producción y prácticas de operación de las maquiladoras, por ejemplo, son importadas y reflejan prácticas industriales extranjeras. En general, las plantas industriales extranjeras están más automatizadas, mientras que la industria mexicana tradicional tiende a aplicar procesos manuales en mayor medida y, con frecuencia, está más basada los aspectos artesanales. Estas diferencias pueden provocar cambios en los estimados de emisión. Por ejemplo, el equipo automatizado para recubrimiento de superficies normalmente aplica una capa de recubrimiento más delgada que cuando se usa equipo manual.

4.1.4. Edad del Equipo

En México, el sector manufacturero está compuesto por un número pequeño de grandes consorcios nacionales y compañías extranjeras (2,481 en 1992), y un gran número de empresas micro (101,226), pequeñas (20,734) y medianas (3,338). En general, las grandes instalaciones manufactureras han instrumentado procesos de producción limpios y competitivos, y usan equipo moderno. Por otra parte, las empresas más pequeñas operan con equipo y tecnología más antiguos, y están consideradas como grandes consumidoras de energía y contaminadoras potenciales, a pesar de su menor tamaño.

La edad del equipo puede influenciar el desarrollo de estimados de emisiones de dos maneras. Primero, los equipos más modernos tienden a aplicar tecnologías diseñadas para reducir las emisiones. Por ejemplo, los Desgrasadores a Vapor de Bajas Emisiones *(Low Emission Vapor Degreasers, LEVDs)*, recientemente diseñados, usan nuevas tecnologías tales como el aspirado total y las cámaras de remoción de grasa totalmente selladas, que reducen las emisiones de manera significativa, si se compara con los removedores convencionales. Segundo, la edad del equipo debe ser considerada al seleccionar un factor de emisión para una fuente dada. Para que el factor de emisión sea aplicable, la edad del equipo examinado debe ser similar a la edad del equipo con el que se desarrolló el factor.

4.1.5. Datos Meteorológicos y Climatológicos

Para estimar las emisiones de ciertas fuentes es necesario contar con información meteorológica y climatológica. Para ecuaciones de estimación de emisiones para tanques de almacenamiento, por ejemplo, se requieren parámetros tales como la temperatura ambiente promedio anual y la velocidad del viento. Por otro lado, puede mencionarse que la cantidad de combustible utilizado por los equipos de acondicionamiento de aire o calefacción varía de acuerdo con las condiciones del clima.

Para obtener la información climatológica específica de cada región , deben utilizarse los reportes desarrollados por el Instituto Nacional de Estadística, Geografía e Informática (INEGI), o por el Centro Nacional de las Ciencias Atmosférica y Meteorológica de la UNAM.

4.2. Fuentes de Emisión Típicamente Omitidas

Algunos procesos que emiten contaminantes atmosféricos de manera rutinaria son, con frecuencia, omitidos en los inventarios de emisiones. Los responsables del desarrollo de los inventarios deben estar enterados de estos procesos, y deben incluir las emisiones de las siguientes fuentes:

- Equipo de procesos alimentado con combustible
- Componentes fugitivos
- Equipo de control
- Uso misceláneo de solventes
- Vehículos en sitio
- Aditivos del proceso
- Instalaciones de almacenamiento
- Manejo de materiales.

La responsabilidad de registrar adecuadamente esta información recae en quien prepare el inventario de emisiones. A continuación se discuten algunos ejemplos de los procesos típicamente omitidos y de ambigüedades en la clasificación del equipo.

4.2.1. Equipo de Proceso Alimentado con Combustible

Muchos procesos industriales de manufactura usan equipo alimentado con combustible. Los hornos de cemento, por ejemplo, utilizan secadores de producto que operan con combustible; así como los secadores de gas natural que se aplican en los procesos de recubrimiento. **Las emisiones por el uso de combustibles dentro del proceso se estiman utilizando las mismas técnicas usadas para estimar las emisiones de otras fuentes de combustión, y deben incluirse en el inventario**.

4.2.2. Fuentes de Emisiones Fugitivas

Existen diversas fuentes potenciales de emisiones por fugas en el equipo, que están asociadas con las industrias de aceite y gas, refinación de petróleo, y distribución de productos del petróleo. Componentes tales como bombas, válvulas, válvulas de presión, bordes, agitadores y compresoras son fuentes potenciales que pueden fallar debido a roturas en los sellos. Las emisiones fugitivas de los componentes ocurren en el equipo de proceso cuando hay escapes accidentales de líquido o gas. En general, estas emisiones se presentan en raras ocasiones y son difíciles de predecir; algunas veces son intermitentes y variar en intensidad a lo largo del tiempo. Por consiguiente, las mediciones de las emisiones que se fugan del equipo representan una sola imagen del proceso de fuga. Otras fuentes, tales como las tuberías abiertas y conexiones de muestreo pueden tener fugas ocasionadas por situaciones diferentes a una falla en los sellos. La mayor parte de la información recopilada en los Estados Unidos para estimar las fugas de cierto equipo se ha centrado en la industria manufacturera química orgánica sintética, refinerías de petróleo, terminales de distribución de petróleo, plantas procesadoras de gas, y establecimientos de producción de gas y aceite, para los compuestos orgánicos totales y los compuestos orgánicos no de metano.

El *Protocolo para Estimados de Emisión por Fugas en Equipos* (U.S. EPA, 1995 c) es una buena referencia con respecto a los procedimientos y enfoques para estimar las emisiones de fugas en equipos. Estos pueden ir desde lo más sencillo (multiplicar el equipo por los factores de emisión promedio) hasta lo más complejo (desarrollar de correlaciones de unidad específica entre las tasas de emisión de masa y los valores de separación (screening)). Gran parte de este documento que describe el enfoque del factor promedio de emisión y el enfoque de los rangos de separación es incluido como Apéndice IV-C.

Además de las fugas derivadas de componentes con fallas en el equipo, existen otras emisiones fugitivas diversas que podrían, en ciertos casos, ser identificadas como “fuentes puntuales”, que están asociadas con un proceso dado o una industria determinada. Los especialistas en inventarios de emisiones utilizan las listas publicadas para iniciar una lista de fuentes puntuales que posteriormente sea desarrollada con base en observaciones personales. Algunos ejemplos de emisiones de procesos fugitivos que podrían ser agregadas incluyen vapores metalúrgicos producidos en operaciones de soldadura y herrería, emisiones de partículas provenientes de operaciones metal-mecánicas, o emisiones de amoniaco de servicios de impresión (por ejemplo, heliografía).

El desarrollo del inventario debe buscar con prontitud las fuentes de emisiones fugitivas, e incluirlas para prevenir la subestimación de las emisiones.

4.2.3. Equipo de Control

Debe tenerse cuidado al considerar la influencia que los equipos de control tienen en las emisiones, dado que, si bien son utilizados para reducir las emisiones, en ocasiones ellos mismos constituyen una fuente adicional de emisiones. El mejor ejemplo es el uso de reducción selectiva para controlar emisiones derivadas de la combustión. Este proceso se utiliza para controlar las emisiones de NO_x, pero puede provocar emisiones de amoniaco debidas al “deslizamiento de amoniaco”, es decir, el exceso de amoniaco que no reacciona y es emitido directamente.

4.2.4. Uso Misceláneo de Solventes

Con frecuencia, los solventes son utilizados para limpiar piezas de equipo antes del recubrimiento o de algún otro proceso de manufactura. Además de las tinas de desgrasado, donde las piezas son literalmente sumergidas en solvente, otros limpiadores pueden aplicarse utilizando pequeñas brochas o trapos. **Las emisiones ocurren cuando estos solventes se evaporan, y deben ser cuantificadas usando la técnica de balance de materiales, e incluidas en el inventario de emisiones**.

4.2.5. Emisiones Vehiculares en Sitio

Los grandes complejos industriales en ocasiones poseen flotillas vehiculares utilizadas para transportar materiales, productos o personal dentro de sus instalaciones. Los vehículos mismos son fuentes de contaminantes relacionados con la combustión de NO_x y CO en particular. Adicionalmente, si los calles dentro de la instalación no están pavimentadas, se genera el levantamiento de partículas. **La agencia regulatoria debe decidir si las emisiones vehiculares en sitio deben ser incluidas en el inventario de fuentes puntuales. Las emisiones provenientes de esta fuente son usualmente estimadas usando factores de emisión**.

4.2.6. Aditivos del Proceso

Cualquier químico que se agregue al proceso de producción o control tiene el potencial de ser emitido a la atmósfera. Ejemplos de estos tipos de fuentes incluyen al amoniaco inyectado al gas de flujo para controlar NO_x, y los catalizadores usados en los procesos de reacción química. **Las emisiones de estos procesos se estiman usando información producida en los exámenes en la fuente, factores de emisión, o técnicas de balance material, y deben ser incluidas en el inventario**.

4.2.7. Pilas de Almacenamiento

Las pilas de almacenamiento pueden ser una fuente de emisiones de partículas, especialmente si no se cubren adecuadamente o se controlan con algún otro método. Los materiales que pueden encontrarse en las instalaciones de almacenamiento incluyen: carbón en las plantas de generación eléctrica; rocas en plantas de producción de asfalto o concreto; y otros materiales almacenados en bultos. **Estas fuentes tienen el potencial de generar emisiones significativas de partículas, y deben estar incluidas en el inventario. En este caso, las emisiones de partículas son estimadas aplicando factores o modelos de emisión**.

4.2.8. Manejo de Materiales

Los materiales transportados en camiones o vagones de ferrocarril, sin ser cubiertos de manera adecuada, también pueden producir emisiones de partículas. Dentro de un establecimiento, los materiales, tales como el carbón, que son transportados en bandas de transferencia o sistemas neumáticos, pueden provocar emisiones fugitivas de partículas. Al igual que en el caso de los establecimientos de almacenamiento, las emisiones de estas fuentes se estiman utilizando factores o modelos de emisión, y deben estar incluidas en cualquier inventario de emisiones.

5.0. EQUIPO DE CONTROL DE LA CONTAMINACION DEL AIRE

Para estimar apropiadamente las emisiones, la efectividad del equipo de control existente debe ser considerada en los cálculos. En general, el equipo de control para reducir las emisiones de compuestos orgánicos volátiles y partículas emplea procesos de combustión o de recolección física. Con frecuencia, los óxidos de azufre y óxidos de nitrógeno son controlados con transformación química. Normalmente, los equipos de control para monóxido de carbono no son utilizados para fuentes puntuales; y las emisiones de amoniaco pueden ser controladas para procesos químicos, físicos y de combustión. Una descripción básica de las técnicas usadas por la industria para controlar partículas menores a 10 micras (PM_{10}), dióxido de azufre (SO_2), óxidos de nitrógeno (NO_x), y contaminantes atmosféricos peligrosos puede encontrarse en el documento *Control Technologies for Hazardous Air Pollutants Handbook* (U.S. EPA, 1991).

5.1. <u>Efectividad del Control</u>

La eficiencia del equipo de control se mide por el porcentaje de contaminantes atmosféricos que se remueven del flujo de emisiones antes de ser liberado. Además de la eficiencia del equipo de control, las emisiones están determinadas por la eficiencia de captura de un sistema, que indica el porcentaje del flujo de emisiones que es atrapado por el equipo de control. La efectividad completa del control es, entonces, producto de la eficiencia del equipo de captura y de la eficiencia del equipo de control. En consecuencia, es necesario generar estimados de la eficiencia del equipo de captura y de control para lograr estimados de emisión precisos.

Ejemplo 5-1:

Si se cuenta con un quemador eficiente (para reducir emisiones de COVs) que logre una destrucción del 99 %, y el sistema de captura tiene una eficiencia de captura de 80 %, entonces la eficiencia total de reducción de COV es solamente de 79.2 %.

Efectividad del Control = eficiencia del equipo de control(%) x eficiencia de captura (%)
= 99/100 x 80/100
= 79.2 %

5.1.1. Eficiencia de Captura

La eficiencia de captura se define como la fracción de contaminantes emitidos desde un punto del proceso que realmente queda atrapada en deflectores, filtros o algún otro equipo de captura, y que posteriormente es enviada al equipo de control. La eficiencia de captura puede ser medida a través de pruebas efectuadas en el establecimiento para el que se desean estimar las emisiones; y con frecuencia, es estimada mediante pruebas en equipos similares que operan en otras instalaciones. De manera alternativa, la eficiencia de captura puede estimarse considerando las especificaciones del fabricante o los valores presentados en la literatura. Si no existen datos sobre la eficiencia de captura, es posible hacer estimaciones con base en juicios ingenieriles.

5.1.2. Eficiencia del Equipo de Control

Existen tres maneras diferentes de determinar la eficiencia de un equipo de control, que se presentan a continuación en orden de preferencia:

Prueba de Fuente: La eficiencia de un equipo de control puede ser determinada para un equipo y condiciones de operación específicos, mediante pruebas de fuente que midan las concentraciones de contaminantes antes y después del equipo de control.

Sin embargo, debido a las posibles variaciones en la operación de los equipos de control ocasionadas por deterioro, mal funcionamiento o falta de adaptación al proceso, las mediciones están sujetas a limitaciones potenciales.

Especificaciones del Fabricante: El segundo método para obtener la eficiencia de control es usar las especificaciones de diseño del fabricante, o las especificaciones de desempeño garantizado.

Sin embargo, la eficiencia de diseño reportada por los productores es la que se logra bajo condiciones óptimas, que pueden no ser representativas de las condiciones reales. Además, un equipo de control puede no ser del tamaño adecuado para el proceso al que se aplica. Puede ser conveniente una evaluación de la eficiencia de diseño para ajustar el equipo a las condiciones de la fuente.

Valores de la Literatura: Cuando los datos de pruebas de fuente o las especificaciones del fabricante no estén disponibles, es posible usar los valores presentados en la literatura para medir la eficiencia de un equipo. La Tabla 5-1 enlista algunos equipos de control usados comúnmente para fuentes puntuales, señalando los contaminantes controlados y la eficiencia de control.

Si bien la Tabla 5-1 puede ser utilizada para realizar estimados "gruesos" de la eficiencia del equipo de control, es necesario tomar en cuenta que ésta puede verse afectada por las condiciones específicas de operación. En consecuencia, los estimados de eficiencia de control pueden no ser aplicables a equipos específicos; por lo tanto, es posible recurrir al conocimiento del proceso y el juicio ingenieril para complementar la estimación.

Es necesario ajustar los estimados de eficiencia del equipo de control de acuerdo con los periodos de falla y las condiciones del equipo (por ejemplo con filtros degradados). Si los equipos de control son desconectados periódicamente para mantenimiento o por descompostura, las emisiones liberadas durante una hora dada pueden exceder las que se emiten durante varias horas de operación en condiciones normales. Si no se consideran las emisiones que resultan durante el tiempo en que los equipos de control no operan u operan deficientemente, se puede generar un error en los estimados de emisión.

Tabla 5-1

Equipos de Control Típicos y Eficiencia de Control (%)[a]

Equipo o Técnica	Contaminante			
	Partículas	**COVs**	**SO_x**	**NO_x**
Ciclón	80-90+			
Filtro de Tela	80-99+			
Precipitador Electrostático	95-99+			
Lavador	80-95	--	80-98	--[b]
Absorción		90-99	--	--[b]
Adsorción		50-99	--[b]	--[b]
Condensación	--	50-95		
Incineración Térmica	--	95-99+		
Incineración Catalítica		95-99+		--
Reducción Catalítica Selectiva				40-90
Reducción No Catalítica Selectiva				40-60

Fuentes: Emission Inventory Improvement Program (EIIP), July 1995a and Nevers, 1995.

[a] Las eficiencias son sólo estimadas. El conocimiento específico sobre el proceso y equipo reales es necesario para generar un estimado de eficiencia más preciso.

[b] Técnica de control experimental.

-- = Datos no disponibles.
SO_x = Oxidos de Azufre
NO_x = Oxidos de Nitrógeno
COVs = Compuestos orgánicos volátiles.

5.2. Descripción de los Equipos de Control

En esta sección se presenta una breve descripción de los equipos y técnicas de control más comunes. En el documento *Air Pollution Control, A Design Approach* (Cooper and Alley, 1994) es posible encontrar información más detallada. Con respecto a las ventajas, desventajas y costo de diversos equipos de control conviene consultar el *Control Technologies for Hazardous Air Pollutants* (U.S. EPA, 1990), y el *Air Pollution Engineering Manual* (Buonicore, 1992).

5.2.1. Ciclón

El ciclón (también conocido como “recolector mecánico”) es un equipo de control de partículas que usa la gravedad, inercia e impacto para remover partículas de un flujo dentro de un ducto. Los ciclones de gran diámetro se utilizan frecuentemente como limpiadores primarios para remover el grueso de partículas pesadas de una corriente de aire, antes de pasarla a limpiadores secundarios (EIIP, 1995b).

5.2.2. Filtro de Tela

Los sistemas de filtros de tela atrapan las partículas en elementos filtradores (bolsas). Las partículas quedan atrapadas en la superficie de las bolsas, mientras la corriente de aire pasa a través de ellas. Los filtros de tela pueden alcanzar la mayor eficiencia en la recolección de partículas de entre todos los equipos de control de partículas (EIIP, 1995b).

5.2.3. Precipitador Electrostático

Los precipitadores electrostáticos (ESPs) se usan para controlar las emisiones de partículas. Los ESPs emplean fuerzas eléctricas para remover partículas de un flujo de gas y llevarlas a un plato recolector. Posteriormente, las partículas son removidas de los platos y depositadas en una tolva de recolección (EIIP, 1995b).

5.2.4. Lavador (*Scrubber*)

Los lavadores se utilizan para remover partículas y óxidos de azufre. Los lavadores húmedos emplean agua para remover partículas mediante el contacto directo con la corriente de aire. Los óxidos de azufre pueden ser controlados con líquidos alcalinos en lavadores húmedos o secos.

5.2.5. Absorción

La absorción es una operación en la que se transfieren componentes de una mezcla de gas a un líquido. Este proceso puede ser físico, cuando los compuestos simplemente se disuelven en el solvente, o químico cuando se presenta una reacción (U.S. EPA, 1991). En la mayoría de las aplicaciones para el control de contaminantes, el líquido es agua y el proceso es algunas veces llamado lavado o tallado (Cooper, 1994). El tipo de equipo más usado para operaciones de contacto para gas/líquido es la torre recubierta. El flujo de gas entra por la parte baja de la columna y circula hacia arriba a través de una cama recubierta húmeda. El líquido entra por la parte alta de la columna y se distribuye uniformemente en la cubierta de la columna. La transferencia de masa de la fase gaseosa a la líquida se realiza a lo largo de la interfase gas-líquido, que provee la superficie húmeda del recubrimiento de la torre (Cooper, 1994).

5.2.6 Adsorción

Un sistema de adsorción controla los COVs adsorbiendo selectivamente los compuestos de una superficie o cama, que típicamente está compuesta de carbón. Los COVs que se adsorben son removidos de la cama de carbón en el proceso de desorción mediante el calentamiento del carbón, usando vapor o reduciendo la presión del sistema. Estos sistemas incluyen camas fijas y movibles, que también se conocen como camas fluidizadas. Para la adsorción de SO_2 Se han diseñado algunos sistemas fluidizados (Nevers, 1995; U.S. EPA, 1991; Cooper, 1994).

5.2.7. Condensación

La condensación es la técnica mediante la cual los COVs son separados de un gas mediante la saturación, seguida por un cambio a estado líquido. Para producir el cambio de estado de estos compuestos, es posible aplicar dos técnicas: (1) incrementar la presión del sistema a una temperatura dada; o (2) reducir la temperatura del sistema a una presión constante. Los dos tipos de condensadores más usuales son los de superficie y los de contacto (U.S. EPA, 1991).

5.2.8. Incineración

La incineración térmica es una técnica de control ampliamente utilizada que provoca la oxidación de los COVs a altas temperaturas. Estos equipos son capaces de lograr un alto nivel de eficiencia (superior al 99 % de destrucción de COVs). Es posible el empleo de catalizadores para ayudar en la oxidación de COVs en un sistema de incineración catalítico (U.S. EPA, 1991).

5.2.9. Reducción Selectiva

La reducción catalítica selectiva es una tecnología que controla los óxidos de nitrógeno, mediante su reacción catalítica con amoníaco para formar nitrógeno y agua. Las tecnologías de reducción no catalítica selectiva utilizan un agente para reducir los óxidos de nitrógeno a agua y nitrógeno (EIIP, 1995a; EIIP, 1995b).

6.0. PARAMETROS DE CHIMENEA

Si el inventario está siendo utilizado para modelar la calidad ambiental los datos de la chimenea son necesarios. Esto incluye tanto los datos de la chimenea misma, como los de respiraderos, tubos u otras aberturas que liberen contaminantes a la atmósfera. Dependiendo del modelo y de su objetivo, las chimeneas pueden ser analizadas individualmente o en grupo. El resto de este capítulo describe los parámetros de chimenea. Para mayor detalle sobre los requerimientos para modelar inventarios ver *Screening Procedures for Estimating the Air Quality Impact of Stationary Sources, Revised* (U.S. EPA, 1992).

Los parámetros de chimenea requeridos usualmente para modelar son:

- Ubicación
- Altura
- Diámetro
- Temperatura
- Velocidad
- Tasa de flujo volumétrica.

En establecimiento grande, la recopilación de los parámetros para todas las chimeneas puede representar un reto. Sin embargo, con frecuencia es posible agrupar diferentes chimeneas y estudiarlas como una sola.

6.1. Localización de la Chimenea

La localización de cada chimenea debe ser identificada mediante el uso de coordenadas geográficas, tales como latitud y longitud. Para modelos de dispersión, la localización debe ser lo más exacta posible, con un margen de error no mayor a 10 metros. Los modelos regionales pueden tolerar datos menos precisos. La ubicación de las chimeneas puede determinarse con diversos métodos, mismos que son descritos a continuación.

6.1.1. Sistema de Posicionamiento Global (GPS)

Un GPS puede utilizarse para determinar una localización de modo muy preciso. Existen numerosos satélites GPS alrededor de la Tierra que sirven como puntos de referencia. La localización de un punto sobre la superficie puede ser determinada con base en la distancia que tenga con cuatro o más satélites.

Un buen sistema de posicionamiento es costoso, y el precio de un receptor GPS con grado de precisión de 1 cm a 1 m fluctúa entre 10,000 y 30,000 dólares. La precisión depende del empleo de un receptor FM para la corrección diferencial o de una estación base sobre un punto dado, y así como del tiempo de ocupación del satélite sobre ese punto (de 10 minutos a una hora para tener aproximación de centímetros).

Los receptores GPS de menor precisión cuestan entre 600 y 4,000 dólares, y tienen un margen de precisión de entre 1 y 10 metros. Los receptores a nivel recreativo, con un margen de precisión de 100 metros tienen un costo entre 200 y 600 dólares. Estos dos tipos de receptores, sin embargo, pueden no ser adecuados para ciertos inventarios que requieren un mayor grado de precisión o un análisis micro.

6.1.2. Datos de Estudios Previos y Mapas CAD

Si el sitio ha sido analizado previamente, la localización de chimeneas específicas puede ser determinada de acuerdo con los mapas existentes o los archivos de diseño ayudado por computadora (CAD, por sus siglas en inglés). Cuando menos dos puntos de referencia pueden ser localizados dentro del área de interés; sin embargo, entre más puntos de referencia se establezcan, más precisión se tendrá al ubicar las chimeneas. Para localizar los puntos de referencia es necesario seguir los estándares y procedimientos del INEGI.

6.1.3. Mapas Topográficos

El método menos adecuado para localizar chimeneas es el uso de mapas topográficos. Si una planta tiene más de una chimenea, es poco probable que este método pueda localizar cada una con precisión. Sin embargo, este método puede ser útil para modelos regionales de gran escala, donde no se precise un alto nivel de detalle (ver discusión en el punto 6.1.,anterior, sobre grupos de chimeneas).

6.2. Altura de la Chimenea

La altura de la chimenea se mide desde el suelo. El error más común en inventarios es medir la chimenea desde el techo y no desde el suelo. A continuación se describen brevemente tres métodos para determinar la altura de una chimenea.

6.2.1. Clinómetro

Un clinómetro es un instrumento muy sencillo que puede ser usado para medir la altura de un objeto. Se requiere conocer la distancia entre la base de la chimenea y la persona que está tomando la medición para completar los cálculos. El nivel de precisión varía, y depende primordialmente de:

- La exactitud de la medición a la base
- La precisión del clinómetro.

La Figura 6-1 ilustra el uso del clinómetro. En esta figura, la chimenea está localizada en el límite del edificio, así que la medición de la distancia a la base no se obstruye. Si la chimenea se localizara a la mitad del edificio, es más recomendable medir la altura del edificio y la altura de la chimenea sobre el techo (usando un clinómetro) y después sumar los dos resultados.

La lectura del clinómetro se da como un porcentaje de la distancia a la base. En el ejemplo de la Figura 6-1, la altura de la chimenea (a nivel del ojo) es:

$$48/100 \times 25 = 12.0 \text{ m} \tag{6-1}$$

La altura a nivel del ojo a partir del suelo (1.7 m) debe agregarse para dar una altura total de 13.7 m.

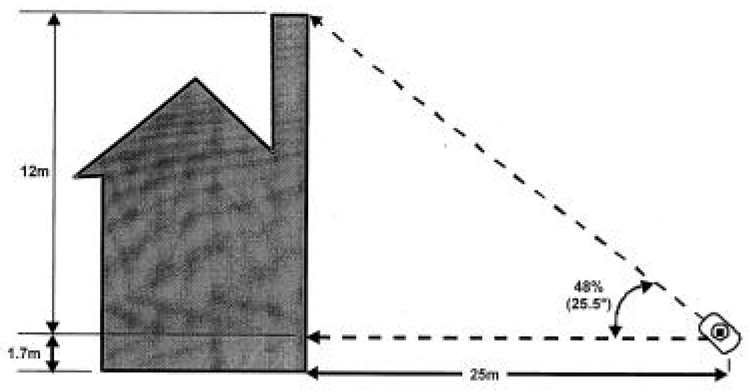


Figura 6-1. Uso del Clinómetro para Medir la Altura de una Chimenéa

6.2.2. Medición Directa

Si la chimenea no es muy alta, la medición puede hacerse directamente. En general, lo más sencillo es extender un flexómetro desde el techo del edificio hasta el suelo, para medir la altura del edificio, hacer lo mismo con la chimenea y y sumar ambos resultados.

6.2.3. Diseños Arquitectónicos e Ingenieriles

Si existen planos o esquemas de otro tipo sobre las edificaciones, es posible obtener los datos sobre la altura de las chimeneas de esos documentos. De cualquier modo es conveniente verificar la altura (usando uno o ambos métodos anteriores).

6.3. Diámetro de la Chimenea

En este caso, los parámetros de interés son diámetro de la boca o el diámetro interior de la chimenea, que debe medirse directamente. Si se utilizan planos o esquemas, es conveniente verificar la certeza de los valores que muestran. Esta es una variable muy importante porque afecta el cálculo de la velocidad de salida y debe, por consiguiente, ser medido con la mayor precisión posible.

Si la chimenea no es redonda, el diámetro debe calcularse de acuerdo con su área. Por ejemplo, el área (A) de un respiradero rectangular se calcula midiendo los dos lados (desiguales), y multiplicándolos. El área de un círculo es πr^2 (donde r es el radio o la mitad del diámetro). El diámetro efectivo (d) se calcula entonces:

$$\mathbf{d = 2 \times (A/\pi)^{1/2}} \tag{6-2}$$

6.4. Temperatura

La temperatura de los gases en el punto donde son liberados de la chimenea es otra variable importante. En la mayoría de los modelos, la temperatura de salida afecta la altura que alcanza la pluma. Este valor debe ser medido al interior de la chimenea, justo en el punto más alto.

Hay que recordar que si una chimenea es muy alta, los gases se enfriarán significativamente conforme suban. La mayor parte de las temperaturas de salida para algunos procesos específicos caen dentro de un rango típico, pero es posible que se registren algunas fuera de ese rango. Algunos procesos de control pueden reducir las temperaturas de los procesos de combustión.

6.5. Velocidad de Salida

La velocidad de salida de los gases se calcula usualmente considerando el diámetro de la chimenea y la tasa de flujo volumétrico, tal como se muestra a continuación:

$$\textbf{Velocidad de salida (m/s)} = \frac{\textbf{tasa de flujo (m}^{3}\textbf{/s}}{\textbf{área de la chimenea (m}^{2}\textbf{)}} \tag{6-3}$$

El área de la chimenea se calcula usando el diámetro de salida (ver sección 6.3 anterior).

6.6. Tasa de Flujo Volumétrico

La tasa de flujo volumétrico es el volumen de gases que salen de la chimenea o de otro punto de emisión por unidad de tiempo (por ejemplo m^3/s).

La tasa de flujo no se usa directamente para modelar. Sin embargo, con frecuencia es más accesible (por ejemplo en las especificaciones de los fabricantes de ventiladores de extracción), que la velocidad de salida. Por consiguiente, la tasa de flujo volumétrico real se usa para calcular la velocidad (ver sección 6.5). Si la tasa de flujo se ha convertido a una estándar (algunas veces expresada como tasa de flujo “normal”), debe ser convertida a la tasa real.

7.0. ASEGURAMIENTO DE CALIDAD Y CONTROL DE CALIDAD

Las actividades de aseguramiento de calidad son esenciales para el desarrollo de inventarios de emisiones completos y de alta calidad; y requieren la instrumentación de procedimientos de aseguramiento de calidad y control de calidad (AC/CC) a lo largo de todo el proceso de inventariado. Para mayor información sobre los aspectos de AC/CC, incertidumbre y verificación de emisiones, ver el Programa de Mejoramiento de Inventarios de Emisiones (EIIP) Volumen VI: *Quality Assurance Procedures for the Emission Inventory Improvement Program*, borrador externo (EIIP, 1995 c).

El aseguramiento de calidad es un sistema integrado de actividades que incluye la planeación, el control, la valoración, los reportes y mejoras de la calidad, que está diseñado para asegurar que el inventario cumpla con las metas u objetivos de calidad establecidos antes de su desarrollo. El control de calidad es el sistema general de actividades técnicas rutinarias diseñadas para evaluar y controlar la calidad del inventario conforme está siendo desarrollado. El objetivo principal del sistema AC/CC para los inventarios de emisiones es la obtención de datos precisos, útiles y confiables.

La Figura 7-1 muestra los pasos básicos con respecto a los procedimientos AC/CC dentro del inventario de fuentes puntuales del INE. Para instrumentar los procedimientos AC/CC, los auditores del INE seleccionan aleatoriamente un establecimiento dentro de un grupo estratégico de sectores industriales. Posteriormente, el auditor obtiene una copia de la Encuesta Industrial que el establecimiento entregó al INE y efectúa una “revisión general”, que consiste en el análisis de los datos presentados para verificar que estén completos y sean razonables. Más tarde, el auditor elabora una lista de los códigos del Sistema Nacional de Información de Fuentes Fijas (SNIFF) que, según su criterio, deben ser asignados a los datos presentados en la encuesta. Los códigos SNIFF asignados por el auditor se comparan con los códigos asignados por el INE en el momento en que los datos del cuestionario fueron capturados en los archivos del SNIFF, y se hacen las modificaciones pertinentes.

A continuación, el auditor analiza las “emisiones revisadas” reportadas por el establecimiento en la encuesta, y las compara con las emisiones calculadas usando una metodología estándar. En la encuesta, una planta debe, por ejemplo, presentar un estimado de emisiones basado en pruebas de fuente, mismo que debe ser comparado con el estimado de emisiones desarrollado por el auditor, con base en el uso de combustibles y factores de emisión del documento AP-42. Si los resultados de estos dos enfoques son razonablemente consistentes, entonces el procedimiento AC/CC está completo. De lo contrario, se requiere que otras actividades AC/CC (por ejemplo una llamada de seguimiento al establecimiento o una revisión del auditor a los resultados de los datos de la fuente) sean realizadas hasta que el auditor quede satisfecho con los estimados de emisión presentados ante el SNIFF.

Un ejemplo de lista de revisión para fuentes puntuales se incluye en el Apéndice IV-D. Esta lista de revisión, diseñada para un inventario de precursores de ozono, incluye aspectos relacionados con el grado en que el inventario está completo, aplica los métodos aprobados y es razonable.

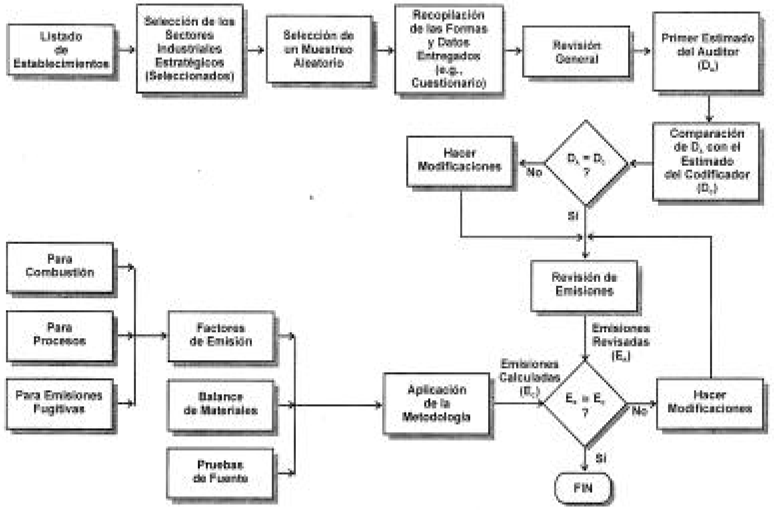


Figura 7-1. Procedimientos de AC/CC para el Inventario de Fuentes Puntuales del INE

7.1. Declaración de los Objetivos de Calidad de los Datos

El primer paso al planear un inventario es definir su propósito y uso. Esta información será aplicada, en su momento, para determinar tanto los objetivos de calidad de los datos (DQOs, por sus siglas en inglés) para el inventario, como los requerimientos AC/CC.

Los DQOs son declaraciones sobre el nivel de incertidumbre que un responsable de la toma de decisiones está dispuesto a aceptar. Su propósito es asegurar que los datos finales sean adecuados para el uso que se pretende darles. Las declaraciones DQO deben identificar el uso final o propuesto para los datos, así como el nivel anticipado de incertidumbre en los estimados de emisión.

Es muy importante reconocer que los DQOs son específicos para cada método; están basados en las posibilidades para una metodología dada y en la calidad de la información disponible. Los responsables del desarrollo del inventario deben revisar los datos históricos. Es importante preguntarse qué problemas en el pasado han ocasionado una disminución de la calidad del inventario y si su resolución es posible. Si este programa es para una fuente o región que nunca ha sido inventariada, debe analizarse la información y las experiencias de esfuerzos similares.

Los DQOs deben ser analizados y redactados por adelantado. Una declaración sobre los objetivos de calidad de los datos debe incluir:

- Precisión (o incertidumbre) de los estimados de emisión
- Nivel en el que los datos están completos
- Representatividad
- Grado de comparación.

A pesar de las mejores intenciones con que trabajan quienes preparan el inventario, es importante considerar las restricciones de tiempo, las limitaciones de recursos y la falta de datos. Los DQOs para el inventario deben ser realistas y considerar cualquier factor que pudiera limitar la calidad. El aspecto más importante es dedicar el tiempo necesario para asegurar la calidad del producto.

La Tabla 7-1 enlista seis objetivos importantes de calidad para los inventarios, y presenta algunos métodos generales para lograr estos objetivos.

7.2. Indicadores de Calidad de la Información

Una vez que los DQOs han sido determinados, el siguiente paso, que con frecuencia es más difícil, consiste en identificar los indicadores de calidad de la información (DQIs) que se utilizarán para medir el avance en los DQOs, siendo preferibles las medidas cuantitativas (tales como los límites de confianza, sistemas de ordenamiento numérico o calificaciones). Cabe señalar que la instrumentación de estas medidas es todavía más compleja. Una alternativa es usar DQIs cualitativos, lo que puede hacerse mediante una discusión crítica y exhaustiva de las limitaciones y fortalezas del inventario. En última instancia, los medios de AC/CC dependerán de los métodos empleados para el inventario. Ver la Sección 7.3. para una guía de métodos AC/CC específicos.

Tabla 7-1

Métodos para Alcanzar los Objetivos de Calidad para los Datos del Inventario de Emisiones

Objetivos de Calidad de los Datos	Métodos
Asegurar la correcta instrumentación de los lineamientos del INE.	• Revisar la documentación del inventario, comparando los procedimientos utilizados en la realidad con aquellos que son requeridos.
En los casos en que los lineamientos del INE no fueron utilizados o no estaban disponibles, determinar el sesgo evaluando qué tan razonable fue enfoque utilizado.	• Revisión técnica del enfoque utilizado. • Comparación de los resultados de otros métodos.
Asegurar la precisión de los datos de entrada.	• Revisar la precisión de la transcripción de los datos. • Revisar cualesquier factores de conversión utilizados. • Determinar qué tan razonables fueron los supuestos utilizados para calcular los datos de entrada. • Verificar que la fuente de datos estuviera actualizada y fuera la mejor disponible.
Asegurar la precisión de los cálculos	• Repetir una muestra representativa (o todas) manualmente.
Determinar el grado de comparación y la representatividad del inventario.	• Comparar las emisiones con otras de inventarios similares. • Hacer una revisión cruzada de los datos comparándolos con los datos oficiales.
Determinar el grado en que el inventario está completo.	• Comparar la lista de categorías de fuente o puntos de emisión con aquellos enlistados en los lineamientos del INE. • Hacer una revisión cruzada con otros inventarios publicados, directorios industriales, etc.

7.3. Procedimientos AC/CC para Métodos Específicos de Estimación de Emisiones

La siguiente sección contiene descripciones detalladas de los procedimientos AC/CC para técnicas específicas de estimación de emisiones, incluyendo pruebas de fuente, factores de emisión, balance de materiales y modelos de emisión.

7.3.1. Pruebas de Fuente

Actualmente existen descripciones completas sobre los procedimientos de muestreo en chimeneas, instrumentos y equipo de muestreo de fuente, identificación y manejo de muestras, análisis de laboratorio, uso de datos de las muestras y elaboración de reportes, que pueden encontrarse en muchas referencias bibliográficas, tales como los *Guidelines for Assessing and Reporting Data Quality for Environmental Measurements* (U.S. EPA, 1983) o el *Quality Assurance Handbook for Air Pollution Measurements Systems : Volume III. Stationary Source Specific Methods* (U.S. EPA, 1984). Estos documentos también contienen una discusión detallada sobre los cálculos de precisión requeridos y la interpretación de datos, los criterios específicos sobre datos inaceptables, así como los indicios de que un sistema está fuera de control. Además, el equipo encargado de la prueba debe desarrollar un Plan de Aseguramiento de Calidad antes de cada prueba de campo específica.

Una auditoría de sistemas en sitio debe conducirse, como una revisión cualitativa de los diversos aspectos de un sistema de muestreo y/o análisis total, con el objetivo de evaluar su efectividad general. La auditoría de sistemas debe representar una evaluación objetiva de las fortalezas, debilidades y áreas de problemas potenciales de cada sistema. La auditoría proporciona una evaluación de la capacidad del sistema de medición completo para generar datos sobre calidad que sean adecuados, en términos de cantidad y calidad, para cumplir con los objetivos del programa.

Los criterios de aceptación, límites y valores para cada parámetro de control asociado con métodos de muestreo manual, tales como calibración métrica de gas seco y tasas de fuga, se resumen en la Tabla 7-2. Los procedimientos AC/CC asociados con el monitoreo continuo de emisiones (por ejemplo, calibración multi-punto de instrumentos, anulación de instrumentos y cálculo de la corriente) están contenidos en los métodos de referencia específicos (40 CFR, Parte 60, Apéndice A).

Tabla 7-2

Resumen de los Criterios de Aceptación y Límites de Control para los Métodos de Muestreo Manual

Parámetro o Criterio	Límite de Control y Valores
TSP Isocinética	100 ±10%
PM_{10} Isocinética	100 ±20%
DP_{50} Tamaño Calculado de Corte	9 - 11 µg
Tasa de Fuga Final (después de cada puerto)	≤0.02 acfm ó 4% de la tasa de muestreo, el que resulte menor
Calibración Seca del Medidor de Gas	Factor post-promedio (γ) tolera ±5% del pre-factor
Factores Individuales de Corrección (Y_i)	Queda dentro del 2% del factor promedio
Factor de Corrección Promedio	1.00 ±1%
Medidor Seco de Gas Intermedio	Calibrado cada seis meses contra el estándar
Balanza Analítica (Top Loader)	0.1 g de los Pesos Clase C del *National Bureau of Standards*
Peso Constante del Filtro	Dos pesadas con una tolerancia de ±0.5 mg

Fuente: EIIP, Volumen VI, Tabla 9-2.

7.3.1.1. Análisis del Error

El propósito de un análisis de error es identificar las fuentes de error, para evaluar la magnitud relativa de cada componente de error en los resultados, con el objetivo fundamental de minimizar los errores a través de esfuerzos AC/CC aplicados en los puntos de mayor impacto potencial.

Las tasas de emisión de un contaminante particular son el producto del gas de chimenea y de las medidas de muestreo, tales como concentración (g/dscm) y tasas de emisión (kg/hr). La magnitud de error en una concentración o tasa de emisión ocasionado por un error de medición puede ser calculada. El error relativo puede ser definido como:

$$\textbf{Error Relativo} = \textbf{(Observado - Verdadero)/ Verdadero} \times \textbf{100} \qquad (7\text{-}1)$$

La Tabla 7-3 ilustra la manera en que los errores en las mediciones de gases de chimenea pueden afectar las concentraciones finales y los valores de emisiones. Los errores resultantes en las concentraciones y las tasas de emisión son causados por un error hipotético de medición aislado de +10 % en diversas medidas de muestreo de varias chimeneas. Las siguientes secciones muestran con mayor detalle cómo un error de medición puede afectar los parámetros medidos durante el muestreo de chimeneas.

7.3.1.2. Flujo contra Diámetro de la Chimenea

La siguiente ecuación calcula el error en un flujo de gases de chimenea ocasionado por un error de medición en el diámetro de la chimenea:

$$E_R = (2E_M + E_M^2) \tag{7-2}$$

donde:

E_R = el error de tasa de flujo resultante (fracción)
E_M = el error de medición del diámetro (fracción)

Si, por ejemplo: E_M = 10 %, entonces

$$E_R = (2 \times 0.1 + 0.1^2)$$
$$= 0.21 \text{ ó } 21\ \%$$

Tabla 7-3

Sensibilidad de los Resultados de las Pruebas de Emisión a los Errores Hipotéticos en las Mediciones Manuales

Medición	**Error Ocasionado por un Error de +10% en la Medición**	
	Error de Concentración[a] (%)	**Error en la Tasa de Emisión[b] (%)**
D_s, Diámetro de la Chimenea (metros)	0	21.0
Δp, Presión de la Velocidad (en H_2O)	0	4.9
P_{static}, Presión Estática (en H_2O)	0	0.03
P_{bar}, Presión Barométrica (en Hg)	-9.0	-3.8
T_s, Temperatura de la Chimenea (°F)	0	-1.8
T_m, Metro-Temperatura (°F)	1.6	1.5
O_2, Medición de Oxígeno (%V)	0	-0.03
CO_2, Medición del Dióxido de Carbono (%V)	0	-0.3
H_2O, Arrastre de Agua (g)	0	-0.9
V, Metro-Volumen (m^3)	-9.1	-8.3
ΔH, Metro-Presión (en H_2O)	-0.05	-0.04
Y, Metro-Calibración	-9.1	-8.3
Análisis de Contaminantes (µg)	10.0	10.0

[a] Concentración del contaminante en el gas de la chimenea. Por ejemplo, un error del 10% en el diámetro de la chimenea medido no tiene efecto alguno sobre la concentración reportada.

[b] Tasa de emisiones en masa por unidad de tiempo o actividad. Por ejemplo, un error del 10% en el diámetro de la chimenea medido, ocasiona un error del 1% en la tasa de emisión estimada.

Fuente: EIIP, Volumen VI, Tabla 9-4.

7.3.1.3. Flujo contra Presión de Velocidad

La siguiente ecuación sirve para calcular el error en una tasa de flujo de gas de chimenea ocasionado por un error de medición en la presión de velocidad:

$$E_R = \sqrt{(1+E_M)} - 1 \tag{7-3}$$

Por ejemplo, si EM = 10%, entonces

$$E_R = \sqrt{(1+0.1) - 1}$$

$= 0.049$ ó 49%

Por consiguiente, un error de 10 % en la presión de velocidad tiene como consecuencia un error de 4.9 % en la medición de flujo.

7.3.2. Factores de Emisión

Los datos utilizados para desarrollar factores de emisión disponibles, por ejemplo, en el documento AP-42 o en el *Factor Information Retrieval System* (FIRE), se obtienen de pruebas de fuente, estudios de balance de materiales, y estimados ingenieriles. Los datos se obtienen a través de artículos y reportes, resultados e informes de exámenes reales, y comunicación personal.

Cada factor de emisión publicado en AP-42 o en el FIRE recibe una calificación de calidad, que sirve como una evaluación del nivel de confianza que el generador de ese valor otorga a la precisión del factor de emisión. Cuando se utilizan factores de emisión existentes, el usuario debe estar familiarizado con los criterios para asignar las calificaciones sobre la calidad de los datos y los factores de emisión, tal como se describe en el documento *Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections* (U.S. EPA, 1993b). El encargado del inventario debe revisar las calificaciones de los datos y de los factores de emisión asociados con las fuentes más importantes del inventario. Si los estimados de emisión para una fuente importante han sido desarrollados con base en datos o factores de emisión con baja calificación, deben hacerse intentos posteriores para obtener datos específicos del sitio o de la región.

Los criterios para asignar las calificaciones sobre la calidad de los datos en las pruebas fuente son los siguientes:

- Las pruebas con calificación A son los desarrolladas con metodologías bien fundamentadas y reportadas con detalle suficiente para soportar una validación adecuada. Estas pruebas no se hacen necesariamente con los métodos de prueba de referencia de la U.S. EPA, si bien éstos pueden ser usados como guía
- Las pruebas con calificación B son generalmente desarrolladas con metodologías bien fundamentadas, pero sin el nivel de detalle necesario para ser validadas

- Las pruebas con calificación C utilizan metodologías no validadas o de prueba, o carecen de datos de antecedentes significativos que los fundamente

- Las pruebas con calificación D, se basan en métodos que en general no son aceptables pero que pueden proporcionar un valor de orden de magnitud para la fuente.

Una vez que las calificaciones sobre calidad de los datos para las pruebas de fuente han sido asignadas, son evaluadas junto con el número de pruebas de fuente disponibles para un punto de emisión dado. Debido a que la tarea de asignar un límite de confianza significativo a las variables específicas de la industria (por ejemplo tamaño de la muestra contra población, variabilidad entre industria y establecimiento, o método de medición) es prácticamente imposible, el uso de un intervalo de confianza estadístico para establecer un factor de emisiones representativo para cada categoría de fuente, en general no es práctico. Por consiguiente, es necesario algún tipo de calificación subjetiva. Las siguientes calificaciones sobre calidad de los factores de emisión se utilizan para los factores encontrados en *AP-42*, *FIRE*, o en cualquier documento publicado por la U.S. EPA.

A - Excelente - El factor de emisión fue desarrollado solamente a partir de datos de pruebas con calificación A, tomados de numerosos establecimientos seleccionados de manera aleatoria dentro de la industria. La categoría de la uente es lo suficientemente específica como para minimizar la variabilidad dentro del total de categorías de fuente.

B - Arriba del Promedio - El factor de emisión se desarrolló solamente con datos de pruebas con calificación A provenientes de un número razonable de establecimientos. Si bien no es evidente un sesgo específico, no queda claro si las plantas examinadas constituyen una muestra representativa de la industria. Al igual que con la calificación A, la categoría de fuente es lo suficientemente específica como para minimizar la variabilidad dentro del total de categorías de fuente.

C - Promedio - El factor de emisión se desarrolló solamente con datos de pruebas con calificación A y B de un número razonable de establecimientos. Si bien no es evidente un sesgo específico, no queda claro si las plantas examinadas constituyen una muestra representativa de la industria. Al igual que con las calificaciones A y B, la categoría de fuente es lo suficientemente específica como para minimizar la variabilidad dentro del total de categorías de la fuente.

D - Debajo del Promedio - El factor se desarrolló solamente con datos de exámenes con calificación A y B de un número pequeño de establecimientos, y hay razón para sospechar que éstas no constituyen una muestra representativa de la industria. Puede también existir evidencia de variabilidad dentro del total de categorías de la fuente.

E - Mala - El factor se desarrolló solamente con datos de pruebas con calificación C y D, y hay razones para suponer que los establecimientos examinados no constituyen una muestra significativa de la industria. También puede existir evidencia de variabilidad dentro del total de categorías de la fuente.

U - No calificada o Incalificable - El factor se desarrolló con datos inferidos o sin fundamento documental alguno. Una calificación “U” puede aplicarse en las siguientes circunstancias (FIRE):

U1 - Balance de Masa (para estimar, por ejemplo, emisiones atmosféricas con base en insumos materiales, eficiencia de recuperación de un producto o control porcentual).

U2 - Deficiencias en la prueba de fuente (tales como control y aseguramiento de calidad inadecuados, métodos de examen cuestionables, o existencia de una sola prueba).

U3 - Transferencia tecnológica.

U4 - Juicio Ingenieril.

U5 - Falta de documentación de apoyo.

7.3.3. Balance de Materiales

Si el método de balance de masa es usado para estimar las emisiones, el responsable del desarrollo del inventario debe:

- Asegurar que todos los supuestos sean razonables
- Asegurar que todos los puntos finales y las rutas sean identificados y cuantificados

- Asegurar que todos los datos sean precisos
- Revisar que las emisiones sean razonables (comparando con los resultados de años anteriores o con otros puntos de referencia).

7.3.4. Modelos de Emisión

Si se utiliza un modelo para estimar las emisiones, el responsable del desarrollo del inventario debe:

- Verificar la precisión de los datos de entrada
- Verificar la calidad del software utilizado
- De ser posible, verificar los resultados de los modelos mediante cálculos manuales, o comparándolos con los resultados de métodos alternativos
- Revisar que las emisiones resultantes sean razonables (comparando con los resultados de años anteriores o con otros puntos de referencia).

8.0. PROCEDIMIENTOS DE CODIFICACION DE DATOS

La codificación de datos es una parte integral del inventario de emisiones. El utilizar códigos únicos para los datos del inventario permite asegurar que la información guardada adecuadamente y es recuperable. Cada establecimiento, por ejemplo, debe tener asignado un número único de identificación (ver Sección 8.2.). Si fuera preciso revisar los inventarios para actualizarlos o analizarlos, la información codificada de una manera exclusiva facilita el proceso.

Para que la información sea transferible a otros usuarios, debe ser presentada en un formato consistente y que pueda reconocerse. Todas las actividades de inventariado en una entidad deben estar coordinadas para que las tareas de almacenamiento y recuperación de la información se realicen sin contratiempo. Para que un sistema de codificación de datos sea útil debe permitir:

- La identificación del tipo de datos que contiene
- El almacenamiento y recuperación de datos específicos.

8.1. Códigos de Identificación de Establecimientos

Para poder analizar o actualizar el inventario de un establecimiento, cada planta debe recibir un código único de identificación. Al respecto, se sugiere hacer lo siguiente:

- Usar un número predeterminado de caracteres en un código (por ejemplo, una letra seguida de cuatro números)

- Hacer que el código de identificación de un establecimiento sea corto (para ahorrar tiempo en la captura y reducir las probabilidades de error)
- Al usar una letra dentro del código se incrementa significativamente el número de combinaciones únicas que se pueden lograr.

Dentro de un establecimiento, cada unidad de emisión (UE), punto de emisión (PE) y equipo de control (EC) deben ser identificados con un código único, por ejemplo: UE1, PE1, PE2 y EC1, EC2, etc.

8.2. Procedimientos de Codificación de Datos del SNIFF

Actualmente, la información compilada a través de la encuesta industrial del INE se integra en la base de datos del Sistema Nacional de Información de Fuentes Fijas (SNIFF). Los parámetros, cantidad de códigos y número de campos de información disponibles en el SNIFF se presentan en la Tabla 8-1.

Los códigos usados para los datos que se incluyen en el SNIFF fueron desarrollados específicamente para el Programa de Inventario de Emisiones del INE, y están incluidos en los catálogos internos de códigos del Instituto. La codificación y captura de los datos, en general son realizadas por personal del INE. Para obtener una copia del catálogo de códigos es recomendable solicitarlo a la Subdirección de Inventario de Emisiones del INE.

En la medida en que el proceso de inventariado en México se desarrolla, y el reporte y almacenamiento electrónico de datos se hace más sofisticado, se requiere un método más descriptivo y preciso para identificar la actividad industrial. El sistema de Código de Clasificación de Fuentes descrito en la Sección 8.3., por ejemplo, introduce un concepto más extenso para aplicar códigos de identificación únicos a procesos individuales.

Tabla 8-1

Características de Identificación del Sistema de Codificación del SNIFF

Parámetro	Número Aproximado de Códigos	Número de Campos
Ubicación	Por distrito, estado y municipio	3
Actividad de la empresa (sector industrial)	450[a]	1
Tipo de proceso	396	1 (sólo el proceso principal)
Maquinaria y equipo	350	5 (uno para cada fase del proceso)
Materias primas	2,000	6
Productos	22,000	7
Combustibles	13	1
Unidades de combustible	28	1
Contaminantes	100[b]	5
Equipos de control	170	10 (2 para cada fase del proceso)
Capacidad del equipo de control	22	1

[a] El sistema de clasificación que es utilizado por el SNIFF para identificar las actividades industriales tiene 7 dígitos. Las primeras dos cifras corresponden al nivel de severidad o potencial de contaminación industrial de un ramo industrial determinado (01 para el grupo de los emisores más grandes; 02 para los siguientes emisores más grandes; 03 para los emisores menores, o aquellos que se consideran como fuentes de área). Los siguientes dos dígitos identifican el ramo o sector industrial (0101 para las plantas de generación eléctrica; 0102 para las refinerías petroleras y plantas petroquímicas; 0103 para los procesos químicos, etc.). Los últimos tres dígitos corresponden al subsector dentro del ramo industrial (0103002 para la fabricación de amoniaco y sus derivados; 0102004 para la fabricación de ácido nítrico).

[b] Sólo se reportan los contaminantes criterio.

8.3. Códigos de Clasificación de Fuentes

Muchas bases de datos utilizan códigos de clasificación de fuentes (CCFs) para relacionar los datos de emisiones con tipos específicos de tecnología. Cada código representa un proceso o función único dentro de una categoría de fuente que se asocia lógicamente con un punto de emisiones de contaminantes. Con un código de identificación apropiado, un proceso puede ser identificado con precisión para los propósitos de recuperación de la información.

Los CCFs están divididos en cuatro niveles: I, II, III y IV, que tienen 1, 2, 3, y 2 dígitos, respectivamente. El nivel I identifica la categoría del proceso con un número de un solo dígito, tal como se muestra en la Tabla 8-2. El segundo nivel (II) de identificación es un código de dos dígitos que indica el grupo industrial. Por ejemplo, los procesos industriales (Nivel I, código 3) están subdivididos en manufacturas químicas (3-01), alimentos/agricultura (3-02), metales primarios (3-03), etc. El tercer nivel, un número de tres dígitos, indica el producto principal, materia prima, combustible, o pieza de equipo. El cuarto nivel de clasificación, un número de dos dígitos, identifica diferentes operaciones en la fuente puntual. La Figura 8-1 presenta el ejemplo de la asignación de un CCF para una planta eléctrica que quema carbón bituminoso pulverizado en un horno con fondo húmedo.

Tabla 8-2

Categorías de CCF de Nivel I

Valores del Nivel	Categoría de Proceso	Descripción de la Categoría
1	Fuentes de Combustión Externa	Calderas y calentadores de espacio
2	Fuentes de Combustión Interna	Turbinas y motores de pistón
3	Procesos Industriales	Todos los procesos industriales distintos a las fuentes de evaporación, y la combustión para vapor o energía, así como la disposición de residuos peligrosos.
4	Fuentes de Evaporación	Operaciones de recubrimiento de superficies, almacenamiento de petróleo y operaciones de impresión.
5	Disposición de Residuos Peligrosos	Incineración de residuos, tratamiento de aguas residuales, rellenos sanitarios; procesos en establecimientos de tratamiento, almacenamiento y disposición de residuos (TSDF, por sus siglas en inglés).

En algunos casos, el término “general” aparece como una descripción de proceso de CCF de cuarto nivel. Esto indica que el proceso o serie de procesos ha sido identificado y simplificado a una “caja negra” o grupo de actividades, más que como un agrupamiento complejo de fuentes de emisión relacionadas. Normalmente, los códigos CCF “Generales” son reemplazados por SCCs más específicos en el momento en que se tiene acceso a información más detallada acerca del proceso.

El término “Otras No Clasificadas” es una descripción de proceso de CCF de cuarto nivel que puede ser utilizado para representar actividades para las que no se ha definido un CCF específico; en general, ésta es representada por códigos que terminan en “99”. Si estos códigos son utilizados, es imperativo que los especialistas del inventario de emisiones capturen en un campo de comentarios de la base de datos, una descripción más detallada de las emisiones descargadas.

Una lista numérica completa de SCC está disponible en el sistema de boletines (BBS) de la Cámara de Compensación para Inventarios y Factores de Emisión (*Clearinghouse for Inventories* *and Emission Factors - CHIEF*) 95-919-541-5742 (línea de acceso a módem), y en la base de datos del Sistema de Recuperación de Factores de Información (FIRE). Una copia documental de la lista SCC se incluye en el Apéndice IV-E de este documento.

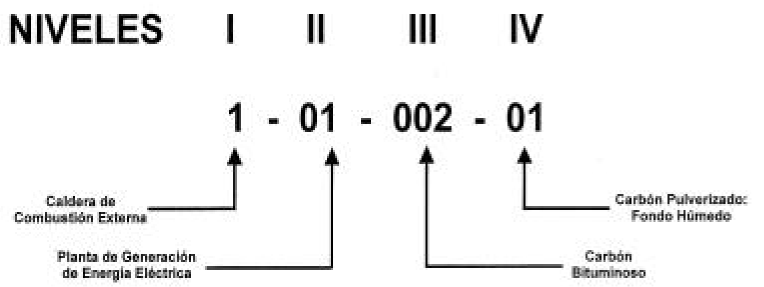


Figura 8-1. CCF para una Planta de Generación Eléctrica Alimentada con Carbón Bituminoso Pulverizado en un Horno de Fondo Húmedo

9.0. RECOPILACION DE INFORMACION

Para obtener los datos requeridos para calcular las emisiones, la recopilación de la información debe hacerse de manera adecuada. Los métodos más eficientes para obtener la información son las formas o los cuestionarios de recolección de datos. Una vez que han sido llenadas, las formas mismas deben ser conservadas como información de respaldo para el desarrollo del inventario de emisiones. Con respecto a su diseño, las formas para la recopilación de información pueden ser genéricas, pudiendo ser utilizadas en cualquier instalación, o bien, ser individuales para cada industria o tipo de equipo. La Sección 5 del Volumen III: *Técnicas Básicas de Estimación de Emisiones* presenta una discusión detallada sobre la manera de inspeccionar instalaciones.

9.1. Cuestionario General

Un cuestionario general es una colección de cuestionarios sobre procesos específicos. Su uso es más frecuente si la lista de distribución es larga, si la entidad no está familiarizada con muchas de las fuentes en la lista o si sus recursos son limitados.

El desarrollo de un cuestionario implica las siguientes actividades:

- Definir un formato adecuado, tan simple y funcional como sea posible
- Identificar e incluir las preguntas apropiadas
- Desarrollar una carta de presentación, portada e instrucciones para llenar el cuestionario

- Diseñar el cuestionario para la persona que lo responderá; considerar la experiencia y antecedentes técnicos de esa persona

- Diseñar el cuestionario para ser comprendido por personas que carezca de una formación técnica especializada

- Hacer un uso adecuado del espacio para las preguntas, dejando espacio suficiente para las respuestas

- Hacer el cuestionario tan corto como sea posible; los cuestionarios muy largos pueden resultar intimidantes

- Usar terminología que sea familiar a quien recibe el cuestionario

- Asegurar que cada pregunta se explique por sí misma o se tenga una explicación clara

- Solicitar toda la información necesaria a través del cuestionario, tratando de evitar peticiones adicionales de información

- Al determinar la información que se solicita, se debe considerar el uso final de los datos

- Recopilar cualesquier datos adicionales necesarios para la aplicación posterior de un modelo fotoquímico

- Solicitar información de proceso adicional a la información general sobre la fuente, tal como la ubicación, propiedad y naturaleza del negocio

- Obtener los niveles de actividad apropiados (tales como los indicadores de producción y consumo de combustibles) para cada tipo de fuente

- Obtener información sobre los instrumentos de control para estimar emisiones controladas y determinar reducciones potenciales en las emisiones para aplicar varias estrategias de control.

De acuerdo con el Artículo 17 del Reglamento en Materia de Prevención y Control de la Contaminación Atmosférica, los responsables de las fuentes puntuales de jurisdicción federal que emitan olores, gases, partículas sólidas o líquidos a la atmósfera deben presentar un inventario de sus emisiones contaminantes. El INE ha desarrollado dos cuestionarios para recopilar esta información. Los datos que se obtienen de la encuesta industrial (Formato LF-CO) y el cuestionario a la microindustria (Formato IE-MI) se integran a la base de datos del SNIFF (ver Sección 8.2.) Ambos cuestionarios están contenidos en el Apéndice IV-F.

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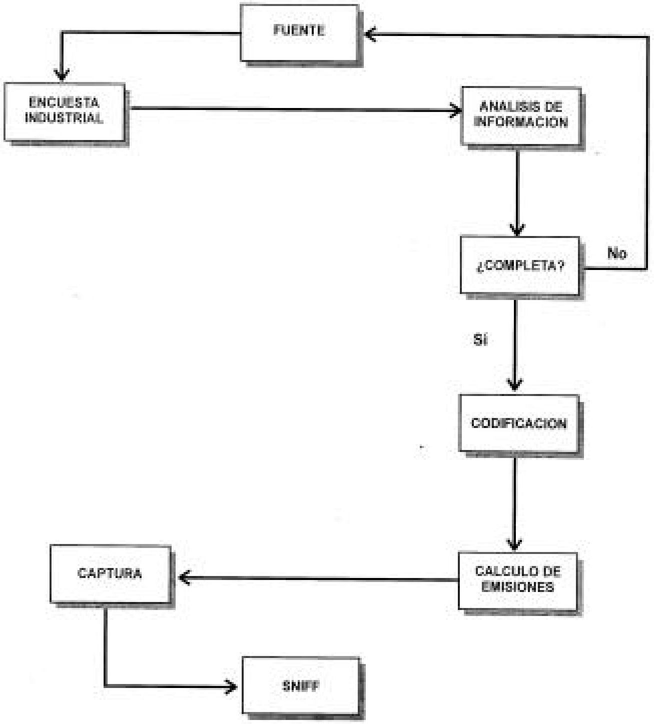
APENDICE IV-A

PROCESO DE DESARROLLO DEL INVENTARIO DE FUENTES PUNTUALES DEL INE



Metodología de Integración de Inventarios

METODOLOGIA PARA EL DESARROLLO DEL INVENTARIO NACIONAL DE EMISIONES

I. RECEPCION DE ENCUESTA INDUSTRIAL

Como primer paso se realiza la recepción y revisión de la Encuesta Industrial conforme al formato LFCO. Este trámite está fundamentado en el Reglamento de la Ley General Del Equilibrio Ecológico y Protección al Ambiente en Materia de Prevención y Control de la Contaminación Atmosférica, en sus Artículos 17, 20 y 21 (Capítulo **II**, que trata de la emisión de contaminantes a la atmósfera, generada por fuentes puntuales), y aplican a las Zonas y Fuentes de la Jurisdicción Federal consideradas en el Artículo 11 (Capítulo **I**, referente a Disposiciones generales).

Este trámite se efectúa en las 31 Subdelegaciones de Protección Ambiental de la SEDESOL, cada una pertenecientes a las 31 entidades federativas del País y en el DF, se realiza conforme el Artículo 9 (Capítulo **I**) de dicho reglamento.

II. ANALISIS DE INFORMACION

Este segundo paso consiste en un análisis detallado de la información presentada en cada uno de los puntos que estructuran el formato LFCO. Este tiene la finalidad de verificar que la información esté completa y que, además, sea congruente, para validarla y procesarla en el Sistema. Si dicha información no cumple con la el objetivo de este punto, se solicita al industrial o al responsable de la información que la complemente con los anexos necesarios y/o la aclare.

III. CALCULO DE EMISIONES

A partir de la información presentada sobre procesos, consumos de materias primas, consumos de combustibles y productos, se hace un cálculo teórico de las emisiones generadas en la fuente puntual (industria) por medio de factores de emisión, que son consultados del AP 42 Compliation of Air Pollutant Emission Factors, publicado por la Agencia de Protección Ambiental (EPA, por sus siglas en inglés) de EU, con los cuales se pueden obtener estimaciones de emisiones contaminantes por tipo de proceso.

Algunas veces, la información de la encuesta industrial en cuanto a emisiones a la atmósfera se apoya en estudios de monitoreo puntual, los cuales arrojan tasas de emisiones contaminantes. Estos valores se pueden comparar, en un primer paso, con los valores obtenidos por medio de factores de emisiones; y en un segundo paso, los valores medidos y estimados teóricos se pueden comparar con un balance de materiales para emisiones. Estas comparaciones tienen el objetivo de determinar los valores representativos de emisiones generadas en la fuente, los cuales se codificarán y formarán parte de la Base de Datos que integra el SNIFF

IV. CODIFICACION

Una vez que toda la información ha sido verificada y validada, y las tasas de emisiones contaminantes han sido determinadas, se procede a la codificación en un formato de codificación diseñado para facilitar el proceso de captura, para integrar la base de datos (DATGEN), que es creada por el SNIFF

Para realizar esta codificación se cuenta con una serie de catálogos (17 en total) en donde se tienen claves de materias primas, contaminantes, equipos de proceso, equipos de control, contaminantes, combustibles, procesos, etc.

V. CAPTURA

Como paso final la información del formato de codificación se captura en el SNIFF, que es un programa integrado en su menú principal por cinco opciones: ALTAS, BAJAS, CAMBIOS, CONSULTAS y SALIR. La creación de una base de datos estructurada en DBASE denominada DATGEN es simultánea a la captura de datos en este programa.

APENDICE IV-B

DATOS MISCELANEOS Y FACTORES DE CONVERSION

ALGUNOS PESOS Y MEDIDAS DE UTILIDAD

Unidad de Medición	Equivalente	
grano	0.002	onzas
gramo	0.04	onzas
onza	28.35	gramos
kilogramo	2.21	libras
libra	0.45	kilogramos
libra (troy)	12	onzas
tonelada (corta)	2000	libras
tonelada (larga)	2240	libras
tonelada (métrica)	2200	libras
tonelada (embarque)	40	pies^3
centímetro	0.39	pulgadas
pulgada	2.54	centímetros
pie	30.48	centímetros
metro	1.09	yardas
yarda	0.91	metros
milla	1.61	kilómetros
centímetro^2	0.16	pulgadas^2
pulgada^2	6.45	centímetros^2
pie^2	0.09	metros^2
metro^2	1.2	yardas^2
yarda^2	0.84	metros^2
milla^2	2.59	kilómetros^2
centímetro^3	0.061	pulgadas^3
pulgada^3	16.39	centímetros^3
pie^3	283.17	centímetros^3
pie^3	1728	pulgadas^3
metro^3	1.31	yardas^3
yarda^3	0.77	metros^3
cuerda	128	pies^3
cuerda	4	metros^3
peck	8	cuartos

ALGUNOS PESOS Y MEDIDAS DE UTILIDAD
(Continuación)

Unidad de Medición	Equivalente	
bushel (seco)	4	pecks
bushel	2150.4	pulgadas^3
galón (EU)	231	pulgadas^3
barril	31.5	galones
hogshead	2	barriles
township	36	millas^2
hectárea	2.5	acres

DATOS MISCELANEOS

- Un pie cúbico de carbón de antracita pesa alrededor de 53 libras.
- Un pie cúbico de carbón de bituminoso pesa alrededor de 47 a 50 libras.
- Una tonelada de carbón es equivalente a dos cuerdas de madera para propósitos de vapor.
- Un galón de agua (Estándar EU) pesa 8.33 libras y contiene 231 pulgadas cúbicas.
- Existen 9 pies cuadrados de superficie calorífica por cada pie cuadrado de superficie de malla.
- Un pie cúbico de agua contiene 7.5 galones y 1728 pulgadas cúbicas, y pesa 62.5 lbs.
- Cada caballo de fuerza nominal de una caldera requiere de 30 a 35 libras de agua por hora.
- Un caballo de fuerza es equivalente a levantar 33,000 libras pie por minuto, ó 550 libras pie por segundo.
- Para encontrar la presión el libras por pulgada cuadrada de una columna de agua, multiplicar la altura de la columna en pies por 0.434.

PARAMETROS TIPICOS DE DIVERSOS COMBUSTIBLES[a]

Tipo de Combustible	Valor Calorífico		Azufre % (por peso)	Ceniza % (por peso)
	kcal	Btu		
Combustibles Sólidos				
Carbón Bituminoso	7,200/kg	13,000/lb	0.6-5.4	4-20
Carbón de Antracita	6,810/kg	12,300/lb	0.5-1.0	7.0-16.0
Lignita (@ 35% humedad)	3,990/kg	7,200/lb	0.7	6.2
Madera (@ 40% humedad)	2,880/kg	5,200/lb	N	1-3
Bagazo (@ 50% humedad)	2,220/kg	4,000/lb	N	1-2
Corteza (@ 50% humedad)	2,492/kg	4,500/lb	N	1-3[b]
Coque, Derivados	7,380/kg	13,300/lb	0.5-1.0	0.5-5.0
Combustibles Líquidos				
Aceite Residual	9.98 x 10^6/m^3	150,000/gal	0.5-4.0	0.05-0.1
Aceite Destilado	9.30 x 10^6/m^3	140,000/gal	0.2-1.0	D
Diesel	9.12 x 10^6/m^3	137,000/gal	0.4	D
Gasolina	8.62 x 10^6/m^3	130,000/gal	0.03-0.04	D
Queroseno	8.32 x 10^6/m^3	135,000/gal	0.02-0.05	D
Gas Licuado	6.25 x 10^6/m^3	94,000/gal	D	D
Combustibles Gaseosos				
Gas Natural	9,341/m^3	1,050/SCF	D	D
Gas de Hornos de Coque	5,249/m^3	590/SCF	0.5-2.0	D
Gas de Horno de Chorro de Aire	890/ m^3	100/SCF	D	D

[a] D = Despreciable.
[b] El contenido de ceniza puede ser considerablemente más elevado cuando existe arena o suciedad.

EQUIVALENTES TERMICOS PARA DIVERSOS COMBUSTIBLES

Tipo de Combustible	kcal	Btu (grueso)
Combustibles Sólidos		
Carbón Bituminoso	(5.8 a 7.8) x 10^6/mg	(21.0 a 28.0) x 10^6/ton
Carbón de Antracita	7.03 x 10^6/mg	25.3 x 10^6/ton
Lignita	4.45 x 10^6/mg	16.0 x 10^6/ton
Madera	1.47 x 10^6/metro cúbico	21.0 x 10^6/cuerda
Combustibles Líquidos		
Aceite Residual Destilado	10 x 10^3/litro	6.3 x 10^6/bbl
Combustóleo Destilado	9.35 x 10^3/litro	5.9 x 10^6/bbl
Combustibles Gaseosos		
Gas Natural	9,350/metro cúbico	1,050/ft^3
Gas LP		
Butano	6,480/litro	97,400/gal
Propano	6,030/litro	90,500/gal

PESO DE SUSTANCIAS SELECCIONADAS

Tipo de Sustancia	g/litro	lb/gal
Asfalto	1030	8.57
Butano, líquido a 60°F	579	4.84
Petróleo crudo	850	7.08
Petróleo destilado	845	7.05
Gasolina	739	6.17
Propano, líquido a 60°F	507	4.24
Aceite residual	944	7.88
Agua	1000	8.4

DENSIDADES DE SUSTANCIAS SELECCIONADAS

Sustancia	Densidad	
Combustibles		
Petróleo Crudo	874 kg/metro cúbico	7.3 lb/gal
Aceite Residual	944 kg/metro cúbico	7.88 lb/gal
Petróleo Destilado	845 kg/metro cúbico	7.05 lb/gal
Gasolina	739 kg/metro cúbico	6.17 lb/gal
Gas Natural	673 kg/metro cúbico	1 lb/23.8 ft^3
Butano	579 kg/metro cúbico	4.84 lb/gal (líquido)
Propano	507 kg/metro cúbico	4.24 lb/gal (líquido)
Madera (Secada con Aire)		
Olmo	561 kg/metro cúbico	35 lb/ft^3
Abeto, Douglas	513 kg/metro cúbico	32 lb/ft^3
Abeto, Balsam	400 kg/metro cúbico	25 lb/ft^3
Tsuga	465 kg/metro cúbico	29 lb/ft^3
Nogal	769 kg/metro cúbico	48 lb/ft^3
Maple, Azucarero	689 kg/metro cúbico	43 lb/ft^3
Maple, Blanco	529 kg/metro cúbico	33 lb/ft^3
Encino, Rojo	673 kg/metro cúbico	42 lb/ft^3
Encino, Blanco	769 kg/metro cúbico	48 lb/ft^3
Pino	641 kg/metro cúbico	40 lb/ft^3
Productos Agrícolas		
Maíz	25.4 kg/bu	56 lb/bu
Sorgo	25.4 kg/bu	56 lb/bu
Avenas	14.5 kg/bu	32 lb/bu
Cebada	21.8 kg/bu	48 lb/bu
Trigo	27.2 kg/bu	60 lb/bu
Algodón	226 kg/paca	500 lb/paca
Productos Minerales		
Ladrillo	2.95 kg/ladrillo	6.5 lb/ladrillo
Cemento	170 kg/bbl	375 lb/bbl
Cemento	1483 kg/metro cúbico	2500 lb/yd^3
Concreto	2373 kg/metro cúbico	4000 lb/yd^3

DENSIDADES DE SUSTANCIAS SELECCIONADAS
(Continuación)

Sustancia	Densidad	
Vidrio, Común	2595 kg/metro cúbico	162 lb/ft^3
Grava, Empacada en Seco	1600 - 1920 kg/metro cúbico	100 - 120 lb/ft^3
Grava, Húmeda	2020 kg/metro cúbico	126 lb/ft^3
Yeso, Calcinado	880 - 960 kg/metro cúbico	55 - 60 lb/ft^3
Caliza, Cantos Rodados	850 - 1025 kg/metro cúbico	53 - 64 lb/ft^3
Arena, Grava (seca, suelta)	1440 - 1680 kg/metro cúbico	90 - 105 lb/ft^3

FACTORES DE CONVERSION

La tabla que se presenta en las siguientes páginas contienen los factores para convertir de unidades inglesas a unidades métricas, de unides métricas a unidades inglesas, así como los factores para manipular las unidades dentro del mismo sistema. Estos factores están organizados alfabéticamente por unidad dentro de los siguientes grupos:

- Area
- Densidad
- Energía
- Fuerza
- Longitud
- Masa
- Presión
- Velocidad
- Volumen
- Tasa Volumétrica

Para convertir un número de una unidad a otra:

1. Localizar la unidad en la que el número está siendo expresado en la columna izquierda de la tabla

2. Encontrar la unidad deseada en el centro de la columna

3. Multiplicar el número por el factor de conversión correspondiente en la columna de la derecha.

FACTORES DE CONVERSION[a]

Para Convertir de…	A…	Multiplicar Por…
Area		
Acres	Pies cuadrados	4.356×10^{4}
Acres	Kilómetros cuadrados	4.0469×10^{-3}
Acres	Metros cuadrados	4.0469×10^{3}
Acres	Millas cuadradas (estatuto)	1.5625×10^{-3}
Acres	Yardas cuadradas	4.84×10^{3}
Pies cuadrados	Acres	2.2957×10^{-5}
Pies cuadrados	Centímetros cuadrados	929.03
Pies cuadrados	Pulgadas cuadradas	144.0
Pies cuadrados	Metros cuadrados	0.092903
Pies cuadrados	Millas cuadradas	3.587×10^{-8}
Pies cuadrados	Yardas cuadradas	0.111111
Pulgadas cuadradas	Pies cuadrados	6.9444×10^{-3}
Pulgadas cuadradas	Metros cuadrados	6.4516×10^{-4}
Pulgadas cuadradas	Milímetros cuadrados	645.16
Kilómetros cuadrados	Acres	247.1
Kilómetros cuadrados	Pies cuadrados	1.0764×10^{7}
Kilómetros cuadrados	Metros cuadrados	1.0×10^{6}
Kilómetros cuadrados	Millas cuadradas	0.386102
Kilómetros cuadrados	Yardas cuadradas	1.196×10^{6}
Metros cuadrados	Centímetros cuadrados	1.0×10^{4}
Metros cuadrados	Pies cuadrados	10.764
Metros cuadrados	Pulgadas cuadradas	1.55×10^{3}
Metros cuadrados	Kilómetros cuadrados	1.0×10^{-6}
Metros cuadrados	Millas cuadradas	3.861×10^{-7}
Metros cuadrados	Milímetros cuadrados	1.0×10^{6}
Metros cuadrados	Yardas cuadradas	1.196
Millas cuadradas	Acres	640.0
Millas cuadradas	Pies cuadrados	2.7878×10^{7}
Millas cuadradas	Kilómetros cuadrados	2.590
Millas cuadradas	Metros cuadrados	2.59×10^{6}
Millas cuadradas	Yardas cuadradas	3.0976×10^{6}

Para Convertir de…	A…	Multiplicar Por…
Yardas cuadradas	Acres	2.0661×10^{-4}
Yardas cuadradas	Centímetros cuadrados	8.3613×10^{3}
Yardas cuadradas	Pies cuadrados	9.0
Yardas cuadradas	Pulgadas cuadradas	1.296×10^{3}
Yardas cuadradas	Metros cuadrados	0.83613
Yardas cuadradas	Millas cuadradas	3.2283×10^{-7}
Densidad		
dinas/centímetro cúbico	Gramos/centímetros cúbicos	1.0197×10^{-3}
Granos/pie cúbico	Gramos/metro cúbico	2.28835
Gramos/centímetro cúbico	Dinas/centímetros cúbicos	980.665
Gramos/centímetro cúbico	Granos/mililitro	15.433
Gramos/centímetro cúbico	Gramos/mililitro	1.0
Gramos/centímetro cúbico	Libras/pulgada cúbica	1.162
Gramos/centímetro cúbico	Libras/pie cúbico	62.428
Gramos/centímetro cúbico	Libras/pulgada cúbica	0.036127
Gramos/centímetro cúbico	Libras/gal (Brit.)	10.022
Gramos/centímetro cúbico	Libras/gal (seca, EU)	9.7111
Gramos/centímetro cúbico	Libras/gal (líquida, EU)	8.3454
Gramos/metro cúbico	Granos/pie cúbico	0.4370
Gramos/litro	Libras/gal (EU)	8.345×10^{-3}
Kilogramos/metro cúbico	Gramos/centímetros cúbicos	0.001
Kilogramos/metro cúbico	Libras/pies cúbicos	0.0624
Kilogramos/metro cúbico	Libras/pulgadas cúbicas	3.613×10^{-5}
Libras/pie cúbico	Gramos/centímetros cúbicos	0.016018
Libras/pie cúbico	kg/metro cúbico	16.018
Libras/pulgada cúbica	Gramos/centímetros cúbicos	27.68
Libras/pulgada cúbica	Gramos/litro	27.681
Libras/pulgada cúbica	kg/metro cúbico	2.768×10^{4}
Libras/gal (líquido, EU)	Gramos/centímetro cúbico	0.1198
Libras/gal (líquido, EU)	Libras/pies cúbicos	7.4805
Energía		
Btu	Cal. gm (IST.)	251.83
Btu	Ergios	1.05435×10^{10}

Para Convertir de…	**A…**	**Multiplicar Por…**
Btu	Pie-libras	777.65
Btu	Hp-horas	3.9275×10^{-4}
Btu	Joules (Int.)	1054.2
Btu	kg-metros	107.51
Btu	Kw-horas (Int.)	2.9283×10^{-4}
Btu/hr	Cal. kg/hr	0.252
Btu/hr	Ergios/seg	2.929×10^{6}
Btu/hr	Pie-libras/hr	777.65
Btu/hr	Caballo de fuerza (mecánico)	3.9275×10^{-4}
Btu/hr	Caballo de fuerza (caldera)	2.9856×10^{-5}
Btu/hr	Caballo de fuerza (eléctrico)	3.926×10^{-4}
Btu/hr	Caballo de fuerza (métrico)	3.982×10^{-4}
Btu/hr	Kilowatts	2.929×10^{-4}
Btu/lb	Pie-libras/lb	777.65
Btu/lb	Hp-hr/lb	3.9275×10^{-4}
Btu/lb	Joules/gramo	2.3244
Calorías, kg (media)	Btu (IST.)	3.9714
Calorías, kg (media)	Ergios	4.190×10^{10}
Calorías, kg (media)	Pie-libras	3.0904×10^{3}
Calorías, kg (media)	Hp-horas	1.561×10^{-3}
Calorías, kg (media)	Joules	4.190×10^{3}
Calorías, kg (media)	kg-metros	427.26
Calorías, kg (media)	kW-horas (Int.)	1.1637×10^{-3}
Ergios	Btu	9.4845×10^{-11}
Ergios	Pie-poundales	2.373×10^{-6}
Ergios	Pie-libras	7.3756×10^{-8}
Ergios	Joules (Int.)	9.99835×10^{-8}
Ergios	kW-horas	2.7778×10^{-14}
Ergios	kg-metros	1.0197×10^{-8}
Pie-libras	Btu (IST.)	1.2851×10^{-3}
Pie-libras	Cal. kg (IST.)	3.2384×10^{-4}
Pie-libras	Ergios	1.3558×10^{7}
Pie-libras	Pie-poundales	32.174

Para Convertir de…	A…	Multiplicar Por…
Pie-libras	Hp-horas	5.0505×10^{-7}
Pie-libras	Joules	1.3558
Pie-libras	kg-metros	0.138255
Pie-libras	kW-horas (Int.)	3.76554×10^{-7}
Pie-libras	Newton-metros	1.3558
Pie-libras/hr	Btu/min	2.1432×10^{-5}
Pie-libras/hr	Ergios/min	2.2597×10^{5}
Pie-libras/hr	Caballo de fuerza (mecánico)	5.0505×10^{-7}
Pie-libras/hr	Caballo de fuerza (métrico)	5.121×10^{-7}
Pie-libras/hr	Kilowatts	3.766×10^{-7}
Caballo de fuerza (mecánico)	Btu (media)/hr	2.5425×10^{3}
Caballo de fuerza (mecánico)	Ergios/seg	7.457×10^{9}
Caballo de fuerza (mecánico)	Pie-libras/hr	1.980×10^{6}
Caballo de fuerza (mecánico)	Caballo de fuerza (caldera)	0.07602
Caballo de fuerza (mecánico)	Caballo de fuerza (eléctrico)	0.9996
Caballo de fuerza (mecánico)	Caballo de fuerza (métrico)	1.0139
Caballo de fuerza (mecánico)	Joules/seg	745.70
Caballo de fuerza (mecánico)	Kilowatts (Int.)	0.74558
Caballo de fuerza (caldera)	Btu (media)/hr	3.3446×10^{4}
Caballo de fuerza (caldera)	Ergios/seg	9.8095×10^{10}
Caballo de fuerza (caldera)	Pie-libras/min	4.341×10^{5}
Caballo de fuerza (caldera)	Caballo de fuerza (mecánico)	13.155
Caballo de fuerza (caldera)	Caballo de fuerza (eléctrico)	13.15
Caballo de fuerza (caldera)	Caballo de fuerza (métrico)	13.337
Caballo de fuerza (caldera)	Joules/seg	9.8095×10^{3}
Caballo de fuerza (caldera)	Kilowatts	9.8095
Caballo de fuerza (eléctrico)	Btu (media)/hr	2.5435×10^{3}
Caballo de fuerza (eléctrico)	Cal. kg/hr	641.87
Caballo de fuerza (eléctrico)	Ergios/seg	7.46×10^{9}
Caballo de fuerza (eléctrico)	Pie-libras/min	3.3013×10^{4}
Caballo de fuerza (eléctrico)	Caballo de fuerza (caldera)	0.07605
Caballo de fuerza (eléctrico)	Caballo de fuerza (métrico)	1.0143
Caballo de fuerza (eléctrico)	Joules/seg	746.0

Para Convertir de…	A…	Multiplicar Por…
Caballo de fuerza (eléctrico)	Kilowatts	0.746
Caballo de fuerza (métrico)	Btu (media)/hr	2.5077×10^{3}
Caballo de fuerza (métrico)	Ergios/seg	7.355×10^{9}
Caballo de fuerza (métrico)	Pie-libras/min	3.255×10^{4}
Caballo de fuerza (métrico)	Caballo de fuerza (mecánico)	0.98632
Caballo de fuerza (métrico)	Caballo de fuerza (caldera)	0.07498
Caballo de fuerza (métrico)	Caballo de fuerza (eléctrico)	0.9859
Caballo de fuerza (métrico)	kg-metros/seg	75.0
Caballo de fuerza (métrico)	Kilowatts	0.7355
Caballo de fuerza-horas	Btu (media)	2.5425×10^{3}
Caballo de fuerza-horas	Pie-libras	1.98×10^{6}
Caballo de fuerza-horas	Joules	2.6845×10^{6}
Caballo de fuerza-horas	kg-metros	2.73745×10^{5}
Caballo de fuerza-horas	kW-horas	0.7457
Joules (Int.)	Btu (IST.)	9.4799×10^{-4}
Joules (Int.)	Ergios	1.0002×10^{7}
Joules (Int.)	Pie-poundales	12.734
Joules (Int.)	Pie-libras	0.73768
Joules (Int.)	kW-horas	2.778×10^{-7}
Joules (Int.)/seg	Btu (media)/min	0.05683
Joules (Int.)/seg	Cal. kg/min	0.01434
Joules (Int.)/seg	Caballo de fuerza	1.341×10^{-3}
Kilogramo-metros	Btu (media)	9.2878×10^{-3}
Kilogramo-metros	Cal. kg (media)	2.3405×10^{-3}
Kilogramo-metros	Ergios	9.80665×10^{7}
Kilogramo-metros	Pie-poundales	232.715
Kilogramo-metros	Pie-libras	7.233
Kilogramo-metros	Hp-horas	3.653×10^{-6}
Kilogramo-metros	Joules (Int.)	9.805
Kilogramo-metros	kW-horas	2.724×10^{-6}
Kilogramo-metros/seg	Watts	9.80665
Kilowatts (Int.)	Btu (IST.)/hr	3.413×10^{3}
Kilowatts (Int.)	Cal. kg (IST.)/hr	860.0

Para Convertir de…	**A…**	**Multiplicar Por…**
Kilowatts (Int.)	Ergios/seg	1.0002×10^{10}
Kilowatts (Int.)	Pie-poundales/min	1.424×10^{6}
Kilowatts (Int.)	Pie-libras/min	4.4261×10^{4}
Kilowatts (Int.)	Caballo de fuerza (mecánico)	1.341
Kilowatts (Int.)	Caballo de fuerza (caldera)	0.10196
Kilowatts (Int.)	Caballo de fuerza (eléctrico)	1.3407
Kilowatts (Int.)	Caballo de fuerza (métrico)	1.3599
Kilowatts (Int.)	Joules (Int.)/hr	3.6×10^{6}
Kilowatts (Int.)	kg-metros/hr	3.6716×10^{5}
Kilowatt-horas (Int.)	Btu (media)	3.41×10^{3}
Kilowatt-horas (Int.)	Pie-libras	2.6557×10^{6}
Kilowatt-horas (Int.)	Hp-horas	1.341
Kilowatt-horas (Int.)	Joules (Int.)	3.6×10^{6}
Kilowatt-horas (Int.)	kg-metros	3.6716×10^{5}
Newton-metros	Gramo-cm	1.01972×10^{4}
Newton-metros	kg-metros	0.101972
Newton-metros	Libra-pies	0.73756
Fuerza		
Dinas	Toneladas Nuevas	1.0×10^{-5}
Dinas	Poundales	7.233×10^{-5}
Dinas	Libras	2.248×10^{-6}
Toneladas Nuevas	Dinas	1.0×10^{-5}
Toneladas Nuevas	Libras (avdp.)	0.22481
Poundales	Dinas	1.383×10^{4}
Poundales	Toneladas Nuevas	0.1383
Poundales	Libras (avdp.)	0.03108
Libras (avdp.)	Dinas	4.448×10^{5}
Libras (avdp.)	Toneladas Nuevas	4.448
Libras (avdp.)	Poundales	32.174
Longitud		
Pies	Centímetros	30.48
Pies	Pulgadas	12
Pies	Kilómetros	3.048×10^{-4}

Para Convertir de…	A…	Multiplicar Por…
Pies	Metros	0.3048
Pies	Millas (estatuto)	1.894×10^{-4}
Pulgadas	Centímetros	2.540
Pulgadas	Pies	0.08333
Pulgadas	Kilómetros	2.54×10^{-5}
Pulgadas	Metros	0.0254
Kilómetros	Pies	3.2808×10^{3}
Kilómetros	Metros	1000
Kilómetros	Millas (estatuto)	0.62137
Kilómetros	Yardas	1.0936×10^{3}
Metros	Pies	3.2808
Metros	Pulgadas	39.370
Micrómetros	Unidades Angstrom	1.0×10^{4}
Micrómetros	Centímetros	1.0×10^{-3}
Micrómetros	Pies	3.2808×10^{-6}
Micrómetros	Pulgadas	3.9370×10^{-5}
Micrómetros	Metros	1.0×10^{-6}
Micrómetros	Milímetros	0.001
Micrómetros	Nanómetros	1000
Millas (estatus)	Pies	5280
Millas (estatus)	Kilómetros	1.6093
Millas (estatus)	Metros	1.6093×10^{3}
Millas (estatus)	Yardas	1760
Milímetros	Unidades Angstrom	1.0×10^{7}
Milímetros	Centímetros	0.1
Milímetros	Pulgadas	0.03937
Milímetros	Metros	0.001
Milímetros	Micrómetros	1000
Nanómetros	Unidades Angstrom	10
Nanómetros	Centímetros	1.0×10^{-7}
Nanómetros	Pulgadas	3.937×10^{-8}
Nanómetros	Micrómetros	0.001
Nanómetros	Milímetros	1.0×10^{-6}

Para Convertir de…	A…	Multiplicar Por…
Yardas	Centímetros	91.44
Yardas	Metros	0.9144
Masa		
Granos	Gramos	0.064799
Granos	Miligramos	64.799
Granos	Libras (apot. ó troy)	1.7361×10^{-4}
Granos	Libras (avdp.)	1.4286×10^{-4}
Granos	Toneladas (métricas)	6.4799×10^{-8}
Gramos	Dinas	980.67
Gramos	Granos	15.432
Gramos	Kilogramos	0.001
Gramos	Microgramos	1×10^{6}
Gramos	Libras (avdp.)	2.205×10^{-3}
Gramos	Tonelads, métrico (megagramos)	1×10^{-6}
Kilogramos	Granos	1.5432×10^{4}
Kilogramos	Poundales	70.932
Kilogramos	Libras (apot. o troy)	2.679
Kilogramos	Libras (avdp.)	2.2046
Kilogramos	Toneladas (largo)	9.842×10^{-4}
Kilogramos	Toneladas (métrico)	0.001
Kilogramos	Toneladas (corta)	1.1023×10^{-3}
Megagramos	Toneladas (métricas)	1.0
Miligramos	Granos	0.01543
Miligramos	Gramos	1.0×10^{-3}
Miligramos	Onzas (apot. o troy)	3.215×10^{-5}
Miligramos	Onzas (avdp.)	3.527×10^{-5}
Miligramos	Libras (apot. o troy)	2.679×10^{-6}
Miligramos	Libras (avdp.)	2.2046×10^{-6}
Onzas (apot. o troy)	Granos	480
Onzas (apot. o troy)	Gramos	31.103
Onzas (apot. o troy)	Onzas (avdp.)	1.097
Onzas (avdp.)	Granos	437.5
Onzas (avdp.)	Gramos	28.350

Para Convertir de…	A…	Multiplicar Por…
Onzas (avdp.)	Onzas (apot. o troy)	0.9115
Onzas (avdp.)	Libras (apot. o troy)	0.075955
Onzas (avdp.)	Libras (avdp.)	0.0625
Libras (avdp.)	Poundales	32.174
Libras (avdp.)	Libras (apot. o troy)	1.2153
Libras (avdp.)	Toneladas (larga)	4.4643×10^{-4}
Libras (avdp.)	Toneladas (métrica)	4.5359×10^{-4}
Libras (avdp.)	Toneladas (corta)	5.0×10^{-4}
Libras (avdp.)	Granos	7000
Libras (avdp.)	Gramos	453.59
Libras (avdp.)	Onzas (apot. o troy)	14.583
Libras (avdp.)	Onzas (avdp.)	16
Tonelada (larga)	Kilogramos	1.016×10^{3}
Tonelada (larga)	Libras (apot. o troy)	2.722×10^{3}
Tonelada (larga)	Libras (avdp.)	2.240×10^{3}
Tonelada (larga)	Toneladas (métrica)	1.016
Tonelada (larga)	Toneladas (corta)	1.12
Tonelada (métrica)	Gramos	1.0×10^{6}
Tonelada (métrica)	Megagramos	1.0
Tonelada (métrica)	Libras (apot. o troy)	2.6792×10^{3}
Tonelada (métrica)	Libras (avdp.)	2.2046×10^{3}
Tonelada (métrica)	Toneladas (larga)	0.9842
Tonelada (métrica)	Toneladas (corta)	1.1023
Tonelada (corta)	Kilogramos	907.18
Toneladas (corta)	Libras (apot. o troy)	2.4301×10^{3}
Toneladas (corta)	Libras (avdp.)	2000
Toneladas (corta)	Tonelada (larga)	0.8929
Toneladas (corta)	Tonelada (métrica)	0.9072
Presión		
Atmósferas	cm de H_2O (4°C)	1.033×10^{3}
Atmósferas	Ft de H_2O (39.2°F)	33.8995
Atmósferas	In. de Hg (32°F)	29.9213
Atmósferas	kg/centímetros cuadrados	1.033

Para Convertir de…	A…	Multiplicar Por…
Atmósferas	mm de Hg (0°C)	760
Atmósferas	Libras/ pulgada cuadrada	14.696
Pulgadas de Hg (60°F)	Atmósferas	0.03333
Pulgadas de Hg (60°F)	Gramos/centímetros cuadrados	34.434
Pulgadas de Hg (60°F)	mm de Hg (60°F)	25.4
Pulgadas de Hg (60°F)	Libras/pies cuadrados	70.527
Pulgadas of H_2O (4°C)	Atmósferas	2.458×10^{-3}
Pulgadas of H_2O (4°C)	In. de Hg (32°F)	0.07355
Pulgadas of H_2O (4°C)	kg/metro cuadrado	25.399
Pulgadas of H_2O (4°C)	Libras/pies cuadrados	5.2022
Pulgadas of H_2O (4°C)	Libras/pulgada cuadrada	0.036126
Kilogramos/centímetros cuadrados	Atmósferas	0.96784
Kilogramos/centímetros cuadrados	cm de Hg (0°C)	73.556
Kilogramos/centímetros cuadrados	Ft of H_2O (39.2°F)	32.809
Kilogramos/centímetros cuadrados	In. de Hg (32°F)	28.959
Kilogramos/centímetros cuadrados	Libras/pulgada cuadrada	14.223
Milímetros de Hg (0°C)	Atmósferas	1.3158×10^{-3}
Milímetros de Hg (0°C)	Gramos/centímetros cuadrados	1.3595
Milímetros de Hg (0°C)	Libras/pulgada cuadrada	0.019337
Libras/pulgada cuadrada	Atmósferas	0.06805
Libras/pulgada cuadrada	cm de Hg (0°C)	5.1715
Libras/pulgada cuadrada	cm de H_2O (4°C)	70.309
Libras/pulgada cuadrada	In. de Hg (32°F)	2.036
Libras/pulgada cuadrada	In. de H_2O (39.2°F)	27.681
Libras/pulgada cuadrada	kg/centímetros cuadrados	0.07031
Libras/pulgada cuadrada	mm de Hg (0°C)	51.715
Velocidad		
Centímetros/seg	Pies/min	1.9685
Centímetros/seg	Pies/seg	0.0328
Centímetros/seg	Kilómetros/hr	0.036

Para Convertir de…	A…	Multiplicar Por…
Centímetros/seg	Metros/min	0.6
Centímetros/seg	Millas/hr	0.02237
Pies/minuto	cm/seg	0.508
Pies/minuto	Kilómetros/hr	0.01829
Pies/minuto	Metros/min	0.3048
Pies/minuto	Metros/seg	5.08×10^{-3}
Pies/minuto	Millas/hr	0.01136
Pies/seg	cm/seg	30.48
Pies/seg	Kilómetros/hr	1.0973
Pies/seg	Metros/min	18.288
Pies/seg	Millas/hr	0.6818
Kilómetros/hr	cm/seg	27.778
Kilómetros/hr	Pies/hr	3.2808×10^{3}
Kilómetros/hr	Pies/min	54.681
Kilómetros/hr	Metros/seg	0.27778
Kilómetros/hr	Millas (estatus)/hr	0.62137
Metros/min	cm/seg	1.6667
Metros/min	Pies/min	3.2808
Metros/min	Pies/seg	0.05468
Metros/min	Kilómetros/hr	0.06
Millas/hr	cm/seg	44.704
Millas/hr	Pies/hr	5280
Millas/hr	Pies/min	88
Millas/hr	Pies/seg	1.4667
Millas/hr	Kilómetros/hr	1.6093
Millas/hr	Metros/min	26.822
Volumen		
Barriles (Petróleo, EU)	Pies cúbicos	5.6146
Barriles (Petróleo, EU)	Galones (EU)	42
Barriles (Petróleo, EU)	Litros	158.98
Barriles (líquido, EU)	Pies cúbicos	4.2109
Barriles (líquido, EU)	Pulgadas cúbicas	7.2765×10^{3}
Barriles (líquido, EU)	Metros cúbicos	0.1192

Para Convertir de…	A…	Multiplicar Por…
Barriles (líquido, EU)	Galones (líquido, EU)	31.5
Barriles (líquido, EU)	Litros	119.24
Centímetros cúbicos	Pies cúbicos	3.5315×10^{-5}
Centímetros cúbicos	Pulgadas cúbicas	0.06102
Centímetros cúbicos	Metros cúbicos	1.0×10^{-6}
Centímetros cúbicos	Yardas cúbicas	1.308×10^{-6}
Centímetros cúbicos	Galones (líquido, EU)	2.642×10^{-4}
Centímetros cúbicos	Cuartos (líquido, EU)	1.0567×10^{-3}
Pies cúbicos	Centímetros cúbicos	2.8317×10^{4}
Pies cúbicos	Metros cúbicos	0.028317
Pies cúbicos	Galones (líquido, EU)	7.4805
Pies cúbicos	Litros	28.317
Pulgadas cúbicas	Centímetros cúbicos	16.387
Pulgadas cúbicas	Pies cúbicos	5.787×10^{-4}
Pulgadas cúbicas	Metros cúbicos	1.6387×10^{-5}
Pulgadas cúbicas	Yardas cúbicas	2.1433×10^{-5}
Pulgadas cúbicas	Galones (líquido, EU)	4.329×10^{-3}
Pulgadas cúbicas	Litros	0.01639
Pulgadas cúbicas	Cuartos (líquido, EU)	0.01732
Metros cúbicos	Barriles (líquido, EU)	8.3864
Metros cúbicos	Centímetros cúbicos	1.0×10^{6}
Metros cúbicos	Pies cúbicos	35.315
Metros cúbicos	Pulgadas cúbicas	6.1024×10^{4}
Metros cúbicos	Yardas cúbicas	1.308
Metros cúbicos	Galones (líquido, EU)	264.17
Metros cúbicos	Litros	1000
Yardas cúbicas	Bushels (Brit.)	21.022
Yardas cúbicas	Bushels (EU)	21.696
Yardas cúbicas	Centímetros cúbicos	7.6455×10^{5}
Yardas cúbicas	Pies cúbicos	27
Yardas cúbicas	Pulgadas cúbicas	4.6656×10^{4}
Yardas cúbicas	Metros cúbicos	0.76455
Yardas cúbicas	Galones	168.18

Para Convertir de…	A…	Multiplicar Por…
Yardas cúbicas	Galones	173.57
Yardas cúbicas	Galones	201.97
Yardas cúbicas	Litros	764.55
Yardas cúbicas	Cuartos	672.71
Yardas cúbicas	Cuartos	694.28
Yardas cúbicas	Cuartos	807.90
Galones (líquido, EU)	Barriles (líquido, EU)	0.03175
Galones (líquido, EU)	Barriles (Petróleo, EU)	0.02381
Galones (líquido, EU)	Bushels (EU)	0.10742
Galones (líquido, EU)	Centímetros cúbicos	3.7854×10^{3}
Galones (líquido, EU)	Pies cúbicos	0.13368
Galones (líquido, EU)	Pulgadas cúbicas	231
Galones (líquido, EU)	Metros cúbicos	3.7854×10^{-3}
Galones (líquido, EU)	Yardas cúbicas	4.951×10^{-3}
Galones (líquido, EU)	Galones (vino)	1.0
Galones (líquido, EU)	Litros	3.7854
Galones (líquido, EU)	Onzas (fluido, EU)	128.0
Galones (líquido, EU)	Pints (líquido, EU)	8.0
Galones (líquido, EU)	Cuartos (líquido, EU)	4.0
Litros	Centímetros cúbicos	1000
Litros	Pies cúbicos	0.035315
Litros	Pulgadas cúbicas	61.024
Litros	Metros cúbicos	0.001
Litros	Galones (líquido, EU)	0.2642
Litros	Onzas (fluido, EU)	33.814
Tasa Volumétrica		
Pies cúbicos/min	Centímetros cúbicos/seg	471.95
Pies cúbicos/min	Pies cúbicos/hr	60. 0
Pies cúbicos/min	Gal (EU)/min	7.4805
Pies cúbicos/min	Litros/seg	0.47193
Metros cúbicos/min	Gal (EU)/min	264.17
Metros cúbicos/min	Litros/min	999.97
Galones (EU)/hr	Pies cúbicos/hr	0.13368

Para Convertir de…	A…	Multiplicar Por…
Galones (EU)/hr	Metros cúbicos/min	6.309×10^{-5}
Galones (EU)/hr	Yardas cúbicas/min	8.2519×10^{-5}
Galones (EU)/hr	Litros/hr	3.7854
Litros/min	Pies cúbicos/min	0.0353
Litros/min	Gal (líquido, EU)/min	0.2642

[a] Donde ha sido pertinente, los factores de conversión que aparecen en esta tabla han sido redondeados de seis a cuatro cifras significativas para facilitar el uso. La precisión de estos números se considera adecuada para ser utilizada con los datos de emisiones. En caso de requerirse una cifra más precisa, deben consultarse las tablas que contienen los factores exactos.

FACTORES DE CONVERSION PARA LAS MEDICIONES COMUNES DE LA CONTAMINACION DEL AIRE

PARTICULAS SUSPENDIDAS

Para Convertir de…	A…	Multiplicar por…
Miligramos/metro cúbico	Gramos/pies cúbicos	283.2×10^{-6}
	Gramos/metros cúbicos	0.001
	Microgramos/metros cúbicos	1000.0
	Microgramos/pies cúbicos	28.32
	Libras/1000 pies cúbicos	62.43×10^{-6}
Gramos/pies cúbicos	Miligramos/metros cúbicos	35.3145×10^{3}
	Gramos/metros cúbicos	35.314
	Microgramos/metros cúbicos	35.314×10^{6}
	Microgramos/pies cúbicos	1.0×10^{6}
	Libras/1000 pies cúbicos	2.2046
Gramos/metros cúbicos	Miligramos/metros cúbicos	1000.0
	Gramos/pies cúbicos	0.02832
	Microgramos/metros cúbicos	1.0×10^{6}
	Microgramos/pies cúbicos	28.317×10^{3}
	Libras/1000 pies cúbicos	0.06243
Microgramos/metros cúbicos	Miligramos/metros cúbicos	0.001
	Gramos/pies cúbicos	28.317×10^{-9}
	Gramos/metros cúbicos	1.0×10^{-6}
	Microgramos/pies cúbicos	0.02832
	Libras/1000 pies cúbicos	62.43×10^{-9}
Microgramos/pies cúbicos	Miligramos/metros cúbicos	35.314×10^{-3}
	Gramos/pies cúbicos	1.0×10^{-6}
	Gramos/metros cúbicos	35.314×10^{-6}
	Microgramos/metros cúbicos	35.314
	Libras/1000 pies cúbicos	2.2046×10^{-6}
Libras/1000 pies cúbicos	Miligramos/metros cúbicos	16.018×10^{3}
	Gramos/pies cúbicos	0.35314
	Microgramos/metros cúbicos	16.018×10^{6}
	Gramos/metros cúbicos	16.018
	Microgramos/pies cúbicos	353.14×10^{3}

FACTORES DE CONVERSION PARA LAS MEDICIONES COMUNES DE LA CONTAMINACION DEL AIRE

MUESTREO DE PRESIÓN

Para Convertir de…	A…	Multiplicar por…
Milímetros de Hg (0°C)	Pulgadas de agua (60°F)	0.5358
Pulgadas de Hg (0°C)	Pulgadas de agua (60°F)	13.609
	Milímetros de Hg (0°C)	1.8663
Pulgadas de agua (60°F)	Pulgadas de Hg (0°C)	73.48×10^{-3}

GASES ATMOSFERICOS

Para Convertir de…	A…	Multiplicar por…
Miligramos/metros cúbicos	Microgramos/metros cúbicos	1000.0
	Microgramos/litro	1.0
	ppm por volumen (20°C)	24.04/m
	ppm por peso	0.8347
	Libras/pies cúbicos	62.43×10^{-9}
Microgramos/metros cúbicos	Miligramos/metros cúbicos	0.001
	Microgramos/litro	0.001
	ppm por volumen (20°C)	0.02404/m
	ppm por peso	834.7×10^{-6}
	Libras/pies cúbicos	62.43×10^{-12}
Microgramos/litro	Miligramos/metros cúbicos	1.0
	Microgramos/metros cúbicos	1000.0
	ppm por volumen (20°C)	24.04/m
	ppm por peso	0.8347
	Libras/pies cúbicos	62.43×10^{-9}
ppm por volumen (20°C)	Miligramos/metros cúbicos	M/24.04
	Microgramos/metros cúbicos	M/0.02404
	Microgramos/litro	M/24.04
	ppm por peso	M/28.8
	Libras/pies cúbicos	$M/385.1 \times 10^{6}$

Para Convertir de…	A…	Multiplicar por…
ppm por peso	Miligramos/metros cúbicos	1.198
	Microgramos/metros cúbicos	1.198 x 10^{-3}
	Microgramos/litro	1.198
	ppm por volumen (20°C)	28.8/m
	Libras/pies cúbicos	7.48 x 10^{-6}
Libras/pies cúbicos	Miligramos/metros cúbicos	16.018 x 10^{6}
	Microgramos/metros cúbicos	16.018x 10^{9}
	Microgramos/litro	16.018x 10^{6}
	ppm por volumen (20°C)	385.1 x 10^{6}/m
	ppm por peso	133.7 x 10^{3}

M = Peso molecular del gas.

VELOCIDAD

Para Convertir de…	A…	Multiplicar por…
Metros/seg	Kilómetros/hr	3.6
	Pies/seg	3.281
	Millas/hr	2.237
Kilómetros/hr	Metros/seg	0.2778
	Pies/seg	0.9113
	Millas/hr	0.6214
Pies/seg	Metros/seg	0.3048
	Kilómetros/hr	1.09728
	Millas/hr	0.6818
Millas/hr	Metros/seg	0.4470
	Kilómetros/hr	1.6093
	Pies/seg	1.4667

PRESION ATMOSFERICA

Para Convertir de…	A…	Multiplicar por…
Atmósferas	Milímetros de Hg	760.0
	Pulgadas de Hg	29.92
	Millibares	1013.2

Para Convertir de…	A…	Multiplicar por…
Milímetros de Hg	Atmósferas	1.316×10^{-3}
	Pulgadas de Hg	39.37×10^{-3}
	Milibares	1.333
Pulgadas de Hg	Atmósferas	0.03333
	Milímetros de Hg	25.4005
	Milibares	33.35
Milibares	Atmósferas	0.00987
	Milímetros de Hg	0.75
	Pulgadas de Hg	0.30

EMISIONES DE VOLUMEN

Para Convertir de…	A…	Multiplicar por…
Metro cúbico/min	Pie cúbico/min	35.314
Pie cúbico/min	Metro cúbico/min	0.0283

FACTORES DE CONVERSION DE CALDERA

1 Megawatt = 10.5×10^6 BTU/hr
(8 a 14×10^6 BTU/hr)

1 Megawatt = 8×10^3 lb vapor/hr
(6 a 11×10^3 lb vapor/hr)

1BHP = 34.5 lb vapor/hr

1 BHP = 45×10^3 BTU/hr
(40 a 50×10^3 BTU/hr)

1 lb vapor/hr = 1.4×10^3 BTU/hr
(1.2 a 1.7×10^3 BTU/hr)

En las relaciones:

- Megawatt es la producción neta de energía eléctrica de una planta de generación eléctrica alimentada con vapor.

- BHP es el caballo de fuerza caldera.

- Lb vapor/hr es la tasa de producción de vapor de la caldera.

- BTU/hr es la entrada calorífica en la caldera (basada en el valor calorífico grueso o superior del combustible quemado).

- Para operaciones de caldera menos eficientes (en general más antiguas y/o pequeñas, usar el valor expresado más alto. Para las operaciones más eficientes (en general más nuevas y/o de mayor tamaño), utilizar los valores más bajos.

VOLUMEN	**Pulgadas Cuadradas**	**Mililitros**	**Litros**	**Onzas (fluidas, EU)**	**Galones (EU)**	**Barriles (EU)**	**Pies Cúbicos**
Pulgadas cúbicas		16.3868	.0163868	0.5541	4.3290x10^{-3}	1.37429x10^{-4}	5.78704x10^{-4}
Milímetros	0.061024		0.001	0.03381	2.6418x10^{-4}	8.387^{-6}	3.5316x10^{-5}
Litros	61.024	1000		33.8147	0.26418	8.387x10-3	0.035316
Onzas (fl, EU)	1.80469	29.5729	0.029573		7.8125x10^{-3}	2.48x10^{-4}	1.0443x10^{-3}
Galones (EU)*	231	3785.3	3.7853	128		0.031746	0.13368
Barriles (EU)	7276.5	1.1924x10^{5}	119.2369	4032.0	31.5		4.2109
Pies cúbicos	1728	2.8316x10^{4}	28.316	957.568	7.481	0.23743	

[1] Un galón EU de agua a 16.7ºC (62ºF) pesa 3.780 kg ó 8.337 libras

MASA	Gramos	Kilogramos	Onzas (avoir.)	Libras (avoir.)	Granos	Toneladas (EU)	Miligramos
Gramos		0.001	3.527x10^{-2}	2.205x10^{-3}	15.432	1.102x10^{-6}	1000
Kilogramos	1000		35.274	2.2046	15432	1.102x10^{-3}	1x10^{6}
Onzas (avoir.)	28.350	0.028350		0.0625	437.5	3.125x10^{-5}	2.8350x10^{4}
Libras (promedio)*	453.59	0.45359	16.0		7000	5.0x10^{-4}	4.5359x10^{5}
Granos	0.06480	6.480x10^{-5}	2.286x10^{-3}	1.429x10^{-4}		7.142x10^{-8}	64.799
Toneladas (EU)	9.072x10^{5}	907.19	3.200x104	2000	1.4x10^{7}		9.0718x10^{8}
Miligramos	0.001	1x10^{-6}	3.527x10^{-5}	2.205x10^{-6}	0.015432	1.102x10^{-9}	

* Masa de 27.692 pulgadas cúbicas de agua pesadas en aire a 4.0ºC, y una presión de 760 Hg mm.

TRABAJO Y ENERGÍA	g. cal	kg. cal	Ergios	Joules	BTU	ft. lb.	kg. metros	L-Atu	HP Horas	ft. poundales	KWW	WH
Gramo Calorías (media)		0.001	4.186x10^{7}	4.186	3.9680x10^{-3}	3.0874	0.42685	0.041311	1.5593x10^{-6}	99.334	1.1628x10^{-6}	1.1628x10^{-3}
Kilogramo Calorías	1000		4.186x10^{10}	4186	3.9680	3087.4	426.85	41.311	1.5593x10^{-3}	99334	1.162x10^{-3}	1.1628
Ergios	2.3889x10^{-6}	2.3889x10^{11}		1x10^{-7}	9.4805x10^{-11}	7.3756x10^{-8}	1.0197x10^{-8}	9.8689x10^{-10}	3.7251x10^{-14}	2.3730x10^{-6}	2.7778x10^{-14}	2.7778x10^{-11}
Joules	0.23889	2.3889x10^{-4}	1x10^{7}		9.4805x10^{-4}	0.73756	0.10197	9.8689x10^{-3}	3.7251x10^{-7}	23.730	2.7778x10^{-7}	2.7778x10^{-4}
BTU (media)	251.98	0.25198	1.0548x10^{10}	1054.8		777.98	107.56	10.409	3.9292x10^{-4}	2.5030x10^{4}	2.930x10^{-4}	0.2930
Pie Libras	0.32389	3.2389x10^{-4}	1.35582x10^{7}	1.3558	1.2854x10^{-3}		0.13825	0.013381	5.0505x10^{-7}	31.174	3.7662x10^{-6}	3.7662x10^{-4}
Kilogramo metros	2.3427	2.3427x10^{-3}	9.8066x10^{7}	9.8066	9.2967x10^{-3}	7.2330		0.096781	3.6529x10^{-6}	232.71	2.7241x10^{-6}	2.7241x10^{-3}
Litro Atmósferas (normal)	24.206	2.4206x10^{-2}	1.0133x10^{9}	101.328	0.09606	74.735	10.333		3.7745x10^{-5}	2404.5	2.8164x10^{-5}	2.8164x10^{-2}
Caballo de fuerza Horas	6.4130x10^{5}	641.30	2.6845x10^{13}	2.6845x106	2454.0	1.9800x10^{6}	2.7374x10^{5}	26494		6.3705x10^{7}	0.7457	745.7
Pie poundales	0.010067	10.067x10^{-6}	4.21402x10^{5}	0.04214	3.9952x10^{-5}	0.031081	4.2972x10^{-3}	4.1558x10^{-4}	1.5297x10^{-8}		1.17055x10^{-8}	1.17055x10^{-5}
Kilowatt Horas	8.6001x105	860.01	3.6000x10^{13}	3.6000x10^{6}	3413.0	2.6552x10^{6}	3.6709x10^{-5}	3.5529x10^{6}	1.3440	8.5430x10^{7}		1000
Watt Horas	860.01	0.86001	3.6000x10^{10}	3600	3.4130	2655.3	367.09	3.5529x10^{3}	1.3410x10^{-3}	8.5430x10^{1}	0.001	

ENERGIA	**watts**	**kw**	**ft. lb./seg**	**erg/seg**	**BTU/min**	**g.cm/seg**	**kg.cal/min**	**HP**	**Lumens**	**Joules/seg**	**BTU/hr.**
Watts		0.001	0.73756	1x10^{7}	0.056884	1.0197x10^{4}	0.01433	1.341x10^{-3}	668	1	3.41304
Kilowatts	1000		737.56	1x10^{10}	56.884	1.0197x10^{7}	14.3334	1.3410	6.68x10^{5}	1000	3413.04
Pie libras /seg	1.35582	1.3558x10^{-3}		1.3558x10^{7}	0.077124	1.3826x10^{4}	0.019433	1.8182x10^{-3}	906.28	1.3558	4.6274
Ergios por segundo	1x10^{-7}	1x10^{-10}	7.3756x10^{-8}		5.688x10^{-9}	1.0197x10^{-3}	1.4333x10^{-9}	1.3410x10^{-10}	6.6845x10^{-5}	1x10^{-7}	3.4130x10^{-7}
BTU* por minuto	17.580	0.017580	12.9600	1.7580x10^{8}		1.7926x10^{5}	0.2520	0.023575	11751	17.580	60
Gramo Centímetros por segundo	9.806x10^{-5}	9.8067x10^{-8}	7.2330x10^{-5}	980.665	5.5783x10^{-6}		1.4056x10^{-6}	1.3151x10^{-7}	0.065552	9.8067x10^{-5}	3.3470x10^{-4}
Kilogramo colories por minuto	69.767	.069767	51.457	6.9770x10^{8}	3.9685	7.1146x10^{5}		0.093557	46636	69.769	238.11
Caballo de fuerza (EU)	745.7	0.7457	550	7.457x10^{9}	42.4176	7.6042x10^{6}	10.688		498129	745.7	2545.1
Lumens	1.496x10^{-3}	1.496x10^{-6}	1.0034x10^{-3}	1.496x10^{4}	8.5096x10^{-5}	15.254	2.1437x10^{-5}	2.0061x10^{-6}		1.496x10^{-3}	5.1069x10^{-3}
Joules por segundo	1	0.001	0.73756	1x10^{7}	0.056884	1.0197x10^{4}	0.01433	1.341x10^{-3}	668		3.41304
Btu* por hora	0.29299	2.9299x10^{-4}	0.21610	2.9299x10^{6}	0.01667	2.9878x10^{3}	4.1997x10^{-3}	3.9291x10^{-4}	185.80	0.29299	

* Unidades Térmicas Británicas (Media)

FACTORES DE CONVERSION PARA DIVERSAS SUSTANCIAS[a]

Tipo de Sustancia	Factores de Conversión
Combustible	
Petróleo	1 bbl = 159 Litros (42 gal)
Gas Natural	1 therm = 100,000 Btu (aprox.25000 kcal)
Contaminantes Gaseosos	
O_3	1 ppm, volumen = 1960µg/metro cúbico
NO_2	1 ppm, volumen = 1880µg/metro cúbico
SO_2	1 ppm, volumen = 2610µg/metro cúbico
H_2S	1 ppm, volumen = 1390 µg/metro cúbico
CO	1 ppm, volumen = 1.14 mg/metro cúbico
HC (como metano)	1 ppm, volumen = 0.654 mg/metro cúbico
Productos Agrícolas	
Maíz	1 bu = 25.4 kg = 56 lb
Sorgo	1 bu = 25.4 kg = 56 lb
Avenas	1 bu = 14.5 kg = 32 lb
Cebada	1 bu = 21.8 kg = 48 lb
Trigo	1 bu = 27.2 kg = 60 lb
Algodón	1 bale = 226 kg = 500 lb
Productos Minerales	
Ladrillo	1 brick = 2.95 kg = 6.5 lb
Cemento	1 bbl = 170 kg = 375 lb
Cemento	1 yd^3 = 1130 kg = 2500 lb
Concreto	1 yd^3 = 1820 kg = 4000 lb
Fuentes móviles, eficiencia del combustible	
Vehículos automotores	1.0 mi/gal = 0.426 km/litro
Embarcaciones	1.0 gal/naut mi = 2.05 Litros/km
Líquidos Misceláneos	
Cerveza	1 bbl = 31.5 gal
Pintura	1 gal = 4.5 a 6.82 kg = 10 a 15 lb
Barniz	1 gal = 3.18 kg = 7 lb
Whiskey	1 bbl = 190 Litros = 50.2 gal
Agua	1 gal = 3.81 kg = 8.3 lb

[a] Muchos de los factores de conversión en esta tabla representan valores promedio y aproximaciones, y algunos valores pueden variar con la temperatura y presión. Estos factores de conversión deben, sin embargo, tener una precisión suficiente para el uso general en campo.

APENDICE IV-C

EXTRACTO DEL *PROTOCOLO PARA LA ESTIMACION DE EMISIONES POR FUGAS EN EL EQUIPO DE 1995*

EPA-453/R-95-017

1995 Protocol for Equipment Leak Emission Estimates

Emission Standards Division

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

November 1995

not statistically equivalent to the leak rate at a refinery. Therefore, data from the Six-Unit Maintenance Study were used to develop the gas valve average emission factor.

2.2.2.5 Revised SOCMI Emission Factors and Correlations. In 1987 and 1988, screening data were obtained from 19 ethylene oxide and butadiene producers, and, in 1990, bagging data were collected from 16 of these process units. Screening and bagging data were collected from light liquid pumps, gas valves, light liquid valves, and connectors. A specific goal of the program was to bag equipment that had screening values less than 1,000 ppmv. The bagging data were combined with bagging data previously collected in the Six-Unit Maintenance Study, and this combined bagging data set was used to revise the SOCMI correlations. Likewise, the new screening data were combined with screening data previously collected in the 24-Unit Study, and this combined screening data set was used with the revised correlations to generate new SOCMI emission factors. Appendix B.2 contains more detailed information on how the revised SOCMI correlations and emission factors were developed.

2.3 APPROACHES FOR ESTIMATING EQUIPMENT LEAK EMISSIONS

In this section, each of the approaches for estimating equipment leak emissions are discussed. The description of each approach focuses on the basic method for estimating TOC emissions. Each of the approaches are demonstrated in example calculations contained in appendix A. Special topics at the end of the chapter have been included to address how to estimate VOC emissions when some of the organic compounds in the stream are not classified as VOC's and also how to speciate emissions for individual chemicals from equipment containing a mixture.

2.3.1 Average Emission Factor Approach

One accepted approach for estimating emissions allows use of average emission factors developed by the EPA in combination with unit-specific data that are relatively simple to obtain. These data include: (1) the number of each type of component in a unit (valve, connector, etc.), (2) the service each component is in (gas, light liquid, or heavy liquid), (3) the TOC concentration

TABLE 2-1. SOCMI AVERAGE EMISSION FACTORS

Equipment type	Service	Emission factor[a] (kg/hr/source)
Valves	Gas	0.00597
	Light liquid	0.00403
	Heavy liquid	0.00023
Pump seals[b]	Light liquid	0.0199
	Heavy liquid	0.00862
Compressor seals	Gas	0.228
Pressure relief valves	Gas	0.104
Connectors	All	0.00183
Open-ended lines	All	0.0017
Sampling connections	All	0.0150

[a] These factors are for total organic compound emission rates.

[b] The light liquid pump seal factor can be used to estimate the leak rate from agitator seals.

TABLE 2-3. MARKETING TERMINAL AVERAGE EMISSION FACTORS

Equipment type	Service	Emission factor (kg/hr/source)[a]
Valves	Gas	1.3E-05
	Light Liquid	4.3E-05
Pump seals	Gas	6.5E-05
	Light Liquid	5.4E-04
Others (compressors and others)[b]	Gas	1.2E-04
	Light Liquid	1.3E-04
Fittings (connectors and flanges)[c]	Gas	4.2E-05
	Light Liquid	8.0E-06

[a] These factors are for total organic compound emission rates (including non-VOC's such as methane and ethane).

[b] The "other" equipment type should be applied for any equipment type other than fittings, pumps, or valves.

[c] "Fittings" were not identified as flanges or non-flanged connectors; therefore, the fitting emissions were estimated by averaging the estimates from the connector and the flange correlation equations.

F_A = Applicable average emission factor for the equipment type (kg/hr/source);

FOR REFINERIES ONLY: The emission factor "F_A" must be adjusted to account for all organic compounds in the stream because the refinery factors are only valid for non-methane organic compounds (percents up to a maximum of 10 percent by weight methane are permitted):

$$F_A = F_A \times \frac{WF_{TOC}}{WF_{TOC} - WF_{methane}} ;$$

WF_{TOC} = Average weight fraction of TOC in the stream;

$WF_{methane}$ = Average weight fraction of methane in the stream; and

N = Number of pieces of equipment of the applicable equipment type in the stream.

Note that the emission factor "F_A" is defined differently for refineries than for SOCMI, marketing terminals, or oil and gas production operations when calculating TOC mass emissions. It is necessary to adjust the "F_A" term when applied to refineries, because when the refinery factors were developed, the methane was subtracted out of the organic total. Adjusting the "F_A" term for refineries is a way to correct for this. Two guidelines when correcting the "F_A" term when applied to refineries are as follows:

- The correction should only be applied to equipment containing a mixture of organics and methane; and
- The maximum correction for the methane weight fraction should not exceed 0.10, even if the equipment contains greater than 10 weight percent methane. (This reflects that equipment in the Refinery Assessment Study[1,2] typically contained 10 weight percent or less methane).

Thus, at a SOCMI process unit, if there were 100 gas valves in a stream containing, on average, 90 weight percent TOC and 10 weight percent water vapor, emissions would be calculated as follows:

several orders of magnitude. As a result, the majority of total emissions from a population of equipment at any given time will normally occur from a small percentage of the total equipment. The average emission factors account for the span of possible leak rates, but, as a result, they are not necessarily an accurate indication of the mass emission rate from an individual piece of equipment.

Furthermore, the average emission factors do not reflect different site-specific conditions among process units within a source category. Site-specific factors can have considerable influence on leak rates from equipment. Nevertheless, in the absence of screening data, the average emission factors do provide an indication of equipment leak emission rates from equipment in a process unit.

2.3.2 Screening Ranges Approach

The Screening Ranges Approach (formerly known as the leak/no-leak approach) offers some refinement over the Average Emission Factor Approach, thereby allowing some adjustment for individual unit conditions and operation. This approach is included in this section primarily to aid in the analysis of old datasets which were collected for older regulations that used 10,000 ppmv as the leak definition. This approach and the other two remaining approaches require that screening data be collected for the equipment in the process unit. The screening data are an indication of leak rates. When applying this approach, it is assumed that components having screening values greater than 10,000 ppmv have a different average emission rate than components with screening values less than 10,000 ppmv.

This approach may be applied when screening data are available as either "greater than or equal to 10,000 ppmv" or as "less than 10,000 ppmv." Emission factors for SOCMI, refineries, marketing terminals, and oil and gas production operations for these two ranges of screening values are presented in tables 2-5, 2-6, and 2-7, and 2-8, respectively. As with the average factors, the SOCMI, marketing terminal, and oil and gas production operations screening range factors predict total

TABLE 2-6. REFINERY SCREENING RANGES EMISSION FACTORS[a]

Equipment type	Service	≥10,000 ppmv Emission factor (kg/hr/source)[b]	<10,000 ppmv Emission factor (kg/hr/source)[b]
Valves	Gas	0.2626	0.0006
	Light liquid	0.0852	0.0017
	Heavy liquid	0.00023	0.00023
Pump seals[c]	Light liquid	0.437	0.0120
	Heavy liquid	0.3885	0.0135
Compressor seals	Gas	1.608	0.0894
Pressure relief valves	Gas	1.691	0.0447
Connectors	All	0.0375	0.00006
Open-ended lines	All	0.01195	0.00150

[a] Source: Reference 6.

[b] These factors are for non-methane organic compound emission rates.

[c] The light liquid pump seal factors can be applied to estimate the leak rate from agitator seals.

TABLE 2-8. OIL AND GAS PRODUCTION OPERATIONS SCREENING RANGES EMISSION FACTORS

Equipment type	Service[b]	≥10,000 ppmv Emission factor (kg/hr/source)[a]	<10,000 ppmv Emission factor (kg/hr/source)[a]
Valves	Gas	1.1E-01	7.9E-04
	Heavy Oil	NA	8.4E-06
	Light Oil	1.1E-01	9.0E-04
	Water/Oil	NA	9.8E-05
Pump seals	Gas	NA	2.4E-03
	Heavy Oil	NA	NA
	Light Oil	1.6E-01	6.7E-03
	Water/Oil	NA	2.4E-05
Others[c]	Gas	1.1E-01	3.8E-03
	Heavy Oil	NA	3.2E-05
	Light Oil	9.5E-02	4.0E-03
	Water/Oil	3.4E-03	1.4E-02
Connectors	Gas	2.4E-02	8.4E-05
	Heavy Oil	NA	7.5E-06
	Light Oil	2.5E-02	1.2E-04
	Water/Oil	NA	1.1E-04
Flanges	Gas	7.9E-02	1.9E-04
	Heavy Oil	NA	3.9E-07
	Light Oil	5.1E-02	8.5E-05
	Water/Oil	NA	2.9E-06
Open-ended lines	Gas	7.7E-02	5.2E-04
	Heavy Oil	NA	1.4E-04
	Light Oil	6.2E-02	5.2E-04
	Water/Oil	NA	2.5E-04

[a] These factors are for total organic compound emission rates (including non-VOC's such as methane and ethane) and apply to light crude, heavy crude, gas plant, gas production, and offshore facilities. "NA" indicates that not enough data were available to develop the indicated emission factor.

[b] Water/Oil emission factors apply to water streams in oil service with a water content greater than 50%, from the point of origin to the point where the water content reaches 99%. For water streams with a water content greater than 99%, the emission rate is considered negligible.

[c] The "other" equipment type was derived from compressors, diaphrams, drains, dump arms, hatches, instruments, meters, pressure relief valves, polished rods, relief valves, and vents. This "other" equipment type should be applied for any equipment type other than connectors, flanges, open-ended lines, pumps, or valves.

$WP_{methane}$ = Average weight percent of methane in the stream;

N_G = Equipment count (specific equipment type) for sources with screening values greater than or equal to 10,000 ppmv;

F_L = Applicable emission factor for sources with screening values less than 10,000 ppmv (kg/hr/source)

FOR REFINERIES ONLY: The emission factor "F_L" must be adjusted to account for all organic compounds in the stream because the refinery factors are only valid for non-methane organic compounds (percents up to a maximum of 10 percent by weight methane are permitted):

$$F_L = F_L \times \frac{WP_{TOC}}{WP_{TOC} - WP_{methane}} \text{ ; and}$$

N_L = Equipment count (specific equipment type) for sources with screening values less than 10,000 ppmv.

Assuming all of the organic compounds in the stream are classified as VOC's, the total VOC emission for each stream is calculated as the sum of TOC emissions associated with each specific equipment type in the stream. Section 2.4.6 discusses an adjustment that can be made to predict the VOC emission rate if some of the organic compounds in the stream are not classified as VOC's (such as methane and ethane).

The screening range emission factors are a better indication of the actual leak rate from individual equipment than the average emission factors. Nevertheless, available data indicate that measured mass emission rates can vary considerably from the rates predicted by use of these factors.

2.3.3 EPA Correlation Approach

This approach offers an additional refinement to estimating emissions from equipment leaks by providing an equation to predict mass emission rate as a function of screening value for a particular equipment type. Correlations developed by the EPA relating screening values to mass emission rates for SOCMI

APENDICE IV-D

EJEMPLO DE LISTA DE REVISION DE CONTROL DE CALIDAD

EJEMPLO DE LA LISTA DE REVISION DE CONTROL DE CALIDAD

Revisiones del Grado en que la Información Está Completa - Fuentes Puntuales	**Sí**	**No**	**Comentarios**
¿Todas las fuentes puntuales de COVs aplicables han sido incluidas en el inventario?			
¿Todos los datos a nivel de proceso, punto y segmento han sido proporcionados para todas las fuentes puntuales de COVs?			
¿Todos los datos de la documentación a nivel de proceso, punto y segmento han sido proporcionados para las fuentes de NO_x y CO?			
¿El Inventario Anual de Emisiones ha sido firmado por la autoridad pertinente, quien asumirá la responsabilidad legal de la precisión de la información verificada en el reporte ante el estado?			
¿La siguiente información ha sido proporcionada en el reporte (a la entidad reguladora), y es precisa: fuente, direcciones, información sobre el contacto, y código(s) de clasificación del proceso industrial)?			
Revisiones de los Procedimientos	**Sí**	**No**	**Comentarios**
¿Se ha hecho una copia del inventario y del reporte que se está enviando por correo a la entidad regulatoria?			
¿La documentación del inventario describe la metodología usada para desarrollar el listado del inventario de fuentes puntuales (i. e., estudio, inspecciones de planta, datos del monitoreo continuo de emisiones, datos del análisis de combustibles, datos del modelado de la calidad del aire y archivos de los permisos)?			
La documentación del inventario de fuentes puntuales incluye al contacto (s) para aclaraciones?			
Seleccionar un subconjunto que represente cuando menos el 10 por ciento de las fuentes puntuales enlistadas y determinar si los siguientes datos han sido recopilados y presentados para cada una de ellas.			
Nota: Registrar en la columna de comentarios el número de registro de las plantas que fueron revisadas.			
• Nombre y ubicación de la planta (incluyendo latitud, longitud, CP)			
• Calendario de operación			
• Reglamentos aplicables			
• Zona UTM			
• Código o número CAS del contaminante			
• ID de la chimenea (para datos de fuentes puntuales)			
• Limitaciones de emisión (sólo si están sujetas a la regulación del INE)			
• Año de cumplimiento (sólo si están sujeto a la regulación del INE)			
• Tasa y unidades del proceso diario			
• Tipo de equipo de control			
• Eficiencia de Control			
• Método de estimación de emisiones			
• Factores de emisión			

Revisiones de la Coherencia de la Información	**Sí**	**No**	**Comentarios**
Si la fuente puntual de emisiones de COVs son atribuidas a la industria manufacturadora de sustancias químicas orgánicas sintéticas/IMSQOS), las emisiones fugitivas también han sido cuantificadas?			
Nota: Las emisiones fugitivas por fugas en el equipo deben ser de 1 a 10 veces mayores que las emisiones de respiraderos, reactores, etc.			
¿Los siguientes elementos de los datos se encuentran dentro de los siguientes límites para los datos generales de las fuentes puntuales?			
• Horas diarias ≤ 24			
• Días por semana ≤ 7			
• Horas anuales = horas x días			
• Rendimientos estacionales 0 - 100			
• Capacidad de la caldera del 80 - 120 por ciento si la tasa por hora máxima se multiplica por el contenido calorífico del combustible			
• ¿El porcentaje de calor espacial para el invierno es mayor que en el verano?			
• Los siguientes elementos de los datos se encuentran dentro de los siguientes límites para los datos de contaminantes puntuales?			
• Altura de la chimenea > 50 ft			
• Diámetro de la chimenea 0.5 > 30 ft			
• Altura de la pluma > 200 ft			
• Temperatura de salida de los gases 60 > 2,000ºF			
• Temperatura de salida de los gases con lavador húmedo > 250ºF			
• Temperatura de salida de los gases sin lavador húmedo > 250ºF			
• Tasa de salida de flujo del gas es igual a capacidad x temperatura			
• Velocidad de salida del gas			
Los siguientes elementos de los datos se encuentran dentro de los límites para siguientes los datos generales de segmento?			
• Unidades de la tasa por hora del proceso < 10 por ciento > 125 por ciento x la máxima capacidad de diseño			
• Para los equipos de control, ¿la eficiencia es entre 0 - 100 por ciento?			

EJEMPLO DE LAS FORMAS DE INSTRUCCIONES PARA LA RECOPILACION DE DATOS - OPERACIONES DE RECUBRIMIENTO DE SUPERFICIES

1. Esta forma puede ser utilizada como hoja de trabajo para ayudar al ingeniero de planta a recopilar la información necesaria para calcular las emisiones de cada operación de recubrimiento de superficies. La información solicitada en las formas se relaciona con los diferentes métodos para cuantificar las emisiones. Esta forma también puede ser utilizada por la entidad regulatoria para ayudar en la elaboración de un inventario a nivel de área.

2. Las formas llenas deben ser mantenidas por el ingeniero de planta en un archivo de referencia junto con otra documentación de apoyo.

3. Si la información solicitada es desconocida, escribir "desconocida" en el espacio correspondiente. Si la información solicitada no es aplicable a un proceso o unidad particular, escribir NA en el espacio.

4. Si la información sobre el uso por hora o mensual del material no está disponible, registrar la información en otra unidad (trimestral o anual). Asegurarse de indicar la unidad de medición en la forma.

5. Usar el campo de comentarios en la forma para registrar toda la información útil que permitirá que su trabajo sea revisado y repetido. Recopilar todas las Hojas de Datos de Seguridad del Material (MSDS, por sus siglas en inglés) para todos los materiales que contengan contaminantes potenciales del aire y que sean utilizados en el establecimiento.

6. Recopilar todas las Hojas de Datos de Seguridad del Material (MSDS, por sus siglas en inglés) para todos los materiales que contengan contaminantes potenciales del aire y que sean utilizados en el establecimiento.

7. Para cada material utilizado, determinar las tasas máximas de uso por hora, así como las tasas de uso anual.

8. El ingeniero de planta debe mantener toda la información sobre el uso de materiales y las MSDSs en un archivo de referencia.

EJEMPLO DE LA FORMA PARA LA RECOPILACION DE DATOS - OPERACIONES DE RECUBRIMIENTO DE SUPERFICIES

INFORMACION GENERAL

Nombre del Establecimiento o Planta:

Descripción del Establecimiento:

Ubicación:

Municipio:

Ciudad:

Estado:

Coordenadas Geográficas de la Planta:
Latitud: ______________________________
Longitud: ______________________________
Zona UTM: ______________________________
UTM Este: ______________________________
UTM Norte: ______________________________

Nombre del Contacto:

Puesto:

Teléfono:

Número de ID de la Unidad:

Número del Permiso:

EJEMPLO DE LA FORMA PARA LA RECOPILACION DE DATOS - OPERACIONES DE RECUBRIMIENTO DE SUPERFICIES

INFORMACION SOBRE EL EQUIPO Y PROCESO		**COMENTARIOS**
Nombre o descripción del equipo:		
Fabricante:		
Modelo:		
Capacidad nominal del equipo:		
Tipo de Operación:		
Recubrimiento de superficies:		
Secador:		
Prensa litográfica:		
Otro:		
Tipo de equipo para esta operación:		
Recubrimiento por inmersión:		
Prensa tipográfica:		
Otro:		
Fraccionamiento de la evaporación de la aplicación o secado (%):		
Uso típico:		
Horas/día:		
Días/semana:		
Semanas/año:		
Variaciones estacionales (%):		
Enero:	Febrero:	Marzo:
Abril:	Mayo:	Junio:
Julio:	Agosto:	Septiembre:
Octubre:	Noviembre:	Diciembre:

EJEMPLO DE LA FORMA PARA LA RECOPILACION DE DATOS - OPERACIONES DE RECUBRIMIENTO DE SUPERFICIES

INFORMACION SOBRE EL MATERIAL

COMPOSICION DEL MATERIAL

Nombre del Material:

Contenido de COVs (lb/gal ó % en peso):

Contenido de sólidos (% en peso):

Densidad del Material:

Composición (lb_x/lb material * 100%:
- Nombre del componente: ______________________________
- % en peso del componente: ______________________________

USO DEL MATERIAL

Rendimiento por hora:

Rendimiento mensual:

Rendimiento anual:

Rendimiento máximo:

OPERACIONES DE RECUBRIMIENTO DE SUPERFICIES

Tipo de recubrimiento (tinta, primer, pintura, etc.):

Sustrato recubierto (madera, metal, etc.):

Nombre de la mezcla (para recubrimientos de partes múltiples):

Marca y Nombre del Producto (para cada parte de la mezcla de recubrimiento):

Proporciones de las Mezclas de Recubrimiento:

% de COVs Evaporados como Fugitivos:

Factor de Emisión Particulado:

- Referencia

HOJA DE TRABAJO A

DESCRIPCION DEL SOLVENTE

Composición del Solvente	**Uso Anual (gal/año)**	**Porcentaje del Total de Solventes Enlistados**	**Peso Molecular (lb/lb $_{\text{mole}}$)**	**Densidad del Líquido (lb/gal)**
Total				
Meso Molecular del Solvente (promedio pesado), (M_i)			(lb/lb $_{\text{mole}}$)	
Densidad del Solvente Líquido (promedio pesado), (d_i)			(lb/lb $_{\text{mole}}$)	

$$Y = \sum_{i=1}^{n} (x_i * y_i)$$

Donde

Y = Peso molecular promedio pesado (M_i) o densidad del líquido (d_i)
y_i = Peso molecular (M_i) o densidad del líquido (d_i) para el COV$_i$
x_i = Fracción del solvente total para el COV$_i$
n = Número de especies de COVs en el(los) solvente(s)

HOJA DE TRABAJO B

CABINAS DE ASPERSION

Horas anuales de operación de esta cabina:							
CARACTERISTICAS DE LA CORRIENTE DE GAS DE SALIDA							
Tasa de Flujo (acfm)		Chimenea de Salida			Altura del Edificio (ft)	Carga de Partículas del Equipo de Abatimiento (lb/hr)	
Máximo de Diseño	Promedio Esperado	Temperatura °F	Altura (ft)	Diámetro (ft)		Entrada	Salida
TIPO DE RECUBRIMIENTO Y TASA MAXIMA DE USO							
Tipo		Tasa Máx. de Uso (lb/hr)		Tasa Máx. de Uso (ton/año)		Porción Volátil (% en peso)	
Laca							
Barniz							
Esmalte							
Primer							
Metálico							
Spray							
Metálico							
Resina							
Sellador							
Goma laca							
Tinta							
Zinc							
Cromado							
Epóxico							
Poliuretano							
Otro							
COMPOSICION DEL SOLVENTE Y TASA DE USO (INCLUYE EL PROPORCIONADO CON EL RECUBRIMIENTO)							
Composición Química de los Volátiles y Peso (%)				Tasa Máx. de Uso (lb/hr)		Tasa Máx. de Uso (ton/año)	
TIPO DE EQUIPO DE ABATIMIENTO DE PM							
☐ Cámara de Aspersión (uso de agua gal/hr): ___________________ ☐ Cortina de Agua (uso de agua gal/hr) : ___________________ ☐ Cojinetes del Filtro Seco (número total en todas las capas) (tamaño) : ___________________ ☐ Otro (explicar) : ___________________ ☐ Tasa del Fabricante para la Eficiencia de Control de PM: ___________________							
TIPO DE EQUIPO DE ABATIMIENTO DE COVs							
Tipo				Eficiencia Nominal de Control			

HOJA DE TRABAJO B

(Continuación)

METODO DE ASPERSION	DESCRIPCION DE LOS ARTICULOS A SER RECUBIERTOS (TAMAÑO Y FORMA)
☐ Atomización de aire ☐ Electrostático sin aire ☐ Disco Sin aire ☐ Aire atomizado ☐ Otro:	

RESULTADOS DE LA ESTIMACION DE EMISIONES - OPERACIONES DE RECUBRIMIENTO DE SUPERFICIES

Contaminante	**ID de la Operación de Recubrimiento**[a]	**Método de Estimación de Emisiones**[b]	**Emisiones**	**Unidades de Emisión**	**Factor de Emisión**[c]	**Unidades del Factor de Emisión**	**Galones de Recubrimiento Aplicados**	**Comentarios**
VOC								
NO_x								
CO								
SO_2								
PM_{10}								
Partículas Totales								
Contaminantes Peligrosos del Aire (CPA) (enlistar individualmente)								

[a] Usar los siguientes códigos para indicar el tipo de operación utilizada:
RS = Recubrimiento de Superficies
S= Secador
PL = Prensa Litográfica
O = Otro

[b] Usar los siguientes códigos para indicar qué método de estimación fue utilizado para cada contaminante:
Balance de masa = BM
Factor de emisión = FE
Prueba de Fuente en Chimenea = PF
Otro (indicar) = O

[c] Cuando sea aplicable, registrar el factor de emisión y proporcionar la cita completa de la referencia o fuente de información de donde proviene el factor de emisión. Si se utilizó el *AP-42,* incluir edición, versión, tabla y número de página.

EJEMPLO DE LAS FORMAS DE INSTRUCCIONES PARA LA RECOPILACION DE DATOS - CALDERAS

1. Esta forma puede ser utilizada como hoja de trabajo para ayudar al ingeniero de planta a recopilar la información necesaria para calcular las emisiones las calderas. La información solicitada en las formas se relaciona con los diferentes métodos para cuantificar las emisiones. Esta forma también puede ser utilizada por la entidad regulatoria para ayudar en la elaboración de un inventario a nivel de área.

2. Las formas llenas deben ser mantenidas por el ingeniero de planta en un archivo de referencia junto con otra documentación de apoyo.

3. La información identificada en estas formas es necesaria para generar un inventario de emisiones completo. Si la información solicitada no es aplicable a una caldera particular, escribir NA en el espacio.

4. Si la capacidad nominal no está documentada en MMBtu/hr, por favor, registre la capacidad en corriente producida lb/hr, u otras unidades de medición pertinentes.

5. Si la información sobre el uso por hora o mensual del material no está disponible, registrar la información en otra unidad (trimestral o anual). Asegurarse de indicar la unidad de medición en la forma

6. Usar el campo de comentarios en la forma para registrar toda la información útil que permitirá que su trabajo sea revisado y repetido.

EJEMPLO DE LA FORMA PARA LA RECOPILACION DE DATOS - CALDERAS

INFORMACION GENERAL

Nombre del Establecimiento o Planta: ______________________

Descripción del Establecimiento:

Generación de Servicios Públicos: ______________________

Comercial: ______________________

Industrial: ______________________

Ubicación: ______________________

Municipio: ______________________

Ciudad: ______________________

Estado: ______________________

Coordenadas Geográficas de la Planta:

Latitud: ______________________

Longitud: ______________________

Zona UTM: ______________________

UTM Este: ______________________

UTM Norte: ______________________

Nombre del Contacto: ______________________

Puesto: ______________________

Teléfono: ______________________

Número de ID de la Unidad: ______________________

Número del Permiso: ______________________

EJEMPLO DE LA FORMA PARA LA RECOPILACION DE DATOS - CALDERAS

INFORMACION DE LA FUENTE		**COMENTARIOS**
ID de la Unidad:		
Fabricante:		
Fecha de Instalación:		
Capacidad Nominal (unidades):		
Entrada Calorífica Máxima (unidades):		
Tipo de Combustible:		
Calendario de Operación:		
Horas/día:		
Días/semana:		
Semanas/año:		
USO DE COMBUSTIBLE[a]:		
Año:		
Uso Máximo de Combustible por Hora (unidades):		
Uso Mensual de Combustible (unidades):		
Enero:	Julio:	
Febrero:	Agosto:	
Marzo	Septiembre:	
Abril:	Octubre:	
Mayo:	Noviembre:	
Junio:	Diciembre:	
Uso Anual Total de Combustible (unidades):		

[a] Esta forma debe ser llenada para cada tipo de combustible utilizado.

EJEMPLO DE LA FORMA PARA LA RECOPILACION DE DATOS - CALDERAS

CONFIGURACION DE LA ALIMENTACION (marcar el tipo apropiado)

Alimentación Tangencial	☐	Alimentación Horizontal	☐	Alimentación Vertical	☐	Alimentación con Carbón pulverizado	☐
Fondo Seco	☐	Fondo Húmedo	☐				☐
Horno de Ciclón	☐						
Cargador de Propagación	☐	No Controlado	☐			Controlado	☐
Cargador de Sobrealimentación	☐	No Controlado	☐			Controlado	☐
Cargador *Underfired*	☐	No Controlado	☐			Controlado	☐
Unidades de Alimentación Manual	☐						

EQUIPO DE CONTROL DE LA CONTAMINACION (Registrar la eficiencia de control y la fuente de información):

ESP:

Casa de Bolsas:

Lavador Húmedo:

Lavador Seco:

Secador de Spray:

Ciclón:

Otro:

EJEMPLO DE LA FORMA PARA LA RECOPILACION DE DATOS - CALDERAS

ANALISIS DE COMBUSTIBLE	**COMENTARIOS**
Contenido de Azufre (S):	
Contenido de Cenizas:	
Contenido de Nitrógeno (N):	
Contenido de Plomo (Pb):	
Mercurio (Hg):	
Otros:	
Valor Calorífico Superior (HHV en Btu/lb):	
Referencia (anexar análisis, si es factible):	

INFORMACIÓN DE LA CHIMENEA	
ID de la Chimenea:	
ID de la Unidad:	
Altura (pies) de la Chimenea (emisión):	
Diámetro de la Chimenea (pulgadas):	
Temperatura del Gas de la Chimenea (ºF)	
Velocidad del Gas de la Chimenea (ft/sec):	
Tasa de Flujo del Gas de la Chimenea (ascf/min):	
¿Esta chimenea es compartida por otras fuentes? (S/N)? (En caso afirmativo, incluir las IDs de cada una de las unidades).	
¿El reporte del muestreo en fuente específico en sitio para la chimenea está disponible? (S/N):	
Referencia (incluir las citas completas de los reportes de pruebas utilizadas):	

EJEMPLO DE LA FORMA PARA LA RECOPILACION DE DATOS - CALDERAS

ID de la Unidad: _______________
Tipo de Combustible: _______________

Contaminante	**Método de Estimación de Emisiones**[a]	**Emisiones**	**Unidades de las Emisiones**	**Factor de Emisión**[b]	**Unidades del Factor de Emisiones**	**Comentarios**
COVs						
NO_x						
CO						
SO_2						
PM_{10}						
Partículas Totales						
Contaminantes Peligrosos del Aire (enlistados individualmente)						

[a] Usar los siguientes códigos para indicar qué tipo de método de estimación de emisiones es utilizado para cada contaminante:

Factor de Emisiones = FE
Datos de Prueba de Fuente en Chimenea = PFC
Balance de Masa = BM
Análisis de Combustible= AC
Otros (indicar) = O

[b] Cuando sea aplicable, registrar el factor de emisión y proporcionar la cita completa de la referencia o fuente de información de donde proviene el factor de emisión. Si se utilizó el *AP-42,* incluir edición, versión, tabla y número de página.

EJEMPLO DE LAS FORMAS DE INSTRUCCIONES PARA LA RECOPILACION DE DATOS - EMISIONES FUGITIVAS DE FUGAS EN EL EQUIPO

1. Esta forma puede ser utilizada como hoja de trabajo para ayudar a recopilar la información o datos necesarios para estimar las emisiones de Contaminantes Peligrosos del Aire (CPAs) y COVs de las fugas en el equipo.

2. La forma se divide en cinco secciones: Información General, Datos de Composición de la Corriente; Cuentas del Equipo; Datos de Selección; y Controles de Fugas en el Equipo.

3. Algunas secciones requieren entradas con base en una corriente. En este caso, será necesario hacer una copia de la sección por separado para cada corriente en la unidad de proceso.

4. Para la sección de los datos de composición de la corriente, los porcentajes en peso pueden no ser proporcionados para los componentes que se encuentren en concentraciones menores que 1.0 por ciento en peso.

5. Para la sección de los datos de composición de la corriente, en el renglón titulado "OTROS", identificar el porcentaje total en peso de todos los componentes no enlistados previamente. Esta cifra no debe exceder el 10 por ciento. El porcentaje total en peso de todos los componentes en la corriente debe ser igual a 100 por ciento.

6. Para la sección de datos de selección, llenar la información o datos para cada corriente seleccionada.

7. Para la sección de cuenta del equipo, responder las preguntas y llenar la tabla para cada corriente en el establecimiento.

8. Para la sección de cuenta del equipo, la concentración de activación de la Detección y Reparación de Fugas (DYRF) se refiere al nivel de concentración en la que se considera que el componente se está fugando.

9. Para la sección de cuenta del equipo, registrar los parámetros de control para cada tipo de componente en la corriente. Registrar el porcentaje del tipo de equipo total en la corriente que tiene los controles enlistados en la Tabla IV-1.

10. Para la sección de cuenta de equipo, si se utilizara otro tipo de controles, especificarlos en el espacio a la izquierda del guión.

11. Para la sección de cuenta del equipo, indicar cualesquier equipos de control secundarios a los que el sistema de venteo cerrado transporte el fluido del proceso.

EJEMPLO DE LAS FORMAS DE INSTRUCCIONES PARA LA RECOPILACION DE DATOS - EMISIONES FUGITIVAS DE FUGAS EN EL EQUIPO

INFORMACION GENERAL						
Capacidad de la Unidad de Proceso (lb/año)						
Instrumento Portátil para el Monitoreo de COVs Utilizado[a]						
Gas de Calibración del Instrumento de Monitoreo[a]						
DATOS DE COMPOSICION DE LA CORRIENTE						
Número CAS	Nombre Químico	**Concentración (% en peso)**				
		Corriente 1	Corriente 2	Corriente 3	Corriente 4	Corriente 5
--	Otro					
--	CPA Totales					
--	COVs Totales					
--	Fuente[b]					
Cantidad del Fluido Tiempo en la Corriente (hr/año)						

[a] Recopilar información si los datos de selección han sido reunidos en la unidad de proceso.
[b] JI = Juicio Ingenieril DP= Datos de Prueba; VL = Valores de la Literatura.

EJEMPLO DE LAS FORMAS DE INSTRUCCIONES PARA LA RECOPILACION DE DATOS - EMISIONES FUGITIVAS DE FUGAS EN EL EQUIPO

CUENTA DEL EQUIPO					
Componente	Servicio	Fuente de Cuenta[b]	Corriente 1	Corriente 2	Corriente 3
Válvulas	gas/vapor				
	Líquido ligero				
	Líquido pesado				
Conectores	Todos				
Bombas	Líquido ligero				
	Líquido pesado				
Compresor	gas/vapor				
Líneas abiertas	Todos				
Conexiones de muestreo	Todos				
Válvula de Alivio de Presión	gas/vapor				

[a] No incluye equipo en servicio de vacío.

[b] D = Especificaciones de Diseño; I = Etiquetas de inspección y mantenimiento; C = Cuenta Real; R = Relación, si es específica (i. e., 25 válvulas por bomba).

EJEMPLO DE LAS FORMAS DE INSTRUCCIONES PARA LA RECOPILACION DE DATOS - EMISIONES FUGITIVAS DE FUGAS EN EL EQUIPO

DATOS DE SELECCIÓN	
ID de la Corriente:	Tipo de Componente:
Datos de los Componentes Seleccionados:	Número Total de Componentes Seleccionados
ID del Componente	**Valor de Selección (ppmv)**

EJEMPLO DE LAS FORMAS DE INSTRUCCIONES PARA LA RECOPILACION DE DATOS - EMISIONES FUGITIVAS DE FUGAS EN EL EQUIPO

CONTROLES DE FUGAS EN EL EQUIPO

ID de la Corriente:

¿El equipo en esta corriente está sujeto a un programa DYRF? (Sí/No)

Tipo de Sistema de Monitoreo[a]:

	Parámetros de Detección y Reparación de Fugas					Parámetros de Control				
Equipo	Cantidad en Programa	Conc. de Activación DYRF	Frecuencia de Monitoreo	Tiempo de Respuesta[b]		Porcentaje con Control A[c]	Porcentaje con Control B[c]	Porcentaje con Control C[c]	Otro	Control Secundario de Venteo Cerrado
Válvulas								NA	/	
Bombas									/	
Compresores								NA	/	
Conectores							NA	NA	/	
Líneas Abiertas								NA	/	
Conexiones de Muestreo	NA	NA	NA	NA					/	
Presión en Válvulas de Alivio								NA	/	

NA = No Aplicable

[a] V = Visual; P = Portátil; F = Punto Fijo; por favor, especificar si fuera otro.

[b] IM = Inmediatamente; D = 1 día; D3 = 3 días; SM = 1 semana; SM2 = 2 semanas; M = 1 mes.

[c] Ver Tabla IV-1 (Controles por Tipo de Equipo).

TABLA IV-1
CONTROLES POR TIPO DE EQUIPO

Opciones de Control	Equipo	Controles
A	Todos	Sistema de venteo cerrado
B	Válvulas	Sin sello
	Bombas	Sello mecánico dual con barrera de fluidos[a]
	Compresores	Tapones, conectores, bridas ciegas.
	Líneas de extremo abierto	Muestreo *in-situ*
	Conexiones de muestreo	Disco de ruptura
	PRV’s	
C	Bombas	Sin sello
	Conexiones de muestreo	Muestreo en circuito cerrado

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MEXICO EMISSIONS INVENTORY PROGRAM MANUALS

VOLUME V - AREA SOURCE INVENTORY DEVELOPMENT

FINAL

Prepared for:

Western Governors' Association
Denver, Colorado

and

Binational Advisory Committee

Prepared by:

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March 31, 1997

PREFACE

Air pollution can negatively impact public health when present in the atmosphere in sufficient quantities. Most rural areas rarely experience air quality problems, while elevated concentrations of air pollution are found in many urban environments. Recently, there has been an increasingly larger degree of urbanization and industrial activity throughout Mexico, resulting in air quality impairment for several regions.

Air pollution results from a complex mix of literally thousands of sources ranging from industrial smoke stacks and motor vehicles, to the individual use of grooming products, household cleaners, and paints. Even plant and animal life can play an important role in the air pollution problem. The complex nature of air pollution requires the development of detailed plans on a regional level that provide a full understanding of the emission sources and methods for reducing the health impacts associated with exposure to air pollution. Example air quality planning activities include:

- Application of air quality models;
- Examination of source attribution for emissions control where deemed necessary;
- Development of emission projections to examine possible changes in future air quality;
- Analysis of emission trends; and
- Analysis of emissions transport from one region to another.

Development of fundamentally sound emissions inventories is a key need for each of these air quality planning functions.

Developing emission estimates to meet air quality planning needs requires continual development and refinement; “one time” inventory efforts are not conducive to the air quality planning process. For lasting benefit, an *inventory program* must be implemented so that accurate emission estimates can be developed for all important geographic regions, refined over time, and effectively applied in the air quality planning and monitoring process. Consequently, a set of inventory manuals will be developed that can be used throughout the country to help coordinate the development of consistent emission estimates. These manuals are intended for use by local, state, and federal agencies, as well as by industry and private consultants. The purpose of these manuals is to assist in implementing the inventory program and in maintaining that program over time so that emissions inventories can be developed in periodic cycles and continually improved.

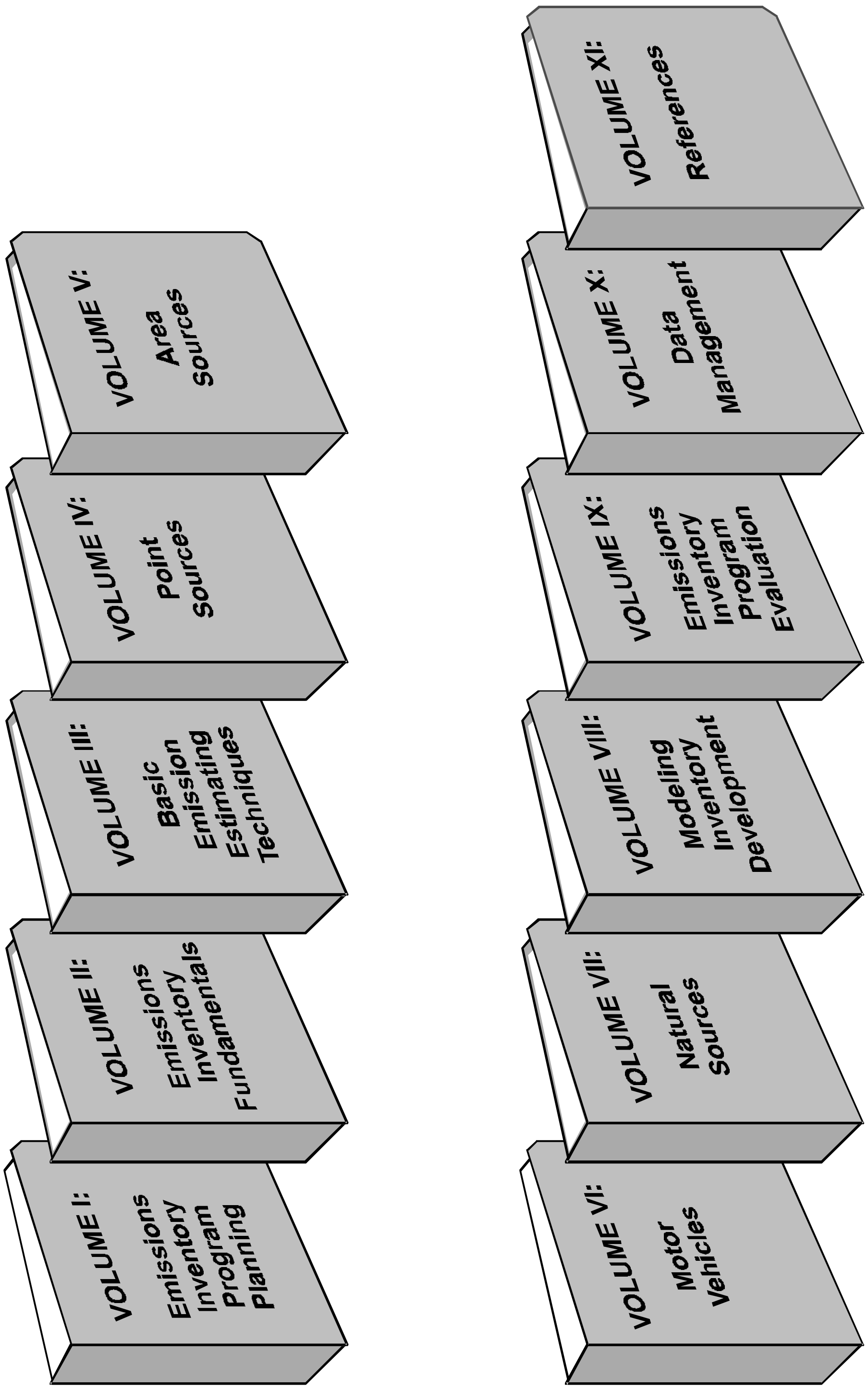

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Figure 1. Mexico Emissions Inventory Program Manuals

The manuals cover inventory program elements such as estimating emissions, program planning, database management, emissions validation, and other important topics. Figure 1 shows the series of manuals that will be developed to support a complete inventory program. The main purpose of each manual or volume is summarized below.

Volume I—Emissions Inventory Program Planning. This manual addresses the important planning issues that must be considered in an air emissions inventory program. Program planning is discussed not as an "up-front" activity, but rather as an ongoing process to ensure the long-term growth and success of an emissions inventory program. *Key Topics*: program purpose, inventory end uses, regulatory requirements, coordination at federal/state/local levels, staff and data management requirements, identifying and selecting special studies.

Volume II—Emissions Inventory Fundamentals. This manual presents the basic fundamentals of emissions inventory development and discusses inventory elements that apply to multiple source types (e.g., point and area) to avoid the need for repetition in multiple volumes. *Key Topics*: applicable regulations, rule effectiveness, rule penetration, pollutant definitions (excluding nonreactive volatile), point/area source delineation, point/area source reconciliation.

Volume III—Basic Emissions Estimating Techniques. This manual presents the basic methodologies used to develop emission estimates, including examples and sample calculations. Inventory tools associated with each methodology are identified and included in Volume XI (References). *Key Topics*: source sampling, emissions models, surveying, emission factors, material balance, extrapolation.

Volume IV—Emissions Inventory Development: Point Sources. This manual provides guidance for developing the point source emissions inventory. A cross-reference table is provided for each industry/device type combination (e.g., petroleum refining/combustion devices) with one or more of the basic methodologies presented in Volume III. *Key Topics*: cross-reference table, stack parameters, control devices, design/process considerations, geographic differences and variability in Mexico, quality assurance/quality control (QA/QC), overlooked processes, data references, data collection forms.

Volume V—Emissions Inventory Development: Area Sources (Includes Non-Road Mobile). This manual provides guidance for developing the area source emissions inventory. After the presentation of general area source information, a table is provided to cross-reference each area source category (e.g., asphalt application) with one or more of the basic methodologies presented in Volume III. Then, source category-specific information is discussed for each source category defined in the table. *Key Topics*: area source categorization and definition, cross-reference table, control factors, geographic differences and variability in Mexico, QA/QC, data references, data collection forms (questionnaires).

Volume VI—Emissions Inventory Development: Motor Vehicles. Because motor vehicles are inherently different from point and area sources, the available estimation methods and required data are also different. To estimate emissions from these complex sources, models are the preferred estimation tool. Many of these models utilize extensive test data applicable to a given country or region. This manual focuses primarily on the data development phase of estimating motor vehicle emissions. *Key Topics*: available estimation methods, primary/secondary/tertiary data and information, source categorization, emission factor sources, geographic variability within Mexico, QA/QC.

Volume VII—Emissions Inventory Development: Natural Sources. This manual provides guidance for developing a natural source emissions inventory (i.e., biogenic volatile organic compounds [VOCs] and soil nitrogen oxide [NO_x]). In addition, this manual includes the theoretical aspects of emission calculations and discussion of specific models. *Key Topics*: source categorization and definition, emission mechanisms, basic emission algorithms, biomass determination, land use/land cover data development, temporal and meteorological adjustments, emission calculation approaches.

Volume VIII—Modeling Inventory Development. This manual provides guidance for developing inventory data for use in air quality models and addresses issues such as temporal allocation, spatial allocation, speciation, and projection of emission estimates. *Key Topics*: definition of modeling terms, seasonal adjustment, temporal allocation, spatial allocation, chemical speciation, projections (growth and control factors).

Volume IX—Emissions Inventory Program Evaluation. This manual consists of three parts: QA/QC, uncertainty analysis, and emissions verification. The QA/QC portion defines the overall QA/QC program and is written to complement source specific QA/QC procedures written into other manuals. The uncertainty analysis includes not only methods of assessing uncertainty in emission estimates, but also for assessing uncertainty in modeling values such as speciation profiles and emission projection factors. The emissions verification section describes various analyses that can be performed to examine the accuracy of the emission estimates. Examples include receptor modeling and trajectory analysis combined with specific data analysis techniques. *Key Topics*: description of concepts and definition of terms, inventory review protocol, completeness review, accuracy review, consistency review, recommended uncertainty methodologies, applicable emission verification methodologies.

Volume X—Data Management. This manual addresses the important needs associated with the data management element of the Mexico national emission inventory program. *Key Topics*: general-purpose data management systems and tools, specific-purpose software systems and tools, coding system, confidentiality, electronic submittal, frequency of updates, recordkeeping, Mexico-specific databases, reports.

Volume XI—References. This manual is a compendium of tools that can be used in emission inventory program development. Inventory tools referenced in the other manuals are included (i.e., hardcopy documents, electronic documents, and computer models).

CONTENTS

Section **Page**

FIGURES AND TABLES

Figures **Page**

Tables **Page**

ACRONYMS

ADT	average daily traffic
ANAFAPYT	Asociación Nacional de Fabricantes de Pinturas y Tintas (National Association of Paint and Ink Manufacturers)
ARB	Air Resources Board
ASA	Aeropuertos y Servicios Auxiliares (Airports and Auxiliary Services)
BOD	biological oxygen demand
Btu	British thermal unit
CANACINTRA	Cámara Nacional de la Industria de la Transformación (National Association of the Manufacturing Industry)
CANALAVA	Cámara Nacional de la Industria de Lavanderías (National Association of the Dry Cleaning Industry)
CE	control efficiency
CE-CERT	College of Engineering - Center for Environmental Research and Technology
CFC	chlorofluorocarbon
CH_4	methane
CICA	Centro de Información sobre Contaminación del Aire (Information Center on Air Pollution)
CICOPLAFEST	Comisión Intersecretarial para el Control del Proceso y Uso delos Plaguicidas, Fertilizantes y Substancias Tóxicas (Intersecretarial Commission for the Control of the Processing and Use of Herbicides and Pesticides, Fertilizers, and Toxic Substances)
cm	centimeter
CO	carbon monoxide
DDF	Departamento del Distrito Federal

DQO	data quality objective
EET	emissions estimating techniques
EF	emission factor
EIIP	Emission Inventory Improvement Program
FAA	Federal Aviation Administration
FAEED	Federal Aircraft Engine Emission Database
FNM	Ferrocarriles Nacionales de México (National Mexican Railways)
g	gram
gr	grain
GEM	Gobierno del Estado de México (Government of the State of Mexico)
GIS	Geographic Information System
ha	hectare
HC	hydrocarbon
HCFC	hydrochlorofluorocarbon
HDDV	heavy duty diesel vehicles
HDGV	heavy duty gasoline vehicles
HFC	hydrofluorocarbon
hp	horsepower
hr	hour
IC	internal combustion
IMP	Instituto Mexicano de Petróleo (Mexican Petroleum Institute)
INE	Instituto Nacional de Ecología (National Institute of Ecology)

INEGI	Instituto Nacional de Estadística, Geografía e Informática (National Institute of Statistics, Geography, and Information)
kcal	kilocalorie
kg	kilogram
km	kilometer
kph	kilometers per hour
lb	pound
LDDT	light duty diesel trucks
LDDV	light duty diesel vehicles
LDGT	light duty gasoline trucks
LDGV	light duty gasoline vehicles
LPG	liquefied petroleum gas
LTO	landing and takeoff
m^3	cubic meter
MC	motorcycle
Mg	megagram (i.e., 10^6 g = 1 metric ton)
mg	milligram
mm	milliliter
mm Hg	millimeters of mercury
mol	mole
mph	miles per hour
NA	not available

NFDR	National Fire Danger Rating
NH_3	ammonia
NMHC	non-methane hydrocarbons
NO	nitrogen monoxide
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
N-P-K	nitrogen-phosphorus-potassium
O_2	oxygen
PEMEX	Petróleos Mexicanos
PM	particulate matter
$PM_{2.5}$	particulate matter of less than 2.5 microns aerodynamic diameter
PM_{10}	particulate matter of less than 10 microns aerodynamic diameter
POTW	publicly owned treatment works
ppmw	parts per million - weight
psi	pounds per square inch
psia	pounds per square inch absolute
QA	quality assurance
QC	quality control
RE	rule effectiveness
ROG	reactive organic gas
RP	rule penetration
RVP	Reid vapor pressure

S	saturation factor
S	sulfur
SAF	Seasonal Adjustment Factor
SAF	Society of American Foresters
SAGAR	Secretaría de Agricultura, Ganadería y Desarrollo Rural (Secretariat of Agriculture, Livestock, and Rural Development)
SCAQMD	South Coast Air Quality Management District
SCERP	Southwest Center for Environmental Research and Policy
SEMARNAP	Secretaría de Medio Ambientes, Recuros Naturals, y Pesca (Secretariat of the Environment, Natural Resources, and Fisheries)
SIMS	Surface Impoundment Modeling System
SNIFF	Sistema Nacional de Información de Fuentes Fijas (National Information System of Point Sources)
SO_2	sulfur dioxide
SO_x	sulfur oxides
SRM	Society for Range Management
THC	total hydrocarbons
TIM	time in mode
TOC	total organic compound
TOG	total organic gas
ton	English ton (i.e., 2,000 lbs)
UNAM	Universidad Nacional Autónoma de Mexico (National Autonomous University of Mexico)

U.S.	United States
USDA	United States Department of Agriculture
U.S. EPA	United States Environmental Protection Agency
VKT	vehicle kilometers traveled
VOC	volatile organic compound
vol	volume
wt	weight
yr	year
ZFN	Zona Fronteriza Norte (Northern Border Zone)
ZMCM	Zona Metropolitana de la Ciudad de México (Mexico City Metropolitan Zone)
ZMG	Zona Metropolitana de Guadalajara (Guadalajara Metropolitan Zone)
ZMM	Zona Metropolitana de Monterrey (Monterrey Metropolitan Zone)
ZMVM	Zona Metropolitana de la Valle de México (Valley of Mexico Metropolitan Zone)

1.0 INTRODUCTION

This manual provides guidance for developing an area and non-road mobile source emissions inventory (hereafter collectively referred to as area sources). Guidance is provided on inventory methods, including sources of activity data and applicable emission factors. General area and non-road mobile source information is presented, followed by a cross-reference table that associates each area source category with one or more of the basic emission estimating techniques (EETs) presented in Volume III of this document series, *Basic Emission Estimating Techniques*. The *Basic EETs Manual* explains and discusses each of the basic EETs, and provides sample calculations to illustrate their implementation.

Area sources represent the emissions from sources that are too numerous and dispersed to efficiently include in a point source inventory. Collectively, however, area sources are significant emitters of air pollutants, and such pollutants must be included in an emissions inventory to ensure completeness. Non-road mobile sources are included with stationary area sources primarily because the methods used to estimate area and non-road mobile emissions are very similar. In contrast, the inventory methodology applied to motor vehicles is significantly different, warranting presentation in a separate manual.

By definition, therefore, area sources are generally small and numerous. For example, gasoline stations and dry-cleaning establishments are often treated as area sources. Such facilities are typically not included in point source inventories because of the extensive effort that would be required to gather data and estimate emissions for each individual facility. One way to define area sources is based on emission level of an individual facility for a given pollutant (e.g., in the U.S., if *facility*-wide hydrocarbon emissions for any given pollutant are less than 10 tons per year, or less than 100 tons per year of oxides of nitrogen (NO_x), carbon monoxide (CO), or sulfur dioxide (SO_2), then it is considered an area source). The end-use of the inventory, the desired accuracy of the emissions, and the resources available for inventory development all contribute to establishing the point/area source cutoff. If the cutoff is too high, many facilities will not be considered individually as point sources—and their emissions may be overlooked—or their emissions may be less accurately estimated. If the cutoff is too low, both the resources needed for contacting plants and the size of the point source database will increase significantly.

Rather than distinguishing between individual facilities and emitting devices—the method in a point source inventory—area source inventories place emissions from similar sources into *categories*. An area source inventory generally consists of the following broad categories:

- Stationary source fuel combustion (e.g., residential fuel combustion);
- Non-road mobile sources (e.g., trains and mobile equipment);
- Solvent use (e.g., small surface coating operations);
- Product storage and transport distribution (e.g., gasoline);
- Light industrial/commercial sources;
- Agriculture (e.g., feedlots, crop burning);
- Waste management (e.g., landfills); and
- Miscellaneous area sources (e.g., forest fires, wind erosion, unpaved roads).

Each of these categories is comprised of more specific source categories (e.g., organic solvent use includes commercial/consumer solvent use, dry cleaning, surface cleaning) that are defined by similar emission processes or a similarity in the methods that best estimate emissions. A comprehensive area source inventory may contain 150 or more individual source categories. For example, dry cleaning is typically represented by two or more source categories to account for the different solvents that are used (i.e., perchloroethylene versus petroleum-based solvents).

From an emissions estimating perspective, area source categories may be organized into the following four groups:

Primary Manufacturing Operations. Manufacturing facilities too small for inclusion in the point source inventory (e.g., tortilla or brick manufacturers) may be inventoried as area sources by surveying a subset of these facilities and extrapolating the results to the entire industry based on some surrogate that is assumed to be associated with emissions (e.g., number of employees, manufacturing level, etc.).

Key Process Operations. Other area source categories consist of process operations that are treated as a group with no attempt to identify the type of facility and products manufactured. Industrial degreasing is an example of this type of category. These emissions result from solvent use in vats, spray and wipe cleaning, or other operations at a wide variety of facilities, making it impractical to identify degreasing usage by industrial sector.

Non-Industrial Human Activities. The next group of area source categories include emissions that occur over broad geographic regions resulting from some form of human activity. Two examples include pesticide use and commercial/consumer solvents.

Non-Road Mobile Sources. Non-road mobile sources represent the last type of source. They are generally defined as having internal combustion engines and being mobile, but are not typically licensed for operation on public roads. The most obvious non-road mobile source categories are airplanes, locomotives, and commercial marine vessels. Other non-road categories consist of agricultural, construction, and recreational equipment. Examples include tractors, bulldozers, and boats.

The remainder of this manual is organized as follows:

- Section 2.0 presents guidance on preparing an area source inventory, including descriptions of emission sources and emission estimating techniques;

- Section 3.0 presents the area and non-road mobile source cross-reference table, linking emission estimation methods discussed in Volume III of the series, *Basic Emission Estimating Techniques*, with specific area source categories;

- Sections 4.0 through 11.0 present each area and non-road mobile source category, including a description of the source category, available emission factors, guidance on potential activity data sources, and a sample calculation.

  The various area and non-road mobile source categories are organized as follows:

  — Section 4.0 - Stationary Source Fuel Combustion,

  — Section 5.0 - Non-Road Mobile Sources,

  — Section 6.0 - Solvent Use,

  — Section 7.0 - Product Storage and Transport,

  — Section 8.0 - Light Industrial/Commercial Sources,

  — Section 9.0 - Agriculture,

  — Section 10.0 - Waste Management,

  — Section 11.0 - Miscellaneous Area Sources; and

- Section 12.0 contains references cited throughout this volume.

> Please note that the activity data (e.g., population, fuel burned, solvent used, acreage, etc.) are generally hypothetical values that were specifically developed for the sample calculations. These values must be replaced by region-specific data in order to develop an area emissions inventory.

This manual presents the most recent recommended emission estimating methods for area sources in Mexico. As of March 1997, these methods are the most appropriate for use in Mexico. However, it is expected that this document will evolve in the future. As new Mexico-specific data and emission factors are developed, they should replace the information that is currently presented in this manual.

2.0 PREPARING AN AREA AND NON-ROAD MOBILE SOURCES EMISSIONS INVENTORY

This section introduces more of the concepts related to development of an area and non-road mobile source inventory. The *Basic EETs Manual* should be consulted for additional guidance on developing an inventory. In this section, area and non-road mobile emission sources are briefly described, planning and quality assurance/quality control (QA/QC) considerations are presented, emission estimating techniques (EETs) are discussed, and the need for adjustments to the emissions estimates is explained and illustrated. Lastly, discussions of reporting and data-coding procedures, geographic differences, and the causes of variability in emissions estimates are discussed.

2.1 Description of Emission Sources

For discussion purposes, area sources can be logically organized into the following general categories:

- Stationary source fuel combustion;
- Non-road mobile sources;
- Solvent use;
- Product storage and transport;
- Light industrial/commercial sources;
- Agriculture;

- Waste management; and
- Miscellaneous area sources.

Emissions from each source occur in a variety of ways. Fuel combustion can take place in a boiler, a fireplace, an internal combustion engine, or a non-road mobile source (e.g., locomotive, marine vessel, or aircraft). Emissions from solvent use occur through evaporation; emissions can be reduced by preventing evaporation or reducing the amount of solvent used. Product storage and transport emissions typically occur through evaporation (e.g., gasoline distribution, liquified petroleum gas [LPG] leaks). Emissions from light industrial/commercial processes occur from combustion (e.g., brick manufacturing), mechanical disturbance (e.g., building construction), or biological processes (e.g., bakeries). Emissions from agriculture occur from combustion (e.g., burning of crop residues), evaporation (e.g., pesticide application), mechanical disturbance (e.g., tilling) or biological processes (e.g., animal waste). Waste management emissions are caused by evaporation (e.g., publicly owned treatment works [POTWs]) and combustion (e.g., incineration). Emissions from miscellaneous area sources occur from combustion (e.g., forest fires, structure fires), mechanical disturbance (e.g., road dust), and biological processes (e.g., livestock ammonia [NH_3]).

A complete list of source categories can be found in Section 3.0 of this manual. Specific information regarding each source category is presented in Sections 4.0 through 11.0 of this manual.

2.2 Planning

Thorough planning at the beginning of the inventory process is essential for the development of a high quality inventory. The inventory scope is delineated in the planning phase. This includes identifying the following:

- End-uses of the inventory;

- Pollutants to be included;
- Geographic boundaries of the inventory region;
- Area and non-road mobile sources present in the inventory region;
- Area and non-road mobile sources to be included in the inventory; and
- EETs that will be used for each source category, including any adjustments that will be made.

These scope items should be clearly documented before any work begins on the emissions estimates. **The document that contains this information is called an inventory work plan.**

The purpose and intended use of an inventory are used to determine the data quality objectives (DQOs) for the inventory, as well as QA/QC requirements. DQOs are statements of the level of uncertainty a decision-maker is willing to accept. They ensure that the final inventory will be sufficient for its intended use. DQO statements must identify the end-use or intended purpose of the data, and the level of uncertainty anticipated in the emissions estimates. Hypothetical DQOs for an area source inventory may include completeness targets (e.g., “Include all sources believed to contribute more than 30,000 kg/year”), accuracy targets (e.g., “Reduce uncertainty of top three sources by conducting surveys to update emissions data”), and comparability items (e.g., “The inventory should include all sources in previously prepared inventory, and be prepared using comparable methods”).

The pollutants to be included in the inventory depend on the end-use and purpose of the inventory. For example, in an ozone nonattainment area emissions inventory, reactive volatile organic compounds (VOCs), carbon monoxide (CO), and NO_x are included. In an inventory that will be used in a visibility study, additional pollutants are included, such as sulfur oxides (SO_x) and fine particulate ($PM_{2.5}$).

The geographic region that the inventory will cover also depends on the end-use of the inventory. Typically, an inventory will cover a discrete area that has a common air pollution problem and/or regulatory entity. An inventory can be developed for the whole country, an individual state, a metropolitan zone, or a municipality. For example the classification of regions done in 1991 by the National Institute of Ecology (INE) could be considered as the geographic boundaries for inventory development (see Table 2-1). These six regions were delineated by INE based on their air quality. These regions also have distinct environmental characteristics, different types of vegetation, and different climatic conditions.

Some examples of the geographic regions covered in an inventory include a study of air pollution control measures for the Monterrey Metropolitan Area (Radian International, 1996). This area comprises the city of Monterrey and the municipalities of Juárez, San Pedro, Santa Catarina, San Nicolas, Guadalupe, Apodaca, and Escobedo. The Departamento del Distrito Federal (DDF) has prepared annual inventories of reactive VOCs, NO_x, and CO for the Zona Metropolitana de la Ciudad de México (ZMCM) (DDF, 1995a and DDF, 1996a).

To determine the area and non-road mobile sources in the inventory region, a comprehensive list of source categories can be compiled from the information presented in Section 3.0 of this manual.

Several of the area source categories that may be included in an area source inventory pertain to emissions from small industrial facilities. Published data by Instituto Nacional de Estadística, Geografía e Informática (INEGI) or the Cámara Nacional de la Industria de la Transformation (CANACINTRA) can be used to determine the extent of these smaller facilities in a geographic region. For example, INEGI provides information on the geographic distribution of principal manufacturing industries by state and aggregated manufacturing value, as well as number of employees by state and industrial sector for some industries. CANACINTRA also publishes data on industrial facilities.

Table 2-1

States Included in Regions of Special Interest

REGION I	REGION II	REGION III	REGION IV	REGION V	REGION VI
Baja California Baja California Sur Nayarit Sinaloa Sonora	Aguascalientes Chihuahua Coahuila Durango Zacatecas	Nuevo León San Luis Potosí Tamaulipas	Colima Guanajuato Guerrero Jalisco Michoacán	Distrito Federal Hidalgo México Morelos Puebla Querétaro Tlaxcala	Campeche Chiapas Oaxaca Quintana Roo Tabasco Veracruz Yucatan

The sources to be included in the inventory should be prioritized based on their importance in the inventory. Resources should be allocated preferentially to the sources that are most important in meeting the end-uses of the inventory. High priority sources include those that are known to be significant contributors of air pollution; are known to be sources of specific, targeted pollutants (e.g., PM_{10}); or are most likely to impact air quality.

Section 3.0 presents the EETs for each area and non-road mobile source category. Selection of the EET for each area and non-road mobile source category also means identifying the agencies, such as PEMEX and the National Mexican Railways (FNM), that will need to be contacted for activity data and information. In the planning process, complementary point, mobile, area, and biogenic inventory activities are also identified. Coordination is needed between these activities to ensure the completeness of the inventory and to make sure that the necessary inventory data are transferred from one group to another. For example, point source data are often needed to make adjustments in the emissions estimates for some area source categories.

Quality assurance/quality control (QA/QC) measures should also be delineated before any area or non-road mobile emissions are calculated. A good QA/QC program ensures that data collection, data handling, emission estimation, emission reporting, and documentation procedures are carefully planned and executed. A QA plan should be included as part of the inventory work plan to specify all QA/QC activities that will be followed.

2.3 Adjustments to Emission Estimates

While preparing the area source emissions estimates, or after the initial estimates have been prepared, the area source emissions estimates may need to be adjusted. Emissions estimates must often be adjusted to avoid double-counting with the point source inventory, to account for controls that are in place for some processes, to present emissions on a daily or seasonal basis rather than on an annual basis, or to adjust total organic compound (TOC) emissions if only reactive VOCs are needed for the inventory. **In general, adjustments should be made to the area source activity or emission factor data prior to calculation rather than to the emission estimate itself**. The methods used to make these adjustments are described below.

2.3.1 Point Source Adjustments

When a point source inventory and an area source inventory include emissions from the same process, the possibility of double-counting emissions exists. In these situations, the area source emission estimate should be adjusted. Certain area source categories such as commercial/consumer solvent use and architectural surface coating do not require any point source adjustments. Others, such as fuel combustion, industrial processes, and solvent utilization, may share processes with point sources. **To avoid double counting, the point source activity is subtracted from the total activity for the source category**. The resulting area source emissions estimate is shown in the following equation:

Area Source Activity = Total Activity of Source Category - Sum of Point Source Activity

For example, if the area source emissions are calculated using employment, the number of employees at the point sources must be subtracted from the inventory region employment to give the area source employment. If the resulting area source activity is less than zero, the point source data should be reviewed for errors, and any errors found should be corrected. If area source activity is still less than zero, the area source activity is assumed to be equal to zero, with emissions only from point sources.

The point source adjustment is sometimes made by subtracting point source emissions from total source emissions, although this should be the method of last resort. If this method is used, make sure to use uncontrolled emissions (from total sources and point sources). Any emission control adjustments needed for the area sources should be made after the point source adjustment.

2.3.2 Emission Control Adjustments

Area source controls are less common than point source controls. Nonetheless, when they occur, they must be factored into the emission calculation.

Types of controls used for area sources include banning, product substitution, and changing work practices, as well as traditional end-of-pipe control

devices. Examples of banning as a method to control emissions include bans on agricultural burning, open burning, and release of open sewage. The use of product substitution to control emissions is particularly effective when solvent-based coatings are replaced with water-based coatings. Changing work practices is an effective way to prevent evaporation of solvents. Some examples include requiring that degreasing units have lids and that the lids be kept closed when not in use; that solvent-laden rags be kept in closed containers; and that automotive repair shops use gun cleaners with enclosed solvent reserve units. Add-on control devices are less commonly used on area sources than on point sources. However, emissions from some area sources could be easily reduced using control devices. Examples include gasoline distribution and landfills.

Control efficiency is the emission reduction efficiency, and is a percentage representing the amount of a source category's emissions that are controlled by a control device, process changes, or reformulation. As discussed in the *Basic EETs Manual*, the overall CE of a control device is a combination of the capture device efficiency and the control device efficiency. The capture device efficiency is the percentage of the emissions stream that is taken into the control device. The control device efficiency is the percentage of the air pollutant that is removed from the emission stream and not released to the atmosphere.

Rule effectiveness is an adjustment to the CE to account for failures and uncertainties that affect the actual performance of the control. For example, control equipment performance may be adversely affected by age of the equipment, lack of maintenance, or improper use. **A default value of 0.80 for RE is recommended if information cannot be acquired to determine the true value of RE**.

Rule penetration is the percentage of the area source category that is covered by the applicable regulation, or is expected to comply with the regulation. The RP value can be based on a percentage of the source that is regulated, a cutoff level, or regulation of an activity. **Both RE and RP are applied to entire source categories when calculating area source emission estimates**. RP is a measure of the extent to which a regulation covers a source category. For example, regulations on gasoline underground tank filling may apply only to stations above a specified size cutoff, or to those built after a certain date.

The RP value must be estimated for each area source category; there is no default value that is feasible for all source categories. RP is calculated as:

$$\text{RP} = (\text{Uncontrolled emissions covered by regulation})/(\text{Total uncontrolled emissions}) \times 100$$

The following equation illustrates the effect of CE, RP, and RE on emissions estimates:

$$\text{Controlled emissions} = (\text{Uncontrolled emission factor}) \times (\text{activity data}) \times [(1-(\text{CE})(\text{RP})(\text{RE})]$$

CE, RE, and RP are discussed in more detail in the Basic EETs manual.

2.3.3 Temporal Adjustments

Source activities for many categories fluctuate on a seasonal basis. Because emissions are generally a direct function of source activity, seasonal changes in activity levels should be examined. **For all categories, the seasonal variations in activity must be considered if seasonal or daily emissions are to estimated**. Emission factors for some categories may also be dependent on seasonal variables. The type of information needed to calculate emissions depends on the source category and the desired temporal resolution of the emissions estimates.

Some operations, such as architectural surface coating, are more active in the warmer months because of the warmer weather. Other sources such as residential heating will exhibit activity only in colder months. Many other sources, such as processes associated with industrial facilities or commercial operations, will show no strong seasonal variability in activity throughout the year.

The best way to calculate daily or seasonal emission estimates is to obtain activity data that are specific for the season of interest. If this is not possible, an estimate of seasonal activity can be calculated using an adjustment factor applied to the annual activity.

Factors for making seasonal adjustments are often expressed as fractions. If the adjustment factor is expressed as a fraction, it is referred to as a seasonal adjustment factor (SAF). The equation below takes into consideration SAF for an ozone season emissions inventory:

$$\text{Ozone season emissions} = (\text{SAF}) \times (\text{Annual emissions estimate}) \qquad (2\text{-}4)$$

If daily emissions are to be calculated, the activity days per week and weeks per year must be identified so they can be used in the emission equation. For most industrial sources, the number of days per week is five. For commercial and consumer activities, six or seven days are generally used. The following equation demonstrates adjustments to calculate a daily emissions estimate for a process with a uniform annual operation:

$$\text{Emissions per day} = (\text{Annual emissions})/[(\text{Operating days/week}) \times (\text{Operating weeks/year})] \qquad (2\text{-}5)$$

A combination of the equations shown above is needed to estimate emissions for an ozone season day from a process that has annual operations that vary by season. This is shown in the following equation:

Ozone season day emissions = [(Annual emissions) × (SAF)]/[Operating days/week) × (Operating

Table 2-2 presents SAFs for ozone and carbon monoxide seasons and default activity days per week that are frequently used in the U.S. for estimating seasonal emissions. These factors are presented as examples; they will vary from area to area according to local conditions. If possible, Mexico-specific SAFs should be created, rather than relying on the U.S. SAFs presented in Table 2-2. SAFs are typically based upon local knowledge of source operations, engineering judgement, and surveying.

2.3.4 Adjustments for Non-reactive Compounds

Many different sources emit organic gases to the atmosphere. Collectively, the compounds that comprise hydrocarbon emissions are known as total organic gases (TOG). The concept of TOG includes all carbonaceous compounds except carbonates, metallic carbides, carbon monoxide, carbon dioxide and carbonic acid. From an air quality perspective, it is important to note that some of the TOG emitted to the atmosphere have limited, or no, photochemical reactivity and therefore do not participate in the formation of ozone. Nonphotochemically reactive compounds include:

- Methane;
- Ethane;
- Acetone;

Table 2-2

Area Source Seasonal Adjustment Factors and Days per Week for the Peak Ozone and CO Seasons

Area Source	**Seasonal Activity Factors**		**Activity Days Per Week**
	Summer	**Winter**	
Gasoline Service Stations			
Tank Trucks in Transit	Seasonal variations in throughput vary from region to region. Use average temperature for a summer day where appropriate. Resort areas, in particular, may show marked seasonality in gasoline sales.		6
Tank Truck Unloading (Stage I)			6
Vehicle Fueling (Stage II)			7
Storage Tank Breathing Losses			7
Solvent Users			
Degreasing	0.25		6
Dry Cleaning	0.25		5
Surface Coatings			
Architectural	0.33		7
Auto Refinishing	0.25		5
Other Small Industrial	0.25		5
Graphic Arts	0.25		5
Cutback Asphalt Paving	Refer to local regulations and practices		
Pesticides	0.33		
Commercial/Consumer	0.25		7

Table 2-2

(Continued)

Area Source	Seasonal Activity Factors		Activity Days Per Week
	Summer	Winter	
Waste Management Practices			
Publicly Owned Treatment Works	0.35		7
Municipal Landfills	0.25		7
Stationary Source Fossil Fuel Use			
Residential	0.08	0.43	7
Commercial/ Institutional	0.15	0.35	6
Industrial	0.25	0.25	6
Solid Waste Disposal			
On-Site Incineration	0.25	0.25	7
Open Burning	Refer to local regulations and practices	Refer to local regulations and practices	7
Structure Fires	0.20	0.33	7
Agricultural and Forest Burning	Refer to local regulations	0.10	7
Wildfires	Refer to local fire conditions	0.05	7

- Perchloroethylene;
- Methylene chloride;
- Methyl chloroform (1,1,1-trichloroethane)
- Chlorofluorocarbons (CFCs);
- Hydrochlorofluorocarbons (HCFCs);
- Hydrofluorocarbons (HFCs); and
- Perfluorocarbons.

Chemicals considered to be photochemically reactive are termed reactive organic gases (ROG). By definition, therefore, ROG is a subset of TOG. This manual encourages the development of both TOG and ROG emission estimates. At first it may seem unnecessary to inventory TOG, but developing TOG emission estimates can facilitate a number of reporting functions for such things as greenhouse gases and air toxics. In addition, TOG emissions are better suited for use in three dimensional grid models used to simulate ozone formation and transport. Therefore, this manual presents hydrocarbon emission factors as TOG, but also provides the fraction of TOG that is ROG. Unless otherwise stated, all ROG/TOG fractions were obtained from the California Air Resources Board (ARB, 1991b).

2.4 Reporting Emission Estimates and Data Coding

Reporting and documentation are integral parts of the inventory development process. **The reporting methods and data coding procedures that will be used should be specified in the inventory work plan**. The level of detail reported for the inventory will depend primarily on the end-use of the inventory. For example, all of the information used to develop an inventory whose results will directly affect rulemaking activities should be well documented. Enough information should be reported so the emissions estimates can be reproduced by independent reviewers.

For other inventories, it may be sufficient to cite the data sources so that an interested reviewer can locate the specific data as needed. Guidance on the importance of reporting and documentation is provided in *Emission Inventory Improvement Program, Volume III* (U.S. EPA, 1996b) and *Example Documentation Report for 1990 Base Year Ozone and Carbon Monoxide State Implementation Plan Emissions Inventories* (U.S. EPA, 1992b).

For each area source emission estimate, it will be necessary to assign the source category a numerical code. This numerical code will facilitate the electronic data management of the emissions and sharing of emissions between different regions. This manual recommends the application of a 10-digit coding system. Each code is divided into segments: xx-xx-xxx-xxx. The first two digits of the code represent the following major categories:

- 21 - stationary source fuel combustion;
- 22 - mobile sources;
- 23 - industrial processes;
- 24 - solvent utilization;
- 25 - storage and transport;
- 26 - waste disposal;
- 27 - natural sources; and
- 28 - miscellaneous sources.

The next two digits provide an indication of the type of source. For example, all industrial fuel combustion inventoried under area sources would be 21-02-xxx-xxx. The remaining six digits describe the type of fuel and type of combustion device. For example, industrial liquefied petroleum gas (LPG) burned in all boiler types is 21-02-007-000 (the last three digits are listed as zeros because a specific combustion device has not been specified). Recommended numerical codes for each area source category are presented in Sections 4.0 through 8.0 with each emission estimating methodology. A master list of the 10 digit codes is contained in Appendix V-A. In some instances, new codes were developed to accommodate Mexico-specific source categories. The Mexico-specific codes are marked with an asterisk (*) in Sections 4.0 through 11.0.

2.5 Geographic Differences and Causes of Variability

The methods used to estimate area and non-road mobile source emissions are generally more accurate on a large geographic scale than a small one. One important reason for this variability involves the use of per capita and per employee emission factors. **Emission factors relate the quantity of a pollutant released by a unit of activity. It is important to note that an average emission factor does not account for geographic variability in activity.** For example, dry-cleaning solvents are much more prevalent in urban areas than they are in rural areas.

For example, if per capita emission factors are used to estimate emissions and there are large regional differences in purchasing practices, product usage, or the use of commercial services such as dry-cleaning and auto body refinishing, they will not be taken into consideration using nationally-based per capita emission factors. The variability in emissions will only be reflected if the per capita emission factors are adjusted in some way. For example, it may be possible to conduct a survey and develop stratified per capita emission factors based on average household income to better represent activity from area and non-road mobile sources.

The use of nationally-based per employee emission factors also introduces uncertainty. These emission factors will overestimate emissions for operations that are very labor-intensive. Again, it may be possible to conduct a survey to develop per employee emission factors that represent the variability associated with the number of employees and production levels.

3.0 RECOMMENDED EMISSION ESTIMATING TECHNIQUES

Air pollutant emissions from area sources can be estimated by different emission estimating techniques (EETs). Volume III of this series, the *Basic EETs Manual*, describes each estimating technique in detail.

The techniques used to estimate area source emissions vary by source category. The selection of an EET requires consideration of the availability of data. If a large amount of data are needed to use a particular method, the costs may have to be weighed against the desired quality of the emissions estimate. For example, if the risks of adverse environmental effects from the source are high, more sophisticated and costly EETs may be necessary. Conversely, where risks are low, less expensive estimation methods may be acceptable. In some ways, the factors that drive selection of an EET for a given source category are identical to those that define the source categories to be included in the inventory (e.g., use of the inventory, costs, availability of data, etc.).

Table 3-1 recommends EETs for various area and non-road mobile source categories and identifies the pollutants that are emitted from each source category. The source categories and recommended EETs shown in Table 3-1 and discussed in Sections 4.0 through 11.0 should not be considered as definitive, but rather as general guidelines that should be adapted to the local conditions of the study area.

In Table 3-1, each applicable EET is given a ranking based on consideration of the emissions source, the availability of data, and the cost and quality of the emissions estimates. A rank of “1" indicates that a method is the most preferred. If a method does not have a ranking,

Table 3-1

Recommended Emission Estimating Techniques

Section Number	Area Source Category	Pollutants	Emission Factor	Survey/ Extrapolation	Emissions Model	Material Balance
4.1	Industrial and Commercial/ Institutional Fuel Combustion	TOG, NO_x, CO, PM, SO_x	1			
4.2	Residential Fuel Combustion (Commercial Fuels)	TOG, NO_x, CO, PM, SO_x	1			
4.3	Residential Fuel Combustion (Biomass or Waste-derived Fuels)	TOG, NO_x, CO, PM, SO_x	1			
5.1	Locomotives	TOG, NO_x, CO, PM, SO_x	1			
5.2	Commercial Marine Vessels	TOG, NO_x, CO, PM, SO_x	1			
5.3	Aircraft	TOG, NO_x, CO, PM, SO_x	1			
5.4	Other Non-Road Mobile Equipment	TOG, NO_x, CO, PM, SO_x	1			
5.5	Border Crossings	TOG, NO_x, CO, PM, SO_x			1	
5.6	Bus/Truck Terminals	TOG, NO_x, CO, PM, SO_x			1	
6.1	Industrial Surface Coating[a]	TOG	2	1		1

Table 3-1

(Continued)

Section Number	Area Source Category	Pollutants	Emission Factor	Survey/ Extrapolation	Emissions Model	Material Balance
6.2	Auto Body Refinishing[a]	TOG	2	1		1
6.3	Architectural Surface Coating[a]	TOG	2	1		1
6.4	Traffic Paints[a]	TOG	2	1		1
6.5	Industrial Surface Cleaning[a] (Degreasing)	TOG	2	1		1
6.6	Dry Cleaning	TOG	2	1		1
6.7	Graphic Arts[a]	TOG	2	1		1
6.8	Asphalt Application[a]	TOG	2	1		1
6.9	Commercial/ Consumer Solvent Use	TOG	1			
7.1	Gasoline Distribution	TOG	1			
7.2	Aircraft Refueling	TOG	1			
7.3	LPG Distribution	TOG		1		1
8.1	Bakeries	TOG	1			
8.2	Brick Manufacturing	TOG, NO_x, CO, PM, SO_x	2	1		
8.3	Construction Activities	PM	2		1	
8.4	Charbroiling	TOG, PM	1	1		
8.5	Street Vendors	TOG, PM	1	1		

Table 3-1

(Continued)

Section Number	Area Source Category	Pollutants	Emission Factor	Survey/ Extrapolation	Emissions Model	Material Balance
9.1	Pesticide Application[b]	TOG		1		1
9.2	Beef Cattle Feedlots	PM	1			
9.3	Agricultural Burning	TOG, CO, PM	1			
9.4	Fertilizer Application	NH_3	2	1		1
9.5	Animal Waste	NH_3	1			
9.6	Agricultural Tilling	PM	1			
10.1	On-Site Incineration	TOG, NO_x, CO, PM, SO_x	1			
10.2	Waste Management—Open Burning	TOG, NO_x, CO, PM, SO_x	1			
10.3	Wastewater Treatment	TOG	2		1	
10.4	Open Channel Sewage and Wastewater[b]	TOG, NH_3		1		1
11.1	Wildfires	TOG, NO_x, CO, PM, SO_x	1			
11.2	Structure Fires	TOG, NO_x, CO, PM	1			
11.3	Paved Road Dust	PM	2		1	

Table 3-1

(Continued)

Section Number	Area Source Category	Pollutants	Emission Factor	Survey/ Extrapolation	Emissions Model	Material Balance
11.4	Unpaved Road Dust	PM	2		1	
11.5	Wind Erosion	PM	2		1	
11.6	Domestic Ammonia Emissions[b]	NH_3		1		1

[a] Emission estimates for solvent use categories can be developed using emission factors or by combining survey/extrapolation with material balance information obtained.

[b] Emission estimates for these categories are developed by combining survey/extrapolation with material balance information obtained.

[c] EETs for this category will vary based on the industries identified in the inventory area.

CO = carbon monoxide
LPG = liquified petroleum gas
NH_3 = ammonia
NO_x = nitrogen oxides
PM = particulate matter
SO_x = sulfur oxides
TOG = total organic gases

then it is not available for that source category. The basic EETs are summarized below with respect to area sources.

No single EET can be used to estimate emissions for all area sources. Volume III of this series, the *EETs Manual* should be consulted for a discussion on the selection and use of the different EETs, cost versus quality considerations, and a discussion of the advantages and disadvantages of the various EETs.

Census-Based Emission Factors. Emission factors relate the quantity of a pollutant released to a unit of activity. Emission factors can be either process-based or census-based. Process-based emission factors are normally used for point sources. Census-based emission factors are commonly used for area sources. The use of census-based emission factors is an efficient method for dispersed and numerous emission source types that cannot be readily characterized by a knowledge of process rates, fuel consumption rates, and/or material feed rates. Compared to other EETs, the use of census-based emission factors is the most cost-effective choice, since census data are readily available for most emission inventory regions from the Instituto Nacional de Estadística, Geografía e Informática (INEGI). Most census-based emission factors, however, have been developed from U.S. data. Over time, these emission factors should be replaced with factors developed from Mexican data. As Mexican data are developed, census-based emission factors will provide a highly efficient method of calculating emissions.

Survey/Extrapolation. A survey questionnaire is the technique commonly used to gather point source inventory data. A survey approach can also be used to gather information needed to calculate area source emissions. For area sources, survey questionnaires are sent to a subset of facilities, and the results are extrapolated to the remaining facilities based on some surrogate that is related to emission levels. It is important to note here that while the survey/extrapolation method is rated higher than the use of emission factors in Table 3-1, the survey must be carefully planned and executed for this ranking to apply. If the survey is sent to a nonrepresentative subset of facilities, if the questions are not asked or answered correctly, or if the data received from respondents are not carefully handled (i.e., data entry errors), grossly inaccurate emissions estimates may result.

Emissions Models. Emissions models are designed to produce more accurate emissions estimates than an emission factor approach. However, emissions models have been developed for only a limited number of area source categories. The accuracy of the results of an emissions model are dependent not only on the quality of the input data, but on the assumptions underlying the model as well.

Material Balance. The material or mass balance approach is suitable for estimating emissions associated with solvent evaporation. In its simplest form, a material balance approach assumes that all solvent consumed by a source evaporates. As shown in Table 3-1, the material balance approach for area sources is combined with survey results and extrapolated to an entire source category.

4.0 STATIONARY SOURCE FUEL COMBUSTION

Some small boilers, furnaces, space heaters, water heaters, and engines may be too small to be included in the point source inventory for a given inventory region. Therefore, these smaller stationary fuel combustion sources need to be included in the area source inventory effort. Inventory guidance for these sources are presented in the following subsections:

- Industrial and Commercial/Institutional Fuel Combustion;
- Residential Fuel Combustion (Commercial Fuels); and
- Residential Fuel Combustion (Biomass or Waste-Derived Fuels).

4.1 Industrial and Commercial/Institutional Fuel Combustion

SOURCE CODE:	DESCRIPTION:
Industrial	
21-02-001-000	Anthracite Coal
21-02-002-000	Bituminous/Subbituminous Coal
21-02-004-000	Distillate Oil: Total - Boilers & Internal Combustion (IC) Engines
21-02-004-001	Distillate Oil: All Boiler Types
21-02-004-002	Distillate Oil: All IC Engine Types
21-02-005-000	Residual Oil
21-02-006-000	Natural Gas: Total - Boilers & IC Engines
21-02-006-001	Natural Gas: All Boiler Types
21-02-006-002	Natural Gas: All IC Engine Types
21-02-007-000	Liquified Petroleum Gas (LPG)
21-02-008-000	Wood
21-02-009-000	Coke
21-02-010-000	Process Gas
21-02-011-000	Kerosene
21-02-012-000	Waste Oil
Commercial/Institutional	
21-03-001-000	Anthracite Coal
21-03-002-000	Bituminous/Subbituminous Coal
21-03-004-000	Distillate Oil: Total - Boilers & IC Engines
21-03-004-001	Distillate Oil: All Boiler Types
21-03-004-002	Distillate Oil: All IC Engine Types
21-03-005-000	Residual Oil
21-03-006-000	Natural Gas: Total - Boilers & IC Engines
21-03-006-001	Natural Gas: All Boiler Types
21-03-006-002	Natural Gas: All IC Engine Types
21-02-007-000	LPG: Total - All Combustor Types
21-03-007-005	LPG: All Boiler Types
21-03-007-010	LPG: Asphalt Kettle Heaters
21-03-008-000	Wood
21-03-011-000	Kerosene: Total - All Combustor Types
21-03-011-005	Kerosene: All Boiler Types
21-03-011-010	Kerosene: Asphalt Kettle Heaters
21-03-012-000	Waste Oil: All Boiler Types
21-03-012-010	Waste Oil: Batch Asphalt Heaters

DESCRIPTION:

Industrial fuel combustion is the use of coal, oil, kerosene, natural gas, liquified petroleum gas (LPG), and wood for heating and power at industrial facilities. These fuels can be burned using a number of different equipment types including boilers, internal combustion (IC) engines, furnaces, heaters, and other heating units too small to be included in a point source inventory. Electric utilities are excluded from this category and should be inventoried as point sources. Commercial/institutional facilities are establishments that engage in retail and wholesale trade, hotels, restaurants, schools, hospitals, government buildings, etc. Note that this source category includes combustion emissions from Mexico-specific sources such as tortilla factories and public baths. The emissions from these facilities are not inventoried separately. Rather, the fuel consumption from all sources is aggregated to yield a total that is used in the emission calculation. This aggregation is done by fuel type because the emission factors vary by fuel. In addition, speciation of the emission estimates for use in a three dimensional grid model requires categorizing emissions by fuel type.

POLLUTANTS: TOG, CO, NO_x, SO_x, and PM

ROG: For combustion sources, adjustments are necessary to account for non-reactive methane and ethane emissions. For most combustion categories, AP-42 provides emission factors for total organic compounds (TOC) and methane. Note that "TOC" in AP-42 is equivalent to "TOG." In these cases, these data should be used to develop an ROG emission factor (EF) (i.e., $EF_{ROG} = EF_{TOC} - EF_{CH4}$) and this ROG emission factor should be used to estimate ROG emissions. If the emission factor data available are not detailed enough to support this approach, then the ROG/TOG factors provided below may be used.

SOURCE CODE:	**ROG/TOG:**	**DESCRIPTION:**
Industrial		
21-02-001-000	NA	Anthracite Coal
21-02-002-000	NA	Bituminous/Subbituminous Coal
21-02-004-000	NA	Distillate Oil: Total - Boilers & IC Engines
21-02-004-001	82.8%	Distillate Oil: All Boiler Types
21-02-004-002	97.2%	Distillate Oil: All IC Engine Types
21-02-005-000	82.8%	Residual Oil
21-02-006-000	NA	Natural Gas: Total - Boilers & IC Engines
21-02-006-001	39.7%	Natural Gas: All Boiler Types
21-02-006-002	7.4%	Natural Gas: All IC Engine Types
21-02-007-000	64.6%	LPG
21-02-008-000	NA	Wood
21-02-009-000	NA	Coke

21-02-010-000	NA	Process Gas
21-02-011-000	NA	Kerosene
21-02-012-000	NA	Waste Oil
Commercial/Institutional		
21-03-001-000	NA	Anthracite Coal
21-03-002-000	NA	Bituminous/Subbituminous Coal
21-03-004-000	NA	Distillate Oil: Total - Boilers & IC Engines
21-03-004-001	82.8%	Distillate Oil: All Boiler Types
21-03-004-002	97.2%	Distillate Oil: All IC Engine Types
21-03-005-000	82.8%	Residual Oil
21-03-006-000	NA	Natural Gas: Total - Boilers & IC Engines
21-03-006-001	39.7%	Natural Gas: All Boiler Types
21-03-006-002	7.4%	Natural Gas: All IC Engine Types
21-02-007-000	64.6%	LPG: Total - All Combustor Types
21-03-007-005	64.6%	LPG: All Boiler Types
21-03-007-010	64.6%	LPG: Asphalt Kettle Heaters
21-03-008-000	NA	Wood
21-03-011-000	NA	Kerosene: Total - All Combustor Types
21-03-011-005	NA	Kerosene: All Boiler Types
21-03-011-010	NA	Kerosene: Asphalt Kettle Heaters
21-03-012-000	NA	Waste Oil: All Boiler Types
21-03-012-010	NA	Waste Oil: Batch Asphalt Heaters

Note: An ROG/TOG ratio of “NA” indicates that no specific ROG/TOG ratio is available from the cited California Air Resources Board (ARB) reference. However, for “other” fuel types or combustion categories not specified in their reference, California ARB indicates that 69.9% may be used as a default value.

POINT SOURCE ADJUSTMENTS:

Emissions for this source category are estimated using emission factors and industrial and commercial/institutional fuel use (from PEMEX). Fuel used at industrial facilities included in the point source inventory should be subtracted from the total fuel used to develop an area source emissions estimate for industrial facilities. Unless specific information is known regarding commercial/institutional point sources, it can be assumed that all commercial/institutional facilities are area sources.

METHODOLOGY:

The amount of each type of fuel should be apportioned by type of combustion equipment for each fuel type. If information on specific types of combustion equipment is not available, assumptions must be made about types of equipment present (if they can be reasonably supported), or the most conservative (highest) emission factors should be used.

Emission factors can be found in Chapter 1 of AP-42 (AP-42, 1995) and in Appendix V-B of this volume (Note: In AP-42, “TOG” is referred to as “TOC”). Sections in this chapter cover emissions from bituminous and subbituminous coal, anthracite coal, lignite, fuel oil, natural gas, LPG, wood waste, and waste oil.

The fuel used at point source facilities should be subtracted from the fuel amounts apportioned by equipment type:

$$\begin{matrix}\text{Area Source}\\ \text{Fuel Burned by}\\ \text{Equipment Type A}\end{matrix} = \begin{pmatrix}\text{Total Fuel}\\ \text{Burned by}\\ \text{Equipment Type A}\end{pmatrix} - \begin{pmatrix}\text{Point Source}\\ \text{Fuel Burned by}\\ \text{Equipment Type A}\end{pmatrix} \qquad (4.1\text{-}1)$$

Some emission factors will need to be adapted to local conditions, such as fuel sulfur or ash characteristics or fuel heat content. Refer to Volume IV of this manual series, *Emissions Inventory Development: Point Sources,* Section 3.1.1, Combustion Characteristics, for more information about fuel properties and operating conditions. A typical calculation multiplies the fuel characteristic by an emission coefficient:

$$\text{Emission Factor} = \text{Fuel Characteristic} \times \text{Emission Coefficient} \qquad (4.1\text{-}2)$$

Emission factors for each combustion equipment type are multiplied by the fuel burned by equipment type at area source facilities as shown below:

$$\text{Emissions} = \begin{pmatrix}\text{Area Source}\\ \text{Fuel Burned by}\\ \text{Equipment Type A}\end{pmatrix} \times \begin{pmatrix}\text{Emission Factor}\\ \text{for Equipment}\\ \text{Type A}\end{pmatrix} \qquad (4.1\text{-}3)$$

DATA NEEDED:

Data	Sources
Fuel used in inventory area, by type	PEMEX
Fuel use by equipment type (if available)	Survey or local information, PEMEX
Point source fuel use, by equipment type	SNIFF Database
Fuel characteristics, as needed	PEMEX
Emission factors by fuel type, equipment type	AP-42, 1995 (see Appendix V-B of this manual)

NOTES:

1. The fuel usage data provided by PEMEX should be adjusted to reflect any local variations in types of fuel used. For example, if wood use is known to be high in the inventory area but no wood usage data are supplied by PEMEX, a survey should be conducted to determine local wood use or other sources of data should be evaluated. The Basic Emissions Estimating Techniques Manual describes the methodology for conducting a survey.

2. If necessary, an assumption may be made that all industrial fuel (100 percent) is consumed at point source facilities, and all commercial/institutional fuel (100 percent) is consumed at area source facilities.

SAMPLE CALCULATIONS:

A. In this example, 60,000 liters of diesel were used by the public baths in the Mexico City Metropolitan Zone (DDF, 1995a) in 1992. Information obtained from the SNIFF Database indicates that no public baths are considered to be point sources. Assume that the sulfur content of the fuel is 0.5 wt%. Emissions for SO_2 and CO are calculated using the following steps:

Steps for calculating SO_2 emissions:

1. Subtract point source fuel use:

$$\begin{array}{c}\text{Area Source}\\\text{Fuel Use}\end{array} = 60{,}000 \text{ liters} - 0 \text{ liters}$$

$$= 60{,}000 \text{ liters}$$

2. Diesel fuel is similar to Number 2 distillate fuel. Therefore, the distillate fuel emission factors from *AP-42, Section 1.3, Fuel Oil Combustion* should be used (see Appendix V-B). The emission factor for SO_2 is a function of a coefficient and the weight percent of sulfur content in the fuel:

$$\text{Sulfur Content} = 0.5\,\%\ \text{by Weight}$$

$$\begin{matrix}\text{AP}-42\ \text{Emission Factor}\\ \text{for } SO_2\ (\text{kg}/10^3\ \text{liters})\end{matrix} = 17 \times 5\%$$

$$\begin{matrix}\text{Emission Factor}\\ \text{for } SO_2\ (\text{kg}/10^3\ \text{liters})\end{matrix} = 17 \times 0.5$$

$$= 8.5\ \text{kg}/10^3\ \text{liters}$$

3. Emissions for SO_2 are then calculated as:

$$60{,}000\ \text{liters} \times 8.5\ \text{kg}/10^3\,\text{liters} = 510\ \text{kg}\ SO_2$$

Steps for calculating CO emissions:

1. Point source subtraction is calculated above.

2. The AP-42 emission factor is 0.6 kg/10^3 liters.

3. Emissions for CO are then calculated as:

$$60{,}000\ \text{liters} \times 0.6\ \text{kg}/10^3\ \text{liters} = 36\ \text{kg}\ \text{CO}$$

B. In this example, 67,030,000 liters of LPG were used by the tortilla factories (tortillerias) in the Mexico City Metropolitan Zone (DDF, 1995a) in 1992. Assume that information obtained from the SNIFF Database indicates that some of these tortilla factories are already included in the point source inventory (and that they use 12,000,000 liters of LPG). Emissions for CO are calculated using the following steps:

1. Subtract point source fuel use

Area Source LPG Use = 67,030,000 liters - 12,000,000 liters
= 55,030,000 liters

2. Determine the CO emission factor:

For LPG combustion, AP-42 presents emission factors for the combustion of butane and the combustion of propane (see Appendix V-B, Section 1.5). For emission calculating purposes, Mexican LPG is approximately 60% propane and 40% butane (PEMEX, 1996).

$$
\begin{aligned}
EF &= (60\% \times EF_{propane}) + (40\% \times EF_{Butane}) \\
&= (60\% \times 0.2) + (40\% \times 0.3) \\
&= 0.24 \text{ kg CO}/10^3 \text{ liters}
\end{aligned}
$$

3. Emissions for CO are then calculated as:

$$(55{,}030{,}000 \text{ liters}) \times (0.24 \text{ kg}/10^3 \text{ liters}) = 13{,}200 \text{ kg CO}$$

4.2 Residential Fuel Combustion (Commercial Fuels)

SOURCE CODE:	**DESCRIPTION:**
21-04-001-000	Anthracite Coal
21-04-002-000	Bituminous/Subbituminous Coal
21-04-004-000	Distillate Oil
21-04-005-000	Residual Oil
21-04-006-000	Natural Gas: Total
21-04-007-000	LPG
21-04-011-000	Kerosene

DESCRIPTION:

The residential fuel combustion (commercial fuels) category is for the combustion of coal, oil, natural gas, and LPG used for heating of individual homes and apartment complexes. Non-commercially available fuels (e.g., wood, crop waste, waste oil, waste solvents, tires, etc.) are excluded from this category and should be inventoried as residential fuel combustion (biomass and waste-derived fuels). Additionally, emissions from leaks and evaporation from LPG storage and distribution systems should be inventoried as LPG distribution sources.

In Mexico, diverse types of fuel are used domestically, principally for cooking food and in water heaters. Each year approximately 2 million tons of LPG are used for residential cooking and heating in Mexico City. (Sacramento Bee, 1995a). The Metropolitan Zone of the Valley of Mexico (ZMVM) is the largest LPG market in the world with the LPG consumption, at 70,000 barrels per day, almost the same as that of gasoline. The use of LPG for cooking and heating water in Mexico extends throughout all regions, and according to the data from INEGI, about 70% of the residential houses in Mexico use gas for cooking. However, in the city of Monterrey, Nuevo León, natural gas is the primary domestic fuel used and in Chiapas and Oaxaca wood and coal predominate.

POLLUTANTS: TOG, CO, NO_x, SO_x, and PM

ROG: For combustion sources, adjustments are necessary to account for methane and ethane emissions. For most combustion categories, AP-42 provides emission factors for TOC and methane. Note that “TOC” in AP-42 is equivalent to “TOG.” In these cases, these data should be used to develop an ROG EF (i.e., $EF_{ROG} = EF_{TOC} - EF_{CH4}$) and this ROG emission factor should be used to estimate ROG emissions. If the emission factor data available are not detailed enough to support this approach, then the ROG/TOG factors provided below may be used.

SOURCE CODE:	ROG/TOG:	DESCRIPTION:
21-04-001-000	NA	Anthracite Coal
21-04-002-000	NA	Bituminous/Subbituminous Coal
21-04-004-000	NA	Distillate Oil
21-04-005-000	82.8%	Residual Oil
21-04-006-000	NA	Natural Gas: Total - All Combustor Types
21-04-007-000	64.6%	LPG: Total - All Combustor Types
21-04-011-000	NA	Kerosene: Total - All Combustor Types

Note: An ROG/TOG ratio of "NA" indicates that no specific ROG/TOG ratio is available from the cited California ARB reference. However, for "other" fuel types or combustion categories not specified in their reference, California ARB indicates that 69.9% may be used as a default value.

POINT SOURCE ADJUSTMENTS:

Emissions for this source category are generally not included in a point source inventory. Therefore, it is not expected that point source adjustments will be necessary. However, as illustrated in the example calculation, care must be taken to ensure that the fuel usage data correctly reflects residential usage and does not include any industrial or commercial usage.

METHODOLOGY:

The amount of each type of fuel combusted for domestic use needs to be determined for the inventory region. If the fuel usage statistics available do not directly correspond to the needs of the inventory effort (e.g., statewide statistics are available but the inventory region includes portion of multiple states; statewide statistics are available, but the inventory requires municipal-level emission estimates), then census data (e.g., population or housing) can be used to resolve this issue. The sample calculation presented below illustrates this procedure.

Emission factors can be found in Chapter 1 of AP-42 (AP-42, 1995) and in Appendix V-B of this volume (Note: In AP-42, "TOG" is referred to as "TOC"). Sections in Chapter 1 cover emissions from bituminous and subbituminous coal, anthracite coal, lignite, fuel oil, natural gas, LPG, wood waste, and waste oil. If AP-42 does not specifically provide "residential" emission factors for a given fuel type (e.g., LPG combustion), the commercial or institutional emission factors should be used.

Some emission factors will need to be adapted to local conditions, such as fuel sulfur or ash characteristics or fuel heat content. Refer to Volume IV in this series of manuals, *Emissions Inventory Development: Point Sources*, Section 3.1.1, Combustion Characteristics, for more information about fuel properties and operating conditions. A typical PM or SO_x emission factor consists of a fuel characteristic (ash or sulfur content) multiplied by an emission coefficient (empirical constant):

$$\text{Emission Factor} = \text{Fuel Characteristic} \times \text{Emission Coefficient} \qquad (4.2\text{-}1)$$

For each fuel type, the quantity of fuel burned by residential sources are multiplied by the emission factors for each combustion equipment type as shown below:

$$\text{Emissions} = \begin{pmatrix} \text{Area Source} \\ \text{Fuel Burned by} \\ \text{Equipment Type A} \end{pmatrix} \times \begin{pmatrix} \text{Emission Factor} \\ \text{for Equipment} \\ \text{Type A} \end{pmatrix} \qquad (4.2\text{-}2)$$

<u>DATA NEEDED</u>:

Data	Sources
Fuel used in inventory area, by fuel type	PEMEX
Population or Housing Data	INEGI, 1993
Fuel characteristics, as needed	PEMEX
Emission factors by fuel type, equipment type	AP-42, 1995 (see Appendix V-B of this manual)

<u>NOTES</u>:

1. The fuel usage data provided by PEMEX should be adjusted to reflect any local variations in types of fuel used. For example, if coal use is known to be high in the inventory area but no coal usage data are supplied by PEMEX, other sources of data should be evaluated or a survey should be conducted to determine local coal use.

2. If fuel characteristics data are not available from PEMEX, the Mexican Official Norm NOM-086-ECOL-1994 have the following specifications for sulfur content of fuels that may be used as default values:

Fuel type	Maximum sulfur level (wt%)[a]	Typical sulfur value in 1995 (wt%)[b]
Magna sin	0.10	—
Magna sin (ZFN)	0.10	—
Magna sin (ZMCM) (a partir de 1998 también en la ZMM y ZMG)	0.10	0.048
Nova plus	0.15	—
Nova plus (ZMCM) (a partir de 1998 también en la ZMM y ZMG)	0.15	0.07
Diesel sin (ZMCM, ZMM y ZMG)	0.05	0.041
Diesel desulfurado	0.5	—
Diesel industrial	0.5	—
Gasóleo industrial	2.0	—
Combustóleo pesado	4.0	—
Combustóleo hidrotratado (ZMCM) (a partir del 1° de enero de 1988)	1.0	—
Combustible ligero (para zonas críticas)	2.0	—
Gas natural	0.32 dm^3/m^3	—
Gas licuado de petróleo (Gas L.P)	0.14 kg/mg	—
Turbosina	0.3	—

[a] Source: Norma Oficial Mexicana NOM-086-ECOL-1994

[b] Source: Programa para mejorar la calidad del aire en el Valle de México 1995-2000; DDF, GEM, SEMARNAP, SSa.; 1996.

3. Detailed studies are not available on the efficiency of LPG combustion equipment that are used in Mexico, but, in general, the efficiency is low. In some cases, up to 20% of the hydrocarbons are released uncombusted, and these equipment tend to work with excess air, which reduces the thermal efficiency even more (DDF, et al, 1996). If available, Mexico-specific data should be used to adjust the AP-42 emission factors to reflect incomplete combustion.

SAMPLE CALCULATION:

This example shows how to calculate emissions from residential LPG combustion in Benito Juárez, a delegation of Mexico City, and is based on data obtained to develop the residential fuel combustion emissions for the Mexico City area source inventory (DDF, 1995a). Emissions for SO_2 and CO are calculated using the following steps:

1. Determine the amount of residential LPG use in the ZMCM:

In Oficio GPASI-1511/93, PEMEX reported that the total amount of LPG consumed in the ZMCM in 1993 was 3830.31 x 10^3 cubic meters (m^3). Based on 1992 PEMEX figures, it was estimated that 80% of the total LPG use was for residential purposes. Therefore,

Total residential LPG use in ZMCM $= (3830.31 \times 10^3\ m^3) \times (80\%)$
$= 3064.25 \times 10^3\ m^3$

2. Determine the amount of residential LPG use in Benito Juárez:

Delegation-specific fuel usage data were not obtained from PEMEX. Therefore, INEGI population data were used to disaggregate the ZMCM fuel usage data to the individual delegations. The total ZMCM population was 14,564,679 and the Benito Juárez population was 407,811. Therefore,

Total residential LPG use in Benito Juárez
$= (3064.25 \times 10^3\ m^3) \times (407{,}811 / 14{,}564{,}679)$
$= 85.799 \times 10^3\ m^3$
$= 85{,}799 \times 10^3$ liters

Note: It is preferable to use housing data if most of the fuel is used for heating. However, in this case, most of the LPG is used for cooking purposes, so population data are preferred.

3. Determine the SO_2 emission factor:

The AP-42 emission factors for SO_2 are (0.011S and 0.012S. That is, they are a function of a coefficient (i.e., 0.011 and 0.012) and the sulfur content in the fuel (i.e., S, expressed in gr/100 ft^3). Based on the metric equivalent used by DDF (i.e., 0.009 g/100 m^3):

S(gr/100 ft^3) $= (0.009\ g/100\ m^3) \times (m^3/35.31\ ft^3) \times (lb/453.6\ g) \times (7000\ gr/lb)$
$= 0.0039\ gr/100\ ft^3$

For LPG combustion, AP-42 presents emission factors for the combustion of butane and the combustion of propane (see Appendix V-B, Section 1.5). Therefore, the composition of the LPG used in the inventory region is needed to determine which set of emission factors to use (or whether to use a combination of the two). In highly industrialized countries, LPG is generally at least 95% propane. In Mexico, however, a mixture is sold in which propane predominates but which also contains an appreciable amount of butane, isobutane, propylene, and butylenes (DDF, et al., 1996). For emission estimating purposes, Mexican

LPG is approximately 60% propane and 40% butane (PEMEX, 1996). Therefore, if region-specific data are not obtained for Benito Juárez, the LPG emission factors could be calculated as follows:

$$
\begin{aligned}
EF_{(SO_x)(\text{Benito Juárez})} &= (60\% \times EF_{\text{Propane}}) + (40\% \times EF_{\text{Butane}}) \\
&= (60\% \times 0.012S) + (40\% \times 0.011S) \\
&= (0.6 \times 0.012 \times 0.0039) + (0.4 \times 0.011 \times 0.0039) \\
&= 4.52 \times 10^{-5} \text{ kg } SO_x/1000 \text{ liters}
\end{aligned}
$$

NOTE: Since "domestic" emission factors are not specified in this section of AP-42, "commercial" emission factors are used.

4. Emissions for SO_2 are then calculated as:

$(85{,}799 \times 10^3 \text{ liters})$ times $(4.52 \times 10^{-5} \text{ kg}/10^3 \text{ liters}) = 3.9 \text{ kg } SO_2$

5. Determine the CO emission factor:

As previously shown, if region-specific data are not obtained for Benito Juárez, the LPG emission factors could be calculated as follows:

$$
\begin{aligned}
EF_{CO(\text{Benito Juárez})} &= (60\% \times EF_{\text{Propane}}) + (40\% \times EF_{\text{Butane}}) \\
&= (60\% \times 0.2 \text{ kg}/1000 \text{ liters}) + (40\% \times 0.3 \text{ kg}/1000 \text{ liters}) \\
&= 0.24 \text{ kg CO}/1000 \text{ liters}
\end{aligned}
$$

6. Emissions for CO are then calculated as:

$(85{,}799 \times 10^3 \text{ liters}) \times (0.24 \text{ kg}/10^3 \text{ liters}) = 20{,}600 \text{ kg CO}$

4.3 Residential Fuel Combustion (Biomass or Waste-Derived Fuels)

SOURCE CODE:	**DESCRIPTION:**
21-04-008-000	Wood or Biomass
21-04-013-000*	Other Waste-Derived Fuels

*Proposed Mexico-specific code for source category not typically inventoried in the U.S.

DESCRIPTION: The residential fuel combustion (biomass and waste-derived fuels) category includes the combustion of wood, biomass, manure, scrap materials, tires, and other waste-derived fuels. These fuels are used for both residential heating and cooking purposes. In most areas, recent regulations have banned the burning of tires and other waste-derived materials which emit strong odors and/or toxic pollutants. However, clandestine burning of these materials is likely to occur in some areas.

Unlike the commercial fuels used in residential fuel combustion (described in Section 4.2), biomass and other waste-derived fuels are usually not distributed commercially (with the exception of commercial firewood). Waste-derived fuels also tend to be used by the lower socioeconomic classes of the population. For these reasons, assessing the amount of biomass and other waste-derived fuels used in a region can be somewhat problematic. The information presented below provides guidance regarding how to estimate emissions from this category.

POLLUTANTS: TOG, CO, NO_x, SO_x, and PM_{10}

ROG: For residential wood combustion, ROG is 41.5% of TOG. ROG fractions have not been developed for waste-derived fuels, although other biomass and scrap material fuels probably have similar ROG fractions compared to residential wood combustion.

POINT SOURCE ADJUSTMENTS: None.

METHODOLOGY:

The amount of each type of biomass and other waste-derived fuel combusted for domestic use needs to be determined for the inventory region. The first step is to estimate the fraction of households that use these types of fuels. The second step is to determine the per household fuel use.

Ideally, the fraction of total households using biomass and other-derived fuels should be determined through region specific surveying. If survey information is not available, the number of households can be calculated from INEGI and other census statistics. INEGI or other census statistics identify the number of households that use commercial fuels (i.e., coal, oil, natural gas, and LPG). Subtracting the fraction of households using commercially available fuels from the total number of households results in the fraction of households using biomass and other waste-derived fuels. It is important to realize that INEGI and other census statistics may present information on the national or state level that might not be accurate at the local level. These situations warrant local level surveying.

After the number of households using biomass or other waste-derived fuels has been established, the next step is to determine the per household amount of fuel combustion. The amount of fuel used for cooking is likely to be similar in different regions. However, the amount of fuel used for heating is a function of local meteorological conditions. Obviously, cooler locations will tend to use more fuel for heating compared to warmer locations.

Once again, local surveying is the preferred method to be used to estimate per household fuel use. If local survey information is unavailable, INEGI statistics or local officials can be consulted for estimates of per household fuel use. However, because these fuels are not commercially available, it is unlikely that INEGI or local officials have compiled per household use statistics for these fuels.

Lacking information from surveying or statistical data, a rough estimate of per household fuel use for biomass and other waste-derived fuels can be made by using the concept of “fuel equivalence.” Per household fuel use for coal, natural gas, LPG, and other commercially available fuels can be estimated by dividing total residential use of a commercially available fuel by the total number of households using that specific fuel. The derived per household fuel use for a certain commercial fuel has a given energy content. This energy content is “equivalent” to some amount of wood, rubber, or other waste-derived fuel. This calculation of biomass or waste fuels is shown in the following equation:

$$\mathrm{Fuel_{BW}} = \mathrm{Fuel_{comm}} \times \left(\frac{\mathrm{EC_{Comm}}}{\mathrm{EC_{BW}}}\right) \times \left(\frac{\mathrm{Eff_{comm}}}{\mathrm{Eff_{BW}}}\right) \qquad (4.3\text{-}1)$$

where:

$\mathrm{Fuel_{BW}}$ = Annual per household biomass/waste fuel usage (kg/yr);

$\mathrm{Fuel_{Comm}}$ = Annual per household commercial fuel usage (kg/yr or liter/yr);

$\mathrm{EC_{Comm}}$ = Energy content of commercial fuel (kcal/kg or kcal/liter);

EC_{BW} = Energy content of biomass/waste fuel (kcal/kg);
EFF_{Comm} = Efficiency of commercial fuel combustion; and
EFF_{BW} = Efficiency of biomass/waste fuel combustion.

The efficiencies of commercial fuel and biomass/waste fuel combustion are also included in Equation 4.3-1. However, due to variable and unknown efficiencies, these effects are often ignored. This method is approximate and should only be used when local surveying and census information is not available. This “fuel equivalence” method was used for the estimation of TOG and PM_{10} as a part of an air toxics inventory in Nogales, Sonora.

U.S.-based emission factors for residential wood combustion (fireplaces and woodstoves) can be found in Sections 1.9 and 1.10 of AP-42 (AP-42, 1995) and in Appendix V-B of this volume (Note: In AP-42, “TOG” is referred to as “TOC”). Mexico-specific emissions data for waste wood combustion have been developed by researchers at the University of Utah and Southwest Center for Environmental Research and Policy (SCERP) (Summit et al, 1996). These emissions data were derived from a limited number of source tests of a residential heater purchased in Ciudad Juárez using various waste wood fuels (U.S. pallets, Mexican pallets, and particle board). Emissions data for CO, total hydrocarbons (THC), and nitrogen monoxide (NO) are presented below in Table 4.3-1; emissions data for PM are still under development. It should be noted that there is a large amount of uncertainty associated with these emissions due to a limited number of source tests.

Table 4.3-1

CO, THC, and NO Emissions Data for Various Waste Wood Fuels

Fuel Type	CO (g/kg wood)	THC (g/kg wood)	NO (g/kg wood)[a]
U.S. Pallet	45 ± 4.5	3.0 ± 1.3	0.76 ± 0.19
Mexican Pallet	31 ± 7.5	2.3 ± 1.2	0.62 ± 0.040
Particle Board	66 ± 23	3.3 ± 1.8	3.5 ± 0.96

Source: Summit et al., 1996
[a] Emissions for NO only are available. It appears that data for NO_x was not developed. NO_x is the combination of NO and NO_2, expressed as NO_2.

U.S.-based emission factors for residential combustion of other types of refuse can be found in Section 2.5 of AP-42. Section 2.5 of AP-42 also includes emission factors for the open burning of crop wastes and tires that could be used to estimate emissions for the residential combustion of these fuels. The use of open burning emission factors, however, would be highly uncertain due to different combustion conditions.

It is recommended that Mexico develop Mexico-specific emission factors for the actual combustion practices and fuels being used. Until these Mexico-specific emission factors have been developed, it is recommended that the emission factors used in Table 4.3-1 be used, where applicable. If these factors are not applicable, then AP-42 emission factors found in Appendix V-B of this manual should be used.

For each fuel type, emissions are calculated by multiplying the quantity of fuel burned by its emission factor as shown below:

$$\text{Emissions} = \text{Fuel}_{\text{Total}} \times \text{EF} \qquad (4.3\text{-}2)$$

DATA NEEDED:

Data	Sources
Number of households using biomass or waste-derived fuels	Survey or local information, INEGI
Per household fuel use	Survey or local information, INEGI, or "fuel equivalence" method
Emission factors by fuel type	AP-42, 1995 (see Appendix V-B) or Summit et al., 1996 (see above)

SAMPLE CALCULATION:

Local survey information indicates that in a metropolitan area containing 80,000 households, 1.5% of the households burn pallets. The survey information, however, does not indicate the average quantity of pallets burned by these households. A typical household using LPG uses 600 liters per year. Annual CO emissions for pallets used as residential fuels are calculated using the following steps:

1. Calculate number of households using wood pallets as fuel:

   80,000 × 0.015 = 1,200 households using pallets as fuel

2. Calculate energy content of LPG:

   Assume that local LPG is 60% propane and 40% butane (rounded values from PEMEX, 1996). Also, assume that the energy content of butane is 6,790 kcal/liter and that the energy content of propane is 6,090 kcal/liter (AP-42, 1995)

$$(0.6 \times 6{,}090) + (0.4 \times 6{,}790) = 6{,}370 \text{ kcal/liter LPG}$$

3. Calculate annual household use of pallets as fuel:

   Assume that the energy content of pallet wood is 4,445 kcal/kg (Summit et al, 1996). Also assume that the combustion efficiencies for LPG and pallet wood are identical and can be ignored.

$$\left(\frac{600 \text{ liters LPG}}{\text{household}}\right) \times \left(\frac{6{,}370 \text{ kcal}}{\text{liters LPG}}\right) \times \left(\frac{1 \text{ kg wood}}{4{,}445 \text{ kcal}}\right) = \frac{860 \text{ kg wood}}{\text{household}-\text{yr}}$$

4. Calculate annual CO emission:

$$(1{,}200 \text{ households}) \times \left(\frac{860 \text{ kg wood}}{\text{household}-\text{yr}}\right) \times \left(\frac{31 \text{ g CO}}{\text{kg wood}}\right) = 31{,}992 \text{ kg CO}$$

$$= 32.0 \text{ Mg CO}$$

5.0 NON-ROAD MOBILE SOURCES

Typically, only on-road motor vehicles (e.g., cars, trucks, buses, motorcycles) are included in the mobile source inventory for a given inventory region. Therefore, non-road mobile sources need to be included in the area source inventory effort. Inventory guidance for these sources are presented in the following subsections:

- Locomotives;
- Commercial Marine Vessels;
- Aircraft;
- Other Non-Road Mobile Equipment (includes Recreational, Construction, Industrial, Lawn and Garden, Farm, Light Commercial, Logging, and Airport Service Equipment);
- Border Crossings; and
- Bus/Truck Terminals.

5.1 Locomotives

SOURCE CODE:	**DESCRIPTION:**
22-85-002-005	Line Haul Locomotives
22-85-002-010	Yard Locomotives

DESCRIPTION:

In Mexico, railway service is provided by a single, state company, Ferrocarriles Nacionales de Mexico (FNM), which has two types of operations: line haul (Foraneas) and yard or switch (Patio) operations. Line haul locomotives generally travel between distant locations, such as from one city to another (including intermodal freight service, mixed freight service, and passenger service) using locomotives rated at 3,000 horsepower (hp). Yard locomotives are primarily responsible for moving railcars within a particular railway yard, and use locomotives rated at 1,800 hp.

There are two types of locomotives used in most railway systems: electric and diesel-electric. Electric locomotives are powered by electricity generated at stationary power plants and distributed by either a third rail or overhead system. Emissions are produced only at the electrical generation plant, and are not covered in a non-road inventory. Diesel-electric locomotives use a diesel engine and an alternator or generator to produce the electricity required to power the traction motors.

POLLUTANTS: TOG, CO, NO_x, SO_x, PM

ROG: ROG emissions are 97.2% of TOG for diesel combustion.

POINT SOURCE ADJUSTMENTS: None.

METHODOLOGY:

Emissions from line haul and yard locomotives must be calculated separately. In this guidance, methods are provided for each of these operations. Note that only emissions from diesel-electric locomotives are considered in this section.

Line Haul Operations

For this source category, emissions are estimated based on the amount of fuel combusted.

If the line haul locomotives only travel within the inventory area, fuel consumption can be determined directly from the amount of fuel dispensed. However, line haul locomotives do not necessarily limit their travel to an inventory area, and therefore do not necessarily consume the fuel in the same location where the fuel is dispensed. The amount of fuel combusted in the area of interest must be first determined in order to estimate emissions.

It is recommended that fuel consumption be allocated by track length so the percentage of fuel consumed is based on the percentage of track length within the inventory area as noted in the following equation:

$$F_{ci} = F_{cn} \times \frac{TL_i}{TL_n} \tag{5.1-1}$$

where:

F_{ci} = Railroad fuel consumption for inventory area i (liter);
F_{cn} = National railroad fuel consumption (liter);
TL_i = Track length for inventory area i (km); and
TL_n = National railroad track length (km).

To estimate emissions, emission factors need to be applied to fuel consumption values, as noted in the following equation:

$$EL_{pi} = F_{ci} \times EF_{lp} \tag{5.1-2}$$

where:

EL_{pi} = Estimated annual emissions (kg) for pollutant p for inventory area i for long haul railroad operations;
F_{ci} = Railroad fuel consumption for inventory area i (liter/year); and
EF_{lp} = Emission factor for pollutant p (kg/liter) (from data table).

Track length data can be obtained from FNM, by measuring distance on local maps, or by using the U.S. Department of Transportation's Geographic Information System (GIS) study (*http://www.bts.gov/cgi-bin/gis/ntad-download.pl/mexrail*). If, for example, it has been estimated that 10 percent of the national track length runs within the inventory area, multiply the total national fuel consumption for the railroad by 0.10, in order to apportion the total fuel consumed in the inventory area.

DATA NEEDED - Line Haul Operations:

Data	Sources
National Railroad Fuel Data (1996): 652.4×10^6 liter/yr	Nava, 1996
National Track Length (1996): 20,447 km	Nava, 1996
Inventory Area Track Length	FNM, measurements from local maps, or GIS Data Base
Inventory Area Fuel Use	Calculated using Equation (5.1-1)
Emission Factors TOG 0.0025 kg/liter CO 0.0075 kg/liter NO_x 0.0591 kg/liter SO_2[a] 0.0043 kg/liter PM 0.0014 kg/liter	U.S. EPA, 1992a

[a] SO_2 emissions are calculated based on an assumed fuel sulfur content of 0.25 percent by weight.

$$\left(\text{i.e. } \frac{0.863\ \text{kg fuel}}{\text{liter fuel}} \times \frac{0.0025\ \text{kg S}}{\text{kg fuel}} \times \frac{2\ \text{kg } SO_2}{\text{kg S}} = \frac{0.004315\ \text{kg } SO_2}{\text{liter fuel}}\right)$$

SAMPLE CALCULATION:

Calculate TOG emissions for Inventory Area A, which has 1,100 km of railroad. National track length in 1996 was 20,447 km and national railroad fuel consumption was 652.4 million liters. Fuel usage in the inventory area is:

$$= 652.4 \times 10^6 \text{ liters} \left(\frac{1{,}100\ \text{km}}{20{,}447\ \text{km}}\right)$$
$$= 35.0 \times 10^6 \text{liters}$$

Estimated Emissions of TOG are:

$$= (35.0 \times 10^6 \text{ liters}) \times (0.0025\ \text{kg/liter})$$
$$= 87{,}500\ \text{kg}$$
$$= 87.5\ \text{Mg}$$

Yard Operations

Yard locomotive emissions are derived by multiplying the number of yard locomotives operating within the inventory area by the emissions generated by each unit during the year. The equation is:

$$EY_{pi} = NY_i \times EF_{yp} \qquad (5.1\text{-}3)$$

where:

EY_{pi} = Estimated annual emissions (kg) for pollutant p for inventory area i for yard railroad operations;
NY_i = Number of yard locomotives that operate in inventory area i; and
EF_{yp} = Yard locomotive emission factors for pollutant p (kg/year) (from the data table).

Because yard locomotives operate within the boundaries of the railway yard, it is possible to estimate the number of yard locomotives operating within the inventory area through interviews with the railway yard managers, who may maintain records of yard locomotive operations. If this approach proves unproductive, the number of yard locomotives can be determined by manually counting the units operating in each railway yard during a given day. This method is sufficient because the number of yard locomotives in operation each day remains relatively constant throughout the year.

The average annual emissions shown in the data table below were calculated based on the assumption that the average yard engine consumes 856 liters of fuel per day. Although these data were developed in the U.S., they are expected to be applicable to Mexico. Since yard locomotives can be assumed to operate 365 days a year (this assumes that when a yard engine is taken in for repairs it is replaced during that period), the average yard engine consumes 312,440 liters of fuel per year. The annual emission per yard locomotive were determined by multiplying the fuel consumption estimate (312,440 liter/year) by each emission factor in the data table.

DATA NEEDED - Yard Operations:

Data	Sources
Number of yard locomotives in operation in inventory area	Railway yard manager or actual count
Emission Factors TOG 1,893 kg/locomotive/yr CO 3,345 kg/locomotive/yr NO_x 18,873 kg/locomotive/yr SO_2[a] 1,395 kg/locomotive/yr PM 516 kg/locomotive/yr	U.S. EPA, 1992a

[a] SO_2 emissions are calculated based on an assumed fuel sulfur content of 0.25 percent by weight. See Note 3.

$$\left(\text{i.e. } \frac{0.004315 \text{ kg } SO_2}{\text{liter fuel}} \times \frac{323{,}312 \text{ liter fuel}}{\text{yr}} = \frac{1{,}395 \text{ kg } SO_2}{\text{locomotive/yr}}\right)$$

SAMPLE CALCULATION:

Inventory Area A has 21 yard locomotives in operation.

Calculated TOG emissions are:

$$\begin{aligned} &= 21 \times (1{,}893 \text{ kg/locomotive/yr}) \\ &= 39{,}753 \text{ kg} \\ &= 39.8 \text{ Mg} \end{aligned}$$

NOTES:

1. For a locomotive inventory to be considered complete, emissions from both line haul and yard locomotives must be estimated.

2. The emission factor of lbs SO_2/liter fuel will change with fuel density and sulfur content according to the following equation:

$$\text{emission factor} \left(\frac{\text{kg } SO_2}{\text{liter fuel}}\right) = \text{density of fuel} \left(\frac{\text{kg fuel}}{\text{liter fuel}}\right) \times \text{\% of sulfur in fuel, expressed as a decimal} \left(\frac{\text{kg S}}{\text{kg fuel}}\right) \times \frac{2 \text{ kg } SO_2}{\text{kg S}}$$

$$\text{For example, } \frac{0.0043\ 15 \text{ kg } SO_2}{\text{liter}} = \frac{0.863 \text{ kg}}{\text{liter}} \times \frac{0.0025 \text{ kg S}}{\text{kg}} \times \frac{2 \text{ kg } SO_2}{\text{kg S}}$$

3. U.S. EPA 1992a, Section 6.0, Emissions from locomotives was used to convert emission factors from English to metric units. The emission factor for SO_2 presented for Yard Operations was obtained using an assumption of 322,312 liters/yr (85,410 gal/yr) fuel use per locomotive. Attention is called to this because U.S. EPA 1992a uses a slightly different fuel use per locomotive of 312,259 liters/yr (82,490 gal/yr) for all other listed pollutants.

5.2 Commercial Marine Vessels

SOURCE CODE:	**DESCRIPTION:**
22-80-002-xxx	Marine Vessels: Diesel fuel
22-80-003-xxx	Marine Vessels: Residual fuel

DESCRIPTION:

Commercial marine vessels include all boats and ships used either directly or indirectly in the conduct of commerce. These include vessels ranging in size from 7 meter charter boats to large tankers and military vessels which can exceed 300 meters in length. In spite of the large range of vessels represented by this category, the majority of vessels in this category are powered either by diesel engines (motor vessels) or steam turbines (steamships). Gasoline powered engines are not typically used for commercial marine vessels. Gasoline powered recreational boats are described in Section 5.4.

The predominant fuel used in all motor vessels and most steamships is oil, both distillate and residual grades. In steamships, residual fuel such as heavy oil, typically Number 6 or Bunker C, is used. Moderate speed diesel engines usually require a blend of distillate and residual oil for satisfactory operation. Motor vessels use diesel engines that require distillate oil. Other fuels are used, but only to a limited extent. Wood, coal, and bagasse may be used in some very limited applications.

POLLUTANTS: TOG, CO, NO_x, SO_x, PM

ROG: For motor vessels, ROG emissions are 97.2% of TOG (distillate); and for steamships, ROG emissions are 82.8% of TOG (residual oil).

POINT SOURCE ADJUSTMENTS: None.

Two methods are available for estimating emissions from commercial marine vessels. The first method is based on the quantity of fuel sold for marine use. Emissions are estimated based on assumptions regarding the percentage of fuel sold that is actually used within the port area, and the emission rate associated with the use of the fuel. The second method attempts to provide a more accurate estimate based on ship movement data. Both methods are described here. Calculations need only be done using one method or the other, not both. The method used will depend upon the availability of local data. Commercial marine vessels used throughout the world are expected to have similar emission characteristics. Although the data provided here are from U.S. references, these data should provide reasonable emission estimates for marine vessels entering Mexican ports.

Fuel Sales Method

METHODOLOGY:

The fuel sales method assumes that 25 percent of the residual oil and 75 percent of the distillate oil sold in port is used there, and that all distillate oil is used by motor vessels and all residual oil is used by steamships. The total estimated quantities of residual and distillate oil used in port are:

$$\begin{aligned} Q_{ri} &= 0.25 \times Q_{rs} \text{ for residual, and} \\ Q_{di} &= 0.75 \times Q_{ds} \text{ for distillate} \end{aligned} \qquad (5.2\text{-}1)$$

where:

Q_{ri} and Q_{di} = The quantities of residual and distillate oil, respectively, used in port i; and

Q_{rs} and Q_{ds} = The total quantities of residual and distillate oil sold in the inventory area for marine use.

To estimate emissions, an emission factor is applied to the quantities Q_{ri} and Q_{di}. These emission factors, for motor vessels, are shown in the data table. Emission factors are given for two general categories of vessels, river and coastal. A river port supports vessels that travel throughout a given river basin; a coastal port supports vessels that travel in and across an ocean. To calculate emissions for motor vessels and steamships the following equation should be used:

$$E_{ip} = \left(Q_{ri} \times EF_{rp}\right) + \left(Q_{di} \times EF_{dp}\right) \qquad (5.2\text{-}2)$$

where:

E_{ip} = Quantity of emissions of pollutant p produced annually by vessels operating within area i waters;

Q_{ri} and Q_{di} = Quantities of residual and distillate oil, respectively, used in port i; and

EF_{rp} and EF_{dp} = Emission factors for pollutant p for residual and distillate oil, respectively

DATA NEEDED - Fuel Sales Method:

Data	Sources
Annual fuel usage (residual/diesel)	Local port authority or Dirección General de Puertos
Percentage of fuel used in port (25 percent for residual fuels and 75 percent for diesel fuel)	U.S. EPA, 1989
Emission Factors Steamships (Residual fuels) TOG[a] 0.463 kg/1000 liter ROG 0.383 kg/1000 liter (3.2 lb/10^3 gal) CO negligible NO_x 4.362 kg/1000 liter (36.4 lb/10^3 gal) SO_x 19 × % sulfur [kg/1000 liter] (159 × % sulfur [lb/10^3 gal]) PM 1.198 kg/1000 liter (10 lb/10^3 gal) Motor Vessels (Diesel fuels) River Vessels TOG 6.2 kg/1000 liter ROG 6.0 kg/1000 liter CO 12.0 kg/1000 liter NO_x 33.0 kg/1000 liter SO_x 3.2 kg/1000 liter Coastal Vessels TOG 6.2 kg/1000 liter ROG 6.0 kg/1000 liter CO 13.0 kg/1000 liter NO_x 32.0 kg/1000 liter SO_x 3.2 kg/1000 liter	U.S. EPA, 1989

[a] TOG emission factor derived from the ROG emission factor and the ROG/TOG ratios presented earlier in this section.

SAMPLE CALCULATION—Fuel Sales Method:

Coastal Port A dispenses 1 million liters of diesel for motor vessels and 459,000 liters of residual fuel for steamships annually.

Fuel used in the port is:

$$
\begin{aligned}
\text{Residual} \quad Q_{ri} &= 0.25 \times Q_{rs} \\
&= 0.25 \times 459{,}000 \text{ liters} \\
&= 114{,}750 \text{ liters} \\
\text{Diesel} \quad Q_{di} &= 0.75 \times Q_{ds} \\
&= 0.75 \times 1{,}000{,}000 \text{ liters} \\
&= 750{,}000 \text{ liters}
\end{aligned}
$$

Estimated emissions for TOG are:

$$
\begin{aligned}
E_{ip} &= (Q_{ri} \times EF) + (Q_{di} \times EF_{dp}) \\
&= 114{,}750 \text{ liters } (0.463 \text{ kg}/1{,}000 \text{ liters}) + 750{,}000 \text{ liters } (6.2 \text{ kg}/1{,}000 \text{ liters}) \\
&= 53.1 + 4{,}650 \text{ kg} \\
&= 4{,}703 \text{ kg} = 4.7 \text{ Mg}
\end{aligned}
$$

Ship Movement Method

METHODOLOGY:

This method utilizes data concerning the number of vessels in various size categories that use a particular port, and assumptions about dockside activity and ship movements in and out of the harbor. This approach has two separate types of emissions associated with it:

- Underway emissions (i.e., emissions from vessels while in transit in the harbor); and
- Dockside emissions (i.e., emissions from vessels that are tied up at docks unloading or loading cargo).

The methods to estimate emissions from underway and dockside emissions are discussed below.

Underway Emissions

The first data element required is the number of vessels, by size category, using the port. Four size categories are of interest:

- Vessels with draft of less than 2 meters;
- Vessels with drafts greater than 2 meters or less than 4 meters;
- Vessels with drafts greater than 4 meters and less than 6 meters; and
- Vessels with drafts of 6 meters or more.

These data are used to compute emissions for vessels underway and at dockside.

Underway emissions occur while the vessel is entering, leaving, or maneuvering in port. Estimates of emissions produced by underway vessels can be developed based on the average travel time by vessels entering, maneuvering, and leaving the port, applying a fuel consumption factor to estimate fuel usage within the port, and applying an emission rate based on the quantity of fuel used.

Vessels with a draft of less than 6 meters (depth of water required for loaded vessel to operate in) are assumed to be powered by diesel engines using distillate fuels, while those vessels with a draft of 6 meters or more are assumed to be steam powered. Although large diesel powered vessels are capable of burning residual oil, it is assumed that distillate is used while underway or maneuvering in port. Further, it is assumed that all steamships use residual oil at all times.

To estimate average travel time, the distance between the outer limits of the study area and a theoretical centroid of activity within the port is determined. This distance is increased by 120 percent to account for maneuvering and leaving port and is divided by an assumed average speed in port of 13 km per hour to yield the estimated average underway travel time of each vessel using the port. This is:

$$\bar{t} = \frac{2.2d}{13} = 0.169\ d \qquad (5.2\text{-}3)$$

where: $\bar{t}$ = Average travel time for vessels using the port (hr); and

d = Distance in km between the outer limit of the study area and the assumed centroid of port activity.

Average travel time data can be applied to fuel consumption rates to estimate underway fuel consumption as noted in the following equation:

$$Q_{ijd} = \bar{t} \times FC_{jd} \times N_{jd} \qquad (5.2\text{-}4)$$

where: Q_{ijd} = Underway fuel consumption for vessel type j (steamship, motor vessels) with draft d, for inventory area i (liter);

$\bar{t}$ = Average travel time (hr);

FC_{jd} = Fuel consumption rate for vessel type j and draft d (liter/hr); and
N_{ijd} = Number of vessels of vessel type j and draft d in inventory area i.

Fuel consumption rates for vessels operating in a Mexican port are provided in the data table. Different rates are given for motor vessels and steamships. To derive the distribution of motor vessels and steamships operating in a Mexican port, determine the relative number of U.S. and non-U.S. registered vessels visiting the port. Essentially all large U.S. registered vessels are steam powered, while most non-U.S. registered vessels are powered by diesel engines. From this information, the composite of motor vessels, and steamships can be approximated.

Once fuel use associated with underway operations has been computed, emissions can be calculated by applying emission factors from the data table. Emissions are calculated using the following equation:

$$E_{ijp} = Q_{ijd} \times EF_{jpd} \qquad (5.2\text{-}5)$$

where: E_{ijp} = The quantity of emissions of pollutant p produced annually by category j vessels with draft d operating within area i waters;

Q_{ijd} = The quantity of fuel (residual or distillate), in liters, consumed by vessel type j with draft d; and

EF_{jpd} = The emission factor for pollutant p and vessel type j with draft d, from the data table.

DATA NEEDED - Ship Movement Method-Underway Emissions:

Data	Sources
Distance between outer limit of study area and assumed centroid of port activity	Measured with assistance of local port authority or Dirección General de Puertos
Travel time	Calculated using Equation 5.2-3
Type of vessel (Motor vessel or steamship) Draft of vessel Number of vessels for each type and draft	Local port authority or Dirección General de Puertos
Fuel consumption rates Motor Vessels Draft <2m 19 liter/hr (5 gal/hr) Draft ≥2 <4m 38 liter/hr (10 gal/hr) Draft ≥4 <6m 167 liter/hr (44 gal/hr) Draft ≥6m 484 liter/hr (128 gal/hr) Steamship Draft ≥6m 606 liter/hr (160 gal/hr)	U.S. EPA, 1989
Fuel consumption for each type of vessel and draft	Calculated using Equation 5.2-4
Emission factors Motor Vessels Draft <2m TOG[a] 6.30 kg/1000 liter ROG 6.12 kg/1000 liter (51.1 lb/10^3 gal) CO 5.67 kg/1000 liter (47.3 lb/10^3 gal) NO_x 46.65 kg/1000 liter (389.3 lb/10^3 gal) SO_x 3.24 kg/1000 liter (27 lb/10^3 gal) Draft ≥2 <4m TOG[a] 5.48 kg/1000 liter ROG 5.33 kg/1000 liter (44.5 lb/10^3 gal) CO 11.95 kg/1000 liter (99.7 lb/10^3 gal) NO_x 40.57 kg/1000 liter (338.6 lb/10^3 gal) SO_x 3.24 kg/1000 liter (27 lb/10^3 gal)	U.S. EPA, 1989

Data			**Sources**
Motor Vessels			U.S. EPA, 1989
Draft ≥4 <6m	TOG[a]	2.07 kg/1000 liter	
	ROG	2.01 kg/1000 liter (16.8 lb/10^3 gal)	
	CO	7.45 kg/1000 liter (62.2 lb/10^3 gal)	
	NO_x	20.03 kg/1000 liter (167.2 lb/10^3 gal)	
	SO_x	3.24 kg/1000 liter (27 lb/10^3 gal)	
Draft ≥6m	TOG[a]	6.16 kg/1000 liter	
	ROG	5.99 kg/1000 liter (50 lb/10^3 gal)	
	CO	13.18 kg/1000 liter (110 lb/10^3 gal)	
	NO_x	32.35 kg/1000 liter	
	SO_x	3.24 kg/1000 liter (27 lb/10^3 gal)	
Steamship			
Draft ≥6m	TOG[a]	0.10 kg/1000 liter	
	ROG	0.08 kg/1000 liter (0.7 lb/10^3 gal)	
	CO	0.42 kg/1000 liter (3.5 lb/10^3 gal)	
	NO_x	6.69 kg/1000 liter (55.8 lb/10^3 gal)	
	SO_x	19 × % sulfur [kg/1000 liter] (159 × % sulfur [lb/10^3 gal])	
	PM	2.4 kg/1000 liter (20 lb/10^3 gal)	

---

[a] TOG emission factor derived from ROG emission factor and ROG/TOG ratio presented earlier in this section.

Dockside Emissions

Large vessels (those with a draft of 6 meters or more) produce emissions while dockside, since either auxiliary diesel generator systems or the main boilers are operated to supply power for the vessels’ utilities. Further, the boilers on most steamships in port for less than 2 days are rarely shut down because of the relatively long time required to restart and prepare them for operation. To estimate the quantity of emissions produced by these vessels, an estimate of the average number of days in port must be developed and a fuel consumption rate determined. After the total quantity of fuel consumed in port is estimated, an emission factor is applied to derive the emission estimate.

The average duration of stay for large commercial vessels is from one to three days. An estimate for a particular port can be derived by inquiring to the port authority, or shipping company, or a default value of three days can be used.

The fuel consumption rates for steamships and motor vessels are assumed to be 7,192 liters per day of residual oil, and 2,490 liters per day of distillate oil, respectively. Again, it is assumed that all U.S. registered vessels are steamships and all non-U.S. registered vessels are motor vessels. Fuel used by each type of vessel while in port is calculated from:

$$Q_{ij} = N_{ij} \times D_{ij} \times f_{cj} \qquad (5.2\text{-}6)$$

where:
Q_{ij} = Total annual fuel consumption of residual or distillate oil, in area i, by type j vessels (steamships or motor vessels) (liters);
N_{ij} = Total number of type j vessels using the port i;
D_{ij} = Average duration of stay for vessel type j in area i (days); and
f_{cj} = Fuel consumption rate for vessel type j (assumed to be 7,192 liters per day of residual oil for steamships and 2,498 liters per day of distillate oil for motor vessels).

Emissions produced by the ships while at dockside are:

$$E_{ijp} = Q_{ij} \times EF_{jp} \qquad (5.2\text{-}7)$$

where:
E_{ijp} = The quantity of emissions of pollutant p produced annually by category j vessels while at dockside in area i waters;
Q_{ij} = The quantity of fuel, in 1,000 liters, consumed at dockside by vessel type j (1,000 liters); and
EF_{jp} = The emission factor for pollutant p and vessel type j.

DATA NEEDED - Ship Movement Method-Dockside Emissions:

Data	Sources
Annual number and type (Motor vessels/Steamships) that visit port	Local port authority or Dirección General de Puertos
Average duration of stay (days)	Local port authority or Dirección General de Puertos
Fuel consumption rate Motor Vessels 2,498 liter/day (660 gal/day) Steamships 7,192 liter/day (1,900 gal/day)	U.S. EPA, 1989
Fuel consumed	Calculated using Equation 5.2-6

Data			Sources
Emission factors			U.S. EPA, 1989
Motor Vessels	TOG[a]	7.27 kg/1000 liter	
	ROG	7.07 kg/1000 liter (59 lb/10^3 gal)	
	CO	5.27 kg/1000 liter (44 lb/10^3 gal)	
	NO_x	43.62 kg/1000 liter (364 lb/10^3 gal)	
	SO_x	3.24 kg/1000 liter (27 lb/10^3 gal)	
	PM	negligible	
Steamships	TOG[a]	0.46 kg/1000 liter	
	ROG	0.38 kg/1000 liter (3.2 lb/10^3 gal)	
	CO	negligible	
	NO_x	4.36 kg/1000 liter (36.4 lb/10^3 gal)	
	SO_x	19 × % sulfur [kg/1,000 liters] (159 × % sulfur [lb/10^3 gal])	
	PM	1.20 kg/1000 liter of fuel (10 lb/10^3 gal)	

[a] TOG emission factor derived from ROG emission factor and ROG/TOG ratio presented earlier in this section.

<u>SAMPLE CALCULATION</u>—Ship Movement Method:

- The distance from the outer limit of the study area to the centroid of Port A is 30 km;
- Port A is visited by 10 motor vessels and 2 steamships weekly (520 motor vessels and 104 steam ships annually);
- All of the motor vessels have a draft between 2 and 4 meters - all steam ships have drafts greater than 6 meters; and
- Number of days vessels typically spent in port is 2.

Underway Emissions

Calculated travel time is:

$$\bar{t} = 0.169d$$

$$= 0.169 \text{ hr/km} \times 30 \text{ km}$$

$$= 5.07 \text{ hr}$$

Calculated fuel consumption is:

Motor vessels = (5.07 hr) (38 liters/hr) (520 vessels)
= 100,183 liters
Steamships = (5.07 hr) (606 liters/hr) (104 vessels)
= 319,532 liters

Estimated TOG emissions are:

Motor vessel emissions = (100,183 liters) (5.48 kg TOG/1,000 liters)
= 549 kg
Steamship emissions = (319,532 liters) (0.10 kg TOG/1,000 liters)
= 32 kg

Total underway emissions = motor vessel emissions + steamship emissions
= 549 kg + 32 kg
= 581 kg

Dockside Emissions

Calculated fuel consumption is:

$\text{Motor vessels}_{ij}$ = (520 vessels) (2 days) (2,498 liters/day)
= 2,597,920 liters
Steamships_{ij} = (104 vessels) (2 days) (7,192 liters/day)
= 1,495,936 liters

Motor vessels emission = (2,597,920 liters) (7.27 kg TOG/1,000 liters)
= 18,887 kg
Steamship emissions = (1,495,936 liters) (0.46 kg TOG/1,000 liters)
= 688 kg

Calculated TOG emissions are:

$$\text{Total dockside TOG emissions} = \text{Motor vessel emissions} + \text{Steamship emissions}$$

$$= 18{,}887 \text{ kg} + 688 \text{ kg}$$

$$= 19{,}575 \text{ kg}$$

$$\text{Total TOG emissions} = \text{Underway emissions} + \text{Dockside emissions}$$

$$= 581 \text{ kg} + 19{,}575 \text{ kg}$$

$$= 20{,}156 \text{ kg}$$

NOTES:

1. The fuel use method combines underway and dockside activities in the estimate of fuel consumed in port. If the ship movement method is used to estimate emissions for this source, underway and dockside emissions must be calculated separately and combined to yield total emissions for commercial marine vessels.

2. To identify seasonal variations in emissions, monthly tabulations of vessel activity must be obtained from the local port authority.

5.3 Aircraft

SOURCE CODE:	**DESCRIPTION:**
22-75-000-000	Aircraft Total
22-75-001-000	Military
22-75-020-000	Commercial Total
22-75-050-000	Civil Aircraft

DESCRIPTION:

Civil aircraft include all categories of fixed and rotary wing craft from the smallest single engine, privately owned and operated, to the largest commercial aircraft. Within the civil category, there are three subcategories: commercial aircraft, air taxis, and general aviation aircraft. In the development of an emission inventory, it is necessary to account for the different types of aircraft using each airfield. Commercial aircraft are used in regularly scheduled flights. Air taxis also fly scheduled service carrying passengers and/or freight, but usually are smaller aircraft and operate on a more limited basis than the commercial carriers. General aviation includes all nonmilitary aircraft not used in scheduled service. Business aircraft support business travel, usually on an unscheduled basis. For the purpose of creating an emissions inventory, business aircraft are combined with general aviation aircraft because of their similar size, use frequency, and operating profiles. In this inventory guidance they are referred to simply as general aviation. Similarly, air taxis are treated much like the general aviation category because they are typically the same types of aircraft. Helicopters, or rotary wing aircraft, can be found in each of the categories. Their operation is distinct because they do not always operate from an airport, but may land and take off from a heliport at a hospital, police station, or similarly dispersed location.

Commercial aircraft typically are the largest source of aircraft emissions. Although they make up less than half of all aircraft in operation around a metropolitan area, their emissions usually represent a large percent of the total emissions because of their size and operating frequency. This will not hold true, of course, for a city with no major civil airports.

Pollutants are emitted from aircraft whenever the engines are operating. In the context of emission inventory development, however, concern is limited to those portions of the flight that occur between ground level and an altitude defined as the above ground level inversion height. Within this layer, the air is fairly stable, and emissions tend to diffuse rather than being transported away. As a result, emissions occurring below the ground level inversion height have an effect on air quality at ground level owing to the mixing that occurs within the air cell.

Aircraft emissions are affected by the throttle power setting, that is, the percentage of maximum power that the engines are producing at a given time. However, the power setting is fairly predictable given the specific operating mode in which the aircraft is operating. For purposes of inventory development, five operating modes are of interest:

- Approach (30-40 percent throttle);
- Taxi/idle in (3-7 percent throttle);
- Taxi/idle out (3-7 percent throttle);
- Takeoff (100 percent throttle); and
- Climb out (85-90 percent throttle).

Collectively, these five modes form the landing and takeoff (LTO) cycle, which provides a basis for allocating aircraft emissions to a specific region. The emissions for a given mode are calculated based on the period of time an aircraft spends in the specified mode. This period of time is called the Time In Mode (TIM).

Duration in approach and climbout depends largely on the local meteorology. Since the period of interest is during operation of the aircraft within the air modeling zone, the inversion layer thickness determines how long the aircraft is in this zone. The inversion layer thickness is also known as the mixing height or mixing zone since the air in this layer is completely mixed and pollutants emitted anywhere within the layer will be carried down to ground level. When the aircraft is above the mixing layer, whether on descent or when climbing to cruising altitude, the emissions tend to disperse, rather than being trapped by the inversion, and have no ground level effect.

Taxi/idle time, whether from the runway to the gate (taxi/idle-in) or from the gate to the runway (taxi/idle-out), depends on the size and layout of the airport, the amount of traffic or congestion on the ground, and airport-specific operational procedures. Taxi/idle time is the most variable of the LTO modes. Taxi/idle time can vary significantly for each airport throughout the day, as aircraft activity changes, and seasonally, as general travel activity increases and decreases.

The takeoff period, characterized primarily by full-throttle operation, typically lasts until the aircraft reaches between 150 and 300 meters above ground level when the engine power is reduced and the climbout mode begins. This transition height is fairly standard and does not vary much from location to location or among aircraft categories.

Commercial aircraft used throughout the world are expected to have similar emission characteristics. Although the data provided here were developed in the U.S., these data should provide reasonable emission estimates for aircraft operating at Mexican airports.

POLLUTANTS: TOG, CO, NO_x, SO_2, PM

ROG: For jet aircraft, ROG emissions are 84.4% of TOG.
For piston aircraft, ROG emissions are 96% of TOG.

POINT SOURCE ADJUSTMENTS: None.

METHODOLOGY:

The steps in the emission estimation methodology are basically the same for each aircraft classification and each location, though several factors used in creating an inventory are site specific. The steps are:

1. Identify all airports to be included in the inventory;
2. Determine the mixing height to be applied to the LTO cycle;
3. Define the fleet make-up for aircraft category using each airport;
4. Determine airport activity as the number of LTOs for each aircraft category;
5. Calculate emission rates from fuel flow rates and emission indexes for each category (presented later in this section);
6. Estimate a TIM for each aircraft category at each airport; and
7. Calculate emissions based on the airport activity, TIM, and aircraft emission factors.

The height of the mixing zone influences only the TIM for approach and climbout. This factor is significant primarily when calculating NO_x emissions rather than

TOG or CO. If NO_x emissions are an important component of the inventory, specific data must be gathered on mixing heights. If NO_x emissions are not important, mixing height will have little effect on the results, and the default value of 900 meters can be used for more generalized results.

To define the fleet make-up and airport activity in Mexico, Airports and Auxiliary Services (ASA) or staff from the airport of interest should be contacted. It is necessary that the LTO data be collected for each aircraft type in the fleet.

The engines used on each aircraft type must be determined to select the emission factors for step 5. Table 5.3-1 lists aircraft and the corresponding engines used to power them. Many aircraft use only a single engine model, while others have been certified to use engines from two or three different manufacturers. When a single engine is listed for an aircraft model, emission data for that engine should be used. For aircraft with engines from more than one manufacturer, defining the specific engine mix used on the fleet of aircraft operating at a specific airport may be extremely difficult.

To develop a representative engine mix for aircraft with more than one engine model, the percentage of each model likely to be found on those aircraft in the U.S. fleet is shown adjacent to the engine model number in Table 5.3-1. The recommended procedure for compensating for the lack of detailed engine data is using the percentages shown in the table as weighing factors. For example, Boeing 757-200 cargo aircraft have been sold to U.S. airlines with Pratt & Whitney PW2040 engines as well as Rolls Royce RF.211-535E4 engines. The number of aircraft with each engine model is 15 and 43, respectively, to give the percentages shown in Table A of 26 and 74. These percentages can be used to divide the total LTOs for B 757-200 cargo aircraft into two groups representing the two engine types. This makes the inventory more representative than assigning a single engine for all cargo versions of B 757-200s, since the emission factors are different for each engine.

After identifying the engines included in the fleet, engine emission factors are used to calculate mass of emissions. For some of the engines shown in Table 5.3-1, emission factors have never been determined. For these engines it is necessary to use emission factors from an alternative engine. Table 5.3-2 lists alternative engines recommended by the engine manufacturers. For most of these engines, emission factors are available for a very similar engine, usually one of the same model and a related series. For a small number of engines there is no emissions data available and there are no suggested alternatives. In these instances there are three approaches available. First, the needed data may appear in the latest update of the Federal Aircraft Engine Emission Database (FAEED) [see http://www.epa.gov/oar/omswww/aviation.html].

Table 5.3-1

Aircraft Types and Engine Models

Aircraft[1]	**Number of Engines**	**Engine Model (% of Aircraft) and Manufacturer**[2]			
Commercial Aircraft					
Aerospatiale ATR-42	2	PW120(53)PWC	PW121(47)PWC		
Airbus A-300-B4	2	CF6-50(100)GE			
Airbus A-300-600	2	CF6-80C2A5(100)GE			
Airbus A-310-200	2	JT9D-7R4E1(100)PW			
Airbus A-310-300	2	PW4152(100)PW			
Airbus A-320-200	2	CFM56-5A(100)GE			
BEECH 18[3]	2	R-985-AN(100)PW[4]			
BEECH BH-C99	2	PT6A-36(100)PWC			
BEECH BH-1900	2	PT6A-65B(100)PWC			
Boeing B-707-300B	4	JT3D-3B(100)PW			
Boeing B-707-300C	4	JT3D-3B(100)PW			
Boeing B-727-100	3	JT8D-7(16)PW JT8D-7D(4)PW	JT8D-7A(4)PW JT8D-9(1)PW	JT8D-7A/7B(< 1)PW JT8D-9A(2)PW	JT8D-7B(73)PW
Boeing B-727-100[3]	3	JT8D-7A(6)PW	JT8D-7B(91)PW	JT8D-9(1)PW	JT8D-9A(2)PW
Boeing B-727-200	3	JT8D-7A(< 1)PW JT8D-15(26)PW JT8D-15B(< 1)PW	JT8D-7B(16)PW JT8D-15A(21)PW JT8D-17(3)PW	JT8D-9(20)PW JT8D-9A(9)PW JT8D-17A(1)PW	JT8D-17R(3)PW
Boeing B-737-100/200	2	JT8D-7B(19)PW JT8D-17(7)PW	JT8D-9A(39)PW JT8D-17A(1)PW	JT8D-15(10)PW	JT8D-15A(24)PW
Boeing B-737-200C	2	JT8D-7A(10)PW JT8D-17(32)PW	JT8D-9/9A(5)PW JT8D-17A(32)PW	JT8D-9A(16)PW	JT8D-15(5)PW
Boeing B-737-300	2	CFM56-3(100)GE[6]			
Boeing B-737-400	2	CFM56-3(100)GE			
Boeing B-747[3]	4	JT9D-7F(100)PW			
Boeing B-747F[3]	4	JT9D-7F(33)PW	JT9D-7Q(17)PW	JT9D-7R4G2(11)PW	JT9D-70A(39)PW
Boeing B-747SP	4	JT9D-7A(85)PW	JT9D-7A-SP(15)PW		
Boeing B-747-200	4	CF6-50(3)GE[6] JT9D-7A(55)PW	JT9D-7R4G2(3)PW JT9D-7AH(13)PW	JT9D-3A(7)PW JT9D-7F(5)PW	JT9D-7(1)PW JT9D-7Q(13)PW
Boeing B-747-400	4	PW4056(100)PW			

Table 5.3-1

(Continued)

Aircraft[1]	Number of Engines	Engine Model (% of Aircraft) and Manufacturer[2]			
Boeing B-757-200	2	RB.211-535E4(1)RR	PW2037(92)PW	PW2040(7)PW	
Boeing B-757-200[3]	2	PW2040(26)PW	RB.211-535E4(74)RR		
Boeing B-767-200	2	CF6-80A2(59)GE	CF6-80C2B2(12)GE[7]	JT9D-7R4D(29)PW	
Boeing B-767-300	2	CF6-80C2B6(100)GE[8]			
Brit. Air. Corp. BAC-111-200	2	Spey Mk 511(100)RR[9]			
Brit. Aero. BAe-146-1	4	ALF502R-5(100)Lyc			
Brit. Aero. BAe-146-2	4	ALF502R-5(100)Lyc			
Brit Aero. Concorde	4	Olympus 593 Mk610(100)RR			
Brit Aero. JETSTREAM 31	2	TPE 331-10UF(100)Grt[9]			
CESSNA 404[3]	2	TSIO-520-VB(100)Con[9]			
Convair CV-580	2	501D13H(100)All.[9]			
Convair CV-640[3]	2	Dart 542-4(100)RR			
de Havilland DASH-7	4	PT6A-50(100)PWC			
de Havilland DHC-6	2	PT6A-20(26)PWC	PT6A-27(74)PWC		
de Havilland DHC-8	2	PW120(17)PWC	PW120A(83)PWC		
deHavilland Twin Otter	2	PT6A-27(100)PW			
EMBRAER[10]	2	PW6A-34(100)PWC			
EMBRAER EMB-120	2	PW118(85)PWC	PW118A(15)PWC		
Fairchild F27	2	R. Da. 7(100)RR			
Fairchild FH-227	2	Dart 532-7(100)RR			
Fokker 100	2	Tay 620-15(75)RR	Tay 650(25)RR		
Fokker F-27 SERIES	2	Dart 514-7(15)RR Dart 532-7P(24)RR Dart 532-7R(29)RR	Dart 528-7E(10)RR Dart 532-7R(3)RR	Dart 532-7(5)RR Dart 535-7R(9)RR	Dart 532-7N(3)RR Dart 536-7E(2)RR
Fokker F-28-100	2	Spey 555-15(100)RR			
Fokker F-28-4000/600	2	Spey 555-15H(12)RR	Spey 555-15P(88)RR		

Table 5.3-1

(Continued)

Aircraft[1]	Number of Engines	Engine Model (% of Aircraft) and Manufacturer[2]
Grumman Goose	2	PT6A-27(100)PWC
Lockheed L100 Hercules	2	501(100)All
Lockheed L100 Hercules	2	501(100)All
Lockheed L-100-30[3]	2	501D22A(100)All.[9]
Lockheed L-188A/C	2	501D13(100)All.[9]
Lockheed L-1011/100/200	3	RB.211-22B(99)RR RB.211-524B4(1)RR
Lockheed L-1011-500 TR	3	RB.211-524B4(100)RR
McDonnell Douglas DC-6[3]	4	R2800(100)PW[9]
McDonnell Douglas DC-6A[3]	4	R2800(100)PW[9]
McDonnell Douglas CD-8-60	4	JT3D-3B(57)PW JT3D-7(43)PW
McDonnell Douglas DC-8-61[3]	4	JT3D-3B(100)PW
McDonnell Douglas DC-8-62[3]	4	JT3D-3B(15)PW JT3D-3BDL(21)PW JT3D-7(64)PW
McDonnell Douglas DC-8-63F[3]	4	JT3D-3B(24)PW JT3D-7(42)PW JT3D-735E4(7)PW JT8D-7(27)PW
McDonnell Douglas DC-8-70	4	CFM56-2-C1(100)GE
McDonnell Douglas CD-8-71	4	CFM56-2(100)GE
McDonnell Douglas DC-9-10	2	JT8D-7(100)PW[9]
McDonnell Douglas DC-9-15F	2	JT8D-7(15)PW JT8D-7A(4)PW JT8D-7A/7B(4)PW JT8D-7B(77)PW
McDonnell Douglas DC-9-30	2	JT8D-9A(23)PW JT8D-7A(5)PW JT8D-7B(68)PW JT8D-15(3)PW JT8D-17(1)PW

Table 5.3-1

(Continued)

Aircraft[1]	Number of Engines	Engine Model (% of Aircraft) and Manufacturer[2]
McDonnell Douglas DC-9-40	2	JT8D-15(100)PW
McDonnell Douglas DC-9-50	2	JT8D-17(87)PW JT8D-17A(13)PW
McDonnell Douglas DC-9-80[11]	2	JT8D-209(5)PW JT8D-217(12)PW JT8D-217A(36)PW JT8D-219(22)PW JT8D-217C(25)PW
McDonnell Douglas DC-10-10	3	CF6-6(100)GE
McDonnell Douglas DC-10-10[3]	3	CF6-6(100)GE
McDonnell Douglas DC-10-30	3	CF6-50(100)GE
McDonnell Douglas DC-10-30[3]	3	CF6-50(100)GE
McDonnell Douglas DC-10-40	3	JT9D-20(100)PW
McDonnell Douglas MD-11	2	CF6-80C2D1F(100)GE
NAMC YS-11	2	Dart 542-10J(25)RR Dart 542-10K(75)RR
Saab SF-340A	2	CT7-5A( )GE[12] CT-5A2( )GE[12] CT7-7E( )GE[12]
SHORT 360	2	PT6A-65AR(17)PWC PT6A-65R(55)PWC PT6A-67R(28)PWC
Swearingen SWEAR-METRO 1	2	TPE 331-11U-611G()Grt[13] PT6A-45R()PW[14]
Swearingen METRO-2	2	TPE 331-1(100)GA
General Aviation and Air Taxis		
Aerospatiale SN601 Corvette	2	JT15D-4(100)PWC
Beech B99 Airliner	2	PT6A-27(100)PWC
Bellanca 7GCBC Seaplane	1	0-320(100)Lyc
Canadair CL-600 Challenger	2	ALF502L-2(100)Lyc

Table 5.3-1

(Continued)

Aircraft[1]	Number of Engines	Engine Model (% of Aircraft) and Manufacturer[2]
Cessna Citation	2	JT15D-1(100)PW
Cessna 150	1	0-200(100)Con
Cessna 150	1	O-200(100)Con
Cessna Pressurized Skymaster	2	TS10-360C(100)Con
Cessna 337 Series	2	TSIO-360C(100)Con
Dassault Bregue Falcon 10	2	TFE731-2(100)Grt
Dassault Bregue Falcon 50	3	TFE731-3(100)Grt
Dassault Falcon 20	2	CF700-2D(100)GE
de Havilland DHC-6-300	2	PT6A-27(100)PWC
de Havilland Twin Otter	2	PT6A-27(100)PWC
Fairchild Pilatus PC6 Series	1	PT6A-27[15](100)PWC
Gates Learjet 24D	2	CJ610-6(100)GE
Gates Learjet 35,36	2	TPE 731-2(100)GE
Gates Learjet 35A/36A	2	TFE731-2-2B(100)Grt
Helio Aircraft HST-550A Stallion	1	PT6A-27(100)PWC
Israel Aircraft IAI 1124	2	TFE731-3(100)Grt
Learjet 31	2	TFE731-2(100)Grt
Mitsubishi MU-300 Series	2	JT15D-4(100)PWC
Piper Navajo Chieftain	2	T10-540(100)Lyc
Piper PA-18 Series	1	0-320[16](100)Lyc
Piper PA-42 Series	2	PT6A-41[17](100)PWC
Piper Warrior	1	0-320(100)Lyc

Table 5.3-1

(Continued)

Aircraft[1]	Number of Engines	Engine Model (% of Aircraft) and Manufacturer[2]
Rockwell International Shoreliner 75A	2	CF 700(100)GE
Shorts Skyvan-3	2	TPE-331-2(100)GA
Swearingen Merline IIIA	2	TPE-331-3(100)GA

[1] Source of Aircraft, Type, and No. of Engines is Airport Activity Statistics of Certificated Route Air Carriers, U.S. Department of Transportation, Research and Special Programs Administration, Federal Aviation Administration, 1989. NTIS Report Number ADA 2290303, and the FAA Aircraft Engine Emission Database (FAEED), U.S. Department of Transportation, Federal Aviation Administration, Office of Environment and Energy, 1991. Source of number of aircraft is Census of U.S. Civil Aircraft, U.S. Department of Transportation, Federal Aviation Administration, Office of Management Systems, 1989.

[2] Following the engine model is the percent of aircraft in parentheses which correspond to the particular engine and the engine manufacturer. GE engine data obtained from GE Aircraft Engines: Commercial Program Status, Volume 1, (General Electric, 1991, Cincinnati, Ohio) and Office of Combustion Technology, GE Aircraft Engines (One Newmann Way MD A309, Cincinnati, Ohio 45215-6301, 513/774-4438). Corresponding percents of aircraft refer to U.S. commercial and government aircraft in operation as of 12/31/90. P&W, P&WC, and RR engine data obtained from Turbine-Engined Fleets of the World's Airlines 1990 (Exxon Corporation, supplement to Air World, Volume 42, Number 2, 1990). Corresponding percents of aircraft refer only to U.S. airlines. Engine Manufacturers: Con - Teledyne/Continental, GE - General Electric, Grt - Garrett AiResearch, Lyc - Avco/Lycoming, PW - Pratt & Whitney, PWC - Pratt & Whitney Canada, RR - Rolls Royce.

[3] All Cargo Services.

[4] Percent of aircraft assumed 100%.

[5] Refers to B-737-300 and -500 aircraft.

[6] Refers to B-747-200, -300, and SR aircraft.

[7] Refers to B-767-200ER aircraft. GE combined the number of aircraft in operation of B-767-200ER and -300ER aircraft. It is assumed that an equal distribution between the two aircraft models exists.

[8] Refers to B-767-300ER aircraft. GE combined the number of aircraft in operation of B-767-200ER and -300ER aircraft. It is assumed that an equal distribution between the two aircraft models exists.

[9] Source of engine information is Modern Commercial Aircraft, Green, W., J. Mowinski, and G. Swanborough, 1987. Percent of aircraft assumed 100%.

[10] Assumed EMB-100 aircraft.

[11] Assumed MD-80 aircraft.

[12] Source of engine information is Modern Commercial Aircraft. Percent of aircraft unknown.

[13] Source of engine information is Modern Commercial Aircraft. Engine refers to METRO III aircraft. Percent of aircraft unknown.

[14] Source of engine information is Modern Commercial Aircraft. Engine refers to METRO IIIA aircraft. Percent of aircraft unknown.

[15] Engine refers to a PC6/B2H2 aircraft.

[16] Engine refers to a PA-18-150 Super aircraft.

[17] Engine refers to PA-42 Cheyenne aircraft.

Source: U.S. EPA, 1992a.

Table 5.3-2

Alternative Source of Emission Data for Some Aircraft Engines[1]

Manufacturer	Engine Model	Recommended Source for Emissions Data[2]
GE	CF6-6	CF6-6D
	CF6-50	CF6-50E/C1/E1/C2/E2
	CT7-5A	CT7-5
	CT7-5A2	CT7-5
	CT7-7E	CT7-5
GE (SCNECMA)	CFM56-2	CFM56-2B
	CFM56-2-C1	CFM56-2B
	CFM56-5A	CFM56-5A1
P&W	JT3D series	Contact manufacturer[3]
	JT8D-7D	JT8D-7/7A/7B
	JT8D-15B	JT8D-15
	JT9D-3A	Contact manufacturer
	JT9D-7A-SP	JT9D-7F/7A
	JT9D-7AH	JT9D-7F/7A
	JT9D-20	JT9D-7F/7A
	JT9D-70A	JT9D-70/59/7Q
	PW4060	PW4460
RR	RB211-535E5	Contact manufacturer[4]
	RB211-535F5	Contact manufacturer
	TRENT 600 series	Contact manufacturer
	TRENT 700 series	Contact manufacturer
	SPEY MK506	Contact manufacturer
	SPEY MK555-15	SPEY MK555
	SPEY MK555-15P	SPEY MK555
	SPEY MK555-15H	SPEY MK555

Table 5.3-2

(Continued)

Manufacturer	Engine Model	Recommended Source for Emissions Data[2]
RR (Continued)	SPEY MK512	Contact manufacturer
	TAY MK651	Contact manufacturer
	Dart 514-7	Dart RDa7
	Dart 528-7E	Dart RDa7
	Dart 532-7	Dart RDa7
	Dart 532-7N	Dart RDa7
	Dart 532-7P	Dart RDa7
	Dart 532-7R	Dart RDa7
	Dart 535-7R	Dart RDa7
	Dart 536-7E	Dart RDa7
	Dart 542-4	Dart RDa10
	Dart 542-10J	Dart RDa10
	Dart 542-10K	Dart RDa10
	Dart 552-7R	Dart RDa7

[1] FAA Aircraft Engine Emission Database does not identify these alternative emission factors. A manual adjustment to the database output may be required.
[2] As recommended by engine manufacturers.
[3] For information, contact the Office of Certification & Airworthiness, Commercial Engine Business, United Technologies Pratt & Whitney, 400 Main Street, East Hartford, Connecticut 06108, 203/565-2269.
[4] For information, contact Manager Project Combustion, Rolls Royce Place. P.O. Box 31, Derby DE2 99J England. Telephone - 0332 242424.

Source: U.S. EPA, 1992a.

Table 5.3-3

Model Emission Rates - Civil Aircraft Engine[1]

Model-Series Manufacturer[2]	Mode	Power Setting	Fuel Flow (kg/min)	Emission Indexes (kg/1000 kg of fuel)				
				TOG	CO	NO_x	SO_2[3]	PM
501D22A[4] All.	Takeoff	100%	17.96	0.28	2.04	8.88	0.54	—
	Climbout	85%	16.62	0.89	2.06	9.22	0.54	—
	Approach	30%	8.62	1.96	5.10	7.49	0.54	—
	Taxi/Idle	7%	4.61	17.61	43.61	3.52	0.54	—
0-200[4] Con.	Takeoff	100%	0.34	20.81	974.1	4.87	0.11	—
	Climbout	85%	0.34	20.81	974.10	4.87	0.11	—
	Approach	40%	0.20	33.22	1187.84	1.14	0.11	—
	Taxi/Idle	7%	0.06	29.00	644.42	1.58	0.11	—
TS10-360C[4]	Takeoff	100%	1.01	9.17	1081.95	2.71	0.11	—
	Climbout	85%	0.75	9.55	960.80	4.32	0.11	—
	Approach	40%	0.46	11.31	995.08	3.77	0.11	—
	Taxi/Idle	7%	0.09	138.26	592.17	1.91	0.11	—
CF6-6D GE	Takeoff	100%	104.16	0.30	0.50	40.00	0.54	—
	Climbout	85%	85.86	0.30	0.50	32.60	0.54	—
	Approach	30%	29.03	0.70	6.50	11.40	0.54	—
	Taxi/Idle	7%	10.37	21.00	54.20	4.50	0.54	—
CF6-45 GE	Takeoff	100%	127.56	0.10	1.00	30.60	0.54	—
	Climbout	85%	106.20	0.10	1.30	26.60	0.54	—
	Approach	30%	36.30	0.70	8.20	10.50	0.54	—
	Taxi/Idle	7%	12.12	32.70	59.20	3.90	0.54	—

Table 5.3-3

(Continued)

Model-Series Manufacturer[2]	Mode	Power Setting	Fuel Flow (kg/min)	Emission Indexes (kg/1000 kg of fuel)				
				TOG	CO	NO_x	SO_2[3]	PM
CF45A/A2 GE	Takeoff	100%	121.62	0.09	0.43	25.45	0.54	—
	Climbout	85%	99.78	0.14	0.54	21.61	0.54	—
	Approach	30%	635.52	0.35	5.01	9.36	0.54	—
	Taxi/Idle	4%	9.78	2.72	24.04	3.40	0.54	—
CF6-50E/C1/E1/C2/E2 GE	Takeoff	100%	145.68	0.60	0.50	36.50	0.54	—
	Climbout	85%	115.50	0.70	0.50	29.60	0.54	—
	Approach	30%	39.85	1.00	5.70	9.70	0.54	—
	Taxi/Idle	3%	10.09	49.30	81.30	2.40	0.54	—
CF6-80A GE	Takeoff	100%	128.70	0.29	1.00	29.80	0.54	—
	Climbout	85%	107.70	0.29	1.10	25.60	0.54	—
	Approach	30%	36.90	0.47	3.10	10.30	0.54	—
	Taxi/Idle	4%	9.00	6.29	28.20	3.40	0.54	—
CF6-80A1 GE	Takeoff	100%	128.70	0.29	1.00	29.80	0.54	—
	Climbout	85%	107.70	0.29	1.10	25.60	0.54	—
	Approach	30%	36.90	0.47	3.10	10.30	0.54	—
	Taxi/Idle	4%	9.00	6.29	28.20	3.40	0.54	—
CF6-80A2 GE	Takeoff	100%	135.24	0.30	1.00	29.60	0.54	—
	Climbout	85%	113.10	0.37	1.10	25.60	0.54	—
	Approach	30%	38.46	0.45	2.80	10.30	0.54	—
	Taxi/Idle	4%	9.00	6.28	28.20	3.40	0.54	—

Table 5.3-3

(Continued)

Model-Series Manufacturer[2]	Mode	Power Setting	Fuel Flow (kg/min)	Emission Indexes (kg/1000 kg of fuel)				
				TOG	CO	NO_x	SO_2[3]	PM
CF6-80A3 GE	Takeoff	100%	135.24	0.30	1.00	29.60	0.54	—
	Climbout	85%	113.10	0.37	1.10	26.60	0.54	—
	Approach	30%	38.46	0.45	2.80	10.80	0.54	—
	Taxi/Idle	4%	9.00	6.28	28.20	3.40	0.54	—
CF6-80C2A1 GE	Takeoff	100%	144.00	0.08	0.56	32.22	0.54	—
	Climbout	85%	117.18	0.09	0.54	24.85	0.54	—
	Approach	30%	38.16	2.00	2.19	9.76	0.54	—
	Taxi/Idle	7%	11.94	9.19	42.24	3.99	0.54	—
CF6-80C2A2 GE	Takeoff	100%	127.02	0.14	0.58	27.90	0.54	—
	Climbout	85%	104.70	0.11	0.56	20.71	0.54	—
	Approach	30%	34.80	0.25	3.04	9.52	0.54	—
	Taxi/Idle	7%	11.34	10.74	46.65	3.91	0.54	—
CF6-80C2A3 GE	Takeoff	100%	147.42	0.08	0.59	34.44	0.54	—
	Climbout	85%	120.18	0.10	0.57	25.45	0.54	—
	Approach	30%	38.94	0.21	2.15	10.01	0.54	—
	Taxi/Idle	7%	12.12	9.21	42.18	3.96	0.54	—
CFM56-2A GE (SNECMA)	Takeoff	100%	67.38	0.03	0.90	21.05	0.54	—
	Climbout	85%	55.62	0.04	1.00	17.18	0.54	—
	Approach	30%	20.70	0.10	3.40	8.62	0.54	—
	Taxi/Idle	7%	7.92	1.17	24.90	4.12	0.54	—

Table 5.3-3

(Continued)

Model-Series Manufacturer[2]	Mode	Power Setting	Fuel Flow (kg/min)	Emission Indexes (kg/1000 kg of fuel)				
				TOG	CO	NO_x	SO_2[3]	PM
CFM56-2B GE (SNECMA)	Takeoff	100%	60.12	0.05	0.90	19.06	0.54	—
	Climbout	85%	50.22	0.08	0.90	16.30	0.54	—
	Approach	30%	19.32	0.10	3.70	8.14	0.54	—
	Taxi/Idle	7%	7.38	1.67	29.50	3.66	0.54	—
CFM56-3 GE (SNECMA)	Takeoff	100%	61.20	0.04	0.90	18.50	0.54	—
	Climbout	85%	50.58	0.05	0.90	16.00	0.54	—
	Approach	30%	20.28	0.10	3.50	8.40	0.54	—
	Take/Idle	7%	7.26	1.83	31.00	3.90	0.54	—
CFM56-3B GE (SNECMA)	Takeoff	100%	68.40	0.04	0.90	20.70	0.54	—
	Climbout	85%	55.80	0.05	0.90	17.30	0.54	—
	Approach	30%	21.60	0.08	3.10	8.70	0.54	—
	Taxi/Idle	7%	7.80	1.25	27.00	4.10	0.54	—
CFM56-3B4 GE (SNECMA)	Takeoff	100%	52.80	0.04	0.90	16.60	0.54	—
	Climbout	85%	43.80	0.05	1.10	14.50	0.54	—
	Approach	30%	16.20	0.11	4.20	8.00	0.54	—
	Taxi/Idle	7%	6.60	3.33	38.50	3.90	0.54	—
CFM56-3C GE (SNECMA)	Takeoff	100%	70.80	0.04	0.90	20.17	0.54	—
	Climbout	85%	58.20	0.04	1.00	17.15	0.54	—
	Approach	30%	20.40	0.09	3.20	8.88	0.54	—

Table 5.3-3

(Continued)

Model-Series Manufacturer[2]	Mode	Power Setting	Fuel Flow (kg/min)	Emission Indexes (kg/1000 kg of fuel)				
				TOG	CO	NO_x	SO_2[3]	PM
CFM56-5A1 GE (SNECMA)	Takeoff	100%	64.77	0.23	0.83	28.03	0.54	—
	Climbout	85%	52.80	0.23	0.87	23.10	0.54	—
	Approach	30%	18.00	0.40	2.47	9.48	0.54	—
	Taxi/Idle	7%	6.60	1.53	18.00	4.36	0.54	—
TFE 731-2 Grt	Takeoff	100%	12.30	0.11	1.39	15.25	0.54	—
	Climbout	85%	10.38	0.13	2.03	13.08	0.54	—
	Approach	30%	4.02	4.26	22.38	5.90	0.54	—
	Taxi/Idle	7%	1.44	20.04	58.60	2.82	0.54	—
TFE 731-3 Grt	Takeoff	100%	13.50	0.06	1.13	19.15	0.54	—
	Climbout	85%	11.16	0.07	1.62	16.02	0.54	—
	Approach	30%	4.32	1.41	15.56	6.92	0.54	—
	Taxi/Idle	7%	1.56	9.04	47.70	3.72	0.54	—
TPE 331-3[6] Grt	Takeoff	100%	3.46	0.11	0.76	12.36	0.54	1.75
	Climbout	90%	3.09	0.15	0.98	11.86	0.54	1.47
	Approach	30%	1.89	0.64	6.96	9.92	0.54	2.40
	Taxi/Idle	7%	0.85	79.11	61.52	2.86	0.54	2.95
ALF 502L-2 Lyc	Takeoff	100%	24.00	0.02	0.40	13.43	0.54	—
	Climbout	85%	19.41	0.02	0.30	12.03	0.54	—
	Approach	30%	7.03	0.18	3.97	6.47	0.54	—
	Taxi/Idle	7%	2.86	6.65	45.63	3.38	0.54	—

Table 5.3-3

(Continued)

Model-Series Manufacturer[2]	Mode	Power Setting	Fuel Flow (kg/min)	Emission Indexes (kg/1000 kg of fuel)				
				TOG	CO	NO_x	SO_2[3]	PM
ALF 502R-3 Lyc	Takeoff	100%	20.86	0.06	0.43	11.20	0.54	—
	Climbout	85%	17.28	0.05	0.50	9.94	0.54	—
	Approach	30%	6.16	0.29	8.43	6.15	0.54	—
	Taxi/Idle	7%	2.59	6.51	44.67	3.30	0.54	—
ALF 502R-5 Lyc	Takeoff	100%	21.49	0.06	0.30	13.53	0.54	—
	Climbout	85%	17.73	0.05	0.25	10.56	0.54	—
	Approach	30%	6.21	0.22	7.10	13.53	0.54	—
	Taxi/Idle	7%	2.45	5.39	40.93	3.78	0.54	—
0-320[4] Lyc	Takeoff	100%	0.67	11.78	1077.44	2.19	0.11	—
	Climbout	85%	0.50	12.38	989.51	3.97	0.11	—
	Approach	40%	0.35	19.25	1221.51	0.95	0.11	—
	Taxi/Idle	7%	0.07	36.92	1077.00	0.52	0.11	—
D-36 MKB	Takeoff	100%	38.04	0.00	0.50	26.00	0.54	—
	Climbout	85%	31.98	0.00	0.40	22.00	0.54	—
	Approach	30%	12.66	0.00	2.70	9.00	0.54	—
	Taxi/Idle	7%	0.00	5.40	20.70	5.50	0.54	—
NK-86 NPO	Takeoff	100%	121.14	0.00	1.30	13.60	0.54	—
	Climbout	85%	99.00	0.00	1.70	10.00	0.54	—
	Approach	30%	34.32	0.00	5.00	3.80	0.54	—

Table 5.3-3

(Continued)

Model-Series Manufacturer[2]	Mode	Power Setting	Fuel Flow (kg/min)	Emission Indexes (kg/1000 kg of fuel)				
				TOG	CO	NO_x	SO_2[3]	PM
IAE V2500 PW	Takeoff	100%	66.78	0.10	0.55	37.13	0.54	—
	Climbout	85%	55.44	0.11	0.55	30.82	0.54	—
	Approach	30%	20.04	0.15	0.77	13.45	0.54	—
	Taxi/Idle	7%	7.44	0.22	7.76	5.91	0.54	—
JT3D-7[4] PW	Takeoff	100%	75.26	0.50	0.90	12.70	0.54	—
	Climbout	85%	61.90	0.40	1.90	9.60	0.54	—
	Approach	30%	23.31	2.10	19.50	5.30	0.54	—
	Taxi/Idle	7%	7.66	123.00	138.99	2.20	0.54	—
JT8D-7/7A/7B PW	Takeoff	100%	59.35	0.40	1.50	17.10	0.54	—
	Climbout	85%	48.68	0.50	2.00	13.50	0.54	—
	Approach	30%	17.16	1.60	10.50	5.50	0.54	—
	Taxi/Idle	7%	7.75	10.60	35.50	2.70	0.54	—
JT8D-9/9A PW	Takeoff	100%	62.40	0.47	1.24	17.92	0.54	—
	Climbout	85%	50.76	0.47	1.66	14.21	0.54	—
	Approach	30%	17.88	1.73	9.43	5.64	0.54	—
	Taxi/Idle	7%	7.92	10.00	34.50	2.90	0.54	—
JT8D-11 PW	Takeoff	100%	67.26	0.40	1.20	18.90	0.54	—
	Climbout	85%	54.82	0.45	1.90	14.60	0.54	—
	Approach	30%	20.04	1.40	9.40	5.80	0.54	—

Table 5.3-3

(Continued)

Model-Series Manufacturer[2]	Mode	Power Setting	Fuel Flow (kg/min)	Emission Indexes (kg/1000 kg of fuel)				
				TOG	CO	NO_x	SO_2[3]	PM
JT8D-15[7] PW	Takeoff	100%	70.68	0.25	0.72	19.12	0.54	—
	Climbout	85%	56.70	0.25	1.01	15.01	0.54	—
	Approach	30%	20.42	1.57	9.12	5.97	0.54	—
	Taxi/Idle	7%	8.86	10.33	33.88	3.01	0.54	—
JT8D-15A PW	Takeoff	100%	66.90	0.25	1.08	18.10	0.54	—
	Climbout	85%	53.73	0.33	1.20	13.90	0.54	—
	Approach	30%	18.72	0.65	2.90	6.60	0.54	—
	Taxi/Idle	7%	8.23	2.29	12.43	3.10	0.54	—
JT8D-17[7] PW	Takeoff	100%	74.70	0.66	0.75	19.30	0.54	—
	Climbout	85%	59.82	0.75	1.01	15.26	0.54	—
	Approach	30%	21.24	1.86	8.13	6.23	0.54	—
	Taxi/Idle	7%	8.82	9.57	29.56	3.29	0.54	—
JT8D-17A PW	Takeoff	100%	70.38	0.25	1.07	19.10	0.54	—
	Climbout	85%	56.06	0.30	1.16	14.30	0.54	—
	Approach	30%	19.82	0.64	2.88	6.70	0.54	—
	Taxi/Idle	7%	8.41	2.02	12.46	3.20	0.54	—
JT8D-17AR PW	Takeoff	100%	81.90	0.21	0.93	24.50	0.54	—
	Climbout	85%	62.82	0.27	1.08	16.00	0.54	—
	Approach	30%	21.45	0.55	2.68	8.00	0.54	—

Table 5.3-3

(Continued)

Model-Series Manufacturer[2]	Mode	Power Setting	Fuel Flow (kg/min)	Emission Indexes (kg/1000 kg of fuel)				
				TOG	CO	NO_x	SO_2[3]	PM
JT8D-17R PW	Takeoff	100%	85.02	0.21	0.95	25.30	0.54	—
	Climbout	85%	66.18	0.27	1.03	17.60	0.54	—
	Approach	30%	22.53	0.53	2.54	8.40	0.54	—
	Taxi/Idle	7%	9.30	0.95	9.43	3.30	0.54	—
JT8D-209 PW	Takeoff	100%	71.46	0.35	1.03	22.80	0.54	—
	Climbout	85%	58.97	0.50	1.40	19.00	0.54	—
	Approach	30%	21.55	1.69	4.37	8.80	0.54	—
	Taxi/Idle	7%	7.82	4.03	14.10	3.50	0.54	—
JT8D-217/217A/217C PW	Takeoff	100%	79.20	0.28	0.80	25.70	0.54	—
	Climbout	85%	64.68	0.43	1.23	20.60	0.54	—
	Approach	30%	23.00	1.60	4.17	9.10	0.54	—
	Taxi/Idle	7%	8.23	3.33	12.27	3.70	0.54	—
JT8D-219 PW	Takeoff	100%	81.24	0.27	0.73	27.00	0.54	—
	Climbout	85%	65.10	0.42	1.20	20.80	0.54	—
	Approach	30%	22.90	1.59	4.07	9.13	0.54	—
	Taxi/Idle	7%	8.06	3.48	12.63	3.60	0.54	—
JT9D-7[4] PW	Takeoff	100%	122.03	0.05	0.20	29.40	0.54	—
	Climbout	85%	99.74	0.10	0.50	21.40	0.54	—
	Approach	30%	35.14	1.00	9.60	7.80	0.54	—

Table 5.3-3

(Continued)

Model-Series Manufacturer[2]	Mode	Power Setting	Fuel Flow (kg/min)	Emission Indexes (kg/1000 kg of fuel)				
				TOG	CO	NO_x	SO_2[3]	PM
JT9D-7F(modV)/ 7A(modV) PW	Takeoff	100%	130.03	0.30	0.40	46.00	0.54	—
	Climbout	85%	105.84	0.30	0.40	34.40	0.54	—
	Approach	30%	37.42	0.50	2.90	7.80	0.54	—
	Taxi/Idle	7%	13.14	26.00	54.00	3.10	0.54	—
JT9D-7R4D/7R4D1 PW	Takeoff	100%	123.30	0.15	0.51	38.50	0.54	—
	Climbout	85%	100.68	0.12	0.48	32.00	0.54	—
	Approach	30%	45.56	0.13	1.36	9.80	0.54	—
	Taxi/Idle	7%	12.32	1.25	10.00	4.10	0.54	—
JT9D-7R4E/ E1(A1500) PW	Takeoff	100%	127.08	0.16	0.57	41.60	0.54	—
	Climbout	85%	103.44	0.13	0.53	34.20	0.54	—
	Approach	30%	39.17	0.13	1.23	10.40	0.54	—
	Taxi/Idle	7%	13.26	1.11	8.27	4.10	0.54	—
JT9D-7R4E1(H) (A1-600) PW	Takeoff	100%	133.08	0.15	0.67	36.90	0.54	—
	Climbout	85%	109.74	0.13	0.67	29.70	0.54	—
	Approach	30%	38.40	0.22	1.46	8.50	0.54	—
	Taxi/Idle	7%	13.23	3.35	14.00	3.50	0.54	—
JT9D-7R4G2 PW	Takeoff	100%	145.74	0.15	0.74	41.30	0.54	—
	Climbout	85%	112.80	0.14	0.63	32.10	0.54	—
	Approach	30%	39.54	0.18	1.40	8.80	0.54	—

Table 5.3-3

(Continued)

Model-Series Manufacturer[2]	Mode	Power Setting	Fuel Flow (kg/min)	Emission Indexes (kg/1000 kg of fuel)				
				TOG	CO	NO_x	SO_2[3]	PM
JT9D-7R4H1/H2 PW	Takeoff	100%	150.72	0.15	0.74	45.20	0.54	—
	Climbout	85%	119.94	0.14	0.63	34.20	0.54	—
	Approach	30%	43.36	0.18	1.39	8.90	0.54	—
	Taxi/Idle	7%	14.72	1.48	11.63	3.80	0.54	—
JT9D-70/59/7Q PW	Takeoff	100%	146.51	0.20	0.20	31.60	0.54	—
	Climbout	85%	119.98	0.20	0.20	25.60	0.54	—
	Approach	30%	40.82	0.30	1.70	7.80	0.54	—
	Taxi/Idle	7%	14.22	12.00	53.00	3.00	0.54	—
PW2037 PW	Takeoff	100%	92.28	0.05	0.40	31.10	0.54	—
	Climbout	85%	75.96	0.06	0.41	24.80	0.54	—
	Approach	30%	23.94	0.21	2.30	10.30	0.54	—
	Taxi/Idle	7%	8.46	2.26	23.10	4.40	0.54	—
PT2040 PW	Takeoff	100%	109.32	0.03	0.20	47.70	0.54	—
	Climbout	85%	86.88	0.04	0.20	27.70	0.54	—
	Approach	30%	29.58	0.18	2.60	11.00	0.54	—
	Taxi/Idle	7%	9.30	2.36	23.60	4.40	0.54	—
PW2041 PW	Takeoff	100%	115.02	0.03	0.20	37.00	0.54	—
	Climbout	85%	92.16	0.04	0.20	29.00	0.54	—
	Approach	30%	31.02	0.16	2.50	11.00	0.54	—

Table 5.3-3

(Continued)

Model-Series Manufacturer[2]	Mode	Power Setting	Fuel Flow (kg/min)	Emission Indexes (kg/1000 kg of fuel)				
				TOG	CO	NO_x	SO_2[3]	PM
PW4056/4156 PW	Takeoff	100%	140.52	0.06	0.44	28.10	0.54	—
	Climbout	85%	115.80	0.01	0.57	22.90	0.54	—
	Approach	30%	39.48	0.13	2.00	11.60	0.54	—
	Taxi/Idle	7%	12.48	1.92	21.86	4.80	0.54	—
PW4152 PW	Takeoff	100%	130.62	0.13	0.12	26.90	0.54	—
	Climbout	85%	107.10	0.16	0.17	22.70	0.54	—
	Approach	30%	35.58	0.15	1.09	11.10	0.54	—
	Taxi/Idle	7%	10.62	0.74	12.76	4.90	0.54	—
PW4158 PW	Takeoff	100%	148.86	0.09	0.40	30.20	0.54	—
	Climbout	85%	120.28	0.02	0.54	23.70	0.54	—
	Approach	30%	40.92	0.14	1.88	11.80	0.54	—
	Taxi/Idle	7%	12.66	1.78	20.99	4.80	0.54	—
PW4460 PW	Takeoff	100%	158.82	0.10	0.37	32.80	0.54	—
	Climbout	85%	125.10	0.03	0.51	24.70	0.54	—
	Approach	30%	42.18	0.14	1.78	12.00	0.54	—
	Taxi/Idle	7%	12.78	1.66	20.32	4.90	0.54	—
JT15D-1 PWC	Takeoff	100%	8.88	0.01	2.65	7.60	0.54	—
	Climbout	85%	7.44	0.01	3.50	6.77	0.54	—
	Approach	30%	3.06	4.43	40.50	3.44	0.54	—

Table 5.3-3

(Continued)

Model-Series Manufacturer[2]	Mode	Power Setting	Fuel Flow (kg/min)	Emission Indexes (kg/1000 kg of fuel)				
				TOG	CO	NO_x	SO_2[3]	PM
JT15D-4 PWC	Takeoff	100%	10.18	0.09	2.10	9.23	0.54	—
	Climbout	85%	8.58	0.19	3.18	8.56	0.54	—
	Approach	30%	3.54	5.15	32.00	5.29	0.54	—
	Taxi/Idle	7%	1.56	40.00	97.00	2.63	0.54	—
PT6A-27[6] PWC	Takeoff	100%	3.21	0.00	1.01	7.81	0.54	—
	Climbout	90%	3.03	0.00	1.20	7.00	0.54	—
	Approach	30%	1.62	2.19	23.02	8.37	0.54	—
	Taxi/Idle	7%	0.87	50.17	64.00	2.43	0.54	—
PT6A-41[4] PWC	Takeoff	100%	3.86	1.75	5.10	7.98	0.54	—
	Climbout	90%	3.57	2.03	6.49	7.57	0.54	—
	Approach	30%	2.06	22.71	34.80	4.65	0.54	—
	Taxi/Idle	7%	1.11	101.63	115.31	1.97	0.54	—
Dart RDa7 RR	Takeoff	100%	10.68	1.00	3.20	5.60	0.54	—
	Climbout	85%	9.42	1.10	3.50	4.50	0.54	—
	Approach	30%	4.89	3.00	33.30	0.90	0.54	—
	Taxi/Idle	7%	3.10	23.90	91.40	0.70	0.54	—
Dart RDa10 RR	Takeoff	100%	12.78	0.00	2.20	4.30	0.54	—
	Climbout	85%	10.20	0.00	3.00	3.90	0.54	—
	Approach	30%	4.74	0.00	23.20	2.20	0.54	—

Table 5.3-3

(Continued)

Model-Series Manufacturer[2]	Mode	Power Setting	Fuel Flow (kg/min)	Emission Indexes (kg/1000 kg of fuel)				
				TOG	CO	NO_x	SO_2[3]	PM
M45H-01 RR	Takeoff	100%	29.88	0.75	6.20	11.50	0.54	—
	Climbout	85%	24.96	0.74	7.90	9.30	0.54	—
	Approach	30%	8.76	7.40	51.00	3.60	0.54	—
	Taxi/Idle	7%	3.18	59.50	178.40	1.50	0.54	—
OLYMPUS 593 MK610 RR	Takeoff	100%	381.90	2.90	29.00	9.50	0.54	—
	Climbout	65%	139.74	1.70	19.90	9.30	0.54	—
	Descent	15%	41.10	22.00	73.20	2.50	0.54	—
	Approach	34%	70.26	11.40	52.90	3.50	0.54	—
	Taxi/Idle	7%	25.26	33.40	100.10	1.70	0.54	—
RB.211-22B RR	Takeoff	100%	111.96	0.36	2.48	34.32	0.54	—
	Climbout	85%	92.52	0.39	4.14	25.63	0.54	—
	Approach	30%	33.18	7.73	26.38	8.05	0.54	—
	Taxi/Idle	7%	13.62	65.37	93.17	2.70	0.54	—
RB.211-524B/B2/ B3/B4 RR	Takeoff	100%	142.98	0.52	1.83	47.00	0.54	—
	Climbout	85%	116.34	0.40	2.82	33.00	0.54	—
	Approach	30%	41.58	4.98	20.00	9.75	0.54	—
	Taxi/Idle	7%	16.32	50.60	82.20	3.53	0.54	—
RB.211-524C2 RR	Takeoff	100%	148.80	0.00	0.66	41.90	0.54	—
	Climbout	85%	121.20	0.22	1.63	32.30	0.54	—
	Approach	30%	44.40	4.42	18.90	10.40	0.54	—

Table 5.3-3

(Continued)

Model-Series Manufacturer[2]	Mode	Power Setting	Fuel Flow (kg/min)	Emission Indexes (kg/1000 kg of fuel)				
				TOG	CO	NO_x	SO_2[3]	PM
RB.211-524D4[7] RR	Takeoff	100%	146.11	0.02	0.53	56.97	0.54	—
	Climbout	85%	117.01	0.42	1.15	41.06	0.54	—
	Approach	30%	43.08	4.68	16.44	9.68	0.54	—
	Taxi/Idle	7%	17.46	45.11	71.87	4.12	0.54	—
RB.211-524G RR	Takeoff	100%	157.20	2.28	0.59	58.71	0.54	—
	Climbout	85%	124.80	1.46	0.43	40.54	0.54	—
	Approach	30%	42.00	1.14	1.01	9.56	0.54	—
	Taxi/Idle	7%	15.60	3.28	13.74	4.63	0.54	—
RB.211-524H RR	Takeoff	100%	163.80	1.00	0.90	65.80	0.54	—
	Climbout	85%	130.20	0.60	0.40	46.30	0.54	—
	Approach	30%	42.60	0.30	1.00	10.30	0.54	—
	Taxi/Idle	7%	15.60	0.50	11.70	4.80	0.54	—
RB.211-535C RR	Takeoff	100%	108.00	0.25	0.70	33.71	0.54	—
	Climbout	85%	88.20	0.14	0.27	24.89	0.54	—
	Approach	30%	32.40	0.44	0.84	6.37	0.54	—
	Taxi/Idle	7%	12.00	1.44	18.79	3.44	0.54	—
RB.211-535E4 RR	Takeoff	100%	111.60	0.69	1.01	52.70	0.54	—
	Climbout	85%	90.60	0.94	1.23	36.20	0.54	—
	Approach	30%	34.20	1.33	1.71	7.50	0.54	—

Table 5.3-3

(Continued)

Model-Series Manufacturer[2]	Mode	Power Setting	Fuel Flow (kg/min)	Emission Indexes (kg/1000 kg of fuel)				
				TOG	CO	NO_x	SO_2[3]	PM
SPEY MK511 RR	Takeoff	100%	53.34	0.98	1.81	23.27	0.54	—
	Climbout	85%	43.56	1.32	2.06	19.18	0.54	—
	Approach	30%	16.74	7.23	20.30	7.94	0.54	—
	Taxi/Idle	7%	7.14	56.73	97.96	1.48	0.54	—
SPEY MK511-8 RR	Takeoff	100%	53.46	0.09	0.12	22.70	0.54	—
	Climbout	85%	43.56	0.12	0.63	17.30	0.54	—
	Approach	30%	16.68	0.18	2.65	7.20	0.54	—
	Taxi/Idle	7%	7.62	3.69	31.77	3.60	0.54	—
SPEY MK555[8] RR	Takeoff	100%	33.34	0.74	0.41	19.61	0.54	—
	Climbout	85%	27.27	1.27	0.16	15.07	0.54	—
	Approach	30%	10.28	5.43	17.96	6.12	0.54	—
	Taxi/Idle	7%	5.33	71.84	74.68	2.26	0.54	—
TAY MK620-15/ MK611-8 RR	Takeoff	100%	45.60	0.80	0.70	21.10	0.54	—
	Climbout	85%	37.80	0.30	0.80	16.80	0.54	—
	Approach	30%	13.80	0.90	3.90	5.70	0.54	—
	Taxi/Idle	7%	6.60	3.40	24.10	2.50	0.54	—
TAY MK650[9] RR	Takeoff	100%	52.44	0.40	1.70	19.80	0.54	—
	Climbout	85%	42.90	0.40	2.00	16.50	0.54	—
	Approach	30%	15.24	0.90	6.50	4.60	0.54	—

Table 5.3-3

(Continued)

[1] SOURCE: ICAO Engine Exhaust Emissions Databank. (ICAO Committee on Aviation Environmental Protection, Working Group Meeting, Mariehamn, Aland., October 1989), unless otherwise noted.

[2] MANUFACTURERS: All. - Allison, Con - Teledyne/Continental, GE - General Electric, Grt - Garrett AiResearch, Lyc - Avco/Lycoming, PW - Pratt & Whitney, PWC - Pratt & Whitney Canada, RR - Rolls-Royce.

[3] SO_2 emissions based on national average sulfur content of aviation fuels from Aviation Turbines Fuels, 1989, Dickson, Cheryl L. and Paul W. Woodward, March, 1990. NIPER Report Number NIPER-164 PPS, National Institute for Petroleum and Energy Research, ITT Research Institute, Bartlesville, Oklahoma.

[4] Source of data is AP-42, Compilation of Air Pollutant Emission Factors, Volume II: Mobile Sources, U.S. Environmental Protection Agency, Ann Arbor, Michigan, September, 1985. (Aircraft data from February 1980).

[5] Source of engine data is General Electric Office of Combustion Technology, GE Aircraft Engines, One Newmann Way MD A309, Cincinnati, Ohio 45215-6301, 513/774-438.

[6] Source of data is AP-42. Source of Particulate data is AP-42 Reference 4 (M. Platt, et al., The Potential Impact of Aircraft Emissions upon Air Quality, APTD-1085, U.S. Environmental Protection Agency, Research Triangle Park, NC, December 1971). The indicated reference does not specify series number for this model engine.

[7] Source of engine data is ICAO, ICAO Engine Exhaust Emissions Databank. Data are sales weighted averages of two versions of this engine. The basis is 93% high emission combustors and 7% low emission combustors.

[8] Source of engine data is ICAO, ICAO Engine Exhaust Emissions Databank. Data are sales weighted averages of two versions of this engine. The basis is 77% high emission combustors and 23% low emission combustors.

[9] Source of engine data is Rolls Royce Combustion Research Department, Rolls Royce plc. P.O. Box 31, Derby DE2 88J England. Telephone - 0332 242424.

The Federal Aviation Administration (FAA) should be contacted for the latest version of the data base. Second, for an aircraft with several potential engine types, where no emissions data are available for one engine, the recommended procedure is to reallocate the market share among the engines for which data is available. Third, if emission rate information (fuel consumption and emission index) for an engine model still cannot be located the engine manufacturer should be contacted directly.

After the engine types have been identified, fuel flow rates and emission indexes can be found in Table 5.3-3. Emission indexes are given for specific fuel flow rates which are representative of the power settings used during the different operating modes. The emission index multiplied by the fuel flow rate yields an emission rate.

Step 6 is to specify a time-in-mode for each aircraft type. Take-off time is fairly standard for commercial aircraft and represents the time for initial climb from ground level to about 150 meters. The default take-off time for calculating emissions is 0.7 minutes (42 seconds) and, unless more specific data are available, should be used in this methodology. The time in the approach and climbout modes depends on mixing height. As mentioned earlier, a default mixing height of 900 meters was assumed for calculating an approach time of 4 minutes and a climbout time of 2.2 minutes, which can be used if specific information on mixing height is not available. The procedure for adjusting these times to correspond to a different mixing height is shown below.

The mode most likely to vary by time for each specific airport is taxi/idle time. Total taxi/idle time for a very congested airport can be as much as three or four times longer than for an uncongested airport. Taxi/idle-in time typically is shorter than taxi/idle-out time because there are usually fewer delays for aircraft coming into a gate than for aircraft lining up to takeoff. For a large congested airport the taxi/idle-out time can be three times longer than taxi/idle-in time. Taxi/idle time also may vary by aircraft type. For example, wide-body jets may all use special gates at the terminal that place them further from the runway than narrow-body jets or small regional commuter aircraft so their taxi/idle-in and taxi/idle-out times are longer. Because of the variation in taxi/idle time, it is important to get data specific to the airports of interest in the inventory. Commercial airlines must keep track of their taxi/idle time at each airport for different aircraft types so that their flight schedules reflect anticipated daily and seasonal variations. Therefore, the airlines' Flight Operations departments at their headquarters locations are the best source of data for taxi/idle time by aircraft type at a particular airport. Since all airlines using a particular airport will experience similar taxi/idle times, it is only necessary to get information from a single source. If taxi/idle times are not available for a particular airport, Table 5.3-4 lists default values of taxi/idle

Table 5.3-4

Default Time-in-Mode for Various Aircraft Categories

Aircraft	Time-in-Mode (minutes)						
	Taxi/ Idle-out	Takeoff	Climbout	Approach	Taxi/ Idle-in	Total	Source
Commercial Carrier							
Jumbo, long and medium range jet	19.0	0.7	2.2	4.0	7.0	32.9	AP-42, 1985
Turboprop	19.0	0.5	2.5	4.5	7.0	33.5	AP-42, 1985
Transport-piston	6.5	0.6	5.0	4.6	6.5	23.2	AP-42, 1985
General Aviation							
Business jet	6.5	0.4	0.5	1.6	6.5	15.5	AP-42, 1985
Turboprop	19.0	0.5	2.5	4.5	7.0	33.5	AP-42, 1985
Piston	12.0	0.3	5.0	6.0	4.0	27.3	AP-42, 1985
Helicopter	3.5	—	6.5	6.5	3.5	20.0	AP-42, 1985

periods, as well as other modes, for different aircraft classifications. For commercial aircraft, this information is based on data collected prior to 1971 at large airports during periods of congestion. For the inventory calculations, taxi/idle-in and taxi/idle-out time are added together to get a total time for the taxi/idle mode.

The final step in the procedure is to calculate total emissions for each aircraft type and to sum them for a total commercial aircraft emission rate. The following series of equations illustrates the calculation.

Adjust Approach and Climbout TIM to Represent Local Conditions

These equations adjust the TIMs, which are based on a default mixing height of 900 meters, to an airport specific value based on the local mixing height.

Equation 5.3-1 assumes the climbout mode begins with the transition from takeoff to climbout at 150 meters and continues until the aircraft exits the mixing layer.

$$\begin{aligned} TIM_{App} &= TIM_{App-Def} \left(\frac{H}{900} \right) \\ TIM_{Clm} &= TIM_{Clm-Def} \left(\frac{H-150}{750} \right) \end{aligned} \qquad (5.3\text{-}1)$$

where:
TIM_{App} = Actual time in approach mode (minutes);
$TIM_{App\text{-}Def}$ = Default time in approach mode (minutes) (see Table 5.3-4);
H = Mixing height used in air quality modeling for time and region of interest;
TIM_{Cln} = Actual time in climbout mode (minutes); and
$TIM_{Clm\text{-}Def}$ = Default time in climbout mode (minutes) (see Table 5.3-4).

If the detailed estimation procedure is being followed based on specific aircraft and engines, airport specific estimates on TIM might be used if available from airport officials. These data likely vary quite widely because of the many different types of services provided by this aircraft category. Otherwise, the estimation procedure is based on the default TIMs from Table 5.3-4. Emissions should be calculated separately for the different aircraft categories.

Calculate Emissions for Each Aircraft Type

$$E_{ij} = \Sigma \, [(TIM_{jk}) \times \left(FF_{jkL}/1{,}000\right) \times (EL_{ijkL}) \times (NE_{j})] \qquad (5.3\text{-}2)$$

where: E_{ij} = Total emissions of pollutant i, produced by aircraft type j for one LTO cycle (kg);
TIM_{jk} = Time in mode for mode k (takeoff, climbout, approach, taxi/idle), in minutes, for aircraft type j;
FF_{jkL} = Fuel flow for mode k, for engine L used on aircraft type j (kg/minute) (from Table 5.3-3);
EL_{ijkL} = Emission index for pollutant i in mode k for aircraft type j for engine L (kg/1,000 kg fuel) (from Table 5.3-3); and
NE_j = Number of engines used on aircraft type j (from Table 5.3-1).

To estimate emissions, the following equation should be used:

$$E_{aij} = E_{ij} \times LTO_j \qquad (5.3\text{-}3)$$

where: E_{aij} = Total emissions of pollutant i for aircraft type j (kg);
E_{ij} = Total emissions of pollutant i, produced by aircraft type j for one LTO (kg); and
LTO_j = Number of LTOs for aircraft type j.

To estimate total emissions from aircraft activity, the emissions for each aircraft are then summed.

Alternative Approach for General Aviation and Air Taxis

In some cases LTO data on general aviation and air taxis may not be reported in the detail required to use the above method.

A rough estimate of emissions for each aircraft category can be made using emission indices based on a representative fleet mix. The following indices were calculated based on 1988 U.S. fleet data for general aviation aircraft:

TOG	0.179 kg per LTO
CO	5.449 kg per LTO
NO_x	0.029 kg per LTO
SO_2	0.005 kg per LTO

Because air taxis have fewer of the smallest engines in their fleet and more turboprop and turbojet engines, their emission factors are somewhat different:

TOG	0.376 kg per LTO
CO	12.76 kg per LTO
NO_x	0.072 kg per LTO

SO_2 0.007 kg per LTO

These emission factors may then be applied to the following equation to estimate emissions:

$$E_{ij} = EF_{ij} \times LTO_{ij} \qquad (5.3\text{-}4)$$

where: E_{ij} = Total emissions of pollutant i, in kg, produced by aircraft type j;
EF_{ij} = Emission factor for pollutant i, in kg of pollutant per LTO for aircraft type j; and
LTO_j = LTO cycle for aircraft type j.

DATA NEEDED:

Data	**Sources**
LTO Data by Aircraft Type	ASA and local airport operation
Aircraft Engine Data	FAA, 1991
Number of Engines	Air World, 1990
Engine Model and Manufacture	FAA, 1991
Market Share	Air World, 1990
Fuel Flow	FAA, 1991
Emission Index	FAA, 1991
Mixing Height	Sosa, 1995
Time-in-Mode Data	Local Airport Operators

SAMPLE CALCULATION:

- Airport A is served twice a week by airline B using a Boeing B-757-200, annually LTOs = 104
  Boeing B-757-20: 2 engines
  26 percent of the market share use Pratt & Whitney engine DW2040 and 74 percent of market share use Rolls Royce engine RB.211-535 E4.

- Ceiling height for Airport A is 800 meters

$$\begin{aligned} TIM_{App} &= TIM_{App-DEF} \times \left(\frac{H}{900}\right) \\ &= 4 \times \left(\frac{800}{900}\right) \\ &= 3.6 \text{ min.} \end{aligned}$$

$$\begin{aligned} TIM_{Clm} &= TIM_{Clm-Def} \times \left(\frac{H-150}{750}\right) \\ &= 2.2 \times \left(\frac{800-150}{750}\right) \\ &= 1.9 \text{ min.} \end{aligned}$$

Time data for taxing in/out of the airport is provided by the airport operations; 25 minutes.

- To calculate emissions of TOG:

$$E_{ij} = \Sigma\ [(TIM_{jk}) \times (EF_{jk}/1{,}000) \times (EL_{ijk}) \times (NE_j)]$$

PW2040 Engine

Approach = (3.6) (29.58/1000) (0.18) (2) = 0.038 kg

Climbout = (1.9) (86.88/1000) (0.04) (2) = 0.013 kg

Taxi = (25) (9.30/1000) (2.36) (2) = 1.097 kg

Take off = (0.7) (109.32/1000) (0.03) (2) = 0.005 kg

Total = Approach + Climbout + Taxi + Takeoff

= 0.038 + 0.013 + 1.097 + 0.005 = 1.153 kg/LTO

RB.211.535E4 Engine

Approach = (3.6) (34.20/1000) (1.33) (2) = 0.327 kg

Climbout = (1.9) (90.60/1000) (0.94) (2) = 0.324 kg

Taxi = (25) (11.40/1000) (2.85) (2) = 1.625 kg

Take off = (0.7) (111.60/1000) (0.69) (2) = 0.108 kg

Total = Approach + Climbout + Taxi + Take off

= 0.327 + 0.324 + 1.625 + 0.108 = 2.384 kg/LTO

Combined Engines

26% (PW2040) + 74% (RB.211-535E4)

0.26 (1.153) + 0.74 (2.384) = 2.064 kg/LTO

Emissions

$$E_{aij} = E_{ij} \times LTO_j$$

= 2.064 kg/LTO x 104 LTOs

= 214.66 kg

5.4 Other Non-Road Mobile Equipment

SOURCE CODE:	**DESCRIPTION:**
22-60-000-000	All Off-Highway Vehicles: Gasoline, 2-Stroke
22-60-001-xxx	Recreational Vehicles: Gasoline, 2-Stroke
22-60-002-xxx	Construction Equipment: Gasoline, 2-Stroke
22-60-003-xxx	Industrial Equipment: Gasoline, 2-Stroke
22-60-004-xxx	Lawn and Garden Equipment: Gasoline, 2-Stroke
22-60-005-xxx	Farm Equipment: Gasoline, 2-Stroke
22-60-006-xxx	Light Commercial: Gasoline, 2-Stroke
22-60-007-xxx	Logging Equipment: Gasoline, 2-Stroke
22-60-008-xxx	Airport Service Equipment: Gasoline, 2-Stroke
22-65-000-000	All Off-Highway Vehicles: Gasoline, 4-Stroke
22-65-001-xxx	Recreational Vehicles: Gasoline, 4-Stroke
22-65-002-xxx	Construction Equipment: Gasoline, 4-Stroke
22-65-003-xxx	Industrial Equipment: Gasoline, 4-Stroke
22-65-004-xxx	Lawn and Garden Equipment: Gasoline, 4-Stroke
22-65-005-xxx	Farm Equipment: Gasoline, 4-Stroke
22-65-006-xxx	Light Commercial: Gasoline, 4-Stroke
22-65-007-xxx	Logging Equipment: Gasoline, 4-Stroke
22-65-008-xxx	Airport Service Equipment: Gasoline, 4-Stroke
22-70-000-000	All Off-Highway Vehicle: Diesel
22-70-001-xxx	Recreational Vehicles: Diesel
22-70-002-xxx	Construction Equipment: Diesel
22-70-003-xxx	Industrial Equipment: Diesel
22-70-004-xxx	Lawn and Garden Equipment: Diesel
22-70-005-xxx	Farm Equipment: Diesel
22-70-006-xxx	Light Commercial: Diesel
22-70-007-xxx	Logging Equipment: Diesel
22-70-008-xxx	Airport Service Equipment: Diesel
22-82-005-xxx	Recreational Boats: Gasoline, 2-Stroke
22-82-010-xxx	Recreational Boats: Gasoline, 4-Stroke
22-82-020-xxx	Recreational Boats: Diesel

DESCRIPTION:

In addition to the nonroad categories noted in earlier sections of this document, there are additional nonroad sources that include motorized equipment and vehicles that normally are not operated on public highways. There are eight categories of these other nonroad sources:

- Recreational Vehicles;
- Construction Equipment;
- Industrial Equipment;
- Lawn and Garden Equipment;
- Farm Equipment;
- Light Commercial Equipment;
- Logging Equipment; and
- Airport Service Equipment.

Some examples of the specific types of equipment included in these general categories are presented in Table 5.4-1.

POLLUTANTS: TOG, CO, NO_x, PM, SO_x

ROG: The ROG/TOG factors provided below may be used. Note that an ROG/TOG ratio of "NA" indicates that no specific ROG/TOG ratio is available from the cited CARB reference. However, based on the available data, it appears that it would be reasonable to use an ROG/TOG ratio of 96.0% for gasoline equipment exhaust and 97.2% for diesel equipment exhaust as a default values. ROG is 100% of TOG for crank, evaporative, and refueling emissions.

SOURCE CODE	ROG/TOG	DESCRIPTION
22-60-000-000	NA	All Off-Highway Vehicles: Gasoline, 2-Stroke
22-60-001-xxx	96.0%	Recreational Vehicles: Gasoline, 2-Stroke
22-60-002-xxx	NA	Construction Equipment: Gasoline, 2-Stroke
22-60-003-xxx	96.0%	Industrial Equipment: Gasoline, 2-Stroke
22-60-004-xxx	NA	Lawn and Garden Equipment: Gasoline, 2-Stroke
22-60-005-xxx	96.0%	Farm Equipment: Gasoline, 2-Stroke

Table 5.4-1

Other Nonroad Mobile Source Categories

Category	
Recreational Vehicles Recreational Boats Motorcycles Snowmobiles All Terrain Vehicles (ATV) Minibikes Golf Carts	**Construction Equipment** Asphalt Pavers Plate Compactors Rollers Scrapers Trenchers Bore/Drill Rigs Cement and Mortar Mixers Cranes
Industrial Equipment Aerial Lifts Forklifts Sweepers/Scrubbers Mobile Refrigerators Auxiliary Engines Portable Well Drilling Equipment	**Lawn and Garden Equipment** Lawn Mowers Trimmers/Edgers Leaf Blowers Chain Saws Wood Splitters Chippers/Stump Grinders
Farm Equipment Combines Balers Harvesters General purpose Machines Tractors	**Light Commercial Equipment** Pumps Generators Air Compressors Gas Compressors Welders Pressure Washers
Logging Equipment Chain Saws Shredders Skidders Fellers/Bunchers	**Airport Service Equipment** Airport Support Equipment Terminal Tractors

22-60-006-xxx	96.0%	Light Commercial: Gasoline, 2-Stroke
22-60-007-xxx	NA	Logging Equipment: Gasoline, 2-Stroke
22-60-008-xxx	NA	Airport Service Equipment: Gasoline, 2-Stroke
22-65-000-000	NA	All Off-Highway Vehicles: Gasoline, 4-Stroke
22-65-001-xxx	96.0%	Recreational Vehicles: Gasoline, 4-Stroke
22-65-002-xxx	NA	Construction Equipment: Gasoline, 4-Stroke
22-65-003-xxx	96.0%	Industrial Equipment: Gasoline, 4-Stroke
22-65-004-xxx	NA	Lawn and Garden Equipment: Gasoline, 4-Stroke
22-65-005-xxx	96.0%	Farm Equipment: Gasoline, 4-Stroke
22-65-006-xxx	96.0%	Light Commercial: Gasoline, 4-Stroke
22-65-007-xxx	NA	Logging Equipment: Gasoline, 4-Stroke
22-65-008-xxx	NA	Airport Service Equipment: Gasoline, 4-Stroke
22-70-000-000	NA	All Off-Highway Vehicle: Diesel
22-70-001-xxx	97.2%	Recreational Vehicles: Diesel Boats
22-70-002-xxx	NA	Construction Equipment: Diesel
22-70-003-xxx	97.2%	Industrial Equipment: Diesel
22-70-004-xxx	NA	Lawn and Garden Equipment: Diesel
22-70-005-xxx	97.2%	Farm Equipment: Diesel
22-70-006-xxx	97.2%	Light Commercial: Diesel
22-70-007-xxx	NA	Logging Equipment: Diesel
22-70-008-xxx	NA	Airport Service Equipment: Diesel

POINT SOURCE ADJUSTMENTS: None.

METHODOLOGY:

Emissions from most nonroad mobile sources are calculated using the following equation:

$$\text{Emissions}_p = N_e \times hr_e \times hp_e \times LF_e \times EF_{p,e} \tag{5.4-1}$$

where:

Emissions_p = emissions of pollutant, p (kg/yr);
N_e = equipment population of equipment type, e;
hr_e = annual hours of use for equipment type, e;
hp_e = average rated horsepower for equipment type, e;
LF_e = typical load factor for equipment type, e; and
$EF_{p,e}$ = emission factor for pollutant, p, and equipment type, e (g/hp-hr).

Emissions from most types of recreational equipment and marine equipment are calculated using different equations. For some types of recreation equipment (all terrain vehicles [ATVs], minibikes, off-road motorcycles, and golf carts), the estimation equation is:

$$\text{Emissions}_p = N_e \times hr_e \times EF_{p,e} \tag{5.4-2}$$

where: Emissions_p = emissions of pollutant, p (kg/yr);
N_e = equipment population of equipment type, e;
hr_e = annual hours of use for equipment type, e; and
$EF_{p,e}$ = emission factor for pollutant, p, and equipment type, e (g/hr).

For recreational marine equipment, the estimation equation is:

$$\text{Emissions}_p = N_e \times \text{Fuel}_e \times EF_{p,e} \tag{5.4-3}$$

where Emissions_p = emissions of pollutant, p (kg/yr);
N_e = equipment population of equipment type, e;
Fuel_e = annual fuel use (gal/yr); and
$EF_{p,e}$ = emission factor for pollutant, p, and equipment type, e (g/hr).

Where possible, local Mexico-specific activity data (i.e., equipment population, hours of use, equipment horsepower, etc.) should be obtained. U.S.-based emission factors, as well as U.S. default activity data, are presented in Appendix V-C. The following tables are presented in Appendix V-C:

- Table 2-04 - Average rated horsepower estimates;
- Table 2-05 - Typical operating load factor estimates;
- Table 2-06 - Annual use estimates;
- Table 2-07a - Diesel equipment emission factors;
- Table 2-07b - 4-Stroke gasoline equipment emission factors (not adjusted for in-use effects);
- Table 2-07c - 4-Stroke gasoline equipment emission factors (adjusted for in-use effects);
- Table 2-07d - 2-Stroke gasoline equipment emission factors (not adjusted for in-use effects); and

- Table 2-07e - 2-Stroke gasoline equipment emission factors (adjusted for in-use effects).

The source of these emission factors and activity data is the U.S. EPA's *Nonroad Engine and Vehicle Emission Study* (U.S. EPA, 1991b). These U.S.-based emission factors and activity data have limited applicability in Mexico and should only be used if no other data are available.

A couple things should be noted about these tables. First of all, activity data presented in Tables 2-04, 2-05, and 2-06 are given for Inventory A and Inventory B. Inventory A activity data were developed solely by U.S. EPA contractors, while Inventory B activity data incorporated addition information from manufacturer associations. Thus, Inventory B activity data is preferred over Inventory A activity data. Also, the emission factors presented in Tables 2-07b and 2-07d are based upon emissions data from new engines, while the emission factors presented in Tables 2-07c and 2-07e represent in-use effects including engine malfunctions, improper maintenance, and engine wear. Therefore, the emission factors presented in Tables 2-07c and 2-07e are preferred over the emission factors in Tables 2-07b and 2-07d.

DATA NEEDED:

Data	Sources
Equipment population	Local agencies or surveys
Hours of use	Local agencies or surveys; U.S. default values (Appendix V-C, Table 2-06)
Average rated horsepower	Local agencies or surveys; U.S. default values (Appendix V-C, Table 2-04)
Load factor	Local agencies or surveys; U.S. default values (Appendix V-C, Table 2-05)
Fuel use (recreational marine only)	Local agencies or surveys; U.S. default values (Appendix V-C, Table 2-06)
Emission factors	U.S. emission factors (Appendix V-C, Table 2-07a through 2-07e);

NOTES:

1. Volume II of the fourth edition of AP-42 (AP-42, 1985) included information on the estimation of emissions from nonroad mobile sources, but this information is outdated. The information presented

in the *Nonroad Engine and Vehicle Emission Study*, along with more recent emissions test data, is currently being incorporated into a fifth edition of Volume II of AP-42. It is unclear when this document will be available.

2. TOG emission factors are <u>not</u> presented in Appendix V-C, Tables 2-07a through 2-07e. Hydrocarbon (HC) emission factors are presented for exhaust, crank, evaporative, and refueling emissions. Elsewhere in the *Nonroad Engine and Vehicle Emission Study*, it is explained that HC is equivalent to volatile organic compounds (VOC). Because methane and ethane are excluded from VOC, then VOC is essentially the same as ROG. Thus, the emission factors presented in Appendix V-C, Tables 2-07a through 2-07e are equivalent to ROG. TOG emission factors can be obtained using the ROG emission factors and the ROG/TOG ratios of 96.0% for gasoline equipment exhaust and 97.2% for diesel equipment exhaust. This is demonstrated in the sample calculation. For crank, evaporative, and refueling emissions, there is virtually no methane and ethane included, so the ROG and TOG are equivalent.

<u>SAMPLE CALCULATION</u>:

Assume that a certain inventory region has 50 4-stroke gasoline welders, 30 diesel pumps, and 15 diesel cranes. Calculate total TOG emissions.

1. Determine hours of use:

   Based on local surveys, it has been estimated that the welders are used 100 hours per year, the pumps are used 200 hours per year, and the cranes are used 600 hours per year.

2. Determine average rated horsepower:

   Because local survey information is unavailable, determine average rated horsepower from Table 2-04 in Appendix V-C.

   Welders - 19.0 hp
   Pumps - 23.0 hp
   Cranes - 194.0 hp

3. Determine typical operating load factors:

Once again, local survey information is unavailable, so operating load factors taken from Table 2-05 in Appendix V-C.

Welders - 51%
Pumps - 74%
Cranes - 43%

4. Calculate emission factors

Diesel emission factors are taken from Table 2-07a and 4-stroke gasoline emission factors from Table 2-07c. Exhaust emission factors must be converted from ROG to TOG. For all other emissions, ROG is equivalent to TOG.

$$\text{Welders Exhaust} = \left(\frac{19.95\ \text{g ROG}}{\text{hp}-\text{hr}}\right)\left(\frac{1}{0.96}\right) = \frac{20.78\ \text{g TOG}}{\text{hp}-\text{hr}}$$

$$\text{Crank} = \frac{3.14\ \text{g TOG}}{\text{hp}-\text{hr}}$$

$$\text{Evaporative} = \frac{9.75\ \text{g TOG}}{\text{hp}-\text{hr}}$$

$$\text{Refueling} = \frac{1.72\ \text{g TOG}}{\text{hp}-\text{hr}}$$

Total = 20.78 + 3.14 + 9.75 + 1.72 = 35.39 g TOG/hp-hr

$$\text{Pumps Exhaust} = \left(\frac{1.20\ \text{g ROG}}{\text{hp}-\text{hr}}\right)\left(\frac{1}{0.972}\right) = \frac{1.235\ \text{g TOG}}{\text{hp}-\text{hr}}$$

$$\text{Crank} = \frac{0.02\ \text{g TOG}}{\text{hp}-\text{hr}}$$

$$\text{Evaporative} = \text{Not applicable}$$

$$\text{Refueling} = \frac{0.003\ \text{g TOG}}{\text{hp}-\text{hr}}$$

$$\text{Total} = 1.235 + 0.02 + 0.003 = 1.26\ \text{g TOG/hp}-\text{hr}$$

$$\text{Crane Exhaust} = \left(\frac{1.26 \text{ g ROG}}{\text{hp-hr}}\right)\left(\frac{1}{0.972}\right) = \frac{1.296 \text{ g TOG}}{\text{hp-hr}}$$

$$\text{Crane} = \frac{0.03 \text{ g TOG}}{\text{hp-hr}}$$

$$\text{Evaporative} = \text{Not applicable}$$

$$\text{Refueling} = \frac{0.003 \text{ g TOG}}{\text{hp-hr}}$$

$$\text{Total} = 1.296 + 0.03 + 0.003 = 1.33 \text{ g TOG/hp-hr}$$

Total = 1.296 + 0.03 + 0.003 = 1.33 g TOG/hp-hr

5. Calculate emissions

$$\text{Welders} = 50\left(\frac{100 \text{ hr}}{\text{yr}}\right)(19.0 \text{ hp})(0.51)\left(\frac{35.39 \text{ g}}{\text{hp-hr}}\right) = 1{,}715 \text{ kg/yr}$$

$$\text{Pumps} = 30\left(\frac{200 \text{ hr}}{\text{yr}}\right)(23.0 \text{ hp})(0.74)\left(\frac{1.26 \text{ g}}{\text{hp-hr}}\right) = 129 \text{ kg/yr}$$

$$\text{Cranes} = 15\left(\frac{600 \text{ hr}}{\text{yr}}\right)(194.0 \text{ hp})(0.43)\left(\frac{1.33 \text{ g}}{\text{hp-hr}}\right) = 999 \text{ kg/hr}$$

$$\text{Total emissions} = 1{,}715 + 129 + 999 = 2{,}843 \text{ kg TOG/yr}$$

$$= 2.8 \text{ Mg TOG/yr}$$

5.5 Border Crossings

SOURCE CODE:	DESCRIPTION:
22-01-001-900*	Light Duty Gasoline Vehicles (LDGV)
22-01-060-900*	Light Duty Gasoline Trucks (LDGT)
22-01-070-900*	Heavy Duty Gasoline Vehicles (HDGV)
22-01-080-900*	Motorcycles (MC)
22-30-001-900*	Light Duty Diesel Vehicles (LDDV)
22-30-060-900*	Light Duty Diesel Trucks (LDDT)
22-30-070-900*	Heavy Duty Diesel Vehicles (HDDV)

* Proposed Mexico-specific codes for source category not typically inventoried in the U.S.

DESCRIPTION:

This section specifically covers emissions from border crossings. This category is of primary interest in the U.S.-Mexico border region. Vehicles (both U.S. and Mexican) often line up for extended periods of time (up to 1 hour) while waiting to enter the United States and pass through customs inspections. Vehicles in the queue typically do not turn off their engines, but idle while they inch forward in line. This emissions category is also applicable for vehicles entering Mexico (although the idling time appears to be shorter compared to vehicles entering the United States) and any other vehicles that idle at other checkpoints. The methodology described below is similar to that described for bus terminals (see Section 5.6).

Because these idling emissions are emitted by on-road motor vehicles, an argument could be made that idling emissions should be included as a mobile source. However, unlike typical mobile source emissions, the location of idling emissions from border crossings is very well defined (i.e., the road segment directly in front of the border crossing). Also, the latest versions of the mobile source emission factor models (MOBILE5a, PART5, and related modified versions) can only be used to estimate emissions from moving vehicles. For these reasons, idling emissions at border crossings should be treated as area sources.

POLLUTANTS: TOG, CO, NO_x, SO_x, PM_{10}

ROG: For non-catalyst gasoline vehicles, ROG is 92.4% of TOG.
For catalyst gasoline vehicles, ROG is 85.2% of TOG.
For diesel vehicles, ROG is 95.7% of TOG (ARB, 1993).

POINT SOURCE ADJUSTMENTS: None.

METHODOLOGY:

As mentioned above, the latest versions of MOBILE5a and PART5 do not provide any idling emission factors. Earlier versions of MOBILE provided some idling emission factors. However, these emission factors represented standard test conditions (stabilized operating mode, 75 °F, and 9.0 psi RVP fuel). Because U.S. EPA has been unable to develop a satisfactory algorithm to account for variations in operating mode, ambient temperature, and fuel RVP, the direct calculation of idling emission factors has been disabled in MOBILE5a while idling emissions data are being collected.

U.S. EPA has provided an interim methodology for estimating idling emissions using MOBILE5a (U.S. EPA, 1993). This methodology can be used to estimate vehicle emissions at border crossings and in other idling situations. It is assumed that this methodology is valid for PART5 and any MOBILE models that have been modified for use in Mexico (i.e., MOBILE-MCMA, MOBILE-MMAp, MOBILE-Juárez, etc.). A MOBILE model will be used to estimate TOG, CO, and NO_x emissions. A PART5 model will be used to estimate PM_{10} emissions. SO_x emissions will be estimated by using a simple fuel balance.

In the U.S. EPA interim methodology, idling emission rates are calculated using exhaust emission factors from a MOBILE run set at the lowest allowable vehicle speed (2.5 miles per hour [mph] for MOBILE5a and PART5 and 4 kilometers per hour [kph] for Mexico-specific modified MOBILE models). The lowest allowable speed is used because it contains the largest percentage of idling time of any of the speed cycles used by the MOBILE model. After running the MOBILE model, exhaust emission factors for TOG, CO, and NO_x will be calculated in units of grams per mile or grams per kilometer. To convert these emission factors to idling emission factors in units of grams per hour, multiply by 4 kph (or 2.5 mph). The resulting idling emission factors should not include any non-exhaust emissions. For more information on running the MOBILE and PART5 models, consult the Motor Vehicle Manual of this series and/or the MOBILE and PART5 User's Guides (U.S. EPA, 1994; U.S. EPA, 1995).

At border crossings, idling vehicles will consist of a mixture of U.S. and Mexican vehicles. Consequently, MOBILE5a would need to be used for the U.S. vehicle fraction and a Mexico-specific MOBILE model would need to be used for the Mexican vehicle fraction. MOBILE-Juárez (Radian, 1996) is the most recent Mexico-specific MOBILE model. It is the current recommended model to estimate emissions from idling Mexican vehicles. However, the

MOBILE model will continue to evolve in Mexico; in the future, INE staff should be contacted to identify the most current MOBILE model.

United States Customs officials maintain vehicle counts of all vehicles that enter into the United States. However, these statistics do not provide U.S. and Mexico vehicle fractions. Also, these statistics do not include a distribution of vehicles into different vehicle classification (i.e., LDGV, HDDV, etc.) The Mexico/U.S. vehicle fraction will have to be determined through a survey at the border crossing(s). The distribution of vehicle classifications can also be determined through the border crossing survey and/or local or regional vehicle registration data.

Finally, the length of idling time is required. U.S. Customs officials can make a rough estimate of this, but a survey should be conducted to assess this duration. Sufficient surveying is important to determine a representative idling time, Mexico/U.S. vehicle fraction, and vehicle distribution. All of these data can vary significantly by hour, by day, and by season.

Given the data listed above, the equation to estimate emissions from idling vehicles is:

$$\begin{aligned}\text{Emissions} = &\sum (\text{Vehicles}_{\text{Total}} \times \text{VF}_{\text{Mexico}} \times \text{VC}_{\text{Mexico,v}} \times \text{EF}_{\text{Mexico,v}} \times 4.0 \times \text{T}_{\text{Idle}}) \\ + &\sum (\text{Vehicles}_{\text{Total}} \times \text{VF}_{\text{US}} \times \text{VC}_{\text{US,v}} \times \text{EF}_{\text{US,v}} \times 2.5 \times \text{T}_{\text{Idle}})\end{aligned} \qquad (5.5\text{-}1)$$

where: $\text{Vehicles}_{\text{Total}}$ = Total number of vehicles passing through the border crossing;

$\text{VF}_{\text{Mexico}}$, VF_{US} = Fraction of vehicles that are from Mexico or the U.S.;

$\text{VC}_{\text{Mexico,v}}$, $\text{VC}_{\text{US,v}}$ = Fraction of Mexico and U.S. vehicles in each vehicle class, v;

$\text{EF}_{\text{Mexico,v}}$, $\text{EF}_{\text{US,v}}$ = Emission factor for Mexico and U.S. vehicle in each vehicle class, v, taken from MOBILE- and/or PART5-based emission factor model;

4.0 (2.5) = Factor used to convert grams per kilometer (grams per mile) emission factor to grams per hour emission factor; and

T_{Idle} = Average time spent idling in queue at border crossing.

DATA NEEDED:

Data	Sources
MOBILE5a and PART5 Emission Factor Model Input Parameters	Description of needed data and available sources can be found in the Motor Vehicle Manual (Volume VI of this series).
Vehicle Counts	U.S. Customs officials and other local officials.
Mexico/U.S. Vehicle Fractions	Site-specific survey.
Distribution of Vehicle Classifications	Site-specific survey or local vehicle registration data.
Idling Time	Site-specific survey or U.S. (and Mexican) Customs officials.

NOTES:

1. Care must be taken to prevent double counting of emissions that are already included as mobile source emissions. Overall VMT from vehicle counts should not need adjustment for double counting. Overall VMT from fuel sales, however, should be adjusted for double counting. Also, there is some question on how "real" the emission estimates become when the speed drops to 4 kph.

SAMPLE CALCULATION:

In 1995, an estimated 800,000 vehicles passed from Mexico into the United States through a particular border crossing. For this example, emissions will not be estimated for those vehicles passing from the United States into Mexico. Survey results indicated an average idling time of 12 minutes per vehicle. Of the vehicles entering the United States, 62% are Mexican vehicles with the remaining vehicles being U.S. vehicles. Seventy percent of U.S. vehicles and 75% of Mexican vehicles are LDGVs. The remaining vehicles are LDGTs. Calculate annual NO_x emissions from these idling vehicles.

1. From MOBILE runs, the following hypothetical fleet average NO_x emission factors were calculated:

U.S. LDGVs:	2.4 g/mile
U.S. LDGTs:	3.2 g/mile
Mexico LDGVs:	2.7 g/mile
Mexico LDGTs:	3.6 g/mile

2. Multiplying these emission factors by 2.5 mph gives the following idling emission factors:

   U.S. LDGVs: 6.0 g/hour
   U.S. LDGTs: 8.0 g/hour
   Mexico LDGVs: 6.75 g/hour
   Mexico LDGTs: 9.0 g/hour

3. The number of vehicles for each category is calculated using vehicle fractions and vehicle class fractions.

   U.S. LDGVs: 800,000 vehicles × 0.38 × 0.70 = 212,800 vehicles
   U.S. LDGTs: 800,000 vehicles × 0.38 × 0.30 = 91,200 vehicles
   Mexico LDGVs: 800,000 vehicles × 0.62 × 0.75 = 372,000 vehicles
   Mexico LDGTs: 800,000 vehicles × 0.62 × 0.25 = 124,000 vehicles

4. The total NO_x emissions are then calculated:

   (212,800 vehicles × 0.2 hours × 6.0 g/hour) + (91,200 vehicles × 0.2 hours × 8.0 g/hour) + (372,000 vehicles × 0.2 hours × 6.75 g/hour) + (124,000 vehicles × 0.2 hours × 9.0 g/hour)
   = 255.4 kg + 145.9 kg + 502.2 kg + 223.2 kg
   = 1.13 Mg NO_x

5.6 Bus/Truck Terminals

SOURCE CODE:	**DESCRIPTION:**
22-01-070-900*	Heavy Duty Gasoline Vehicles (HDGV)
22-30-070-900*	Heavy Duty Diesel Vehicles (HDDV)

* Proposed Mexico-specific codes for source category not typically inventoried in the U.S.

DESCRIPTION:

This section addresses emissions from bus/truck terminals. In Mexico, buses and trucks often line up for extended periods of time while waiting to load and/or unload passengers or cargo. Vehicles in the queue typically do not turn off their engines, but idle while they inch forward in line. The methodology described below is similar to that described for border crossings (see Section 5.5).

Because these idling emissions are emitted by on-road motor vehicles, an argument could be made that idling emissions should be included as a mobile source. However, unlike typical mobile source emissions, the location of idling emissions from bus/truck terminals is very well defined (i.e., the road segments or stations that make up the bus/truck terminal). Also, the latest versions of the mobile source emission factor models (MOBILE5a, PART5, and related modified versions) can only be used to estimate emissions from moving vehicles. For these reasons, idling emissions at bus/truck terminals should be treated as area sources.

POLLUTANTS: TOG, CO, NO_x, SO_x, PM_{10}

ROG: For non-catalyst gasoline vehicles, ROG is 92.4% of TOG.
For catalyst gasoline vehicles, ROG is 85.2% of TOG.
For diesel vehicles, ROG is 95.7% of TOG.

POINT SOURCE ADJUSTMENTS: None.

METHODOLOGY:

As discussed in Section 5.5 above, the latest versions of MOBILE5a and PART5 do not provide any idling emission factors. Earlier versions of MOBILE provided some idling emission factors. However, these emission factors represented standard test conditions (stabilized operating mode, 75 °F, and 9.0 psi RVP fuel). Because U.S. EPA has been unable to develop a satisfactory algorithm to account for variations in operating mode, ambient temperature, and fuel RVP, the direct calculation of idling emission factors has been disabled in MOBILE5a while idling emissions data are being collected.

U.S. EPA has provided an interim methodology for estimating idling emissions using MOBILE5a (U.S. EPA, 1993). This methodology can be used to estimate vehicle emissions at bus/truck terminals and in other idling situations. It is assumed that this methodology is valid for PART5 and any MOBILE models that have been modified for use in Mexico (i.e., MOBILE-MCMA, MOBILE-MMAp, MOBILE-Juárez, etc.). A MOBILE model will be used to estimate TOG, CO, and NO_x emissions. A PART5 model will be used to estimate PM_{10} emissions. SO_x emissions will be estimated by using a simple fuel balance.

In the U.S. EPA interim methodology, idling emission rates are calculated using exhaust emission factors from a MOBILE run set at the lowest allowable vehicle speed (4 kilometers per hour [kph] for Mexico-specific modified MOBILE models). The lowest allowable speed is used because it contains the largest percentage of idle time of any of the speed cycles used by the MOBILE model. After running the MOBILE model, exhaust emission factors for TOG, CO, and NO_x will be calculated in units of grams per kilometer. To convert these emission factors to idling emission factors in units of grams per hour, multiply by 4 kph. The resulting idling TOG emission factor should not include any non-exhaust emissions. For more information on running the MOBILE and PART5 models, consult the Motor Vehicle Manual (Volume VI of this series) and/or the MOBILE and PART5 User’s Guides (U.S. EPA, 1994; U.S. EPA, 1995). MOBILE-Juárez (Radian, 1996) is the most recent Mexico-specific MOBILE model. It is the current recommended model to estimate emissions from idling Mexican vehicles. However, the MOBILE model will continue to evolve in Mexico; in the future, INE staff should be contacted to identify the most current MOBILE model.

Finally, the length of idling time is needed to estimate emissions. Bus/truck terminal employees might be able to estimate this, but a survey may be needed to determine accurate durations. It is important that sufficient surveying be conducted to determine representative idling time and vehicle distribution. All of these data can vary significantly by hour, by day, and by season.

Given the data listed above, the equation to estimate emissions from idling vehicles is:

$$\text{Emissions} = \sum (\text{Vehicles}_{\text{Total}} \times \text{VC}_{\text{Mexico,v}} \times \text{EF}_{\text{Mexico,v}} \times 4.0 \times \text{T}_{\text{Idle}}) \qquad (5.6\text{-}1)$$

where:

$\text{Vehicles}_{\text{Total}}$ = Total number of vehicles passing through the bus/truck terminal;

VC_{v} = Fraction of vehicles in each vehicle class, v;

EF_{v} = Emission factor for vehicle in each vehicle class, v, taken from MOBILE- and/or PART5-based emission factor model;

4.0 = Factor used to convert grams per kilometer emission factor to grams per hour emission factor; and

T_{Idle} = Average time spent idling in queue at the bus/truck terminal.

DATA NEEDED:

Data	Sources
MOBILE5a and PART5 Emission Factor Model Input Parameters	Description of needed data and available sources can be found in the Motor Vehicle Manual (Volume VI of this series).
Vehicle Counts	Bus/truck terminal employees or other local officials.
Distribution of Vehicle Classifications	Site-specific survey.
Idling Time	Site-specific survey, bus/truck terminal employees, or frequent terminal users

NOTES:

1. Care must be taken to prevent double counting of emissions that are already included as mobile source emissions. Overall VMT from vehicle counts should not need adjustment for double counting. Also, there is some question on how “real” the emission estimates become when the speed drops to 4 kph.

EXAMPLE CALCULATION:

In 1995, an estimated 20,000 vehicles passed through a particular bus terminal. Survey results indicate an average waiting time of 15 minutes per vehicle.

Forty percent of vehicles are HDGVs and the remaining vehicles are HDDVs. Calculate annual NO_x emissions from these idling vehicles.

1. Assume that from the latest MOBILE model, the following NO_x emission factors were calculated:

   HDGVs: 2.8 g/km
   HDDVs: 13.3 g/km

2. Multiplying these emission factors by 4.0 kph gives the following idle emission factors:

   HDGVs: 11.2 g/hour
   HDDVs: 53.2 g/hour

3. The number of vehicles for each category is calculated using the total number of vehicles and vehicle class fractions:

   HDGVs: 20,000 vehicles × 0.40 = 8,000 vehicles
   HDDVs: 20,000 vehicles × 0.60 = 12,000 vehicles

4. The total NO_x emissions are then calculated:

   (8,000 vehicles × 0.25 hours × 11.2 g/hour) +
   (12,000 vehicles × 0.25 hours × 53.2 g/hour)
   = 22.4 kg + 159.6 kg
   = 182 kg
   = 0.18 Mg NO_x

6.0 SOLVENT USE

Many solvent use activities may be too small or too numerous to be included in the point source inventory for a given inventory region. Therefore, these smaller solvent evaporation sources need to be included in the area source inventory effort. Inventory guidance for these sources are presented in the following subsections:

- Industrial Surface Coating;
- Auto Body Refinishing;
- Architectural Surface Coating;
- Traffic Paint;
- Industrial Surface Cleaning (Degreasing);
- Dry Cleaning;
- Graphic Arts;
- Asphalt Application; and
- Commercial/Consumer Solvent Use.

6.1 Industrial Surface Coating

SOURCE CODE:	**DESCRIPTION:**
24-01-010-xxx	Textile Products
24-01-015-xxx	Factory Finished Wood
24-01-020-xxx	Wood Furniture
24-01-025-xxx	Metal Furniture
24-01-030-xxx	Paper
24-01-035-xxx	Plastic Products
24-01-040-xxx	Metal Cans
24-01-045-xxx	Metal Coils
24-01-050-xxx	Miscellaneous Finished Materials
24-01-055-xxx	Machinery and Equipment
24-01-060-xxx	Large Appliances
24-01-065-xxx	Electronic and Other Electrical
24-01-070-xxx	Motor Vehicles
24-01-075-xxx	Aircraft
24-01-080-xxx	Marine
24-01-085-xxx	Railroad
24-01-090-xxx	Miscellaneous Manufacturing
24-01-100-xxx	Industrial Maintenance Coatings
24-01-200-xxx	Other Special Purpose Coatings
24-01-990-xxx	All Surface Coating Categories

DESCRIPTION:

Surface coating operations consist of applying a thin layer of coating such as paint, varnish, lacquer, or paint primer to an object for decorative or protective purposes. There are a number of steps involved in the coating process. Surface coatings are applied during the manufacture of a wide variety of products, including furniture, cans, automobiles, airplanes and other transportation equipment, machinery, appliances, flat wood, wire, and other miscellaneous products. In addition, coatings are used in maintenance operations at industrial facilities.

Solvents contained in the surface coatings evaporate as the coating is applied and dries. Although residual solvents may remain in the coating after the coating has dried, and some of the coating will not be used and will be disposed of in facility wastewater or sent to a landfill, most inventory efforts assume that all of the coating solvents evaporate into the air.

Emissions from surface coating operations can be reduced by the use of water-based coatings, the use of filters, condensation systems, afterburners, and more efficient application processes in which less solvent is applied.

POLLUTANTS: TOG

ROG: ROG emissions are 98.8% of TOG.

POINT SOURCE ADJUSTMENTS:

Surface coating operations may occur at large facilities that may be inventoried as point sources. Therefore, the emission calculation procedure for area source estimates must be adjusted to prevent double counting with the point source estimates. If per employee emission factors are used, employment at the point source facilities should be subtracted from the total inventory area employment. If employment data are not available, then the point emissions can be subtracted from total emissions.

METHODOLOGY:

Emissions from this source can be calculated using one of two methods.

Method 1: The first method uses a per capita emission factor developed for Mexico City (DDF, 1995b).

The calculation using the per capita emission factor is:

$$\text{Annual TOG Emissions} = (\text{Population}) \times (\text{Emission Factor}) \qquad (6.1\text{-}1)$$

If any industrial surface coating facilities are included in this point source inventory, their emissions should be removed from this estimate to yield an area source emission estimate.

Method 2: The second method uses per employee emission factors that are based on national averages from the U.S. These U.S.-based per employee emission factors have limited applicability in Mexico and should only be used if no other Mexico-specific data are available. The use of the per employee emission factors requires collection of data on the number of people employed within certain industries. A brief industry description is provided in the table in the **DATA NEEDED** portion of this section. After local or regional industries are matched to the groupings in the table, the employment for point source facilities in those groups must be subtracted from the total number of people employed in each industrial category. The remaining number is the area source employment. Emissions are then calculated as:

$$\begin{matrix}\text{Annual TOG}\\ \text{Emissions}\end{matrix} = \begin{pmatrix}\text{Area Source}\\ \text{Industry Group}\\ \text{Employment}\end{pmatrix} \times \begin{pmatrix}\text{Emission}\\ \text{Factor}\end{pmatrix} \qquad (6.1\text{-}2)$$

Emission factors for both of these methods are provided in the **DATA NEEDED** portion of this section.

DATA NEEDED:

Data		Sources
Per Capita Emission Factor Method:		
Population		INEGI
TOG Emission Factor	1.28 kg/person/yr	DDF, 1995b
Per Employee Method:		
Employment by Industry Type		SNIFF Database, CANACINTRA, INEGI
TOG Emission Factor		U.S. EPA, 1991a
Factory Finished Wood	59 kg/employee/yr (131 lb/employee/yr)	
Metal Furniture and Fixtures	428 kg/employee/yr (944 lb/employee/yr)	
Electrical Insulation	132 kg/employee/yr (290 lb/employee/yr)	
Metal Cans	2,735 kg/employee/yr (6,029 lb/employee/yr)	
Miscellaneous Finished Metal (sheet, strip and coil)	1,305 kg/employee/yr (2,877 lb/employee/yr)	
Machinery and Equipment	35 kg/employee/yr (77 lb/employee/yr)	
Appliances	210 kg/employee/yr (463 lb/employee/yr)	
Motor Vehicles (new)	360 kg/employee/yr (794 lb/employee/yr)	
Other Transportation (includes aircraft and railroad)	16 kg/employee/yr (35 lb/employee/yr)	
Marine	140 kg/employee/yr (308 lb/employee/yr)	

NOTES:

1. The emission factor for industrial surface coatings was developed by DDF (1995b), based on information on national product sales (for 1993) provided by ANAFAPYT (National Association of Paint and Ink Manufacturers).

2. The per capita emission factor was developed by multiplying the total volume of paint by 0.45 to reflect that the average paint is estimated to contain 45% solvent.

3. Adjustments to both the per capita and the per employee emission factors may be needed to reflect local conditions, and, over time, to reflect changes in coating usage and composition.

4. The emission estimates calculated using the per employee factors will need to be linked to industrial codes in SNIFF to facilitate reconciliation with the point source inventory.

5. An alternative to the emission factors presented above is to survey a representative number of surface coating operations. Results from the survey should then be scaled up to the entire inventory area.

    - The section on surveys in Volume III, *Basic Emission Estimating Techniques*, should be reviewed before conducting a survey.

    - The entire population of facilities must be identified, but only a representative sample of these facilities will be surveyed.

Surveys should request information that can be used to calculate emissions using the material balance method (see *Basic Emission Estimating Techniques*). A survey should request the following information:

- Name and location of the facility;
- Name of the person filling out the survey, or the person who can be contacted for further questions;
- Number of employees at the facility;
- Type of product coated at the facility (e.g., wood or metal furniture, household appliances, machinery, boats);
- Kilograms of surface coatings used at the facility (if amounts of coatings are recorded as liters, then it will be necessary to collect information on the coating density to calculate the weight), weight for each type of coating used; and
- Chemical constituents in each coating.

If this method is done properly, the results will be much more accurate than the results from the first method. However, this method requires more effort and expense. If this method is not done correctly, the results may be less accurate than using emission factors.

SAMPLE CALCULATION:

For example, total annual TOG emissions from industrial surface coatings in a state with a population of 1,250,000 are:

$$\begin{aligned}(1{,}250{,}000 \text{ persons}) \times (1.28 \text{ kg/person/yr}) &= 1{,}600{,}000 \text{ kg/yr} \\ &= 1{,}600 \text{ Mg/yr}\end{aligned}$$

If there are large facilities that have surface coating operations in the inventory area, and they have been inventoried as point sources, then the emissions assigned to those facilities need to be subtracted from the total calculated above. For example, if the point source emissions are:

- 124 Mg per year for Facility A;
- 83 Mg per year for Facility B; and
- 17 Mg per year for Facility C.

Then:

$$\begin{aligned}\begin{matrix}\text{Area Source} \\ \text{Emissions}\end{matrix} &= 1{,}600 \text{ Mg} - (124 \text{ Mg} + 83 \text{ Mg} + 17 \text{ Mg}) \\ &= 1{,}376 \text{ Mg/yr}\end{aligned}$$

Calculations needed for the second method are similar. However, in this case, subtracting the employment at point sources from the total employment should result in a more accurate emission estimate. For example,

- Total employment at metal furniture and fixture factories in the inventory area is 623; and
- Point source employment at two metal furniture factories is 479.

Then:

$$\begin{aligned}\begin{matrix}\text{Area Source} \\ \text{Employment}\end{matrix} &= 623 - 479 \\ &= 144 \text{ metal furniture factory employees}\end{aligned}$$

Area source emissions are then calculated as:

$$\text{Area Source Emissions} = (144 \text{ employees}) \times (428 \text{ kg/employee/yr})$$

$$= 61{,}632 \text{ kg/yr}$$

$$= 61.6 \text{ Mg/yr}$$

6.2 Auto Body Refinishing

SOURCE CODE: 24-01-005-000

DESCRIPTION:

Auto body refinishing is the repair and restoration of automobile, light truck, and other vehicle bodies. Refinishing operations occur subsequent to those at original equipment manufacturer assembly plants. Coating of new vehicles is not included in this source category, but falls under the industrial surface coating source category in a point source inventory. Most auto body refinishing jobs are performed as part of collision repair and involve only portions of a vehicle. Painting may take place in a spray booth.

Auto body refinishing operations can range in size from large production shops with many employees to very small operations where an individual works part time. In some instances, the large operations may be inventoried as point source facilities.

Emissions occur during surface cleaning, filling and priming, painting, and cleanup. Emissions from refinishing operations are influenced by the solvent content of the product, transfer efficiency of the spray equipment used to apply the coatings, and cleanup practices. Controls can include using lower solvent coatings, increased transfer efficiency for spray equipment, and enclosed cleaning devices.

POLLUTANTS: TOG

ROG: ROG emissions are 98.8% of TOG.

POINT SOURCE ADJUSTMENTS:

Auto body refinishing may take place at point source facilities. Uncontrolled emissions that have been calculated for point source facilities should be subtracted from the uncontrolled emissions total to yield an estimate of area source emissions.

METHODOLOGY:

$$\text{Annual TOG Emissions} = (\text{Population}) \times (\text{Emission Factor}) \tag{6.2-1}$$

DATA NEEDED:

Data	Sources
Population	INEGI
TOG emission factor 0.14 kg/person/yr	DDF, 1995b

NOTES:

1. The emission factor shown for auto body refinishing was developed by DDF (1995b) based on information on national solvent content and product sales (for 1993) provided by ANAFAPYT (National Association of Paint and Ink Manufacturers).

2. The emission factor was developed by multiplying the total volume of paint by 0.45 to reflect that the average paint is estimated to contain 45% solvent.

3. Adjustments to this per capita emission factor may be needed to reflect local conditions. Additional adjustments over time may be required because substitution of compounds contained in auto body refinishing may alter the non-reactive fraction.

SAMPLE CALCULATION:

For example, total annual TOG emissions from auto body refinishing use in the state of Colima (population 428,510) are:

$$\begin{aligned}(428{,}510 \text{ persons}) \times (0.14 \text{ kg/person/yr}) &= 59{,}991 \text{ kg/yr} \\ &= 59.99 \text{ Mg/yr}\end{aligned}$$

6.3 Architectural Surface Coating

SOURCE CODE: 24-01-001-000

DESCRIPTION:

Architectural surface coatings are used by painting contractors and individuals to protect and enhance building interior and exterior surfaces. Architectural surface coating involves spreading a thin layer of coating such as paint, paint primer, varnish, or lacquer to architectural surfaces, and the use of solvents for thinning and cleanup. This category does not include auto refinishing, traffic paint application, industrial surface coating, industrial maintenance coatings, or paints used in graphic arts applications. Because emissions from this category will be distributed throughout the inventory area and will not occur repeatedly at a single place during an inventory period, this category should be treated only as an area source.

TOG that are used as solvents in the coatings are emitted during application of the coating and as the coating dries. Control techniques involve either the substitution of products or the reformulation of products. Alternative products include low solvent content coatings, waterborne coatings, and powder coatings.

POLLUTANTS: TOG

ROG: ROG emissions are 94.5% of TOG for water-based architectural coatings, 96.8% of TOG for oil-based architectural coatings, and 69.9% of TOG for thinners/clean-up solvents used with architectural coatings.

POINT SOURCE ADJUSTMENTS: None.

METHODOLOGY:

$$\text{Annual TOG Emissions} = (\text{Population}) \times (\text{Emission Factor}) \qquad (6.3\text{-}1)$$

DATA NEEDED:

Data		Sources
Population		INEGI
TOG Emission Factor	1.36 kg/person/yr	DDF, 1995b

NOTES:

1. The emission factor shown for architectural surface coatings was developed by DDF (1995b) based on information on solvent content and product sales (for 1993) provided by ANAFAPYT (National Association of Paint and Ink Manufacturers).

2. The emission factor was developed by multiplying the total volume of paint by 0.45 to reflect that the average paint is estimated to contain 45% solvent.

3. Adjustments to this per capita emission factor may be needed to reflect local conditions. Additional adjustments over time may be required because substitution of compounds contained in architectural surface coatings may alter the non-reactive fraction.

SAMPLE CALCULATION:

For example, total annual TOG emissions from architectural surface coating use in the state of Colima (population 428,510) are:

$$\begin{aligned}(428{,}510 \text{ persons}) \times (1.36 \text{ kg/person/yr}) &= 582{,}774 \text{ kg/yr}\\ &= 582.77 \text{ Mg/yr}\end{aligned}$$

6.4 Traffic Paint

SOURCE CODE: 24-01-008-000

DESCRIPTION:

Traffic paint application is the painting of centerlines, edge stripes, directional markings, parking lot markings, and paved and unpaved surfaces to improve traffic flow. Traffic markings can include solvent- and water-based paints, which are usually applied with a spray, or in the form of thermoplastics or preformed tapes that are epoxied to the road surface. Traffic paints are applied by maintenance crews and traffic paint contractors during road construction and repairs. Because emissions from this category will be scattered throughout the inventory area and will not occur repeatedly at a single place during an inventory period, this category should be treated only as an area source.

Factors such as climatic conditions, the durability of the paint, pavement type, traffic density, and position of the marking will determine how often the paint will need to be re-applied, and thereby influence emissions. Control techniques involve the substitution or reformulation of products. Alternative formulations include water-based paints, thermoplastics, permanent markers, and preformed tapes.

POLLUTANTS: TOG

ROG: ROG emissions are 98.8% of TOG.

POINT SOURCE ADJUSTMENTS: None.

METHODOLOGY:

$$\text{Annual TOG Emissions} = (\text{Population}) \times (\text{Emission Factor}) \qquad (6.4\text{-}1)$$

DATA NEEDED:

Data		Sources
Population		INEGI, 1993
TOG emission factor	0.04 kg/person/yr	DDF, 1995b

NOTES:

1. The emission factor shown for traffic paint application was developed by DDF (1995b) based on information on solvent content and product sales (for 1993) provided by ANAFAPYT (National Association of Paint and Ink Manufacturers).

2. The emission factor was developed by multiplying the total volume of paint by 0.45 to reflect that the average paint is estimated to contain 45% solvent.

3. Adjustments to this per capita emission factor may be needed to reflect local conditions. Additional adjustments over time may be required because substitution of compounds contained in traffic paint application may alter the non-reactive fraction.

SAMPLE CALCULATION:

For example, total annual TOG emissions from traffic paint application use in the state of Colima (population 428,510) are:

$$(428{,}510 \text{ persons}) \times (0.04 \text{ kg/person/yr}) = 17{,}140 \text{ kg/yr}$$

$$= 17.14 \text{ Mg/yr}$$

6.5 Industrial Surface Cleaning (Degreasing)

SOURCE CODE:	**DESCRIPTION:**
24-15-000-xxx	All Processes/All Industries
24-15-005-xxx	Furniture and Fixtures
24-15-010-xxx	Primary Metal Industries
24-15-015-xxx	Secondary Metal Industries
24-15-020-xxx	Fabricated Metal Products
24-15-025-xxx	Industrial Machinery and Equipment
24-15-030-xxx	Electronic and Other Electrical Processes
24-15-035-xxx	Transportation Equipment
24-15-040-xxx	Instruments and Related Products
24-15-045-xxx	Miscellaneous Manufacturing
24-15-050-xxx	Transportation Maintenance Facilities
24-15-055-xxx	Automotive Dealers
24-15-060-xxx	Miscellaneous Repair Services
24-15-065-xxx	Auto Repair Services

DESCRIPTION:

Surface cleaning operations involve the use of solvent liquids or solvent vapors to remove water-insoluble contaminants such as grease, oils, waxes, carbon deposits, fluxes, and tars from metal, plastic, glass, and other surfaces. This process takes place in a large variety of manufacturing, scientific, and repair operations. Solvent cleaning operations involve the use of a number of different solvents and different solvent cleaning procedures.

Solvent cleaning equipment can be categorized as:

- Batch cold cleaning machines -- these machines are batch loaded and liquid solvent is sprayed, dipped, or brushed onto the surfaces that are to be cleaned.

- Batch vapor cleaning machines -- these machines are batch loaded, and the materials to be cleaned are exposed to vaporized solvent. The condensing solvent flushes the contaminants from the surfaces to be cleaned.

- In-line cleaning machines -- these machines are loaded on a continual basis and are often custom made for large-scale operations. An in-line solvent cleaning machine may use liquid solvent or vapor solvent.

- Cleanup solvent use -- this process involves wiping a surface with the solvent and a rag, mop, or sponge.

POLLUTANTS: TOG

ROG: ROG emissions are 100% of TOG for petroleum solvents and 0% of TOG for synthetic solvents. If chemical speciation data are available for the inventory region, the ROG/TOG ratio should be adjusted accordingly. If only the total amount of surface cleaning solvents is known, then it may be estimated that ROG emissions are 60% of TOG emissions (U.S. EPA, 1991a).

POINT SOURCE ADJUSTMENTS:

Solvent cleaning operations may occur at large facilities that may be inventoried as point sources. Therefore, the emission calculation procedure must be adjusted to prevent double counting with the point source estimates. If per employee emission factors are used, employment at the point source facilities should be subtracted from the total inventory area employment. If employment data are not available, then the point emissions can be subtracted from total emissions.

METHODOLOGY:

Emissions from this source can be calculated using one of two emission factors. The second method, which uses a per capita emission factor, should be used only as a last resort.

Method 1: The first group of emission factors, derived in the U.S., are based on the number of employees for facilities that typically have solvent cleaning operations. These U.S.-based per employee emission factors have limited applicability in Mexico and should only be used if no other data are available. The use of per employee emission factors requires collection of data on the number of people employed within certain industries. A brief industry description is provided in the following table under **DATA NEEDED**. After local or regional industries are matched to the groupings in the table, the employment for point source facilities in those groups must be subtracted from the total number of people employed in each industrial category. The remaining number is the area source employment.

$$\begin{matrix}\text{Annual}\\\text{Emissions}\end{matrix} = \begin{pmatrix}\text{Area Source}\\\text{Industry Group}\\\text{Employment}\end{pmatrix} \times \begin{pmatrix}\text{Emission}\\\text{Factor}\end{pmatrix} \qquad (6.5\text{-}1)$$

Method 2: The second group of emission factors, also derived in the U.S., are based on population (U.S. EPA, 1991a). These U.S.-based per capita emission factors have limited applicability in Mexico and should only be used if no other data are available. The calculation using the per capita emission factor is:

$$\text{Annual Emissions} = (\text{Population}) \times (\text{Emission Factor}) \qquad (6.5\text{-}2)$$

If any solvent cleaning operations are included in the point source inventory, their emissions should be removed from this estimate to yield an area source emission estimate.

Per employee and per capita emission factors are provided in the **DATA NEEDED** portion of this section. If information is available on the specific solvent cleaning operations in the geographic region of interest, emission factors for only those operations should be used. If information is not available on the types of cleaning operations, the "solvent cleaning (total)" emission factor should be used.

DATA NEEDED:

Data		Sources
Per Employee Method:		
Employment by Industry Type		SNIFF Database, CANACINTRA, INEGI
TOG Emission Factors		U.S. EPA, 1991a
Solvent Cleaning (total)	65 kg/employee/yr	
Batch Cold Cleaning		
Auto Repair	122 kg/employee/yr	
Manufacturing	11 kg/employee/yr	
Batch Vapor and In-line Machines		
Electronics and Electrical	68 kg/employee/yr	
Other	22 kg/employee/yr	

Data		Sources
Per Capita Emission Factor Method:		
Population		INEGI
TOG Emission Factors		U.S. EPA, 1991a
Solvent Cleaning (total)	3.27 kg/person/yr	
Batch Cold Cleaning		
Auto Repair	1.13 kg/person/yr	
Manufacturing	0.50 kg/person/yr	
Batch Vapor and In-line Machines		
Electronic and Electrical	0.50 kg/person/yr	
Other	1.13 kg/person/yr	

NOTES:

1. Adjustments to both the per capita and the per employee emission factors may be needed to reflect local conditions, and, over time, to reflect changes in solvent usage and composition.

2. The emission estimates calculated using the per employee factors will need to be correctly linked to SNIFF to facilitate reconciliation with the point source inventory.

3. An alternative to using the emission factors presented above is to a survey a representative number of surface cleaning operations. Results from this the survey then must be scaled up to the entire inventory area. See the **NOTES** portion of the Industrial Surface Coating section (Section 6.1) for an outline of the survey procedure. Surveying procedures are also contained in the *Basic Emissions Estimating Technique* manual.

SAMPLE CALCULATION:

Per Employee Method

Calculations needed for both methods are similar. However, in the first method, subtraction of the point source employment from the total employment should result in a more accurate emission estimate. For example,

- Total employment at manufacturing plants that use cleaning in the inventory area is 623; and

- Point source employment at two equipment manufacturing factories that use cold cleaning in their process is 379.

Then:

$$\begin{aligned} \text{Area Source Employment} &= 623 - 379 \\ &= 244 \text{ manufacturing factory employees} \end{aligned}$$

Emissions are calculated as:

$$\begin{aligned} \text{Area Source TOG Emissions} &= (244 \text{ employees}) \times (11 \text{ kg/employee/yr}) \\ &= 2{,}684 \text{ kg/yr} \\ &= 2.7 \text{ Mg/yr} \end{aligned}$$

The same procedure is used if there are other point source surface cleaning operations in the inventory area.

Per Capita Method

If the second method is used, total annual TOG emissions from surface cleaning in a state with a population of 1,250,000 are:

$$\begin{aligned} (1{,}250{,}000 \text{ persons}) \times (3.27 \text{ kg/person/yr}) &= 4{,}087{,}500 \text{ kg/yr} \\ &= 4{,}087.5 \text{ Mg/yr} \end{aligned}$$

If there are large facilities that use cold cleaning processes in the inventory area, and they have been inventoried as point sources, then the emissions assigned to those facilities need to be subtracted from the total calculated above. For example, if the point source emissions are:

- 178 Mg per year for Facility A;
- 123 Mg per year for Facility B; and
- 56 Mg per year for Facility C.

Then:

$$\text{Area Source Emissions} = 4{,}087.5 \text{ Mg} - (178 \text{ Mg} + 123 \text{ Mg} + 56 \text{ Mg})$$

$$= 3{,}730.5 \text{ Mg/yr}$$

6.6 Dry Cleaning

SOURCE CODE:	**DESCRIPTION:**
24-20-000-000	All Processes, All Solvent Types
24-20-000-055	All Processes, Perchloroethylene
24-20-000-370	All Processes, Special Naphthas
24-20-000-999	All Processes, Other Solvents
24-20-010-000	Commercial/Industrial Cleaners, All Solvent Types
24-20-010-055	Commercial/Industrial Cleaners, Perchloroethylene
24-20-010-370	Commercial/Industrial Cleaners, Special Naphthas
24-20-010-999	Commercial/Industrial Cleaners, Other Solvents

DESCRIPTION:

The dry cleaning industry is a service industry for the cleaning of clothing, draperies, leather goods, and other fabric items. Dry cleaning operations use halogenated or petroleum distillate organic solvents for cleaning. Dry cleaners can range in size from large industrial plants, which are typically treated as point sources, to very small operations with one unit, which may only be used intermittently. Commercial plants are the intermediate size between the two extremes.

Dry cleaning typically uses the following solvents: perchloroethylene, 1,1,1-trichloroethane, trichlorofluoroethane (CFC-113), as well as Stoddard solvent and other petroleum solvents. Perchloroethylene, trichloroethane, and CFC-113 are not considered photochemically reactive and should not be included in an inventory for ozone precursors.

Emissions occur from dry cleaning facilities when the solvents evaporate during the process, from leaks in the equipment, and from solvent recovery or disposal systems. Emissions can be controlled by using add-on control devices such as refrigerated condensers, reducing fugitive emissions from equipment leaks, and minimizing evaporation from solvent storage containers.

POLLUTANTS: TOG

ROG: As mentioned above, perchloroethylene, 1,1,1-trichloroethane, and CFC-113 are not considered photochemically reactive and should not be included in an inventory for ozone precursors. Only dry cleaning processes that use petroleum solvents will have ROG emissions. Therefore, ROG emissions are 100% of TOG for petroleum solvents and 0% of TOG for synthetic solvents. If only the total amount of dry cleaning solvents is known, then it may be estimated that ROG emissions are 58% of TOG emissions (U.S. EPA, 1991a).

POINT SOURCE ADJUSTMENTS:

Industrial dry cleaning facilities may be inventoried as point sources. Therefore, the area source emission calculation procedure must be adjusted to prevent double counting with the point source estimates. If per employee emission factors are used, employment at the point source facilities should be subtracted from the total inventory area employment. If employment data are not available, then the point emissions can be subtracted from total emissions.

METHODOLOGY:

Emissions from this source can be calculated using one of two emission factors. Emission factors for halogenated and petroleum solvent emissions are provided in the **DATA NEEDED** portion of this section.

Method 1: The first method uses per employee emission factors (based on national averages from the U.S.). These U.S.-based per employee emission factors have limited applicability in Mexico and should only be used if no other data are available. Emissions and reactivity of TOG emissions vary by the type of solvent used in the different types (sizes) of dry cleaning facilities (industrial, commercial, or small).

The use of per employee emission factors requires collection of data on the number of people employed by dry cleaning facilities that use either halogenated solvents (perchloroethylene, trichloroethane, or CFC-113) or petroleum solvents. Because small facilities are assumed to use only halogenated solvents, employees in these facilities should be excluded from the employment total if an inventory for ROG is being prepared. After employment data for dry cleaning facilities have been collected, the employment at point source facilities is subtracted from the total number of people employed. The resulting number of employees represents the area source employment. Emissions are then calculated as:

$$\text{Annual Emissions} = \left(\begin{array}{c}\text{Area Source Dry}\\ \text{Cleaning Employment}\end{array}\right) \times (\text{Emission Factor}) \qquad (6.6\text{-}1)$$

Method 2: The second emission factor is based on population calculated from national average solvent use in the U.S. (U.S. EPA, 1991a). These U.S.-based per capital emission factors have limited applicability in Mexico and should only be used if no other data are available.

The calculation using the per capita emission factor is:

$$\text{Annual Emissions} = (\text{Population}) \times (\text{Emission Factor}) \qquad (6.6\text{-}2)$$

If any dry cleaning operations are included in the point source inventory, their emissions should be removed from this estimate to yield an area source emission estimate.

DATA NEEDED:

Data		Sources
Per Employee Method:		
Employment in Dry cleaning Facilities		SNIFF Database, CANALAVA[a], INEGI
TOG Emission Factor		U.S. EPA, 1991a
Dry cleaning (total)	1,043 kg/employee/yr (2,300 lb/employee/yr)	
Halogenated solvents	445 kg/employee/yr (980 lb/employee/yr)	
Small facilities	24 kg/employee/yr (52 lb/employee/yr)	
Commercial/industrial facilities	544 kg/employee/yr (1,200 lb/employee/yr)	
ROG Emission Factor		
Petroleum solvents	816 kg/employee/yr (1,800 lb/employee/yr)	
Per Capita Emission Factor Method:		
Population		INEGI
TOG Emission Factor		U.S. EPA, 1991a
Dry cleaning (total)	0.86 kg/person/yr (1.9 lb/person/yr)	
Halogenated solvents	0.37 kg/person/yr (0.81 lb/person/yr)	
Small facilities	0.005 kg/person/yr (0.01 lb/person/yr)	
Commercial/industrial facilities	0.36 kg/person/yr (0.80 lb/person/yr)	
ROG Emission Factor		U.S. EPA, 1991a
Petroleum solvents	0.50 kg/person/yr (1.1 lb/person/yr)	

[a] Information from CANALAVA may be available only for Chamber members.

NOTES:

1. The per capita and per employee factors presented here are based on U.S. national solvent use averages, not on data specific to Mexico. More accurate estimates should be made with emission factors developed from data specific to the dry cleaning industry in Mexico obtained from CANALAVA.

2. Adjustments to both the per capita and the per employee emission factors may be needed to reflect local variation, and over time, to reflect changes in solvent usage and composition.

3. The emission estimates calculated using the per employee factors will need to be correctly linked to SNIFF to facilitate reconciliation with the point source inventory.

4. An alternative to the emission factors presented above is a survey of a representative number of dry cleaning operations. Results from this survey should then be scaled up to the entire inventory area. See the **NOTES** portion of the Industrial Surface Coating section (Section 6.1) for an outline of the survey procedure. Surveying procedures are also contained in the *Basic Emissions Estimating Techniques* Manual.

SAMPLE CALCULATION:

Calculations needed for both methods are similar. However, in the first method, subtracting the employment at point sources from the total employment should result in a more accurate emission estimate. For example,

- Total employment at dry cleaning plants that use halogenated solvents in the inventory area is 990; and

- Point source employment at Facilities A, B, and C totals 170.

Then:

$$\begin{aligned}\text{Area Source Employment} &= 990 - 170 \\ &= 820 \text{ halogenated solvent dry cleaning employees}\end{aligned}$$

Emissions are then calculated as:

$$\begin{array}{l} \text{Area Source} \\ \text{TOG Emissions} \end{array} = (820 \text{ employees}) \times (445 \text{ kg/employee/yr})$$

$$= 364{,}900 \text{ kg/yr}$$

$$= 364.9 \text{ Mg/yr}$$

If the second method is used, total annual TOG emissions from facilities using halogenated solvents in a state with a population of 1,250,000 are:

$$(1{,}250{,}000 \text{ persons}) \times (0.37 \text{ kg/person/yr}) = 462{,}500 \text{ kg/yr}$$

$$= 462.5 \text{ Mg/yr}$$

If there are large facilities that use halogenated solvents for dry cleaning in the inventory area, and they have been inventoried as point sources, then the emissions assigned to those facilities need to be subtracted from the total calculated above. For example, if the point source emissions are:

- 32 Mg per year for Facility A;
- 11.2 Mg per year for Facility B; and
- 23 Mg per year for Facility C.

Then:

$$\text{Area Source Emissions} = 462.5 \text{ Mg} - (32 \text{ Mg} + 11.2 \text{ Mg} + 23 \text{ Mg})$$

$$= 396.3 \text{ Mg/yr}$$

6.7 Graphic Arts

SOURCE CODE:	**DESCRIPTION:**
24-25-000-xxx	All Processes
24-25-010-xxx	Lithography
24-25-020-xxx	Letterpress
24-25-030-xxx	Rotogravure
24-25-040-xxx	Flexography

DESCRIPTION:

Graphic arts includes operations that are involved in the printing of newspapers, magazines, books, and other printed materials. Printing may be performed on various substrates (e.g., coated or uncoated paper, metal, or fabric). The difference between printing on paper coating is that printing always involves the application of ink by a printing press. The four basic operations used in graphic arts in the U.S. are web lithography, rotogravure, web letterpress, and flexography. Screen printing and manual or sheet-fed techniques are less common. Lithography is characterized by a planographic image carrier (i.e., the image and nonimage areas are on the same plane). In gravure printing, the image area is engraved (i.e., “intaglio”) relative to the surface of the image carrier. In letterpress, the image area is raised, and the ink is transferred to the substrate directly from the image surface. Flexography also uses an image area above the surface of the plate, but flexography uses a rubber image carrier, whereas letterpress uses a metal or plastic one.

Printing inks vary widely in composition, but all consist of three major components: pigments, binders, and solvents. The majority of solvent use in graphic arts operations is consumed in printing ink formulations, with lesser amounts of solvents used for equipment cleaning or as a component in fountain solutions for dampening systems in lithographic printing. The solvents evaporate from the inks into the atmosphere during the drying process. Although residual solvents may remain in the printed product after the ink has dried, and some of the inks will not be used and will be disposed of in facility wastewater or to a landfill, most inventory efforts conservatively assume that all of the ink solvents evaporate into the air.

Emissions from graphic arts operations can be reduced by the use of water-based inks, more efficient application processes in which less ink is applied, filters, condensation systems, and afterburners.

POLLUTANTS: TOG

ROG: ROG emissions are 100% of TOG.

POINT SOURCE ADJUSTMENTS:

Graphic arts operations may occur at large facilities that may be inventoried as point sources. Therefore, the emission calculation procedure must be adjusted to prevent double-counting with the point source estimates.

METHODOLOGY:

The calculation using the per capita emission factor is:

$$\text{Annual TOG Emissions} = (\text{Population}) \times (\text{Emission Factor}) \qquad (6.7\text{-}1)$$

If any large graphic arts facilities are included in the point source inventory, their emissions should be removed from this estimate to yield an area source emission estimate.

Note that this U.S.-based per capita emission factor has limited applicability in Mexico and should only be used if no other data are available.

DATA NEEDED:

Data	Sources
Per Capita Emission Factor Method:	
Population	INEGI
TOG Emission Factor (for all types of graphic arts operations) 0.59 kg/person/yr (1.3 lb/person/yr)	U.S. EPA, 1991a

NOTES:

1. The fifth edition of AP-42 (AP-42, 1995) presents a per capita emission factor of 0.4 kg non-methane volatile organic compound (VOC)/person/yr. However, this emission factor is based on 1981 data and, therefore, the 1991 U.S. EPA guidance is considered to be more current.

2. It may soon be possible to develop a Mexico-specific per capita emission factor for graphic arts based on information on product sales available from the

National Association of Paint and Ink Manufacturers (ANAFAPYT) and population estimates as summarized below:

Per capita EF = (total annual inks usage, liters) × (DDF adjustment factor for growth from data year to inventory year) × (percentage of ink solvent) × (average ink density, g/liter)/(population) (6.7-2)

DDF has already developed some Mexico-specific per capita emission factors for various surface coating categories using this approach (DDF, 1995b).

3. Adjustments to per capita emission factors may be needed to reflect local conditions and to reflect changes in ink usage and composition over time.

4. An alternative to the emission factor approach presented above is to survey a representative number of graphic arts operations. Results from the survey should then be scaled up to the entire inventory area. See the **NOTES** portion of the Industrial Surface Coating Section (Section 6.1) for an outline of the survey procedure. Surveying procedures are also contained in the *Basic Emissions Estimating Techniques* Manual.

SAMPLE CALCULATION:

For example, total annual TOG emissions from graphic arts in a state with a population of 1,250,000 are:

(1,250,000 persons) x (0.59 kg/person/yr) = 737,500 kg/yr
= 737.5 Mg/yr

If there are large graphic arts facilities in the inventory region that have been inventoried as point sources, then the emissions assigned to those facilities need to be subtracted from the total calculated above. For example, if the point source emissions are:

- 12 Mg/yr for Facility A; and
- 15 Mg/yr for Facility B;

Then:

Area Source Emissions = (Total Emissions) - (Point Emissions)
= 737.5 - (12 + 15)
= 710.5 Mg/yr

6.8 Asphalt Application

SOURCE CODE:	**DESCRIPTION:**
24-61-021-000	Cutback Asphalts
24-25-022-000	Emulsified Asphalt

DESCRIPTION:

Asphalt surfaces and pavements are composed of compacted aggregate and an asphalt binder. The aggregate transmits the load from the surface to the base course, takes the abrasive wear of traffic, and provides a nonskid surface. The binder holds the aggregate together and prevents movement or loss of aggregate. This source category addresses hydrocarbon emissions from the evaporation of these binders.

Asphalt binders may be asphalt cement or liquified asphalts. Asphalt cement is the residue of distillation processes. There are two types of liquified asphalts: cutback asphalts and emulsified asphalts. Cutback asphalts are asphalt cement thinned or "cutback" with volatile petroleum distillates, and they are generally categorized as rapid cure, medium cure, and slow cure. Asphalt characterization is based on the solvent used as a diluent and the corresponding time needed for curing (i.e., gasoline or naphtha is used as a diluent for rapid cure, whereas kerosene and other low volatility fuel oils are used for medium and slow cure). Emulsified asphalts use a blend of water and emulsifier (i.e., soap) instead of solvent diluent, and they rely on water evaporation or ionic bonding to cure.

TOG emissions result from the evaporation of the petroleum distillate solvent used to liquify the asphalt cement. The type and quantity of diluent used are the two major variables affecting the total VOC emissions and the time over which emissions occur. Long-term emissions can be estimated by assuming that 95 wt% of the diluent evaporates from rapid cure, 70 wt% from medium cure, and 25 wt% from slow cure (U.S. EPA, 1995a). Some of the diluent appears to be permanently retained in the road surface after application.

POLLUTANTS: TOG

ROG: ROG emissions are 100% of TOG.

POINT SOURCE ADJUSTMENTS:

Asphalt batch plants may be inventoried as point sources. Emissions that have been calculated for these point source facilities may include TOG estimates for emissions from the diluents during mixing or material handling. If this is the case, these diluent emissions should be subtracted from the emissions total in order to estimate area source emissions.

METHODOLOGY:

To calculate emissions, required data include the total amount of each type of asphalt applied in the inventory region and the type and amount of diluent used in each region. Since the amount of diluent in the asphalt is usually provided in percent by volume, the general emission estimating equations are:

Density of the asphalt = (density of asphalt cement) × (vol% asphalt cement) +
(density of asphalt diluent) × (vol% asphalt diluent) (6.8-1)

Volume of asphalt applied = (mass of asphalt applied) / (density of the asphalt) (6.8-2)

Total volume of diluent = (volume of asphalt applied) × (vol% diluent) (6.8-3)

Total mass of diluent = (total volume of diluent) × (diluent density) (6.8-4)

Total TOG emissions = (Total mass of diluent) × (% of diluent evaporated based
on cure type) (6.8-5)

If the amount of diluent in the asphalt is provided in percent by weight, then the general emission estimating equations are simply:

Total mass of diluent = (mass of asphalt applied) × (wt% diluent density) (6.8-6)

Total TOG emissions = (Total mass of diluent) × (% of diluent evaporated based
on cure type) (6.8-7)

DATA NEEDED:

Data	Sources
Amount of each type of asphalt applied in the inventory region	Municipal agency (e.g., *Dirección General de Obras Públicas* in Mexico City)
Physical properties of the asphalt (asphalt cement and diluent)	Municipal agency (e.g., *Dirección General de Obras Públicas* in Mexico City)
TOG Emission Factor (i.e., wt% evaporated) 95 wt% for rapid cure 70 wt% for medium cure 25 wt% for slow cure	AP-42

NOTES:

1. If region-specific physical properties for asphalt are not available, the following default values may be used:

Physical Property	Default Value	Source
wt% diluent in asphalt	0.34 wt% (Mexico City) 6.2 wt% (all other areas of Mexico)	DDF, 1996b
diluent density	0.7 kg/liter (naphtha, rapid cure) 0.8 kg/liter (medium cure) 0.9 kg/liter (slow cure)	AP-42
asphalt cement density	1.1 kg/liter 1.1 - 1.5 kg/liter	AP-42 CRC, 1985, p. F-1

2. If the amount of asphalt applied is only available for a portion of the inventory region, these available data should be used to develop a per capita emission factor to be used together with population data to develop emission estimates for the other portion of the region as shown in the Sample Calculation.
DDF has used this approach to develop emission estimates for asphalt application in the Mexico City Metropolitan Zone (ZMCM)(DDF, 1996b).

SAMPLE CALCULATION:

Local records show that 10,000 kg of rapid cure cutback asphalt was applied in a given area during the year. This asphalt is reported to be 45 vol% naphtha. Assuming that the density of naphtha is 0.7 kg/liter and the density of the asphalt cement is 1.1 kg/liter, calculate the annual TOG emissions.

1. Density of the asphalt = (density of asphalt cement) × (vol% asphalt cement) + (density of asphalt diluent) × (vol% asphalt diluent)

   = (1.1 kg/liter) x (55 vol%) + (0.7 kg/liter) x (45 vol%)
   = 0.92 kg/liter

2. Volume of asphalt applied = (mass of asphalt applied) / (density of the asphalt)

   = (10,000 kg) / (0.92 kg/liter)
   = 10,870 liters

3. Total volume of diluent = (volume of asphalt applied) × (vol% diluent)

   = (10,870 liters) × (45 vol%)
   = 4,891 liters

4. Total mass of diluent = (total volume of diluent) x (diluent density)

   = (4,891 liter) × (0.7 kg/liter)
   = 3,424 kg

5. Total TOG emissions = (Total mass of diluent) × (% of diluent evaporated based on cure type)

   = (3,424 kg) × (95% evaporation for rapid cure)
   = 3,253 kg TOG/yr

If there are large asphalt batch plants in the inventory region that have been inventoried as point sources, then the diluent emissions reported by those facilities need to be subtracted from the total calculated above. For example, if the point source emissions are:

- 500 kg TOG/yr for Facility A (400 kg from diluent, 100 kg from combustion); and
- 300 kg TOG/yr for Facility B (250 kg from diluent, 50 kg from combustion);

Then:

Area Source Emissions = (Total Emissions) - (Point Emissions)
= 3,253 - (400 + 250)
= 2,603 kg TOG/yr

6.9 Commercial/Consumer Solvent Use

SOURCE CODE:	**DESCRIPTION:**
Consumer	
24-65-000-000	All Consumer Products
24-65-100-000	Personal Care Products
24-65-200-000	Household Products
24-65-300-000	Aerosol Products
24-65-400-000	Automotive Aftermarket Products
24-65-600-000	Adhesives and Sealants
24-65-800-000	Household Pesticides
24-65-900-000	Miscellaneous Products
Commercial	
24-61-000-000	Total Commercial Products
24-61-600-000	Adhesives and Sealants
24-61-800-000	Commercial Pesticides

DESCRIPTION:

Hydrocarbons are ingredients of consumer and commercial products which serve as propellants, aid in product drying (through evaporation), act as co-solvents and cleaning agents, and are emitted during product use. Typically these hydrocarbon sources are large in number, highly dispersed, and individually emit relatively small amounts of TOG. Commercial and consumer products which release TOG include aerosols, household products, personal care products, automotive aftermarket products, adhesives and sealants, and commercial and household pesticides.

Solvents contained in consumer and commercial products are primarily released during product use. Residual amounts of solvent may remain in discarded product packaging, enter the municipal solid waste stream, and be disposed of in landfills. Solvents from these products may also enter the wastewater treatment system through use and disposal. Most inventory efforts assume that all TOG in consumer and commercial products volatilize to the air.

Typical TOG constituents that are released to the atmosphere from this source category include special naphthas, alcohols and various chloro- and fluorocarbons. Approximately 31% of the TOG released from these products is considered non-photochemically reactive (AP-42, 1995).

POLLUTANTS: TOG

ROG: ROG emissions are estimated to be 69% of TOG.

POINT SOURCE ADJUSTMENTS: None.

METHODOLOGY:

$$\text{Annual TOG Emissions} = (\text{Population}) \times (\text{Emission Factor}) \qquad (6.9\text{-}1)$$

DATA NEEDED:

Data		Sources
Population		INEGI
ROG Emission Factors		
Aerosol Products	0.046 kg/person/yr	DDF, 1995b
Household Products	0.36 kg/person/yr	U.S. EPA, 1996a
Personal Care Products	1.05 kg/person/yr	U.S. EPA, 1996a
Automotive Aftermarket Products	0.61 kg/person/yr	U.S. EPA, 1996a
Adhesives and Sealants	0.26 kg/person/yr	U.S. EPA, 1996a
Commercial/Household Pesticides	0.81 kg/person/yr	U.S. EPA, 1996a
Miscellaneous Products	0.03 kg/person/yr	U.S. EPA, 1996a
TOTAL ROG	3.17 kg/person/yr	
TOG Emission Factors		
Aerosol Products	0.067 kg/person/yr	DDF, 1995b
Household Products	0.52 kg/person/yr	U.S. EPA, 1996a
Personal Care Products	1.52 kg/person/yr	U.S. EPA, 1996a
Automotive Aftermarket Products	0.88 kg/person/yr	U.S. EPA, 1996a
Adhesives and Sealants	0.38 kg/person/yr	U.S. EPA, 1996a
Commercial/Household Pesticides	1.17 kg/person/yr	U.S. EPA, 1996a
Miscellaneous Products	0.04 kg/person/yr	U.S. EPA, 1996a
TOTAL TOG	4.58 kg/person/yr	

NOTES:

1. The TOG emission factors have been developed from the referenced ROG emission factors and estimating that ROG emissions are 69% of the TOG.

2. The emission factor shown for aerosol products was developed by DDF (1995b) based on information on solvent content and product sales (for

1993) provided by ANAFAPYT (National Association of Paint and Ink Manufacturers).

3. Adjustments to these per capita emission factors may be needed over time because substitution of compounds contained in commercial/ consumer products may alter the non-reactive fraction of compounds.

SAMPLE CALCULATION:

For example, total annual TOG emissions from consumer and commercial solvent use in the state of Colima (population 428,510) are:

$$\begin{aligned}(428{,}510\ \text{persons}) \times (4.58\ \text{kg/capita/yr}) &= 1{,}962{,}576\ \text{kg/yr}\\ &= 1{,}963\ \text{Mg/yr}\end{aligned}$$

7.0 PETROLEUM PRODUCT STORAGE AND TRANSPORT

The various emission points associated with petroleum product storage and transport are generally considered too numerous to be included in the point source inventory for a given inventory region. Therefore, these smaller evaporation sources need to be included in the area source inventory effort. Inventory guidance for these sources are presented in the following subsections:

- Gasoline Distribution (includes gasoline tank trucks in transit, tank truck unloading [Stage I], underground tank breathing, and vehicle refueling [Stage II] and spillage);
- Aircraft Refueling; and
- Liquified Petroleum Gas (LPG) Distribution.

7.1 Gasoline Distribution

SOURCE CODE:	**DESCRIPTION:**
25-01-060-000	Gasoline Service Stations: All Processes
25-01-060-050	Stage I: Total
25-01-060-051	Stage I: Submerged Filling
25-01-060-052	Stage I: Splash Filling
25-01-060-053	Stage I: Balanced Submerged Filling
25-01-060-100	Stage II: Total
25-01-060-101	Stage II: Displacement Loss/Uncontrolled
25-01-060-102	Stage II: Displacement Loss/Controlled
25-01-060-103	Stage II: Spillage
25-05-030-120	Truck Transportation: Gasoline
25-01-060-200	Underground Tank: Total
25-01-060-201	Underground Tank: Breathing and Emptying

DESCRIPTION:

In the gasoline distribution industry, gasoline is transported from refineries by tanker trucks to bulk plants and terminals, and ultimately to service stations. The procedures discussed below relate directly to the emissions that occur during the transportation and distribution of gasoline from bulk plants and terminals to service stations.

Evaporative emissions occur at all points in the gasoline distribution process. Those operations generally thought of as area sources are gasoline dispensing stations (service stations) and gasoline tank trucks in transit. Bulk terminals and gasoline bulk plants, which are intermediate distribution points between refineries and outlets, should be inventoried as point sources.

Area sources of TOG from the transportation and distribution of gasoline involve the following types of emissions:

- Breathing losses
    - Evaporation of gasoline from the tank truck during transportation of the gasoline from the bulk plant/terminal to the service station or other dispensing outlet;
    - Evaporation of gasoline from the empty tank truck on the return trip from the service station within an inventory area to the bulk plant/terminal; and

  - Evaporation of gasoline from the underground storage tank(s) or the lines going to the gasoline dispensing outlet (pumps) when standing and not in use.

- Working losses

  - Evaporation of gasoline during the transfer of gasoline from the tank truck to underground storage at the service station (often referred to as “Stage I”);

  - Evaporation of gasoline during the transfer of gasoline from the pump to vehicles (often referred to as “Stage II”);

  - Spillage of gasoline (and subsequent evaporation) during either delivery activity, above. This loss is made up of contributions from prefill and postfill nozzle drip and from spit-back and overflow from the filler pipe of the vehicle’s fuel tank during filling; and

  - Evaporation of gasoline from the underground storage tank or the lines going to the pumps during transfer of gasoline.

POLLUTANTS: TOG

ROG: For gasoline, the fraction of the total emissions that is methane or ethane is negligible; therefore, ROG emissions are estimated to be 100% of TOG. For diesel fuels, methane and ethane constitute 15% of total TOG evaporative emissions, so ROG emissions are estimated to be 85% of TOG.

POINT SOURCE ADJUSTMENTS:

Gasoline distribution activities may occur at large facilities that may be inventoried as point sources. Emissions that have been calculated for point source facilities must be subtracted from the emissions total in order to estimate area source emissions.

METHODOLOGY:

The most accurate approach to estimate area source gasoline distribution emissions is to acquire gasoline consumption data, which is then multiplied by a number of emission factors to determine evaporative losses. Gasoline distribution and consumption statistics are collected and maintained by PEMEX.

The flow of gasoline through the inventory area should be mapped to gasoline consumption. The best approach is to develop a chart showing overall gasoline flow within the inventory area, from the point of entry, through bulk storage, to service stations and vehicle loading operations. Construction of this flowchart provides a valuable overview of the gasoline distribution system and facilitates detection of gross anomalies in the distribution data. Care should be taken that all gasoline consumed in the inventory area is accounted for, including that dispensed at marinas, airports, military bases, and government motor pools.

Tank Truck Unloading

Emissions from tank truck unloading are affected by whether the service station tank is equipped for submerged, splash, or balance filling. Therefore, information must be obtained on the fraction of stations using each filling method. A survey of several service stations in the area will produce an estimate of the number of stations employing each filling method. PEMEX is another source of information on station characteristics.

Tank truck unloading losses occur as hydrocarbon vapors in “empty” cargo tanks are displaced to the atmosphere by the liquid being loaded into the tanks. These vapors are a composite of (1) vapors formed in the empty tank by evaporation of residual product from previous loads, (2) vapors transferred to the tank in vapor balance systems as product is being unloaded, and (3) vapors generated in the tank as the new product is being loaded.

In the splash loading method, the fill pipe dispensing the gasoline is lowered only part way into the cargo tank. Significant turbulence and vapor/liquid contact occur during the splash loading operation, resulting in high levels of vapor generation and loss. If the turbulence is great enough, liquid droplets will be entrained in the vented vapors.

A second method of loading is submerged loading. Two types are the submerged fill pipe method and the bottom loading method. In the submerged fill pipe method, the fill pipe extends almost to the bottom of the tank. In the bottom loading method, a permanent fill pipe is attached to the tank bottom. During most of submerged loading by both methods, the fill pipe opening is below the liquid surface level. Liquid turbulence is controlled significantly during submerged loading, resulting in much lower vapor generation than encountered during splash loading.

One control measure for vapors displaced during gasoline loading is called “vapor balance” or Stage I vapor control, in which the vapors displaced during product unloading return to the tank truck cargo compartment. The control efficiency of the recovery units range from 90 to over 99 percent.

Emissions from loading gasoline (or any petroleum liquid) can be estimated (with a probable error of ±30 percent) using the following expression:

$$EF_{tu} = 12.46 \frac{SPM}{T} \qquad (7.1\text{-}1)$$

where:
EF_{tu} = Loading loss, lbs per 1,000 gallons of liquid loaded;
S = Saturation factor (see Table 7.1-1). The saturation factor, S, represents the expelled vapor's fractional approach to saturation, and it accounts for the variations observed in emission rates from the different unloading and loading methods;
P = True vapor pressure of liquid loaded, pounds per square inch absolute (psia) (see Table 7.1-2);
M = Molecular weight of vapors, pounds per pound-mole (lb/lb-mole) (see Table 7.1-2); and
T = Temperature of bulk liquid loaded, °R (°F + 460).

To estimate emissions, the emission factor for tank truck unloading is applied to the total fuel dispensed, as noted in the following equation:

$$E_{tu} = EF_{tu} \times F \qquad (7.1\text{-}2)$$

where:
E_{tu} = Total emissions from tank truck unloading (kg/year);
EF_{tu} = Emission factor for tank truck unloading (kg/liter); and
F = Fuel dispensed (liters/year).

Table 7.1-1

Saturation Factors (S) For Calculating Petroleum Liquid Loading Losses

Cargo Carrier	Mode of Operation	S Factor
Tank trucks and rail tank cars	Submerged loading: clean cargo tank	0.50
	Submerged loading: dedicated normal service	0.60
	Submerged loading: dedicated vapor balance service	1.00
	Splash loading: clean cargo tank	1.45
	Splash loading: dedicated normal service	1.45
	Splash loading: dedicated vapor balance service	1.00
Marine vessels[a]	Submerged loading: ships	0.2
	Submerged loading: barges	0.5

[a] For products other than gasoline and crude oil.

Source: AP-42, 1995a, Section 5.2.

Note: the saturation factor reflects the degree to which the vented vapors are saturated, relative to equilibrium conditions. That is, S = 1.00 represents vented vapors at equilibrium conditions. If liquid droplets are entrained in the vented vapors, S > 1.0.

Table 7.1-2

Properties (M_V and P_{VA}) of Selected Petroleum Liquids

Petroleum Liquid	Vapor Molecular Weight at 60°F, M_V (lb/lb-mole)	True Vapor Pressure, P_{VA} (psia)						
		40°F	50°F	60°F	70°F	80°F	90°F	100°F
Gasoline RVP 13	62	4.7	5.7	6.9	8.3	9.9	11.7	13.8
Gasoline RVP 10	66	3.4	4.2	5.2	6.2	7.4	8.8	10.5
Gasoline RVP 7	68	2.3	2.9	3.5	4.3	5.2	6.2	7.4
Crude Oil RVP 5	50	1.8	2.3	2.8	3.4	4.0	4.8	5.7
Jet naphtha (JP-4)	80	0.8	1.0	1.3	1.6	1.9	2.4	2.7
Jet kerosene	130	0.0041	0.0060	0.0085	0.011	0.015	0.021	0.029
Distillate Fuel Oil No. 2	130	0.0031	0.0045	0.0074	0.0090	0.012	0.016	0.022
Residual Oil No. 6	190	0.00002	0.00003	0.00004	0.00006	0.00009	0.00013	0.00019

Source: AP-42, 1995a, Section 7.1. Where possible, values for these properties for Mexican petroleum derivatives should be obtained from PEMEX.

DATA NEEDED:

Data	Sources
Fuel consumption dispensed	PEMEX
TOG Emission factors[a] Calculated using Equation 7.1-1 or Submerged filling: 880 mg/liter of fuel Splash filling: 1,380 mg/liter of fuel Balanced submerged filling: 40 mg/liter of fuel	AP-42, 1995

[a] Factors are for TOG as well as ROG because the methane and ethane content of gasoline vapors is negligible.

SAMPLE CALCULATION-TANK TRUCK UNLOADING:

Assume that in the inventory region, 100,000 m^3 of gasoline (RVP = 10 psia) are unloaded from tank trucks at service stations in a given year. Assume that all the service station tanks are equipped for submerged filling and that the tank trucks are operated in dedicated normal service. Finally, assume that the average loading temperature is 21°C.

1. Determine the saturation factor, S.

   Use Table 7.1-1 for submerged loading dedicated normal service, S = 0.6.

2. Determine the true vapor pressure and the vapor molecular weight.

   Use Table 7.1-2. For RVP = 10 psia, the default value for vapor molecular weight is 66 lb/lb-mole.

   The average loading temperature is 21°C or 70°F. Therefore, the default value for the true vapor pressure is 6.2 psia.

3. Determine the emission factor, using equation 7.1-1:

$$\begin{aligned} EF_{tu} &= 12.46 \ \frac{SPM}{T} \\ &= 12.46 \times \left[\frac{(0.6)\ (6.2)\ (66)}{(70\ +\ 460)} \right] \\ &= 5.77\ \text{lb/1000 gal} \\ &= 0.69\ \text{kg/1000 liters} \\ &= 0.69\ \text{kg/m}^3 \end{aligned}$$

4. Determine the TOG emissions from these tank truck unloading operations using equation 7.1-2:

E_{tu}
$=$ $EF_{tu} \times F$

E_{tu} $=$
$(0.69\ \text{kg/m}^3) \times (100{,}000\ \text{m}^3)$
$=$
69,000 kg TOG = 69 Mg TOG

Underground Tank Breathing

A second source of vapor emissions from service stations is underground tank breathing. Breathing losses occur daily and are attributable to gasoline evaporation and barometric pressure changes. The frequency with which gasoline is withdrawn from the tank, allowing fresh air to enter to enhance evaporation, also has a major effect on the quantity of these emissions. An average breathing emission rate is 120 mg/liter of throughput.

To estimate emissions, the emission factor for tank breathing is applied to the total fuel dispensed, as noted in the following equation:

$$E_b = EF_b \times F \qquad (7.1\text{-}3)$$

where:
E_b = Total underground tank breathing emissions (mg/year);
EF_b = Emission factor for tank breathing (mg/liter); and
F = Fuel dispensed (liter/year).

DATA NEEDED:

Data	Sources
Fuel Dispensed	PEMEX
TOG Emission factor[a] 120 mg/liter of fuel dispensed	AP-42, 1995

[a] Factor is for TOG as well as ROG because the methane and ethane content of gasoline vapors is negligible.

SAMPLE CALCULATION - UNDERGROUND TANK BREATHING:

As in Sample Calculation #1, assume that 100,000 m^3 of gasoline are dispensed from service stations in the inventory region in a given year. Use equation 7.1-3 to determine the TOG emissions from underground tank breathing:

$$E_b = EF_b \times F$$

$$EF_b = (120 \text{ mg/liters}) \times (1 \text{ kg}/10^6 \text{ mg}) \times (1000 \text{ liters/m}^3) = 0.120 \text{ kg/m}^3$$

$$E_b = (0.120 \text{ kg/m}^3) \times (100{,}000 \text{ m}^3)$$

$$= 12{,}000 \text{ kg TOG}$$

$$= 12 \text{ Mg TOG}$$

Gasoline Tank Trucks In Transit

Breathing losses from tank trucks during the transport of gasoline are caused by leaking delivery trucks, pressure in the tanks, and thermal effects on the vapor and on the liquid. A worst case situation arises if a poorly sealed tank has been loaded with gasoline and pure air becomes saturated. During the vaporization process, pressure increases and venting occurs.

Because some gasoline is delivered to bulk plants, rather than delivered directly to service stations from bulk terminals, the amount of gasoline transferred in any area may exceed the total gasoline consumption due to the additional trips involved. Therefore, transit emissions involve not only end consumption, but also gasoline transport from outside the inventory area to the intermediate bulk plants, and should be based on total gasoline transferred rather than on consumption. For example, if gasoline sales in an area are 300 million liters per year, and 50 million liters of this goes through bulk plants, then 350 million liters is the amount transported by tank trucks and is the appropriate figure to use to estimate transit losses. In the U.S., a default assumption of 25 percent is applied if site-specific data cannot be obtained. In other words, gasoline distribution in an area could be multiplied by 1.25 to estimate gasoline transportation (AP-42, 1991a). This U.S.-based default value has limited applicability in Mexico and should only be used if no other data are available.

To estimate emissions the emission factor for tank trucks in transit is applied to the total fuel transferred, as noted in the following equation:

$$E_{tt} = EF_{tt} \times F_t \qquad (7.1\text{-}4)$$

where:
E_{tt} = Total emissions from tank trucks in transit (mg/year);
EF_{tt} = Emission factor for tank trucks in transit (mg/liter); and
F_t = Fuel in transit through inventory area, including through bulk plants (liter/year).

DATA NEEDED:

Data	Sources
Fuel transferred into and through inventory area	PEMEX
TOG Emission factors[a] Tank truck loaded with product 0-1 mg/liter transported Tank truck returning with vapor 0-13 mg/liter transported	AP-42, 1995

[a] Factors are for TOG as well as ROG because the methane and ethane content of gasoline vapors is negligible.

NOTES:

1. The U.S. EPA default (25 percent) used for gasoline transit through bulk plants is meant to correct for gasoline going through bulk terminals. A more accurate adjustment can be created using data from the bulk terminals in the inventory area.

SAMPLE CALCULATION - GASOLINE TANK TRUCKS IN TRANSIT:

As in the previous sample calculations, assume that 100,000 m^3 of gasoline are delivered to service stations in the inventory region in a given year. Assume that the amount delivered to bulk plants is unknown.

1. Determine the total amount of gasoline in transit.

   Since the amount delivered to bulk plants is unknown, use the U.S. default value of 25 percent.

$$\begin{aligned} F_t &= F_{\text{service station}} + F_{\text{bulk plants}} \\ &= F_{\text{service stations}} + 0.25F_{\text{service stations}} \\ &= 1.25 \times 100{,}000\ m^3 \\ &= 125{,}000\ m^3 \text{ gasoline} \end{aligned}$$

2. Determine the TOG emissions from gasoline tank trucks in transit and loaded with product using equation 7.1-4.

$$\begin{aligned} E_{tt} &= EF_{tt} \times F_t \\ EF_{tt} &= (0.5\ \text{mg/liters}) \times (1\ \text{kg}/10^6\ \text{mg}) \times (1000\ \text{liters/m}^3) \\ &= 0.0005\ \text{kg/m}^3 \\ E_{tt} &= (0.0005\ \text{kg/m}^3) \times (125{,}000\ \text{m}^3) \\ &= 62.5\ \text{kg TOG} \end{aligned}$$

3. Determine the TOG emissions from gasoline tank trucks in transit and returning with vapor.

$$\begin{aligned} E_{tt} &= EF_{tt} \times F_t \\ EF_{tt} &= (6.5\ \text{mg/liters}) \times (1\ \text{kg}/10^6\ \text{mg}) \times (1000\ \text{liters/m}^3) \\ &= 0.0065\ \text{kg/m}^3 \\ E_{tt} &= (0.0065\ \text{kg/m}^3) \times (125{,}000\ \text{m}^3) \\ &= 812.5\ \text{kg TOG} \end{aligned}$$

Vehicle Refueling (Stage II) and Spillage

Vehicle refueling emissions come from vapors displaced from the automobile tank by dispensed gasoline and from spillage. The quantity of displaced vapors depends on gasoline temperature, auto tank temperature, gasoline Reid vapor pressure (RVP), and dispensing rate. Equation 7.1-5 can be used to estimate uncontrolled displacement losses from vehicle refueling for a particular set of conditions.

$$264.2\ [(-5.909) - 0.0949\ (\Delta T) + 0.0884\ (T_D) + 0.485\ (\qquad (7.1\text{-}5)$$

where:
EF_r = TOG emission factor for vehicle refueling (mg/liter);
ΔT = Difference between temperature of fuel in vehicle tank and temperature of dispensed fuel, °F;
T_D = Temperature of dispensed fuel, °F; and
RVP = Reid vapor pressure, psia.

It is estimated that the uncontrolled emissions from the vapors displaced during vehicle refueling average 1,320 mg/liter of dispensed gasoline (AP-42, 1995). This U.S.-based average value has limited applicability in Mexico and should only be used if no other data are available.

Spillage loss is made up of contributions from prefill and postfill nozzle drip and from spit-back and overflow from the vehicle's fuel tank filler pipe during filling. The amount of spillage loss can depend on several variables, including service station business characteristics, tank configuration, and operator refueling techniques. An average spillage loss is 80 mg/liter of dispensed gasoline (AP-42, 1995). The U.S.-based average value has limited applicability in Mexico and should only be used if no other data are available.

To estimate emissions, the emission factor for vehicle refueling is applied to the total fuel dispensed, as noted in the following equation:

$$E_{rs} = EF_{rs} \times F \qquad (7.1\text{-}6)$$

where:
E_{rs} = Emissions associated with vehicle refueling and spillage (kg/year);
EF_{rs} = Emission factors for refueling and spillage (mg/liter); and
F = Fuel dispensed (liter/year).

DATA NEEDED:

Data	Sources
Fuel dispensed	PEMEX
TOG Emission factors[a] Refueling Emissions Equation 7.1-5 or Uncontrolled: 1320 mg/liter of fuel Controlled: 132 mg/liter of fuel Spillage 80 mg/liter of fuel	AP-42, 1995

[a] Factors are for TOG as well as ROG because the methane and ethane content of gasoline vapors is negligible.

SAMPLE CALCULATION - VEHICLE REFUELING AND SPILLAGE

Assume again that 100,000 m^3 of gasoline (RVP = 10 psia) are dispensed in the inventory region in a given year. Assume that the temperature of the dispensed fuels is 15°C and the temperature of the fuel in the vehicle tank is about 21°C. Finally assume that the U.S.-based average value for spillage loss is applicable.

1. Determine the TOG emission factor for vehicle refueling, using equation 7.1-5.

$$EF_r = 264.2\ [(-5.909) - 0.0949\ (\Delta T) + 0.0884\ (T_D) + 0.485\ (RVP)]$$

$$= 264.2\ [(-5.909) - 0.0949\ (70°F - 59°F) + 0.0884\ (59°) + 0.485\ (10)$$

$$= 822\ \text{mg/liter}$$

$$= 0.822\ \text{kg/m}^3$$

2. Determine the TOG emission factor for spillage.

$$EF_s = 80\ \text{mg/liter}$$

$$= 0.080\ \text{kg/m}^3$$

3. Determine the TOG emissions from vehicle refueling and spillage, using equation 7.1-6.

$$E_{rs} = EF_{rs} \times F$$

$$EF_{rs} = (0.822 \text{ kg/m}^3) + (0.080 \text{ kg/m}^3)$$

$$= 0.902 \text{ kg/m}^3$$

$$E_{rs} = (0.902 \text{ kg/m}^3) \times (100{,}000 \text{ m}^3)$$

$$= 90{,}200 \text{ kg TOG}$$

$$= 90.2 \text{ Mg TOG}$$

7.2 Aircraft Refueling

SOURCE CODE:	**DESCRIPTION**:
22-75-900-000	Refueling: All Fuels

DESCRIPTION:

Gasavión and Turbosina are the most common types of aircraft fuels used in Mexico. Emissions occur when vapor-laden air in a partially empty fuel tank is displaced to the atmosphere when the tank is refilled. The quantity of vapor displaced depends on the fuel temperature, fuel vapor pressure, aircraft fuel tank temperature, and fuel dispensing rate.

Commercial and general aviation aircraft may not contribute enough emissions to be treated as point sources. Their refueling emissions exhibit regional, seasonal, and temporal variations determined by the concentration of air traffic at the airports in the study area (typically located close to urban areas), the airlines' daily schedules, and the travel seasons.

POLLUTANTS: TOG

ROG: ROG emissions are estimated to be 100% of TOG since it is assumed that the fraction of methane and ethane are negligible.

POINT SOURCES:

Some large airports that are point sources may have reported refueling emissions. If so, the emissions included in the point source inventory must be subtracted from the emissions total in order to estimate area emissions.

METHODOLOGY:

Emissions from aircraft refueling can be estimated using fuel sales data by type of fuel multiplied by the corresponding fuel emission factors. Regional, state, and national fuel consumption data are available from PEMEX and ASA. Local fuel sales data may also be obtained either from local airport officials or by apportioning regional-level fuel sales to airports based on flight activities. Emission factors can be developed using the following equation (AP-42, 1995):

$$EF_a = 12.46 \times \frac{SPM}{T} \tag{7.2-1}$$

where:
EF_a = Emission factor in lbs TOG per 1000 gallons fuel throughput;
S = Saturation factor of 1.45 (from Table 7.1-1);
P = True vapor pressure of fuel in psia (Table 7.1-2);
M = Molecular weight of vapors in lb/lb mol (Table 7.1-2); and
T = Temperature of bulk liquid loaded °R.

To estimate emissions the emission factor for aircraft refueling, the aircraft emission factor is applied to the total aircraft fuel dispensed, as noted in the following equation:

$$E_a = EF_a \times F_a \tag{7.2-2}$$

where:
E_a = Total emissions from aircraft refueling (mg/year);
EF_a = Emission factor for aircraft refueling (mg/liter); and
F_a = Aircraft fuel dispensed in inventory areas (liter/year).

DATA NEEDED:

Data	Sources
Aircraft fuel dispensed in inventory area	PEMEX, ASA
TOG Emission factor Equation 7.2-1	AP-42, 1995

SAMPLE CALCULATION:

Assume that 100,000 m^3 of turbosina are used to refuel aircraft in the inventory region in a given year. Assume that the physical properties of turbosina are similar to jet kerosene in the U.S. Finally, assume that average loading temperature is 21°C.

1. Determine the vapor molecular weight and the true vapor pressure.

   Use Table 7.1-2. For jet kerosene, the default value for vapor molecular weight is 130 lb/lb-mol.

The average loading temperature is 21°C or 70°F.
Therefore, the default value for the true vapor pressure is 0.011 psia.

2. Determine the emission factor, using equation 7.2-1:

$$EF_a = 12.46\ \frac{SPM}{T}$$

$$= 12.46 \times \left[\frac{(1.45)\ (0.011)\ (130)}{(70\ +\ 460)}\right]$$

$$= 0.0487\ \text{lb/1000 gal}$$

$$= 0.0058\ \text{kg/1000 liter}$$

$$= 0.0058\ \text{kg/m}^3$$

3. Determine the TOG emissions from these aircraft refueling operations, using equation 7.2-2:

$$E_a = EFa \times F_a$$

$$= (0.0058\ \text{kg/m}^3) \times (100{,}000\ \text{m}^3)$$

$$= 580\ \text{kg TOG}$$

$$= 0.58\ \text{mg TOG}$$

7.3 Liquified Petroleum Gas Distribution

SOURCE CODE:	**DESCRIPTION:**
25-01-210-210*	LPG Storage
25-05-000-210*	LPG Transport

*Proposed Mexico-specific codes for source category not typically inventoried in the U.S.

DESCRIPTION:

In addition to the emissions from the combustion of LPG, emissions due to leaks and evaporation from the storage and distribution systems, represent an important source of pollution that should be considered when developing an area emissions inventory. The Mexican Petroleum Institute (IMP) and researchers from the University of California have identified LPG leaks as a potentially significant source of hydrocarbons emissions. Though some LPG is used by the industrial and commercial/services sectors, in Mexico, LPG is predominately used domestically, principally for cooking food and heating water. This source category addresses emissions from all LPG distribution.

The Metropolitan Zone of the Valley of Mexico (ZMVM) is the largest LPG market in the world with the LPG consumption at 70,000 barrels per day, almost the same as that of gasoline (DDF et al, 1996). The use of LPG for cooking and heating water in Mexico extends throughout all regions, and according to the data from INEGI, about 70% of the residential houses in Mexico use LPG for cooking. Only Chiapas and Oaxaca have less than 50%, where wood and coal predominate.

The distribution and storage of LPG for domestic use in Mexico is principally done via 20-40 kg portable cylinders which are sold from distributor trucks. The empty tanks are collected and refilled at specialized centers. Another form of domestic LPG distribution is done via stationary tanks, usually 300 kg in size, which are filled at the home by special trucks equipped with fill pipes. In Mexico City, 32 independent companies make an estimated 200,000 deliveries a day. Five million steel tanks are installed in the millions of urban homes where they are hooked up with pipes and tubes that may or may not be properly maintained. (Sacramento Bee, 1995a).

LPG, in highly industrialized countries, is primarily made up of propane (at least 95%). In Mexico, a mixture is sold in which propane predominates (60%) but which also contains an appreciable amount of butane, isobutane, propylene, and butylenes (PEMEX, 1996). Since the butanes and olefins are more photochemically reactive than propane, the high photochemical reactivity of Mexico's LPG also contributes to its potential significance as an emission source.

POLLUTANTS: TOG

ROG: ROG emissions are 98.4% of TOG (PEMEX, 1996).

POINT SOURCE ADJUSTMENTS:

Emissions for this source category are generally not included in a point source inventory. However, if any bulk distribution centers are inventoried as point sources, emission from these facilities should be subtracted from the total emissions in order to estimate area source emissions.

METHODOLOGY:

The amount of LPG consumed needs to be determined for the inventory region. If the LPG usage statistics available do not directly correspond to the needs of the inventory effort (e.g., statewide statistics are available but the inventory region includes portion of multiple states; statewide statistics are available, but the inventory requires municipal-level emission estimates), then census data (e.g., population or housing) can be used to apportion the regional data to the smaller geographic area. The sample calculation for residential fuel combustion (commercial fuels) illustrates this procedure.

The expected form of the emission calculation is:

$$\text{Emissions TOG} = (\text{volume of LPG used}) \times (\text{LPG density}) \times (\text{EF [expressed as \%leakage]}) \quad (7.3\text{-}1)$$

DATA NEEDED:

Data	Sources
Total LPG usage in inventory area	PEMEX
Population or Housing Data	INEGI
LPG leakage emission factor - 3.6%	PEMEX, 1996
LPG chemical composition, density	PEMEX

NOTES:

1. The emission factor is based on a study completed for the Metropolitan Zone of Mexico City (PEMEX, 1996):

$$\begin{aligned} \text{EF} &= \text{total LPG emissions/total LPG usage} \\ &= (76{,}414 \text{ tons/yr})/(2{,}136{,}000 \text{ tons/yr}) \\ &= 3.6\% \end{aligned}$$

2. If specific LPG density data are not available, the value from AP-42, 507 g/liter, may be used as a default value (included in Appendix V-B of this document).

3. The high photochemical reactivity of the LPG used in Mexico, combined with the large LPG consumption, means that two types of process changes are being considered. The elimination of a significant part of the leaks in residential and commercial installations, or the enrichment of the LPG with propane. However, there is some risk associated with propane. Because propane has higher bottled pressure than other LPG components, the propane-enriched reformulated LPG would also have a higher bottled pressure than the LPG that is currently used. As a result, it would be necessary to verify that the receiving containers are in good shape and able to withstand the pressure of the new formulation (DDF, et al, 1996).

SAMPLE CALCULATION:

This example shows how to calculate emissions from LPG distribution leaks in the Metropolitan Zone of Mexico City (ZMCM) and is based on fuel usage data obtained to develop fuel combustion emissions for the Mexico City area source inventory (DDF, 1995a). If possible region-specific data should be obtained. In lieu of region-specific data, the following information can be used.

TOG emissions are calculated using the following steps:

1. Determine the amount of LPG use in the ZMCM:

In Oficio GPASI-1511/93, PEMEX reported that the total amount of LPG consumed in the ZMCM in 1993 was 3830.31×10^3 m^3. Based on 1992

PEMEX figures, it was estimated that 13% of the total LPG was used by industry, 7% by commercial/services, and 80% for residential purposes.

2. Determine the LPG distribution emission factor:

From the PEMEX study, the emission factor is 3.6%.

3. Emissions for TOG are then calculated as:

$$
\begin{aligned}
E_{TOG} &= (3830.31 \times 10^6 \text{ liters/yr}) \times (507 \text{ g/liter}) \times (3.6\%) \\
&= 69{,}911 \text{ Mg/yr}
\end{aligned}
$$

8.0 LIGHT INDUSTRIAL/ COMMERCIAL SOURCES

Some light industrial or commercial activities may be too small or too numerous to be included in the point source inventory for a given inventory region. Therefore, these smaller sources need to be included in the area source inventory effort. Inventory guidance for these sources are presented in the following subsections:

- Bakeries;
- Brick Manufacturing;
- Construction Activities;
- Traffic Markings;
- Charbroiling; and
- Street Vendors.

8.1 Bakeries

SOURCE CODE: 23-02-050-000

DESCRIPTION:

Yeast fermentation in bakeries produces hydrocarbon emissions. Other emissions from bakeries due to fuel combustion are not covered in this section; they should be calculated as part of the commercial fuel use category. Bakeries that produce baked goods that are not yeast-leavened will not produce any organic gases from yeast fermentation.

Hydrocarbon emissions from bakeries consist primarily of ethanol that is produced during yeast fermentation. Ethanol is emitted during the fermentation and rising process, as well as during baking. Emissions are from a biological process, and, as is typical with biological processes, emission are dependant on a number of variables, such as the length of rising time for the yeast, the amount of fermentable sugars in the dough and the temperature of fermentation. For an area source inventory, the effort required to collect data about these details is very time consuming compared to the magnitude of emissions.

POLLUTANTS: TOG

ROG: ROG emissions are 100% of TOG.

POINT SOURCE ADJUSTMENTS:

Any bakery included in the point source inventory should be identified, and emission from the yeast fermentation should be subtracted from emissions calculated using the methods described here.

METHODOLOGY:

Emission from this source are calculated using a per capita emission factor developed for the U.S. (Adams, 1992). This source contains a range of emission factors for straight-dough and sponge-dough yeast leavening processes:

Process	Emission Factor (kg TOG/Mg Bread)	Source
Straight-Dough	0.5 kg/Mg	Adams, 1992
Sponge-Dough	5 to 8 kg/Mg	Adams, 1992

Most bakeries use sponge-dough for yeast leavening. So the emission factor was taken from this category. As emission estimates will be higher and thus more conservative with sponge-dough than straight-dough, the lower end of the range of emission factors was chosen. A per capita bread consumption rate of 28.02 kg bread/person was used to determine the following per capita emission factor (source: U.S. Department of Commerce, International Trade Administration).

$$\frac{5\ \text{kg TOG}}{\text{Mg bread}} \times \frac{1\ \text{Mg}}{1{,}000\ \text{kg}} \times \frac{28.02\ \text{kg bread}}{\text{person} - \text{yr}} = 0.14\frac{\text{kg TOG}}{\text{person} - \text{yr}}$$

This U.S.-based emission factor has limited applicability in Mexico and should only be used if no other data are available.

The calculation using the per capita emission factor is:

$$\text{Annual Emissions} = (\text{Population}) \times (\text{Emission Factor}) \qquad (8.1\text{-}1)$$

<u>DATA NEEDED</u>:

Data	Sources
Per capita method:	
Population	INEGI
TOG emission factor 0.14 kg/person-yr	Adams, 1992

<u>NOTES</u>:

1. If national data for production of yeast leavened baked goods are available, then a Mexico specific emission factor can be developed for this source category. To do this, an emission rate per kilogram of bread baked emission factors (5 kg TOG/Mg bread produced) could be used to estimate national emissions from the source category, and the resulting emissions then apportioned by the total national population. It is important to remember, however, that the use of per capita emission factors do not reflect local variations, and bread production data should be for the year of the inventory or similar to that year. Information on production may be available from the Cámara Nacional de la Industria Panificadora. Emissions should be calculated by the following methods:

$$\text{TOG emissions} = \frac{5 \text{ kg TOG}}{\text{Mg bread produced}} \times \frac{\text{Mg bread produced}}{\text{yr}} \qquad (8.1\text{-}2)$$

2. The emission estimates calculated using the bread production method will need to be correctly linked to SNIFF to facilitate reconciliation with the point source inventory.

SAMPLE CALCULATION:

For example, emissions from bakeries in a state with a population of 1,250,000 are:

$$(1{,}250{,}000 \text{ persons}) \times (0.14 \text{ kg/person-yr}) = 175{,}000 \text{ kg/yr}$$

$$= 175 \text{ Mg/yr}$$

If there are large bakeries in the inventory area, and they have been inventoried as point sources, then the emissions assigned to those facilities need to be subtracted from the total calculated above. For example, if the point source emissions are:

- 32 Mg per year for Facility A;
- 11.2 Mg per year for Facility B; and
- 23 Mg per year for Facility C.

Then:

$$\begin{aligned}\text{Area Source Emissions} &= 175 \text{ Mg} - (32 \text{ Mg} + 11.2 \text{ Mg} + 23 \text{ Mg}) \\ &= 108.8 \text{ Mg/yr}\end{aligned}$$

8.2 Brick Manufacturing

SOURCE CODE: 23-05-090-000* Brick Manufacturing

*Proposed Mexico-specific code for source category not typically inventoried in the U.S.

DESCRIPTION:

Numerous small brick kilns are located in some portions of northern Mexico. For example, there are an estimated 200-300 kilns in Ciudad Juárez. Many of these units are domestic operations, making it impractical to include them in point source inventories. Wood is the predominant fuel used to fuel domestic brick kilns. Some use of other waste-derived materials, such as trash or waste solvents, has been reported. In addition, in the Ciudad Juárez area, efforts are being made to try and convince some domestic operators to use LPG.

POLLUTANTS: TOG, CO, NO_x, SO_x, PM

ROG: Adjustment factors for ROG are dependent upon the fuel type. See Sections 4.1 and 4.2 for fuel combustion ROG/TOG adjustment factors.

POINT SOURCE ADJUSTMENTS:

Larger industrial brick manufacturing facilities may be included in a point source inventory. Care should be taken to ensure that there is no double-counting of emissions in the area source inventory.

METHODOLOGY:

The amount of each type of fuel combusted in small brick manufacturing kilns needs to be determined for the inventory region. A special survey effort should be conducted to obtain data on the number of kilns, number of bricks produced per kiln, and the types and amounts of fuels they are consuming.

Emission factors can be found in Chapter 1 of AP-42 (AP-42, 1995) and are included in Appendix V-B of this volume (Note: in AP-42, “TOG” is often referred to as “TOC”). Sections in Chapter 1 cover emissions from commercial fuels, wood, and waste oil. Section 2.5 of AP-42 also includes emission factors for the open burning of crop wastes and tires that could be used to estimate emissions from brick kilns. The use of open burning emission factors, however, would be highly uncertain due to different combustion conditions.

For each fuel type, the quantity of fuel burned by small brick manufacturing kilns is then multiplied by the appropriate emission factors as shown below:

$$\text{Emissions} = \begin{pmatrix} \text{Area Source} \\ \text{Fuel Burned by} \\ \text{Equipment Type A} \end{pmatrix} \times \begin{pmatrix} \text{Emission Factor} \\ \text{for Equipment} \\ \text{Type A} \end{pmatrix} \qquad (8.2\text{-}1)$$

DATA NEEDED:

Data	Sources
Fuel used in inventory region, by fuel type	Survey; engineering judgement (default)
Number of brick kilns in inventory region	Survey; engineering judgement (default)
Fuel characteristics (heat content, wood moisture content)	AP-42, 1995, Appendix A; Technical Handbook (e.g., Marks Mechanical Handbook—see data presented in the sample calculation)
Emission factors by fuel type	AP-42, 1995

NOTES:

1. If region-specific fuel usage quantities are not available, it may be assumed that an average kiln produces 16,000 bricks/day and that it takes approximately 5000 Btu (1260 kcal) to fire one 2.2 kg (4.8 lb) brick (Valenzuela, 1996). Then, for each fuel, usage quantities may be estimated as follows:

$$\text{Amount of fuel burned} = \frac{(\#\ \text{kilns/day}) \times (16{,}000\ \text{bricks/kiln/day}) \times (5{,}000\ \text{kcal/brick})}{(\text{fuel heat content [kcal/fuel unit]})}$$

(8.2-2)

2. For regions where brick manufacturing is a significant activity, it is strongly recommended that a survey be conducted of a representative sample of typical operations. Results from this sample should then be

scaled up to the entire inventory area. See the *Basic Emissions Estimating Techniques* Manual for an outline of the survey procedure.

SAMPLE CALCULATION:

This example is based on calculations developed to estimate emissions from brick manufacturing in the Ciudad Juárez area (Valenzuela, 1996).

(1) Determine the amount of each fuel burned in the brick kilns:

For this example, it is assumed that an average kiln produces 16,000 bricks/day and that it takes approximately 5,000 Btu (1260 kcal) to fire one 2.2 kg (4.8 lb) brick (Valenzuela, 1996). If 10 kilns are fired with yellow pine, then, the quantity of fuel may be estimated as follows:

Amount of yellow pine burned = (# kilns) × (16,000 bricks/kiln/day) × (1,260 kcal/brick) / (fuel heat content [kcal/fuel unit])

= (10 kilns/day) × (16,000 bricks/kiln/day) × (1260 kcal/brick) / (3720 kcal/kg)

= 54,194 kg/day of yellow pine

where the yellow pine fuel content was calculated as follows *(using data from Marks Mechanical Handbook)*:

12% moisture (dry) yellow pine weighs 3,240 lb/cord
50% moisture (green) yellow pine weighs 4,770 lb/cord

12% moisture (dry) yellow pine - 26 × 10^6 Btu/cord
50% moisture (green) yellow pine - 23.7 × 10^6 Btu/cord

Assume wood moisture is 25% on the average; then by interpolation:

25% moisture pine weighs 3,764 lbs/cord
25% moisture pine - 25.2 × 10^6 Btu/cord

or (25.2 × 10^6 Btu/cord)/(3764 lbs/cord) = 6,695 Btu/lb of pine

(2) Identify appropriate emission factors:

Use emission factors from AP-42, Section 1.9-4 developed for residential fireplaces (i.e., wood burning):

PM_{10}	17.3 g/kg
CO	126.3 g/kg
SO_x	0.2 g/kg
NO_x	1.3 g/kg
TOG	114.5 g/kg

$$\begin{aligned} E_{PM10} &= (54{,}194 \text{ kg/day of pine}) \times (17.3 \text{ g/kg}) / (1{,}000 \text{ g/kg}) \\ &= 938 \text{ kg } PM_{10}\text{/day} \end{aligned}$$

$$\begin{aligned} E_{CO} &= (54{,}194 \text{ kg/day of pine}) \times (126.3 \text{ g/kg}) / (1{,}000 \text{ g/kg}) \\ &= 6{,}845 \text{ kg CO/day} \end{aligned}$$

$$\begin{aligned} E_{SO2} &= (54{,}194 \text{ kg/day of pine}) \times (0.2 \text{ g/kg}) / (1{,}000 \text{ g/kg}) \\ &= 11 \text{ kg } SO_x\text{/day} \end{aligned}$$

$$\begin{aligned} E_{NOx} &= (54{,}194 \text{ kg/day of pine}) \times (1.3 \text{ g/kg}) / (1{,}000 \text{ g/kg}) \\ &= 70 \text{ kg } NO_x\text{/day} \end{aligned}$$

$$\begin{aligned} E_{TOG} &= (54{,}194 \text{ kg/day of pine}) \times (114.5 \text{ g/kg}) / (1{,}000 \text{ g/kg}) \\ &= 6{,}205 \text{ kg VOC/day} \end{aligned}$$

8.3 Construction Activities

SOURCE CODE: 23-11-000-000

DESCRIPTION:

Building, road, and other construction activities are a potentially significant source of fugitive PM emissions. These emissions can be generated through a variety of activities, including land clearing, drilling and blasting, ground excavation, earth moving, and actual building construction. Emissions due to construction activities vary by site due to different levels of activity, operations, and meteorological conditions.

This section focuses solely on fugitive PM emissions generated by construction activities. Exhaust and evaporative emissions from construction equipment and vehicles are addressed in Section 5.4 of this manual.

POLLUTANTS: PM_{10}

ROG: Not Applicable

POINT SOURCE ADJUSTMENTS:

None.

METHODOLOGY:

Because of potentially significant differences in Mexican construction practices, it is recommended that Mexico-specific data be collected through surveys. These data can then be used in the development of a multivariate model for Mexican construction activities. Until these data are collected, it is recommended that U.S. emission factors be used to estimate emissions from construction activities.

Until a multivariate emissions model can be developed using Mexico-specific data, the following equation can be used to estimate fugitive dust emissions from overall regional construction activities:

$$\text{Emissions} = \text{Area} \times \text{Time} \times \text{EF} \qquad (8.3\text{-}1)$$

where: Emissions =
Total annual fugitive (PM_{10}) dust emissions;

Area =
Total area of specific construction site;
Time = Total duration of construction activities; and
EF =
Fugitive dust (PM_{10}) emission factor.

Table 8.3-1 presents overall uncontrolled PM_{10} emission factors for seven construction sites located in California and Nevada, as well as the resulting geometric mean. A description of the type and level of construction activity at each of the seven sites is also included.

Table 8.3-1

Summary of Uncontrolled PM_{10} Emission Rates Estimated for Construction Sites[a]

Site	Overall Uncontrolled PM_{10} Emission Factor (Mg/hectare/month)	Construction Type and Activity Level
A	0.072	Industrial - Moderate Activity (trenching, prepaving, small-scale earthmoving)
B	0.72	Residential - Moderate to Heavy Activity (trenching, earthmoving, drilling/blasting, compaction)
C	0.18	Residential - Moderate to Heavy Activity (trenching, prepaving, trucking of road base)
D	0.0087	Residential - Low to Moderate Activity (framing, landscaping)
E	0.90	Residential - Heavy Activity (earthmoving, hauling, stockpiling)
F	0.96	Residential - Heavy Activity (earthmoving)
G	0.76	Commercial - Moderate to Heavy Activity (trenching, trucking of fill material)
Geometric Mean	0.25	

[a] Table derived from MRI, 1996 (pg. 3-2, Table 2; pg. 4-2, Table 3)

It is recommended that the geometric mean emission factor (0.25 Mg PM_{10}/hectare-month) be used. However, other emission factors from the table could be used if the specific construction activity is similar to those included in the table. Because these emission factors represent construction activities in the United States, caution should be exercised when these emission factors are applied in Mexico. Different construction practices and levels of mechanization in Mexico might introduce considerable uncertainty into the emissions estimates.

The emissions estimating methodology presented above is most applicable for regional construction emissions. If emissions need to be estimated for individual sites, then an alternative methodology is presented in AP-42, Table 13.2.3-1 (summarized in MRI, 1996 [pgs. 2-3 through 2-5, Table 1]). This methodology provides different emission factors for several different construction operations (i.e. bulldozing, compacting, land clearing, etc.). These emission factors will provide a more accurate estimate of emissions than the emission factors presented in Table 8.4-1, but more detailed, site-specific data must be collected.

DATA NEEDED:

Data	Sources
Construction Area	Local authorities or the Cámara Nacional de la Industria de la Construcción
Construction Duration	Local authorities or the Cámara Nacional de la Industria de la Construcción
Emission Factor	Table 8.3-1
Site Specific Data (see AP-42, Table 13.2.3-1)	Construction site personnel

SAMPLE CALCULATION:

In 1995, local officials indicated that there were 120 hectares of construction activity. These officials estimated that these areas were under construction for a average period of 2.5 months. The total estimated annual PM_{10} emissions for 1995 are calculated below.

1. Assuming a wide variety of construction types, the geometric mean emission factor of 0.25 Mg/hectare-month seems to be most appropriate.

2. Total PM_{10} emissions:

$$120 \text{ hectares} \times 2.5 \text{ months} \times 0.25 \text{ Mg } PM_{10}/\text{hectare-month} = 75 \text{ Mg } PM_{10}$$

8.4 Charbroiling

SOURCE CODE: 23-02-002-000

DESCRIPTION:

Charbroiling refers to the cooking of meat (typically beef or chicken) over an open flame in which grease is allowed to drip down onto the open flame. This category is limited to commercial charbroiling; charbroiling in the form of residential barbecues is thought to be extremely limited. In Mexico, charbroiling is limited to small-scale restaurants and street vendors. Small-scale restaurants are discussed in this section; street vendors are addressed in Section 8.5. Based upon observations in Nogales, Sonora, beef is usually cooked using LPG and chicken is typically cooked using charcoal.

The primary pollutant of concern for charbroiling is PM_{10}. Virtually all of the PM_{10} emitted from charbroiling is of sub-micron size. Also, a significant amount of the PM emitted consists of organic carbon.

Emissions from charbroiling are dependent upon a number of variables, such as type of fuel used, type of meat charbroiled, fat content of meat, flame temperature. However, until recently, the effects of these variables were not very well quantified. The existing emissions data were primarily limited to charbroiled hamburgers cooked over a natural gas flame, which is a significant fraction of charbroiling that occurs within the United States. Researchers at the University of California Riverside's CE-CERT (College of Engineering Center for Environmental Research and Technology) have recently completed work for the South Coast Air Quality Management District (SCAQMD) which examines the effects of meat type of type on emissions. Preliminary results from this research are presented in Table 8.4-1.

POLLUTANTS: TOG and PM_{10}

ROG: ROG emissions are approximately 100% of TOG (Welch, 1997).

POINT SOURCE ADJUSTMENTS:

With the exception of an industrial meat-cooking facility, emissions from this source category would not be included in a point source inventory. In general, therefore, point source adjustments should not be necessary.

METHODOLOGY:

It is thought that emission factors based on the amount of meat charbroiled are most reliable. Consequently, it is necessary to develop an estimate of the amount of meat charbroiled.

The equation used to estimate emissions from charbroiling is:

$$\text{Emissions}_m = N_m \times A_m \times EF_m \tag{8.4-1}$$

where:

Emissions_m = Emissions for meat type, m;

N_m = Number of charbroiling operations for meat type, m;

A_m = Average amount of meat charbroiled for meat type, m at each charbroiling operation; and

EF_m = Emission factor for meat type, m.

The first step in estimating charbroiler emissions is to determine the number of charbroilers. Local health officials might be able to provide some information relating to the number of restaurants with charbroilers. Because these restaurants usually are concentrated in shopping and commercial districts, rough restaurant counts could be derived from informal surveying.

The amount of meat charbroiled and other related information (fuel use, cooking practices, meat characteristics, etc.) should be estimated through local surveys. Cultural and socio-economic differences between different regions makes the application of another region’s survey data highly uncertain.

Table 8.4-1 presents recently developed charbroiling emission factors. These emission factors may not exactly represent actual charbroiling operations, but emission factors are still somewhat limited. Further refinement and development of charbroiling emission factors is expected in the future.

Table 8.4-1

Charbroiling Emission Factors[a]

Meat Type	PM_{10}[b] (g/kg meat)	TOG[c] (g/kg meat)	Comments
Beef	32.7	3.9	25% fat hamburgers
Chicken	10.4	1.8	Butterflied whole chicken
Fish	3.2	0.4	Atlantic salmon fillets

[a] All emission factors based upon source testing of under-fired charbroilers using natural gas (SCAQMD, 1997).

[b] Virtually all PM_{10} has an aerodynamic diameter < 2.5 μm or less (Welch, 1997).

[c] Original emission factors were for ROG. However, measured methane was near detection limits, so TOG is nearly equivalent to ROG (Welch, 1997)

DATA NEEDED:

Data	Sources
Number of charbroilers	Local health officials or survey data
Average amount of meat charbroiled	Local survey data
Type and amount of fuel	Local survey data
Emission factors	Table 8.4-1 of this section; also see Note 1

SAMPLE CALCULATION:

A certain metropolitan area has 80 restaurants that each charbroil an average of 60 kg of beef per day. Charbroiling operations are assumed to occur on every day of the year. Calculate the annual PM emissions.

$$\text{80 restaurants} \times \text{60 kg meat/day} \times \text{365 days/yr}$$
$$\times\ 32.7\ \text{g } PM_{10}/\text{kg meat} = 57{,}290\ \text{kg } PM_{10} = 57.3\ \text{Mg } PM_{10}/\text{yr}$$

NOTES:

1. Charbroiling emissions are mainly dependent upon the flame temperature at the flame-meat interface. Higher flame temperatures result in higher emissions. Although the CE-CERT research did not examine the effects of different fuels, previous research on residential barbecues has indicated that fuels with higher flame temperatures (i.e., natural gas or propane) have higher emissions than fuels with lower flame temperatures (i.e., charcoal) (Welch, 1997).

8.5 Street Vendors

SOURCE CODE: 23-02-002-005*

*Proposed Mexico-specific code for source category not typically

DESCRIPTION:

Street vendors sell a variety of food products in commercial and shopping districts. Street vendors typically sell their food products out of portable carts that are moved from place to place. Many of the street vendor operations do not produce emissions. However, some street vendors charbroil meat which can be a significant source of TOG and PM_{10}. LPG appears to be the fuel of choice for street vendor charbroiling. For a more detailed discussion of charbroiling, refer to Section 8.4.

POLLUTANTS: TOG and PM_{10}

ROG: ROG emissions are approximately 100% of TOG (Welch, 1997).

POINT SOURCE ADJUSTMENTS: None

METHODOLOGY:

The methodology used to estimate emissions from street vendor charbroiling is identical to that for general restaurant charbroiling. See Section 8.4 for details.

DATA NEEDED:

Data	Sources
Number of street vendor charbroilers	Local health officials or survey data
Average amount of meat charbroiled	Local survey data
Type and amount of fuel	Local survey data
Emission factors	Table 8.4-1 of Section 8.4; also see Note 1 of Section 8.4

SAMPLE CALCULATION:

A certain metropolitan area has 140 street vendors that each charbroil an average of 25 kg of beef per day. Charbroiling operations are assumed to occur on every day of the year. Assuming the beef PM_{10} emission factor presented in Table 8.4-1, calculate the annual PM emissions.

140 street vendors × 25 kg meat/day × 365 days/yr
× 32.7 g PM/kg meat = 41,774 kg PM = 41.8 Mg PM_{10}/yr

9.0 AGRICULTURE

Most agricultural emission sources may be too small or too numerous to be included in the point source inventory for a given inventory region. Therefore, these sources need to be included in the area source inventory effort. Inventory guidance for these sources are presented in the following subsections:

- Pesticide Application;
- Beef Cattle Feedlots;
- Agricultural Burning;
- Fertilizer Application;
- Animal Waste; and
- Agricultural Tilling.

9.1 Pesticide Application

SOURCE CODE: 24-61-850-000

DESCRIPTION:

Pesticides are used to kill or retard the growth of insects, weeds, or other pests. Most air emissions from pesticide use primarily occur because of the volatile nature of the active ingredients, carrier solvents, and other chemicals in pesticide formulations. Volatilization of pesticides can occur both during application and for some time after application. Some pesticide formulations are dusts, granules, or powders. These dry formulations can result in particulate emissions. However, particulate emission factors have not been developed due to insufficient data. The following discussion is limited to emissions due to hydrocarbon-based pesticide volatilization.

Volatile pesticides usually are applied as liquid formulations, such as solutions, emulsions, or aerosols. In general, volatile pesticides consist of an “active” ingredient and various “inert” ingredients. The terms “active” and “inert” do not refer to photochemical activity; rather, they are a measure of compound toxicity. The active and inert fractions can vary depending upon the specific type of pesticide application.

The volatility of active ingredients can also be quite variable. Volatilization is typically assumed to occur during the first 30 days after application. After approximately 30 days, degradation and surface runoff become the primary removal mechanisms for pesticides. Laboratory and field research indicates that active ingredient volatility appears to be dependent on three major parameters: the physical and chemical properties of the active ingredient, local meteorological conditions, and soil adsorption. Additional discussion about the effects of these three parameters can be found in Section 9.2.2.3 of AP-42 (AP-42, 1995).

Most pesticides are not applied at full concentration (i.e., direct application of the pure form of the active ingredient); rather, the active ingredient is mixed with an inert “carrier”. Sometimes, water is used as the carrier for liquid pesticide formulations. However, many of the inert carriers used in pesticides are volatile organic liquids and gases. It is assumed that 100 percent of the volatile inert carriers volatilize within 30 days of application.

In addition to the synthetic organic pesticides described above, petroleum distillates are sometimes used in weed, fungus, and insect control applications.

When petroleum distillates are used, it is assumed that 100 percent of the distillates volatilize.

POLLUTANTS: TOG

ROG: ROG emissions are 100% of TOG.

POINT SOURCE ADJUSTMENTS:

None.

METHODOLOGY:

For synthetic organic pesticides,

$$\text{Emissions}_i = (\text{Usage}_i \times \%\text{active}_i \times \text{EF}_i) + (\text{Usage}_i \times \%\text{inert}_i \times \%\text{V}_i) \qquad (9.1\text{-}1)$$

where:

Emissions_i = Total annual TOG emissions from pesticide, i;
Usage_i = Total annual usage of pesticide, i;
$\%\text{active}_i$ = Percentage of active ingredients in pesticide, i;
EF_i = Emission factor for active ingredients in pesticide, i;
$\%\text{inert}_i$ = Percentage of inert ingredients in pesticide, i (100% - $\%\text{active}_i$); and
$\%\text{V}_i$ = Volatile content of inert fraction of pesticide, i.

The emission factor used in the above equation depends upon the vapor pressure of the specific active ingredients and the method of pesticide application. Emission factors for surface application and soil incorporation are presented in Table 9.1-1. Emission factors are not available for aerial application of pesticides. Current research indicates that volatilization is small compared to drift effects in aerial applications.

For petroleum distillates,

$$\text{Emissions}_i = \text{Usage}_i \qquad (9.1\text{-}2)$$

Table 9.1-1

Uncontrolled Emission Factors for Pesticide Active Ingredients[a]

Type of Application	Vapor Pressure Range (mm Hg at 20 to 25 °C)[b]	Emission Factor (kg/Mg)[c]
Surface Application	1×10^{-4} to 1×10^{-6}	350
	$> 1 \times 10^{-4}$	580
Soil Incorporation	$< 1 \times 10^{-6}$	2.7
	1×10^{-4} to 1×10^{-6}	21
	$> 1 \times 10^{-4}$	52

[a] Table modified from AP-42, Table 9.2.2-4.

[b] Vapor pressures of some specific active ingredients can be found in AP-42, Table 9.2.2-1. For other active ingredients, pesticide reference materials should be consulted.

[c] Emission factors expressed as equivalent weight of active ingredients volatilized per unit weight of active ingredients applied.

The above method provides an accurate estimate of emissions from pesticide application. However, if the data listed in the table below are not available, a conservative, but less accurate, method can be used. The conservative approach is to assume that 100 percent of the applied pesticide volatilizes. This will result in an overestimation of emissions, but it is a reasonable alternative method if detailed data are not available.

DATA NEEDED:

Data	**Sources**
Annual Pesticide Usage (by specific formulation)	Local SAGAR/CICOPLAFEST office
Method of Application	Local SAGAR/CICOPLAFEST office
Types of Active Ingredients in Formulation	Pesticide container, pesticide manufacturer, end-use formulator, or local distributor. Active ingredients for common trade name pesticides provided in AP-42, Table 9.2.2-2. Also, *Farm Chemicals Handbook - 1992*. (Meister, 1992)
Vapor Pressures of Active Ingredients	Some vapor pressures provided in AP-42, Table 9.2.2-1. Additional vapor pressures in Wauchope et al., 1992.
Type of Formulation (e.g., emulsion, solution, granules, etc)	Pesticide container, pesticide manufacturer, end-use formulator, or local distributor.
Percentage of Active and Inert Ingredients	Pesticide container, pesticide manufacturer, end-use formulator, or local distributor.
Volatile Content of Inert Ingredients	Pesticide manufacturer or end-use formulator. Also, estimated average volatile contents provided in AP-42, Table 9.2.2-3.

SAMPLE CALCULATION:

5,000 kg of Lazo® have been surface applied to cropland for weed control, and an estimate is desired of the total quantity of emissions within 30 days after application.

1. The active ingredient in Lazo® is alachlor (AP-42 [Table 9.2.2-2] or *Farm Chemicals Handbook - 1992*). The pesticide container states that the formulation is an emulsion consisting of 41% active ingredient and 59% inert ingredient.

2. Total quantity of active ingredient applied:

   $0.41 \times 5{,}000 \text{ kg} = 2{,}050 \text{ kg}$ of alachlor applied

3. From AP-42, Table 9.2.2-1, the vapor pressure of alachlor is 1.4×10^{-5} millimeters (mm) mercury between 20 and 25 °C. From AP-42, Table 9.2.2-4, this corresponds to an emission factor of 350 kg active ingredient volatilized per Mg of active ingredient applied. So, the total quantity of active ingredient volatized is given by:

   2.05 Mg × (350 kg/Mg) = 718 kg of alachlor volatilized within 30 days of application

4. From AP-42, Table 9.2.2-3, it can be determined that the average volatile content of the inert portion of emulsions (emulsible concentrates) is 56 percent.

   Total quantity of emissions from inert ingredients:

   5,000 kg × 0.59 × 0.56 = 1,652 kg of volatile inert ingredients (100% of the volatile inert ingredients is assumed to volatilize within 30 days of application)

5. The total quantity of emissions during the 30 days after application is the sum of emission from active ingredients and inert ingredients. In this example, the emissions are:

   718 kg (active ingredients) + 1,652 kg (volatile inert ingredients) = 2,370 kg

9.2 Beef Cattle Feedlots

SOURCE CODE: 28-05-001-000

DESCRIPTION:

Beef cattle feedlots and stock yards are areas used for fattening or holding cattle prior to marketing or transfer to another location. The fattening process typically consists of feeding cattle a high energy ration of feed grains for a period of four or five months. Feedlots and stock yards can be a significant source of fugitive particulate matter. The primary generation mechanism is cattle movement over soil dust and dried manure. Vehicle traffic and wind action in the vicinity of the feedlot can also contribute to particulate emissions. Similar emissions are not expected to occur when cattle are put out to pasture for grazing because there will be minimal concentrated manure accumulation and disturbed surface area.

Ammonia emissions are also generated by beef cattle through the anaerobic decomposition of manure on feedlot surfaces, as well as volatilization from urine. Ammonia emissions from beef cattle will be addressed in the section on livestock waste (Section 9.5).

POLLUTANTS: PM_{10}

ROG: Not Applicable.

POINT SOURCE ADJUSTMENTS: None.

METHODOLOGY:

Feedlot emissions can be estimated using the following equation based on feedlot throughput:

$$\text{Emissions} = \text{Throughput}_{\text{Cattle}} \times \text{EF}_{\text{Throughput}} \qquad (9.2\text{-}1)$$

where: Emissions = Total annual PM_{10} emissions;
$\text{Throughput}_{\text{Cattle}}$ = Annual cattle throughput; and
$\text{EF}_{\text{Throughput}}$ = PM_{10} emission factor based on annual throughput.

Alternatively, feedlot emissions can be estimated using the following equation based on feedlot capacity:

$$\text{Emissions} = \text{Cattle} \times \text{Days} \times EF_{\text{Capacity}} \qquad (9.2\text{-}2)$$

where:
Emissions = Total annual PM_{10} emissions;
Cattle = Average number of cattle present in feedlot;
Days = Annual number of days that cattle are in feedlot;
EF_{Capacity} = PM_{10} emission factor based on average capacity.

DATA NEEDED:

Data	Sources
PM_{10} Emission Factor[a] 12.0 Mg/1000 head throughput (13.0 tons/1,000 head throughput)	AP-42, 1985
PM_{10} Emission Factor[a] 62.4 kg/day-1000 head capacity (134.4 lbs/day-1,000 head capacity)	AP-42, 1985
Annual Cattle Throughput	SAGAR, INEGI, or local feedlots
Average Number of Cattle in Feedlot	SAGAR, INEGI, or local feedlots
Number of Days Cattle are in Feedlot	SAGAR, INEGI, or local feedlots

[a] AP-42 emission factors are actually given for PM. Air Resource Board (ARB) documents indicate that 48% of PM from beef cattle feedlots is PM_{10} (ARB, 1995).

NOTES:

1. All emission factors assume that no housekeeping measures for air pollution control are implemented. Normal housekeeping measures to prevent unacceptable quantities of manure typically are used at most feedlots and stockyards.

2. Current emission factors are highly uncertain. U.S. EPA is currently conducting research on this source category. Improved emission factors should be available in the future, but none were available as of March 1997. Improved emission factors will eventually be presented in Section 9.4.1 of AP-42.

SAMPLE CALCULATION:

A beef cattle feedlot indicated an annual throughput of 23,200 head of cattle.

1. Total amount of PM_{10} emissions for this feedlot:

   23,200 head × (12.0 Mg/1,000 head throughput) = 278 Mg PM_{10}

9.3 Agricultural Burning

SOURCE CODE: 28-01-500-000

DESCRIPTION:

Agricultural burning refers to the burning of field crops, wood, and leaves associated with agricultural activities. In Mexico, agricultural burning is mainly limited to the burning of crop remains in order to prepare the agricultural fields for new crops. Agricultural burning is permitted in Mexico, provided that prior notification has been given to SEMARNAP or SAGAR. All agricultural burning should conform with NOM-EM-003-SEMARNAP/ SAGAR-1996.

Emissions from agricultural burning are dependent upon several different factors. Some primary factors include type of crop, fuel loading (how much organic material per unit of land area), and type of burning (headfire or backfire). Headfires are started at the upwind side of a field and allowed to progress in the direction of the wind; backfires are started at the downwind side of a field and forced to progress in a direction against the wind. Other factors that can affect emissions include moisture content and arrangement of the organic material to be burned. Additional discussion concerning these factors can be found in Section 2.5.2.3 of AP-42 (AP-42, 1995).

POLLUTANTS: TOG, CO, and PM

ROG: ROG emissions are 72.2% of TOG.

POINT SOURCE ADJUSTMENTS: None.

METHODOLOGY:

$$\text{Emissions}_c = \text{Area}_c \times \text{Fuel Load}_c \times \text{EF}_c \tag{9.3-1}$$

where:
Emissions_c = Total annual emissions from crop type, c;
Area_c = Total area burned of crop type, c;
Fuel Load_c = Average fuel loading for crop type, c; and
EF_c = Emission factor for crop type, c.

The Secretary of Agriculture, Livestock, and Rural Development (SAGAR) keeps statistics on the amount of area cultivated for various crops. This information can be obtained from the state level SAGAR offices. INEGI also compiles and publishes some of this agricultural information. However, SAGAR currently does not have any information on the amount or method of agricultural burning that occurs. As NON-EM-003-SEMARNAP/SAGAR-1996 is implemented, it is expected this type of information will become available from SAGAR. Until that time, this type of information will need to be collected on the local level.

The emission factor used in the above equation mainly depends upon the crop type and the type of burning. Emission factors for agricultural burning can be found in Table 2.5-5 of AP-42. The following types of burning are given: unspecified field crops, specific field crops (headfire, backfire, and independent of headfire/backfire), vine crops, weeds, orchard crops, and forest residues. These groups are broken down further into specific crop types (e.g., orchard crops include avocado, citrus, fig, olive, etc.). Table 2.5-5 of AP-42 also includes different fuel loading factors for each crop type.

It must be noted that the agricultural burning emission factors and fuel loading factors presented in AP-42 were developed in the United States. Mexican agricultural practices that are significantly different and other factors may result in different emission factors and fuel loading factors. An example of different fuel loading factors within the United States can be found in footnote “i” of Table 2.5-5 of AP-42. The sugar cane fuel loading factor for Louisiana is given as 8-13.6 Mg/hectare, while the fuel loading factor for Hawaii is given as 30-48 Mg/hectare. These fuel loading factors are significantly different due to differences in climate and/or agricultural practices. Instead of relying upon the fuel loading factors presented in AP-42, Mexico-specific fuel loading factors should be developed whenever possible. This will require performing field studies to determine the amount (i.e., weight) of crop residue present per unit of land area.

DATA NEEDED:

Data	Sources
Agricultural Area Burned (by crop type)	Local data collection
Fuel Loading Factor	Local data collection, U.S. values presented in AP-42, Table 2.5-5
Emission Factor	AP-42, Table 2.5-5

NOTES:

1. Particulate emission factors are presented as total particulate. Research has indicated that particulate matter from most agricultural burning is in the submicrometer range. Therefore, total particulate can be assumed to be equivalent to PM_{10}.

2. TOG emission factors are presented separately as non-methane TOG and methane emission factors. The overall TOG emission factor can be calculated by adding the non-methane TOG and methane emission factors together.

SAMPLE CALCULATION:

Local officials indicate that approximately 75% of the 120 hectares of melon fields are burned after harvest. Calculate the amount of CO emissions from this agricultural burning.

1. Total area burned:

   120 hectares × 0.75 = 90 hectares of fields burned

2. From Table 2.5-5 of AP-42, the fuel loading factor for melons (vine crops) is 5.6 Mg/hectare. However, this agricultural region practices more concentrated cultivation. Consequently, a hypothetical region-specific fuel loading factor of 7.8 Mg/hectare will be used.

3. The CO emission factor for vine crops from Table 2.5-5 of AP-42 is 26 kg/Mg of agricultural waste.

4. Total CO emissions:

   90 hectares × (7.8 Mg waste/hectare) × (26 kg/Mg waste)
   = 18,252 kg CO
   = 18.3 Mg CO

9.4 Fertilizer Application

SOURCE CODE:	**DESCRIPTION:**
28-01-700-001	Anhydrous Ammonia
28-01-700-002	Aqua Ammonia (Ammonia in Solution)
28-01-700-003	Nitrogen Solutions
28-01-700-004	Urea
28-01-700-005	Ammonium Nitrate
28-01-700-006	Ammonium Sulfate
28-01-700-007	Ammonium Thiosulfate
28-01-700-008	Other Straight Nitrogen
28-01-700-009	Ammonium Phosphates
28-01-700-010	N-P-K (Nitrogen[N]-Phosphorus[P]-Potassium[K] Mixtures)

DESCRIPTION:

Fertilizers are used extensively to add or replenish nutrients that are depleted or otherwise missing from agricultural soil. Because of the large number of soil and crop types, many different types of fertilizers have been formulated. After application, the nitrogen-based fertilizers release ammonia to the atmosphere. The amount of ammonia emissions is dependent upon the type of fertilizer applied and is typically expressed as some percent of the nitrogen content of the fertilizer.

The development of ammonia emission factors for fertilizer application is still in its beginning stages. Some generalized emission factors have been developed, however, there are many influencing factors that have not been adequately addressed in these generalized emission factors. These influencing factors include meteorological conditions, soil properties, application technique (surface or subsurface), and application cycles.

POLLUTANTS: NH_3

ROG: Not applicable

POINT SOURCE ADJUSTMENTS: None.

METHODOLOGY:

Ammonia emissions from fertilizer application can be estimated using the following equation:

$$\text{Emissions}_f = \text{Use}_f \times \%\text{N}_f \times \text{EF}_f \qquad (9.4\text{-}1)$$

where:

Emissions_f = Total annual NH_3 emissions for fertilizer type, f;
Use_f = Total annual use of fertilizer type, f;
$\%\text{N}_f$ = Nitrogen content of fertilizer type, f; and
EF_f = Emission factor for fertilizer type, f.

DATA NEEDED:

Data		Sources
Annual Fertilizer Usage (by fertilizer type)		Local SAGAR/CICOPLAFEST Office
Nitrogen Content (by fertilizer type)		Local SAGAR/CICOPLAFEST Office
NH_3 Emission Factors		Battye et al., 1994
Anhydrous Ammonia	12 kg NH_3/Mg total N	
Aqua Ammonia	12 kg NH_3/Mg total N	
Nitrogen Solution	30 kg NH_3/Mg total N	
Urea	187 kg NH_3/Mg total N	
Ammonium Nitrate	25 kg NH_3/Mg total N	
Ammonium Sulfate	97 kg NH_3/Mg total N	
Ammonium Thiosulfate	30 kg NH_3/Mg total N	
Other Straight Nitrogen	30 kg NH_3/Mg total N	
Ammonium Phosphates	48 kg NH_3/Mg total N	
N-P-K	48 kg NH_3/Mg total N	

NOTES:

1. U.S. EPA is currently developing fertilizer application ammonia emission factors. As of March 1997 these factors were unavailable. These factors will eventually be presented in Section 9.2.1 of AP-42. It is expected that some of the emission factors presented above will be included in the AP-42 documentation.

SAMPLE CALCULATION:

It has been reported that 42 Mg of N-P-K have been applied to melon fields in a certain region. The N-P-K fertilizer has a total nitrogen content of 32%. What are the resultant NH_3 emissions?

1. Total NH_3 emissions from N-P-K fertilizer:

$$(42 \text{ Mg N-P-K}) \times (0.32 \text{ Mg total N/Mg N-P-K}) \times$$
$$(48 \text{ kg } NH_3\text{/Mg total N}) = 645 \text{ kg } NH_3$$

9.5 Animal Waste

SOURCE CODE:	**DESCRIPTION:**
Cattle and Calves	
28-05-020-001	Beef cows
28-05-020-002	Milk cows
28-05-020-003	Heifers (Beef cow replacements)
28-05-020-004	Heifers (Milk cow replacements)
28-05-020-005	Heifers (Other)
28-05-020-006	Steers
28-05-020-007	Bulls
28-05-020-008	Calves
Hogs and Pigs	
28-05-025-011	Breeding sows (> 50 kg)
28-05-025-011	Breeding sows (20-50 kg)
28-05-025-021	Market hogs (< 27.2 kg)
28-05-025-022	Market hogs (27.2-54.0 kg)
28-05-025-023	Market hogs (54.1-81.2 kg)
28-05-025-024	Market hogs (> 81.3 kg)
Chickens	
28-05-030-001	Mother animals (> 6 months)
28-05-030-002	Laying hens (> 18 weeks)
28-05-030-003	Mother animals (< 6 months)
28-05-030-004	Laying hens (< 18 weeks)
28-05-030-005	Other chickens
28-05-030-006	Broilers
Other Poultry	
28-05-035-001	Ducks
28-05-035-002	Turkeys
28-05-035-003	Turkeys (< 7 months)
28-05-035-004	Turkeys (> 7 months)
28-05-035-005	Turkeys (fryer-roaster)
Miscellaneous Farm Animals	
28-05-040-000	Sheep and Lambs
28-05-045-001	Goats
28-05-045-004	Rabbit
27-10-020-030	Horses

DESCRIPTION:

Livestock and other domesticated farm animals are a significant source of ammonia emissions. In some locations, they constitute the largest single source of ammonia emissions. Ammonia emissions from livestock animals result from the conversion of excreted nitrogen to ammonia and its subsequent volatilization. It is thought that nitrogen contained in livestock urine is easily converted to and emitted as ammonia. In contrast, ammonia emissions from manure typically require considerable decomposition.

The magnitude of livestock ammonia emissions is dependent upon many factors. These factors include type of livestock, animal size and weight, manure storage practices, nitrogen content of livestock feed, and meteorology. In additional, there are a large number of environmental factors that govern the rate of manure decomposition. Because livestock ammonia emissions are dependent upon a wide range of environmental variables, it is quite difficult to establish an accurate set of emission factors. The emission factors presented below represent current recommended emission factors for regional-scale emission inventories.

Additional emission factors for specialized livestock sources (i.e. dairies, slaughterhouses, etc.) have been developed. Two references for these are presented in the **NOTES**.

POLLUTANTS: NH_3

ROG: Not Applicable

POINT SOURCE ADJUSTMENTS: None.

METHODOLOGY:

Ammonia emissions from livestock and other domesticated farm animals can be estimated using the following equation:

$$\text{Emissions}_a = \text{Population}_a \times \text{EF}_a \times \text{RT}_a \tag{9.5-1}$$

where:

Emissions_a = Total annual NH_3 emissions for animal type, a;

Population_a = Total livestock population for animal type, a; and

EF_a = NH_3 emission factor for animal type, a; and

RT_a = Livestock residence time for animal type, a, as a fraction of a year.

DATA NEEDED:

Data		Sources
Livestock Populations		Local SAGAR office. INEGI statistics may also be useful.
Livestock Residence Time		Local SAGAR office.
Emission Factors		Battye et. al, 1994
Beef Cows	39.7 kg NH_3/head-yr	
Milk Cows	39.7 kg NH_3/head-yr	
Heifers (Beef Cow Replacements)	15.2 kg NH_3/head-yr	
Heifers (Milk Cow Replacements)	13.0 kg NH_3/head-yr	
Heifers (Other)	13.0 kg NH_3/head-yr	
Steers	8.2 kg NH_3/head-yr	
Bulls	27.9 kg NH_3/head-yr	
Calves	5.2 kg NH_3/head-yr	
Breeding Sows (> 50 kg)	16.1 kg NH_3/head-yr	
Breeding Sows (20-50 kg)	5.2 kg NH_3/head-yr	
Market Hogs (< 27.2 kg)	7.0 kg NH_3/head-yr	
Market Hogs (27.2-54.0 kg)	7.0 kg NH_3/head-yr	
Market Hogs (54.1-81.2 kg)	11.0 kg NH_3/head-yr	
Market Hogs (> 81.3 kg)	11.0 kg NH_3/head-yr	
Chickens (Mother Animals > 6 months)	0.60 kg NH_3/head-yr	
Chickens (Laying Hens > 18 weeks)	0.31 kg NH_3/head-yr	
Chickens (Mother Animals < 6 months)	0.27 kg NH_3/head-yr	
Chickens (Laying Hens < 18 weeks)	0.17 kg NH_3/head-yr	
Other Chickens	0.18 kg NH_3/head-yr	
Broilers	0.17 kg NH_3/head-yr	
Ducks	0.12 kg NH_3/head-yr	
Turkeys	0.86 kg NH_3/head-yr	
Turkeys (< 7 months)	0.89 kg NH_3/head-yr	
Turkeys (> 7 months)	1.3 kg NH_3/head-yr	
Turkeys (fryer-roaster)	0.86 kg NH_3/head-yr	
Sheep and Lambs	3.4 kg NH_3/head-yr	
Goats	6.4 kg NH_3/head-yr	
Rabbits	2.8 kg NH_3/head-yr	
Horses	12.2 kg NH_3/head-yr	

NOTES:

1. Specialized ammonia emission factors have been developed for southern California dairies (Schmidt and Winegar, 1996). Per animal emission factors were developed for individual unit processes, as well as overall

dairy averages. It is uncertain how applicable these emission factors would be for Mexican dairies.

2. Specialized ammonia emission factors have been developed for U.S. beef and chicken processing plants (Radian, 1995). Emission factors are given in terms of number of animals processed per day, amount of meat processed per day, amount of discharged wastewater, and amount of effluent ammonia or BOD (biological oxygen demand). It is uncertain how applicable these emission factors would be for Mexican meat processing plants.

SAMPLE CALCULATION:

A certain region has a year-round livestock population of 25,000 beef cows and 5,000 bulls. For three months of the year, 15,000 sheep are brought into the region for grazing. Calculate the total NH_3 emissions.

1. Total emissions from 25,000 beef cows:

   25,000 beef cows × (39.7 kg NH_3/head-yr) × 1.0 = 992,500 kg NH_3/yr

2. Total emissions from 5,000 bulls:

   5,000 bulls × (27.9 kg NH_3/head-yr) × 1.0 = 139,500 kg NH_3/yr

3. Total emissions from 15,000 sheep:

   15,000 sheep × (3.4 kg NH_3/head-yr) × 0.25 = 12,750 kg NH_3/yr

4. Total livestock emissions:

   992,500 kg NH_3/yr + 139,500 kg NH_3/yr + 12,750 kg NH_3/yr
   = 1,144,750 kg NH_3 = 1,145 Mg NH_3

9.6 Agricultural Tilling

SOURCE CODE: 28-01-000-003

DESCRIPTION:

Fugitive dust from agricultural operations can be a significant contributor of PM_{10} emissions in some rural areas. Agricultural operations are typically divided into three classifications: soil preparation, soil maintenance, and crop harvesting. The agricultural tilling source category focuses primarily on soil preparation. Soil preparation includes such operations as plowing, harrowing, leveling, and dicing.

POLLUTANTS: PM_{10}

ROG: Not applicable

POINT SOURCE ADJUSTMENTS: None.

METHODOLOGY:

To estimate emissions from agricultural tilling, the following equation derived from AP-42 and the Air Resources Board's *Emission Inventory Procedural Manual* (ARB, 1995) is used:

$$\text{Emissions}_c = 5.38(s)^{0.6} \times k \times HP_c \times \text{Area}_c \qquad (9.6\text{-}1)$$

where:

Emissions_c = Annual PM_{10} emissions for crop type, c;
$5.38(s)^{0.6}$ = Base emission factor (kg PM/hectare-pass);
k = Particle size multiplier (0.21 for PM_{10} from AP-42);
s = Silt content (%) - (see **NOTE** #2);
HP_c = Number of hectare-passes per hectare for crop type, c; and
Area_c = Total cultivated area for crop type, c.

The first term of the equation is taken from Section 11.2.2 of the 4th Edition of AP-42 (AP-42, 1993). This term is used to estimate emissions from a specific operation.

The second term of the equation (the number of hectare-passes per hectare) is used to account for the multiple tilling operations that are used for most crop types. The number of hectare-passes per hectare is calculated by multiplying the number of typical tilling operations by the percent of agricultural land that is actually tilled. For most types of field crops, 100% of the land is tilled. However, for orchard crops, a smaller fraction (5-20%) of the area is tilled. Table II of Section 7.4 in ARB's *Emission Inventory Procedural Manual* presents some typical values for the number of tilling operations and the percent of cultivated area actually tilled for various crop types. These values, however, represent California agricultural practices. Because Mexican agricultural practices might be significantly different, it is recommended that Mexico-specific data be developed.

Although a default value (18%) is available for the silt content, region-specific data are highly desirable. Appendices C.1 and C.2 of AP-42 provide procedures for determining silt content.

DATA NEEDED:

Data	Sources
Silt Content of Soil	Site specific measurements, INEGI, or Instituto de Geología of the Universidad Nacional Autónoma de Mexico (UNAM)
Agricultural Area Under Cultivation	SAGAR or local agricultural officials
Number of Yearly Operations	SAGAR or local agricultural officials; California values presented in Emission Inventory Procedural Manual
Percentage of Land Area Tilled	SAGAR or local agricultural officials; California values presented in Emission Inventory Procedural Manual

NOTES:

1. The methodology presented above (particularly the $5.38(s)^{0.6}$ factor) is based on limited data. U.S. EPA is currently revising its methodology for estimating emissions from agricultural tilling. When completed, this methodology will appear in Section 9.1 of the 5th Edition of AP-42.

2. The default value for silt content is 18%. Equation 8.12-1 is valid for silt contents ranging from 1.7% to 88%.

3. Some researchers believe that agricultural tilling emissions are not solely a function of silt content as described above. Instead, they believe there are other parameters that would better describe the emission mechanisms for agricultural tilling. Data collection and statistical analysis for new emission factors are currently being conducted by research personnel at the Crocker Nuclear Laboratory at the University of California at Davis (Ashbaugh, 1996).

4. Current research indicates that agricultural tilling emissions vary depending upon the type of crop and tilling implement. For instance, concentrations of respirable dust (50% of the particles have an aerodynamic diameter of 4 microns or less) sampled at the implement level revealed that soil ripping results in concentrations that are 31 times greater than for dicing of corn stubble. Also, concentrations from dicing of wheat stubble is 7.5 times greater than that for dicing of corn stubble. Agricultural tilling emissions may also be influenced by various environmental factors such as soil moisture and wind speed. Further research is currently being conducted in an attempt to try and quantify these factors (Clausnitzer and Singer, 1996).

<u>SAMPLE CALCULATION</u>:

A certain agricultural area has a soil silt content of 20%. The two main crops produced in this region are cotton and oranges. There are 110 hectares of cotton and 35 hectares of oranges. It is determined from local agricultural practices that 100% of the land used for cotton is tilled 5 times per year and that 15% of the land used for oranges is tilled 3 times per year. What are the annual PM_{10} emissions?

1. Hectare passes per hectare for cotton are:

   $5 \times 100\% = 5$

2. Hectare passes per hectare for oranges are:

   $3 \times 15\% = 0.45$

3. Annual PM_{10} emissions from cotton are:

$$5.38\ (20)^{0.6}\ (\text{kg PM}_{10}/\text{hectare-pass}) \times 0.21 \times 5\ (\text{hectare-pass/hectare}) \times 110\ \text{hectares} = 3{,}750\ \text{kg}$$

4. Annual PM_{10} emissions from oranges are:

$5.38\ (20)^{0.6}$ (kg PM_{10}/hectare-pass) × 0.21 × 0.45 (hectare-pass/hectare) × 35 hectares = 107 kg

5. Total annual PM_{10} emissions from agricultural tilling are:

3,750 kg + 107 kg = 3,856 kg PM_{10} = 3.86 Mg PM_{10}

10.0 WASTE MANAGEMENT

Some waste management emission sources may be too small or too numerous to be included in the point source inventory for a given inventory region. Therefore, these sources need to be included in the area source inventory effort. Inventory guidance for these sources are presented in the following subsections:

- On-Site Incineration;
- Open Burning;
- Wastewater Treatment; and
- Open Channel Sewage and Wastewater.

10.1 On-Site Incineration

SOURCE CODE:	**DESCRIPTION:**
26-01-000-000	All Categories
26-01-020-000	Commercial/Institutional
26-01-030-000	Residential

DESCRIPTION:

On-site incineration is the confined burning of trash and other refuse. Open burning of these materials is addressed in Section 10.2 of this manual. Municipal waste, hazardous waste, or industrial incinerators are usually classified as point sources and fall under federal jurisdiction. These incinerators will not be addressed in this section. Only commercial, institutional, and residential on-site incineration devices are included in this section. Direct statistics related to on-site incineration are not readily available in Mexico because it is not a widespread activity. However, the material balance method described below can be used to estimate emissions.

POLLUTANTS: TOG, CO, NO_x, SO_x, and PM_{10}

ROG: ROG emissions are 75% of TOG.

POINT SOURCE ADJUSTMENTS:

Emissions from on-site incineration should be adjusted downward to account for any incineration point sources (i.e., municipal incinerators, etc.) within the region. This is done by subtracting the waste that goes to these sources from the overall incinerated waste stream. INE or other government agencies should have information on incineration point sources.

METHODOLOGY:

The first step in estimating emissions from on-site incineration is to perform a solid waste material balance. In general, a solid waste material balance is in the form of:

$$\sum \text{Waste}_{\text{Generated}} = \sum \text{Waste}_{\text{Disposed}} \qquad (10.1\text{-}1)$$

where:
$\Sigma \text{Waste}_{\text{Generated}}$ = Total amount of waste generated; and
$\text{Waste}_{\text{Disposed}}$ = Total amount of waste disposed.

The total amount of waste generated is usually calculated by multiplying a per capita waste generation rate by the inventory area population. This is mathematically represented below.

$$\sum \text{Waste}_{\text{Generated}} = \text{Population} \times \text{Waste}_{\text{per capita}} \qquad (10.1\text{-}2)$$

According to INE, the 1994 per capita waste generation rate for the entire country of Mexico was 0.893 kg/person-day (INE, 1994). Regional socioeconomic differences will result in higher or lower waste generation rates for different regions. For example, it has been estimated that the waste generation rate for Nogales, Sonora is approximately 0.8 kg/person-day (Monroy, 1996). It is recommended that local officials be contacted to obtain an appropriate waste generation rate.

The total amount of disposed waste is given by the following equation:

$$\sum \text{Waste}_{\text{Disposed}} = \text{Waste}_{\text{Landfill}} + \text{Waste}_{\text{Recycle}} + \text{Waste}_{\text{Incinerator}} + \text{Waste}_{\text{Open Burn}} + \text{Waste}_{\text{Other}} \qquad (10.1\text{-}3)$$

where:
$\text{Waste}_{\text{Landfill}}$ = Total amount of waste sent to sanitary landfill;
$\text{Waste}_{\text{Recycle}}$ = Total amount of recycled waste;
$\text{Waste}_{\text{Incinerator}}$ = Total amount of waste sent to an incinerator;
$\text{Waste}_{\text{Open Burn}}$ = Total amount of waste consumed through open refuse burning; and
$\text{Waste}_{\text{Other}}$ = Total amount of waste “disposed” of through other means (i.e., abandonment, etc.)

Rearranging Equations 10.1-1, 10.1-2, and 10.1-3 results in the following equation which gives the amount of waste combusted in incinerators. As indicated above, this amount of waste must be further adjusted for point source incinerators:

$$\text{Waste}_{\text{Incinerator}} = (\text{Population} \times \text{Waste}_{\text{per capita}}) - \text{Waste}_{\text{Landfill}} - \text{Waste}_{\text{Recycle}} - \text{Waste}_{\text{Open Burn}} - \text{Waste}_{\text{Other}} \qquad (10.1\text{-}4)$$

INE has estimated that approximately 70% of the waste generated in Mexican cities ends up being collected and sent to the sanitary landfill. Other areas may have different fractions of the overall waste stream sent to the landfill.

The amount of overall waste that is recycled is probably small for most areas of Mexico. For example, it has been estimated that 1.3% of the total generated waste in Nogales, Sonora was recycled in 1990 (Monroy, 1996). However, it is expected that the amount of recycling will increase in the future as the practice of recycling expands worldwide.

Local officials will need to be consulted concerning the amount of waste that is disposed of by open burning and other means.

After estimating the amount of waste sent to incinerators, the amount of waste sent to point source incinerators must be subtracted. After that, emissions can be calculated using the following equation:

$$\text{Emissions}_i = \text{Waste}_{\text{Incinerator}} \times \text{EF}_i \tag{10.1-5}$$

where: Emissions_i = Total annual emissions for pollutant, i;

$\text{Waste}_{\text{Incinerator}}$ = Total waste incinerated (adjusted for point source incinerators); and

EF_i = Emission factor for pollutant, i.

Some emission factors for on-site incinerators are presented below in Table 10.1-1.

Table 10.1-1

Uncontrolled Emission Factors for On-Site Incinerators Other than Municipal Waste[a]

Combustor Type		**TOC[b] (kg/Mg)**	**CO (kg/Mg)**	**NO_x (kg/Mg)**	**PM (kg/Mg)**	**SO_2 (kg/Mg)**
Commercial/ Institutional	Multiple Chamber	1.5	5.0	1.5	3.5	1.25
	Single Chamber	75	10	1.0	7.5	1.25
Residential	Without Primary Burner	50	150	0.5	17.5	0.25
	With Primary Burner	1.0	0	1.0	3.5	0.25

[a] Emission factors taken from Table 2.1-12 of AP-42. Additional emission factors for other non-municipal waste incinerators can be found there.

[b] Expressed as methane.

DATA NEEDED:

Data	**Sources**
Population	INEGI or local officials
Per Capita Waste Generation Rate (default - 0.893 kg/person-day)	INE, INEGI, or local officials
Amount of Waste Disposed in Landfill (default - 70% of total waste)	INE or local officials
Amount of Waste Recycled	Local officials
Amount of Waste Disposed by Open Burning	Local officials
Amount of Waste Disposed by Other Means (abandonment, etc.)	Local officials
Amount of Waste Disposed by Point Source Incinerators	INE or local facilities
Emission Factors	Table 10.1-1 of this manual or Table 2.1-12 of AP-42

SAMPLE CALCULATION:

A certain municipality has a population of 160,000 people. Local officials have indicated that the per capita waste generation factor is slightly lower than the national average (0.85 kg/person-day). Local officials also indicate that 65% of the total waste is landfilled, 3% is recycled, 10% is disposed through open burning, and the remainder is incinerated. Five percent is abandoned or dumped. A municipal waste incinerator within the municipality incinerates 5,500 Mg of waste yearly. Calculate annual CO emissions from on-site incineration assuming that all waste is burned in a commercial single chamber combustor.

1. Total annual waste generated:

   160,000 people × (0.85 kg/person-day) × 365 days = 49,640,000 kg
   = 49,640 Mg

2. Total annual waste that is landfilled:

   49,640 Mg × 0.65 = 32,266 Mg

3. Total annual waste that is recycled:

   49,640 Mg x 0.03 = 1,489 Mg

4. Total annual waste that is disposed through open burning:

   49,640 Mg × 0.10 = 4,964 Mg

5. Total annual waste that is abandoned or dumped:

   49,640 Mg × 0.05 = 2,482 Mg

6. Total annual waste that is incinerated:

   49,640 Mg - 32,266 Mg - 1,489 Mg - 4,964 Mg
   - 2,482 Mg = 8,439 Mg

7. Total annual waste that is incinerated (adjusted for point source incinerators):

   8,439 Mg - 5,500 Mg = 2,939 Mg

8. Total CO emissions:

2,939 Mg waste × (10 kg CO/Mg waste) = 29,390 kg CO/yr
= 29.4 Mg CO/yr

10.2 Waste Management - Open Burning

SOURCE CODE:	**DESCRIPTION**:
26-10-000-000	All Categories
26-10-010-000	Industrial
26-10-020-000	Commercial/Institutional
26-10-030-000	Residential

DESCRIPTION:

In some areas, open burning is the preferred method of disposal of solid waste. The confined burning of waste materials is addressed under on-site incineration (Section 10.1). Large scale agricultural burning is not included in this section; the methodology for agricultural burning can be found in Section 9.3. Large open burning dumps are usually classified as point sources and will not be addressed in this section.

Direct statistics related to open refuse burning are somewhat limited. Mexican law states that open burning will only be permitted in zones under Federal jurisdiction when it occurs with permission from SEMARNAP for training firefighting personnel. In such a request, the type and quantity of fuel that will be burned should be provided. The practice of small-scale open refuse burning without permission from SEMARNAP, however, also seems to be prevalent. The effects of local rules and regulations should also be considered when estimating emissions from open burning. The material balance method described below can be used to estimate emissions.

POLLUTANTS: TOG, CO, NO_x, SO_x, and PM_{10}

ROG: ROG emissions are 38.7% of TOG.

POINT SOURCE ADJUSTMENTS:

Emissions from open refuse burning should be adjusted downward to account for any open burning point sources (i.e., large open burning dumps, etc.) within the region. This is done by subtracting the waste that goes to these sources from the overall incinerated waste stream. Local officials should have information on these point sources.

METHODOLOGY:

The first step in estimating emissions from open refuse burning is to perform a solid waste material balance. In general, a solid waste material balance is in the form of:

$$\sum \text{Waste}_{\text{Generated}} = \sum \text{Waste}_{\text{Disposed}} \qquad (10.2\text{-}1)$$

where:

$\Sigma\text{Waste}_{\text{Generated}}$ = Total amount of waste generated; and
$\text{Waste}_{\text{Disposed}}$ = Total amount of waste disposed.

The total amount of waste generated is usually calculated by multiplying a per capita waste generation rate by the inventory area population. This is mathematically represented below.

$$\sum \text{Waste}_{\text{Generated}} = \text{Population} \times \text{Waste}_{\text{per capita}} \qquad (10.2\text{-}2)$$

According to INE, the 1994 per capita waste generation rate for the entire country of Mexico was 0.893 kg/person-day (INE, 1994). Regional socioeconomic differences will result in higher or lower waste generation rates for different regions. For example, it has been estimated that the waste generation rate for Nogales, Sonora is approximately 0.8 kg/person-day (Monroy, 1996). It is recommended that local officials be contacted to obtain an appropriate waste generation rate.

The total amount of disposed waste is given by the following equation:

$$\sum \text{Waste}_{\text{Disposed}} = \text{Waste}_{\text{Landfill}} + \text{Waste}_{\text{Recycle}} + \text{Waste}_{\text{Incinerator}} + \text{Waste}_{\text{Open Burn}} + \text{Waste}_{\text{Other}} \qquad (10.2\text{-}3)$$

where:

$\text{Waste}_{\text{Landfill}}$ = Total amount of waste sent to sanitary landfill;
$\text{Waste}_{\text{Recycle}}$ = Total amount of recycled waste;
$\text{Waste}_{\text{Incinerator}}$ = Total amount of waste sent to an incinerator;
$\text{Waste}_{\text{Open Burn}}$ = Total amount of waste consumed through open refuse burning; and
$\text{Waste}_{\text{Other}}$ = Total amount of waste “disposed” of through other means (i.e., abandonment, etc.)

Rearranging Equations 10.2-1, 10.2-2, and 10.2-3 results in the following equation which gives the amount of waste combusted in open burning.

$$\text{Waste}_{\text{Open Burn}} = (\text{Population} \times \text{Waste}_{\text{per capita}}) - \text{Waste}_{\text{Landfill}} - \text{Waste}_{\text{Recycle}} - \text{Waste}_{\text{Incinerator}} - \text{Waste}_{\text{Other}} \tag{10.2-4}$$

INE has estimated that approximately 70% of the waste generated in Mexican cities ends up being collected and sent to the sanitary landfill. Other areas may have different fractions of the overall waste stream sent to the landfill.

The amount of overall waste that is recycled is probably small for most areas of Mexico. For example, it has been estimated that 1.3% of the total generated waste in Nogales, Sonora was recycled in 1990 (Monroy, 1996). However, it is expected that the amount of recycling will increase in the future as the practice of recycling expands worldwide.

Local officials will need to be consulted concerning the amount of waste that is disposed of by incineration and other means.

After estimating the amount of waste combusted by open burning, then emissions can be calculated using the following equation:

$$\text{Emissions}_i = \text{Waste}_{\text{Open Burn}} \times \text{EF}_i \tag{10.2-5}$$

where:

Emissions_i = Total annual emissions for pollutant, i;
$\text{Waste}_{\text{Open Burn}}$ = Total waste burned (adjusted for point source incinerators); and
EF_i = Emission factor for pollutant, i.

Emission factors for typical municipal refuse can be found in Table 10.2-1. The open burning of organic or agricultural refuse is addressed in Section 9.3 of this manual. Specialized discussion concerning the open burning of automobile components, tires, and agricultural plastic film are presented in Sections 2.5.2.2, 2.5.2.3, and 2.5.2.4 of AP-42 (AP-42, 1995).

Table 10.2-1

Emission Factors for Open Burning of Municipal Refuse Municipal Waste[a]

Source	TOG (kg/Mg)[b]		CO (kg/Mg)	NO_x (kg/Mg)	PM[c] (kg/Mg)	SO_2 (kg/Mg)
	Methane	Non-methane				
Municipal Refuse	6.5	15	42	3	8	0.5

[a] Emission factors taken from Table 2.5-1 of AP-42.

[b] TOG emission factors are presented separately as non-methane TOG and methane emission factors together.

[c] Particulate emission factors are presented as total particulate. Although not stated, it seems reasonable to assume that a significant fraction of PM is PM_{10}.

DATA NEEDED:

Data	Sources
Population	INEGI or local officials
Per Capita Waste Generation Rate (default - 0.893 kg/person-day)	INE, INEGI, or local officials
Amount of Waste Disposed in Landfill (default - 70% of total waste)	INE or local officials
Amount of Waste Recycled	Local officials
Amount of Waste Disposed by Incineration	Local officials and facilities
Amount of Waste Disposed by Other Means (abandonment, etc.)	Local officials
Emission Factors	Table 10.2-1

SAMPLE CALCULATION:

A certain municipality has a population of 140,000 people. Local officials have indicated that the per capita waste generation factor is lower than the national average (0.75 kg/person-day). Local officials also indicate that 60% of the total waste is landfilled, 2% is recycled, 10% is disposed through incineration (municipal and on-site), 5% is abandoned or dumped, and the remainder is open-burned. Calculate annual NO_x emissions from open burning assuming that all waste generated is typical municipal waste.

1. Total annual waste generated:

   140,000 people × (0.75 kg/person-day) × 365 days = 38,325,000 kg
   = 38,325 Mg

2. Total annual waste that is landfilled:

   38,325 Mg × 0.60 = 22,995 Mg

3. Total annual waste that is recycled:

   38,325 Mg x 0.02 = 767 Mg

4. Total annual waste that is disposed of through incineration:

   38,325 Mg × 0.10 = 3,833 Mg

5. Total annual waste that is abandoned or dumped:

   38,325 Mg × 0.05 = 1,916 Mg

6. Total annual waste that is disposed of through open burning:

   38,325 Mg - 22,995 Mg - 767 Mg - 3,833 Mg
   - 1,916 Mg = 8,814 Mg

7. Total NO_x emissions:

   8,814 Mg waste × (3 kg NO_x/Mg waste) = 26,442 kg NO_x/yr
   = 26.4 Mg NO_x/yr

10.3 Wastewater Treatment

SOURCE CODE:	**DESCRIPTION**:
26-30-000-000	All Categories/Composite
26-30-010-000	Industrial/Composite
26-30-020-000	Public Owned/Composite
26-30-030-000	Residential or Subdivision Owned/Composite

DESCRIPTION:

Various industrial processes generate wastewater streams that contain organic compounds. These streams typically undergo collection, contaminant treatment, and/or storage steps before they are discharged into either a receiving body of water or a municipal treatment plant (also called publicly owned treatment works [POTWs] in the U.S.) for further treatment. During some of these operations, the wastewater is open to the atmosphere and organic compounds may be emitted into the air.

In addition to industrial wastewater, POTWs may also treat water from residential, institutional, or commercial facilities, water that enters the sewer system from the ground and/or storm water runoff. These other types of wastewater generally do not contain significant levels of TOG. In the U.S., if the actual annual industrial wastewater contribution to the POTWs of an inventory region is not known, then 16% of the total annual flow (i.e., the national average) is recommended as a default value. This U.S.-based default value has limited applicability in Mexico and should only be used if no other data are available.

The effluent from the wastewater treatment plant must meet federal, state, and municipal quality standards before it is discharged into a receiving body of water. The size and degree of treatment of wastewater streams will depend on the volume and degree of contamination of the wastewater and on the extent of contaminant removal desired.

POLLUTANTS: TOG

ROG: Most of the non-reactive hydrocarbons that should be excluded are halogenated organics. If chemical-specific wastewater concentration data are available, the TOG emissions can be adjusted to exclude the halogenated organic portion.

For example, if the TOG emissions are 100 Mg/yr, the sum of the halogenated organic compound concentrations is 40 ppmw and the TOC concentration is 500 ppmw, then:

Non-reactive portion = (40 ppmw) / (500 ppmw) = 8%

ROG emissions = (TOG emissions) x (ROG fraction)
= (100 Mg/yr) x (1 - 0.08)
= 92 Mg/yr

POINT SOURCE ADJUSTMENTS:

Wastewater treatment may occur at large facilities that may be inventoried as point sources. Ideally, the total volume of wastewater treated at point sources should be subtracted from the total volume of wastewater treated in the inventory region and the resulting "total volume of wastewater treated at area sources" should be used in the emissions calculations. If only emissions data are available for the point source facilities, then these emissions must be subtracted from the total emissions calculated using the methods described here to yield the final area source emissions estimate.

METHODOLOGY:

The amount of industrial wastewater treated needs to be determined for the inventory region. If the statistics available do not directly correspond to the needs of the inventory effort (e.g., statewide statistics are available but the inventory region includes portion of multiple states; statewide statistics are available, but the inventory requires municipal-level emission estimates), then census data (e.g., population or housing) or other available statistics can be used to disaggregate the totals to the inventory region. For example, population data might be used for municipal wastewater treatment and the number of industrial facilities or industrial revenues might be used for industrial wastewater treatment. The sample calculation for residential fuel combustion (commercial fuels) (Section 4.2) illustrates this procedure.

The emission factor developed must relate the mass of pollutant emitted to the amount of wastewater treated (e.g., kg TOG/liter). Then, the equation for uncontrolled TOG emissions is simply:

$$\text{Emissions}_{\text{TOG}} = (\text{volume of wastewater treated}) \times \text{EF}_{\text{TOG}} \qquad (10.3\text{-}1)$$

As an alternative, a much more rigorous approach using an emissions model such as CHEMDAT8 or WATER8 may be applied. See Section 4.1.4 of *Basic*

Emission Estimating Techniques (Volume III of this series) for more information on these computer models, the emission model equations, and data requirements. Also, Section 4.2.8 (i.e., Tratamiento de Aguas Residuales) of the documentation for the development of an area source inventory for the Mexico City Metropolitan Area (DDF, 1995a) provides more detailed information on how a older emissions model (i.e., the Surface Impoundment Modeling System [SIMS]) has previously been used in Mexico to develop area source emission estimates from wastewater treatment. However, U.S. EPA no longer supports this model.

DATA NEEDED:

Data	Sources
Quantity of industrial wastewater treated in the inventory region	Federal agency: *Comisión Nacional del Agua* State or local agency: (e.g., *Dirección General de Construcción y Operación Hidráulica*, Mexico City)
Emission factor 1.3×10^{-5} kg TOG/liter (1.1×10^{-4} TOG lb/gal)	U.S. EPA, 1991a

NOTES:

1. The information about wastewater treatment plants by regions in the country can be found in the *Comisión Nacional del Agua* (National Water Commission), a source of information for municipal wastewater treatment plants. The Commission is the federal agency that compiles information about use and discharge to federal bodies of water.

2. The only currently published emission factor is 1.3×10^{-5} kg/liter (1.1×10^{-4} lb/gal) (U.S. EPA, 1991a). This emission factor is based on the reported total industrial flow discharged to POTWs in the U.S. in 1984 which was 1.6×10^{12} gallons and a national VOC emissions estimate from POTWs of 78,540 Mg/yr. This VOC emissions estimate was based on the annual VOC loadings reported for raw POTW influent and an assumption, supported by research, that in the event of heavy chemical loading, 85% of all volatile pollutants discharged to wastewater treatment systems are stripped to the ambient air. That is:

$$\begin{aligned} EF_{VOC} &= (78540 \text{ Mg/yr}) (10^6 \text{ g/Mg}) / (453.6 \text{ g/lb}) / (1.6 \text{ x } 10^{12} \text{ gal/yr}) \\ &= 1.1 \text{ x } 10^{-4} \text{ lbs VOC/gal} \end{aligned}$$

This U.S.-based emission factor has limited applicability in Mexico and should only used if no other data are available.

SAMPLE CALCULATION:

1. Determine the amount of wastewater treated. Assume that the total amount of wastewater treated in the inventory region is $2{,}500 \times 10^6$ liters/yr. Since the amount of industrial wastewater treated is not known, the U.S. default of 16% is used:

$$(2{,}500 \times 10^6 \text{ liters/yr}) \times (16\%) = 400 \times 10^6 \text{ liters/yr}$$

2. Determine the TOG emissions

For example, the total annual TOG emissions from a state that treats 400×10^6 liters/yr of industrial wastewater are:

$$\begin{aligned} (400 \times 10^6 \text{ liters/yr}) \times (1.3 \times 10^{-5} \text{ kg TOG/liter}) &= 5200 \text{ kg/yr} \\ &= 5.2 \text{ Mg/yr} \end{aligned}$$

3. Subtract point source emissions, if necessary

If there are large wastewater treatment plants in the inventory region that have been inventoried as point sources, then preferably, the total volume of wastewater treated at point sources should be subtracted from the total volume of wastewater treated in the inventory region and the resulting “total volume of wastewater treated at area sources” should be used in the emissions calculations. For example, if the point source throughputs are:

- 10 million liters/yr for Facility A; and
- 20 million liters/yr for Facility B;

Then:

$$\begin{aligned} [(400) - (10 + 20)] \times 10^6 \text{ liters/yr} \times (1.3 \times 10^{-5} \text{ kg TOG/liter}) &= 4810 \text{ kg/yr} \\ &= 4.8 \text{ Mg/yr} \end{aligned}$$

If only emissions data are available for the point source facilities, then the emissions assigned to those facilities need to be subtracted from the total calculated for the inventory region. For example, if the point source emissions are:

- 100 kg/yr for Facility A; and
- 150 kg/yr for Facility B;

Then:

Area Source Emissions = (Total Emissions) - (Point Emissions)
= 5200 - (100 + 150)
= 4950 kg/yr
= 4.95 Mg/yr

10.4 Open Channel Sewage and Wastewater

SOURCE CODE:	**DESCRIPTION**:
26-30-090-000*	Wastewater Treatment

*Proposed Mexico-specific code for source category not typically inventoried in the U.S.

DESCRIPTION:

In some areas of Mexico, open channels may be used to conduct human sewage and/or industrial wastewaters. For example, Ciudad Juárez, with around 1 million people, has no sewage systems and diverts about 55 million gallons of raw sewage each day into open unlined channels that flow along the Rio Grande (*Sacramento Bee*, 1995b). These canals, streams, rivers, and ditches, are sources of emissions to the atmosphere from the decomposition of organic material and the evaporation of hydrocarbons present in the discharges.

POLLUTANTS: TOG and NH_3.

ROG: Industrial wastewaters may include chlorofluorocarbons (CFCs) or other organic compounds that are not considered reactive and that should be excluded from ROG inventory efforts.

POINT SOURCE ADJUSTMENTS:

Open channel sewage and wastewater sources are not generally included in a point source inventory. No adjustments should be necessary.

METHODOLOGY:

Further studies are needed to develop a methodology for estimating volatile hydrocarbon emissions from the decomposition of organic material and emissions in open channels. U.S. EPA is currently funding at least one such effort through the Centro de Informacion sobre Contaminacion del Aire (CICA). CICA Project No. 2, *Emission Estimation Techniques for Unique Source Categories in Mexicali, Mexico*, will present and evaluate specific methodologies for developing emission factors for open wastewater ditches/canals. It is expected that the draft report for this project will be complete by April 1997 and might be available to the public on the CICA Home Page at (*http://www.epa.gov/oar/oaqps/cica/*).

Data to support a simple mass balance approach (e.g., total amount of wastewater, concentrations of pollutants to be inventoried) may be available in some regions. However, the methodology likely would need to account for the effects of decomposition, since this chemical reaction will both destroy some chemical species originally discharged into the open channels and create other byproducts. It is interesting to note that a Rice University study suggests that in some cases it is possible that the human waste may not decompose because the concentration levels of industrial chemicals kill the bacteria in the water (*http://www.rice.edu/projects/TELRC/Colonias/file5.html*).

DATA NEEDED:

Data	Sources
General information on length and conditions of open channels	Municipal agencies (e.g., Mexico City - *Dirección General de Construcción y Operación Hidráulica* of the Government of the Federal District).
Number of houses and occupants by availability and type of drainage	INEGI (e.g., 1990 Census report)
Amount of wastewater generated per capital (potentially developed from amount of wastewater treated and number of people serviced by existing wastewater treatment facilities).	Local wastewater treatment facilities

NOTES:

1. To be determined.

SAMPLE CALCULATION:

To be determined.

11.0 MISCELLANEOUS AREA SOURCES

Some miscellaneous emission sources may be too small or too numerous to be included in the point source inventory for a given inventory region. Therefore, these sources need to be included in the area source inventory effort. Inventory guidance for these sources are presented in the following subsections:

- Wildfires;
- Structure Fires;
- Paved Road Dust;
- Unpaved Road Dust;
- Wind Erosion; and
- Domestic Ammonia Emissions.

11.1 Wildfires

SOURCE CODE: 28-10-001-000

DESCRIPTION:

Wildfires occur naturally in Mexico, but another significant cause of wildland fire emissions are intentionally-ignited fires intended to promote the growth of grass for cattle grazing. The use of prescribed fires to manage forest ecosystems is not practiced in Mexico. Most fires occur in central and southern Mexico during the January through May time period. These fires are set not only on range land, but also in forested areas. By June, the fire season ends as the summer rains begin. An exception to this is Baja California, where brush fires occur much as they do in California.

Because fires tend to occur during the cooler part of the year, they usually do not burn very hot. This results in mostly ground fires, rather than crown fires. In addition, the fires tend to be small, though numerous. This is particularly true for public lands, where more fires are set than on private lands. Statistics on the amount of acres burned per year are maintained by SEMARNAP.

POLLUTANTS: TOG, CO, and PM_{10}

ROG: ROG emissions are 45% of TOG.

POINT SOURCE ADJUSTMENTS: None.

METHODOLOGY:

The basic equation for estimating wildfire emissions is:

$$\text{Emissions}_i = EF_i \times L \times C \times A \qquad (11.1\text{-}1)$$

where:
Emissions_i = total emissions of pollutant i;
EF_i = emission factor for pollutant i (g/kg);
L = fuel loading (kg/ha);
C = percent of fuel loading that is consumed by the fire; and
A = land area burned (ha).

Fuel loading values are site-specific estimates of the oven-dry mass of vegetative fuels that are available for consumption by a fire. Ideally, these are further defined in terms of fuel size class, such as fine fuels (those 0-1" in diameter), small fuels (those between 1" and 3" in diameter), large woody fuels (those greater than 3" in diameter), live vegetation, and duff (partially decomposed litter). Each fuel component has different propensity to burn in a fire and equilibrates its moisture content with the surrounding environment at a different rate.

The amount of available fuel actually consumed by a fire is a complex function of many variables, but the main parameters are the fuel moisture content, fuel size class distribution and arrangement, ambient windspeed, and fire intensity. Consumption models, such as CONSUME, exist for many fuel types in the U.S. (Ottmar et al., 1993). If such consumption models are unavailable, then the conservative assumption can be made that 100% of the available fuel is consumed (i.e., $C = 1.0$).

Ideally, consumption estimates are derived separately for fuel consumed in the flaming and smoldering phases of combustion. This distinction is important because each phase of combustion occurs with a characteristic combustion efficiency (η). Complete combustion efficiency ($\eta = 1.00$) produces only water, carbon dioxide, and a small amount of inorganic pollutants. In practice, however, complete combustion never occurs. Smoldering combustion is very inefficient and produces a higher proportion of pollutants in comparison to flaming combustion. In general, the emission factors presented in this section are a function of the combustion efficiency. For detailed emission estimates, separate estimates for flaming and smoldering emissions should be performed because flaming phase emissions, although “cleaner”, can be transported long distances when contained in a strongly buoyant plume from a large fire, while smoldering phase emissions are “dirtier” and very important for assessing local impacts. Emissions management can be practiced by limiting smoldering phase combustion, which can be achieved by: 1) scheduling ignitions to take advantage of fuel moisture to limit the duration of smoldering combustion; and 2) aggressive mop-up after the flaming phase to extinguish smoldering fires.

Estimated total fuel consumption (after summing together both flaming and smoldering phases) is given in Table 11.1-1 for a variety of western U.S. fuels. These fuels (or similar species) also extend down into Mexico, so the total fuel consumption values are expected to be representative of conditions in Mexico. The values for fuel consumption presented in Table 11.1-1 are actually the products of the L and C terms from equation 11.1-1. The fuel consumption estimates are given for a “dry” fire weather scenario (use for wildfires in severely dry conditions), a “normal” fire weather scenario (use for prescribed burning or wildfires in moderately dry conditions), and a “wet” weather scenario (use for prescribed burning or wildfires under moister conditions). The fuel combustion estimates in Table 11.1-1 were obtained by assigning standard vegetation classifications from the Society of American Foresters (SAF) and the Society for Range Management (SRM) to one of the National Fire Danger Rating (NFDR) system fuel models (Deeming and Cohen, 1982). For each vegetation classification presented in Table 11.1-1, the specific NFDR model (T, F, L, H, or C) used for fuel combustion estimates is identified. Also, for each specific model, the fuel loading and resulting fire intensity has been identified as either low, medium, or high (Hardy et al., 1997).

The data presented in Table 11.1-1 mainly represent vegetation in an early mature level of development. Vegetation stands in earlier or later stages of development will have different loadings.

As mentioned earlier, the species presented in Table 11.1-1 ar those that are found both in the U.S. and Mexico. Data presented in Table 11.1-1 are not appropriate for native Mexico species, particularly for those species found in the tropical areas of the country. Also included in Table 11.1-1 are average $PM_{2.5}$ emission factors for each fuel/weather scenario, calculated from average PM_{10} emission factors (Hardy et al., 1997) by a regression model developed by Ward et al. (1993).

Table 11.1-1.

Total Fuel Consumption, $PM_{2.5}$ Emission Factors and Combustion Efficiency Estimates for Some Representative Western U.S. Fuels

Fuel[a]	Fire Weather Scenario	Total Fuel Consumption (kg/ha)	$PM_{2.5}$ Emission Factor (g/kg)	Fire-Average Combustion Efficiency η
Antelope Bitterbrush-Bluebunch Wheatgrass: SRM104, T, M	Dry	2,317	6.99	0.90
	Normal	2,317	6.99	0.90
	Wet	2,317	6.78	0.90
Blue Oak-Digger Pine: SAF250, F, H	Dry	2,317	6.95	0.90
	Normal	2,197	6.65	0.91
	Wet	1,877	5.55	0.93
Blue Oak Woodland: SRM201, L, M	Dry	819	8.09	0.89
	Normal	799	8.09	0.89
	Wet	799	7.75	0.89
Chamise Chaparral: SRM206, F, M	Dry	2,317	6.99	0.90
	Normal	2,317	6.99	0.90
	Wet	2,317	6.78	0.91
Interior Douglas fir: SAF210, H, L	Dry	7,749	9.32	0.87
	Normal	7,050	9.36	0.87
	Wet	4,553	8.81	0.88
Interior Ponderosa Pine: SAF237, T, H	Dry	5,772	8.52	0.88
	Normal	5,292	8.52	0.88
	Wet	3,715	7.75	0.89

Table 11.1-1

(Continued)

Fuel[a]	Fire Weather Scenario	Total Fuel Consumption (kg/ha)	$PM_{2.5}$ Emission Factor (g/kg)	Fire-Average Combustion Efficiency η
Juniper-Pinyon Woodland: SAF412, L, M	Dry	1,038	7.20	0.90
	Normal	1,038	7.20	0.90
	Wet	1,038	6.95	0.90
Lodgepole Pine: SAF218, H, H	Dry	4,993	7.46	0.90
	Normal	4,733	7.50	0.90
	Wet	4,074	7.58	0.90
Mesquite: SAF242, T, M	Dry	2,396	6.99	0.90
	Normal	1,358	5.81	0.92
	Wet	1,138	4.45	0.94
Ponderosa Pine-shrubland: SRM109, T, M	Dry	7,649	8.26	0.89
	Normal	7,130	8.43	0.88
	Wet	5,372	8.05	0.89
Ponderosa Pine-grassland: SRM110, C, H	Dry	5,951	9.45	0.87
	Normal	5,432	9.41	0.87
	Wet	3,415	8.14	0.89
White Fir: SAF211, H, M	Dry	7,968	9.28	0.87
	Normal	7,269	9.36	0.87
	Wet	4,813	8.98	0.87

[a] Basis for fuel consumption (vegetation classification, NFDR model used, assumed fire intensity [high, medium, or low]).

Additional emission factors for wildland fuels are presented in Table 11.1-2. These data are based on measured emissions from some representative U.S. fuels (Ward et al., 1993). The interrelationships among the emitted pollutants enable calculation of the emission factor from either the combustion efficiency or the $PM_{2.5}$ data in Table 11.1-1.

Table 11.1-2.

Emission Factor Algorithms

Pollutant (EF)	Emission Factor Algorithm	Units	Uncertainty
Carbon monoxide (CO)	$961 - (\eta \times 984)$	g/kg	± 10%
Methane (CH_4)	$42.7 - (\eta \times 43.2)$	g/kg	± 20%
Nonmethane hydrocarbons (NMHC)	$0.76 + (EF_{CH4} \times 0.616)$	g/kg	± 25%
TOG	$EF_{CH4} + EF_{NMHC}$	g/kg	± 25%
PM_{10}	$1.18 \times EF_{PM2.5}$	g/kg	± 25%

DATA NEEDED:

Data	Sources
Land area burned	SEMARNAP
Fuel loading and consumption	Mexico specific data; Table 11.1-1
Emission factors	Mexico specific data; Table 11.1-2

NOTES:

1. The information presented in Tables 11.1-1 and 11.1-2 is not intended to be exhaustive; rather, representative values are presented. If further detailed information is required, the references cited in this section should be consulted.

2. Fuel loading values for Mexico have not yet been developed. The fuel loading depends on the age and distribution of species for each site burned; this is best determined from vegetative biomass inventories of representative sites. Until these values are available, fuel models from other regions, such as the United States, may be used to estimate Mexican fuel loading. Refer to Table 11.1-1 for U.S. fuel loading data that may be utilized in lieu of Mexico-specific data.

3. Fuel consumption data for Mexico have not yet been developed. The fuel consumption in flaming and smoldering phases of the fire is best determined from pre- and post-burn vegetative biomass inventories.

4. Emission factors for Mexican vegetative biomass have not yet been developed. Until these data are available, fuel models from other regions, such as the United States, may be used to estimate emission factors for Mexican vegetation fires. Refer to Tables 11.1-1 and 11.1-2 for U.S. emission factors that may be utilized in lieu of Mexico-specific values.

5. Radian is currently working with Ernesto Alvarado and Roger Ottmar of the USDA Forest Service, Pacific Northwest Research Station (206-553-7815) to develop fuel loading data and appropriate emission factors for use in Mexico.

SAMPLE CALCULATION:

Given a 120 hectare prescribed burn of interior Douglas fir during the early spring, estimate CO emissions.

1. Determine the fuel consumption for the 120 hectare fire (assume early spring conditions are represented by the “wet” consumption data in Table 11.1-1):

   $A = 120$ ha;
   $(L \times C) = 4{,}553$ kg/ha;

   120 ha burned × 4,553 kg fuel consumed / ha = 546,360 kg fuel consumed

2. Next estimate the carbon monoxide emission factor from the appropriate equation in Table 11.1-2. The combustion efficiency estimate (η) is used from Table 11.1-1:

   $EF_{CO} = 961 - (0.88 \times 984) = 95.08$ g CO / kg fuel consumed

3. Finally, estimate the total emissions from the fire using the derived emission factor for carbon monoxide and the fuel consumption from step 1:

$$546{,}360\ \text{kg fuel} \times \left(\frac{95.08\ \text{g CO}}{\text{kg fuel}}\right) = 51{,}948\ \text{kg CO}$$

$$= 51.9\ \text{Mg CO}$$

11.2 Structure Fires

SOURCE CODE: 28-10-030-000

DESCRIPTION:

Like other combustion sources, structure fires generate TOG, CO, NO_x, and PM emissions. However, unlike many other combustion sources, building fires are unintentional. Consequently, the amount of material burned can be difficult to determine.

To estimate emissions from structure fires, it is first necessary to estimate the amount of material combusted. This includes both structural materials and building contents. Typical values for residential buildings in the United States are included in this section, however, it is thought that values in Mexico may be drastically different due to structural differences (i.e., U.S. homes are predominantly built out of wood, while Mexican homes tend to be built out of brick and other non-wood materials). Mexico-specific values are desirable and should be developed.

POLLUTANTS: TOG, CO, NO_x, and PM

ROG: ROG emissions are 69.9% of TOG.

POINT SOURCE ADJUSTMENTS: None

EQUATIONS:

$$\text{Emissions}_p = \text{Fires} \times \%\text{Loss} \times (\text{CM}_{\text{Building}} + \text{CM}_{\text{Content}}) \times \text{EF}_p \qquad (11.2\text{-}1)$$

where:
Emissions_p = Total annual emissions for pollutant, p;
Fires = Total annual number of fires;
%Loss = Average percent structural loss;
$\text{CM}_{\text{Building}}$ = Amount of combustible material from building itself;
$\text{CM}_{\text{Content}}$ = Amount of combustible material from building contents; and
EF_p = Emission factor for pollutant, p.

The average percent structural loss must be estimated, because most structure fires do not consume 100% of the available combustible material. Many structure fires are extinguished before the structure has been completely consumed. In California, the average percent structural loss has been estimated to be 7.3%. This could be used as a default value for Mexico, but a Mexico-specific estimate is desirable.

In the United States, the average residential home has 1,200-1,500 ft^2 (111-139 m^2) of floor space with 10-12 tons (9.1-10.9 Mg) of combustible structural materials. These statistics probably do not accurately describe residential homes in Mexico. Specifically, the widespread brick, cinder block, and adobe houses in Mexico would probably have much lower amounts of combustible structural materials in them.

In the United States, values have been determined for the combustible contents per square foot for different functional areas of the average home. These values are presented in Table 11.2-1 (CARB, 1995).

Table 11.2-1

Combustible Contents for Different Functional Areas in the United States

Functional Area	Origin of Fires (%)	Combustibles (lbs/ft^2)	Combustibles (kg/m^2)	Weighted Average (lbs/ft^2)
Bedroom	28.96	10.4	50.8	3.01
Sleeping Area	0.20	10.4	50.8	0.02
Dining Area	2.20	7.2	35.2	0.16
Kitchen	53.92	6.8	33.2	3.67
Bathroom	6.32	7.0	34.2	0.44
Laundry	8.08	7.2	35.2	0.58
Office	0.17	7.9	38.6	0.01
Other	0.13	9.6	46.9	0.01
Total	100.00	—	—	7.90

A weighted average of 7.90 lbs/ft^2 (38.6 kg/m^2) of combustible contents has been estimated for the United States by using the fire occurrence distribution for different functional areas and multiplying by the combustible content loading in each functional area. This value might not be accurate for Mexico; in which case, a Mexico-specific combustible content loading would need to be estimated.

DATA NEEDED:

Data	Sources
Number of Fires	Local fire department
Average Percent Structural Loss	Local fire department or national fire protection association; U.S. default values.
Amount of Combustible Structural Material	INEGI, national fire protection association, or national builders association; U.S. default values.
Amount of Combustible Building Contents	INEGI, national fire protection association, or national builders association; U.S. default values.
TOG Emission Factor[a] 6.95 kg/Mg (13.9 lbs/ton)	ARB, 1995
CO Emission Factor[a] 84 kg/Mg (168 lbs/ton)	ARB, 1995
NO_x Emission Factor[b] 2.0 kg/Mg (4.0 lbs/ton)	ARB, 1995
PM Emission Factor[a] 5.4 kg/Mg (10.8 lbs/ton)	ARB, 1995

[a] TOG, CO, and PM emission factors obtained from tests on the burning of model wood buildings.
[b] NO_x emission factor assumed to be similar to that listed in AP-42 for municipal refuse.

SAMPLE CALCULATION:

A municipality reported 1,100 fires in 1995. The percent structural loss in this municipality was estimated to be approximately 14%. Most of the houses in this municipality were constructed out of brick or cinder block, so the amount of combustible building material was estimated to be only 2.5 Mg per house. It was also estimated that there are 25 kg of combustible contents per square meter with the typical house measuring 90 m^2. The values used in this example calculation are for illustrative purposes only. The values are not intended to represent conditions in Mexico and should not be used in emission estimates.

1. Total amount of combustible contents per house:

$$(25\ \text{kg/m}^2) \times 90\ \text{m}^2 = 2{,}250\ \text{kg} = 2.25\ \text{Mg}$$

2. Total CO emissions:

$$1{,}100\ \text{fires} \times 0.14 \times (2.5\ \text{Mg} + 2.25\ \text{Mg}) \times (84\ \text{kg CO/Mg burned}) = 61{,}446\ \text{kg CO} = 61.4\ \text{Mg CO}$$

11.3 Paved Road Dust

SOURCE CODE:	**DESCRIPTION**:
22-94-000-000	All paved roads
22-94-005-000	Interstate/arterial
22-94-010-000	All other public roads
22-94-015-000	Industrial roads

DESCRIPTION:

As motor vehicles move over paved road surfaces, dust that has either settled or been carried onto the paved surface is entrained by the turbulent wake of the vehicle and emitted as particulate matter. Currently, emissions are estimated as a function of the silt loading of the paved surface and the mean weight of the vehicles traveling over the surface. Silt loading, in turn, is a function of the road type. Roads with high traffic volumes typically have lower silt loadings than roads with small traffic volumes. Silt is defined as the material that passes through a 200-mesh screen using method ASTM-C-136.

Additional research is underway to possibly refine the current method used to estimate emissions. Additional updates to this section will be made as new information becomes available. Check with INE to identify the most current estimation method.

POLLUTANTS: PM_{10}

ROG: Not applicable.

POINT SOURCE ADJUSTMENTS: None.

METHODOLOGY:

The following empirical equation is used to develop a region-specific emission factor:

$$EF = k \left(\frac{sL}{2} \right)^{0.65} \left(\frac{W}{3} \right)^{1.5} \qquad (11.3\text{-}1)$$

where:
EF = particulate matter emission factor;
k = particle size multiplier (g/VKT);
sL = road surface silt loading (g/m^2); and
W = mean vehicle weight (Mg).

Based on data collected in the U.S., silt loadings have been found to have significant spatial and temporal variation. For roads with high average daily traffic (ADT), a frequency distribution of the available data yields a size loading value of 0.4 g/m^2 for the 50th percentile and 7 g/m^2 for the 90th percentile. Similar data for low-ADT roads are 2.5 and 25 g/m^2 , respectively. For a freeway, the mean silt loading drops to 0.02 g/m^2 (the 90th percentile value is not available).

In addition, this equation is most applicable for the following conditions:

Silt loading:	0.02 to 400 g/m^2;
Mean vehicle weight:	1.8 to 38 Mg; and
Mean vehicle speed:	16 to 88 kilometers/hour.

Applying this equation in regions with parameters outside of these ranges will result in highly uncertain estimates. Paved road dust emissions are estimated by using the following equation.

$$\text{Emissions}_p = EF_p \times VKT_p \qquad (11.3\text{-}2)$$

where:
Emissions_p = Annual PM_{10} emissions from paved road dust;
EF_p = Paved road dust emission factor; and
VKT_p = Annual paved road VKT.

DATA NEEDED:

Data	Sources
Vehicle Kilometers Traveled (VKT)	Obtain from motor vehicle emissions modeling calculations. See also Motor Vehicle Emissions Manual.
Particle Size Multiplier (k): 4.6 g/VKT for PM_{10}	U.S. EPA, 1995
Silt Loading	Local samples (preferably by type of road)
Mean Vehicle Weight	Analysis of motor vehicle fleet, see motor vehicle emissions data for characteristics of the fleet

NOTES:

1. Methods for determining region-specific silt data can be found in Appendices C.1 and C.2 of AP-42.
2. If region-specific silt loading data can not be developed, the tables in Appendix V-D of this manual may be consulted. Appropriate data from this table can be extrapolated to other regions, if needed.
3. If needed, a default mean vehicle weight of 2.2 Mg can be used.

SAMPLE CALCULATION:

For a defined geographic region, the following daily estimates of traffic activity were developed: 1.1 million VKT for freeways, 500,000 VKT for high-ADT roads, and 175,000 VKT for low-ADT roads. Using default values, a first order approximation of the PM_{10} emissions are:

$$\text{Freeways} = (1{,}100{,}000)\ (4.6) \left(\frac{0.02}{2}\right)^{0.65} \left(\frac{2.2}{3}\right)^{1.5} (10^{-6})\ (365)$$

$$= 58.1 \text{ Mg/yr}$$

$$\text{High-ADT roads} = (500{,}000)\ (4.6) \left(\frac{0.4}{2}\right)^{0.65} \left(\frac{2.2}{3}\right)^{1.5} (10^{-6})\ (365)$$

$$= 185.2 \text{ Mg/yr}$$

$$\text{Low-ADT roads} = (175{,}000)\,(4.6)\left(\frac{2.5}{2}\right)^{0.65}\left(\frac{2.2}{3}\right)^{1.5}(10^{-6})\,(365)$$

$$= 213.3 \text{ Mg/yr}$$

$$\text{Total emissions} = 58.1 + 185.2 + 213.3$$

$$= 456.5 \text{ Mg/yr}$$

11.4 Unpaved Road Dust

SOURCE CODE:	**DESCRIPTION**:
22-96-000-000	All unpaved roads
22-96-005-000	Public unpaved roads
22-96-010-000	Industrial unpaved roads

DESCRIPTION:

As motor vehicles move over unpaved surfaces, silt contained within the road surface is entrained by the turbulent wake of the vehicle and emitted as particulate matter. As vehicles pass over the surface, the force of the wheels on the surface grinds the road material into smaller particles, thereby partially replenishing the silt content of the road.

Emissions are estimated as a function of traffic volume, silt content of the unpaved surface, speed of the vehicles, mean number of wheels and mean weight of the vehicles traveling over the surface, and the number of days with precipitation greater than 0.254 mm. Road silt content, defined as particles less than 75 micrometers in size, varies spatially and by road type (e.g., gravel roads have different silt contents than dirt roads). The silt content of a road is determined by measuring the proportion of the loose dry surface dust that passes through a 200-mesh screen using the method ASTM-C-136.

POLLUTANTS: PM_{10}

ROG: Not applicable.

POINT SOURCE ADJUSTMENTS: None.

METHODOLOGY:

The following empirical equation is used to develop a site specific emission factor:

$$EF = k\ (1.7) \left(\frac{s}{12}\right) \left(\frac{S}{48}\right) \left(\frac{W}{2.7}\right)^{0.7} \left(\frac{w}{4}\right)^{0.5} \left(\frac{365-p}{365}\right) \qquad (11.4\text{-}1)$$

where:
EF = emission factor (kg/VKT);
k = particle size multiplier (dimensionless);
s = silt content of road surface material (%);
S = mean vehicle speed (km/hr);
W = mean vehicle weight (Mg);
w = mean number of wheels; and
p = number of days with precipitation $>$ 0.25 mm

Prior studies in the U.S. have found that the silt loading of unpaved roads varies significantly. For example, on dirt roads, silt content values of 1.6% to 68% have been observed, with a mean value of 12%. Whenever possible, it is desirable to obtain local samples and measure the silt content.

In addition, the empirical equation presented above is most applicable for the following conditions:

Silt content:	4.3 to 20%;
Mean vehicle weight:	2.7 to 142 Mg;
Mean vehicle speed:	21 to 64 km/hr and
Mean number of wheels:	4 to 13.

Applying this equation in regions with parameters outside these values may result in highly uncertain estimates. Unpaved road dust emissions are estimated by using the following equations.

$$\text{Emissions}_u = EF_u \times VKT_u \qquad (11.4\text{-}2)$$

where:
Emissions_u = Annual PM_{10} emissions from unpaved road dust;
EF_u = Unpaved road dust emission factor; and
VKT_u = Annual unpaved road VKT.

DATA NEEDED:

Data	Sources
Vehicle Kilometers Traveled (VKT)	Local vehicle usage data. See also Motor Vehicle Emissions Manual
Particle Size Multiplier (k): 0.36	U.S. EPA, 1995
Silt Content	Local samples (preferably by type of road)
Mean Vehicle Weight	Analysis of motor vehicle fleet, see motor vehicle emissions modeling data for characteristics of the fleet
Vehicle Speed	Observation of local speeds
Mean Number of Wheels	Analysis of motor vehicle fleet, see motor vehicle emissions modeling data for characteristics of the fleet

NOTES:

1. Methods for determining site-specific silt data can be found in Appendices C.1 and C.2 of AP-42.

2. If site specific silt loading data cannot be developed, the following default values can be used. Rural gravel road: 5.0% to 13%, with a mean value of 8.9%. Rural dirt road: 1.6% to 68%, with a mean value of 12%. Municipal unpaved road: 0.4% to 13%, with a mean value of 5.7%. Additional values can be found in AP-42 for industrial roads.

3. As a default, a mean vehicle weight of 2.2 Mg can be used.

SAMPLE CALCULATION:

For a defined geographic region, the annual VKT for municipal unpaved roads is an estimated 2.3 million VKT. It is further estimated that 80% of this VKT occurs on gravel roads and 20% on rural dirt roads. Speeds on the gravel road average 20 km/hour, while speeds on the dirt road average 10 km/hour. Annually, there are 20 days with precipitation greater than >0.25 mm. Using default values, a first order approximation of the PM_{10} emissions is:

$$\text{avel Roads} = (2.3 \text{ x } 10^{6} \text{ VKT})\ (0.80)\ (0.36)\ (1.7) \left(\frac{8.9}{12}\right) \left(\frac{20}{48}\right) \left(\frac{2.2}{2.7}\right)^{0.7} \left(\frac{5}{4}\right)^{0.5} \left(\frac{365-20}{365}\right) (10^{-}$$

$$= 319 \text{ Mg}$$

$$\text{Dirt Roads} = (2.3 \text{ x } 10^6)\ (0.20)\ (0.36)\ (1.7) \left(\frac{12}{12}\right) \left(\frac{10}{48}\right) \left(\frac{2.2}{2.7}\right)^{0.7} \left(\frac{4}{4}\right)^{0.5} \left(\frac{365-20}{365}\right)\left(10^{-3}\right)$$

$$= 48 \text{ Mg}$$

$$\text{Total emissions} = 319 + 48$$

$$= 367 \text{ Mg/yr}$$

11.5 Wind Erosion

SOURCE CODE: 27-30-100-000

DESCRIPTION:

During periods of high wind events, small dust particles may be entrained by the wind and emitted to the atmosphere as particulate matter. These emissions are typically associated with disturbed land, such as agricultural fields under cultivation, or large construction sites. In addition, emissions may result from vacant lots, road shoulders that contain loose dirt, and from unpaved roads. Natural lands that have not been disturbed are considered negligible sources of windblown dust. Sources that are not periodically disturbed also gradually lose their ability to emit windblown dust.

POLLUTANTS: PM_{10}

ROG: Not applicable.

POINT SOURCE ADJUSTMENTS: None.

METHODOLOGY:

The current emission estimating technique for this category is based on a modified version of the soil erodibility equation developed by the U.S. Department of Agriculture (U.S. EPA, 1977). The following equation presents the modified USDA approach.

$$E_s = (FS)\ I\ C\ K\ L\ \ V \qquad (11.5\text{-}1)$$

where:
E_s = suspended PM emission factor (tons/acre/year);
FS = fraction of total wind erosion losses measured as suspended PM;
I = soil erodibility (tons/acre/year);
C = climatic factor (dimensionless);
K = surface roughness factor (dimensionless);
L = unsheltered field width factor (dimensionless); and
V = vegetative cover factor (dimensionless).

Fraction of Wind Erosion Loss - FS

This term represents the fraction of wind erosion losses that would be measured as suspended particulate. A certain amount of soil “creeps” along the ground and is not suspended in the atmosphere as an emission source. A value of 2.5%

is typically assumed for agricultural land, while 3.8% is used for unpaved roads and other areas. Of the suspended amount, approximately 50% is PM_{10}.

Soil Erodibility- I

The soil erodibility factor is a function of the soil texture or soil type. The soil type is obtained from soil maps of the area. An inventory region may have one or more soil types, and therefore have different degrees of soil erodibility in different parts of the region. Because of lack of information on the area boundaries of the soil types, the soil erodibility factor is generally based on the predominant soil type in the inventory region. Table 11.5-1 lists soil erodibility factors (I) for 12 predominant soil types.

Climatic Factor - C

The climatic factor, C, is dependent on wind speed and soil surface moisture. The rate of soil movement varies directly with the wind velocity and inversely with the soil surface moisture. The climatic factor is calculated from the following equation:

$$C = \frac{(.345)\ V^3}{\left[115 \sum_{i=1}^{12} \left(\frac{PM_i}{TM_i - 10} \right)^{\frac{10}{9}} \right]^2} \qquad (11.5\text{-}2)$$

where:
V = mean annual wind velocity (mph), corrected to 30 feet;
PM = monthly precipitation in inches; and
TM = average monthly temperature in degrees Fahrenheit (set equal to 28.4° if below 28.4°).

The climatic factor, more than the other factors in the windblown dust equation, quickly becomes less exact as an averaged value is applied to smaller areas and shorter time spans. It is also important to note that, given equivalent values for the other parameters, a 100 mph wind entrains 125 times as much particulate in an hour as a 20 mph wind. A year with severe wind storms can therefore have wind blown dust emissions four or five times greater than those of a year with no such storms.

Wind velocity is also an important parameter for developing temporally resolved emission estimates. The mean wind velocity cannot be used for this purpose because it is cubed in the equation.

Table 11.5-1

Soil Erodibility Factors for Various Soil Textural Classes

Predominant Soil Textural Class	Erodibility, I, tons/acre/yr
Sand[a]	220
Loamy sand[a]	134
Sandy loam[a]	86
Clay	86
Silty clay	86
Loam	56
Sandy clay loam[a]	56
Sandy clay[a]	56
Silt loam	47
Clay loam	47
Silty clay loam	38
Silt	38

[a] Very fine, fine, or medium sand

Source: U.S. EPA, 1977

The following example demonstrates this point.

Area A: Wind speed = 10 mph over 100% of time period
Area B: Wind speed = 40 mph over 25% of time period
0 mph over 75% of time period

Both areas have a numeric mean wind speed of 10 mph. In equation 11.5-2, the wind speed term for Area A has the value:

$$(10 \text{ mph})^3 \times 100\% = 1{,}000$$

While the wind speed term for Area B is:

((40 mph)^3 x 25%) + ((0 mph)^3 x 75%) = 16,000

Thus, while both areas have the same mean wind speed, Area B would actually suffer 16 times as much wind erosion as Area A. For this reason, the U.S. Soil Conservation Service weights its short term C factors with the fraction of the wind's annual mean energy velocity during the time period in question. The mean energy velocity (V_e) for a time period during which "n" measurements of the wind velocity (V) are taken at equal intervals is given as:

$$V_e = \left(\frac{\sum_{i=1}^{n} (V_i)^3}{n} \right)^{\frac{1}{3}} \qquad (11.5\text{-}3)$$

In calculating the wind blown dust emissions from California's South East Desert Air Basin, the U.S. EPA estimated the emissions resulting from each measured wind speed separately (Ono and Bird, 1987). This method is mathematically analogous to using the mean energy velocity. The mean energy velocity weighting technique should be used just as the U.S. Soil Conservation Service does if temporally resolved estimates are required.

In addition, neglecting the effects of irrigation in arid regions results in a C factor as much as an order of magnitude high for some crop types. The preferred method is to modify the C factor of each region for each crop. This involves gathering data on the average quantity of irrigation water required to raise each crop in each soil and temperature area. This irrigation water is added to the rainfall value used to calculate the C factor.

Surface Roughness Factor - K

The surface roughness factor, K, accounts for the resistance of wind blowing over ridges, furrows, or large clods in a field. For regional areas, K is a function of crop type, because field preparation techniques are relatively uniform for a specified crop. Values of K are listed in Table 11.5-2. Since Table 11.5-2 lists only a limited number of field crops, some of the crops must be assigned the same value as the ones on the list, based on the type of crop.

For unpaved roads, the value of K is set equal to 1.0 (i.e., there are minimal ridges/furrows on unpaved roads).

Unsheltered Field Width Factor - L

Soil erosion across a field is directly related to the unprotected width of the field in the prevailing wind direction. Knowing the unsheltered width of the field (L), and the surface erodibility (IK), the L factor is obtained using the graph on Figure 11.5-1 (U.S. EPA, 1977). Values of L for common field crops are listed in Table 11.5-2.

A similar situation exists for unpaved roads. The actual value of L varies with the angle of the wind to the road. Over the long term, it can be assumed that L for a given road surface in the prevailing wind direction varies continually. To assess an average effective distance factor, it may be assumed that in the long term, wind direction is equally distributed for all roads. Any error in this assumption is offset by the probable assumption that roads are distributed in all different directions. With these assumptions, L becomes a function of IK as shown below:

IK	Average L
40	0.29
60	0.32
80	0.34

Vegetative Cover Factor - V

Vegetative cover such as crop residue (stubble or mulch) on agricultural fields during periods other than the primary crop season greatly reduces wind erosion of the soil. The V factor is the fractional amount of annual soil loss which results when the field has vegetative cover. It is estimated from Figure 11.5-2 (U.S. EPA, 1977). The amount of vegetative cover, V, is the amount in pounds of air-dried residue left on a field per acre. Values of V for common field crops are obtained from Table 11.5-2.

Knowing the values of I, K, C, L, and V, the V factor is obtained from Figure 11.5-2.

For unpaved roads, V is equal to 1.0.

Figure 11.5-1. Effect of Field Length on Relative Emission Rate (not available).

Table 11.5-2

Values of K, L, and V for Common Field Crops

Crop	K	L, ft	V, lb/acre
Alfalfa	1.0	1,000	3,000
Barley	0.6	2,000	1,100
Beans	0.5	1,000	250
Corn	0.6	2,000	500
Cotton	0.5	2,000	250
Grain hays	0.8	2,000	1,250
Oats	0.8	2,000	1,250
Peanuts	0.6	1,000	250
Potatoes	0.8	1,000	400
Rice	0.8	1,000	1,000
Rye	0.6	2,000	1,250
Safflower	1.0	2,000	1,500
Sorghum	0.5	2,000	900
Soybeans	0.6	2,000	250
Sugar beets	0.6	1,000	100
Vegetables	0.6	500	100
Wheat	0.6	2,000	1,350

Source: U.S. EPA, 1977

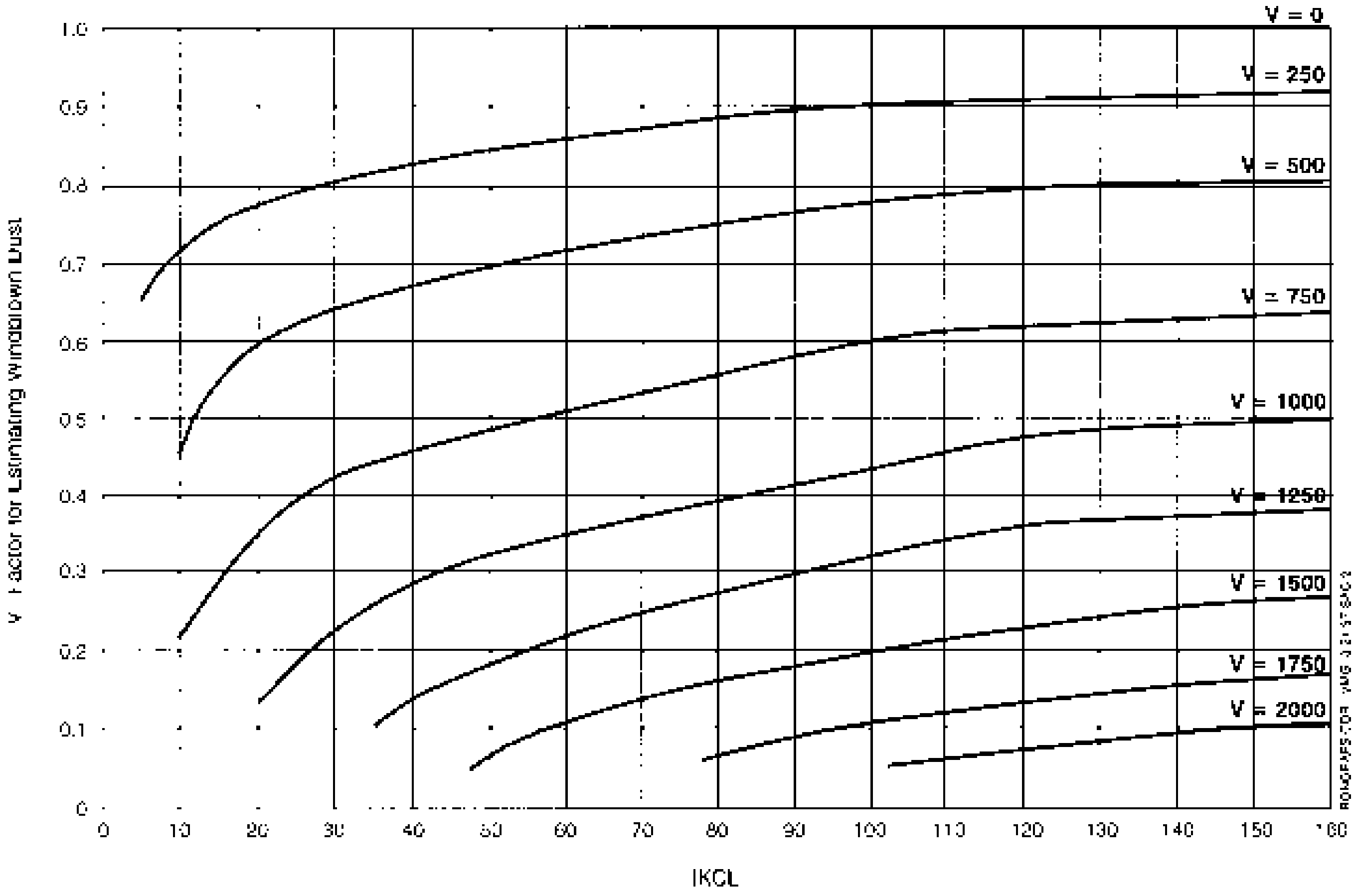

Figure 11.5-2. Effect of Vegetative Cover on Relative Emission Rate

DATA NEEDED:

Data	Sources
Meteorological Data	1. National Institute of Statistics, Geography and Computer Science (INEGI) 2. National Meteorological and Atmospheric Science Center at the National University (UNAM) 3. Servicio Meterológico Nacional dependiente de la Comisión National del Agua.
Crop Acreage	SAGAR, INEGI

NOTES:

1. The emission estimating technique presented here is thought to provide highly uncertain, and possibly misleading results. The U.S. EPA is currently sponsoring the development a new methodology for this emission source.

SAMPLE CALCULATION:

Determine the windblown dust emissions from an area that has 1,000 acres of tomatoes under cultivation. The soil for this area has been determined to be sandy loam. The climatic factor (C) is calculated to be 0.30 (including irrigation).

From Table 11.5-1, the erodibility (I) is 86 tons/acre/yr. From Table 11.5-2, the values of (K), (L), and (V) are taken for vegetables:

- $K = 0.6$;
- $L = 500$ ft; and
- $V = 100$ lb/acre.

The product of (IK) is 52. Using this value of (IK) and (L) of 500 feet yields an (L) value of 0.57 based on the information presented in Figure 11.5-1.

To determine (V), first calculate the product of (IKCL). This value is 8.9. From Figure 11.5-2, read V as approximately 0.85. From these data, the annual suspended particulate emissions per acre are:

$$\begin{aligned} E_s &= FS\ I\ CK\ L\ \ V \\ &= (0.025)\ (86)\ (0.30)\ (0.6)\ (0.57)\ (0.85) \\ &= 0.19 \text{ tons/acre/year} \end{aligned}$$

The annual emissions of PM_{10} are:

$$\begin{aligned} EE &= (\text{Area})\ (E_s)\ (0.50) \\ &= (1{,}000)\ (0.19)\ (0.50) \\ &= 95 \text{ tons/year of } PM_{10} \end{aligned}$$

11.6 Domestic Ammonia Emissions

SOURCE CODE:	**DESCRIPTION**:
27-10-020-020	Dogs
27-10-020-010	Cats
28-10-010-000	Human Respiration
28-10-010-000	Human Perspiration
28-10-010-000	Household Ammonia Use
28-10-060-000	Cigarette Smoke
28-10-010-000	Diapers
28-10-010-000	Human Waste - Homeless
28-10-010-000	Human Waste - Other

DESCRIPTION:

This category consists of various domestic ammonia (NH_3) sources, including pet waste, human perspiration and respiration, household ammonia use, cigarette smoke, and untreated human waste. Individually, emissions from these sources are relatively small. Collectively, however, emissions from these sources can be significant.

POLLUTANTS: NH_3

ROG: Not Applicable.

POINT SOURCE ADJUSTMENTS: None.

METHODOLOGY:

For ammonia emissions from pets (dogs and cats), emission estimates can be made using the following equation:

$$\text{Emissions}_p = \text{Population} \times PR_p \times EF_p \qquad (11.6\text{-}1)$$

where:

Emissions_p = Annual emissions for pet type, p;
Population = Total population within region;
PR_p = Pet ratio (number of pets per 1,000 people) for pet type, p; and
EF_p = Emission factor for pet type, p.

Typical U.S. pet ratios are given in Table 11.6-1. These are the only data readily available. To the extent possible, Mexico-specific data should be developed and used to replace these values.

Table 11.6-1

Typical Pet Ratios for Various Regions

Type of Region	Pet Ratio - Dogs (pets/1,000 people)	Pet Ratio - Cats (pets/1,000 people)	Reference
Urban (> 800,000 inhabitants)	122	83	Coe et al, 1996
Suburban (200,000-800,000 inhabitants)	167	111	
Rural (< 200,000 inhabitants)	220	133	

For ammonia emissions from cigarette smoking, emissions can be estimated using the following equation:

$$\text{Emissions} = \text{Cigarettes} \times \text{EF} \qquad (11.6\text{-}2)$$

where: Cigarettes = Number of cigarettes sold within the region.

For all other types of ammonia sources, emissions can be estimated using the following equation:

$$\text{Emissions}_s = \text{Population}_s \times \text{EF}_s \qquad (11.6\text{-}3)$$

where: Emissions_s = Annual emissions from source type, s;

Population_s = Applicable population within region for source type, s (Overall population for human perspiration and respiration, household ammonia use, and human waste [other]; homeless population for human waste [homeless]; and infants under 3 years of age for diapers); and

EF_s = Emission factor for source type, s.

DATA NEEDED:

Data		Sources
Overall Population		INEGI
Homeless Population		INEGI or local officials
Population (under age of 3 years)		INEGI
Pet Ratio		Table 11.6-1
Number of Cigarettes Sold		INEGI or local officials
Emission Factors:		Radian, 1991
Dogs	2.49 kg/head-yr	
Cats	0.82 kg/head-yr	
Cigarettes	5.2 mg/cigarette	
Human Perspiration	0.25 kg/person-yr	
Human Respiration	0.0016 kg/person-yr	
Household Ammonia Use	0.023 kg/person-yr	
Diapers (Cloth)	3.13 kg/infant-yr	
Diapers (Disposable)	0.16 kg/infant-yr	
Human Waste (Homeless)	4.99 kg/person-yr	
Human Waste (Other)	0.023 kg/person-yr	

NOTES:

1. The pet ratios presented in Table 11.6-1 are based upon dog and cat population studies performed in California during the 1970s. These pet ratios might not be applicable for Mexico. New statistics for Mexico can be obtained from either veterinary offices or through surveys. See the Basic Emission Estimating Techniques Manual for the survey methodology.

2. The use of disposable diapers has increased significantly in Mexican cities and urban areas; cloth diapers are still used considerably in rural areas.

SAMPLE CALCULATION:

Estimate the total annual ammonia emissions from a municipality of 175,000 people (defined as a rural area in Table 11.6-1).

Assume that 15% of the population smokes (average of 20 cigarettes/day). Assume that infants make up 3% of the population and all of them wear disposable diapers. Finally, assume that there are no homeless people.

Dogs: The pet ratio for rural areas is 220 dogs per 1,000 people.

$$\text{Emissions} = (175{,}000 \text{ people}) \left(\frac{220 \text{ dogs}}{1{,}000 \text{ people}} \right) \left(\frac{2.49 \text{ kg } NH_3}{\text{dogs} - \text{yr}} \right) = 95{,}865 \text{ kg}$$

Cats: The pet ratio for rural areas is 133 cats per 1,000 people.

$$\text{Emissions} = (175{,}000 \text{ people}) \left(\frac{133 \text{ cats}}{1{,}000 \text{ people}} \right) \left(\frac{0.82 \text{ kg}}{\text{cat} - \text{yr}} \right) = 19{,}086 \text{ kg}$$

Cigarettes:

$$\text{Emissions} = (175{,}000 \text{ people}) (0.15) \left(\frac{20 \text{ cigarettes}}{\text{day}} \right) \left(\frac{365 \text{ days}}{\text{yr}} \right) \left(\frac{5.2 \text{ mg}}{\text{cigarette}} \right) = 996 \text{ kg}$$

Human Perspiration:

$$\text{Emissions} = (175{,}000 \text{ people}) \left(\frac{0.25 \text{ kg}}{\text{person} - \text{yr}} \right) = 43{,}750 \text{ kg}$$

Human Respiration:

$$\text{Emissions} = (175{,}000 \text{ people}) \left(\frac{0.0016 \text{ kg}}{\text{person} - \text{yr}} \right) = 280 \text{ kg}$$

Household Ammonia Use:

$$\text{Emissions} = (175{,}000 \ \text{people}) \left(\frac{0.023 \ \text{kg}}{\text{person}-\text{yr}} \right) = 4{,}025 \ \text{kg}$$

Diapers (Disposable):

$$\text{Emission} = (175{,}000 \ \text{people}) \ (0.03) \left(\frac{0.16 \ \text{kg}}{\text{person}-\text{yr}} \right) = 840 \ \text{kg}$$

Human Waste (Other):

$$\text{Emission} = (175{,}000 \ \text{people}) \left(\frac{0.023 \ \text{kg}}{\text{person}-\text{yr}} \right) = 4{,}025 \ \text{kg}$$

$$\begin{aligned}\text{Total Ammonia Emissions} &= 95{,}865 + 19{,}086 + 996 + 43{,}750 + 280 + 4{,}025 + 840 + 4{,}025 \\ &= 168{,}867 \ \text{kg/yr} \\ &= 168.9 \ \text{Mg/yr}\end{aligned}$$

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APPENDIX V-A

AREA SOURCE CATEGORY CODES

APPENDIX V-B

INDUSTRIAL, COMMERCIAL, INSTITUTIONAL FUEL COMBUSTION EMISSION FACTORS (FROM AP-42)

APPENDIX V-C

NON-ROAD MOBILE EQUIPMENT ACTIVITY DATA AND EMISSION FACTORS

APPENDIX V-D

PAVED ROAD SAMPLING DATA (FROM AP-42)

DCN 97-670-017-05
RCN 670-017-51-02

MANUALES DEL PROGRAMA DE INVENTARIOS DE EMISIONES DE MEXICO

VOLUMEN V - DESARROLLO DE INVENTARIOS DE EMISIONES DE FUENTES DE AREA

FINAL

Elaborado para:

La Asociación de Gobernadores del Oeste
Denver, Colorado

y

El Comité Asesor Binacional

Elaborado por:

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10389 Old Placerville Road
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Marzo 31, 1997

PREFACIO

La contaminación del aire puede tener impactos negativos sobre la salud pública cuando su concentración en la atmósfera alcanza niveles significativos. En la mayor parte de las áreas rurales los problemas de calidad del aire se dejan sentir sólo en raras ocasiones mientras que muchos ambientes urbanos con frecuencia registran elevadas concentraciones de contaminantes. Durante los últimos años, México ha tenido un gran crecimiento en la urbanización y en la actividad industrial, lo que ha generado serias preocupaciones acerca de la calidad del aire en diversas regiones del país.

La contaminación del aire resulta de una compleja mezcla de, literalmente, miles de fuentes, que van desde las chimeneas industriales y los vehículos automotores, hasta el uso individual de productos de aseo, limpiadores domésticos y pinturas; incluso la vida animal y vegetal puede desempeñar un papel importante en el problema. Debido a la compleja naturaleza de la contaminación del aire se requieren planes regionales detallados para identificar las fuentes de emisión, así como el desarrollo de métodos para reducir el impacto sobre la salud ocasionado por la exposición a los contaminantes. Entre algunos ejemplos de las actividades de gestión de la calidad del aire se encuentran:

- La aplicación de modelos de calidad del aire
- El examen de las fuentes emisoras de contaminantes para analizar el control de emisiones, cuando así se requiere
- El desarrollo de proyecciones de las emisiones para examinar posibles cambios en la futura calidad del aire

- El análisis de las tendencias de emisión
- El análisis del transporte de las emisiones de una región a otra.

El desarrollo de inventarios de emisión bien fundamentados es un aspecto clave en cada una de estas funciones de gestión de la calidad del aire.

El cálculo de estimaciones de emisión que cumplan con las necesidades de la gestión de la calidad del aire requiere de un desarrollo y refinamiento continuos; los esfuerzos de inventarios “de un solo paso” no son adecuados para el proceso de gestión de la calidad del aire. Para obtener un beneficio de larga duración debe instrumentarse un *programa de inventarios,* de manera que sea posible el desarrollo de estimaciones exactas de las emisiones para todas las regiones geográficas de importancia, que tengan la capacidad de ser refinadas con el paso del tiempo y que puedan aplicarse efectivamente en el proceso de gestión y monitoreo de la calidad del aire. De esta manera, se está desarrollando un conjunto de manuales de inventarios que puedan ser aplicados en todo el país para ayudar a coordinar el desarrollo de estimaciones de emisiones consistentes. Estos manuales han sido diseñados para ser utilizados por las autoridades locales, estatales y federales, así como por consultores privados e industriales. El propósito de estos manuales es ayudar en el proceso de instrumentación del programa de inventarios y en su mantenimiento a lo largo del tiempo, de manera tal que los inventarios de emisiones se puedan desarrollar en ciclos periódicos mejorándolos continuamente.

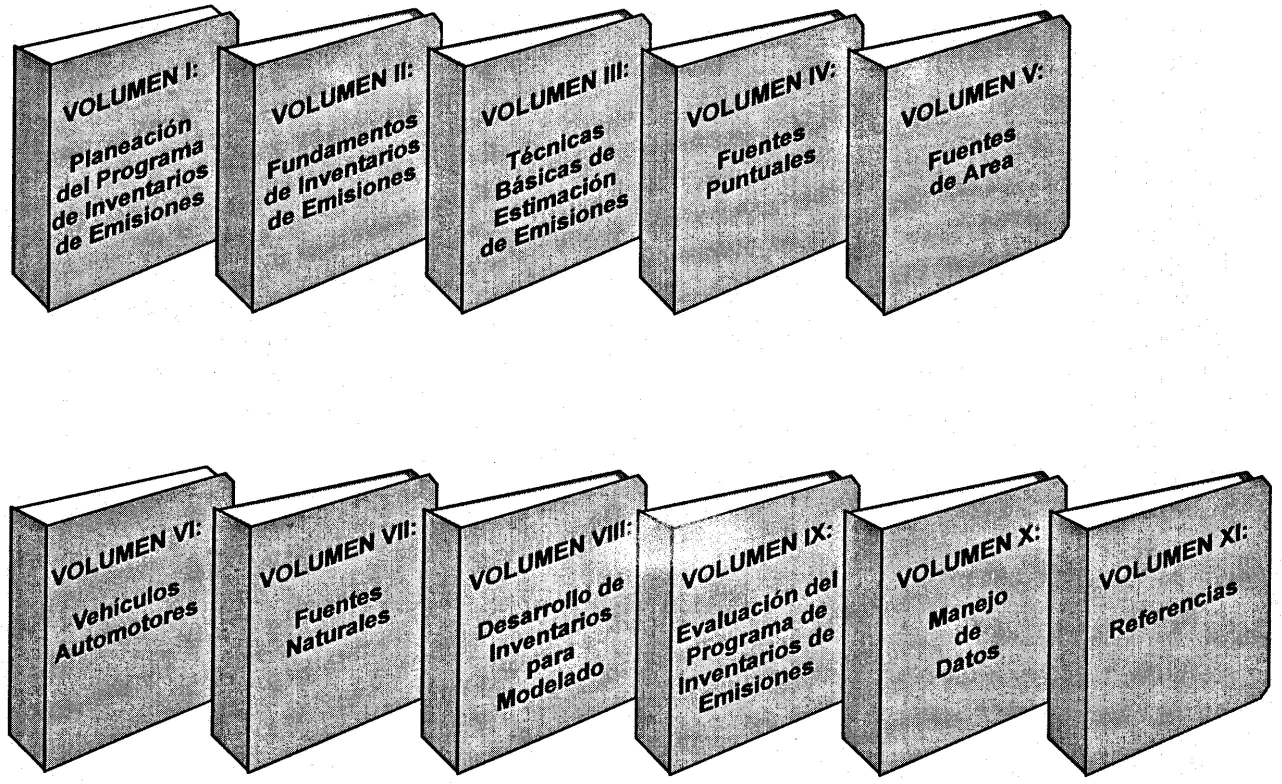

Figura 1. Manuales del Programa de Inventarios de Emisiones de México

Los manuales abarcan elementos del programa de inventarios tales como la estimación de emisiones, la planeación del programa, manejo de bases de datos, validación de emisiones y otros temas de importancia. La Figura 1 muestra la serie completa de manuales que serán desarrollados para apoyar un programa de inventarios de largo alcance. A continuación se resume el propósito principal de cada manual.

Volumen I - Planeación del Programa de Inventarios de Emisiones. Este manual presenta los aspectos de gestión que deben ser considerados en un programa de inventario de emisiones al aire. La planeación del programa no se presenta como una actividad "terminal", sino más bien como un proceso continuo para asegurar el crecimiento en el largo plazo y el éxito del programa de inventarios. *Temas Clave:* propósito del programa; usos finales del inventario; requerimientos regulatorios; coordinación en los niveles federal, estatal y local; requerimientos de personal y de manejo de datos; identificación y selección de estudios especiales.

Volumen II - Fundamentos de Inventarios de Emisiones. Este manual presenta los fundamentos básicos para el desarrollo de inventarios de emisiones, así como los elementos que son aplicables a los diversos tipos de fuentes (e. g., puntuales y de área), para evitar la necesidad de que sean repetidos en cada volumen. *Temas Clave*: regulaciones aplicables; efectividad de la regla; penetración de la regla; definiciones sobre contaminantes (e. g., cómo excluir de manera adecuada los compuestos volátiles no reactivos); definición de fuentes puntuales y de área; reconciliación de fuentes puntuales y de área.

Volumen III - Técnicas Básicas de Estimación de Emisiones (TEEs). Este documento presenta las TEEs básicas utilizadas para hacer estimaciones de emisiones, incluyendo ejemplos y cálculos como muestra. Por otro lado se identifican las herramientas para inventarios asociadas con cada metodología y se incluyen en el Volumen XI (Referencias). *Temas Clave*: muestreo en la fuente, modelos de emisiones, encuestas, factores de emisión, balance de materiales y extrapolación.

Volumen IV - Fuentes Puntuales. Este manual proporciona guías para elaborar inventarios de emisiones de fuentes puntuales. Incluye una tabla de referencias cruzadas para cada combinación de industria y tipo de dispositivo (e. g., refinación de petróleo y dispositivos de combustión), con una o más de las TEEs presentadas en el Volumen III. *Temas Clave:* tabla de referencias cruzadas; parámetros de chimenea; dispositivos de control; consideraciones de diseño y de proceso; diferencias geográficas y variabilidad en México; aseguramiento y control de calidad (AC/CC); procesos omitidos; referencias de datos y formas para recopilación de datos.

Volumen V - Fuentes de Area (incluyendo fuentes móviles que no circulan por carreteras). Este manual contiene los lineamientos para el desarrollo de inventarios de emisiones de fuentes de área. Además de presentar información general sobre las fuentes de área, se proporciona una tabla de referencias cruzadas entre cada categoría de fuente de área (e. g., aplicación de asfalto) con una o más de las TEEs básicas incluidas en el Volumen III. Posteriormente, se discute la información específica para cada categoría de fuente definida en la tabla. *Temas Clave:* categorización y definición de fuentes de área; tabla de referencias cruzadas; factores de control; diferencias geográficas y variabilidad en México; AC/CC; referencias de datos; formas para recopilación de datos (cuestionarios).

Volumen VI - Vehículos Automotores. Debido a que los vehículos automotores son intrínsecamente diferentes a las fuentes puntuales y a las de área, tanto los métodos de estimación disponibles como los datos requeridos son también diferentes. Los modelos han sido las herramientas preferidas para estimar las emisiones de estas complejas fuentes. Muchos de estos modelos utilizan datos de pruebas extensivas aplicables a un país o a una región determinados. Este manual se enfoca principalmente en la fase de desarrollo de datos para la estimación de emisiones de vehículos automotores. *Temas Clave:* métodos de estimación disponibles; datos e información primarios, secundarios y terciarios; clasificación de fuentes; fuentes de factores de emisión; variabilidad geográfica dentro de México, AC/CC.

Volumen VII - Fuentes Naturales. Este manual proporciona los lineamientos para el desarrollo de inventarios de emisiones de fuentes naturales (e. g., compuestos orgánicos volátiles biogénicos [COVs] y óxidos de nitrógeno [NO_x]) en suelos. Además, incluye los aspectos teóricos de los cálculos de emisiones y la discusión de modelos específicos. *Temas Clave:* clasificación y definición de fuentes; mecanismos de emisión; algoritmos básicos de emisión; determinación de biomasa; desarrollo de datos de uso y cobertura del suelo; ajustes temporales y meteorológicos; enfoques para el cálculo de emisiones.

Volumen VIII - Desarrollo de Inventarios para Modelado. Este manual proporciona los lineamientos para el desarrollo de datos de inventarios que serán utilizados en modelos de calidad del aire, y trata aspectos tales como la localización temporal y espacial, la especiación y la proyección de estimaciones de emisiones. *Temas Clave:* definición de términos de modelado; ajuste estacional; localización temporal y espacial; especiación química y proyecciones (factores de crecimiento y control).

Volumen IX - Evaluación del Programa de Inventarios de Emisiones. Este manual consta de tres partes: AC y CC, análisis de incertidumbre y verificación de emisiones. La parte de AC y CC define el programa global de aseguramiento y control de calidad, y ha sido escrito para complementar los procedimientos de AC y CC para fuentes específicas que se presentan en otros manuales. El análisis de incertidumbre no sólo incluye métodos para evaluar la incertidumbre en las estimaciones de emisiones, sino también para evaluar la incertidumbre en los valores de modelado tales como los perfiles de especiación y los factores de proyección de emisiones. La sección de verificación de emisiones describe varios análisis para evaluar la exactitud de las estimaciones. Los ejemplos incluyen modelos de receptores y análisis de trayectoria, combinados con técnicas específicas para el análisis de datos. *Temas Clave:* descripción de conceptos y definición de términos; protocolo de revisión de inventarios; evaluación de integridad, exactitud y consistencia; TEEs de incertidumbre recomendadas, y metodología aplicable para la verificación de emisiones.

Volumen X - Manejo de Datos. Este manual trata de las necesidades asociadas con los aspectos del manejo de datos del programa nacional de inventarios de emisiones de México. *Temas Clave:* sistemas y herramientas generales para el manejo de datos; sistemas y herramientas de software específicos; sistemas de codificación; confidencialidad; presentación electrónica; frecuencia de actualizaciones, mantenimiento de registros; bases de datos específicas de México y reportes.

Volumen XI - Referencias. Este manual es un compendio de las herramientas que pueden utilizarse en el desarrollo de un programa de inventarios de emisiones. Se incluyen las herramientas citadas para hacer inventarios en los otros manuales (e. g., documentos impresos y electrónicos, así como modelos de computadora).

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APENDICE V-B: FACTORES DE EMISION DE PROCESOS DE COMBUSTION INDUSTRIALES, COMERCIALES E INSTITUCIONALES (TOMADOS DEL AP-42)

APENDICE V-C: DATOS DE ACTIVIDAD Y FACTORES DE EMISION PARA EQUIPO MOVIL QUE NO CIRCULA POR CARRETERAS

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FIGURAS Y TABLAS

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ACRONIMOS

AC	Aseguramiento de Calidad
ADT	average daily traffic *(tráfico diario promedio)*
ANAFAPYT	Asociación Nacional de Fabricantes de Pinturas y Tintas
ARB	Air Resources Board *(Consejo de Recursos del Aire)*
ASA	Aeropuertos y Servicios Auxiliares
Btu	British thermal unit *(Unidad Térmica Británica)*
CANACINTRA	Cámara Nacional de la Industria de la Transformación
CANALAVA	Cámara Nacional de la Industria de Lavanderías
CC	Control de Calidad
CE-CERT	College of Engineering - Center for Environmental Research and Technology *(Colegio de Ingeniería - Centro de Investigación y Tecnología Ambiental)*
CFC	Clorofluorocarbono
CICA	Centro de Información sobre Contaminación del Aire
CICOPLAFEST	Comisión Intersecretarial para el Control del Proceso y Uso de los Plaguicidas, Fertilizantes y Sustancias Tóxicas
cm	Centímetro
CO	monóxido de carbono
COV	Compuesto orgánico volátil
CH_4	metano
DBO	Demanda Biológica de Oxígeno
DDF	Departamento del Distrito Federal
DQO	Data Quality Objective *(Objetivo de Calidad de los Datos)*
EC	Eficiencia de control
EET	técnicas de estimación de emisiones
EIIP	Emission Inventory Improvement Program *(Programa para el Mejoramiento de los Inventarios de Emisión)*
ER	Efectividad de la regla
EU	Estados Unidos
FAA	Federal Aviation Administration *(Administración Federal de Aviación)*

FAEED	Federal Aircraft Engine Emission Database *(Base de Datos Federal de Emisiones de Motores de Aeronaves)*
FE	factor de emisión
FNM	Ferrocarriles Nacionales de México
g	gramo
Gas LP	Gas Licuado de Petróleo
GEM	Gobierno del Estado de México
GOR	Gas orgánico reactivo
GOT	Gas orgánico total
gr	grano
ha	hectárea
HC	hidrocarbono
HCFC	hidrofluorocarbono
HCT	hidrocarburos totales
HDDV	heavy duty diesel vehicles (*vehículos pesados a diesel)*
HDGV	heavy duty gasoline vehicles *(vehículos pesados a gasolina)*
hp	caballo de fuerza
hr	hora
IC	combustión Interna
IMP	Instituto Mexicano del Petróleo
INE	Instituto Nacional de Ecología
INEGI	Instituto Nacional de Estadística, Geografía e Informática
kcal	kilocaloría
kg	kilogramo
km	kilómetro
kph	kilómetros por hora
lb	libra
LDDT	light duty diesel trucks *(camiones ligeros a diesel)*
LDDV	light duty diesel vehicles *(vehículos ligeros a gasolina)*
LDGT	light duty gasoline trucks *(camiones ligeros a gasolina)*
LDGV	light duty gasoline vehicles *(vehículos ligeros a gasolina)*
AD	Aterrizaje y despegue
m^3	metro cúbico
MC	motocicleta

Mg	megagramo (i.e., 10^6 g = 1 tonelada métrica)
mg	miligramo
mm	milímetro
mm Hg	milímetros de mercurio
mol	mole
mph	millas por hora
ND	No Disponible
NFDR	National Fire Danger Rating *(Clasificación Nacional del Peligro de Incendio)*
NH_3	Amoniaco
NMHC	non-methane hydrocarbons *(hidrocarburos no metano)*
NO	Monóxido de nitrógeno (óxido nítrico)
NO_2	Dióxido de nitrógeno
NO_x	Oxidos de nitrógeno
N-P-K	Nitrógeno-Fósforo-Potasio
O_2	Oxígeno
PEMEX	Petróleos Mexicanos
PM	Material Particulado (partículas)
PM_{10}	Partículas de diámetro inferior o igual a 10 micrómetros
$PM_{2.5}$	Partículas de diámetro inferior o igual a 2.5 micrómetros
POTWs	publicly owned treatment works *(Obras de Tratamiento de Propiedad Pública)*
ppmw	partes por millón en peso
PRRP	Penetración de la regla
psi	libras por pulgada cuadrada
psia	libras por pulgada cuadrada absoluta
RVP	Presión de vapor Reid
S	Factor de saturación
S	Azufre
SAF	Seasonal Adjustment Factor *(Factor de Ajuste Estacional)*
SAF	Sociedad de Silvicultores Americanos
SAGAR	Secretaría de Agricultura, Ganadería y Desarrollo Rural
SCAQMD	South Coast Air Quality Management District *(Distrito para el Manejo de la Calidad del Aire de la Costa Sur)*

SCERP	Southwest Center for Environmental Research and Policy *(Centro del Suroeste para la Investigación y Política Ambiental)*
SEMARNAP	Secretaría de Medio Ambiente, Recursos Naturales y Pesca
SIG	Sistema de Información Geográfica
SIMS	Surface Impoundment Modeling System *(Sistema de Modelado de Estanques Superficiales)*
SNIFF	Sistema Nacional de Información de Fuentes Fijas
SO_2	Dióxido de azufre
SO_x	Oxidos de axufre
SRM	Society for Range Management *(Sociedad de Manejo de Praderas)*
TIM	Tiempo en Modo
TOC	Compuestos orgánicos totales
ton	Tonelada inglesa (i.e., 2,000 lb)
UNAM	Universidad Nacional Autónoma de México
US EPA	United States Environmental Protection Agency *(Agencia de Protección Ambiental de EU)*
USDA	United States Department of Agriculture *(Departamento de Agricultura de EU)*
VKT	Kilómetros recorridos por vehículo
vol	Volumen
wt	Peso
yr	Año
ZFN	Zona Fronteriza Norte
ZMCM	Zona Metropolitana de la Ciudad de México
ZMG	Zona Metropolitana de Guadalajara
ZMM	Zona Metropolitana de Monterrey
ZMVM	Zona Metropolitana del Valle de México

1.0 INTRODUCCION

Este manual proporciona una guía para el desarrollo de un inventario de emisiones de fuentes de área y de fuentes móviles que no circulan por carreteras (en lo sucesivo denominadas colectivamente “fuentes de área”). La guía abarca los métodos de inventario, incluyendo las fuentes de datos de actividad y factores de emisión aplicables. Se presenta información general sobre las fuentes de área y las móviles que no circulan por carretera, seguida por una tabla de referencia cruzada que asocia cada categoría de fuente con una o más de las técnicas básicas de estimación de emisiones (TEEs) contenidas en el Volumen III de esta serie de documentos. El *Manual de TEEs Básicas* explica y discute cada una de las técnicas básicas y presenta ejemplos de los cálculos para ilustrar su instrumentación.

Las fuentes de área representan las emisiones de fuentes que son demasiado numerosas y dispersas para ser incluidas de manera eficiente dentro de un inventario de fuentes puntuales. En conjunto, sin embargo, las fuentes de área son emisores significativos de contaminantes al aire, y dichos contaminantes deben ser incluidos en un inventario de emisiones para garantizar que esté completo. Las fuentes móviles que no circulan por carreteras son incluidas con las fuentes estacionarias de área, debido principalmente a que los métodos utilizados para estimar sus emisiones son muy similares a los aplicados para fuentes estacionarias de área. Por otro lado, la metodología de inventario utilizada para vehículos automotores es difiere de manera significativa, lo que amerita su presentación en un manual independiente.

Por definición, en consecuencia, las fuentes de área en general son pequeñas y numerosas. Por ejemplo, las gasolineras y establecimientos de lavado en seco a menudo son tratados como fuentes de área. Dichas instalaciones no son típicamente incluidas en los inventarios de fuentes puntuales debido al enorme esfuerzo que sería requerido para recopilar los datos y estimar las emisiones de cada establecimiento individual. Una manera de definir las fuentes de área se basa en un nivel de emisión de un contaminante determinado en un establecimiento individual (e. g., en EU, si las emisiones de hidrocarburos *a nivel de establecimiento* para un contaminante determinado son menores a 10 toneladas anuales, o menores a 100 toneladas anuales de óxidos de nitrógeno (NO_x), monóxido de carbono (CO), o dióxido de azufre (SO_2), dicho establecimiento es considerado como fuente de área). El uso final del inventario, la precisión deseada en las emisiones y los recursos disponibles para el desarrollo del inventario, son factores que pueden determinar el punto de corte entre las fuentes puntuales y de área. Si el punto de corte es demasiado alto, muchos establecimientos no serán considerados individualmente como fuentes puntuales, y sus emisiones serán omitidas, o bien, sus emisiones podrían ser estimadas con menor precisión. Si el punto de corte es demasiado bajo, los recursos necesarios para contactar a las plantas y el tamaño de la base de datos de las fuentes puntuales se incrementarán de manera significativa.

Más que distinguir entre los establecimientos individuales y los equipos emisores, que es el método aplicado en un inventario de fuentes puntuales, los inventarios de fuentes de área colocan a las emisiones de fuentes similares dentro de *categorías*. Un inventario de fuentes de área, en general, consiste de las siguientes y amplias categorías:

- Combustión en fuente estacionaria (e. g., combustión doméstica)

- Fuentes móviles que no circulan por carreteras (e. g., trenes y equipo móvil)

- Uso de solventes (e. g., pequeñas operaciones de recubrimiento de superficies)

- Almacenamiento, transporte y distribución de productos (e. g., gasolina)
- Fuentes industriales ligeras y comerciales.

- Agricultura (e. g., corrales de engorda, quema agrícola)

- Manejo de residuos (e. g., rellenos sanitarios)

- Fuentes de área misceláneas (e. g., incendios forestales, erosión eólica, caminos no pavimentados).

Cada una de estas categorías está integrada por subcategorías de fuente más específicas (e. g., el uso de solventes orgánicos incluye el uso comercial y doméstico, el lavado en seco y el lavado de superficies), que son definidas por un proceso de emisión similar, o bien por la similitud de los métodos para una mejor estimación de las emisiones. Un extenso inventario de fuentes de área puede contener 150 o más categorías de fuentes individuales. Por ejemplo, la limpieza en seco típicamente está representada por dos o más categorías de fuente para abarcar los diferentes solventes que son utilizados (i. e., percloroetileno vs. los solventes con base de petróleo).

Desde la perspectiva de una estimación de emisiones, las categorías de fuentes de área pueden ser organizadas en los siguientes cuatro grupos:

Operaciones Primarias de Manufactura. Los establecimientos de manufactura que son demasiado pequeños para ser incluidos en el inventario de fuentes puntuales (e. g., tortillerías o ladrilleras) pueden ser inventariados como fuentes de área a través de la aplicación de una encuesta a un subconjunto de estos establecimientos y la extrapolación de los resultados a toda la industria, con base en algún factor que se asuma asociado con las emisiones (e. g., número de empleados, magnitud de producción, etc.).

Operaciones Clave de Proceso. Otra categoría de fuentes de área está integrada por las operaciones de proceso que son manejadas como un grupo sin intención de identificar el tipo de establecimiento y los productos manufacturados. El desengrasado industrial es un ejemplo de este tipo de categoría. Estas emisiones resultan del solvente utilizado en las tinas, el asperjado y limpieza de matrices, u otras operaciones en una amplia variedad de establecimientos, que harían impráctica la identificación del uso del desengrasado por sector industrial.

Actividades Humanas No Industriales. El siguiente grupo de categorías de área incluye las emisiones que se presentan sobre extensas regiones geográficas y que son resultado de alguna forma de actividad humana. Dos ejemplos incluyen el uso de pesticidas, y la aplicación comercial o doméstica de solventes.

Fuentes Móviles que No Circulan Por Carretera. Estas constituyen el último tipo de fuente. En general, son definidas por tener motores de combustión interna y ser móviles, pero no contar con licencias típicas para ser operadas en caminos públicos. Las categorías más evidentes de fuentes móviles que no circulan por carretera son las aeronaves, locomotoras y embarcaciones marítimas comerciales; otras incluyen al equipo agrícola, de construcción y recreativo, por ejemplo, tractores, motoconformadoras y botes.

El resto de este manual está organizado de la manera siguiente:

- La sección 2.0 presenta una guía para elaborar un inventario de fuentes de área, incluyendo las descripciones de fuentes de emisión y técnicas de estimación de emisiones

- La Sección 3.0 presenta la tabla de referencia para fuentes de área y fuentes móviles que no circulan por carreteras, relacionando los métodos de estimación de emisiones discutidos en el Volumen III de la serie, *Técnicas Básicas de Estimación de Emisiones*, con las categorías específicas de fuentes de área

- Las secciones 4.0 a 11.0 presentan cada categoría fuentes de área y de fuentes móviles que no circulan por carreteras, incluyendo una descripción de la categoría, los factores de emisión disponibles, una guía sobre las fuentes de datos de actividades potenciales, y un ejemplo de cálculos.

  Las diferentes categorías de fuentes de área y móviles que no circulan por carreteras están estructuradas de la siguiente manera:

  - Sección 4.0 - Fuentes Estacionarias de Combustión
  - Sección 5.0 - Fuentes Móviles que No Circulan por Carreteras
  - Sección 6.0 - Uso de Solventes
  - Sección 7.0 - Almacenamiento y Transporte de Productos
  - Sección 8.0 - Fuentes Industriales Ligeras y Comerciales
  - Sección 9.0 - Agricultura
  - Sección 10.0 - Manejo de Residuos,
  - Sección 11.0 - Fuentes de Area Misceláneas.

- La Sección 12.0 contiene las referencias citadas en este volumen.

NOTA: Los datos de actividad (e. g., población, combustible quemado, solvente utilizado, superficie, etc.), en general, son **valores hipotéticos** que fueron específicamente desarrollados para los ejemplos de cálculos. Estos valores deben ser reemplazados por los datos específicos de la región para el desarrollo de un inventario de emisiones de área.

Este manual presenta los métodos más recientes recomendados para la estimación de emisiones para fuentes de área en México. Para marzo de 1997, estos métodos son los más adecuados para ser utilizados en este país. Sin embargo, se espera que este documento evolucione en el futuro. En la medida en que nuevos datos y factores de emisión específicos sean desarrollados para México, se deberá reemplazar a la información actualmente contenida en este manual.

2.0 PREPARACION DE UN INVENTARIO DE EMISIONES DE FUENTES DE AREA Y DE FUENTES MOVILES QUE NO CIRCULAN POR CARRETERA

Esta sección presenta algunos otros conceptos relacionados con el desarrollo de un inventario de fuentes de área y móviles que no circulan por carretera (en lo sucesivo denominadas colectivamente “fuentes de área”). El *Manual de TEEs Básicas* debe ser consultado para obtener una guía adicional sobre el desarrollo de un inventario. En esta sección se describen brevemente las fuentes de emisión de área; se presentan aspectos de planeación y de aseguramiento y control de calidad; se discuten las técnicas de estimación de emisiones (TEEs), y se explican e ilustran las necesidades de ajuste para los estimados de emisión. Finalmente, se analizan los procedimientos de reporte y codificación de datos, las diferencias geográficas y las causas de la variabilidad en los estimados de emisiones.

2.1 Descripción de las Fuentes de Emisión

Para propósitos de discusión, las fuentes de área pueden ser organizadas de manera lógica dentro de las siguientes categorías generales:

- Fuentes Estacionarias de Quemado de Combustible
- Fuentes Móviles que No Circulan por Carreteras
- Uso de Solventes
- Almacenamiento y Transporte de Productos
- Fuentes Industriales Ligeras y Comerciales

- Agricultura
- Manejo de Residuos,
- Fuentes de Area Misceláneas.

Las emisiones de cada una de estas fuentes se presentan en una gran variedad de formas. El quemado de combustible puede ocurrir en una caldera, chimenea, motor de combustión interna, o bien en fuentes móviles que no circulan por carretera (e. g., ferrocarriles, embarcaciones o aeronaves). Las emisiones del uso de solventes se generan por evaporación, y pueden ser reducidas evitando la evaporación o disminuyendo la cantidad de solvente usado. En general, las emisiones del almacenamiento y transporte de productos se generan por evaporación (e. g., distribución de gasolina, fugas de gas licuado [LP]). Las emisiones de los procesos de la industria ligera o el comercio se originan por combustión (e. g., fabricación de ladrillos), perturbaciones mecánicas (e. g., construcción), o procesos biológicos (e. g., panificación). Las emisiones agrícolas provienen de la combustión(e. g., quema de residuos de la cosecha previa), evaporación (e. g. aplicación de pesticidas); perturbaciones mecánicas (arado) y procesos biológicos (residuos animales). Las emisiones del manejo de residuos son ocasionadas por la evaporación (establecimientos de tratamiento de propiedad pública [POTWs, por sus siglas en inglés]) y combustión (e. g., incineración). Las emisiones de fuentes de área misceláneas se generan de la combustión (e. g., incendios forestales, incendios estructurales), perturbaciones mecánicas (e. g., polvo de caminos no pavimentados), y procesos biológicos (e. g., amoniaco [NH_3] de las actividades ganaderas).

Una lista completa de las categorías de fuente se encuentra en la Sección 3.0 de este manual; mientras que la información específica relacionada con cada categoría de fuente se presenta de la Sección 4.0 a la 11.0.

2.2 Planeación

Una planeación exhaustiva al inicio del proceso es esencial para el desarrollo de un inventario de alta calidad. El alcance de esta actividad se define en la fase de planeación, e incluye la identificación de los siguientes aspectos:

- Usos finales del inventario
- Contaminantes a ser incluidos
- Límites geográficos de la región del inventario
- Fuentes de área y fuentes móviles que no circulan por carretera presentes en la región del inventario
- Fuentes de área y fuentes móviles que no circulan por carretera a ser incluidas en el inventario
- TEEs que serán aplicadas para cada categoría de fuente, incluyendo cualesquier ajustes que deban realizarse.

Estos aspectos del alcance deben ser documentados claramente antes de iniciar cualquier actividad sobre la estimación de emisiones. **El documento que contiene esta información se denomina "plan de trabajo del inventario".**

El propósito y uso que se pretende dar a un inventario son utilizados para determinar los objetivos de calidad de los datos (OCDs), así como los objetivos de control y aseguramiento de calidad (CC/AC). Los OCDs son postulados sobre el nivel de incertidumbre que un responsable de la toma de decisiones está dispuesto a aceptar. Estos aseguran que el inventario final será adecuado para el uso que se le pretende dar. Dichos postulados deben identificar el uso final o el propósito de los datos, y el nivel de incertidumbre anticipado en los estimados de emisión. Los OCDs hipotéticos para un inventario de fuentes de área puede incluir los objetivos con respecto al grado en que los datos estarán completos (e. g., "incluir todas las fuentes cuya contribución se considera superior a 30,000 kg/año”); objetivos de precisión (e. g., “reducir la incertidumbre de las tres fuentes principales efectuando encuestas para actualizar los datos de emisión”); y factores del grado de comparación (e. g., “el inventario debe incluir todas las fuentes de inventarios previos, y ser elaborado utilizando métodos comparables”).

Los contaminantes a ser incluidos dependen del uso final y propósito del inventario. Por ejemplo, en un inventario de emisiones de área generadoras de ozono, los compuestos orgánicos volátiles (COVs) reactivos, el monóxido de carbono (CO) y NO_x deben ser incluidos. Por otro lado, un inventario que será utilizado en un estudio de visibilidad, debe incluir contaminantes adicionales tales como los óxidos de azufre (SO_x) y los particulados finos ($PM_{2.5}$).

La región geográfica que será cubierta por el inventario también depende de su uso final. Típicamente, un inventario abarcará un área discreta que tiene un problema común de contaminación del aire y/o una entidad normativa. Un inventario puede ser desarrollado para todo el país, un estado individual, una zona metropolitana o un municipio. Por ejemplo, la clasificación de regiones hecha en 1991 por el Instituto Nacional de Ecología (INE), podría ser utilizada para definir los límites geográficos para el desarrollo del inventario (ver Tabla 2-1). Estas seis regiones fueron establecidas por el INE con base en su calidad del aire, y tienen características ambientales, vegetales y climáticas diferentes.

Tabla 2-1

Estados Incluidos en las Regiones de Interés Especial

REGION I	REGION II	REGION III	REGION IV	REGION V	REGION VI
Baja California Baja California Sur Nayarit Sinaloa Sonora	Aguascalientes Chihuahua Coahuila Durango Zacatecas	Nuevo León San Luis Potosí Tamaulipas	Colima Guanajuato Guerrero Jalisco Michoacán	Distrito Federal Hidalgo México Morelos Puebla Querétaro Tlaxcala	Campeche Chiapas Oaxaca Quintana Roo Tabasco Veracruz Yucatán

Algunos ejemplos de las regiones geográficas cubiertas en un inventario incluyen un estudio de medidas para el control de la contaminación del aire para la Zona Metropolitana de Monterrey (Radian International, 1996). Esta área abarca la ciudad de Monterrey y los municipios de Juárez, San Pedro, Santa Catarina, San Nicolás, Guadalupe, Apodaca y Escobedo. El Departamento del Distrito Federal (DDF) ha elaborado inventarios anuales para los COVs reactivos, NO_x y CO para la Zona Metropolitana de la Ciudad de México (ZMCM) (DDF, 1995a; DDF, 1996a).

Para determinar las fuentes de área en la región del inventario, una extensa lista de categorías puede ser compilada a partir de la información que se presenta en la Sección 3.0 de este manual.

Algunas de las categorías que pueden ser incluidas en un inventario de fuentes de área corresponden a las emisiones de los pequeños establecimientos industriales. Los datos publicados por el Instituto Nacional de Estadística, Geografía e Informática (INEGI) o la Cámara Nacional de la Industria de la Transformación (CANACINTRA), pueden ser utilizados para determinar el alcance de estos pequeños establecimientos en una región geográfica. Por ejemplo, el INEGI brinda información sobre la distribución geográfica de las principales industrias manufacturadoras por estado y valor de manufactura agregado, así como el número de empleados por estado y sector industrial para algunas industrias. Por su parte, la CANACINTRA también publica datos sobre los establecimientos industriales.

Las fuentes a ser incluidas en el inventario deben ser jerarquizadas con base en su importancia para éste. Los recursos deben asignarse preferentemente a las fuentes que son más importantes para satisfacer los usos finales del inventario. Las fuentes de alta prioridad incluyen aquellas que se sabe son contribuyentes significativos a la contaminación del aire, son fuentes conocidas de los contaminantes seleccionados específicos (e. g., PM_{10}); o tienen un potencial importante para afectar la calidad del aire.

La Sección 3.0 presenta las TEEs para cada categoría de fuentes de área. La selección de la TEE adecuada para cada categoría de fuentes de área también implica la identificación de las entidades, tales como Pemex o Ferrocarriles Nacionales de México (FNM), que deberán ser contactadas para obtener la información y datos de actividad. En el proceso de planeación, también se deben identificar las actividades puntuales, móviles, de área y biogénicas complementarias del inventario. La coordinación entre estas actividades es necesaria para asegurar que el inventario esté completo, y que los datos requeridos sean transferidos de un grupo a otro. Por ejemplo, con frecuencia, los datos de fuentes puntuales son necesarios para hacer los ajustes en los estimados de emisión para algunas categorías de fuentes de área.

Los parámetros de control y aseguramiento de la calidad (CC/AC) también deben ser definidos antes de calcular cualesquier emisiones de fuentes de área. Un buen programa de CC/AC asegurará que la recopilación y manejo de los datos, la estimación de emisiones, el reporte de emisiones y los procedimientos para el manejo de la documentación sean cuidadosamente planeados y ejecutados. Un plan de AC debe formar parte del plan de trabajo del inventario para especificar todas las actividades de CC/AC que deberán realizarse.

2.3 Ajustes a los Estimados de Emisión

Es probable que durante la elaboración de estimados de emisión de fuentes de área, o después de que los estimados iniciales han sido elaborados, los valores necesiten ser ajustados para evitar ser duplicados en el inventario de fuentes puntuales; para compensar los controles que estén instalados en algunos procesos; para presentar las emisiones en una base diaria o estaciona, más que anual; o para ajustar las emisiones de compuestos orgánicos totales (COT) si en el inventario sólo se requieren COVs reactivos. **En general, los ajustes deben hacerse a los datos de actividad de fuente de área o a los factores de emisión previo al cálculo, más que en los estimados de emisión mismos.** A continuación se describen los métodos utilizados para hacer estos ajustes.

2.3.1 Ajustes de las Fuentes Puntuales

Cuando un inventario de fuentes puntuales y un inventario de fuentes de área incluyen emisiones del mismo proceso, existe la posibilidad de duplicar dichas emisiones. En estos casos, el estimado de emisión de la fuente de área debe ser ajustado. Ciertas categorías de fuentes de área, tales como el uso comercial y doméstico de solventes, y el recubrimiento de superficies arquitectónicas no requieren ningún ajuste de fuente puntual. Otras, como el quemado de combustible, los procesos industriales y la utilización de solventes pueden compartir procesos con las fuentes puntuales. **Para evitar la duplicación, la actividad de la fuente puntual es restada de la actividad total para la categoría de fuente.** El estimado de emisiones de fuentes de área se muestra en la siguiente ecuación:

$$\text{Actividad de Fuente de Area} = \text{Actividad Total de la Categoría de Fuente} - \text{Suma de la Actividad de Fuentes Puntuales} \qquad (2\text{-}1)$$

Por ejemplo, si las emisiones de fuentes de área son calculadas utilizando el empleo, el número de empleos en las fuentes puntuales debe restarse del inventario regional de empleo, para arrojar el empleo de las fuentes de área. Si la actividad de fuentes de área resultante es menor que cero, los datos de fuentes puntuales deben ser revisados, y cualesquier errores encontrados, deben corregirse. Si, después de esto la actividad de fuentes sigue siendo menor que cero, se asume que la actividad de fuentes de área es igual a cero, con emisiones generadas solamente en fuentes puntuales.

En algunas ocasiones, el ajuste a las fuentes puntuales se hace restando las emisiones de las fuentes puntuales a las emisiones de fuentes totales, si bien esto debe utilizarse como último recurso. Si este método fuera aplicado, es necesario asegurarse de utilizar emisiones no controladas (de las fuentes totales y puntuales). Cualesquier ajustes de control de emisiones necesario para las fuentes de área deben hacerse antes del ajuste de fuentes puntuales.

2.3.2 Ajustes en el Control de Emisiones1.0.2 Emission Control Adjustments1.0.2 Emission Control Adjustments

Los controles de fuentes de área son menos comunes que los de fuentes puntuales; sin embargo, cuando se presentan, deben ser incorporados dentro del cálculo de emisiones.

Los tipos de controles utilizados para las fuentes de área incluyen: prohibiciones, sustitución de productos y cambio en las prácticas laborales, así como equipos en línea para el control de emisiones. Los ejemplos de prohibición de actividades como método de control de emisiones incluyen la quema agrícola, la quema al aire libre y la emisión de drenajes abiertos. El uso de sustitución de productos para controlar las emisiones es particularmente efectivo cuando los recubrimientos con base de solvente son reemplazados por recubrimientos con base de agua. El cambio en las prácticas laborales es una manera efectiva de prevenir la evaporación de solventes; algunos ejemplos incluyen el requerimiento de que las unidades de desengrasado tengan tapas, y que se mantengan tapados cuando no estén en uso; que los trapos impregnados con solvente se mantengan en contenedores cerrados; y que los talleres automotrices utilicen pistolas limpiadoras con unidades de solvente de reserva anexos. El uso de equipos de control incorporados es menos común en las fuentes de área que en las puntuales. Sin embargo, las emisiones de algunas fuentes de área podrían ser fácilmente reducidas utilizando equipos de control. Los ejemplos incluyen las actividades de distribución de gasolina y los rellenos sanitarios.

Los parámetros de eficiencia del control (EC), eficacia de la regla (ER) y penetración de la regla (PR) son aplicados a una estimación de emisiones de fuentes de área si las regulaciones que afectan a cualquiera de las fuentes individuales dentro de la categoría están vigentes. **Las fuentes que no están controladas (no reguladas) carecen de EC, ER o RP aplicable.**

La EC es la eficiencia para la reducción de emisiones, y es un porcentaje que representa la cantidad de las emisiones de la categoría de fuente que es controlada por un equipo de control, cambios en el proceso o reformulación. Como se discutió en el *Manual de TEEs Básicas,* la EC general de un equipo de control es una combinación de la eficiencia de captura del equipo y la eficiencia del equipo de control. La primera es el porcentaje de la corriente de emisiones introducido en el equipo de control. La segunda es el porcentaje del contaminante del aire que es eliminado de la corriente de emisión y no liberado a la atmósfera.

La ER es un ajuste a la EC que incorpora las fallas e incertidumbre que afectan el desempeño real del control. Por ejemplo, el desempeño del equipo de control puede ser afectado por la edad, la falta del mantenimiento o el uso inadecuado del equipo. **Un valor de ER por omisión de 0.80 es recomendado si no es posible obtener la información para determinar el valor real de la ER.**

La PR es el porcentaje de la categoría de fuentes de área que es cubierto por la normatividad aplicable, o que se espera que cumpla con la normatividad. El valor de PR puede estar basado en un porcentaje de la fuente que es regulada, un nivel de corte o la regulación de una actividad. **Tanto la ER y la PR son aplicadas a las categorías de fuentes completas cuando se calculan estimados de emisión de fuentes de área.** La PR es una medición del grado en el que una regla cubre a una categoría de fuente. Por ejemplo, las regulaciones sobre el llenado de tanques subterráneos de gasolina pueden aplicar sólo a estaciones sobre un punto de corte específico, o que fueron construidas después de una fecha determinada.

El valor de la PR debe ser estimado para cada categoría de fuente, dado que no existe un valor por omisión que sea aplicable para todas las categorías de fuente. Este se calcula como:

$$PR = \frac{\text{Emisiones No Controladas Cubiertas por la Regulación}}{\text{Emisiones no Controladas Totales x 100}} \tag{2-2}$$

La siguiente ecuación ilustra el efecto de la EC, PR y ER en los estimados de emisiones:

$$\text{Emisiones Controladas} = (\text{Factor de Emisiones No Controladas}) \times (\text{Datos de Actividad}) \times [(1-(EC)(PR)(ER)] \tag{2-3}$$

La EC, ER y PR se discuten con mayor detalle en el *Manual de TEEs Básicas.*

2.3.3 Ajustes Temporales1.0.3 Temporal Adjustments1.0.3 Temporal Adjustments

Las actividades de fuente para muchas categorías fluctúan en una base estacional. Dado que las emisiones en general son una función directa de la actividad de fuente, los cambios estacionales en los niveles de actividad deben ser analizados. **En el caso de todas las categorías, si las emisiones estacionales o diarias serán determinadas, las variaciones estacionales deben ser consideradas.** Los factores de emisión para algunas categorías también pueden depender de las variables estacionales. El tipo de información necesaria para calcular las emisiones depende de la categoría de fuente y de la resolución temporal deseada de los estimados de emisión.

Algunas operaciones tales como el recubrimiento de superficies arquitectónicas, tienen mayor actividad en los meses cálidos; mientras que otras, como la calefacción residencial, tendrán actividad solamente en los meses más fríos. Muchas otras fuentes, por ejemplo, los procesos asociados con los establecimientos industriales o las operaciones comerciales, no mostrarán una gran variabilidad estacional en su actividad a lo largo del año.

La mejor manera de calcular los estimados de emisión diarios o estacionales es obtener los datos de actividad que son específicos para la estación de interés. Si esto no fuera posible, puede calcularse un estimado de actividad estacional utilizando un factor de ajuste aplicado a la actividad anual.

Con frecuencia, los factores para hacer los ajustes estacionales son expresados como fracciones, y en estos casos se denominan “factores de ajuste estacional” (FAEs). La siguiente ecuación utiliza un FAE para un inventario de emisiones en la temporada de ozono:

$$\text{Emisiones en la Temporada de Ozono} = \text{FAE} \times \text{Estimado de Emisiones Anuales} \tag{2-4}$$

Si se calculan las emisiones diarias, los días de actividad por semana y las semanas por año deben ser identificados, de manera tal que puedan utilizarse en la ecuación de emisiones. Para la mayoría de las fuentes industriales, el número de días a la semana es de cinco; mientras que para las actividades comerciales y domésticas, generalmente se utilizan seis o siete días. La siguiente ecuación muestra los ajustes para calcular un estimado de emisión diario de un proceso con una operación anual uniforme:

$$\text{Emisiones Diarias} = \frac{\text{(Emisiones Anuales)}}{\text{[(Días de Operación /Semana) x (Semanas de Operación/Año)]}} \tag{2-5}$$

Una combinación de las ecuaciones mostradas anteriormente es necesaria para estimar las emisiones para un día en la temporada de ozono de un proceso que tiene operaciones anuales que varían de acuerdo con la estación. Esto se muestra en la siguiente ecuación:

$$\text{Emisiones Diarias en la Temporada de Ozono} = \frac{\text{[(Emisiones Anuales) x FAE]}}{\text{[(Días de Operación /Semana) x (Semanas de Operación/Año)]}} \tag{2-6}$$

La Tabla 2-2 presenta los FAEs para las temporadas de ozono y monóxido de carbono, así como los días de actividad por semana por omisión que son frecuentemente utilizados en EU para estimar las emisiones estacionales. Estos factores se presentan como ejemplos, y variarán de un área a otra, dependiendo de las condiciones locales. De ser posible, deben generarse los FAEs específicos para México, más que depender de los FAEs estadounidenses presentados en la Tabla 2-2. Los FAEs típicamente se basan en el conocimiento local de las operaciones de la fuente, el juicio ingenieril y las encuestas.

Tabla 2-2

Factores de Ajuste Estacional para Fuentes de Area y Días por Semana para las Estaciones Pico de Ozono y CO

Fuentes de Area	Factores de Actividad Estacional		Días de Actividad por Semana
	Verano	Invierno	
Gasolineras			
Pipas en Tránsito	Variaciones estacionales en el rendimiento entre regiones. Utilizar la temperatura promedio para un día de verano cuando resulte conveniente. Las áreas turísticas pueden mostrar una marcada estacionalidad en las ventas de gasolina.		6
Descarga de Pipas (Etapa I)			6
Carga a Vehículos (Etapa II)			7
Pérdidas por Respiración del Tanque			7
Uso de Solventes			
Desengrasado	0.25		6
Lavado en Seco	0.25		5
Recubrimiento de Superficies			
Arquitectura	0.33		7
Pintado de Autos	0.25		5
Otra Industria Pequeña	0.25		5
Artes Gráficas	0.25		5
Pavimentación de Asfalto	Referirse a las regulaciones y prácticas locales		
Pesticidas	0.33		
Comercial y Doméstico	0.25		7

Tabla 2-2 (Continuación)

Factores de Ajuste Estacional para Fuentes de Area y Días por Semana para las Estaciones Pico de Ozono y CO

Fuentes de Area	**Factores de Actividad Estacional**		**Días de Actividad por Semana**
	Verano	**Invierno**	
Prácticas de Manejo de Residuos			
POTWs	0.35		7
Rellenos Sanitarios Municipales	0.25		7
Uso de Combustibles Fósiles en Fuente Estacionarias			
Doméstica	0.08	0.43	7
Comercial/Institucional	0.15	0.35	6
Industrial	0.25	0.25	6
Disposición de Residuos Sólidos			
Incineración en Sitio	0.25	0.25	7
Incineración Abierta	Referirse a las regulaciones y prácticas locales	Referirse a las regulaciones y prácticas locales	7
Incendios de Estructuras	0.20	0.33	7
Quema Agrícola y Forestal	Referirse a las regulaciones locales	0.10	7
Incendios Forestales	Referirse a las condiciones de incendios locales	0.05	7

2.3.4 Ajuste para los Compuestos No Reactivos

Muchas fuentes diferentes emiten gases orgánicos a la atmósfera. En conjunto, los compuestos que integran las emisiones de hidrocarburos se denominan gases orgánicos totales (GOT). El concepto de GOT incluye todos los compuestos carbónicos, excepto los carbonatos, carburos metálicos, monóxido y dióxido de carbono, y ácido carbónico. Desde una perspectiva de calidad del aire, es importante señalar que algunos de los GOTs emitidos a la atmósfera tienen una reactividad fotoquímica limitada o carecen de ella y, por lo tanto no participan en la formación de ozono. Los compuestos no fotoquímicamente reactivos incluyen:

- Metano
- Etano
- Acetona
- Percloroetileno
- Cloruro de metileno
- Metil-cloroformo (1,1,1-tricloroetano)
- Clorofluorocarbonos (CFCs)
- Hidroclorofluorocarbonos (HCFCs)
- Hidrofluorocarbonos (HFCs)
- Perfluorocarbonos.

Las sustancias consideradas como fotoquímicamente reactivas son denominadas gases orgánicos reactivos (GOR). Entonces, por definición, los GORs son un subconjunto de GOTs. Este manual promueve el desarrollo de estimados de emisión tanto GOT como GOR. Al principio podría parecer innecesario inventariar los GOTs, pero el desarrollo de estos estimados puede facilitar un gran número de funciones de reporte para parámetros tales como los gases con efecto invernadero y los compuestos tóxicos del aire. Adicionalmente, las emisiones GOT son más adecuadas para ser utilizadas en modelos tridimensionales de simulación de formación y transporte de ozono. Por lo tanto, este manual presenta los factores de emisión de hidrocarburos como GOT, y también la fracción de GOTs que son GOR. A menos que se indique lo contrario, todas las proporciones GOR/GOT fueron obtenidas del *California Air Resources Board* (ARB, 1991b).

2.4 Reporte de Estimados de Emisión y Codificación de Datos

El reporte y la documentación son partes integrales del proceso de desarrollo de inventarios. **Los métodos de reporte y los procedimientos de codificación de datos que serán utilizados deberán ser especificados en el plan de trabajo del inventario.** El nivel de detalle reportado para el inventario dependerá principalmente del uso final para el que esté destinado. Por ejemplo, toda la información utilizada para desarrollar un inventario cuyos resultados afecten directamente las actividades para la elaboración de reglas, deberán estar bien documentados. Debe reportarse información suficiente, de manera tal que los estimados puedan ser reproducidos por los revisores independientes.

Para otros inventarios puede bastar con citar las fuentes de datos, de manera tal que un revisor interesado localice los datos específicos de acuerdo con sus necesidades. Una guía sobre la importancia del reporte y documentación se presenta en el *Emission Inventory Improvement Program, Volume III* (Programa de Mejora del Inventario de Emisiones) (U.S. EPA, 1996b), y en el *Example Documentation Report for 1990 Base Year Ozone and Carbon Monoxide State Implementation Plan Emissions Inventories* (Ejemplo de la Documentación para el Reporte del Año Base 1990 del Plan Estatal de Instrumentación para Ozono y Monóxido de Carbono) (U.S. EPA, 1992b).

Para cada estimado de emisión de fuente de área, será necesario asignar un código numérico a la categoría de fuente. Dicho código facilitará el manejo electrónico y el intercambio de datos entre diferentes regiones. Este manual recomienda la aplicación de un sistema de codificación de 10 dígitos. Cada código se divide en segmentos: xx-xx-xxx-xxx. Los primeros dos dígitos representan las siguientes categorías principales:

- 21 - fuentes estacionarias combustión
- 22 - fuentes móviles
- 23 - procesos industriales
- 24 - uso de solventes
- 25 - almacenamiento y transporte
- 26 - disposición de residuos
- 27 - fuentes naturales
- 28 - fuentes misceláneas.

Los siguientes dos dígitos proporcionan una indicación del tipo de fuente. Por ejemplo, toda la quema de combustible industrial inventariado dentro de las fuentes de área sería 21-02-xxx-xxx. Los seis dígitos restantes describen el tipo de combustible y el tipo de equipo de combustión. Por ejemplo, el gas LP industrial quemado en todos los tipos de caldera es 21-02-007-000 (los últimos tres dígitos se presentan como ceros debido a que no se ha especificado un equipo de combustión particular). Los códigos numéricos recomendados para cada una de las categorías de fuentes de área se presentan de la Sección 4.0 a 8.0 con cada metodología para la estimación de emisiones. Una lista maestra de los códigos de 10 dígitos se presenta en el Apéndice V-A. En algunos casos se han desarrollado nuevos códigos para incorporar algunas fuentes particulares de México. Los códigos específicos para México están marcados con un asterisco (*) en las Secciones 4.0 a 11.0.

2.5 Diferencias Geográficas y Causas de la Variabilidad

Los métodos para estimar las emisiones de fuentes de área y de fuentes móviles que no circulan por carretera, generalmente son más precisas en una escala geográfica grande que en una pequeña. Una importante razón de esta variabilidad involucra el uso de factores de emisión per cápita y por empleado. **Los factores de emisión se refieren a la cantidad de contaminante emitido por una unidad de actividad. Es importante señalar que un factor de emisión promedio no representa la variabilidad geográfica de la actividad;** i e. , los solventes de lavado en seco son mucho más utilizados en las áreas urbanas que en las rurales.

Por ejemplo, si los factores de emisión per cápita fueran utilizados para estimar las emisiones y existieran grandes diferencias regionales en las prácticas de compra, uso de productos o uso de servicios comerciales tales como el lavado en seco y pintado de autos, éstas no serán tomadas en cuenta si se utilizan factores nacionales de emisión per cápita. La variabilidad en las emisiones sólo será reflejada si los factores de emisión per cápita son ajustados de alguna manera. Por ejemplo, sería posible realizar una encuesta y desarrollar factores de emisión estratificados per cápita basados en el ingreso doméstico promedio, para obtener una mejor representación de la actividad de las fuentes de área y de las fuentes móviles que no circulan por carretera.

El uso de factores de emisión por empleado a nivel nacional también introducen incertidumbre. Estos sobrestimarán las emisiones de operaciones que son intensivas en el uso de mano de obra. Una vez más, sería posible efectuar una encuesta para desarrollar factores de emisión por empleado que representen la variabilidad asociada con el número de empleados y los niveles de producción.

3.0 TECNICAS RECOMENDADAS PARA LA ESTIMACION DE EMISIONES

Las emisiones contaminantes del aire provenientes de fuentes de área pueden ser calculadas a través de diferentes técnicas de estimación de emisiones (TEEs). El volumen III de esta serie, el *Manual de TEEs Básicas* describe detalladamente cada una de estas técnicas

Las técnicas utilizadas para estimar las emisiones de fuentes de área varían de acuerdo con la categoría de fuente. La selección de una TEE requiere la evaluación de la disponibilidad de los datos. Si para utilizar un método particular se requiere una gran cantidad de datos, los costos deben ser ponderados contra la calidad deseada en los estimados de emisión. Por ejemplo, si la fuente representa un alto riesgo de efectos ambientales adversos, los costos pueden requerirse TEEs más sofisticadas y costosas. De manera inversa, cuando los riesgos son bajos, los métodos de estimación baratos pueden ser aceptables. De alguna forma, los factores que permiten la selección de una TEE para una categoría de fuente determinada son idénticos a los que definen qué categorías de fuente serán incluidas en el inventario (e. g., uso del inventario, costos, disponibilidad de los datos, etc.).

La Tabla 3-1 recomienda TEEs para diversas categorías de fuentes de área y móviles que no circulan por carreteras, e identifican a los contaminantes que son emitidos por cada una. Las categorías de fuente y las TEEs mostradas en esta tabla son discutidas en las secciones 4.0 a 11.0, no deben ser consideradas como definitivas, sino como lineamientos generales que deberían ser adaptados a las condiciones locales del área de estudio.

En la Tabla 3-1, cada TEE aplicada está calificada con base en el análisis de la fuente de emisión, la disponibilidad de los datos, y el costo y calidad de los estimados de emisión. Una calificación de “1” indica que un método es el más preferible. Si un método no tiene calificación, significa que no está disponible para esa categoría de fuente. A continuación se resumen las TEEs básicas con respecto a las fuentes de área.

No existe una TEE individual que pueda ser utilizada para estimar emisiones en todas las fuentes de área. El volumen III de esta serie, el *Manual de TEEs Básicas* contiene una discusión sobre la selección y uso de las diferentes TEEs, análisis de los costos contra la calidad, así como las ventajas y desventajas de las diversas TEEs.

Factores de Emisión Basados en los Censos. Los factores de emisión relacionan la cantidad de un contaminante emitido con una unidad de actividad. Estos pueden estar basados en el proceso o en el censo. En general, los primeros son utilizados para las fuentes puntuales; mientras que los segundos lo son para las fuentes de área. El uso de factores de emisión basados en el censo es un método eficiente para tipos de fuentes de emisión que están dispersas y son numerosas, que no pueden ser caracterizadas por el conocimiento de las tasas de proceso, de consumo de combustible y/o de alimentación de material. Comparado con otras TEEs, el uso de factores de emisión basados en el censo es la opción más costo-efectiva, dado que los datos de los censos están disponibles para la mayor parte de las regiones del inventario, en el Instituto Nacional de Estadística, Geografía e Informática (INEGI). Sin embargo, cabe señalar que gran parte de los factores de emisión basados en el censo han sido desarrollados a partir de datos estadounidenses. Con el tiempo, estos factores deberán ser reemplazados con otros desarrollados a partir de datos mexicanos. En la medida en que esto suceda, los factores de emisión basados en el censo van a constituir un método sumamente eficiente para el cálculo de emisiones.

Encuesta y Extrapolación. El cuestionario es una técnica utilizada comúnmente para agrupar datos de inventario de fuentes puntuales. Un enfoque de encuesta también puede ser utilizado para reunir la información necesaria para calcular las emisiones de fuentes de área. En estos casos, los cuestionarios son enviados a un conjunto de establecimientos, y los resultados son extrapolados a los establecimientos restantes con base en algún parámetro que esté relacionado con los niveles de emisión. Es importante señalar que, si bien en la Tabla 3-1 el método de encuesta y extrapolación tiene una calificación más alta que el uso de factores, la encuesta debe ser cuidadosamente planeada y ejecutada para que esta calificación tenga validez. Si la encuesta es enviada a un conjunto no representativo de establecimientos si las preguntas no son hechas o respondidas correctamente, o si los datos recibidos de los participantes no son manejados cuidadosamente (i. e., errores en la captura), los resultados serán estimados de emisión sumamente imprecisos.

Modelos de Emisión. Los modelos de emisión están diseñados para producir estimados de emisiones más precisos que un enfoque de factores de emisión. Sin embargo, estos modelos han sido desarrollados sólo para un número limitado de categorías de fuentes de área. La precisión de los resultados de un modelo de emisiones depende no sólo de la calidad de los datos de entrada, sino también de los supuestos sobre los que se basa el modelo.

Balance de Materiales. El enfoque de balance de materiales es adecuado para estimar emisiones asociadas con la evaporación de solventes. En su forma más sencilla, este método asume la evaporación de todo el solvente consumido por una fuente. Como se muestra en la Tabla 3-1, el enfoque de balance de materiales para las fuentes de área está combinado con los resultados de una encuesta, y se extrapola a una categoría de fuentes completa.

Tabla 3-1

Técnicas de Estimación de Emisiones Recomendadas

No. de Sección	Categoría de Fuente de Area	Contami-nantes	Factor de Emisión	Encuesta y Extrapolación	Modelo de Emisión	Balance de Materiales
4.1	Combustión Industrial, Comercial e Institucional	GOT, NO_x, CO, PM, SO_x	1			
4.2	Combustión Doméstica (Combustibles comerciales)	GOT, NO_x, CO, PM, SO_x	1			
4.3	Combustión Doméstica (biomasa o combustibles derivados de residuos)	GOT, NO_x, CO, PM, SO_x	1			
5.1	Locomotoras	GOT, NO_x, CO, PM, SO_x	1			
5.2	Embarcaciones Marítimas Comerciales	GOT, NO_x, CO, PM, SO_x	1			
5.3	Aeronaves	GOT, NO_x, CO, PM, SO_x	1			
5.4	Otro Equipo Móvil que no Circula por Carreteras	GOT, NO_x, CO, PM, SO_x	1			

5.5	Cruces Fronterizos	GOT, NO_x, CO, PM, SO_x			1	
5.6	Terminales de autobuses o camiones	GOT, NO_x, CO, PM, SO_x			1	
6.1	Recubrimiento industrial de superficies[a]	GOT	2	1		1
6.2	Pintado de autos[a]	GOT	2	1		1
6.3	Recubrimiento arquitectónico de superficies[a]	GOT	2	1		1
6.4	Pinturas de tráfico[a]	GOT	2	1		1
6.5	Limpieza industrial de superficies[a] (desengrasado)	GOT	2	1		1
6.6	Lavado en seco	GOT	2	1		1
6.7	Artes gráficas[a]	GOT	2	1		1
6.8	Aplicación de asfalto[a]	GOT	2	1		1
6.9	Uso comercial y doméstico de solventes	GOT	1			
7.1	Distribución de gasolina	GOT	1			
7.2	Carga de combustible en areonaves	GOT	1			
7.3	Distribución de gas LP	GOT		1		1
8.1	Panaderías	GOT	1			

8.2	Fabricación de ladrillos	GOT, NO$_x$, CO, PM, SO$_x$	2	1		
8.3	Actividades de construcción	PM	2		1	
8.4	Asados al carbón	GOT, PM	1	1		
8.5	Vendedores ambulantes	GOT, PM	1	1		
9.1	Aplicación de pesticidas[b]	GOT		1		1
9.2	Corrales de engorda de ganado	PM	1			
9.3	Quema agrícola	GOT, CO, PM	1			
9.4	Aplicación de fertilizantes	NH$_3$	2	1		1
9.5	Residuos animales	NH$_3$	1			
9.6	Arado agrícola	PM	1			
10.1	Incineración en sitio	GOT, NO$_x$, CO, PM, SO$_x$	1			
10.2	Manejo de residuos - incineración a cielo abierto	GOT, NO$_x$, CO, PM, SO$_x$	1			
10.3	Tratamiento de aguas residuales	GOT	2		1	
10.4	Aguas negras aguas residuales en canal abierto[b]	GOT, NH$_3$		1		1
11.1	Incendios forestales	GOT, NO$_x$, CO, PM, SO$_x$	1			
11.2	Incendios	GOT,	1			

	estructurales	NO_x, CO, PM				
11.3	Polvo de caminos pavimentados	PM	2		1	
11.4	Polvo de caminos no pavimentados	PM	2		1	
11.5	Erosión eólica	PM	2		1	
11.6	Emisiones domésticas de amoniaco[b]	NH_3		1		1

[a] Los estimados de emisión para las categorías de uso de solventes pueden desarrollarse utilizando factores de emisión o combinando las encuestas y extrapolación con la información obtenida del balance de materiales.

[b] Los estimados de emisión para estas categorías son desarrollados combinando las encuestas y extrapolación con la información obtenida del balance de materiales.

[c] Las TEES para esta categoría tendrán variaciones con base en las industrias identificadas en el área de inventario.

CO = Monóxido de carbono
Gas LP = Gas licuado de petróleo
NH_3 = Amoniaco
NO_x = Oxidos de Nitrógeno
PM = Partículas
SO_x = Oxidos de azufre
TOG = Gases orgánicos totales.

4.0 QUEMADO DE COMBUSTIBLES EN FUENTES ESTACIONARIAS

Algunas calderas pequeñas, hornos, calefactores, calentadores de agua y motores pueden ser demasiado pequeños para ser incluidos en el inventario de fuentes puntuales del inventario de una región determinada; por lo tanto, podrían ser incorporadas en un esfuerzo de inventario de fuentes de área. Las siguientes subsecciones presentan una guía para el inventario de estas fuentes.

- Combustión Industrial, Comercial e Institucional
- Combustión Doméstica (Combustibles Comerciales)
- Combustión Doméstica (Biomasa o Combustibles Derivados de Residuos).

4.1 Combustión Industrial, Comercial e Institucional

CODIGO DE FUENTE	DESCRIPCION
Industrial	
21-02-001-000	Carbón de Antracita
21-02-002-000	Carbón Bituminoso y Sub-bituminoso
21-02-004-000	Aceite Destilado: Total - Calderas y Motores de combustión interna (CI)
21-02-004-001	Aceite Destilado: Todos los Tipos de Calderas
21-02-004-002	Aceite Destilado: Todos los Tipos de Motores CI
21-02-005-000	Aceite Residual
21-02-006-000	Gas Natural: Total - Calderas y Motores de CI
21-02-006-001	Gas Natural: Todos los Tipos de Calderas
21-02-006-002	Gas Natural: Todos los Tipos de Motores CI
21-02-007-000	Gas Licuado de Petróleo(gas LP)
21-02-008-000	Madera
21-02-009-000	Coque
21-02-010-000	Gas de Proceso
21-02-011-000	Queroseno
21-02-012-000	Aceite Residual
Comercial/Institucional	
21-03-001-000	Carbón de Antracita
21-03-002-000	Carbón Bituminoso y Sub-bituminoso
21-03-004-000	Aceite Destilado: Total - Calderas y Motores de CI
21-03-004-001	Aceite Destilado: Todos los Tipos de Calderas
21-03-004-002	Aceite Destilado: Todos los Tipos de Motores CI
21-03-005-000	Aceite Residual
21-03-006-000	Gas Natural: Total - Calderas y Motores de CI
21-03-006-001	Gas Natural: Todos los Tipos de Calderas
21-03-006-002	Gas Natural: Todos los Tipos de Motores CI
21-02-007-000	Gas LP: Total - Todos los Tipos de Combustores
21-03-007-005	Gas LP: Todos los Tipos de Combustores
21-03-007-010	Gas LP: Pailas para Asfalto
21-03-008-000	Madera
21-03-011-000	Queroseno: Total - Todos los Tipos de Combustores
21-03-011-005	Queroseno: Todos los Tipos de Calderas
21-03-011-010	Queroseno: Pailas para Asfalto
21-03-012-000	Aceite Residual: Todos los Tipos de Calderas
21-03-012-010	Aceite Residual: Pailas para Asfalto en Lotes

DESCRIPCION:

La combustión industrial de combustible es el uso de carbón, petróleo, queroseno, gas natural, gas licuado de petróleo (gas LP) y madera para la generación de calor y energía en los establecimientos industriales. Estos combustibles pueden ser quemados en un gran número de tipos diferentes de equipo, incluyendo calderas, motores de combustión interna (CI), hornos, calentadores y otras unidades de calentamiento que son demasiado pequeñas para ser incluidas en un inventario de fuentes puntuales. Las plantas termoeléctricas son excluidas de esta categoría, y deben ser inventariados como fuentes puntuales.

Los establecimientos comerciales e institucionales son aquellos relacionados con el comercio minorista y mayorista, hoteles, restaurantes, escuelas, hospitales, edificios gubernamentales, etc. Nótese que en esta categoría de fuentes se incluyen las emisiones de combustión de las fuentes específicas de México, tales como las tortillerías y los baños públicos. Las emisiones de estos establecimientos no son inventariados de manera independiente, sino que el consumo de combustible de todas las fuentes es agregado para arrojar un total que es utilizado en el cálculo de emisiones. Esta agregación se hace por tipo de combustible, debido a que los factores de emisión varían con base en éstos. Adicionalmente, la especiación de los estimados de emisión para ser usados en un modelo de red tridimensional requiere la clasificación de las emisiones por tipo de combustible.

CONTAMINANTES: GOT, CO, NO_x, SO_x y PM

GOR: Para las fuentes de combustión se requieren ajustes para incorporar las emisiones de metano y etano no reactivos. Para la mayoría de las categorías de combustión, el AP-42 proporciona factores de emisión para los compuestos orgánicos totales (COT) y el metano. Nótese que los "COT" en el AP-42 son equivalentes a los gases orgánicos totales ("GOT"). En estos casos, dichos datos pueden ser utilizados para desarrollar un factor de emisión (FE) para los gases orgánicos reactivos (GOR) (i. e., $FE_{GOR} = FE_{COT} - FE_{CH4}$), que debe ser utilizado para estimar las emisiones de GORs. Si los datos disponibles del factor de emisión no tienen el detalle necesario para soportar este enfoque, pueden utilizarse los factores GOR/GOT que se presentan a continuación.

CODIGO DE FUENTE	GOR/GOT	DESCRIPCION
Industrial		
21-02-001-000	ND	Carbón de Antracita
21-02-002-000	ND	Carbón Bituminoso y Sub-bituminoso
21-02-004-000	ND	Aceite Destilado: Total - Calderas y Motores de CI
21-02-004-001	82.8%	Aceite Destilado: Todos los Tipos de Calderas
21-02-004-002	97.2%	Aceite Destilado: Todos los Tipos de Motores CI
21-02-005-000	82.8%	Aceite Residual
21-02-006-000	ND	Gas Natural: Total - Calderas y Motores de CI
21-02-006-001	39.7%	Gas Natural: Todos los Tipos de Calderas
21-02-006-002	7.4%	Gas Natural: Todos los Tipos de Motores CI
21-02-007-000	64.6%	Gas LP
21-02-008-000	ND	Madera
21-02-009-000	ND	Coque
21-02-010-000	ND	Gas de Proceso
21-02-011-000	ND	Queroseno
21-02-012-000	ND	Aceite Residual
Comercial/Institucional		
21-03-001-000	ND	Carbón Antracita
21-03-002-000	ND	Carbón Bituminoso y Sub-bituminoso
21-03-004-000	ND	Aceite Destilado: Total - Calderas y Motores de CI
21-03-004-001	82.8%	Aceite Destilado: Todos los Tipos de Calderas
21-03-004-002	97.2%	Aceite Destilado: Todos los Tipos de Motores CI
21-03-005-000	82.8%	Aceite Residual
21-03-006-000	ND	Gas Natural: Total - Calderas y Motores de CI
21-03-006-001	39.7%	Gas Natural: Todos los Tipos de Calderas
21-03-006-002	7.4%	Gas Natural: Todos los Tipos de Motores CI
21-02-007-000	64.6%	Gas LP: Total - Todos los Tipos de Combustores
21-03-007-005	64.6%	Gas LP: Todos los Tipos de Calderas
21-03-007-010	64.6%	Gas LP: Pailas para Asfalto
21-03-008-000	ND	Madera
21-03-011-000	ND	Queroseno: Total - Todos los Tipos de Combustores
21-03-011-005	ND	Queroseno: Todos los Tipos de Calderas
21-03-011-010	ND	Queroseno: Pailas para Asfalto
21-03-012-000	ND	Aceite Residual: Todos los Tipos de Calderas
21-03-012-010	ND	Aceite Residual: Pailas de Asfalto en Lotes

Nota: Una relación GOR/GOT “ND” indica que no existe una relación específica en la referencia citada del California Air Resources Board (ARB) *(Consejo para los Recursos del Aire de California)*. Sin embargo, para “otros” tipos de combustible o categorías de combustión no especificados en su referencia, la California ARB indica que la cifra 69.9% puede ser usada como valor por omisión.

AJUSTES DE FUENTES PUNTUALES

Las emisiones de esta categoría de fuente son estimadas utilizando factores de emisión y los valores del uso industrial, comercial e institucional de combustible (de PEMEX). Para desarrollar un estimado de emisión para los establecimientos industriales, el uso de combustible en los establecimientos industriales incluidos en el inventario de fuentes puntuales debe ser restado del combustible total utilizado. A menos que se cuente con información específica sobre las fuentes puntuales comerciales e institucionales, puede asumirse que todas éstas son fuentes de área.

METODOLOGIA:

La cantidad de cada tipo de combustible debe ser clasificada por el tipo de equipo de combustión para cada tipo de combustible. Si la información sobre los tipos específicos de equipos de combustión no está disponible, deben hacerse supuestos acerca de los tipos de equipo existentes (si tienen fundamentos razonables), o deben usarse los factores de emisión más conservadores (los más elevados).

Los factores de emisión se pueden encontrar en el Capítulo 1 del AP-42 (AP-42, 1995) y en el Apéndice V-B de este volumen (nota: en el AP-42, el término “GOT” es referido como “COT”). Las secciones en este capítulo cubren las emisiones de carbón bituminoso y sub-bituminoso, carbón de antracita, lignita, combustóleo, gas natural, gas LP, residuos de madera y aceite residual.

El combustible utilizado en los establecimientos de fuentes puntuales debe ser restado de las cantidades correspondientes por tipo de equipo:

$$\begin{array}{l}\text{Combustible Quemado}\\ \text{en Fuente de Area}\\ \text{por Equipo Tipo A}\end{array} = \left[\begin{array}{c}\text{Combustible Total}\\ \text{Quemado}\\ \text{por Equipo Tipo A}\end{array}\right] - \left[\begin{array}{c}\text{Combustible Quemado}\\ \text{en Fuente Puntual}\\ \text{por Equipo Tipo A}\end{array}\right] \qquad (4.1\text{-}1)$$

Algunos factores de emisión requerirán ser adaptados a las condiciones locales, tales como el contenido de azufre o de ceniza en el combustible, o sus propiedades caloríficas. Para mayor información sobre las propiedades de los combustibles y condiciones de operación, referirse al Volumen IV de esta serie de manuales, *Desarrollo del Inventario de Emisiones: Fuentes Puntuales,* Sección 3.1.1, Características de la Combustión,. Un cálculo típico multiplica las características del combustible por un coeficiente de emisión:

Factor de Emisión = Característica de Combustible x Coeficiente de Emisión (4.1.2)

Los factores de emisión para cada tipo de equipo de combustión son multiplicados por el combustible quemado por tipo de equipo en los establecimientos de las fuentes de área, como se muestra a continuación:

$$\text{Emisiones} = \left[\begin{array}{c}\text{Combustible Quemado}\\ \text{en Fuente de Area por}\\ \text{Equipo Tipo A}\end{array}\right] - \left[\begin{array}{c}\text{Factor de}\\ \text{Emisión para}\\ \text{Equipo Tipo A}\end{array}\right] \qquad (4.1\text{-}3)$$

DATOS NECESARIOS:

Datos	Fuentes
Combustible usado en el área de inventario, por tipo	PEMEX
Combustible utilizado por tipo de equipo (si está disponible)	Encuesta o información local, PEMEX
Combustible utilizado en fuente puntual, por tipo de equipo	Base de Datos SNIFF
Características del combustible, de acuerdo con las necesidades	PEMEX
Factores de emisión por tipo de combustible y tipo de equipo	AP-42, 1995 (Apéndice V-B de este manual)

NOTAS:

1. Los datos de uso de combustibles proporcionados por PEMEX deben ajustarse para reflejar cualesquier variaciones locales en los tipos de combustible quemados. Por ejemplo, si se sabe que la madera es sumamente utilizada en el área de inventario, pero PEMEX no proporciona ningún dato sobre el uso de madera, será necesario realizarse una encuesta para determinar el uso local de la madera, o bien evaluar otras fuentes de datos. El Manual de TEEs Básicas describe la metodología para llevar a cabo una encuesta.

2. En caso necesario, puede hacerse el supuesto de que todo el combustible industrial (100%) es consumido en establecimientos de fuentes puntuales; y que todo el combustible comercial e institucional (100%), es consumido en establecimientos de fuentes de área.

EJEMPLO DE CALCULO:

A. En este ejemplo, 60,000 litros de diesel fueron utilizados en los baños públicos de la Zona Metropolitana de la Ciudad de México (ZMCM) (DDF, 1995a) en 1992. La información obtenida en la Base de Datos del SNIFF indica que ningún baño público es considerado como fuente puntual. Asumir que el contenido de azufre en el combustible es del 0.5% en peso. Las emisiones de SO_2 y CO son calculadas aplicando los siguientes pasos:

Pasos para calcular las emisiones de SO_2:

1. Restar el uso de combustibles de fuentes puntuales:

Uso de Combustible en Fuentes de Area = 60,000 litros - 0 litros
= 60,000 litros

2. El diesel es similar al combustible destilado No.2. Por lo tanto, deberán utilizarse los factores de emisión para el combustible destilado del *AP-42, Sección 1.3, Combustión de Combustóleo* (ver Apéndice V-B). El factor de emisión para el SO_2 es función de un coeficiente y del peso porcentual del contenido de azufre en el combustible:

Contenido de Azufre = 0.5% en peso
Factor de Emisión del AP-42 para SO_2 (kg/10^3 litros) = 17 x 5%
Factor de Emisión para SO_2 (kg/10^3 litros) = 17 x 0.5
= 8.5 kg/10^3 litros

3. Finalmente, las emisiones de SO_2 son calculadas como:

60,000 litros x 8.5 kg/10^3 litros = 510 kg SO_2

Pasos para calcular las emisiones de CO:

1. La resta de las fuentes puntuales fue calculada anteriormente.

2. El factor de emisión del AP-42 es de 0.6 kg/10^3 litros.

3. Finalmente, las emisiones de CO son calculadas como:

60,000 litros x 0.6 kg/10^3 litros = 36 kg CO

B. En este ejemplo, 67,030,000 litros de gas LP fueron utilizados en las tortillerías de la ZMCM (DDF, 1995a) en 1992. Asumir que la información obtenida de la Base de Datos del SNIFF indica que algunas de estas tortillerías ya están incluidas en el inventario de fuentes puntuales (y que han utilizado 12,000,000 litros de gas LP). Las emisiones de CO son calculadas de acuerdo con los siguientes pasos:

1. Restar el uso de combustible de fuentes puntuales.

Uso de gas LP en fuentes de área = 67,030,000 litros - 12,000,000 litros
= 55,030,000 litros

2. Determinar el factor de emisión de CO:

Para la combustión de gas LP, el AP-42 presenta factores de emisión para la combustión de butano y la de propano (ver Apéndice V-B, Sección 1.5). Para los propósitos de cálculo de emisiones, se asume que el gas LP mexicano está compuesto por aproximadamente 60% de propano y 40% de butano (PEMEX, 1996).

$$\begin{aligned} FE &= (60\% \times FE_{propano}) + (40\% \times FE_{Butano}) \\ &= (60\% \times 0.2) + (40\% \times 0.3) \\ &= 0.24 \text{ kg CO}/10^3 \text{ litros} \end{aligned}$$

3. Finalmente, las emisiones de CO son calculadas como:

$(55{,}030{,}000 \text{ litros}) \times (0.24 \text{ kg}/10^3 \text{ litros}) = 13{,}200 \text{ kg CO}$

4.2 Combustión Doméstica (Combustibles Comerciales)

CODIGO DE FUENTE	DESCRIPCION
21-04-001-000	Carbón de Antracita
21-04-002-000	Carbón Bituminoso y Sub-bituminoso
21-04-004-000	Aceite Destilado
21-04-005-000	Aceite Residual
21-04-006-000	Gas Natural: Total
21-04-007-000	Gas LP
21-04-011-000	Queroseno

DESCRIPCION:

La categoría de combustión doméstica (combustibles comerciales) se refiere a la combustión de carbón, aceite, gas natural y gas LP, para la calefacción de viviendas individuales y unidades habitacionales. Los combustibles no comercialmente disponibles (e. g., madera, residuos de cosechas, aceites y solventes residuales, llantas, etc.), están excluidos de esta categoría y deben ser inventariados dentro de la categoría de combustión doméstica(biomasa y combustibles derivados de residuos). Adicionalmente, las emisiones de fugas y evaporación de los sistemas de almacenamiento y distribución de gas LP deben ser inventariados como fuentes de distribución de gas LP.

En México, diversos tipos de combustible son utilizados a nivel doméstico, principalmente para cocinar y en calentadores de agua. Cada año, cerca de dos millones de toneladas de gas LP son utilizadas para la cocina y calefacción doméstica en la Ciudad de México. La Zona Metropolitana del Valle de México (ZMVM) es el mayor mercado de gas LP a nivel mundial, con un consumo de 70,000 barriles al día. El uso del gas LP para cocinar y en calentadores de agua en México es común en todas las regiones; de acuerdo con los datos del INEGI, aproximadamente el 70%de las casas habitación en este país usan gas para cocinar. Sin embargo, en la ciudad de Monterrey, Nuevo León, el gas natural es el principal combustible doméstico, mientras que en Chiapas y Oaxaca predominan la madera y el carbón.

CONTAMINANTES: GOT, CO, NO_x, SO_x, y PM

GOR: Para los ajustes de las fuentes de combustión, es necesario tomar en cuenta las emisiones de metano y etano. Para la mayoría de las categorías de combustión, el AP-42 proporciona los factores de emisión para COT y metano. Nótese que en el AP-42, el término “COT”es equivalente a “GOT.” En tales casos, estos datos deben ser utilizados para desarrollar un FE GOR (i. e., $EF_{GOR} = FE_{COT} - FE_{CH4}$) y este factor de emisión GOR debe ser utilizado para estimar las emisiones GOR. Si los datos disponibles para el factor de emisión no están lo suficientemente detallados como para soportar este enfoque, entonces pueden utilizarse los factores GOR/GOT que se proporcionan a continuación:

CODIGO DE FUENTE	GOR/GOT	DESCRIPCION
21-04-001-000	ND	Carbón Antracita
21-04-002-000	ND	Carbón Bituminoso y Sub-bituminoso
21-04-004-000	ND	Aceite Destilado
21-04-005-000	82.8%	Aceite Residual
21-04-006-000	ND	Gas Natural: Total - Todos los Tipos de Combustores
21-04-007-000	64.6%	Gas LP: Total - Todos los Tipos de Combustores
21-04-011-000	ND	Queroseno: Total - Todos los Tipos de Combustores

Nota: Una relación GOR/GOT "ND" indica que no existe ninguna relación específica en la referencia citada del California ARB. Sin embargo, para "otros" tipos de combustible o categorías de combustión no especificados en su referencia, la California ARB indica que la cifra 69.9% puede ser usada como valor por omisión.

AJUSTES DE FUENTES PUNTUALES:

En general, las emisiones para esta categoría de fuente no son incluidas en un inventario de fuentes puntuales. Por lo tanto, no se espera que los ajustes de fuentes puntuales sean necesarios. Sin embargo como se ilustra en el ejemplo de cálculo, se debe tener cuidado para asegurar que los datos de uso del combustible reflejen sólo el uso **doméstico,** y no incluyan ningún uso industrial o comercial.

METODOLOGIA:

Es necesario determinar la cantidad de cada tipo de combustible quemado para el uso doméstico en la región del inventario. Si las estadísticas disponibles no satisfacen directamente las necesidades del esfuerzo de inventario [e. g., se dispone de las estadísticas a nivel estatal, pero: (1) la región del inventario incluyen porciones de diversos estados; o (2) el inventario requiere estimados de emisión a nivel municipal], entonces podrían utilizarse los datos de censo (e. g., población o vivienda) para resolver este problema. El siguiente ejemplo de cálculo ilustra este procedimiento.

Los factores de emisión pueden encontrarse en el Capítulo 1 del AP-42 (AP-42, 1995) y en el Apéndice V-B de este volumen (note: en el AP-42, el término “GOT” es referido como “COT”). Las secciones en el Capítulo 1 cubren las emisiones para carbón bituminoso y sub-bituminoso, carbón de antracita, lignita, combustóleo, gas natural, gas LP, residuos de madera y aceite residual. Si el AP-42 no proporciona específicamente los factores de emisión “domésticos” para un tipo de combustible determinado (e. g., combustión de gas LP), deben aplicarse los factores de emisión institucionales o comerciales.

Algunos factores de emisión requerirán ser adaptados a condiciones locales tales como el contenido de azufre o de ceniza en el combustible, o su contenido calorífico. Para mayor información sobre las propiedades de los combustibles y condiciones de operación, referirse al Volumen IV de esta serie de manuales, *Desarrollo del Inventario de Emisiones: Fuentes Puntuales,* Sección 3.1.1, Características de la Combustión,. Un factor de emisión PM o SO_x típico está formado por las características del combustible (contenido de ceniza o azufre), multiplicadas por un coeficiente de emisión (constante empírica):

$$\text{Factor de Emisión} = \text{Característica del Combustible} \times \text{Coeficiente de Emisión} \qquad (4.2\text{-}1)$$

Para cada tipo de combustible, la cantidad que es quemada por fuentes domésticas se multiplica por los factores de emisión para cada tipo de equipo de combustión, como se muestra a continuación:

$$\text{Emisiones} = \left[\begin{array}{c} \text{Combustible Quemado} \\ \text{en Fuente de Area por} \\ \text{Equipo Tipo A} \end{array} \right] - \left[\begin{array}{c} \text{Factor de Emisión} \\ \text{para Equipo Tipo A} \\ \end{array} \right] \qquad (4.2\text{-}2)$$

DATOS NECESARIOS:

Datos	Fuentes
Combustible utilizado en un inventario de área, por tipo de combustible	PEMEX
Datos de población o vivienda	INEGI, 1993
Características del combustible, conforme a las necesidades	PEMEX
Factores de emisión por tipo de combustible y tipo de equipo	AP-42, 1995 (ver Apéndice V-B de este manual)

NOTAS:

1. Los datos de uso de combustibles proporcionados por PEMEX deben ajustarse para reflejar cualesquier variaciones locales en los tipos de combustible utilizados. Por ejemplo, si se sabe que el carbón es sumamente utilizado en el área de inventario, pero PEMEX no proporciona ningún dato sobre el uso de carbón, debe realizarse una encuesta para determinar el uso local del carbón.

2. Si los datos de las características del combustible no están disponibles en PEMEX, la Norma Oficial Mexicana NOM-086-ECOL-1994 contiene las siguientes especificaciones para el contenido de azufre en combustibles, que pueden ser utilizadas como valores por omisión:

Tipo de Combustible	**Máximo Nivel de Azufre (wt%)**[a]	**Valor Típico de Azufre en 1995 (wt%)**[b]
Magna Sin	0.10	—
Magna Sin (Zona Fronteriza Norte, ZFN))	0.10	—
Magna Sin (ZMCM) [a partir de 1998 también en la Zona Metropolitana de Monterrey (ZMM) y Zona Metropolitana de Guadalajara, (ZMG)]	0.10	0.048
Nova Plus	0.15	—
Nova Plus (ZMCM) (a partir de 1998 también en la ZMM y ZMG)	0.15	0.07
Diesel Sin (ZMCM, ZMM y ZMG)	0.05	0.041
Diesel Desulfurado	0.5	—
Diesel Industrial	0.5	—
Gasóleo Industrial	2.0	—
Combustóleo Pesado	4.0	—
Combustóleo Hidrotratado (ZMCM) (a partir del 1° de enero de 1988)	1.0	—
Combustible Ligero (para zonas críticas)	2.0	—
Gas Natural	0.32 dm^3/m^3	—
Gas licuado de petróleo (Gas L.P)	0.14 kg/mg	—
Turbosina	0.3	—

[a] Fuente: Norma Oficial Mexicana NOM-086-ECOL-1994

[b] Fuente: Programa para mejorar la calidad del aire en el Valle de México 1995-2000; DDF, GEM, SEMARNAP, SSA; 1996.

3. No existen estudios detallados sobre la eficiencia del equipo de combustión de gas LP en México, pero en general, es baja. En algunos casos, hasta el 20% de los hidrocarburos son emitidos sin ser quemados, y este equipo tiende a trabajar con un exceso de aire, que reduce la eficiencia térmica aún más (DDF, *et al*, 1996). Si estuvieran disponibles, los datos específicos para México deben ser utilizados para ajustar los factores de emisión del AP-42, para reflejar la combustión incompleta.

EJEMPLO DE CALCULO:

Este ejemplo muestra la manera de calcular las emisiones de la combustión doméstica de gas LP en la Delegación Benito Juárez del DF, y se basa en los datos obtenidos para estimar las emisiones de la combustión doméstica para el inventario de fuentes de área (DDF, 1995a). Las emisiones de SO_2 y CO son calculadas de acuerdo con los siguientes pasos:

1. Determinar la cantidad doméstica de gas LP usada en la ZMCM:

En el Oficio GPASI-1511/93, PEMEX reportó que la cantidad total de gas LP consumida en la ZMCM en 1993 fue de 3,830.31 x 10^3 m^3. Con base en las cifras de 1992, PEMEX estimó que el 80% del gas LP total utilizado fue para propósitos domésticos. Por lo tanto:

Uso Doméstico Total de Gas LP en la ZMCM $= (3830.31 \times 10^3\ m^3) \times (80\%)$
$= 3{,}064.25 \times 10^3\ m^3$

2. Determinar la cantidad de gas LP doméstico utilizada en la Del. Benito Juárez:

No fue posible obtener los datos específicos del uso de combustible en la delegación por parte de PEMEX. Por lo tanto, se utilizaron los datos poblacionales del INEGI para disgregar los datos del uso de combustible en la ZMCM en las delegaciones individuales. La población total de la ZMCM fue de 14,564,679 habitantes, y en la Del. Benito Juárez fue de 407,811 habitantes. Por lo tanto:

Uso Doméstico Total de Gas LP en la delegación Benito Juárez
$= (3064.25 \times 10^3\ m^3) \times (407{,}811 / 14{,}564{,}679)$
$= 85.799 \times 10^3\ m^3$
$= 85{,}799 \times 10^3$ litros

Nota: Es preferible utilizar los datos de vivienda si la mayor parte del combustible es utilizado para calefacción. Sin embargo, en este caso, la mayor parte del gas LP es usado para cocinar, por lo tanto, los datos de población son preferibles.

3. Determinar el factor de emisión de SO_2:

Los factores de emisión del AP-42 para SO_2 (0.0115 y 0.0125) son función de un coeficiente (i. e., 0.011 y 0.012) y del contenido de azufre en el combustible (i. e., S, expresado en gr/100 ft^3). Con base en el parámetro equivalente utilizado por el DDF (i. e., 0.009 g/100 m^3):

$$\begin{aligned} S(gr/100\ ft^3) &= (0.009\ g/100\ m^3) \times (m^3/35.31\ ft^3) \times (lb/453.6\ g) \times (7000\ gr/lb) \\ &= 0.0039\ gr/100\ ft^3 \end{aligned}$$

Para la combustión de gas LP, el AP-42 presenta los factores de emisión para la combustión de butano y propano (ver Apéndice V-B, Sección 1.5). Por lo tanto, la composición del gas LP utilizado en la región del inventario es necesaria para determinar el conjunto de factores de emisión que debe ser utilizado (o incluso si se debe utilizar una combinación de ambos). En los países altamente industrializados, el gas LP contiene cuando menos un 95% de propano. Sin embargo, en México se vende una mezcla en la que el propano predomina, pero que también contiene una significativa proporción de butano, isobutano, propileno y butilenos (DDF, *et al*., 1996). Para los propósitos de estimación de emisiones, se asume que el gas LP mexicano es aproximadamente 60% propano y 40% de butano (PEMEX, 1996). Por lo tanto, si los datos regionales específicos no son obtenidos para la delegación Benito Juárez, los factores de emisión del gas LP pueden ser calculados como se muestra a continuación:

$$\begin{aligned} FE_{(SO_x)(\text{Benito Juárez})} &= (60\% \times FE_{\text{Propano}}) + (40\% \times EF_{\text{Butano}}) \\ &= (60\% \times 0.012S) + (40\% \times 0.011S) \\ &= (0.6 \times 0.012 \times 0.0039) + (0.4 \times 0.011 \times 0.0039) \\ &= 4.52 \times 10^{-5}\ kg\ SO_x/1{,}000\ litros \end{aligned}$$

NOTA: Dado que los factores de emisión "domésticos" no están especificados en esta Sección del AP-42, se utilizan los factores de emisión "comerciales".

4. Entonces, las emisiones de SO_2 son calculadas como:

$$(85{,}799 \times 10^3\ litros)\ x\ (4.52 \times 10^{-5}\ kg/10^3\ litros) = 3.9\ kg\ SO_2$$

5. Determinar el factor de emisión de CO:

Como se mostró anteriormente, si los datos regionales específicos no son obtenidos para la delegación Benito Juárez, los factores de emisión del gas LP pueden ser calculados como se muestra a continuación

$$\begin{aligned} FE_{CO(\text{Benito Juárez})} &= (60\% \times FE_{\text{Propano}}) + (40\% \times FE_{\text{Butano}}) \\ &= (60\% \times 0.2 \text{ kg/1000 litros}) + (40\% \times 0.3 \text{ kg/1000 litros}) \\ &= 0.24 \text{ kg CO/1000 litros} \end{aligned}$$

6. Entonces, las emisiones de CO son calculadas como:

$$(85{,}799 \times 10^3 \text{ litros}) \times (0.24 \text{ kg}/10^3 \text{ litros}) = 20{,}600 \text{ kg CO}$$

4.3 Combustión Doméstica (Biomasa o Combustibles Derivados de Residuos)

CODIGO DE FUENTE:	DESCRIPCION:
21-04-008-000	Madera o Biomasa
21-04-013-000*	Otros Combustibles Derivados de Residuos

* Código propuesto específico para México para las categorías de fuente no típicamente inventariadas en EU.

DESCRIPCION: La categoría de combustión doméstica (biomasa y combustibles derivados de residuos) incluye la combustión de madera, biomasa, boñiga, materiales de desecho, llantas y otros combustibles derivados de residuos, Estos son utilizados para propósitos tanto de calentamiento como de cocinado doméstico, En la mayoría de las áreas, la normatividad reciente ha prohibido la quema de llantas y otros materiales derivados de residuos que emiten fuertes olores y/o contaminantes tóxicos. Sin embargo, es probable que la quema clandestina de estos materiales siga ocurriendo en algunas áreas.

A diferencia de los combustibles comerciales utilizados en la combustión doméstica (descritos en la Sección 4.2), la biomasa y otros combustibles derivados de residuos no son usualmente distribuidos a nivel comercial (con excepción de la madera), y tienden a ser utilizados por las clases socioeconómicas bajas de la población. Por estas razones, la determinación de la cantidad de la biomasa y los combustibles derivados de residuos que se utilizan en una región, puede ser problemática. La siguiente información proporciona una guía con respecto a la manera de estimar las emisiones en esta categoría.

CONTAMINANTES: GOT, CO, NO_x, SO_x, y PM_{10}

GOR: Para la combustión doméstica de madera, el GOR está compuesto por un 41.5% de GOT. Las fracciones de GOR no han sido desarrolladas para los combustibles derivados de residuos, si bien otros combustibles de biomasa y material de desecho probablemente tienen fracciones GOR similares, al ser comparadas con la combustión doméstica de madera.

AJUSTES DE FUENTE PUNTUAL: Ninguno.

METODOLOGIA:

La cantidad de cada tipo de biomasa y otro combustible derivado de residuos para uso doméstico necesita ser determinado para la región de inventario. El primer paso consiste en estimar la fracción de viviendas que usan estos tipos de combustibles; y el segundo paso es determinar el uso de combustible por vivienda.

De manera ideal, la fracción total de viviendas que usan biomasa u otro combustible derivado de residuos debe ser determinada a través de una encuesta específica para la región. Si la información del estudio no está disponible, el número de viviendas puede ser calculado a partir de las estadísticas del INEGI y otros censos que identifiquen el número de viviendas que usan combustibles comerciales (i. e., carbón, petróleo, gas natural y gas LP). Al restar la fracción de viviendas que utilizan éstos últimos del número total de viviendas, se obtiene la fracción que utiliza biomasa u otro combustible derivado de residuos. Es importante darse cuenta de que las estadísticas del INEGI y otros censos pueden presentar información a nivel estatal o nacional que puede no ser adecuada a nivel local. Estas situaciones ameritan la realización de una encuesta local.

Después de que se ha establecido el número de viviendas que utilizan biomasa y otro combustible derivado de residuos, el siguiente paso es determinar la cantidad de combustible quemado por vivienda. La cantidad de combustible utilizado para cocinar puede ser similar en diferentes regiones; sin embargo, el que se usa para fines de calefacción está en función de las condiciones meteorológicas. Obviamente, las localidades más frías tenderán a utilizar más combustible para calefacción que aquellas con climas cálidos.

Una vez más, la encuesta local es el método preferible a ser utilizado para estimar el uso de combustible por vivienda. Si la información de una encuesta local no está disponible, las estadísticas del INEGI o los funcionarios locales pueden ser consultados para obtener los estimados. Sin embargo, debido a que los combustibles no están comercialmente disponibles, es poco probable que el INEGI o los funcionarios locales hayan recopilado estadísticas del uso de estos combustibles por vivienda.

Si se carece de la información a partir de datos de encuestas o estadísticas, es posible hacer un estimado grueso del uso por vivienda de biomasa y otro combustible derivado de residuos, utilizando el concepto de “equivalencia de combustible”. El uso de carbón, gas natural, gas LP y otros tipos de combustibles comerciales por vivienda puede ser estimado dividiendo el uso doméstico total de un combustible comercialmente disponible, entre el número total de viviendas que utilizan ese combustible específico. El uso por vivienda derivado para un combustible comercial específico tiene un contenido de energía determinado que es equivalente a cierta cantidad de madera, hule u otro combustible derivado de residuos. Este cálculo se muestra en la siguiente ecuación.

$$\text{Combustible}_{\text{BW}} = \text{Combustible}_{\text{comm}} \times \left(\frac{\text{EC}_{\text{Comm}}}{\text{EC}_{\text{BW}}} \right) \times \left(\frac{\text{Eff}_{\text{comm}}}{\text{Eff}_{\text{BW}}} \right) \qquad (4.3\text{-}1)$$

donde:

$\text{Combustible}_{\text{BW}}$ = Uso anual por vivienda de la biomasa o combustible derivado de residuos (kg/año)
$\text{Combustible}_{\text{Comm}}$ = Uso anual por vivienda del combustible comercial (kg/año ó litro/año)
EC_{Comm} = Contenido energético del combustible comercial (kcal/kg ó kcal/litro)
EC_{BW} = Contenido energético de la biomasa o combustible derivado de residuos (kcal/kg)
EFF_{Comm} = Eficiencia de combustión del combustible comercial
EFF_{BW} = Eficiencia de combustión de la biomasa o combustible derivado de residuos.

Las eficiencias de la combustión de combustible comercial y de la biomasa u otro combustible derivado de residuos también se incluyen en la Ecuación 4.3-1. Sin embargo, debido a las variables y eficiencias desconocidas, con frecuencia estos efectos son ignorados. El método de “equivalencia de combustible” es aproximado, y debe ser utilizado solamente cuando no se disponga información de encuestas o censos locales. Este método fue utilizado para la estimación de GOT y PM_{10} como parte de un inventario de tóxicos del aire en Nogales, Sonora.

Los factores de emisión para la combustión doméstica de madera (chimeneas y estufas de madera) basados en los factores de emisión estadounidenses, pueden encontrarse en las secciones 1.9 y 1.10 del AP-42 (AP-42, 1995), y en el Apéndice V-B de este volumen (nota: en el AP-42, “GOT” es referido como “COT”). Los datos de emisión específicos para México, para la combustión de madera residual, han sido desarrollados por los investigadores en la Universidad de Utah y el Southwest Center for Environmental Research and Policy (SCERP) *(Centro del Suroeste para la Investigación y Política Ambiental)* (Summit, *et al*, 1996). Estos datos fueron obtenidos en un número limitado de pruebas de fuente con calentadores domésticos adquiridos en Ciudad Juárez, utilizando diversos combustibles de madera residual (tarimas estadounidenses y mexicanas y tablas de aglomerado), Los datos de emisión para CO, hidrocarburos totales (HCT), óxido nítrico (NO) se presentan en la Tabla 4.3-1; los datos de emisiones para PM todavía están en desarrollo. Debe notarse que existe una gran incertidumbre asociada a estas emisiones, debido al limitado número de pruebas en fuente.

Tabla 4.3-1

Datos de Emisiones de CO, HCT y NO para Diversos Combustibles de Madera Residual

Tipo de Combustible	CO (g/kg madera)	HCT (g/kg madera)	NO (g/kg madera)[a]
Tarima de EU	45 ± 4.5	3.0 ± 1.3	0.76 ± 0.19
Tarima de México	31 ± 7.5	2.3 ± 1.2	0.62 ± 0.040
Tabla de aglomerado	66 ± 23	3.3 ± 1.8	3.5 ± 0.96

Fuente: Summit, *et al.*, 1996

[a] Sólo están disponibles las emisiones de NO, Al parecer, el dato para NO no fue desarrollado. El NO_x es la combinación de NO y NO_2, expresada como NO_2.

Los factores de emisión para la combustión doméstica de otros tipos de residuos basados en los factores estadounidenses pueden encontrarse en la Sección 2.5 del AP-42; misma que también incluye los factores de emisión para la quema a cielo abierto de residuos agrícolas y llantas, que pueden ser utilizados para estimar las emisiones de la combustión doméstica de estos combustibles. El uso de los factores de emisión de, sin embargo, pueden tener una elevada incertidumbre debido a las diferentes condiciones de combustión.

Se recomienda que México desarrolle factores de emisión específicos para las prácticas reales de combustión y los combustibles que están siendo utilizados. Hasta que dichos factores hayan sido desarrollados, es recomendable que los factores de emisión presentados en la Tabla 4.3-1 sean utilizados de acuerdo con las necesidades. Si estos factores no fueran aplicables, entonces deben utilizarse los factores de emisión del AP-42 que se presentan en el Apéndice V-B de este manual.

Para cada tipo de combustible, las emisiones son calculadas multiplicando la cantidad de combustible quemado por su factor de emisión, tal y como se muestra a continuación:

$$\text{Emisiones} = \text{Combustible}_{\text{Total}} \times \text{FE} \qquad (4.3\text{-}2)$$

DATOS NECESARIOS:

Datos	Fuentes
Número de viviendas que usan biomasa o combustibles derivados de residuos	Encuesta o información local, INEGI
Uso de combustible por vivienda	Encuesta o información local, INEGI, o método de la "equivalencia de combustible"
Factores de emisión por tipo de combustible	AP-42, 1995 (ver Apéndice V-B), ó Summit *et al.*, 1996 (ver párrafos anteriores)

EJEMPLO DE CALCULO:

La información de la encuesta local indica que un área metropolitana tiene 80,000 viviendas, 1.5% de las cuales queman tarimas de madera. Sin embargo, dicha información no indica la cantidad promedio de tarimas quemadas en estas viviendas. Una vivienda típica que usa gas LP utiliza 600 litros anuales. Las emisiones anuales de CO para tarimas utilizadas como combustible doméstico se calculan se acuerdo con los siguientes pasos:

1. Calcular el número de viviendas que usan tarimas de madera como combustible:

$$80{,}000 \times 0.015 = 1{,}200 \text{ viviendas que usan tarimas de madera como combustible}$$

2. Calcular el contenido de energía del gas LP:

   Asumir que el gas LP local está formado por 60% de propano y 40% de butano (valores redondeados de PEMEX, 1996). Asimismo, asumir que el contenido de energía del butano es de 6,790 kcal/litro, mientras que el del propano es de 6,090 kcal/litro (AP-42, 1995)

$$(0.6 \times 6{,}090) + (0.4 \times 6{,}790) = 6{,}370 \text{ kcal/litro gas LP}$$

3. Calcular el uso anual por vivienda de tarimas como combutible.

   Asumir que el contenido de las tarimas de madera es de 4,445 kcal/kg (Summit, *et al*, 1996). Asumir también que las eficiencias de combustión del gas LP y las tarimas de madera son idénticas y que pueden ser ignoradas.

$$\left(\frac{\text{600 litros gas LP}}{\text{vivienda}}\right) \text{ x } \left(\frac{\text{6,370 kcal}}{\text{litros gas LP}}\right) \text{ x } \left(\frac{\text{1 kg madera}}{\text{4,445 kcal}}\right) = \frac{\text{860 kg madera}}{\text{vivienda-año}}$$

4. Calcular la emisión anual de CO:

$$\text{1,200 viviendas} \text{ x } \left(\frac{\text{860 kg madera}}{\text{vivienda-año}}\right) \text{ x } \left(\frac{\text{31 g CO}}{\text{kg madera}}\right) = \text{31,992 kg CO}$$

5.0 FUENTES MOVILES QUE NO CIRCULAN POR CARRETERAS

En general, sólo los vehículos de motor que circulan por carretera (e. g., automóviles, camiones, autobuses, motocicletas), son incluidos en el inventario de fuentes móviles para una determinada región de inventario. Por lo tanto, las fuentes móviles que no circulan por carreteras deben ser incluidas en un inventario de fuentes de área. La guía para el inventario de estas fuentes se presenta en las siguientes subsecciones:

- Locomotoras
- Embarcaciones marítimas comerciales
- Aeronaves
- Otro equipo móvil que no circula por carretera (incluyendo equipo recreativo, de construcción, industrial, de jardinería, agrícola, comercial ligero, de explotación forestal y de servicio de aeropuertos).
- Cruces fronterizos
- Terminales de autobuses y camiones.

5.1 Locomotoras

CODIGO DE FUENTE	**DESCRIPCION**
22-85-002-005	Locomotoras de arrastre
22-85-002-010	Locomotoras de patio

DESCRIPCION:

En México, el servicio de ferrocarriles es proporcionado por una sola empresa de propiedad pública: Ferrocarriles Nacionales de México (FNM), que tiene dos tipos de operación: de arrastre (foránea) y de patio (o cambio). Las locomotoras de arrastre generalmente viajan entre localidades distantes, desde una ciudad a otra (incluyendo el servicio de carga intermodal, el servicio de carga mixto y el transporte de pasajeros), usando locomotoras con una potencia de 3,000 hp. Las locomotoras de patio básicamente son responsables del movimiento de vagones dentro de un patio de trenes particular, tienen una potencia de 1,800 hp.

En la mayoría de los sistemas ferroviarios existen dos tipos de locomotoras: diesel y diesel-eléctricas. Las primeras son alimentadas por la electricidad que es generada en las plantas estacionarias de energía y distribuida por un tercer riel, o por un sistema aéreo. Las emisiones son producidas solamente en la planta de generación eléctrica y no son cubiertas en un inventario de fuentes móviles que no circulan por carreteras. Las locomotoras diesel-eléctricas utilizan un motor de diesel, y un alternador o generador para producir la electricidad requerida para alimentar los motores de tracción.

CONTAMINANTES: GOT, CO, NO_x, SO_x, PM

GOR: Las emisiones de GOR constituyen 97.2% del GOT para la combustión diesel.

AJUSTE DE FUENTES PUNTUALES: Ninguno.

METODOLOGIA:

Las emisiones de las locomotoras de arrastre y de patio deben ser calculadas por separado. En esta guía se presentan los métodos para cada una de estas operaciones. Nótese que en esta sección sólo se consideran las emisiones de las locomotoras diesel-eléctricas.

Operaciones de arrastre

Para esta categoría de fuentes, las emisiones se estiman con base en la cantidad de combustible quemado.

Si las locomotoras en línea sólo viajan dentro del área del inventario, el consumo de combustible puede ser determinado directamente a partir de la cantidad dispensada. Son embargo, las locomotoras de arrastre no limitan sus recorridos dentro del área de un inventario y, por lo tanto, no necesariamente consumen el combustible en la misma localidad en que fue dispensado. Para estimar las emisiones, primero debe estimarse la cantidad de combustible quemado en el área de interés.

Es recomendable que el consumo de combustible sea determinado de acuerdo con la longitud de la vía, de manera tal que el porcentaje de combustible quemado se base en el porcentaje de la longitud de la vía dentro del área del inventario, tal y como se indica en la siguiente ecuación.

$$F_{ci} = F_{cn} \text{ x } \frac{TL_i}{TL_n}$$

$$C_{ci} = C_{cn} \text{ x } LV_i/LV_n \tag{5.1-1}$$

donde:
C_{ci} = Consumo de combustible ferroviario para el área de inventario i (litros)
C_{cn} = Consumo nacional de combustible ferroviario (litros)
LV_i = Longitud de las vías en el área de inventario i (km)
LV_n = Longitud nacional de las vías ferroviarias (km).

Para estimar las emisiones, los factores de emisión deben ser aplicados a los valores de consumo de combustible, como se indica en la siguiente ecuación:

$$El_{pi} = C_{ci} \text{ x } FE_{lp} \tag{5.1-2}$$

donde:
EL_{pi} = Estimado de emisiones anuales (kg) para el contaminante p para el área de inventario i, para operaciones ferroviarias largas
F_{ci} = Consumo de combustible ferroviario para el área de inventario i (litros/año)
FE_{lp} = Factor de emisión para el contaminante p (kg/litro) (de la tabla de datos.

Los datos de longitud de las vías se pueden obtener de FNM, midiendo la distancia en los mapas locales, o utilizando los datos del estudio del Sistema de Información Geográfica (SIG) del Departamento de Transporte de EU (*http://www.bts.gov/cgi-bin/gis/ntad-download.pl/mexrail*). Si, por ejemplo, se ha estimado que el 10 por ciento de la longitud nacional de las vías corre dentro del área de inventario, para determinar el combustible total consumido en ésta es necesario multiplicar el consumo nacional total por 0.10.

DATOS NECESARIOS- Operaciones en Línea:

Datos	Fuentes
Datos nacionales del combustible ferroviario (1996): 652.4×10^6 litro/año	Nava, 1996
Longitud nacional de vías (1996): 20,447 km	Nava, 1996
Longitud de vías en el área de inventario	FNM, mediciones en los mapas locales o base de datos SIG
Uso de combustible en el área de inventario	Calculado utilizando la Ecuación (5.1-1)
Factores de Emisión: GOT 0.0025 kg/litro CO 0.0075 kg/litro NO_x 0.0591 kg/litro SO_2[a] 0.0043 kg/litro PM 0.0014 kg/litro	U.S. EPA, 1992a

[a] Las emisiones de SO_2 son calculadas sobre un contenido de azufre supuesto en el combustible de 0.25% en peso.

i. e., $$\frac{0.863 \text{ kg combustible}}{\text{litro de combustible}} \times \frac{0.0025 \text{ kg S}}{\text{kg combustible}} \times \frac{2 \text{ kg } SO_2}{\text{kg S}} = \frac{0.004315 \text{ kg } SO_2}{\text{litro de combustible}}$$

EJEMPLO DE CALCULO:

Calcular las emisiones GOT para un Area de Inventario A, que tiene 1,100 km de vías. En 1996, la longitud nacional de las vías era de 20,447 km y el consumo nacional de combustible ferroviario fue de 652.4 millones de litros. El uso de combustible en el área de inventario es de:

$$= 652.4 \times 10^6 \text{ litros} \left(\frac{1,100 \text{ km}}{20,447 \text{ km}} \right)$$

$$= 35.0 \times 10^6 \text{ litros}$$

Las emisiones de GOT estimadas son:

$$= (35.0 \times 10^6 \text{ litros}) \times (0.0025 \text{ kg/litro})$$
$$= 87{,}500 \text{ kg}$$
$$= 87.5 \text{ Mg}$$

Operaciones de Patio

Las emisiones de las locomotoras de patio se obtienen multiplicando el número de unidades que operan dentro del área del inventario, por las emisiones generadas por cada unidad durante el año. La ecuación es:

$$EP_{pi} = NP_i \times FE_{pp} \tag{5.1-3}$$

donde:

EP_{pi} = Emisiones anuales estimadas (kg) para el contaminante p para un área de inventario i, para las operaciones de locomotoras de patio
NP_i = Número de locomotoras de patio que operan en un área de inventario i
FE_{pp} = Factores de emisión para las locomotoras de patio para el contaminante p (kg/año) (de la tabla de datos).

Debido a que este tipo de locomotoras opera dentro de los límites de un patio de trenes, es posible estimar el número de éstas que operan dentro del área de inventario, a través de entrevistas a los gerentes de patio, quienes mantienen registros sobre las operaciones de las locomotoras. Si este enfoque no es productivo, el número puede ser determinado manualmente, contando el número de unidades que operan en cada patio de trenes durante un día determinado. Este método es adecuado porque el número de locomotoras permanece relativamente constante durante todo el año.

El promedio anual de emisiones mostrado en la siguiente tabla fue calculado con base en el supuesto de que un motor de patio promedio consume 856 litros de combustible diarios. Si bien estos datos fueron desarrollados en EU, se considera que son aplicables en México. Dado que es posible asumir que las locomotoras de patio operan 365 días al año (esto supone el reemplazo de una unidad que es retirada para reparación), el motor promedio consume 312,440 litros de combustible al año. La emisión anual por locomotora de patio fue determinado multiplicando el estimado de consumo de combustible (312,440 litros/año) por cada factor de emisión en la tabla de datos.

DATOS NECESARIOS - Operaciones de Patio:

Datos	Fuentes
Número de locomotoras de patio en operación en el área de inventario	Gerente de patio o conteo manual
Factores de Emisión GOT 1,893 kg/locomotora/año CO 3,345 kg/locomotora/año NO_x 18,873 kg/locomotora/año SO_2[a] 1,395 kg/locomotora/año PM 516 kg/locomotora/año	U.S. EPA, 1992a

[a] Las emisiones de SO_2 son calculadas sobre un contenido de azufre supuesto en el combustible de 0.25% en peso. Ver nota 3.

$$\text{i. e.,}\quad \frac{0.004315\ \text{kg } SO_2}{\text{litro de combustible}} \times \frac{0.0025\ \text{litro de combustible}}{\text{año}} = \frac{1{,}395\ \text{kg } SO_2}{\text{locomotora año}}$$

EJEMPLO DE CALCULO:

El Area de Inventario A tiene 21 locomotoras de patio en operación.

Las emisiones GOT calculadas son:

= 21 x (1893 kg/locomotora/año)
= 39,753 kg
= 39.8 Mg

NOTAS:

1. Para que un inventario de locomotoras sea considerado completo, deben estimarse las emisiones tanto de las locomotoras en línea como de las de patio.

2. El factor de emisión de libras de SO_2/litro de combustible cambiará con la densidad de éste y su contenido de azufre de acuerdo con la siguiente ecuación:

$$\text{factor de emisión} \left(\frac{\text{kg } SO_2}{\text{litro de comb.}} \right) = \frac{\text{kg de comb.}}{\text{litro de comb.}} \times \begin{matrix}\text{\% de azufre en} \\ \text{combustible, expresado} \\ \text{como decimal}\end{matrix} \left(\frac{\text{kg S}}{\text{kg comb.}} \right) \times \frac{2 \text{ kg } SO_2}{\text{kg S}}$$

por ejemplo:

$$\left(\frac{0.0043\ 15 \text{ kg } SO_2}{\text{litro.}} \right) = \frac{0.863 \text{ kg}}{\text{litro}} \times \left(\frac{0.0025 \text{ kg S}}{\text{kg}} \right) \times \frac{2 \text{ kg } SO_2}{\text{kg S}}$$

3. Las emisiones de locomotoras de la U.S. EPA 1992a, Sección 6.0, fueron utilizadas para convertir los factores de emisión de unidades inglesas a métricas. El factor de emisión para SO_2 presentado para las operaciones de patio fue obtenido aplicando un uso de combustible supuesto de 322,312 litros/año (85,410 gal/año) por locomotora. Resalta el hecho de que la U.S. EPA 1992a utiliza un uso de combustible ligeramente menor por locomotora de 312,259 litros/año (82,490 gal/año) para todos los otros contaminantes enlistados.

5.2 Embarcaciones Marítimas Comerciales

CODIGO DE FUENTE	DESCRIPCION
22-80-002-xxx	Embarcaciones marítimas: combustible diesel
22-80-003-xxx	Embarcaciones marítimas: aceite residual

DESCRIPCION:

Las embarcaciones marítimas comerciales incluyen todos los botes y barcos utilizados directa o indirectamente para el comercio. Esto incluye embarcaciones que van desde botes charter de 7 metros de eslora, hasta grandes buques-tanque y embarcaciones militares que pueden exceder los 300 metros de eslora. A pesar de la amplia gama de embarcaciones representadas en esta categoría, la mayor parte de ellas tiene motores diesel (embarcaciones de motor) o turbinas de vapor (barcos de vapor). En general, los motores de gasolina no son utilizados para las embarcaciones marítimas comerciales. Los botes recreativos de gasolina se describen en la Sección 5.4.

El combustible predominante en todas las embarcaciones de motor y la mayoría de los barcos de vapor es el aceite, tanto destilado como en grados residuales. En los barcos de vapor, típicamente se utiliza combustible residual, por ejemplo, aceite pesado No. 6 o Bunker C. Los motores diesel de velocidad moderada requieren una mezcla de aceite destilado y residual para tener una operación satisfactoria. Las embarcaciones de motor utilizan máquinas que requieren aceite destilado. También se manejan otros combustibles, aunque en una proporción limitada. La madera, carbón y bagazo son consumidos en situaciones sumamente excepcionales.

CONTAMINANTES: GOT, CO, NO_x, SO_x, PM

GOR: Para embarcaciones de motor, las emisiones de GOR constituyen 97.2% del GOT (destilado); y para las de vapor, las emisiones de GOR constituyen 82.8% del GOT (aceite residual).

AJUSTES DE FUENTE PUNTUAL: Ninguno.

Existen dos métodos para la estimación de emisiones para las embarcaciones marítimas comerciales. El primer método se basa en la cantidad de combustible vendido para uso marítimo. Las emisiones son estimadas con base en los supuestos con respecto al porcentaje del combustible vendido que en realidad es utilizado dentro del área del puerto, y en la tasa de emisión asociada con el uso del combustible. El segundo método busca proporcionar una estimación más precisa basada en los datos de movimiento del barco. Esta sección describe ambos métodos. Los cálculos requieren sólo de un método, no de ambos, que dependerá de la disponibilidad de los datos locales. Es razonable suponer que las embarcaciones marítimas comerciales utilizadas en todo el mundo tendrán características de emisión similares. Si bien los datos aquí proporcionados provienen de referencias estadounidenses, constituyen estimados de emisión razonables para las embarcaciones marítimas que entran en los puertos mexicanos.

Método de las Ventas de Combustible

METODOLOGIA:

El método de las ventas de combustible asume que el 25% del aceite residual, y 75% del aceite destilado vendido en puerto es utilizado en puerto; que todo el aceite destilado es utilizado en embarcaciones de motor y que todo el aceite residual, en barcos de vapor. Las cantidades totales estimadas de aceite residual y destilado usadas en puerto son:

$$C_{ri} = 0.25 \text{ x } C_{rs} \text{ para residual}$$
$$C_{rs} = 0.25 \text{ x } C_{ds} \text{ para destilado} \qquad (5.2\text{-}1)$$

donde:

C_{ri} y C_{di} = Cantidades de aceite residual y destilado, respectivamente, utilizadas en el puerto i

C_{rs} y C_{ds} = Cantidades totales de aceite residual y destilado vendidas en el área de inventario para uso marítimo.

Para calcular los estimados, se aplica un factor de emisión a las cantidades Q_{ri} y Q_{di}. Estos factores de emisión para embarcaciones de motor se muestran en la tabla de datos, y se dan para dos categorías: fluviales y costeras. Un puerto fluvial recibe embarcaciones que navegan a lo largo de la cuenca de un río. Un puerto marino recibe embarcaciones que viajan dentro y a través de un océano. Para calcular las emisiones para embarcaciones de motor y barcos de vapor debe utilizase la siguiente ecuación:

$$E_{ip} = (C_{ri} \text{ x } FE_{rp}) + (C_{di} \text{ x } FE_{dp}) \tag{5.2-2}$$

donde:
E_{ip} = Cantidad de emisiones de contaminante p producido anualmente por embarcaciones que operan dentro de un área i
C_{ri} y C_{di} = Cantidades de aceite residual y destilado, respectivamente, usadas en el puerto i
FE_{rp} y FE_{dp} = Factores de emisión para el contaminante p, para el aceite residual y destilado, respectivamente.

DATOS NECESARIOS - Método de las Ventas de Combustible:

Datos	Fuentes
Uso anual de combustible (residual y diesel)	Autoridad portuaria local o Dirección General de Puertos
Porcentaje de combustible utilizado en puerto (25% para combustibles residuales y 75% para combustible diesel)	U.S. EPA, 1989
Factores de Emisión: Barcos de Vapor (Combustibles residuales) GOT[a] 0.463 kg/1000 litro GOR 0.383 kg/1000 litro (3.2 lb/10^3 gal) CO despreciable NO_x 4.362 kg/1000 litro (36.4 lb/10^3 gal) SO_x 19 × % azufre [kg/1000 litro] (159 × % azufre [lb/10^3 gal]) PM 1.198 kg/1000 litro (10 lb/10^3 gal) Embarcaciones de Motor (combustibles diesel): Embarcaciones Fluviales GOT 6.2 kg/1000 litro GOR 6.0 kg/1000 litro CO 12.0 kg/1000 litro NO 33.0 kg/1000 litro SO_x 3.2 kg/1000 litro Embarcaciones Costeras GOT 6.2 kg/1000 litro GOR 6.0 kg/1000 litro CO 13.0 kg/1000 litro NO_x 32.0 kg/1000 litro SO_x 3.2 kg/1000 litro	U.S. EPA, 1989

[a] El factor de emisión GOT derivado del factor de emisión GOR y las relaciones GOR/GOT se presentaron previamente en esta sección.

EJEMPLO DE CALCULO - Método de las Ventas de Combustible:

El puerto costero A surte anualmente 1 millón de litros de diesel a embarcaciones de motor y 459,000 litros de combustible residual a barcos de vapor.

El combustible utilizado en el puerto es:

Residual C_{ir} = 0.25 x C_{rs}
= 0.25 x 459,000 litros
= 114.750 litros

Diesel C_{rs} = 0.25 x C_{ds}
= 0.75 x 1,000,000 litros
= 750,000 litros

Los estimados de emisión para GOT son:

$$E_{ip} = (Q_{ri} \text{ x } FE_{rp}) + (Q_{di} \text{ x } FE_{dp})$$

= 114.750 litros (0.463 kg/1,000 litros) + 7500,000 litros (6.2 kg/1,000 litros)
= 53.1 + 4,650 kg
= 4,703 kg
= 4.7 Mg

Método de los Movimientos del Barco

METODOLOGIA:

Este método utiliza datos relacionados con el número de embarcaciones en diversas categorías de tamaños que usan un puerto particular, así como supuestos sobre la actividad del barco en los muelles y sus movimientos dentro y fuera de la bahía. Este enfoque tiene asociados dos tipos independientes de emisiones:

- Emisiones en ruta (i .e., emisiones de las embarcaciones mientras transitan en la bahía)

- Emisiones en muelle (i. e., emisiones de las embarcaciones que están atracadas en los muelles cargando o descargando mercancías)

A continuación se discuten los métodos para estimar emisiones a partir de las emisiones en ruta y en muelle.

Emisiones en Ruta

El primer elemento requerido de los datos es el número de embarcaciones, por categoría de tamaño, que usan el puerto. Hay cuatro categorías que son de interés:

- Embarcaciones de calado menor a dos metros
- Embarcaciones de calado mayor a dos metros pero menor a cuatro
- Embarcaciones de calado mayor a cuatro metros pero menor a seis
- Embarcaciones de calado de seis metros o más.

Estos datos son utilizados para calcular las emisiones de embarcaciones en ruta y en muelle.

Las emisiones en ruta se generan mientras la embarcación está entrando, saliendo o maniobrando en puerto. Los estimados de las emisiones producidas por las embarcaciones en ruta se pueden desarrollar con base en el tiempo promedio de viaje de las embarcaciones que entran, maniobran y abandonan el puerto, aplicando un factor de consumo para estimar el uso del combustible dentro del puerto, y aplicando una tasa de emisión basada en la cantidad del combustible usado.

Se asume que las embarcaciones de calado menor que seis metros (profundidad requerida del agua para que las embarcaciones cargadas puedan operar) tienen motores diesel que utilizan combustibles destilados; mientras que aquellas con calados mayores que 6 metros se alimentan con vapor. Si bien las grandes embarcaciones alimentadas con diesel son capaces de quemar aceite residual, se asume que durante la ruta o la maniobra en el puerto utilizan aceite destilado. Más aún, se asume que todos los barcos de vapor siempre utilizan aceite residual.

Para estimar el tiempo de viaje promedio, se determina la distancia entre los límites exteriores del área de estudio y el centroide teórico de actividad dentro del puerto. Esta distancia es incrementada hasta 120%, para considerar las maniobras y la salida del puerto, y es dividida entre una velocidad promedio supuesta en puerto de 13 km por hora, para arrojar el tiempo promedio en ruta de cada embarcación que usa el puerto. Esto es:

$$\bar{t} = \frac{2.2d}{13} = 0.169d \tag{5.2-3}$$

donde:

$\bar{t}$ = Tiempo de viaje promedio para embarcaciones que usan el puerto (hr)

d = Distancia entre el límite exterior del área de estudio y el centroide supuesto de actividad portuaria.

Los datos de tiempo promedio de viaje pueden ser aplicados a las tasas de consumo de combustible para estimar el consumo en ruta, como se indica en la siguiente ecuación:

$$Qi_{jd} = \bar{t} \times FC_{jd} \times N_{jd} \tag{5.2-4}$$

donde:

Q_{ijd} = Consumo en ruta de una embarcación de tipo j (de vapor o de motor) con calado d para el área de inventario i (litros)

$\bar{t}$ = Tiempo promedio de viaje (hr)

FC_{jd} = Tasa de consumo de combustible de una embarcación tipo j y calado d (litros/hr)

N_{ijd} = Número de embarcaciones de tipo j y calado d en un área de inventario i.

Las tasas de consumo de combustible para las embarcaciones que operan en un puerto mexicano se proporcionan en la tabla de datos; y se presentan tasas diferentes para las embarcaciones de motor y vapor. Para determinar la distribución de las embarcaciones que operan en un puerto mexicano, es necesario determinar el número relativo de embarcaciones con y sin bandera estadounidense que visitan el puerto. Esencialmente, todas las grandes embarcaciones con bandera estadounidense son de vapor, mientras que las de otras banderas tienen motores diesel. A partir de esta información, es posible hacer una aproximación de la composición de embarcaciones de motor y de vapor.

Una vez que se ha calculado el uso de combustible asociado con las operaciones en ruta, es posible determinar las emisiones aplicando los factores de emisión de la tabla de datos, de acuerdo con la siguiente ecuación:

$$E_{ijp} = Q_{ijd} \times FE_{jpd} \tag{5.2-5}$$

donde:

E_{ijp} = Cantidad de emisiones de un contaminante p generadas anualmente por una categoría de embarcaciones tipo j con calado d, que operan dentro de aguas con un área i

Q_{ijd} = Cantidad de combustible (residual o destilado) en litros, consumido por embarcaciones tipo j con calado d

FE_{jpd} = Factor de emisiones para el contaminante p y embarcación tipo j con calado d, de la tabla de datos.

DATOS NECESARIOS - Método de Movimientos de Barcos - Emisiones en Ruta

Datos	Fuentes
Distancia entre el límite exterior del área de estudio y el centroide supuesto de actividad portuaria	Medido con ayuda de la autoridad portuaria local o la Dirección General de Puertos
Tiempo de viaje	Calculado de acuerdo con la Ecuación 5.2-3
Tipo de embarcación (de motor o vapor) Calado de la embarcación Número de embarcaciones de cada tipo y calado	Autoridad portuaria local o Dirección General de Puertos
Tasas de consumo de combustible Embarcaciones de motor Calado <2m 19 litros/hr (5 gal/hr) Calado ≥2 <4m 38 litros/hr (10 gal/hr) Calado ≥4 <6m 167 litros/hr (44 gal/hr) Calado ≥6m 484 litros/hr (128 gal/hr) Barco de Vapor Calado ≥6m 606 litros/hr (160 gal/hr)	U.S. EPA, 1989
Consumo de combustible para cada tipo y calado de embarcación	Calculado de acuerdo con la Ecuación 5.2-4
Factores de Emisión Embarcaciones de Motor Calado <2m GOT[a] 6.30 kg/1000 litro GOR 6.12 kg/1000 litro (51.1 lb/10^3 gal) CO 5.67 kg/1000 litro (47.3 lb/10^3 gal) NO_x 46.65 kg/1000 litro (389.3 lb/10^3 gal) SO_x 3.24 kg/1000 litro (27 lb/10^3 gal) Calado ≥2 <4m GOT[a] 5.48 kg/1000 litro GOR 5.33 kg/1000 litro (44.5 lb/10^3 gal) CO 11.95 kg/1000 litro (99.7 lb/10^3 gal) NO_x 40.57 kg/1000 litro (338.6 lb/10^3 gal) SO_x 3.24 kg/1000 litro (27 lb/10^3 gal)	U.S. EPA, 1989
Embarcaciones de Motor Calado ≥4 <6m GOT[a] 2.07 kg/1000 litro GOR 2.01 kg/1000 litro (16.8 lb/10^3 gal) CO 7.45 kg/1000 litro (62.2 lb/10^3 gal) NO_x 20.03 kg/1000 litro (167.2 lb/10^3 gal) SO_x 3.24 kg/1000 litro (27 lb/10^3 gal)	U.S. EPA, 1989

Datos			Fuentes
Calado $\geq$6m	GOT[a]	6.16 kg/1000 litro	
	GOR	5.99 kg/1000 litro (50 lb/10^3 gal)	
	CO	13.18 kg/1000 litro (110 lb/10^3 gal)	
	NO_x	32.35 kg/1000 litro	
	SO_x	3.24 kg/1000 litro (27 lb/10^3 gal)	
Barcos de Vapor			
Calado $\geq$6m	GOT[a]	0.10 kg/1000 litro	
	GOR	0.08 kg/1000 litro (0.7 lb/10^3 gal)	
	CO	0.42 kg/1000 litro (3.5 lb/10^3 gal)	
	NO_x	6.69 kg/1000 litro (55.8 lb/10^3 gal)	
	SO_x	19 × % azufre [kg/1000 litro] (159 × % azufre [lb/10^3 gal])	
	PM	2.4 kg/1000 litro (20 lb/10^3 gal)	

[a] El factor de emisión GOT derivado del factor de emisión GOR y las relaciones GOR/GOT se presentaron previamente en esta sección.

Emisiones en Muelle

Las grandes embarcaciones (calado de 6 metros o más) producen emisiones mientras están atracados en el muelle, dado que los sistemas auxiliares diesel de generación o las calderas principales permanecen en operación para alimentar las funciones básicas de la embarcación. Por otro lado, las calderas de la mayor parte de los barcos de vapor que estarán en puerto por menos de dos días se apagan sólo en raras ocasiones, debido al tiempo relativamente largo que es necesario para reiniciar y preparar su operación. Para estimar las emisiones producidas por estas embarcaciones, debe desarrollarse un estimado del número promedio de días en puerto, y debe determinarse una tasa de consumo de combustible. Después de que la cantidad total de combustible consumido en puerto es estimada, se aplica un factor de emisión para generar el estimado de emisión.

La estancia promedio de una embarcación comercial de gran tamaño es de uno a tres días. Un estimado para un puerto particular puede determinarse cuestionando a la autoridad portuaria, a la empresa naviera o bien, utilizando un valor por omisión de tres días.

Se asume que las tasas de consumo de combustible para las embarcaciones de vapor y motor son 7,192 litros diarios de aceite residual, y 2,490 litros diarios de aceite destilado, respectivamente. Una vez más, se asume que todas las embarcaciones con bandera estadounidense son de vapor, y las de otras banderas, de motor. El combustible usado por cada tipo de embarcación en puerto se calcula como se muestra a continuación:

$$Q_{ij} = N_{ij} \text{ x } D_{ij} \text{ x } f_{cj} \tag{5.1-6}$$

donde:

Q_{ij} = Consumo anual de combustible de aceite residual o destilado, en el área i, por tipo de embarcación j (embarcaciones de vapor o motor) (litros)
N_{ij} = Número total de embarcaciones tipo j que utilizan el puerto i
D_{ij} = Tiempo de estancia promedio de una embarcación tipo j en un área i (días)
f_{cj} = Tasa de consumo de combustible para una embarcación tipo j (se asume que es de 7,192 litros diarios de aceite residual para barcos de vapor, y de 2,498 litros diarios de aceite destilado para embarcaciones de motor).

Las emisiones producidas por los barcos atracados en muelle son:

$$E_{ijp} = Q_{ij} \text{ x } FE_{jp} \tag{5.2-8}$$

donde:

E_{ijp} = La cantidad de emisiones del contaminante p producidas anualmente por las embarcaciones de la categoría j mientras están en puerto en aguas de área i
Q_{ij} = La cantidad de combustible consumida en muelle por embarcación tipo j (en 1,000 litros)
FE_{jp} = El factor de emisión para el contaminante p y la embarcación tipo j.

DATOS NECESARIOS - Método de Movimientos de Barcos - Emisiones en Muelle

Datos	Fuentes
Número anual y tipo (embarcaciones de motor/vapor) que visitan el puerto	Autoridad portuaria local o Dirección General de Puertos
Duración promedio de la estadía (días)	Autoridad portuaria local o Dirección General de Puertos
Tasa de consumo de combustible Embarcaciones de motor 2,498 litros/día (660 gal/día) Embarcaciones de vapor 7,192 litros/día (1,900 gal/día)	U.S. EPA, 1989
Combustible consumido	Calculado de acuerdo con la Ecuación 5.2-6
Factores de Emisión Embarcaciones de Motor GOT[a] 7.27 kg/1000 litros GOR 7.07 kg/1000 litros (59 lb/10^3 gal) CO 5.27 kg/1000 litros (44 lb/10^3 gal) NO_x 43.62 kg/1000 litros (364 lb/10^3 gal) SO_x 3.24 kg/1000 litros (27 lb/10^3 gal) PM despreciable Embarcaciones de Vapor GOT[a] 0.46 kg/1000 litros GOR 0.38 kg/1000 litros (3.2 lb/10^3 gal) CO despreciable NO_x 4.36 kg/1000 litros (36.4 lb/10^3 gal) SO_x 19 × % azufre [kg/1,000 litros] (159 × % azufre [lb/10^3 gal]) PM 1.20 kg/1000 litros de combustible (10 lb/10^3 gal)	U.S. EPA, 1989

[a] El factor de emisión GOT derivado del factor de emisión GOR y las relaciones GOR/GOT se presentaron previamente en esta sección.

EJEMPLO DE CALCULO - Método de Movimientos de Barcos:

- La distancia desde el límite exterior del área de estudio hasta el centroide del Puerto A es de 30 km;

- El Puerto A es visitado por 10 embarcaciones de motor y dos barcos de vapor por semana (520 embarcaciones de motor y 104 barcos de vapor, anualmente)
- Todas las embarcaciones de motor tienen calado de entre dos y cuatro metros. Todas las embarcaciones de vapor tienen calado de seis metros o más.

- El número de días que las embarcaciones permanecen atracadas es 2.

Emisiones en Ruta

El tiempo calculado de viaje es de:

$$\begin{aligned} \bar{t} &= 0.169d \\ &= 0.169 \text{ hr / km x } 30 \text{ km} \\ &= 5.07 \text{ hr} \end{aligned}$$

El consumo calculado de combustible es de:

Embarcaciones de motor = (5.07 hr) (38 litros/hr) (520 embarcaciones)
= 100,183 litros

Barcos de vapor = (5.07 hr) (606 litros/hr) (104 embarcaciones)
= 319,532 litros

Las emisiones estimadas de GOT son:

Embarcaciones de motor = (100,183 litros) (5.48 kg GOT/1,000 litros)
= 549 kg

Barcos de vapor = (319,532 litros) (0.10 kg GOT/1,000 litros)
= 32 kg

Emisiones totales en ruta = Emisiones de embarcaciones de motor + Emisiones de embarcaciones de vapor

Emisiones en Muelle

El consumo calculado de combustible es de:

Embarcaciones de motor$_{ij}$ = (520 embarcaciones) (2 días) (2,498 litros/día)
= 2,597,920 litros

Barcos de vapor$_{ij}$ = (104 embarcaciones) (2 días) (7,192 litros/día)
= 1,495,936 litros.

Las emisiones calculadas son:

Embarcaciones de motor = (2,597,920 litros) (7.27 kg GOT/1,000 litros)
= 18,887 kg

Barcos de vapor = (1,495,936 litros) (0.46 kg GOT/1,000 litros)
= 688 kg

Las emisiones estimadas de GOT son:

Emisiones TOG totales en muelle = Emisiones de embarcaciones de motor + Emisiones de embarcaciones de vapor

= 18,887 kg + 688 kg
= 19,575 kg.

Emisiones TOG totales = Emisiones en ruta + Emisiones en muelle

= 581 kg + 19,575 kg
= 20,156 kg.

NOTAS:

1. El método del uso de combustible combina las actividades en ruta y en muelle en el estimado del combustible consumido en puerto, Si el método del movimiento del barco es utilizado para estimar emisiones de esta fuente, las emisiones en ruta y en muelle deben ser calculadas por separado y, posteriormente, combinadas para arrojar las emisiones totales de las embarcaciones marítimas comerciales.

2. Para identificar las variaciones estacionales en emisiones, las tabulaciones mensuales de la actividad de las embarcaciones debe obtenerse con la autoridad portuaria local.

5.3 Aeronaves

CODIGO DE FUENTE	**DESCRIPCION**
22-75-000-000	Total de Aeronaves
22-75-001-000	Militares
22-75-020-000	Total de Comerciales
22-75-050-000	Aeronaves civiles

DESCRIPCION:

Las aeronaves civiles incluyen todas las categorías de naves con alas fijas y rotatorias, desde el motor individual más pequeño, de propiedad y operación privada, hasta las aeronaves comerciales de mayor tamaño. Dentro de la categoría civil, existen tres subcategorías: aeronaves comerciales, aerotaxis y aeronaves de aviación general. En el desarrollo de un inventario de emisión, es necesario tomar en cuenta los diferentes tipos de aeronaves que utilizan cada aeropuerto. Las aeronaves comerciales se usan en vuelos regularmente programados. Los aerotaxis también viajan con un programa, llevando pasajeros y/o carga, pero en general son naves más pequeñas y operan en una base más limitada que los transportes comerciales. La aviación general incluye a cualquier nave no militar que no se utiliza en un servicio programado, La aviación de negocios realiza viajes, normalmente en un esquema no programado. Para propósitos de elaboración de un inventario de emisiones, los aviones de negocios son combinados con las aeronaves de aviación general debido a que su tamaño, frecuencia de uso y perfiles de operación son similares. En esta guía de inventario, son referidos simplemente como aviación general. De manera similar, los aerotaxis son manejados en gran medida dentro de la categoría de aviación general, debido a que típicamente tienen los mismos tipos de aeronaves. Los helicópteros, o aeronaves de alas rotatorias, pueden encontrarse en todas las categorías. Su operación es distinta debido a que no siempre operan en un aeropuerto, sino que pueden despegar y aterrizar en un helipuerto, en un hospital, estación de policía u otra localidad.

En general, las aeronaves comerciales son la mayor fuente de emisiones. Si bien constituyen menos de la mitad de todas las aeronaves en operación alrededor de un área metropolitana, sus emisiones representan un gran porcentaje de las emisiones totales debido a su tamaño y frecuencia de operación. Esto no será aplicable, desde luego, a las ciudades que no tienen grandes aeropuertos civiles.

Los contaminantes son emitidos por una aeronave cuando los motores están en operación. En el contexto del desarrollo de un inventario de emisiones, sin embargo, el interés está limitado a aquellas porciones del vuelo que se presentan entre el nivel de piso y una altitud definida como altura de inversión. Dentro de esta franja, el aire es sumamente estable y las emisiones tienden más a difundirse que a ser transportadas. Como resultado, las emisiones por debajo de la altura de inversión tienen un efecto sobre la calidad del aire a nivel de piso, debido a la mezcla que se presenta dentro de la celda de aire.

Las emisiones de las aeronaves son afectadas el ajuste de la válvula de estrangulación, es decir, el porcentaje de máximo poder que los motores producen en un tiempo dado. Sin embargo, el ajuste de potencia es predecible, dado el modo de operación específico en el que la aeronave está funcionando. Para propósitos del desarrollo del inventario, se considera que existen cinco modos de operación:

- Aproximación (30-40% de estrangulación)
- Carreteo/Reposo Llegada (3-7% de estrangulación)
- Carreteo/Reposo Salida (3-7% de estrangulación)
- Despegue (100% de estrangulación)
- Ascenso (85-90% de estrangulación).

En conjunto, estos cinco modos integran el ciclo de aterrizaje y despegue (AD), que constituye las bases para asignar las emisiones de la aviación a una región determinada. Las emisiones para un modo dado son calculadas con base en el periodo de tiempo que la aeronave pasa en un modo específico. Este periodo se denomina Tiempo En Modo (TIM, por sus siglas en inglés).

La duración de la aproximación y ascenso depende en gran medida de la meteorología local. Debido a que el periodo de interés se ubica durante la operación de la nave dentro de la zona de modelado del aire. El espesor de la capa de inversión determina el tiempo en que la aeronave se encuentra en esta zona. La masa de aire colocada debajo de la capa de inversión y que tiene una altura conocida como altura de mezclado, constituye la zona de mezclado. Dentro de esta zona existe una gran turbulencia que permite que el aire se mezcle, diluyendo así la contaminación. Por otro lado los contaminantes emitidos dentro de la capa de inversión, que es una zona de gran estabilidad, quedan atrapados en su interior.

Cuando la aeronave se encuentra sobre la capa de inversión, ya sea en su descenso o en su ascenso a la altitud de crucero, las emisiones tienden a dispersarse más que a quedar atrapadas por la inversión, y no tienen efectos a nivel de suelo.

El tiempo de carreteo e inactividad, ya sea desde la pista a la puerta (carreteo/llegada) o de la puerta a la pista, depende del tamaño y diseño del aeropuerto, el tráfico o congestión en tierra, y de los procedimientos operativos específicos del aeropuerto. El tiempo de carreteo y espera es el más variable de los modos AD, dado que puede variar significativamente en cada aeropuerto a lo largo del día, en la medida en que la actividad cambia; y a nivel estacional, conforme la actividad en los viajes aumenta o disminuye.

El periodo de despegue, caracterizado principalmente por la operación al 100% de estrangulación, en general dura hasta que la nave alcanza entre 150 y 300 metros sobre el nivel de piso, cuando la potencia del motor es reducida e inicia el modo de ascenso. Esta altura de transición es bastante regular y no varía demasiado de una localidad a otra, o entre las categorías de aeronaves.

Se asume que las aeronaves comerciales utilizadas alrededor del mundo tienen características de emisión similares. Si bien los datos que aquí se presentan fueron desarrollados en EU, podrían constituir estimados de emisión razonables para las aeronaves que operan en los aeropuertos mexicanos.

CONTAMINANTES: GOT, CO, NO_x, SO_2, PM

GOR: Para aviones de reacción, las emisiones de GOR constituyen 84.4% del GOT.
Para aviones de pistón, las emisiones de GOR constituyen 96% del GOT.

AJUSTES DE FUENTES PUNTUALES: Ninguno.

METODOLOGIA:

Los pasos en la metodología para la estimación de emisiones son básicamente los mismos para todas las clasificaciones de aeronaves y todas las localidades, si bien algunos de los factores utilizados para la generación de un inventario son específicos del sitio. Los pasos son:

1. Identificar todos los aeropuertos a ser incluidos en el inventario.

2. Determinar la altura de mezcla a ser aplicada en el ciclo AD.

3. Definir las características de la flota aérea para la categoría de aeronaves que utiliza cada aeropuerto.
4. Determinar la actividad del aeropuerto como el número de ADs para

cada categoría de aeronave.

5. Calcular las tasas de emisión a partir de las tasas de flujo de combustible y los índices de emisión para cada categoría (posteriormente discutidos en esta sección).

6. Estimar un TIM para cada categoría de aeronaves en cada aeropuerto.

7. Calcular las emisiones con base en la actividad del aeropuerto, el TIM y los factores de emisión de las aeronaves.

La altura de la zona de mezcla influencía el TIM sólo para la aproximación y ascenso. Este factor es importante, en particular cuando se calculan las emisiones NO_x más que las GOT o de CO. Si las emisiones NO_x son un componente importante del inventario, deben recopilarse los datos específicos sobre las alturas de mezcla. Si las emisiones de NO_x no son importantes, la altura de mezcla tendrá un efecto mínimo sobre los resultados, y el valor por omisión de 900 metros puede ser utilizado para obtener resultados más generalizados.

Para definir las características de la flota y la actividad del aeropuerto en México, debe contactarse a Aeropuertos y Servicios Auxiliares (ASA) o al personal del aeropuerto de interés. Es necesario que los datos AD sean recopilados para cada tipo de aeronave en la flota.

Deben identificarse los motores utilizados en cada tipo de aeronave para seleccionar los factores de emisión del paso 5. La Tabla 5.3-1 enlista las aeronaves y los motores correspondientes a cada una de ellas. Muchos aviones utilizan un solo modelo de motor, mientras que otros están certificados para usar motores de dos o tres fabricantes diferentes. Cuando un solo motor es enlistado para un modelo de aeronave, pueden usarse los datos de emisión para dicho motor. Para las aeronaves con motores de más de un fabricante, la identificación de la mezcla de motores utilizados en la flota aérea que opera en un aeropuerto específico puede ser extremadamente compleja.

Para desarrollar una mezcla de motores representativa de los aviones con más de un modelo de motor, la Tabla 5.3-1 muestra el porcentaje de cada motor que se puede encontrar en esos aviones en la flota aérea estadounidense, a un lado del número de modelo de motor. El procedimiento recomendado para compensar la falta de datos detallados sobre los motores es usar los porcentajes mostrados en la tabla como factores de ponderación. Por ejemplo, los aviones de carga Boeing 757-200 han sido vendidos a las aerolíneas estadounidenses con motores tanto PW2040 de Pratt & Whitney como RF.211-535E4 de Rolls Royce. El número de aviones con cada modelo de motor es de 15 y 43, respectivamente, lo que arroja los porcentajes mostrados en la Tabla A de 26 y 74. Estos valores pueden ser usados para dividir los ADs totales de aviones de carga B 757-200 en dos grupos que representan ambos tipos de motor.

Esto hace que el inventario sea más representativo que el asignar un solo motor para todas las versiones de carga de los B 757-200, dado que los factores de emisión son diferentes para cada motor.

Después de identificar los motores incluidos en la flota aérea, se utilizan los factores de emisión para calcular la masa de emisiones. Para algunos de los motores mostrados en la Tabla 5.3-1, los factores de emisión no han sido determinados nunca. En estos casos, es necesario utilizar los factores de un motor alternativo. La Tabla 5.3-2 enlista los motores alternativos recomendados por los fabricantes. Para la mayoría de estos motores existen factores de emisión disponibles a partir de un motor muy similar, generalmente uno del mismo modelo y de una serie relacionada. Un pequeño grupo de motores carece de datos sobre las emisiones y sobre las alternativas sugeridas. En estos casos, se pueden aplicar tres enfoques. Primero, los datos necesarios pueden encontrarse en la última versión de la Federal Aircraft Engine Emission Database (FAEED) *(Base de Datos Federal de Emisiones de Aeronaves)* [ver http://www.epa.gov/oar/omswww/aviation.html].

Debe recurrirse a Federal Aviation Administration (FAA) *(Administración Federal de Aviación)* para obtener la última versión de la base de datos. Segundo, para un avión con diversos tipos de motores, en los que los datos de emisión no estén disponibles para un motor, el procedimiento recomendado es determinar la participación de mercado entre los motores para los que sí existen datos. Tercero, si la información sobre la tasa de emisión (consumo de combustible e índice de emisión) para un modelo de motor no puede ser localizada, debe contactarse directamente al fabricante.

Después de que los tipos de motor han sido identificados, las tasas de flujo de combustible e índices de emisión pueden encontrarse en la Tabla 5.3-3. Los índices de emisión son proporcionados para tasas de flujo de combustible específicas que son representativas de los arreglos de potencia usados durante los diferentes modos de operación. El índice de emisión multiplicado por la tasa de flujo de combustible arroja una tasa de emisión.

El paso 6 consiste en especificar un tiempo TIM para cada tipo de aeronave. El tiempo de despegue es bastante estándar para los aviones comerciales, y representa el tiempo para el ascenso inicial desde nivel de tierra hasta aproximadamente 150 metros. El tiempo de despegue por omisión para calcular las emisiones es del 0.7 minutos (42 segundos) y, a menos que se disponga de datos más específicos, es el que debe usarse en esta metodología. El tiempo en los modos de aproximación y ascenso dependen de la altura de mezcla. Como se mencionó anteriormente, una altura de mezcla por omisión de 900 metros fue supuesta para calcular un tiempo de aproximación de 4 minutos y un tiempo de ascenso de 2.2 minutos, que pueden ser utilizados si no se dispone de información específica sobre la altura de mezcla. A continuación se presenta el procedimiento para ajustar estos tiempos con respecto a diferentes alturas de mezcla.

El modo con la duración más variable para cada aeropuerto específico es el tiempo de carreteo/reposo. El tiempo total de carreteo/reposo para un aeropuerto muy congestionado puede ser hasta tres o cuatro veces más largo que para un aeropuerto con poco tránsito. Típicamente, el tiempo de carreteo de llegada es menor que el de salida, debido a que, en general, existen menos retrasos para los aviones que llegan que para los que están en espera para despegar. En el caso de un aeropuerto grande y congestionado, el tiempo de carreteo de salida puede ser hasta tres veces mayor que el de llegada. Este tiempo también puede variar dependiendo del tipo de avión. Por ejemplo, los jets de fuselaje ancho pueden usar puertas especiales en las terminales, que los colocan más lejos de la pista, que los jets de fuselaje angosto o los pequeños aviones de conexión regional, de manera tal que sus tiempos de carreteo tanto de entrada como de salida son más largos. Debido a la variación del tiempo de carreteo y reposo, es importante obtener datos específicos para los aeropuertos de interés en un inventario. Las aerolíneas comerciales deben mantener registros de sus tiempos de carreteo y reposo en cada aeropuerto para cada tipo de avión diferente, de manera tal que sus horarios reflejen las variaciones diarias y estacionales anticipadas. Por lo tanto, los departamentos de Operaciones de Vuelo de las aerolíneas en sus oficinas generales son las mejores fuentes de datos para el tiempo de carreteo y reposo por tipo de avión en un aeropuerto particular. Dado que todas las aerolíneas que usan un aeropuerto particular tendrán tiempos de carreteo y reposo similares, sólo es necesario obtener la información de una sola fuente. Si estos tiempos no estuvieran disponibles para un aeropuerto particular, la Tabla 5.3-4 enlista los valores por omisión para los periodos de carreteo y reposo, así como para otros modos, para las diferentes clasificaciones de aeronaves. Para los aviones comerciales, esta información se basa en datos recopilados antes de 1971 para aeropuertos de gran tamaño durante periodos de congestionamiento. Para los cálculos de un inventario, los tiempos en modo de carreteo y reposo de llegada o salida son sumados para obtener el tiempo total.

El paso final en el procedimiento consiste en calcular las emisiones totales para cada tipo de avión y sumarlas para obtener una tasa de emisión total para la aviación comercial. La siguiente serie de ecuaciones ilustra el cálculo.

Ajuste del TIM de Acercamiento y Ascenso para Representar las Condiciones Locales

Estas ecuaciones ajustan los TIMs que se basan en la altura de mezcla por omisión de 900 metros, para un valor específico de aeropuerto basado en la altura de mezcla local. La ecuación 5.3-1 supone que el modo de ascenso comienza con la transición del despegue al ascenso a 150 metros, y continúa hasta que el avión sale de la capa de mezcla.

$$TIM_{App} = TIM_{App\text{-}Def} \left(\frac{H}{900} \right)$$
$$TIM_{Clm} = TIM_{Clm\text{-}Def} \left(\frac{H - 150}{750} \right)$$

(5.3-1)

donde:
TIM_{App} = Tiempo real en modo de aproximación (minutos)
$TIM_{App\text{-}Def}$ = Tiempo por omisión en modo de aproximación (minutos) (ver Tabla 5.3-4)
H = Altura de mezcla utilizada en el modelado de calidad del aire para el tiempo y región de interés
TIM_{Cln} = Tiempo real en modo de ascenso (minutos)
$TIM_{Clm\text{-}Def}$ = Tiempo por omisión en modo de ascenso (minutos) (ver Tabla 5.3-4).

Si el procedimiento detallado de estimación está siendo seguido con base en aviones y motores específicos, los estimados específicos por aeropuerto para cada TIM pueden ser utilizados si están disponibles con los funcionarios del aeropuerto. Es posible que estos datos varíen ampliamente debido a los diferentes tipos de servicios proporcionados por esta categoría de aviones. De otra manera, el procedimientos de estimación se basa en los TIMs por omisión de la Tabla 5.3-4. Las emisiones deben ser calculadas por separado para las diferentes categorías de aviones.

Calcular las Emisiones para Cada Tipo de Aeronave

$$E_{ij} = \Sigma \left[(TIM_{jk}) \text{ x } (FF_{jkL}/1000) \text{ x } (EL_{ijkL}) \text{ x } (NE_j) \right]$$

(5.3-2)

donde:
E_{ij} = Emisiones totales de contaminante i, producidas por un avión tipo j para un ciclo AD (kg)
TIM_{jk} = Tiempo en modo para el modo k (despegue, ascenso, aproximación, carreteo y espera), en minutos, para un avión tipo j

FF_{jkL} = Flujo de combustible para el modo k, para el motor L utilizado en un avión tipo j (kg/minuto) (de la Tabla 5.3-3)

EL_{ijkL} = Indice de emisión para el contaminante i en el modo k para un avión tipo j, para un motor L (kg/1,000 kg combustible) (de la Tabla 5.3-3)

NE_j = Número de motores utilizados en un avión tipo j (de la Tabla 5.3-1).

Para estimar las emisiones, debe utilizarse la siguiente ecuación:

$$E_{aij} = E_{ij} \text{ x } AD_j \tag{5.3-3}$$

donde:

E_{aij} = Emisiones totales de un contaminante i para un tipo de avión j (kg)

E_{ij} = Emisiones totales de un contaminante i, producidas por un tipo de avión j para un AD (kg)

AD_j = Número de ADs para un tipo de avión j.

Para estimar las emisiones totales de la actividad de la aviación, las emisiones de cada avión son sumadas posteriormente.

Enfoque Alternativo para la Aviación General y Aerotaxis

En algunos casos, los datos AD sobre la aviación general y los aerotaxis pueden no ser reportados con el detalle requerido para utilizar el método anterior.

Es posible hacer un estimado grueso de las emisiones para cada categoría de aviones, utilizando los índices de emisión basados en una mezcla representativa de la flota aérea. Los siguientes índices fueron calculados con base en los datos de la flota aérea estadounidense de 1988 para la aviación general:

GOT	0.179 kg por AD
CO	5.449 kg por AD
NO_x	0.029 kg por AD
SO_2	0.005 kg por AD

Debido a que los aerotaxis tienen menos de los motores más pequeños en su flota, y más motores de turbopropulsión y turbojets, sus factores de emisión son ligeramente diferentes:

GOT	0.376 kg por AD
CO	12.76 kg por AD
NO_x	0.072 kg por AD
SO_2	0.007 kg por AD

Estos factores de emisión pueden ser aplicados a la siguiente ecuación para estimar las ecuaciones:

$$E_{ij} = FE_{ij} \text{ x } AD_j \tag{5.3-4}$$

donde:
E_{ij} = Emisiones totales de contaminante i, en kg, producidos por avión tipo j
FE_{ij} = Factor de emisión para el contaminante i, en kg de contaminante por AD para avión tipo j
AD_j = Ciclo AD para avión tipo j.

DATOS NECESARIOS:

Datos	Fuentes
Datos de AD por tipo de avión	ASA y operación del aeropuerto local
Datos de los motores del avión:	FAA, 1991
Número de motores	Air World, 1990
Modelo de motor y fabricante	FAA, 1991
Participación de mercado	Air World, 1990
Flujo de combustible	FAA, 1991
Indice de emisión	FAA, 1991
Altura de mezcla	Sosa, 1995
Datos de Tiempo en Modo	Operadores de los aeropuertos locales

EJEMPLO DE CALCULO:

- El Aeropuerto A es utilizado dos veces por semana por la aerolínea B, con un Boeing B-757-200, ADs anuales = 104
  Boeing B-757-20: 2 motores. El 26% del mercado usa un motor DW2040 de Pratt & Whitney; y el 74% usa un motor RB.211-535 E4 de Rolls Royce.

- La altura de techo para el Aeropuerto A es de 800 metros.

$$
\begin{aligned}
TIM_{App} &= TIM_{App\text{-}Def} \left(\frac{H}{900} \right) \\
&= 4 \left(\frac{800}{900} \right) \\
&= 3.6 \text{ min}
\end{aligned}
$$

$$
\begin{aligned}
TIM_{Clm} &= TIM_{Clm\text{-}Def} \left(\frac{H - 150}{750} \right) \\
&= 4 \left(\frac{800 - 150}{750} \right) \\
&= 1.9 \text{ min}
\end{aligned}
$$

Los datos de tiempo de carreteo de entrada y salida del aeropuerto son proporcionados por operaciones en el aeropuerto: 25 minutos.

- Para calcular las emisiones de GOT:

$$E_{ij} = \Sigma \left[(TIM_{jk}) \text{ x } (FF_{jkL}/1000) \text{ x } (EL_{ijkL}) \text{ x } (NE_j) \right]$$

Motor PW2040

Aproximación = (3.6) (29.58/1000) (0.18) (2) = 0.038 kg

Ascenso = (1.9) (86.88/1000) (0.04) (2) = 0.013 kg

Carreteo = (25) (9.30/1000) (2.36) (2) = 1.097 kg

Despegue = (0.7) (109.32/1000) (0.03) (2) = 0.005 kg

Total = Aproximación + Ascenso + Carreteo + Despegue

= 0.038 + 0.013 + 1.097 + 0.005 = 1.153 kg/AD

Motor RB.211.535E4

Aproximación = (3.6) (34.20/1000) (1.33) (2) = 0.327 kg

Ascenso = (1.9) (90.60/1000) (0.94) (2) = 0.324 kg

Carreteo = (25) (11.40/1000) (2.85) (2) = 1.625 kg

Despegue = (0.7) (111.60/1000) (0.69) (2) = 0.108 kg

Total = Aproximación + Ascenso + Carreteo + Despegue

= 0.327 + 0.324 + 1.625 + 0.108 = 2.384 kg/AD

Motores Combinados

26% (PW2040) + 74% (RB.211-535E4)

0.26 (1.153) + 0.74 (2.384) = 2.064 kg/AD

Emisiones

$E_{ij} = FE_{ij}$ x AD_j

= 2.064 kg/AD x 104 ADs
= 214.66 kg.

Tabla 5.3-1

Tipos de Aeronaves y Modelos de Motor

Aeronave [1]	No. de Motores	Modelo de Motor (% de Aeronaves) y Fabricante [2]			
Aeronaves Comerciales					
Aerospatiale ATR-42	2	PW120(53)PWC	PW121(47)PWC		
Airbus A-300-B4	2	CF6-50(100)GE			
Airbus A-300-600	2	CF6-80C2A5(100)GE			
Airbus A-310-200	2	JT9D-7R4E1(100)PW			
Airbus A-310-300	2	PW4152(100)PW			
Airbus A-320-200	2	CFM56-5A(100)GE			
BEECH 18[3]	2	R-985-AN(100)PW[4]			
BEECH BH-C99	2	PT6A-36(100)PWC			
BEECH BH-1900	2	PT6A-65B(100)PWC			
Boeing B-707-300B	4	JT3D-3B(100)PW			
Boeing B-707-300C	4	JT3D-3B(100)PW			
Boeing B-727-100	3	JT8D-7(16)PW JT8D-7D(4)PW	JT8D-7A(4)PW JT8D-9(1)PW	JT8D-7A/7B(<1)PW JT8D-9A(2)PW	JT8D-7B(73)PW
Boeing B-727-100[3]	3	JT8D-7A(6)PW	JT8D-7B(91)PW	JT8D-9(1)PW	JT8D-9A(2)PW
Boeing B-727-200	3	JT8D-7A(<1)PW JT8D-15(26)PW JT8D-15B(<1)PW	JT8D-7B(16)PW JT8D-15A(21)PW JT8D-17(3)PW	JT8D-9(20)PW JT8D-9A(9)PW JT8D-17A(1)PW	JT8D-17R(3)PW
Boeing B-737-100/200	2	JT8D-7B(19)PW JT8D-17(7)PW	JT8D-9A(39)PW JT8D-17A(1)PW	JT8D-15(10)PW	JT8D-15A(24)PW
Boeing B-737-200C	2	JT8D-7A(10)PW JT8D-17(32)PW	JT8D-9/9A(5)PW JT8D-17A(32)PW	JT8D-9A(16)PW	JT8D-15(5)PW
Boeing B-737-300	2	CFM56-3(100)GE[6]			
Boeing B-737-400	2	CFM56-3(100)GE			
Boeing B-747[3]	4	JT9D-7F(100)PW			
Boeing B-747F[3]	4	JT9D-7F(33)PW	JT9D-7Q(17)PW	JT9D-7R4G2(11)PW	JT9D-70A(39)PW
Boeing B-747SP	4	JT9D-7A(85)PW	JT9D-7A-SP(15)PW		
Boeing B-747-200	4	CF6-50(3)GE[6] JT9D-7A(55)PW	JT9D-7R4G2(3)PW JT9D-7AH(13)PW	JT9D-3A(7)PW JT9D-7F(5)PW	JT9D-7(1)PW JT9D-7Q(13)PW
Boeing B-747-400	4	PW4056(100)PW			
Boeing B-757-200	2	RB.211-535E4(1)RR	PW2037(92)PW	PW2040(7)PW	

Aeronave [1]	No. de Motores	Modelo de Motor (% de Aeronaves) y Fabricante [2]			
Boeing B-757-200[3]	2	PW2040(26)PW	RB.211-535E4(74)RR		
Boeing B-767-200	2	CF6-80A2(59)GE	CF6-80C2B2(12)GE[7]	JT9D-7R4D(29)PW	
Boeing B-767-300	2	CF6-80C2B6(100)GE[8]			
Brit. Air. Corp. BAC-111-200	2	Spey Mk 511(100)RR[9]			
Brit. Aero. BAe-146-1	4	ALF502R-5(100)Lyc			
Brit. Aero. BAe-146-2	4	ALF502R-5(100)Lyc			
Brit Aero. Concorde	4	Olympus 593 Mk610(100)RR			
Brit Aero. JETSTREAM 31	2	TPE 331-10UF(100)Grt[9]			
CESSNA 404[3]	2	TSIO-520-VB(100)Con[9]			
Convair CV-580	2	501D13H(100)All.[9]			
Convair CV-640[3]	2	Dart 542-4(100)RR			
de Havilland DASH-7	4	PT6A-50(100)PWC			
de Havilland DHC-6	2	PT6A-20(26)PWC	PT6A-27(74)PWC		
de Havilland DHC-8	2	PW120(17)PWC	PW120A(83)PWC		
deHavilland Twin Otter	2	PT6A-27(100)PW			
EMBRAER[10]	2	PW6A-34(100)PWC			
EMBRAER EMB-120	2	PW118(85)PWC	PW118A(15)PWC		
Fairchild F27	2	R. Da. 7(100)RR			
Fairchild FH-227	2	Dart 532-7(100)RR			
Fokker 100	2	Tay 620-15(75)RR	Tay 650(25)RR		
Fokker F-27 SERIES	2	Dart 514-7(15)RR Dart 532-7P(24)RR Dart 532-7R(29)RR	Dart 528-7E(10)RR Dart 532-7R(3)RR	Dart 532-7(5)RR Dart 535-7R(9)RR	Dart 532-7N(3)RR Dart 536-7E(2)RR
Fokker F-28-100	2	Spey 555-15(100)RR			
Fokker F-28-4000/600	2	Spey 555-15H(12)RR	Spey 555-15P(88)RR		
Grumman Goose	2	PT6A-27(100)PWC			
Lockheed L100 Hercules	2	501(100)All			
Lockheed L100 Hercules	2	501(100)All			
Lockheed L-100-30[3]	2	501D22A(100)All.[9]			
Lockheed L-188A/C	2	501D13(100)All.[9]			

Aeronave [1]	No. de Motores	Modelo de Motor (% de Aeronaves) y Fabricante [2]			
Lockheed L-1011/100/200	3	RB.211-22B(99)RR	RB.211-524B4(1)RR		
Lockheed L-1011-500 TR	3	RB.211-524B4(100)RR			
McDonnell Douglas DC-6[3]	4	R2800(100)PW[9]			
McDonnell Douglas DC-6A[3]	4	R2800(100)PW[9]			
McDonnell Douglas CD-8-60	4	JT3D-3B(57)PW	JT3D-7(43)PW		
McDonnell Douglas DC-8-61[3]	4	JT3D-3B(100)PW			
McDonnell Douglas DC-8-62[3]	4	JT3D-3B(15)PW	JT3D-3BDL(21)PW	JT3D-7(64)PW	
McDonnell Douglas DC-8-63F[3]	4	JT3D-3B(24)PW	JT3D-7(42)PW	JT3D-735E4(7)PW	JT8D-7(27)PW
McDonnell Douglas DC-8-70	4	CFM56-2-C1(100)GE			
McDonnell Douglas CD-8-71	4	CFM56-2(100)GE			
McDonnell Douglas DC-9-10	2	JT8D-7(100)PW[9]			
McDonnell Douglas DC-9-15F	2	JT8D-7(15)PW	JT8D-7A(4)PW	JT8D-7A/7B(4)PW	JT8D-7B(77)PW
McDonnell Douglas DC-9-30	2	JT8D-9A(23)PW JT8D-17(1)PW	JT8D-7A(5)PW	JT8D-7B(68)PW	JT8D-15(3)PW
McDonnell Douglas DC-9-40	2	JT8D-15(100)PW			
McDonnell Douglas DC-9-50	2	JT8D-17(87)PW	JT8D-17A(13)PW		
McDonnell Douglas DC-9-80[11]	2	JT8D-209(5)PW JT8D-217C(25)PW	JT8D-217(12)PW	JT8D-217A(36)PW	JT8D-219(22)PW
McDonnell Douglas DC-10-10	3	CF6-6(100)GE			
McDonnell Douglas DC-10-10[3]	3	CF6-6(100)GE			
McDonnell Douglas DC-10-30	3	CF6-50(100)GE			
McDonnell Douglas DC-10-30[3]	3	CF6-50(100)GE			
McDonnell Douglas	3	JT9D-20(100)PW			

Aeronave [1]	**No. de Motores**	**Modelo de Motor (% de Aeronaves) y Fabricante** [2]			
DC-10-40					
McDonnell Douglas MD-11	2	CF6-80C2D1F(100)GE			
NAMC YS-11	2	Dart 542-10J(25)RR	Dart 542-10K(75)RR		
Saab SF-340A	2	CT7-5A( )GE[12]	CT-5A2( )GE[12]	CT7-7E( )GE[12]	
SHORT 360	2	PT6A-65AR(17)PWC	PT6A-65R(55)PWC	PT6A-67R(28)PWC	
Swearingen SWEAR-METRO 1	2	TPE 331-11U-611G()Grt[13]	PT6A-45R()PW[14]		
Swearingen METRO-2	2	TPE 331-1(100)GA			
General Aviation and Air Taxis					
Aerospatiale SN601 Corvette	2	JT15D-4(100)PWC			
Beech B99 Airliner	2	PT6A-27(100)PWC			
Bellanca 7GCBC Seaplane	1	0-320(100)Lyc			
Canadair CL-600 Challenger	2	ALF502L-2(100)Lyc			
Cessna Citation	2	JT15D-1(100)PW			
Cessna 150	1	0-200(100)Con			
Cessna 150	1	O-200(100)Con			
Cessna Pressurized Skymaster	2	TS10-360C(100)Con			
Cessna 337 Series	2	TSIO-360C(100)Con			
Dassault Bregue Falcon 10	2	TFE731-2(100)Grt			
Dassault Bregue Falcon 50	3	TFE731-3(100)Grt			
Dassault Falcon 20	2	CF700-2D(100)GE			
de Havilland DHC-6-300	2	PT6A-27(100)PWC			
de Havilland Twin Otter	2	PT6A-27(100)PWC			
Fairchild Pilatus PC6 Series	1	PT6A-27[15](100)PWC			
Gates Learjet 24D	2	CJ610-6(100)GE			
Gates Learjet 35,36	2	TPE 731-2(100)GE			

Aeronave [1]	**No. de Motores**	**Modelo de Motor (% de Aeronaves) y Fabricante** [2]			
Gates Learjet 35A/36A	2	TFE731-2-2B(100)Grt			
Helio Aircraft HST-550A Stallion	1	PT6A-27(100)PWC			
Israel Aircraft IAI 1124	2	TFE731-3(100)Grt			
Learjet 31	2	TFE731-2(100)Grt			
Mitsubishi MU-300 Series	2	JT15D-4(100)PWC			
Piper Navajo Chieftain	2	T10-540(100)Lyc			
Piper PA-18 Series	1	0-320[16](100)Lyc			
Piper PA-42 Series	2	PT6A-41[17](100)PWC			
Piper Warrior	1	0-320(100)Lyc			
Rockwell International Shoreliner 75A	2	CF 700(100)GE			
Shorts Skyvan-3	2	TPE-331-2(100)GA			
Swearingen Merline IIIA	2	TPE-331-3(100)GA			

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[1] La fuente de la aeronave, tipo y número de motores es Airport Activity Statistics of Certificated Route Air Carriers, U.S. Department of Transportation, Research and Special Programs Administration, Federal Aviation Administration, 1989. NTIS Report Number ADA 2290303, y la FAA Aircraft Engine Emission Database (FAEED), U.S. Department of Transportation, Federal Aviation Administration, Office of Environment and Energy, 1991. La fuente del número de aeronaves es el Census of U.S. Civil Aircraft, U.S. Department of Transportation, Federal Aviation Administration, Office of Management Systems, 1989.

[2] A continuación del modelo de motor, entre paréntesis se encuentra el porcentaje de aeronaves que corresponde al motor particular y el fabricante del motor. Los datos de los motores GE fueron obtenidos de GE Aircraft Engines: Commercial Program Status, Volume 1, (General Electric, 1991, Cincinnati, Ohio) y la Office of Combustion Technology, GE Aircraft Engines (One Newmann Way MD A309, Cincinnati, Ohio 45215-6301, 513/774-4438). Los porcentajes correspondientes a las aeronaves se refieren a las aeronaves comerciales y gubernamentales estadounidenses en operación al 12/31/90. Los datos de los motoes P&W, P&WC y RR fueron obtenidos de Turbine-Engined Fleets of the World's Airlines 1990 (Exxon Corporation, suplemento de Air World, Volume 42, Number 2, 1990). Los porcentajes correspondientes a las aeronaves se refieren sólo a las aerolíneas estadounidenses. Fabricantes de motores: Con - Teledyne/Continental, GE - General Electric, Grt - Garrett AiResearch, Lyc - Avco/Lycoming, PW - Pratt & Whitney, PWC - Pratt & Whitney Canada, RR - Rolls Royce.

[3] Todos los servicios de carga.

[4] Se asume que el porcentaje de aeronaves es de 100%.

[5] Se refiere a las aeronaves B-737-300 y -500.

[6] Se refiere a las aeronaves B-747-200, -300 y SR.

[7] Se refiere a las aeronaves B-767-200ER. GE combinó el número aeronaves B-767-200ER y -300ER de en operación. Se asume que existe una distribución equivalente entre los dos modelos de aeronaves.

[8] Se refiere a las aeronaves B-767-300ER. GE combinó el número aeronaves B-767-200ER y -300ER de en operación. Se asume que existe una distribución equivalente entre los dos modelos de aeronaves.

[9] La fuente de la información de los motores es Modern Commercial Aircraft, Green, W., J. Mowinski, and G. Swanborough, 1987. Porcentaje de aeronaves supuesto 100%.

[10] Aeronaves EMB-100 supuestas.

[11] Aeronaves MD-80 supuestas.

[12] La fuente de la información de los motores es Modern Commercial Aircraft. Porcentaje de aeronaves desconocido.

[13] La fuente de la información de los motores es Modern Commercial Aircraft. El motor se refiere a las aeronaves METRO III. Porcentaje de aeronaves desconocido.

[14] La fuente de la información de los motores es Modern Commercial Aircraft. El motor se refiere a las aeronaves METRO III. Porcentaje de aeronaves desconocido.

[15] El motor se refiere a una aeronave PC6/B2H2.

[16] El motor se refiere a una aeronave PA-18-150 Super.

[17] El motor se refiere a una aeronave PA-42 Cheyenne.

Fuente: U.S. EPA, 1992a.

Tabla 5.3-2

Fuentes Alternativas de Datos de Emisiones para Algunos Motores de Aeronaves

Fabricante	Modelo de Motor	Fuente Recomendada para los Datos de Emisión[2]
GE	CF6-6	CF6-6D
	CF6-50	CF6-50E/C1/E1/C2/E2
	CT7-5A	CT7-5
	CT7-5A2	CT7-5
	CT7-7E	CT7-5
GE (SCNECMA)	CFM56-2	CFM56-2B
	CFM56-2-C1	CFM56-2B
	CFM56-5A	CFM56-5A1
P&W	JT3D series	Comunicarse con el fabricante[3]
	JT8D-7D	JT8D-7/7A/7B
	JT8D-15B	JT8D-15
	JT9D-3A	Comunicarse con el fabricante
	JT9D-7A-SP	JT9D-7F/7A
	JT9D-7AH	JT9D-7F/7A
	JT9D-20	JT9D-7F/7A
	JT9D-70A	JT9D-70/59/7Q
	PW4060	PW4460
RR	RB211-535E5	Comunicarse con el fabricante[4]
	RB211-535F5	Comunicarse con el fabricante
	TRENT 600 series	Comunicarse con el fabricante
	TRENT 700 series	Comunicarse con el fabricante
	SPEY MK506	Comunicarse con el fabricante
	SPEY MK555-15	SPEY MK555
	SPEY MK555-15P	SPEY MK555

Tabla 5.3-2

Fuentes Alternativas de Datos de Emisiones para Algunos Motores de Aeronaves (continnuación)

Fabricante	Modelo de Motor	Fuente Recomendada para los Datos de Emisión[2]
RR (continuación)	SPEY MK555-15H	SPEY MK555
	SPEY MK512	Comunicarse con el fabricante
	TAY MK651	Comunicarse con el fabricante
	Dart 514-7	Dart RDa7
	Dart 528-7E	Dart RDa7
	Dart 532-7	Dart RDa7
	Dart 532-7N	Dart RDa7
	Dart 532-7P	Dart RDa7
	Dart 532-7R	Dart RDa7
	Dart 535-7R	Dart RDa7
	Dart 536-7E	Dart RDa7
	Dart 542-4	Dart RDa10
	Dart 542-10J	Dart RDa10
	Dart 542-10K	Dart RDa10
	Dart 552-7R	Dart RDa7

[1] La FAA Aircraft Engine Emission Database *(Base de Datos de las Emisiones de Motores de Aeronaves, de la FAA)* no identifica estos factores de emisión alternativos. Puede requerirse un ajuste manual de la información de las bases de datos.

[2] Como es recomendado por los fabricantes de los motores.

[3] Para mayor información, contactar a la Office of Certification & Airworthiness, Commercial Engine Business, United Technologies Pratt & Whitney, 400 Main Street, East Hartford, Connecticut 06108, 203/565-2269.

[4] Para mayor información, contactar al Gerente de Proyecto de Combustión, Rolls Royce Place. P.O. Box 31, Derby DE2 99J England. Teléfono - 0332 242424.

Fuente: U.S. EPA, 1992a.

Tabla 5.3-3

Tasas de Emisión por Modelo - Motores de Aeronaves Civiles[1]

Fabricante de la Serie del Modelo[2]	Modo	Ajuste de Potencia	Flujo de Combustible (kg/min)	Indice de Emisión (kg/1,000 kg de combustible)				
				GOT	CO	NO_x	SO_2[3]	PM
501D22A[4] All.	Despegue	100%	17.96	0.28	2.04	8.88	0.54	—
	Ascenso	85%	16.62	0.89	2.06	9.22	0.54	—
	Aproximación	30%	8.62	1.96	5.10	7.49	0.54	—
	Carreteo/Reposo	7%	4.61	17.61	43.61	3.52	0.54	—
0-200[4] Con.	Despegue	100%	0.34	20.81	974.1	4.87	0.11	—
	Ascenso	85%	0.34	20.81	974.10	4.87	0.11	—
	Aproximación	40%	0.20	33.22	1187.84	1.14	0.11	—
	Carreteo/Reposo	7%	0.06	29.00	644.42	1.58	0.11	—
TS10-360C[4]	Despegue	100%	1.01	9.17	1081.95	2.71	0.11	—
	Ascenso	85%	0.75	9.55	960.80	4.32	0.11	—
	Aproximación	40%	0.46	11.31	995.08	3.77	0.11	—
	Carreteo/Reposo	7%	0.09	138.26	592.17	1.91	0.11	—

Tabla 5.3-3 (continuación)

Fabricante de la Serie del Modelo[2]	Modo	Ajuste de Potencia	Flujo de Combustible (kg/min)	Indice de Emisión (kg/1,000 kg de combustible)				
				GOT	CO	NO_x	SO_2[3]	PM
CF6-6D GE	Despegue	100%	104.16	0.30	0.50	40.00	0.54	—
	Ascenso	85%	85.86	0.30	0.50	32.60	0.54	—
	Aproximación	30%	29.03	0.70	6.50	11.40	0.54	—
	Carreteo/Reposo	7%	10.37	21.00	54.20	4.50	0.54	—
CF6-45 GE	Despegue	100%	127.56	0.10	1.00	30.60	0.54	—
	Ascenso	85%	106.20	0.10	1.30	26.60	0.54	—
	Aproximación	30%	36.30	0.70	8.20	10.50	0.54	—
	Carreteo/Reposo	7%	12.12	32.70	59.20	3.90	0.54	—
CF45A/A2 GE	Despegue	100%	121.62	0.09	0.43	25.45	0.54	—
	Ascenso	85%	99.78	0.14	0.54	21.61	0.54	—
	Aproximación	30%	35.52	0.35	5.01	9.36	0.54	—
	Carreteo/Reposo	4%	9.78	2.72	24.04	3.40	0.54	—

Tabla 5.3-3 (continuación)

Fabricante de la Serie del Modelo[2]	Modo	Ajuste de Potencia	Flujo de Combustible (kg/min)	Indice de Emisión (kg/1,000 kg de combustible)				
				GOT	CO	NO_x	SO_2[3]	PM
CF6-50E/C1/E1/C2/E2 GE	Despegue	100%	145.68	0.60	0.50	36.50	0.54	—
	Ascenso	85%	115.50	0.70	0.50	29.60	0.54	—
	Aproximación	30%	39.85	1.00	5.70	9.70	0.54	—
	Carreteo/Reposo	3%	10.09	49.30	81.30	2.40	0.54	—
CF6-80A GE	Despegue	100%	128.70	0.29	1.00	29.80	0.54	—
	Ascenso	85%	107.70	0.29	1.10	25.60	0.54	—
	Aproximación	30%	36.90	0.47	3.10	10.30	0.54	—
	Carreteo/Reposo	4%	9.00	6.29	28.20	3.40	0.54	—
CF6-80A1 GE	Despegue	100%	128.70	0.29	1.00	29.80	0.54	—
	Ascenso	85%	107.70	0.29	1.10	25.60	0.54	—
	Aproximación	30%	36.90	0.47	3.10	10.30	0.54	—
	Carreteo/Reposo	4%	9.00	6.29	28.20	3.40	0.54	—

Tabla 5.3-3 (continuación)

Fabricante de la Serie del Modelo[2]	Modo	Ajuste de Potencia	Flujo de Combustible (kg/min)	Indice de Emisión (kg/1,000 kg de combustible)				
				GOT	CO	NO_x	SO_2[3]	PM
CF6-80A2 GE	Despegue	100%	135.24	0.30	1.00	29.60	0.54	—
	Ascenso	85%	113.10	0.37	1.10	25.60	0.54	—
	Aproximación	30%	38.46	0.45	2.80	10.30	0.54	—
	Carreteo/Reposo	4%	9.00	6.28	28.20	3.40	0.54	—
CF6-80A3 GE	Despegue	100%	135.24	0.30	1.00	29.60	0.54	—
	Ascenso	85%	113.10	0.37	1.10	26.60	0.54	—
	Aproximación	30%	38.46	0.45	2.80	10.80	0.54	—
	Carreteo/Reposo	4%	9.00	6.28	28.20	3.40	0.54	—
CF6-80C2A1 GE	Despegue	100%	144.00	0.08	0.56	32.22	0.54	—
	Ascenso	85%	117.18	0.09	0.54	24.85	0.54	—
	Aproximación	30%	38.16	2.00	2.19	9.76	0.54	—
	Carreteo/Reposo	7%	11.94	9.19	42.24	3.99	0.54	—

Tabla 5.3-3 (continuación)

Fabricante de la Serie del Modelo[2]	Modo	Ajuste de Potencia	Flujo de Combustible (kg/min)	Indice de Emisión (kg/1,000 kg de combustible)				
				GOT	CO	NO_x	SO_2[3]	PM
CF6-80C2A2 GE	Despegue	100%	127.02	0.14	0.58	27.90	0.54	—
	Ascenso	85%	104.70	0.11	0.56	20.71	0.54	—
	Aproximación	30%	34.80	0.25	3.04	9.52	0.54	—
	Carreteo/Reposo	7%	11.34	10.74	46.65	3.91	0.54	—
CF6-80C2A3 GE	Despegue	100%	147.42	0.08	0.59	34.44	0.54	—
	Ascenso	85%	120.18	0.10	0.57	25.45	0.54	—
	Aproximación	30%	38.94	0.21	2.15	10.01	0.54	—
	Carreteo/Reposo	7%	12.12	9.21	42.18	3.96	0.54	—
CFM56-2A GE (SNECMA)	Despegue	100%	67.38	0.03	0.90	21.05	0.54	—
	Ascenso	85%	55.62	0.04	1.00	17.18	0.54	—
	Aproximación	30%	20.70	0.10	3.40	8.62	0.54	—
	Carreteo/Reposo	7%	7.92	1.17	24.90	4.12	0.54	—

Tabla 5.3-3 (continuación)

Fabricante de la Serie del Modelo[2]	Modo	Ajuste de Potencia	Flujo de Combustible (kg/min)	Indice de Emisión (kg/1,000 kg de combustible)				
				GOT	CO	NO_x	SO_2[3]	PM
CFM56-2B GE (SNECMA)	Despegue	100%	60.12	0.05	0.90	19.06	0.54	—
	Ascenso	85%	50.22	0.08	0.90	16.30	0.54	—
	Aproximación	30%	19.32	0.10	3.70	8.14	0.54	—
	Carreteo/Reposo	7%	7.38	1.67	29.50	3.66	0.54	—
CFM56-3 GE (SNECMA)	Despegue	100%	61.20	0.04	0.90	18.50	0.54	—
	Ascenso	85%	50.58	0.05	0.90	16.00	0.54	—
	Aproximación	30%	20.28	0.10	3.50	8.40	0.54	—
	Carreteo/Reposo	7%	7.26	1.83	31.00	3.90	0.54	—
CFM56-3B GE (SNECMA)	Despegue	100%	68.40	0.04	0.90	20.70	0.54	—
	Ascenso	85%	55.80	0.05	0.90	17.30	0.54	—
	Aproximación	30%	21.60	0.08	3.10	8.70	0.54	—
	Carreteo/Reposo	7%	7.80	1.25	27.00	4.10	0.54	—

Tabla 5.3-3 (continuación)

Fabricante de la Serie del Modelo[2]	Modo	Ajuste de Potencia	Flujo de Combustible (kg/min)	Indice de Emisión (kg/1,000 kg de combustible)				
				GOT	CO	NO_x	SO_2[3]	PM
CFM56-3B4 GE (SNECMA)	Despegue	100%	52.80	0.04	0.90	16.60	0.54	—
	Ascenso	85%	43.80	0.05	1.10	14.50	0.54	—
	Aproximación	30%	16.20	0.11	4.20	8.00	0.54	—
	Carreteo/Reposo	7%	6.60	3.33	38.50	3.90	0.54	—
CFM56-3C GE (SNECMA)	Despegue	100%	70.80	0.04	0.90	20.17	0.54	—
	Ascenso	85%	58.20	0.04	1.00	17.15	0.54	—
	Aproximación	30%	20.40	0.09	3.20	8.88	0.54	—
	Carreteo/Reposo	7%	7.20	2.14	33.40	4.00	0.54	—
CFM56-5A1 GE (SNECMA)	Despegue	100%	64.77	0.23	0.83	28.03	0.54	—
	Ascenso	85%	52.80	0.23	0.87	23.10	0.54	—
	Aproximación	30%	18.00	0.40	2.47	9.48	0.54	—
	Carreteo/Reposo	7%	6.60	1.53	18.00	4.36	0.54	—

Tabla 5.3-3 (continuación)

Fabricante de la Serie del Modelo[2]	**Modo**	**Ajuste de Potencia**	**Flujo de Combustible (kg/min)**	**Indice de Emisión (kg/1,000 kg de combustible)**				
				GOT	**CO**	**NO_x**	**SO_2**[3]	**PM**
TFE 731-2 Grt	Despegue	100%	12.30	0.11	1.39	15.25	0.54	—
	Ascenso	85%	10.38	0.13	2.03	13.08	0.54	—
	Aproximación	30%	4.02	4.26	22.38	5.90	0.54	—
	Carreteo/Reposo	7%	1.44	20.04	58.60	2.82	0.54	—
TFE 731-3 Grt	Despegue	100%	13.50	0.06	1.13	19.15	0.54	—
	Ascenso	85%	11.16	0.07	1.62	16.02	0.54	—
	Aproximación	30%	4.32	1.41	15.56	6.92	0.54	—
	Carreteo/Reposo	7%	1.56	9.04	47.70	3.72	0.54	—
TPE 331-3[6] Grt	Despegue	100%	3.46	0.11	0.76	12.36	0.54	1.75
	Ascenso	90%	3.09	0.15	0.98	11.86	0.54	1.47
	Aproximación	30%	1.89	0.64	6.96	9.92	0.54	2.40
	Carreteo/Reposo	7%	0.85	79.11	61.52	2.86	0.54	2.95

Tabla 5.3-3 (continuación)

Fabricante de la Serie del Modelo[2]	Modo	Ajuste de Potencia	Flujo de Combustible (kg/min)	Indice de Emisión (kg/1,000 kg de combustible)				
				GOT	CO	NO_x	SO_2[3]	PM
ALF 502L-2 Lyc	Despegue	100%	24.00	0.02	0.40	13.43	0.54	—
	Ascenso	85%	19.41	0.02	0.30	12.03	0.54	—
	Aproximación	30%	7.03	0.18	3.97	6.47	0.54	—
	Carreteo/Reposo	7%	2.86	6.65	45.63	3.38	0.54	—
ALF 502R-3 Lyc	Despegue	100%	20.86	0.06	0.43	11.20	0.54	—
	Ascenso	85%	17.28	0.05	0.50	9.94	0.54	—
	Aproximación	30%	6.16	0.29	8.43	6.15	0.54	—
	Carreteo/Reposo	7%	2.59	6.51	44.67	3.30	0.54	—
ALF 502R-5 Lyc	Despegue	100%	21.49	0.06	0.30	13.53	0.54	—
	Ascenso	85%	17.73	0.05	0.25	10.56	0.54	—
	Aproximación	30%	6.21	0.22	7.10	13.53	0.54	—
	Carreteo/Reposo	7%	2.45	5.39	40.93	3.78	0.54	—

Tabla 5.3-3 (continuación)

Fabricante de la Serie del Modelo[2]	Modo	Ajuste de Potencia	Flujo de Combustible (kg/min)	Indice de Emisión (kg/1,000 kg de combustible)				
				GOT	CO	NO_x	SO_2[3]	PM
0-320[4] Lyc	Despegue	100%	0.67	11.78	1077.44	2.19	0.11	—
	Ascenso	85%	0.50	12.38	989.51	3.97	0.11	—
	Aproximación	40%	0.35	19.25	1221.51	0.95	0.11	—
	Carreteo/Reposo	7%	0.07	36.92	1077.00	0.52	0.11	—
D-36 MKB	Despegue	100%	38.04	0.00	0.50	26.00	0.54	—
	Ascenso	85%	31.98	0.00	0.40	22.00	0.54	—
	Aproximación	30%	12.66	0.00	2.70	9.00	0.54	—
	Carreteo/Reposo	7%	0.00	5.40	20.70	5.50	0.54	—
NK-86 NPO	Despegue	100%	121.14	0.00	1.30	13.60	0.54	—
	Ascenso	85%	99.00	0.00	1.70	10.00	0.54	—
	Aproximación	30%	34.32	0.00	5.00	3.80	0.54	—
	Carreteo/Reposo	7%	14.58	4.40	27.60	2.50	0.54	—

Tabla 5.3-3 (continuación)

Fabricante de la Serie del Modelo[2]	**Modo**	**Ajuste de Potencia**	**Flujo de Combustible (kg/min)**	**Indice de Emisión (kg/1,000 kg de combustible)**				
				GOT	**CO**	**NO_x**	**SO_2**[3]	**PM**
IAE V2500 PW	Despegue	100%	66.78	0.10	0.55	37.13	0.54	—
	Ascenso	85%	55.44	0.11	0.55	30.82	0.54	—
	Aproximación	30%	20.04	0.15	0.77	13.45	0.54	—
	Carreteo/Reposo	7%	7.44	0.22	7.76	5.91	0.54	—
JT3D-7[4] PW	Despegue	100%	75.26	0.50	0.90	12.70	0.54	—
	Ascenso	85%	61.90	0.40	1.90	9.60	0.54	—
	Aproximación	30%	23.31	2.10	19.50	5.30	0.54	—
	Carreteo/Reposo	7%	7.66	123.00	138.99	2.20	0.54	—
JT8D-7/7A/7B PW	Despegue	100%	59.35	0.40	1.50	17.10	0.54	—
	Ascenso	85%	48.68	0.50	2.00	13.50	0.54	—
	Aproximación	30%	17.16	1.60	10.50	5.50	0.54	—
	Carreteo/Reposo	7%	7.75	10.60	35.50	2.70	0.54	—

Tabla 5.3-3 (continuación)

Fabricante de la Serie del Modelo[2]	Modo	Ajuste de Potencia	Flujo de Combustible (kg/min)	Indice de Emisión (kg/1,000 kg de combustible)				
				GOT	CO	NO_x	SO_2[3]	PM
JT8D-9/9A PW	Despegue	100%	62.40	0.47	1.24	17.92	0.54	—
	Ascenso	85%	50.76	0.47	1.66	14.21	0.54	—
	Aproximación	30%	17.88	1.73	9.43	5.64	0.54	—
	Carreteo/Reposo	7%	7.92	10.00	34.50	2.90	0.54	—
JT8D-11 PW	Despegue	100%	67.26	0.40	1.20	18.90	0.54	—
	Ascenso	85%	54.82	0.45	1.90	14.60	0.54	—
	Aproximación	30%	20.04	1.40	9.40	5.80	0.54	—
	Carreteo/Reposo	7%	8.73	10.00	35.00	2.75	0.54	—
JT8D-15[7] PW	Despegue	100%	70.68	0.25	0.72	19.12	0.54	—
	Ascenso	85%	56.70	0.25	1.01	15.01	0.54	—
	Aproximación	30%	20.42	1.57	9.12	5.97	0.54	—
	Carreteo/Reposo	7%	8.86	10.33	33.88	3.01	0.54	—

Tabla 5.3-3 (continuación)

Fabricante de la Serie del Modelo[2]	**Modo**	**Ajuste de Potencia**	**Flujo de Combustible (kg/min)**	**Indice de Emisión (kg/1,000 kg de combustible)**				
				GOT	**CO**	**NO_x**	**SO_2**[3]	**PM**
JT8D-15A PW	Despegue	100%	66.90	0.25	1.08	18.10	0.54	—
	Ascenso	85%	53.73	0.33	1.20	13.90	0.54	—
	Aproximación	30%	18.72	0.65	2.90	6.60	0.54	—
	Carreteo/Reposo	7%	8.23	2.29	12.43	3.10	0.54	—
JT8D-17[7] PW	Despegue	100%	74.70	0.66	0.75	19.30	0.54	—
	Ascenso	85%	59.82	0.75	1.01	15.26	0.54	—
	Aproximación	30%	21.24	1.86	8.13	6.23	0.54	—
	Carreteo/Reposo	7%	8.82	9.57	29.56	3.29	0.54	—
JT8D-17A PW	Despegue	100%	70.38	0.25	1.07	19.10	0.54	—
	Ascenso	85%	56.06	0.30	1.16	14.30	0.54	—
	Aproximación	30%	19.82	0.64	2.88	6.70	0.54	—
	Carreteo/Reposo	7%	8.41	2.02	12.46	3.20	0.54	—

Tabla 5.3-3 (continuación)

Fabricante de la Serie del Modelo[2]	Modo	Ajuste de Potencia	Flujo de Combustible (kg/min)	Indice de Emisión (kg/1,000 kg de combustible)				
				GOT	CO	NO_x	SO_2[3]	PM
JT8D-17AR PW	Despegue	100%	81.90	0.21	0.93	24.50	0.54	—
	Ascenso	85%	62.82	0.27	1.08	16.00	0.54	—
	Aproximación	30%	21.45	0.55	2.68	8.00	0.54	—
	Carreteo/Reposo	7%	8.86	1.33	10.70	3.20	0.54	—
JT8D-17R PW	Despegue	100%	85.02	0.21	0.95	25.30	0.54	—
	Ascenso	85%	66.18	0.27	1.03	17.60	0.54	—
	Aproximación	30%	22.53	0.53	2.54	8.40	0.54	—
	Carreteo/Reposo	7%	9.30	0.95	9.43	3.30	0.54	—
JT8D-209 PW	Despegue	100%	71.46	0.35	1.03	22.80	0.54	—
	Ascenso	85%	58.97	0.50	1.40	19.00	0.54	—
	Aproximación	30%	21.55	1.69	4.37	8.80	0.54	—
	Carreteo/Reposo	7%	7.82	4.03	14.10	3.50	0.54	—

Tabla 5.3-3 (continuación)

Fabricante de la Serie del Modelo[2]	**Modo**	**Ajuste de Potencia**	**Flujo de Combustible (kg/min)**	**Indice de Emisión (kg/1,000 kg de combustible)**				
				GOT	**CO**	**NO_x**	**SO_2**[3]	**PM**
JT8D-217/217A/217C PW	Despegue	100%	79.20	0.28	0.80	25.70	0.54	—
	Ascenso	85%	64.68	0.43	1.23	20.60	0.54	—
	Aproximación	30%	23.00	1.60	4.17	9.10	0.54	—
	Carreteo/Reposo	7%	8.23	3.33	12.27	3.70	0.54	—
JT8D-219 PW	Despegue	100%	81.24	0.27	0.73	27.00	0.54	—
	Ascenso	85%	65.10	0.42	1.20	20.80	0.54	—
	Aproximación	30%	22.90	1.59	4.07	9.13	0.54	—
	Carreteo/Reposo	7%	8.06	3.48	12.63	3.60	0.54	—
JT9D-7[4] PW	Despegue	100%	122.03	0.05	0.20	29.40	0.54	—
	Ascenso	85%	99.74	0.10	0.50	21.40	0.54	—
	Aproximación	30%	35.14	1.00	9.60	7.80	0.54	—
	Carreteo/Reposo	7%	13.98	29.80	77.02	3.10	0.54	—

Tabla 5.3-3 (continuación)

Fabricante de la Serie del Modelo[2]	**Modo**	**Ajuste de Potencia**	**Flujo de Combustible (kg/min)**	**Indice de Emisión (kg/1,000 kg de combustible)**				
				GOT	**CO**	**NO_x**	**SO_2**[3]	**PM**
JT9D-7F(modV)/ 7A(modV) PW	Despegue	100%	130.03	0.30	0.40	46.00	0.54	—
	Ascenso	85%	105.84	0.30	0.40	34.40	0.54	—
	Aproximación	30%	37.42	0.50	2.90	7.80	0.54	—
	Carreteo/Reposo	7%	13.14	26.00	54.00	3.10	0.54	—
JT9D-7R4D/7R4D1 PW	Despegue	100%	123.30	0.15	0.51	38.50	0.54	—
	Ascenso	85%	100.68	0.12	0.48	32.00	0.54	—
	Aproximación	30%	45.56	0.13	1.36	9.80	0.54	—
	Carreteo/Reposo	7%	12.32	1.25	10.00	4.10	0.54	—
JT9D-7R4E/ E1(A1500) PW	Despegue	100%	127.08	0.16	0.57	41.60	0.54	—
	Ascenso	85%	103.44	0.13	0.53	34.20	0.54	—
	Aproximación	30%	39.17	0.13	1.23	10.40	0.54	—
	Carreteo/Reposo	7%	13.26	1.11	8.27	4.10	0.54	—

Tabla 5.3-3 (continuación)

Fabricante de la Serie del Modelo[2]	Modo	Ajuste de Potencia	Flujo de Combustible (kg/min)	Indice de Emisión (kg/1,000 kg de combustible)				
				GOT	CO	NO_x	SO_2[3]	PM
JT9D-7R4E1(H) (A1-600) PW	Despegue	100%	133.08	0.15	0.67	36.90	0.54	—
	Ascenso	85%	109.74	0.13	0.67	29.70	0.54	—
	Aproximación	30%	38.40	0.22	1.46	8.50	0.54	—
	Carreteo/Reposo	7%	13.23	3.35	14.00	3.50	0.54	—
JT9D-7R4G2 PW	Despegue	100%	145.74	0.15	0.74	41.30	0.54	—
	Ascenso	85%	112.80	0.14	0.63	32.10	0.54	—
	Aproximación	30%	39.54	0.18	1.40	8.80	0.54	—
	Carreteo/Reposo	7%	13.44	1.55	11.82	3.80	0.54	—
JT9D-7R4H1/H2 PW	Despegue	100%	150.72	0.15	0.74	45.20	0.54	—
	Ascenso	85%	119.94	0.14	0.63	34.20	0.54	—
	Aproximación	30%	43.36	0.18	1.39	8.90	0.54	—
	Carreteo/Reposo	7%	14.72	1.48	11.63	3.80	0.54	—

Tabla 5.3-3 (continuación)

Fabricante de la Serie del Modelo[2]	Modo	Ajuste de Potencia	Flujo de Combustible (kg/min)	Indice de Emisión (kg/1,000 kg de combustible)				
				GOT	CO	NO_x	SO_2[3]	PM
JT9D-70/59/7Q PW	Despegue	100%	146.51	0.20	0.20	31.60	0.54	—
	Ascenso	85%	119.98	0.20	0.20	25.60	0.54	—
	Aproximación	30%	40.82	0.30	1.70	7.80	0.54	—
	Carreteo/Reposo	7%	14.22	12.00	53.00	3.00	0.54	—
PW2037 PW	Despegue	100%	92.28	0.05	0.40	31.10	0.54	—
	Ascenso	85%	75.96	0.06	0.41	24.80	0.54	—
	Aproximación	30%	23.94	0.21	2.30	10.30	0.54	—
	Carreteo/Reposo	7%	8.46	2.26	23.10	4.40	0.54	—
PT2040 PW	Despegue	100%	109.32	0.03	0.20	47.70	0.54	—
	Ascenso	85%	86.88	0.04	0.20	27.70	0.54	—
	Aproximación	30%	29.58	0.18	2.60	11.00	0.54	—
	Carreteo/Reposo	7%	9.30	2.36	23.60	4.40	0.54	—

Tabla 5.3-3 (continuación)

Fabricante de la Serie del Modelo[2]	Modo	Ajuste de Potencia	Flujo de Combustible (kg/min)	Indice de Emisión (kg/1,000 kg de combustible)				
				GOT	CO	NO_x	SO_2[3]	PM
PW2041 PW	Despegue	100%	115.02	0.03	0.20	37.00	0.54	—
	Ascenso	85%	92.16	0.04	0.20	29.00	0.54	—
	Aproximación	30%	31.02	0.16	2.50	11.00	0.54	—
	Carreteo/Reposo	7%	9.54	2.23	23.10	4.50	0.54	—
PW4056/4156 PW	Despegue	100%	140.52	0.06	0.44	28.10	0.54	—
	Ascenso	85%	115.80	0.01	0.57	22.90	0.54	—
	Aproximación	30%	39.48	0.13	2.00	11.60	0.54	—
	Carreteo/Reposo	7%	12.48	1.92	21.86	4.80	0.54	—
PW4152 PW	Despegue	100%	130.62	0.13	0.12	26.90	0.54	—
	Ascenso	85%	107.10	0.16	0.17	22.70	0.54	—
	Aproximación	30%	35.58	0.15	1.09	11.10	0.54	—
	Carreteo/Reposo	7%	10.62	0.74	12.76	4.90	0.54	—

Tabla 5.3-3 (continuación)

Fabricante de la Serie del Modelo[2]	Modo	Ajuste de Potencia	Flujo de Combustible (kg/min)	Indice de Emisión (kg/1,000 kg de combustible)				
				GOT	CO	NO_x	SO_2[3]	PM
PW4158 PW	Despegue	100%	148.86	0.09	0.40	30.20	0.54	—
	Ascenso	85%	120.28	0.02	0.54	23.70	0.54	—
	Aproximación	30%	40.92	0.14	1.88	11.80	0.54	—
	Carreteo/Reposo	7%	12.66	1.78	20.99	4.80	0.54	—
PW4460 PW	Despegue	100%	158.82	0.10	0.37	32.80	0.54	—
	Ascenso	85%	125.10	0.03	0.51	24.70	0.54	—
	Aproximación	30%	42.18	0.14	1.78	12.00	0.54	—
	Carreteo/Reposo	7%	12.78	1.66	20.32	4.90	0.54	—
JT15D-1 PWC	Despegue	100%	8.88	0.01	2.65	7.60	0.54	—
	Ascenso	85%	7.44	0.01	3.50	6.77	0.54	—
	Aproximación	30%	3.06	4.43	40.50	3.44	0.54	—
	Carreteo/Reposo	7%	1.38	50.50	132.00	1.75	0.54	—

Tabla 5.3-3 (continuación)

Fabricante de la Serie del Modelo[2]	Modo	Ajuste de Potencia	Flujo de Combustible (kg/min)	Indice de Emisión (kg/1,000 kg de combustible)				
				GOT	CO	NO_x	SO_2[3]	PM
JT15D-4 PWC	Despegue	100%	10.18	0.09	2.10	9.23	0.54	—
	Ascenso	85%	8.58	0.19	3.18	8.56	0.54	—
	Aproximación	30%	3.54	5.15	32.00	5.29	0.54	—
	Carreteo/Reposo	7%	1.56	40.00	97.00	2.63	0.54	—
PT6A-27[6] PWC	Despegue	100%	3.21	0.00	1.01	7.81	0.54	—
	Ascenso	90%	3.03	0.00	1.20	7.00	0.54	—
	Aproximación	30%	1.62	2.19	23.02	8.37	0.54	—
	Carreteo/Reposo	7%	0.87	50.17	64.00	2.43	0.54	—
PT6A-41[4] PWC	Despegue	100%	3.86	1.75	5.10	7.98	0.54	—
	Ascenso	90%	3.57	2.03	6.49	7.57	0.54	—
	Aproximación	30%	2.06	22.71	34.80	4.65	0.54	—
	Carreteo/Reposo	7%	1.11	101.63	115.31	1.97	0.54	—

Tabla 5.3-3 (continuación)

Fabricante de la Serie del Modelo[2]	Modo	Ajuste de Potencia	Flujo de Combustible (kg/min)	Indice de Emisión (kg/1,000 kg de combustible)				
				GOT	CO	NO_x	SO_2[3]	PM
Dart RDa7 RR	Despegue	100%	10.68	1.00	3.20	5.60	0.54	—
	Ascenso	85%	9.42	1.10	3.50	4.50	0.54	—
	Aproximación	30%	4.89	3.00	33.30	0.90	0.54	—
	Carreteo/Reposo	7%	3.10	23.90	91.40	0.70	0.54	—
Dart RDa10 RR	Despegue	100%	12.78	0.00	2.20	4.30	0.54	—
	Ascenso	85%	10.20	0.00	3.00	3.90	0.54	—
	Aproximación	30%	4.74	0.00	23.20	2.20	0.54	—
	Carreteo/Reposo	7%	3.16	8.90	41.40	1.60	0.54	—
M45H-01 RR	Despegue	100%	29.88	0.75	6.20	11.50	0.54	—
	Ascenso	85%	24.96	0.74	7.90	9.30	0.54	—
	Aproximación	30%	8.76	7.40	51.00	3.60	0.54	—
	Carreteo/Reposo	7%	3.18	59.50	178.40	1.50	0.54	—

Tabla 5.3-3 (continuación)

Fabricante de la Serie del Modelo[2]	Modo	Ajuste de Potencia	Flujo de Combustible (kg/min)	Indice de Emisión (kg/1,000 kg de combustible)				
				GOT	CO	NO_x	SO_2[3]	PM
OLYMPUS 593 MK610 RR	Despegue	100%	381.90	2.90	29.00	9.50	0.54	—
	Ascenso	65%	139.74	1.70	19.90	9.30	0.54	—
	Descent	15%	41.10	22.00	73.20	2.50	0.54	—
	Aproximación	34%	70.26	11.40	52.90	3.50	0.54	—
	Carreteo/Reposo	7%	25.26	33.40	100.10	1.70	0.54	—
RB.211-22B RR	Despegue	100%	111.96	0.36	2.48	34.32	0.54	—
	Ascenso	85%	92.52	0.39	4.14	25.63	0.54	—
	Aproximación	30%	33.18	7.73	26.38	8.05	0.54	—
	Carreteo/Reposo	7%	13.62	65.37	93.17	2.70	0.54	—
RB.211-524B/B2/ B3/B4 RR	Despegue	100%	142.98	0.52	1.83	47.00	0.54	—
	Ascenso	85%	116.34	0.40	2.82	33.00	0.54	—
	Aproximación	30%	41.58	4.98	20.00	9.75	0.54	—
	Carreteo/Reposo	7%	16.32	50.60	82.20	3.53	0.54	—

Tabla 5.3-3 (continuación)

Fabricante de la Serie del Modelo[2]	Modo	Ajuste de Potencia	Flujo de Combustible (kg/min)	Indice de Emisión (kg/1,000 kg de combustible)				
				GOT	CO	NO_x	SO_2[3]	PM
RB.211-524C2 RR	Despegue	100%	148.80	0.00	0.66	41.90	0.54	—
	Ascenso	85%	121.20	0.22	1.63	32.30	0.54	—
	Aproximación	30%	44.40	4.42	18.90	10.40	0.54	—
	Carreteo/Reposo	7%	18.00	54.20	81.00	3.37	0.54	—
RB.211-524D4[7] RR	Despegue	100%	146.11	0.02	0.53	56.97	0.54	—
	Ascenso	85%	117.01	0.42	1.15	41.06	0.54	—
	Aproximación	30%	43.08	4.68	16.44	9.68	0.54	—
	Carreteo/Reposo	7%	17.46	45.11	71.87	4.12	0.54	—
RB.211-524G RR	Despegue	100%	157.20	2.28	0.59	58.71	0.54	—
	Ascenso	85%	124.80	1.46	0.43	40.54	0.54	—
	Aproximación	30%	42.00	1.14	1.01	9.56	0.54	—
	Carreteo/Reposo	7%	15.60	3.28	13.74	4.63	0.54	—

Tabla 5.3-3 (continuación)

Fabricante de la Serie del Modelo[2]	Modo	Ajuste de Potencia	Flujo de Combustible (kg/min)	Indice de Emisión (kg/1,000 kg de combustible)				
				GOT	CO	NO_x	SO_2[3]	PM
RB.211-524H RR	Despegue	100%	163.80	1.00	0.90	65.80	0.54	—
	Ascenso	85%	130.20	0.60	0.40	46.30	0.54	—
	Aproximación	30%	42.60	0.30	1.00	10.30	0.54	—
	Carreteo/Reposo	7%	15.60	0.50	11.70	4.80	0.54	—
RB.211-535C RR	Despegue	100%	108.00	0.25	0.70	33.71	0.54	—
	Ascenso	85%	88.20	0.14	0.27	24.89	0.54	—
	Aproximación	30%	32.40	0.44	0.84	6.37	0.54	—
	Carreteo/Reposo	7%	12.00	1.44	18.79	3.44	0.54	—
RB.211-535E4 RR	Despegue	100%	111.60	0.69	1.01	52.70	0.54	—
	Ascenso	85%	90.60	0.94	1.23	36.20	0.54	—
	Aproximación	30%	34.20	1.33	1.71	7.50	0.54	—
	Carreteo/Reposo	7%	11.40	2.85	15.44	4.30	0.54	—

Tabla 5.3-3 (continuación)

Fabricante de la Serie del Modelo[2]	Modo	Ajuste de Potencia	Flujo de Combustible (kg/min)	Indice de Emisión (kg/1,000 kg de combustible)				
				GOT	CO	NO_x	SO_2[3]	PM
SPEY MK511 RR	Despegue	100%	53.34	0.98	1.81	23.27	0.54	—
	Ascenso	85%	43.56	1.32	2.06	19.18	0.54	—
	Aproximación	30%	16.74	7.23	20.30	7.94	0.54	—
	Carreteo/Reposo	7%	7.14	56.73	97.96	1.48	0.54	—
SPEY MK511-8 RR	Despegue	100%	53.46	0.09	0.12	22.70	0.54	—
	Ascenso	85%	43.56	0.12	0.63	17.30	0.54	—
	Aproximación	30%	16.68	0.18	2.65	7.20	0.54	—
	Carreteo/Reposo	7%	7.62	3.69	31.77	3.60	0.54	—
SPEY MK555[8] RR	Despegue	100%	33.34	0.74	0.41	19.61	0.54	—
	Ascenso	85%	27.27	1.27	0.16	15.07	0.54	—
	Aproximación	30%	10.28	5.43	17.96	6.12	0.54	—
	Carreteo/Reposo	7%	5.33	71.84	74.68	2.26	0.54	—

Tabla 5.3-3 (continuación)

Fabricante de la Serie del Modelo[2]	Modo	Ajuste de Potencia	Flujo de Combustible (kg/min)	Indice de Emisión (kg/1,000 kg de combustible)				
				GOT	CO	NO_x	SO_2[3]	PM
TAY MK620-15/ MK611-8 RR	Despegue	100%	45.60	0.80	0.70	21.10	0.54	—
	Ascenso	85%	37.80	0.30	0.80	16.80	0.54	—
	Aproximación	30%	13.80	0.90	3.90	5.70	0.54	—
	Carreteo/Reposo	7%	6.60	3.40	24.10	2.50	0.54	—
TAY MK650[9] RR	Despegue	100%	52.44	0.40	1.70	19.80	0.54	—
	Ascenso	85%	42.90	0.40	2.00	16.50	0.54	—
	Aproximación	30%	15.24	0.90	6.50	4.60	0.54	—
	Carreteo/Reposo	7%	7.14	3.30	33.80	1.70	0.54	—

[1] Fuente: ICAO Engine Exhaust Emissions Databank. (ICAO Committee on Aviation Environmental Protection, Working Group Meeting, Mariehamn, Aland., October 1989), a menos que se indique lo contrario.

[2] Fabricantes: All. - Allison, Con - Teledyne/Continental, GE - General Electric, Grt - Garrett AiResearch, Lyc - Avco/Lycoming, PW - Pratt & Whitney, PWC - Pratt & Whitney Canada, RR - Rolls-Royce.

[3] Las emisiones de SO_2 se basan en el promedio nacional de contenido de azufre en combustibles para aeronave de Aviation Turbines Fuels, 1989, Dickson, Cheryl L. and Paul W. Woodward, March, 1990. NIPER Report Number NIPER-164 PPS, National Institute for Petroleum and Energy Research, ITT Research Institute, Bartlesville, Oklahoma.

[4] La fuente de datos es AP-42, Compilation of Air Pollutant Emission Factors, Volume II: Mobile Sources, U.S. Environmental Protection Agency,

Ann Arbor, Michigan, September, 1985. (Aircraft data from February 1980).

[5] La fuente de datos de los motores es General Electric Office of Combustion Technology, GE Aircraft Engines, One Newmann Way MD A309, Cincinnati, Ohio 45215-6301, 513/774-438.

[6] La fuente de datos es AP-42. La fuente de datos sobre partículas es el AP-42 Reference 4 (M. Platt, et al., The Potential Impact of Aircraft Emissions upon Air Quality, APTD-1085, U.S. Environmental Protection Agency, Research Triangle Park, NC, December 1971). La referencia indicada no especifica el número de serie para este modelo de motor.

[7] La fuente de datos de los motores es ICAO, ICAO Engine Exhaust Emissions Databank. Los datos son promedios ponderados de ventas de las dos versiones de este motor. La base es 93% de combustores de alta emisión y 7% de combustores de baja emisión.

[8] La fuente de datos de los motores es ICAO, ICAO Engine Exhaust Emissions Databank. Los datos son promedios ponterados de ventas de las dos versiones de este motor. La base es 77% de combustores de alta emisión y 23% de combustores de baja emisión.

[9] La fuente de datos de los motores es Rolls Royce Combustion Research Department, Rolls Royce plc. P.O. Box 31, Derby DE2 88J England. Teléfono - 0332 242424.

Tabla 5.3-4

Tiempo en Modo por Omisión para Diversas Categorías de Aeronaves

Aeronave	Tiempo en Modo (minutos)						
	Carreteo/Reposo Salida	Despegue	Ascenso	Aproximación	Carreteo/Reposo Llegada	Total	Fuente
Transporte Comercial							
Jumbo, jets de distancia larga y media	19.0	0.7	2.2	4.0	7.0	32.9	AP-42, 1985
Turbopropulsión	19.0	0.5	2.5	4.5	7.0	33.5	AP-42, 1985
Transportes de pistones	6.5	0.6	5.0	4.6	6.5	23.2	AP-42, 1985
Aviación General							
Jets de Negocios	6.5	0.4	0.5	1.6	6.5	15.5	AP-42, 1985
Turbopropulsión	19.0	0.5	2.5	4.5	7.0	33.5	AP-42, 1985
Pistones	12.0	0.3	5.0	6.0	4.0	27.3	AP-42, 1985
Helicoptero	3.5	—	6.5	6.5	3.5	20.0	AP-42, 1985

5.4 Otro Equipo Móvil que No Circula por Carreteras

CODIGO DE FUENTE	DESCRIPCION
22-60-000-000	Todos los vehículos que transitan fuera de carreteras: gasolina, 2 tiempos
22-60-001-xxx	Vehículos recreativos: Gasolina, 2 tiempos
22-60-002-xxx	Equipo de construcción: Gasolina, 2 tiempos
22-60-003-xxx	Equipo industrial: Gasolina, 2 tiempos
22-60-004-xxx	Equipo de jardinería: Gasolina, 2 tiempos
22-60-005-xxx	Equipo agrícola: Gasolina, 2 tiempos
22-60-006-xxx	Comercial ligero: Gasolina, 2 tiempos
22-60-007-xxx	Equipo de explotación forestal: Gasolina, 2 tiempos
22-60-008-xxx	Equipo de servicios aeroportuarios: Gasolina, 2 tiempos
22-65-000-000	Todos los que transitan fuera de carreteras: Gasolina, 4 tiempos
22-65-001-xxx	Vehículos recreativos: Gasolina, 4 tiempos
22-65-002-xxx	Equipo de construcción: Gasolina, 4 tiempos
22-65-003-xxx	Equipo industrial: Gasolina, 4 tiempos
22-65-004-xxx	Equipo de jardinería: Gasolina, 4 tiempos
22-65-005-xxx	Equipo agrícola: Gasolina, 4 tiempos
22-65-006-xxx	Comercial ligero: Gasolina, 4 tiempos
22-65-007-xxx	Equipo de explotación forestal: Gasolina, 4 tiempos
22-65-008-xxx	Equipo de servicios aeroportuarios: Gasolina, 4 tiempos
22-70-000-000	Todos los equipos de campo traviesa: Diesel
22-70-001-xxx	Vehículos recreativos: Diesel
22-70-002-xxx	Equipo de construcción: Diesel
22-70-003-xxx	Equipo industrial: Diesel
22-70-004-xxx	Equipo de jardinería: Diesel
22-70-005-xxx	Equipo agrícola: Diesel
22-70-006-xxx	Comercial ligero: Diesel
22-70-007-xxx	Equipo de explotación forestal: Diesel
22-70-008-xxx	Equipo de servicios aeroportuarios: Diesel
22-82-005-xxx	Botes recreativos: Gasolina, 2 tiempos
22-82-010-xxx	Botes recreativos: Gasolina, 4 tiempos
22-82-020-xxx	Botes recreativos: Diesel

DESCRIPCION:

Además de las categorías de fuentes móviles que no circulan por carretera discutidas en las primeras secciones de este documento, existen otras fuentes adicionales que incluyen equipos y vehículos motorizados que normalmente no son operados en carreteras públicas, y que se clasifican en las siguientes ocho categorías:

- Vehículos Recreativos
- Equipo de Construcción
- Equipo Industrial
- Equipo de Jardinería
- Equipo Agrícola
- Equipo Comercial Ligero
- Equipo de Explotación Forestal
- Equipo de Servicios Aeroportuarios.

Algunos de los ejemplos de tipos específicos de equipo incluido en estas categorías generales se presentan en la Tabla 5.4-1.

Tabla 5.4-1

Otras Categorías de Fuentes que No Circulan Por Carreteras

Categoría	
Vehículos Recreativos Botes recreativos Motocicletas Vehículos para nieve Vehículos Todo Terreno Mini-motos Carros de golf	**Equipo de Construcción** Pavimentadoras de asfalto Compactadoras de lámina Aplanadoras Trascabos Excavadoras Equipo de perforación Mezcladoras de cemento y mortero Grúas
Equipo Industrial Grúas aéreas Montacargas Aspiradoras y Lavadoras Refrigeradores móviles Motores auxiliares Equipo portátil de perforación de pozos	**Equipo de Jardinería** Segadoras de pasto Bordeadoras Sopladoras Sierras de Cadena Partidores de madera Picadoras, molinos de tocones
Equipo Agrícola Segadoras Trilladoras Empaquetadoras Máquinas todo uso Tractores	**Equipo Comercial Ligero** Bombas Generadores Compresoras de aire Compresoras de gas Soldadoras Lavadores a presión
Equipo de Silvicultura Sierras de Cadena Desmenuzadoras Desligadores Agrupadores Taladoras	**Equipo de Servicios Aeroportuarios** Equipo de apoyo en aeropuerto Tractores de terminal

CONTAMINANTES: GOT, CO, NO_x, PM, SO_x

GOR: Pueden utilizarse los factores GOR/GOT que se proporcionan a continuación. Nótese que una relación GOR/GOT de “ND” indica que no existe un valor específico GOR/GOT en la referencia citada de la CARB. Sin embargo, al parecer sería razonable utilizar una relación GOR/GOT de 96.0% para equipo de escape de gasolina, y de 97.2% para el equipo de escape diesel como valores por omisión. El GOR constituye 100% del GOT para las emisiones de cigüeñal, evaporativas y carga de combustible.

CODIGO DE FUENTE	GOR/ GOT	DESCRIPCION
22-60-000-000	ND	Todos los vehículos que transitan fuera de carreteras: Gasolina, 2 tiempos
22-60-001-xxx	96.0%	Vehículos recreativos: Gasolina, 2 tiempos
22-60-002-xxx	ND	Equipo de construcción: Gasolina, 2 tiempos
22-60-003-xxx	96.0%	Equipo industrial: Gasolina, 2 tiempos
22-60-004-xxx	ND	Equipo de jardinería: Gasolina, 2 tiempos
22-60-005-xxx	96.0%	Equipo agrícola: Gasolina, 2 tiempos
22-60-006-xxx	96.0%	Comercial ligero: Gasolina, 2 tiempos
22-60-007-xxx	ND	Equipo de explotación forestal: Gasolina, 2 tiempos
22-60-008-xxx	ND	Equipo de servicios aeroportuarios: Gasolina, 2 tiempos
22-65-000-000	ND	Todos vehículos los que transitan fuera de carreteras: Gasolina, 4 tiempos
22-65-001-xxx	96.0%	Vehículos recreativos: Gasolina, 4 tiempos
22-65-002-xxx	ND	Equipo de construcción: Gasolina, 4 tiempos
22-65-003-xxx	96.0%	Equipo industrial: Gasolina, 4 tiempos
22-65-004-xxx	ND	Equipo de jardinería: Gasolina, 4 tiempos
22-65-005-xxx	96.0%	Equipo agrícola: Gasolina, 4 tiempos
22-65-006-xxx	96.0%	Comercial ligero: Gasolina, 4 tiempos
22-65-007-xxx	ND	Equipo de explotación forestal: Gasolina, 4 tiempos
22-65-008-xxx	ND	Equipo de servicios aeroportuarios: Gasolina, 4 tiempos
22-70-000-000	ND	Todos vehículos los que transitan fuera de carreteras: Gasolina: Diesel
22-70-001-xxx	97.2%	Vehículos recreativos: Botes Diesel
22-70-002-xxx	ND	Equipo de construcción: Diesel
22-70-003-xxx	97.2%	Equipo industrial: Diesel
22-70-004-xxx	ND	Equipo de jardinería: Diesel
22-70-005-xxx	97.2%	Equipo agrícola: Diesel
22-70-006-xxx	97.2%	Comercial ligero: Diesel
22-70-007-xxx	ND	Equipo de explotación forestal: Diesel
22-70-008-xxx	ND	Equipo de servicios aeroportuarios: Diesel

AJUSTES DE FUENTES PUNTUALES: Ninguno.

METODOLOGIA:

Las emisiones de cualesquier fuentes móviles que no circulan por carreteras son calculadas utilizando la siguiente ecuación:

$$\text{Emisiones}_p = N_e \times hr_e \times hp_e \times FC_e \times FE_p \tag{5.4-1}$$

Donde:

Emisiones_p = Emisiones de contaminante p (kg/año)
N_e = Número de equipos tipo e
hr_e = Horas anuales de uso del equipo tipo e
hp_e = Potencia nominal promedio para el equipo tipo e
FC_e = Factor de carga típico para el equipo tipo e
$FE_{p,e}$ = Factor de emisión para el contaminante p y el equipo tipo e (g/hp-hr).

Las emisiones para la mayoría de los tipos de equipo recreativo y marino son calculadas utilizando ecuaciones diferentes. Para algunos tipos de equipo recreativo (vehículos todo terreno [ATVs, por sus siglas en inglés], mini-motos, motocicletas campo traviesa y carros de golf), la ecuación de estimación es:

$$\text{Emisiones}_p = N_e \times hr_e \times FE_{p,e} \tag{5.4-2}$$

donde:

Emisiones_p = Emisiones de contaminante p (kg/año)
N_e = Población del equipo tipo e
hr_e = Horas anuales de uso del equipo tipo e
$FE_{p,e}$ = Factor de emisión para el contaminante p y el equipo tipo e (g/hp-hr).

Para el equipo recreativo marino, la ecuación para hacer estimaciones es:

$$\text{Emisiones}_p = N_e \times \text{Combustible}_e \times FE_p \tag{5.4-3}$$

donde: Emisiones_p = Emisiones de contaminante p (kg/año)
N_e = Número de equipos tipo e
Combustible_e = Uso anual de combustible (gal/año)
$FE_{p,e}$ = Factor de emisión para el contaminante p y el equipo tipo e (g/hp-hr).

En los casos en que sea posible, deben obtenerse los datos de actividad específicos para México (i. e., población de los equipos, horas de uso, potencia del equipo, etc.). Los factores de emisión con bases estadounidenses, así como los datos de actividades estadounidenses por omisión se presentan en el Apéndice V-C, que contiene las siguientes tablas:

- Tabla 2-04 - Estimaciones promedio de potencias nominales
- Tabla 2-05 – Estimaciones de los factores de operación de carga típicos
- Tabla 2-06 - Estimaciones del uso anual
- Tabla 2-07a - Factores de emisión del equipo diesel
- Tabla 2-07b - Factores de emisión del equipo de gasolina de 4 tiempos (no ajustados para los efectos en uso)
- Tabla 2-07c - Factores de emisión del equipo de gasolina de 4 tiempos (ajustados para los efectos en uso)
- Tabla 2-07d - Factores de emisión del equipo de gasolina de 2 tiempos (no ajustados para los efectos en uso)
- Tabla 2-07e - Factores de emisión del equipo de gasolina de 2 tiempos (ajustados para los efectos en uso).

La fuente de estos factores de emisión y datos de actividad es el *Nonroad Engine and Vehicle Emission Study* (Estudio de Emisiones de los Motores y Vehículos que No Circulan por Carreteras) (U.S. EPA, 1991b) de la EPA. Estos factores de emisión y datos de actividad estadounidenses tienen una aplicación limitada en México, y deben ser utilizados solamente en el caso de que no se disponga de otros datos.

Deben señalarse dos puntos con respecto a estas tablas. Primero que nada, los datos de actividad presentados en las Tablas 2-04, 2-05 y 2-06 están dados para un Inventario A y un Inventario B. Los datos del primero fueron desarrollados exclusivamente por contratistas de la EPA, mientras que los segundos incorporaron información adicional de asociaciones de fabricantes. Por lo tanto, los datos del Inventario B son preferibles sobre los del A. Asimismo, los factores de emisión presentados en las

Tablas 2-07b y 2-07d se basan en los datos de emisión de motores nuevos, mientras que aquellos contenidos en las Tablas 2-07c y 2-07e representan los efectos del uso, incluyendo mal funcionamiento de los motores, mantenimiento inadecuado y desgaste. Por lo tanto, los factores de emisión que se presentan en las Tablas 2-07c y 2-07e son preferibles sobre los de las Tablas 2-07b y 2-07d.

DATOS NECESARIOS:

Datos	Fuentes
Población de equipos	Entidades locales o encuestas
Horas de uso	Entidades locales o encuestas; valores estadounidenses por omisión (Apéndice V-C, Tabla 2-06)
Caballaje promedio	Entidades locales o encuestas; valores estadounidenses por omisión (Apéndice V-C, Tabla 2-04)
Factor de carga	Entidades locales o encuestas; valores estadounidenses por omisión (Apéndice V-C, Tabla 2-05)
Uso de combustible (sólo equipo recreativo marino)	Entidades locales o encuestas; valores estadounidenses por omisión (Apéndice V-C, Tabla 2-06)
Factores de emisión	Factores de emisión estadounidenses (Apéndice V-C, Tablas 2-07a a 2-07e)

NOTAS:

1. El Volumen II de la cuarta edición del AP-42 (AP-42, 1985) incluyó información sobre la estimación de emisiones de fuentes móviles que no circulan por carretera, pero está información ya no es vigente. La información presentada en el Estudio de Emisiones de los Vehículos y Motores que No Circulan por Carreteras, junto con datos de pruebas de emisiones más recientes, actualmente está siendo incorporado en una quinta edición del Volumen II del AP-42. La fecha en que este documento estará disponible es todavía incierta.

2. Los factores de emisión GOT **NO** se presentan en las tablas 2-07a a 2-07e en el Apéndice V-C. Los factores de emisión de hidrocarburos (HC) se presentan para emisiones de escape, cárter, evaporativas y carga de combustible. En otra sección del Estudio de Emisiones de los Vehículos y Motores que No Circulan por Carreteras, se explica que el valor de HC es equivalente a los compuestos orgánicos volátiles (VOCs). Debido a que el metano y el etano son excluidos de los VOCs, en esencia, los VOCs son iguales a los GOR. Por lo tanto, los factores de emisión que se presentan en el Apéndice V-C, Tablas 2-07a a 2-07e son equivalentes a los GOR. Los factores de emisión de GOT pueden ser obtenidos utilizando los factores de emisión de GOR, así como las relaciones GOR/GOT de 96.0% para equipo de escape de gasolina y 97.2% para el equipo de escape de diesel. Esto se demuestra en el ejemplo de cálculo. Para las emisiones de cárter, evaporativas y carga de combustible, el metano y etano virtualmente no están incluidos, por lo

tanto, los GOR y GOT son equivalentes.

EJEMPLO DE CALCULO:

Asumir que cierta región del inventario tiene 50 soldadoras de gasolina de cuatro tiempos, 30 bombas diesel y 15 grúas diesel. Calcular las emisiones GOT totales:

1. Determinar las horas de uso:

   Con base en encuestas locales, se ha estimado que las soldadoras son utilizadas 100 horas al año; las bombas 200 horas y las grúas 600 horas.

2. Determinar la potencia nominal promedio:

   Debido a que no existe información sobre encuestas locales disponible, la potencia nominal promedio se determinará utilizando la Tabla 2-04 en el Apéndice V-C.

   Soldadoras - 19.0 hp
   Bombas - 23.0 hp
   Grúas - 194.0 hp

3. Determinar los factores de carga de operación típicos:

   La información de encuestas locales tampoco está disponible, por lo tanto, se aplicarán los factores de carga tomados de la Tabla 2-05 en el Apéndice V-C.

   Soldadoras - 51%
   Bombas - 74%
   Grúas - 43%

4. Calcular los factores de emisión:

   Los factores de emisión diesel son tomados de la Tabla 2-07a, y los de gasolina de 4 tiempos de la Tabla 2-07c. Los factores de emisión de escape deben ser convertidos de GOR a GOT. Para todas las otras emisiones, GOR es equivalente a GOT.

$$\text{Escape de Soldadoras} = \left(\frac{19.95 \text{ g GOR}}{\text{hp - hr}} \right) \left(\frac{1}{0.96} \right) = \frac{20.78 \text{ g GOT}}{\text{hp - hr}}$$

$$\text{Grúas} = \left(\frac{3.14 \text{ g GOT}}{\text{hp - hr}} \right)$$

$$\text{Evaporativo} = \left(\frac{9.75\ \text{g GOT}}{\text{hp - hr}} \right)$$

$$\begin{array}{c}\text{Carga de}\\ \text{Combustible}\end{array} = \left(\frac{1.72\ \text{g GOT}}{\text{hp - hr}} \right)$$

Total = 20.78 + 3.14 + 9.75 + 1.72 = 35.39 g GOT/hp-hr

$$\begin{array}{c}\text{Escape de}\\ \text{Bombas}\end{array} = \left(\frac{1.20\ \text{g GOR}}{\text{hp - hr}} \right) \left(\frac{1}{0.972} \right) = \frac{1.235\ \text{g GOT}}{\text{hp - hr}}$$

$$\text{Grúas} = \left(\frac{0.02\ \text{g GOT}}{\text{hp - hr}} \right)$$

$$\text{Evaporativo} = \left(\text{No Aplicable} \right)$$

$$\begin{array}{c}\text{Carga de}\\ \text{Combustible}\end{array} = \left(\frac{0.003\ \text{g GOT}}{\text{hp - hr}} \right)$$

Total = 1.236 + 0.02 + 0.003 = 1.26 g GOT/hp-hr

$$\begin{array}{c}\text{Escape de}\\ \text{Grúas}\end{array} = \left(\frac{1.26\ \text{g GOR}}{\text{hp - hr}} \right) \left(\frac{1}{0.972} \right) = \frac{1.296\ \text{g GOT}}{\text{hp - hr}}$$

$$\text{Grúas} = \left(\frac{0.03\ \text{g GOT}}{\text{hp - hr}} \right)$$

$$\text{Evaporativo} = \left(\text{No Aplicable} \right)$$

$$\begin{array}{c}\text{Carga de}\\ \text{Combustible}\end{array} = \left(\frac{0.003\ \text{g GOT}}{\text{hp - hr}} \right)$$

Total = 1.296 + 0.03 + 0.003 = 1.33 g GOT/hp-hr

5. Calcular las emisiones

$$\text{Soldadoras} = 50 \left(\frac{100\ \text{hr}}{\text{año}} \right) (19.0\ \text{hp})\ (0.51) \left(\frac{35.39\ \text{g}}{\text{hp - hr}} \right) = 1{,}715\ \text{kg/año}$$

$$\text{Bombas} = 30\left(\frac{200\text{ hr}}{\text{año}}\right)(23.0\text{ hp})(0.74)\left(\frac{1.26\text{ g}}{\text{hp - hr}}\right) = 129\text{ kg/año}$$

$$\text{Grúas} = 15\left(\frac{600\text{ hr}}{\text{año}}\right)(194.0\text{ hp})(0.43)\left(\frac{1.33\text{ g}}{\text{hp - hr}}\right) = 999\text{ kg/año}$$

$$\begin{aligned}\text{Emisiones totales} &= 1{,}715 + 129 + 999\\ &= 2{,}843\text{ kg GOT/año}\\ &= 2.8\text{ Mg GOT/año}\end{aligned}$$

5.5 Cruces Fronterizos 4.5 Border Crossings4.5 Border Crossings

CODIGO DE FUENTE	DESCRIPCION
22-01-001-900*	Vehículos ligeros a gasolina (LDGV, por sus siglas en inglés)
22-01-060-900*	Camiones ligeros a gasolina (LDGT, por sus siglas en inglés)
22-01-070-900*	Vehículos pesados a gasolina (HDGV, por sus siglas en inglés)
22-01-080-900*	Motocicletas (MC)
22-30-001-900*	Vehículos ligeros a diesel (LDDV, por sus siglas en inglés)
22-30-060-900*	Camiones ligeros a diesel (LDDT, por sus siglas en inglés)
22-30-070-900*	Vehículos pesados a diesel (HDDV, por sus siglas en inglés)

* Códigos propuestos específicos para México, para categorías de fuente que no son típicamente inventariadas en EU.

DESCRIPCION:

Esta sección cubre específicamente las emisiones de los cruces fronterizos. Esta categoría es de particular interés en la región fronteriza entre México y EU. Los vehículos (tanto mexicanos como estadounidenses),a menudo se forman por largos periodos de tiempo (hasta de 1 hora), mientras esperan ingresar a EU y pasar las inspecciones aduanales. Los vehículos en la cola normalmente no apagan sus motores, sino que los mantienen encendidos mientras avanzan lentamente. Esta categoría de emisiones también es aplicable a los vehículos que entran en México (si bien el tiempo de espera al parecer es menor, comparado con los vehículos que esperan entrar en EU), y a cualesquier otros vehículos que esperan en otros puntos de revisión. La metodología que se describe a continuación es similar a la de las terminales de autobuses (ver Sección 5.6).

Debido a que estas emisiones son generadas por vehículos que circulan por carreteras, podría argumentarse que deberían ser incluidas como fuentes móviles. Sin embargo, a diferencia de las emisiones de fuentes móviles típicas, la ubicación de estas emisiones en los cruces fronterizos está muy bien definida (i. e., el segmento de carretera que se encuentra exactamente frente al cruce de frontera). Asimismo, las últimas versiones de los modelos de factores de emisión de fuentes móviles (MOBILE5a, PART5, y otras versiones modificadas relacionadas), sólo pueden ser utilizadas para estimar las emisiones de los vehículos en movimiento. Por estas razones, las emisiones estáticas en los cruces fronterizos deben ser manejadas como fuentes de área.

CONTAMINANTES: GOT, CO, NO_x, SO_x, PM_{10}

GOR: Para los vehículos de gasolina sin catalizador, las emisiones GOR constituyen

92.4% del GOT. Para los vehículos de gasolina con catalizador, las emisiones GOR constituyen 85.2% del GOT. Para los vehículos diesel, las emisiones GOR constituyen 95.7% del GOT (ARB, 1993).

AJUSTES DE FUENTES PUNTUALES: Ninguno.

METODOLOGIA:

Como se mencionó anteriormente, las últimas versiones del MOBILE5a y PART5 no proporcionan ningún factor de emisión para vehículos en reposo. Algunas versiones anteriores del MOBILE sí lo hacían, sin embargo, dichos factores representaban condiciones estándar de prueba (modo estabilizado de operación, 75 °F y un combustible con RVP de 9.0 psi). Debido a que la EPA no ha podido desarrollar un algoritmo satisfactorio para manejar las variaciones en el modo de operación, temperatura ambiente y RVP del combustible, la función de cálculo directo del factor de emisión en reposo ha sido eliminada del MOBILE5a, al mismo tiempo que se siguen recopilando datos de emisión en reposo.

La EPA ha proporcionado una metodología provisional para la estimación de las emisiones en reposo usando el MOBILE5a (U.S. EPA, 1993), que puede ser utilizada para estimar las emisiones vehiculares en los cruces fronterizos y en otras situaciones de reposo. Se asume que esta metodología es válida para el PART5 y cualesquier modelos MOBILE que hayan sido modificados para ser aplicados en México (i. e., MOBILE-MCMA, MOBILE-MMAp, MOBILE-Juárez, etc.). Un modelo MOBILE será utilizado para estimar las emisiones de GOT, CO y NO_x. Un modelo PART5 será utilizado para estimar las emisiones de PM_{10}; mientras que las emisiones de SO_x serán estimadas utilizando un balance de combustible simple.

En la metodología provisional de la EPA, las emisiones en reposo son calculadas utilizando factores de emisión de escape de un modelo MOBILE a la velocidad más baja permisible del vehículo (2.5 millas por hora [mph] para MOBILE5a y PART5; y 4 kilómetros por hora [kph] para los modelo MOBILE modificados específicos para México). Se utiliza la menor velocidad permisible debido a que tiene el mayor porcentaje de tiempo en reposo que cualquier otro ciclo de velocidad utilizado por el modelo MOBILE. Después de correr el modelo, los factores de emisión de escape para GOT, CO y NO_x serán calculados en unidades de gramo por milla o gramo por kilómetro. Para convertir estos factores de emisión en factores de emisión en reposo en unidades de gramos por hora, es necesario multiplicar por 4 kph (o 2.5 mph). Los factores de emisión en reposo resultantes no deben incluir ninguna emisión que no sea de escape. Para mayor información sobre la forma de correr los modelos MOBILE y PART5 consulte en Manual de Vehículos Automotores (Volumen VI) de esta serie y/o los manuales de usuario de los modelos MOBILE y PART5 (U.S. EPA, 1994; U.S. EPA, 1995).

En los cruces fronterizos, los vehículos en reposo serán una mezcla de vehículos mexicanos y estadounidenses. En consecuencia, el modelo MOBILE5a debería ser utilizado para la fracción vehicular estadounidense, y un modelo MOBILE específico para México, para la fracción mexicana. El modelo MOBILE-Juárez (Radian, 1996) es el más reciente de ellos y actualmente es el modelo recomendado para estimar las emisiones de vehículos mexicanos. Sin embargo, el modelo MOBILE seguirá evolucionando en México y, en el futuro, deberá contactarse al personal del INE para identificar el modelo MOBILE más reciente.

Los oficiales de aduanas estadounidenses mantienen un conteo de los vehículos que entran en EU; sin embargo, estas estadísticas no proporcionan las fracciones vehiculares mexicana y estadounidense, y tampoco incluyen una distribución de los vehículos en las diferentes clasificaciones (i. e., LDGV, HDDV, etc.). La fracción vehicular México/EU deberá ser determinada a través de un estudio en los cruces fronterizos. Asimismo, la distribución de las clasificaciones vehiculares también pueden ser determinadas mediante estudios en los cruces fronterizos y/o en los datos locales y regionales de registro vehicular.

Finalmente, se requiere conocer la duración del tiempo en reposo. Los oficiales estadounidenses de aduanas pueden hacer una estimación gruesa al respecto, pero deben realizarse un estudio profundo para determinar un tiempo en reposo que sea representativo, la fracción y la distribución vehicular tanto mexicana como estadounidense. Todos estos datos pueden variar significativamente por hora, por día y por estación.

Dados los datos anteriores, la ecuación para estimar las emisiones de vehículos en reposo es:

$$\text{Emisiones} = \Sigma(\text{Vehículos}_{\text{Tot}} \times FV_{\text{Mexico}} \times FE_{\text{Mexico,v}} \times VC_{\text{Mexico,v}} \times 4.0 \times T_{\text{Rep}}) + \Sigma(\text{Vehículos}_{\text{Tot}} \times FV_{\text{US}} \times FE_{\text{US,v}} \times VC_{\text{US,v}} \times 2.5 \times T_{\text{Rep}}) \quad 5.5\text{-}1$$

donde:

$\text{Vehículos}_{\text{Total}}$ = Número total de vehículos que pasan a través del cruce de frontera

FV_{Mexico}, FV_{US} = Fracción de vehículos que son de México o de EU

$VC_{\text{Mexico,v}}$, $VC_{\text{US,v}}$ = Fracción de vehículos mexicanos y estadounidenses en cada clase vehicular v

$FE_{\text{Mexico,v}}$, $FE_{\text{US,v}}$ = Factor de emisión para los vehículos mexicanos y estadounidenses en cada clase vehicular v, tomada del factor de emisión basado en el modelo MOBILE y PART5

4.0 (2.5) = Factor utilizado para convertir factores de emisión en gramos por kilómetro (gramos por milla) en factores de emisión en gramos por hora

T_{Rep} = Tiempo promedio en reposo consumido en el cruce de frontera.

DATOS NECESARIOS:

Datos	Fuentes
Parámetros de entrada del modelo de factores de emisión MOBILE5a y PART5	La descripción de los datos necesarios y las fuentes disponibles se pueden encontrar en el Manual de Vehículos Automotores (Volumen VI de esta serie)
Conteos vehiculares	Oficiales aduanales estadounidenses y otros oficiales locales.
Fracciones vehiculares mexicana y estadounidense	Encuesta específica en sitio.
Distribución de las clasificaciones vehiculares	Encuesta específica en sitio o datos del registro vehicular local.
Tiempo en reposo	Estudio de sitio específico u oficiales aduanales estadounidenses y mexicanos.

NOTAS:

1. Debe tenerse cuidado para evitar la duplicación de las emisiones que ya han sido incluidas como emisiones de fuentes móviles. La VMT general de las cuentas vehiculares puede no necesitar ser ajustada debido a la duplicación. Las ventas generales VMT de combustible, sin embargo, sí deben ser ajustadas. Adicionalmente, existe cierta incertidumbre con respecto a qué tan "real" es la estimación de emisiones cuando la velocidad se reduce hasta 4 kph.

EJEMPLO DE CALCULO:

En 1995, un estimado de 800,000 vehículos pasaron de México a EU a través de un cruce de frontera particular. Para este ejemplo, no se estimarán las emisiones de los vehículos que pasaron de EU a México. Los resultados del estudio indican un tiempo en reposo promedio de 12 minutos por vehículo. De los vehículos que entran en EU, 62% son mexicanos, y el resto son estadounidenses; 70% de los vehículos estadounidenses y 75% de los mexicanos son LDGVs. El resto de los vehículos, en ambos casos son LDGTs. Calcular las emisiones anuales de NO_x de estos vehículos en reposo.

1. A partir de las corridas de MOBILE, se calcularon los siguientes factores de emisión promedio hipotéticos de NO_x para una flota:

LDGVs estadounidenses:	2.4 g/milla
LDGTs estadounidenses:	3.2 g/milla
LDGVs mexicanos:	2.7 g/milla
LDGTs mexicanos:	3.6 g/milla

2. Multiplicando estos factores de emisión por 2.5 mph se obtienen los siguientes factores de emisión en reposo:

LDGVs estadounidenses:	6.0 g/hora
LDGTs estadounidenses:	8.0 g/hora
LDGVs mexicanos:	6.75 g/hora
LDGTs mexicanos:	9.0 g/hora

3. El número de vehículos para cada categoría es calculado utilizando las fracciones vehiculares y las fracciones de clase vehicular:

LDGVs estadounidenses: 800,000 vehículos × 0.38 × 0.70 = 212,800 vehículos
LDGTs estadounidenses: 800,000 vehículos × 0.38 × 0.30 = 91,200 vehículos

LDGVs mexicanos: 800,000 vehículos × 0.62 × 0.75 = 372,000 vehículos
LDGTs mexicanos: 800,000 vehículos × 0.62 × 0.25 = 124,000 vehículos

4. Posteriormente se calculan las emisiones NO_x totales:

(212,800 vehículos × 0.2 horas × 6.0 g/hora) + (91,200 vehículos × 0.2 horas × 8.0 g/hora)
+ (372,000 vehículos × 0.2 horas × 6.75 g/hora) + (124,000 vehículos × 0.2 horas × 9.0 g/hora)
= 255.4 kg + 145.9 kg + 502.2 kg + 223.2 kg
= 1.13 Mg NO_x

5.6 Terminales de Autobuses y Camiones 4.6 Bus/Truck Terminals4.6Bus/Truck Terminals

CODIGO DE FUENTE	DESCRIPCION
22-01-070-900*	Vehículos pesados a gasolina (HDGV, por sus siglas en inglés)
22-30-070-900*	Vehículos pesados a diesel (HDDV, por sus siglas en inglés)

* Códigos propuestos específicos para México, para categorías de fuente que no son típicamente inventariadas en EU.

DESCRIPCION:

Esta sección se refiere a las emisiones de las terminales de autobuses y camiones. En México, estos vehículos a menudo hacen cola por largos periodos de tiempo esperando cargar y/o descargar carga o pasajeros. Los vehículos en la cola normalmente no apagan sus motores, sino que los mantienen encendidos mientras avanzan lentamente. La metodología que se describe a continuación es similar a la que se describe para los cruces fronterizos (ver Sección 5.5).

Debido a que estas emisiones son generadas por vehículos que circulan por carreteras, podría argumentarse que deberían ser incluidas como fuentes móviles. Sin embargo, a diferencia de las emisiones de fuentes móviles típicas, la ubicación de estas emisiones en las terminales de autobuses y camiones está muy bien definida (i. e., el segmento de carretera o estaciones en las que se encuentra la terminal). Asimismo, las últimas versiones de los modelos de factores de emisión de fuentes móviles (MOBILE5a, PART5, y otras versiones modificadas relacionadas), sólo pueden ser utilizadas para estimar las emisiones de los vehículos en movimiento. Por estas razones, las emisiones en reposo en las terminales de autobuses y camiones deben ser manejadas como fuentes de área.

CONTAMINANTES: GOT, CO, NO_x, SO_x, PM_{10}

GOR: Para los vehículos de gasolina sin catalizador, las emisiones GOR constituyen 92.4% del GOT. Para los vehículos de gasolina con catalizador, las emisiones GOR constituyen 85.2% del GOT. Para los vehículos diesel, las emisiones GOR constituyen 95.7% del GOT.

AJUSTES DE FUENTES PUNTUALES: Ninguno.

METODOLOGIA:

Como se mencionó en la Sección 5.5, las últimas versiones del MOBILE5a y PART5 no proporcionan ningún factor de emisión en reposo. Algunas versiones anteriores del MOBILE sí lo hacían, sin embargo, dichos factores representaban condiciones estándar de prueba (modo estabilizado de operación, 75 °F y un combustible con una RVP de 9.0 psi). Debido a que la EPA no ha podido desarrollar un algoritmo satisfactorio que tome en cuenta las variaciones en el modo de operación, la temperatura y la RVp del combustible, el cálculo directo de los factores de emisión en reposo se ha desactivado en el MOBILE5a, mientras se recopilan datos sobre estas emisiones.

La EPA ha proporcionado una metodología provisional para la estimación de las emisiones en reposo usando el MOBILE5a (U.S. EPA, 1993), que puede ser utilizada para estimar las emisiones vehiculares en las terminales de autobuses y camiones y en otras situaciones de reposo. Se asume que esta metodología es válida para el PART5 y cualesquier modelos MOBILE que hayan sido modificados para ser aplicados en México (i. e., MOBILE-MCMA, MOBILE-MMAp, MOBILE-Juárez, etc.). Un modelo MOBILE será utilizado para estimar las emisiones de GOT, CO y NO_x. Un modelo PART5 será utilizado para estimar las emisiones de PM_{10}; mientras que las emisiones de SO_x serán estimadas utilizando un balance de combustible simple.

En la metodología provisional de la EPA, las emisiones en reposo son calculadas utilizando factores de emisión de escape de un modelo MOBILE a la velocidad más baja permisible del vehículo (4 kilómetros por hora [kph] para los modelo MOBILE modificados específicos para México). Se usa la velocidad más baja posible porque contiene el mayor porcentaje de tiempo en reposo en comparación con cualquiera de los ciclos de velocidad usados por el modelo MOBILE. Después de correr el modelo, los factores de emisión de escape para GOT, CO y NO_x serán calculados en unidades de gramo por milla o gramo por kilómetro. Para convertir estos factores de emisión en factores de emisión en reposo en unidades de gramos por hora, es necesario multiplicar por 4 kph. Los factores de emisión en reposo resultantes no deben incluir ninguna emisión que no sea de escape. Para mayor información sobre la forma de correr los modelos MOBILE y PART5 consulte en Manual de Vehículos Automotores (Volumen VI) de esta serie y/o los manuales de usuario de los modelos MOBILE y PART5 (U.S. EPA, 1994; U.S. EPA, 1995). El MOBILE-Juárez (Radian, 1996) es el más reciente de los modelos MOBILE específico para México, y actualmente es el modelo recomendado para estimar las emisiones de vehículos mexicanos. Sin embargo, el modelo MOBILE seguirá evolucionando en México. En el futuro, será necesario comunicarse con el personal del INE para identificar el modelo MOBILE más reciente.

Finalmente, se requiere la duración del tiempo en reposo. Los empleados de la terminal de autobuses o camiones de pueden hacer un estimado grueso al respecto, pero deben realizarse un estudio profundo para determinar tanto un tiempo en reposo representativo como la distribución vehicular. Todos estos datos pueden variar significativamente por hora, por día y por estación.

Dados los datos anteriores, la ecuación para estimar las emisiones de vehículos en reposo es:

$$\text{Emisiones} = \Sigma(\text{ Vehículos}_{\text{Tot}} \text{ x } \text{FV}_{\text{Mexico,v}} \text{ x } \text{FE}_{\text{Mexico,v}} \text{ x } 4.0 \text{ x } \text{T}_{\text{Rep}}) \tag{5.6-1}$$

donde:

$\text{Vehículos}_{\text{Total}}$ = Número total de vehículos que pasan a través de la terminal de camiones o autobuses

VC_{v} = Fracción de vehículos en cada clase vehicular v

FE_{v} = Factor de emisión para los vehículos en cada clase vehicular v, tomada del factor de emisión basado en el modelo MOBILE y PART5

4.0 = Factor utilizado para convertir factores de emisión en gramos por kilómetro (gramos por milla) en factores de emisión en gramos por hora

T_{Rep} = Tiempo promedio pasado en reposo en cola en la terminal de autobuses o camiones.

DATOS NECESARIOS:

Datos	Fuentes
Parámetros de entrada del modelo de factores de emisión MOBILE5a y PART5	La descripción de los datos necesarios y las fuentes disponibles se pueden encontrar en el Manual de Vehículos Automotores (Volumen VI de esta serie)
Conteos vehiculares	Empleados de la terminal de autobuses o camiones, u otros empleados locales
Distribución de las clasificaciones vehiculares	Encuesta específica en sitio
Tiempo en reposo	Encuesta específica en sitio, empleados de la terminal de autobuses o camiones, o usuarios frecuentes

NOTAS:

1. Debe tenerse cuidado para evitar la duplicación de las emisiones que ya han sido incluidas como emisiones de fuentes móviles. La VMT general de las cuentas vehiculares puede no requerir ser ajustada para un doble conteo. Adicionalmente, existe cierta incertidumbre con respecto a qué tan “real” es la estimación de emisiones cuando la velocidad se reduce hasta 4 kph.

EJEMPLO DE CALCULO:

En 1995, se estima que 20,000 vehículos pasaron a través de una terminal de autobuses particular. Los resultados del estudio indican un tiempo en reposo promedio de 15 minutos por vehículo. De estos vehículos, 40% son HDGVs y el resto son HDDVs. Calcular las emisiones anuales de NO_x de estos vehículos en reposo

1. Asumir que, a partir del último modelo MOBILE, se calcularon los siguientes factores de emisión:

HDGVs:	2.8 g/km
HDDVs:	13.3 g/km

2. Multiplicando estos factores de emisión por 4 kph se obtienen los siguientes factores de emisión en reposo

HDGVs:	11.2 g/hora
HDDVs:	53.2 g/hora

3. El número de vehículos para cada categoría es calculado utilizando el número total de vehículos y las fracciones de clase vehicular

HDGVs: 20,000 vehículos × 0.40 = 8,000 vehículos
HDDVs: 20,000 vehículos × 0.60 = 12,000 vehículos

4. Posteriormente se calculan las emisiones totales de NO_x:

(8,000 vehículos × 0.25 horas × 11.2 g/hora) +
(12,000 vehículos × 0.25 horas × 53.2 g/hora)
= 22.4 kg + 159.6 kg
= 182 kg
= 0.18 Mg NO_x

6.0 USO DE SOLVENTES

Muchas de las actividades que utilizan solventes pueden ser demasiado pequeñas o numerosas para ser incluidas en el inventario de fuentes puntuales de una región determinada, y deben ser incluidas en un inventario de fuentes de área. La guía para elaborar un inventario de estas fuentes se presenta en las siguientes subsecciones:

- Recubrimiento de Superficies en la Industria
- Pintado de Carrocerías
- Recubrimiento de Superficies Arquitectónicas
- Pintura de Tráfico
- Limpieza de Superficies en la Industria(Desengrasado)
- Limpieza en Seco
- Artes Gráficas
- Aplicación de Asfalto
- Uso Comercial y Doméstico de Solventes.

6.1 Recubrimiento de Superficies en la Industria

CODIGO DE FUENTE	DESCRIPCION
24-01-010-xxx	Productos Textiles
24-01-015-xxx	Madera con Acabados de Fábrica
24-01-020-xxx	Muebles de Madera
24-01-025-xxx	Muebles Metálicos
24-01-030-xxx	Papel
24-01-035-xxx	Productos Plásticos
24-01-040-xxx	Latas Metálicas
24-01-045-xxx	Bobinas Metálicas
24-01-050-xxx	Materiales Acabados Misceláneos
24-01-055-xxx	Maquinaria y Equipo
24-01-060-xxx	Aparatos Domésticos de Gran Tamaño
24-01-065-xxx	Equipos Electrónicos y Otros Eléctricos
24-01-070-xxx	Vehículos Automotores
24-01-075-xxx	Aeronaves
24-01-080-xxx	Embarcaciones Marinas
24-01-085-xxx	Ferrocarriles
24-01-090-xxx	Manufactura Miscelánea
24-01-100-xxx	Recubrimientos Industriales de Mantenimiento
24-01-200-xxx	Otros Recubrimientos con Propósitos Especiales
24-01-990-xxx	Todas las Categorías de Recubrimiento de Superficies.

DESCRIPCION:

Las operaciones de recubrimiento de superficie consisten en la aplicación de una delgada capa de recubrimiento, por ejemplo pintura, barniz, laca o primer a un objeto para propósitos decorativos o de protección y el proceso abarca un gran número de pasos. Los recubrimientos son aplicados durante la manufactura de una amplia gama de productos, incluyendo mobiliario, latas, automóviles, aviones y otro equipo de transporte, maquinaria, aparatos domésticos, madera, alambre y otros productos misceláneos. Adicionalmente, los recubrimientos son utilizados en operaciones de mantenimiento en los establecimientos industriales.

Los solventes contenidos en los recubrimientos se evaporan en la medida en que estos compuestos se aplican y secan. Si bien los solventes residuales pueden permanecer en el recubrimiento después de que se ha secado, y una fracción del recubrimiento no será utilizada y se dispondrá en un establecimiento de tratamiento de aguas residuales, o será enviado a un relleno sanitario, la mayoría de los esfuerzos de inventario asumen que todo los solventes contenidos en recubrimientos se evaporan en el aire.

Las emisiones de las operaciones de recubrimiento de superficies se pueden reducir utilizando compuestos con base de agua, filtros, sistemas de condensación, post-quemadores y procesos de aplicación más eficientes en los que se aplique una menor cantidad de solvente.

CONTAMINANTES: GOT

GOR: Las emisiones GOR constituyen 98.8% de GOT.

AJUSTES DE FUENTES PUNTUALES:

Las operaciones de recubrimiento de superficies se pueden presentar en grandes establecimientos que podrían ser inventariados como fuentes puntuales. Por lo tanto, el procedimiento para el cálculo de emisiones para estimados de fuentes de área debe ser ajustado para evitar la duplicación con los estimados de fuentes puntuales. Si se utilizan factores de emisión por empleado, el empleo en los establecimientos de las fuentes puntuales debe ser restado del empleo total en el área de inventario. Si los datos de empleo no están disponibles, entonces las emisiones puntuales pueden ser restadas de las emisiones totales.

METODOLOGIA:

Las emisiones de estas fuentes pueden ser calculadas usando uno de los siguientes dos métodos:

Método 1: El primer método utiliza un factor de emisión per cápita desarrollado para la Ciudad de México (DDF, 1995b).

El cálculo utilizando el factor de emisión per cápita es:

$$\text{Emisiones Anuales de GOT} = (\text{Población}) \times (\text{Factor de Emisión}) \qquad (6.1\text{-}1)$$

Si cualesquier establecimientos de recubrimiento de superficies estuvieran incluidos en el inventario de fuentes puntuales, sus emisiones deben ser eliminadas para arrojar un estimado de emisiones de las fuentes de área.

Método 2: El segundo método utiliza factores de emisión por empleado que se basan en los promedios nacionales de EU. Estos factores tienen una aplicación limitada en México, y deben ser utilizados solamente si no existen otros datos específicos disponibles. El uso de factores de emisión por empleado requiere la recopilación de datos sobre el número de empleados dentro de determinadas industrias. Una breve descripción de la industria se presenta en la tabla de **DATOS NECESARIOS** de esta sección. Después de que las industrias locales o regionales han sido asociadas con los agrupamientos de la tabla, el empleo para los establecimientos de las fuentes puntuales en dichos grupos debe ser restado del número total de individuos empleados en cada categoría industrial. La diferencia es el empleo en las fuentes de área. Posteriormente, las emisiones son calculadas como:

$$\begin{array}{c}\text{Emisiones Anuales}\\ \text{de GOT}\end{array} = \left(\begin{array}{c}\text{Empleo del Grupo}\\ \text{Industrial de la Fuente de}\\ \text{Area}\end{array}\right) \text{x} \left(\begin{array}{c}\text{Factor de}\\ \text{Emisión}\end{array}\right) \qquad (6.1\text{-}2)$$

Los factores de emisión para estos dos métodos se presentan en la parte de **DATOS NECESARIOS** de esta sección.

DATOS NECESARIOS:

Datos		Fuentes
Método del Factor de Emisión per Cápita:		
Población		INEGI
Factor de Emisión GOT	1.28 kg/persona/año	DDF, 1995b
Método Por Empleado		
Empleo por Tipo de Industria		SNIFF DATOSbase, CANACINTRA, INEGI
Factor de Emisión GOT		U.S. EPA, 1991a
Madera con Acabado de Fábrica	59 kg/empleado/año (131 lb/empleado/año)	
Muebles y Accesorios de Metal	428 kg/empleado/año (944 lb/empleado/año)	
Aislamiento Eléctrico	132 kg/empleado/año (290 lb/empleado/año)	
Latas Metálicas	2,735 kg/empleado/año (6,029 lb/empleado/año)	

Datos		Fuentes
Metales Acabados Misceláneos (láminas, bandas y bobinas)	1,305 kg/empleado/año (2,877 lb/empleado/año)	
Maquinaria y Equipo	35 kg/empleado/año (77 lb/empleado/año)	
Aparatos Domésticos	210 kg/empleado/año (463 lb/empleado/año)	
Vehículos Automotores (nuevos)	360 kg/empleado/año (794 lb/empleado/año)	
Otros Transportes (incluye aeronaves y ferrocarriles)	16 kg/empleado/año (35 lb/empleado/año)	
Embarcaciones Marinas	140 kg/empleado/año (308 lb/empleado/año)	

NOTAS:

1. El factor de emisión para el recubrimiento industrial de superficies fue desarrollado por el DDF (1995b), con base en la información sobre las ventas nacionales de productos (para 1993), proporcionada por la Asociación Nacional de Fabricantes de Pinturas y Tintas (ANAFAPYT).

2. El factor de emisión per cápita fue desarrollado multiplicando el volumen total de pintura por 0.45 para reflejar que se estima que la pintura contiene 45% de solvente.

3. Los ajustes a ambos factores de emisión, per cápita y por empleado, pueden ser necesarios para reflejar las condiciones locales y, con el tiempo, para reflejar los cambios en el uso y composición de los recubrimientos.

4. Los estimados de emisión calculados utilizando los factores por empleado necesitarán ser asociados con los códigos en el SNIFF para permitir su relación con el inventario de fuentes puntuales.

5. Una alternativa para los factores de emisión presentados anteriormente, consiste en encuestar a un número representativo de operaciones de recubrimiento de superficies. Los resultados de dicha encuesta podrían ser extrapolados al área total del inventario.

- Antes de realizar una encuesta es conveniente revisar la sección sobre encuestas en el Volumen III, *Técnicas Básicas de Estimación de Emisiones*

- Debe identificarse a la población completa de establecimientos, pero sólo debe encuestarse a una muestra representativa.

Las encuestas deben solicitar información que pueda ser utilizada para calcular las emisiones utilizando el método de balance de materiales (ver las *Técnicas Básicas de Estimación de Emisiones*). Una encuesta debe requerir la siguiente información:

- Nombre y ubicación del establecimiento

- Nombre de la persona que responderá el cuestionario, o nombre del contacto para solicitar información adicional

- Número de empleados en el establecimiento

- Tipo de productos que son recubiertos en el establecimiento (e. g., muebles de madera o metal, aparatos electrodomésticos, maquinaria, botes)

- Kilogramos de cada tipo de recubrimiento utilizado en el establecimiento (si las cantidades son registradas en litros, será necesario recopilar información sobre su densidad para calcular el peso), y peso

- Componentes químicos de cada recubrimiento.

Si este método se realiza adecuadamente, sus resultados serán mucho más precisos que los obtenidos con el primer método; sin embargo, requiere un mayor esfuerzo y gasto. Si el método no es aplicado de manera correcta, los resultados podrían ser menos precisos que si se utilizaran los factores de emisión.

EJEMPLO DE CALCULO:

Por ejemplo, las emisiones totales anuales de GOT de los recubrimientos industriales de superficies en un estado con una población con 1,250,000 habitantes son:

(1,250,000 personas) x (1.28 kg/persona/año) = 1,600,000 kg/año
= 1,600 Mg/año

Si existen grandes establecimientos que realicen operaciones de recubrimiento de superficies en el área de inventario, y que hayan sido inventariados como fuentes puntuales, entonces las emisiones calculadas para dichos establecimientos deben ser restadas del total calculado anteriormente. Por ejemplo, si las emisiones de fuentes puntuales son:

- 124 Mg por año para el Establecimiento A
- 83 Mg por año para el Establecimiento B
- 17 Mg por año para el Establecimiento C.

Entonces:

Emisiones de Fuente de Area = 1,600 Mg - (124 Mg + 83 Mg + 17 Mg)
= 1,376 Mg/año

Los cálculos necesarios para el segundo método son similares. Sin embargo, en este caso, el restar el empleo en las fuentes puntuales del empleo total resultará en un estimado de emisiones más preciso. Por ejemplo:

- El empleo total en las fábricas de muebles y accesorios de metal en el área de inventario es de 623
- El empleo de fuentes puntuales en dos fábricas de muebles de metal es de 479.

Entonces:

Empleo en Fuente de Area = 623 - 479
= 144 empleados en fábricas de muebles de metal

Las emisiones de fuentes de área son calculadas como:

Emisiones de Fuente de Area = (144 empleados) x (428 kg/empleado/año)
= 61,632 kg/año
= 61.6 Mg Mg/año

6.2 Pintado de Carrocerías

CODIGO DE FUENTE: 24-01-005-000

DESCRIPCION:

El pintado de autos engloba la reparación y restauración de carrocerías de automóviles, camiones ligeros y otros vehículos. Las operaciones de pintado son posteriores a las que el equipo original recibe en las plantas de ensamble del fabricante. El recubrimiento de vehículos nuevos no está incluida en esta categoría de fuente; pero en un inventario de fuentes puntuales queda dentro de la categoría de recubrimiento de superficies industriales. La mayoría de los trabajos de pintado de carrocerías son realizados como parte de la reparación de una colisión y sólo involucra partes de un vehículo. La pintura puede aplicarse en una cabina de aspersión.

Las operaciones de pintado pueden variar desde talleres de gran producción con numerosos empleados, hasta pequeñas operaciones en las que una persona trabaja tiempo parcial. En algunos casos, las grandes operaciones pueden ser inventariadas como establecimientos de fuentes puntuales.

Las emisiones se generan durante la limpieza de superficies, resanado y apresto, pintado y pulido, y son influenciadas por el contenido de solvente en el producto, la eficiencia de transferencia del equipo de aspersión utilizado para aplicar los recubrimientos, y las prácticas de pulido. Los controles pueden incluir el uso de compuestos con menor cantidad de solventes, un incremento de la eficiencia de transferencia en el equipo de aspersión, y equipos de limpieza cerrados.

CONTAMINANTES: GOT

GOR: Las emisiones de GOR constituyen 98.8% del GOT.

AJUSTES DE FUENTES PUNTUALES:

El pintado de carrocerías puede realizarse en establecimientos de fuentes puntuales. Las emisiones no controladas que han sido calculadas para los establecimientos de fuentes puntuales deben ser restadas de las emisiones no controladas totales, para arrojar un estimado de las emisiones de las fuentes de área.

METODOLOGIA:

Emisiones Anuales de GOT = (Población) x (Factor de Emisión) (6.2-1)

DATOS NECESARIOS:

Datos		Fuentes
Población		INEGI
Factor de emisión GOT	0.14 kg/persona/año	DDF, 1995b

NOTAS:

1. El factor de emisión para el recubrimiento industrial de superficies fue desarrollado por el DDF (1995b), con base en la información sobre las ventas nacionales de productos (para 1993), proporcionada por la ANAFAPYT.

2. El factor de emisión per cápita fue desarrollado multiplicando el volumen total de pintura por 0.45 para reflejar que se estima que la pintura contiene 45% de solvente.

3. Los ajustes a ambos factores de emisión, per cápita y por empleado, pueden ser necesarios para reflejar las condiciones locales. Con el tiempo, pueden requerirse ajustes adicionales debido a que la sustitución de los compuestos utilizados en el pintado de carrocerías podría alterar la fracción no reactiva.

EJEMPLO DE CALCULO:

Por ejemplo, las emisiones anuales totales de GOT del pintado de carrocerías en el estado de Colima (población 428,510) son:

(428,510 personas) x (0.14 kg/persona/año) = 59,991 kg/año
= 59.99 Mg/año

6.3 Recubrimiento de Superficies Arquitectónicas 5.3 Architectural Surface Coating5.3 Architectural Surface Coating

CODIGO DE FUENTE: 24-01-001-000

DESCRIPCION:

Los recubrimientos para superficies arquitectónicas son utilizados por los contratistas e individuos para proteger y mejorar las superficies interiores y exteriores de las construcciones. El proceso implica la aplicación de una delgada capa de recubrimiento tal como pintura, aprestador, barniz o laca a las superficies arquitectónicas, y el uso de solventes para adelgazar y limpiar. Esta categoría no incluye el pintado de carrocerías, la aplicación de pintura de tráfico, el recubrimiento industrial de superficies, los recubrimientos industriales de mantenimiento, ni las pinturas utilizadas en artes gráficas. Dado que las emisiones de esta categoría estarán distribuidas en toda el área de inventario y no se presentarán repetidamente en un solo sitio durante el periodo de inventario, deben ser tratadas solamente como una fuente de área.

Los GOT que son utilizados como solventes en los recubrimientos son emitidos durante la aplicación del recubrimiento y durante el secado. Las técnicas de control involucran la sustitución o la reformulación de compuestos. Los productos alternativos incluyen recubrimientos con bajo contenido de solvente, con base de agua, o en polvo.

CONTAMINANTES: GOT

GOR: Las emisiones de GOR constituyen 94.5% del GOT para los recubrimientos arquitectónicos con base de agua; 96.8% del GOT para los recubrimientos arquitectónicos con base de aceite; y 69.9% del GOT para los solventes adelgazadores y limpiadores utilizados con los recubrimientos arquitectónicos.

AJUSTES DE FUENTES PUNTUALES: Ninguno.

METODOLOGIA:

$$\text{Emisiones Anuales de GOT} = (\text{Población}) \times (\text{Factor de Emisión}) \qquad (6.3\text{-}1)$$

DATOS NECESARIOS:

DATOS		FUENTES
Población		INEGI
Factor de emisión GOT	1.36 kg/persona/año	DDF, 1995b

NOTAS:

1. El factor de emisión para el recubrimiento de superficies arquitectónicas fue desarrollado por el DDF (1995b), con base en la información sobre el contenido de solvente y las ventas nacionales de productos (para 1993), proporcionada por la ANAFAPYT.

2. El factor de emisión fue calculado multiplicando el volumen total de pintura por 0.45 para reflejar que se estima que la pintura contiene un promedio de 45% de solvente.

3. Los ajustes este factor de emisión per cápita pueden ser necesarios para reflejar las condiciones locales. Con el tiempo, pueden requerirse ajustes adicionales debido a que la sustitución de los compuestos utilizados en el recubrimiento de superficies arquitectónicas podría alterar la fracción no reactiva.

EJEMPLO DE CALCULO:

Por ejemplo, las emisiones anuales totales de GOT del recubrimiento arquitectónico de superficies en el estado de Colima (población 428,510) son:

$$
\begin{aligned}
(428{,}510 \text{ personas}) \times (1.36 \text{ kg/persona/año}) &= 582{,}774 \text{ kg/año} \\
&= 582.77 \text{ Mg/año}
\end{aligned}
$$

6.4 Pintura de Tráfico

CODIGO DE FUENTE: 24-01-008-000

DESCRIPCION:

La aplicación de pintura de tráfico consiste en el pintado de carriles, banquetas, marcas de dirección, señales de estacionamiento y superficies pavimentadas y no pavimentadas para facilitar el flujo del tránsito. Las señales de tráfico pueden utilizar pinturas con base de solvente y de agua, que generalmente se aplican con spray, o en forma de cintas termoplásticas o preformadas que son aplicadas con epóxicos sobre la superficie de los caminos. Las pinturas de tráfico son aplicadas por cuadrillas de mantenimiento y contratistas durante la construcción y reparación de caminos. Debido a que las emisiones de esta categoría serán escasas dentro del área del inventario, y no se presentarán repetidamente en un solo sitio durante el periodo de inventario, deben ser tratadas solamente como una fuente de área.

Factores tales como las condiciones climáticas, la durabilidad de la pintura, tipo de pavimento, densidad del tráfico y posición de las señales, determinarán la frecuencia con la que la pintura debe ser reaplicada y, por lo tanto, tendrán influencia sobre las emisiones. Las técnicas de control incluyen la sustitución y reformulación de productos. Por su parte, las formulaciones alternativas incluyen pinturas con base de agua, termoplásticos, marcadores permanentes y cintas preformadas.

CONTAMINANTES: GOT

GOR: Las emisiones de GOR constituyen 98.8% del GOT.

AJUSTES DE FUENTES PUNTUALES: Ninguno.

METODOLOGIA:

$$\text{Emisiones Anuales de GOT} = (\text{Población}) \times (\text{Factor de Emisión}) \qquad (6.4\text{-}1)$$

DATOS NECESARIOS:

DATOS		FUENTEs
Población		INEGI, 1993
Factor de emisión GOT	0.04 kg/persona/año	DDF, 1995b

NOTAS:

1. El factor de emisión mostrado para la aplicación de pintura de tráfico fue desarrollado por el DDF (1995b), con base en la información sobre el contenido de solvente y las ventas nacionales de productos (para 1993), proporcionada por la ANAFAPYT.

2. El factor de emisión fue desarrollado multiplicando el volumen total de pintura por 0.45 para reflejar que se estima que la pintura promedio contiene 45% de solvente.

3. Los ajustes este factor de emisión per cápita pueden ser necesarios para reflejar las condiciones locales. Con el tiempo, pueden requerirse ajustes adicionales debido a que la sustitución de los compuestos utilizados en la pintura de tráfico podría alterar la fracción no reactiva.

EJEMPLO DE CALCULO:

Por ejemplo, las emisiones anuales totales de GOT de la aplicación de pintura de tráfico en el estado de Colima (población 428,510) son:

$$\begin{aligned}(428{,}510 \text{ personas}) \times (0.04 \text{ kg/persona/año}) &= 17{,}140 \text{ kg/año} \\ &= 17.14 \text{ Mg/año}\end{aligned}$$

6.5 Limpieza de Superficies en la Industria (Desengrasado)

CODIGO DE FUENTE	DESCRIPCION
24-15-000-xxx	Todos los Procesos y Todas las Industriales
24-15-005-xxx	Muebles y Accesorios
24-15-010-xxx	Industrias Metálicas Básicas
24-15-015-xxx	Industrias Metálicas Secundarias
24-15-020-xxx	Productos Metálicos Elaborados
24-15-025-xxx	Maquinaria y Equipo Industrial
24-15-030-xxx	Procesos Electrónicos y Otros Procesos Eléctricos
24-15-035-xxx	Equipo de Transporte
24-15-040-xxx	Instrumentos y Productos Relacionados
24-15-045-xxx	Manufactura Miscelánea
24-15-050-xxx	Establecimientos de Mantenimiento al Transporte
24-15-055-xxx	Vendedores de Automóviles
24-15-060-xxx	Servicios de Reparación Misceláneos
24-15-065-xxx	Servicios de Reparación Automotriz.

DESCRIPCION:

Las operaciones de limpieza de superficies involucran el uso de solventes líquidos o vapores de solventes, para eliminar contaminantes insolubles en agua tales como grasa, aceite, ceras, depósitos de carbón, óxidos y alquitranes de superficies tales como metales, plásticos, vidrios y otros. Este proceso se lleva a cabo en una gran variedad de operaciones de manufactura, científicas y de reparación. Las operaciones de limpieza con solventes implican el uso de un gran número de sustancias diferentes, así como de distintos procedimientos de limpieza.

El equipo de limpieza con solventes puede ser clasificado como:

- Máquinas de limpieza por lotes en frío: Estas máquinas se cargan con el lote y el solvente líquido es asperjado, vertido o cepillado sobre las superficies a ser limpiadas.

- Máquinas de limpieza por lotes con vapor: Estas máquinas se cargan con el lote, y los materiales a ser limpiados son expuestos al solvente vaporizado. Al condensarse, el solvente arrastra los contaminantes de las superficies.

- Máquinas de limpieza en línea: Estas máquinas son cargadas de manera continua y con frecuencia están diseñadas para operaciones a gran escala. Por otro lado, pueden utilizar solventes líquidos o vaporizados.

- Uso de solventes para la limpieza: Este proceso implica el tallado de una superficie con el solvente y un trapo, estopa o esponja.

CONTAMINANTES: GOT

GOR: Las emisiones de GOR constituyen el 100% del GOT para los solventes de petróleo, y 0% del GOT para los solventes sintéticos. Si existen datos disponibles sobre la especiación para la región del inventario, la relación GOR/GOT debe ser ajustada de acuerdo con éstos. Si sólo se conoce la cantidad total de solventes limpiadores de superficies, puede asumirse que las emisiones GOR constituyen 60% del GOT (U.S. EPA, 1991a).

AJUSTES DE FUENTES PUNTUALES:

Las operaciones de limpieza de superficies con solventes se pueden presentar en grandes establecimientos que podrían ser inventariados como fuentes puntuales. Por lo tanto, el procedimiento para el cálculo de emisiones para estimados de fuentes de área deben ser ajustados para evitar la duplicación con los estimados de fuentes puntuales. Si se utilizan factores de emisión por empleado, el empleo en los establecimientos de las fuentes puntuales debe ser restado del empleo total en el área de inventario. Si los datos de empleo no están disponibles, entonces las emisiones puntuales pueden ser restadas de las emisiones totales.

METODOLOGIA:

Las emisiones de esta fuente pueden ser calculados aplicando uno de los dos siguientes factores de emisión. El segundo método, que usa un factor de emisión per cápita, debe ser utilizado solamente como último recurso.

Método 1: El primer grupo de factores de emisión, derivados en EU, se basan en el número de empleados en los establecimientos que típicamente realizan operaciones de limpieza con solventes. Estos factores de emisión estadounidenses por empleado tienen una aplicación limitada en México, y deben ser utilizados solamente si no existen otros datos disponibles. El uso de factores de emisión por empleado requiere la recopilación de datos sobre el número de empleados dentro de determinadas industrias.

Una breve descripción de la industria se presenta en la tabla de **DATOS NECESARIOS** de esta sección. Después de que las industrias locales o regionales han sido asociadas con los agrupamientos de la tabla, el empleo para los establecimientos de las fuentes puntuales en dichos grupos debe ser restado del número total de individuos empleados en cada categoría industrial. La diferencia representa el empleo en las fuentes de área

$$\begin{matrix}\text{Emisiones Anuales} \\ \text{de GOT}\end{matrix} = \left(\begin{matrix}\text{Empleo del Grupo} \\ \text{Industrial de la Fuente de} \\ \text{Area}\end{matrix}\right) \text{x} \left(\begin{matrix}\text{Factor de} \\ \text{Emisión}\end{matrix}\right)$$

(6.5-1)

<u>Método 2</u>: El segundo grupo de factores de emisión, también derivados en EU, se basan en la población (U.S. EPA, 1991a), y tienen una aplicación limitada en México, debiendo ser utilizados solamente en el caso de que no hubiera otros datos disponibles. El cálculo utilizando el factor de emisión per cápita es:

$$\text{Emisiones Anuales} = (\text{Población}) \text{ x } (\text{Factor de Emisión})$$

(6.5-2)

Si cualesquier operaciones de limpieza con solventes son incluidas en el inventario de fuentes puntuales, sus emisiones deberían ser eliminadas de este estimado, para arrojar el estimado de emisiones de las fuentes de área.

Los factores de emisión por empleado y per cápita son proporcionados en el inciso **DATOS NECESARIOS** de esta sección. Si existe información disponible sobre las operaciones específicas de limpieza de solventes en la región geográfica de interés, sólo deben utilizarse los factores de emisión para dichas operaciones. Si la información con respecto a los tipos de operaciones de limpieza no está disponible, debe utilizarse el factor de emisión de la “limpieza con solvente (total)”.

DATOS NECESARIOS:

Datos		Fuentes
Método por Empleado:		
Empleo por Tipo de industria		Base de datos SNIFF, CANACINTRA, INEGI
Factores de emisión GOT		U.S. EPA, 1991a
Limpieza con Solventes (total)	65 kg/empleado/año	
Limpieza de Lotes en Frío		
Reparaciones Automotrices	122 kg/empleado/año	
Manufactura	11 kg/empleado/año	
Máquinas de Lotes de Vapor y en Línea		
Electrónicos y Eléctricos	68 kg/empleado/año	
Otros	22 kg/empleado/año	
Método de Factor de Emisión Per Cápita:		
Población		INEGI
Factores de emisión GOT		U.S. EPA, 1991a
Limpieza con Solventes (total)	3.27 kg/persona/año	
Limpieza de Lotes en Frío		
Reparaciones Automotrices	1.13 kg/persona/año	
Manufactura	0.50 kg/persona/año	
Máquinas de Lotes de Vapor y en Línea		
Electrónicos y Eléctricos	0.50 kg/persona/año	
Otros	1.13 kg/persona/año	

NOTAS:

1. Los ajustes a los factores emisión tanto per cápita como por empleado pueden ser necesarios para reflejar las condiciones locales, y para reflejar los cambios en el uso y composición de los solventes.

2. Los estimados de emisión calculados con los factores por empleado necesitarán ser correctamente asociados con el SNIFF para permitir su relación con el inventario de fuentes puntuales.

3. Una alternativa para el uso de los factores de emisión presentados anteriormente es encuestar a un número representativo de operaciones de limpieza de superficies. Los resultados de esta encuesta deben ser extrapolados a toda el área del inventario. Ver **NOTAS** de la sección Recubrimiento Industrial de Superficies (Sección 6.1) para una breve descripción del procedimiento de encuesta. Los procedimientos de encuesta también se presentan en el Manual *Técnicas Básicas de Estimación de Emisiones*.

EJEMPLO DE CALCULO:

Método Por Empleado

Los cálculos necesarios para ambos métodos son similares; sin embargo, en el primer método, la resta del empleo de la fuente puntual del empleo total resultará en una estimación más precisa. Por ejemplo:

- El empleo total en las plantas de manufactura que usan limpieza dentro del área del inventario es de 623
- El empleo de fuentes puntuales en dos fábricas manufacturadoras de equipo que usan limpieza en frío dentro de su proceso es de 379.

Entonces:

Empleo en Fuente de Area = 623 - 379
= 244 empleados en fábricas manufactura

Las emisiones son calculadas como:

Emisiones GOT de Fuente de Area = (244 empleados) x (11 kg/empleado/año)
= 2,684 kg/año
= 2.7 Mg Mg/año

El mismo procedimiento sería utilizado si existieran otras operaciones de limpieza de superficies en fuentes puntuales dentro del área de inventario.

Método Per Cápita

Si se utiliza el segundo método, las emisiones anuales totales de GOT de la limpieza de superficies en un estado con una población de 1,250,000 son:

(1,250,000 personas) x (3.27 kg/persona/año) = 4,087,500 kg/año
= 4,087.5 Mg/año

Si existen grandes establecimientos que utilicen los procesos de limpieza en frío en el área de inventario, y que hayan sido inventariados como fuentes puntuales, entonces las emisiones calculadas para dichos establecimientos deben ser restadas del total calculado anteriormente. Por ejemplo, si las emisiones de fuentes puntuales son:

- 178 Mg por año para el Establecimiento A
- 123 Mg por año para el Establecimiento B
- 56 Mg por año para el Establecimiento C.

Entonces:

Emisiones de Fuente de Area = 4,087.5 Mg - (78 Mg + 123 Mg + 56 Mg)
= 3,730.5 Mg/año

6.6 Lavado en Seco (Tintorerías)

CODIGO DE FUENTE	DESCRIPCION
24-20-000-000	Todos los Procesos, Todos los Tipos de Solventes
24-20-000-055	Todos los Procesos, Percloroetileno
24-20-000-370	Todos los Procesos, Naftas Especiales
24-20-000-999	Todos los Procesos, Otros Solventes
24-20-010-000	Limpiadores Comerciales e Industriales, Todos los Tipos de Solventes
24-20-010-055	Limpiadores Comerciales e Industriales, Percloroetileno
24-20-010-370	Limpiadores Comerciales e Industriales, Naftas Especiales
24-20-010-999	Limpiadores Comerciales e Industriales, Otros Solventes

DESCRIPCION:

La industria del lavado en seco es una industria de servicios para la limpieza de ropa, cortinas, artículos de cuero y otros productos de tela. En sus operaciones se utilizan solventes orgánicos halogenados o destilados de petróleo. El tamaño de los establecimientos de lavado en seco pueden ir desde grandes plantas industriales, que en general son tratadas como fuentes puntuales, hasta operaciones sumamente pequeñas con una unidad que puede ser utilizada sólo de manera esporádica. Las plantas comerciales tienen un tamaño intermedio entre estos dos extremos.

Normalmente, el lavado en seco utiliza los siguientes solventes: percloroetileno, 1,1,1-tricloroetano, triclorofluoroetano (CFC-113), así como solvente de Stoddard y otros solventes derivados del petróleo. El percloroetileno, 1,1,1-tricloroetano y CFC-113 no son considerados fotoquímicamente reactivos, y no deben ser incluidos en un inventario de precursores de ozono.

Las emisiones en los establecimientos de lavado en seco se presentan cuando los solventes se evaporan durante el proceso, en fugas del equipo y de los sistemas de recuperación o disposición de solventes. Las emisiones pueden ser controladas incorporando equipos tales como condensadores refrigerados, reduciendo las emisiones fugitivas del equipo, y minimizando la evaporación de los contenedores para el almacenamiento de solventes.

CONTAMINANTES: GOT

GOR: Como se mencionó anteriormente, el percloroetileno, 1,1,1-tricloroetileno y CFC-113 no son considerados fotoquímicamente reactivos, y no deben ser incluidos en un inventario de precursores de ozono. Sólo los procesos de lavado en seco que usan solventes derivados de petróleo tendrán emisiones GOR. Por lo tanto, las emisiones GOR constituyen 100% del GOT para los solventes de petróleo, y 0% del GOT para los solventes sintéticos. Si sólo se conoce la cantidad total de solventes para el lavado en seco, puede asumirse que las emisiones GOR constituyen 58% del GOT (U.S. EPA, 1991a).

AJUSTES DE FUENTES PUNTUALES:

Los establecimientos industriales de lavado en seco pueden ser inventariados como fuentes puntuales. Por lo tanto, el procedimiento para el cálculo de las fuentes de área debe ser ajustado para evitar la duplicación con los estimados de fuentes puntuales. Si se utilizan factores de emisión por empleado, el empleo en los establecimientos de las fuentes puntuales debe ser restado del empleo total en el área de inventario. Si los datos de empleo no están disponibles, entonces las emisiones puntuales pueden ser restadas de las emisiones totales

METODOLOGIA:

Las emisiones de esta fuente pueden ser calculadas utilizando uno de los dos siguientes factores de emisión. Los factores para las emisiones de solventes halogenados y derivados de petróleo se presentan en el inciso **DATOS NECESARIOS** de esta sección.

Método 1: El primer método utiliza factores de emisión por empleado (basados en los promedios nacionales de EU). Estos factores de emisión tienen una aplicación limitada en México, y deben ser utilizados solamente si no existen otros datos específicos disponibles. Las emisiones y reactividad de las emisiones de GOT varían por tipo de solvente utilizado en los diferentes tipos (tamaños) de establecimientos de lavado en seco (industrial, comercial o pequeño).

El uso de factores de emisión por empleado requiere la recopilación de datos sobre el número de personas empleadas en los establecimientos de lavado en seco que utilizan solventes halogenados (percloroetileno, tricloroetano o CFC-113) o solventes derivados de petróleo. Debido a que se asume que los pequeños establecimientos sólo utilizan solventes halogenados, sus empleados deben ser excluidos del empleo total si se está elaborando un inventario de GOR.

Una vez que los datos de empleo para los establecimientos de lavado en seco han sido recopilados, el empleo en los establecimientos de fuentes puntuales se resta del número de empleados total. La diferencia resultante representa el empleo en fuentes de área. Posteriormente, las emisiones se calculan como:

$$\text{Emisiones Anuales} = \left(\begin{array}{c} \text{Empleo en el lavado en} \\ \text{seco en la fuente de área} \end{array} \right) \times \left(\begin{array}{c} \text{Factor de} \\ \text{Emisión} \end{array} \right)$$

(6.6-1)

Método 2: El segundo factor de emisión se basa en la población, calculada a partir de un promedio nacional de uso de solventes en EU (U.S. EPA, 1991a). Estos factores de emisión per cápita estadounidenses tienen una aplicación limitada en México y deben ser utilizados solamente si no se dispone de otros datos.

El cálculo utilizando el factor de emisión per cápita es:

$$\text{Emisiones Anuales} = (\text{Población}) \times (\text{Factor de Emisión})$$

(6.6-2)

Si cualesquier operaciones de lavado en seco son incluidas en el inventario de fuentes puntuales, sus emisiones deben ser eliminadas de este estimado para arrojar un estimado de emisiones de las fuentes de área.

DATOS NECESARIOS:

Datos		Fuente
Método por Empleado:		
Empleo en los Establecimientos de Lavado en Seco		Base de datos SNIFF, CANALAVA[a], INEGI
Factor de emisión GOT		U.S. EPA, 1991a
Lavado en Seco (total)	1,043 kg/empleado/año (2,300 lb/empleado/año)	
Solventes Halogenados	445 kg/empleado/año (980 lb/empleado/año)	

Datos	Fuentes
Establecimientos Pequeños 24 kg/empleado/año (52 lb/empleado/año)	
Establecimientos Comerciales e Industriales 544 kg/empleado/año (1,200 lb/empleado/año)	
Factor de emisión GOR	
Solventes Derivados de Petróleo 816 kg/empleado/año (1,800 lb/empleado/año)	
Método del Factor de Emisión Per Cápita:	
Población	INEGI
Factor de Emisión GOT	U.S. EPA, 1991a
Lavado en Seco (total) 0.86 kg/persona/año (1.9 lb/persona/año)	
Solventes Halogenados 0.37 kg/persona/año (0.81 lb/persona/año)	
Establecimientos Pequeños 0.005 kg/persona/año (0.01 lb/persona/año)	
Establecimientos Comerciales e Industriales 0.36 kg/persona/año (0.80 lb/persona/año)	
Factor de Emisión GOR	U.S. EPA, 1991a
Solventes Derivados de Petróleo 0.50 kg/persona/año (1.1 lb/persona/año)	

[a] Es probable que la información de la CANALAVA esté disponible sólo para los miembros de la Cámara.

NOTAS:

1. Los factores per cápita y por empleado que aquí se presentan se basan en los promedios nacionales estadounidenses de uso de solventes, no en datos específicos de México. Deben elaborarse estimados de emisión más precisos utilizando factores de emisión desarrollados a partir de datos específicos para la industria del lavado en seco en México, obtenidos en la CANALAVA.

2. Los ajustes a los factores de emisión tanto per cápita como por empleado pueden ser necesarios para reflejar las variaciones locales y, con el tiempo, para reflejar los cambios en el uso y composición de los solventes.

3. Los estimados de emisión calculados utilizando los factores por empleados requerirán ser correctamente asociados con el SNIFF para permitir la relación con el inventario de fuentes puntuales.

4. Una alternativa para los factores de emisión presentados anteriormente, consiste en encuestar a un número representativo de operaciones de recubrimiento de superficies. Los resultados de dicha encuesta podrían ser extrapolados al área total del inventario. Ver **NOTAS** de la sección Recubrimiento de Superficies en la Industria (Sección 6.1) para una breve descripción del procedimiento de encuesta. Los procedimientos de encuesta también se presentan en el Manual de *Técnicas Básicas de Estimación de Emisiones*.

EJEMPLO DE CALCULO:

Los cálculos necesarios para ambos métodos son similares; sin embargo, en el primer método, la resta del empleo de fuentes puntuales del empleo total resultará en una estimación más precisa. Por ejemplo,

- El empleo total en las plantas de lavado en seco que utilizan solventes halogenados dentro del área del inventario es de 990

- El empleo de fuentes puntuales en los Establecimientos A, B y C tiene un total de 170.

Entonces:

Empleo en Fuente de Area = 990 - 170
= 820 empleados en establecimientos de lavado en seco que usan solventes halogenados

Las emisiones son calculadas como:

Emisiones GOT de Fuente de Area = (820 empleados) x (445 kg/empleado/año)
= 364,900 kg/año
= 364.9 Mg Mg/año

Si se utiliza el segundo método, las emisiones anuales totales de GOT de los establecimientos que usan solventes halogenados en un estado con una población de 1,250,000 son:

(1,250,000 personas) x (0.37 kg/persona/año) = 462,500 kg/año
= 462.5 Mg/año

Si existen grandes establecimientos que utilicen solventes halogenados para la limpieza en seco en el área de inventario, y que hayan sido inventariados como fuentes puntuales, entonces las emisiones calculadas para dichos establecimientos deben ser restadas del total calculado anteriormente. Por ejemplo, si las emisiones de fuentes puntuales son:

- 32 Mg por año para el Establecimiento A
- 11.2 Mg por año para el Establecimiento B
- 23 Mg por año para el Establecimiento C.

Entonces:

Emisiones de Fuente de Area = 462.5 Mg - (32 Mg + 11.2 Mg + 23 Mg)
= 396.3 Mg/año

6.7 Artes Gráficas

CODIGO DE FUENTE	DESCRIPCION
24-25-000-xxx	Todos los Procesos
24-25-010-xxx	Litografía
24-25-020-xxx	Tipografía
24-25-030-xxx	Rotograbado
24-25-040-xxx	Flexografía

DESCRIPCION:

Las artes gráficas incluyen las operaciones que están relacionadas con la impresión de periódicos, revistas, libros y otros materiales impresos. La impresión puede ser realizada sobre diversos sustratos (e. g., papel con y sin estuco, metal o tela). La diferencia de la impresión sobre papel estucado es que ésta siempre involucra la aplicación de tinta con una prensa de impresión. Las cuatro operaciones básicas utilizadas en las artes gráficas en EU son la litografía con rotativa, el rotograbado, la tipografía con rotativa y la flexografía. La impresión con retícula y las técnicas manuales o de alimentación de hojas son menos comunes. La litografía se caracteriza por un transportador planográfico de la imagen (i. e., las áreas de imagen y de no imagen están en el mismo plano). En la impresión por grabado, el área de imagen es grabada (i. e., “intaglio”) con respecto a la superficie del transportador de imagen. En la tipografía, el área de la imagen es levantada y la tinta es transferida al sustrato directamente a partir de la superficie de la imagen. La flexografía también usa un área de imagen sobre la superficie de la placa, pero utiliza un transportador de goma, mientras que la tipografía lo utiliza de metal o plástico.

La composición de las tintas de impresión es sumamente variable, pero todas constan de tres componentes principales: pigmentos, aglutinantes y solventes. La mayoría de los solventes utilizados en las operaciones de artes gráficas se consumen en las formulaciones de tintas de impresión, y cantidades menores son utilizadas para la limpieza del equipo o como componentes en la soluciones de fuente para sumergir los sistemas en la impresión litográfica. Los solventes se evaporan de las tintas hacia la atmósfera durante el proceso de secado. Si bien los solventes residuales pueden permanecer en el producto impreso después de que la tinta se ha secado, y que algunas de las tintas no serán utilizadas y serán dispuestas como aguas residuales en el establecimiento o en un relleno sanitario, la mayoría de los esfuerzos de inventario asumen, de manera conservadora, que todos los solventes de las tintas se evaporan en el aire.

Las emisiones de las operaciones de artes gráficas pueden ser reducidas utilizando tintas con base de agua, procesos de aplicación más eficientes que requieran menos tinta, filtros, sistemas de condensación y post-quemadores.

CONTAMINANTES: GOT

GOR: Las emisiones GOR constituyen 100% del GOT.

AJUSTES DE FUENTES PUNTUALES:

Las operaciones de artes gráficas se pueden presentar en grandes establecimientos que pudieron ser inventariados como fuentes puntuales. Por lo tanto, el procedimiento de cálculo de emisiones de fuentes de área debe ser ajustado para evitar la duplicación con los estimados de las fuentes puntuales.

METODOLOGIA:

El cálculo utilizando el factor de emisión per cápita es:

$$\text{Emisiones Anuales de GOT} = (\text{Población}) \times (\text{Factor de Emisión}) \qquad (6.7\text{-}1)$$

Si cualesquier grandes establecimientos de artes gráficas son incluidos en el inventario de fuentes puntuales, sus emisiones deben ser eliminadas de este estimado para arrojar un estimado de emisión de las fuentes de área.

Nótese que este factor de emisión per cápita estadounidense tiene una aplicación limitada en México, y que debe ser utilizado solamente si se carece de otros datos.

DATOS NECESARIOS:

Datos	Fuentes
Método del Factor de Emisión Per Cápita:	
Población	INEGI
Factor de Emisión GOT (para todos los tipos de operaciones de artes gráficas) 0.59 kg/persona/año (1.3 lb/persona/año)	U.S. EPA, 1991a

NOTAS:

1. La quinta edición del AP-42 (AP-42, 1995) presenta un factor de emisión per cápita de 0.4 kg compuestos orgánicos volátiles no de metano (COVs)/ persona/año. Sin embargo, este factor de emisión se basa en datos de 1981; por lo tanto, la guía de la EPA de 1991 se considera más actualizada.

2. Es posible que en el corto plazo se desarrolle un factor de emisión per cápita para las artes gráficas específico para México, basado en la información sobre ventas de productos disponible en la ANAFAPYT y los estimados de población, como se resume a continuación:

   FE Per Cápita = (uso anual total de tintas, litros) (factor de ajuste de crecimiento del DDF a partir de los datos del año al año de inventario) x (porcentaje de solvente de tinta) x (densidad promedio de la tinta, g/litro)/población (6.7-2)

   El DDF ya ha desarrollado factores de emisión per cápita específicos para México, para diversas categorías de recubrimiento de superficies utilizando este enfoque (DDF, 1995b).

3. Los ajustes a los factores emisión per cápita pueden ser necesarios para reflejar las condiciones locales y con el tiempo, para reflejar los cambios en el uso y composición de la tinta.

4. Una alternativa para el uso de los factores de emisión presentados anteriormente es encuestar a un número representativo de operaciones de artes gráficas. Los resultados de esta encuesta deben ser extrapolados a toda el área del inventario. Ver el inciso **NOTAS** de la sección Recubrimiento Industrial de Superficies (Sección 6.1) para una breve descripción del procedimiento de encuesta. Los procedimientos de encuesta también se presentan en el Manual de *Técnicas Básicas de Estimación de Emisiones*.

EJEMPLO DE CALCULO:

Por ejemplo, las emisiones anuales totales de GOT de las artes gráficas en un estado con una población de 1,250,000 son:

(1,250,000 personas) x (0.59 kg/persona/año) = 737,500 kg/año
= 737.5 Mg/año

Si existen grandes establecimientos de artes gráficas en el área de inventario que hayan sido inventariados como fuentes puntuales, entonces las emisiones calculadas para dichos establecimientos deben ser restadas del total calculado anteriormente. Por ejemplo, si las emisiones de fuentes puntuales son

- 12 Mg/año para el Establecimiento A
- 15 Mg/año para el Establecimiento B

Entonces:

Emisiones de Fuente de Area = (Emisiones Totales) - (Emisiones Puntuales)
= 737.5 - (12 + 15)
= 710.5 Mg/año

6.8 Aplicación de Asfalto

CODIGO DE FUENTE	DESCRIPCION
24-61-021-000	Asfaltos Diluidos
24-25-022-000	Asfaltos Emulsificados

DESCRIPCION:

Las superficies y pavimentos de asfalto están compuestos por un agregado compactado y un adhesivo de asfalto. El agregado transmite la carga desde la superficie hacia la base, absorbe el desgaste abrasivo del tráfico y proporciona una superficie antiderrapante. El adhesivo mantiene al agregado unido y evita los movimientos o pérdida de éste. Esta categoría de fuente maneja las emisiones de hidrocarburos de la evaporación de estos adhesivos.

Los aglomerantes de asfalto pueden ser cementos asfálticos o asfaltos licuados. Los primeros son el residuo de los procesos de destilación. Por otro lado, existen dos tipos de asfaltos licuados: los diluidos y los emulsificados. Los asfaltos diluidos son cementos asfálticos adelgazados o “diluidos” con destilados volátiles de petróleo, y en general están clasificados como de cura rápida, media y lenta. La caracterización del asfalto se basa en el solvente que es utilizado como diluyente, y el tiempo necesario para su curado (i .e, la gasolina o nafta son utilizadas como diluyentes para un curado rápido, mientras que el queroseno y otros aceites combustibles de baja volatilidad son utilizados para un curado medio y lento. Los asfaltos emulsificados usan una mezcla de agua y emulsificante (i. e., jabón), en lugar de un solvente diluyente, y su curado depende de la evaporación del agua o del enlace iónico.

Las emisiones GOT provienen de la evaporación del solvente destilado de petróleo que se utiliza para licuar el cemento asfáltico. El tipo y cantidad de diluyente usado son las dos variables principales que afectan las emisiones COVs totales y el tiempo en el que se presentan. Las emisiones en el largo plazo pueden ser estimadas asumiendo que el 95% en peso del diluyente se evapora a partir de un curado rápida; el 70% en un curado medio y el 25% en uno lento (U.S. EPA, 1995a). Al parecer, una parte del diluyente queda retenido de manera permanente en la superficie de camino después de la aplicación.

CONTAMINANTES: GOT

GOR: Las emisiones GOR constituyen 100% del GOT.

AJUSTES DE FUENTES PUNTUALES:

Las plantas de asfalto pueden ser inventariadas como fuentes puntuales y las emisiones que han sido calculadas para estos establecimientos pueden incluir estimaciones GOT de las emisiones de los diluyentes durante la mezcla o manejo de los materiales. Si este fuera el caso, estas emisiones de diluyentes deben ser restadas de las emisiones totales para estimar las emisiones de fuentes de área.

METODOLOGIA:

Para estimar las emisiones, los datos requeridos incluyen la cantidad total de cada tipo de asfalto aplicado en la región del inventario, y el tipo y cantidad del diluyente usado en cada región. Dado que normalmente la cantidad de diluyente en el asfalto se proporciona en porcentaje por volumen, las ecuaciones para la estimación general de emisiones son:

Densidad del asfalto = (densidad del cemento asfáltico) × (% en vol. cemento asfáltico) + (densidad del diluyente asfáltico) × (% en vol. diluyente asfáltico) (6.8-1)

Volumen de asfalto aplicado = (masa del asfalto aplicado) / (densidad del asfalto) (6.8-2)

Volumen total del diluyente = (volumen de asfalto aplicado) × (% en vol. diluyente) (6.8-3)

Masa total del diluyente = (volumen total de diluyente) × (densidad del diluyente) (6.8-4)

Emisiones GOT totales = (Masa total del diluyente) × (% de diluyente evaporado con base en el tipo de curado) (6.8-5)

Si la cantidad de diluyente en el asfalto es proporcionada en porcentaje por peso, entonces las ecuaciones para la estimación de emisiones son simplemente:

Masa total del diluyente = (masa del asfalto aplicado) × (densidad del diluyente como %en peso) (6.8-6)

Emisiones GOT totales = (Masa total del diluyente) × (%diluyente evaporado según tipo de curado) (6.8-7)

DATOS NECESARIOS:

DATOS	FUENTES
Cantidad de cada tipo de asfalto aplicado en la región del inventario	Entidad municipal (e. g., *Dirección General de Obras Públicas* en la Ciudad de México)
Propiedades físicas del asfalto (cemento asfáltico y diluyente)	Entidad municipal (e. g., *Dirección General de Obras Públicas* en la Ciudad de México)
Factor de emisión GOT (i. e., % en peso evaporado) 95 % en peso para curado rápido 70 % en peso para curado medio 25 % en peso para curado lento	AP-42

NOTAS:

1. Si las propiedades físicas del asfalto específicas para la región no están disponibles, pueden utilizarse los siguientes valores por omisión:

Propiedad Física	Valor por Omisión	Fuente
% en peso del diluyente en el asfalto	0.34 % en peso (Ciudad de México) 6.2 % en peso (resto del país)	DDF, 1996b
Densidad del diluyente	0.7 kg/litro (nafta, curado rápido) 0.8 kg/litro (curado medio) 0.9 kg/litro (curado lento)	AP-42
Densidad del cemento asfáltico	1.1 kg/litro 1.1 - 1.5 kg/litro	AP-42 CRC, 1985, p. F-1

2. Si la cantidad de asfalto aplicado está disponible solamente para una parte de la región del inventario, estos datos deben ser utilizados para desarrollar un factor de emisión per cápita a ser utilizado en conjunto con los datos de población, para desarrollar estimados de emisión para la otra parte de la región como se muestra en el ejemplo de cálculo.

   El DDF ha utilizado este enfoque para desarrollar estimados de emisión para la aplicación de asfalto en la Zona Metropolitana de la Ciudad de México (ZMCM)(DDF, 1996b).

EJEMPLO DE CALCULO:

Los registros locales muestran que 10,000 kg de asfalto diluido de cura rápida han sido aplicados en un área determinada durante el año. Se ha reportado que este asfalto contiene 45% en volumen de nafta. Asumiendo que la densidad de la nafta es de 0.7 kg/litro, y que la del cemento asfáltico es de 1.1 kg/litro, calcular las emisiones DE GOT anuales.

1. Densidad del asfalto = (densidad del cemento asfáltico) × (% en vol. del cemento asfáltico) + (densidad del diluyente asfáltico) × (% en vol. diluyente asfáltico)
= (1.1 kg/litro) x ((% en vol) + (0.7 kg/litro) x (45 % en vol.)
= 0.92 kg/litro

2. Volumen de asfalto aplicado = (masa de asfalto aplicado) / (densidad del asfalto)
= (10,000 kg) / (0.92 kg/litro)
= 10,870 litros

3. Volumen total del diluyente = (volumen de asfalto aplicado) × (% en vol. del diluyente)
= (10,870 litros) × (45 % en vol.)
= 4,891 litros

4. Masa total del diluyente = (volumen total del diluyente) x (densidad del diluyente)
= (4,891 litro) × (0.7 kg/litro)
= 3,424 kg

5. Emisiones GOT totales = (masa total del diluyente) × (% del diluyente evaporado con base en el tipo de curado)
= (3,424 kg) × (95% de evaporación para cura rápida)
= 3,253 kg GOT/año

Si existen grandes plantas de asfalto en la región de inventario que hayan sido inventariadas como fuentes puntuales, entonces las emisiones de diluyentes reportadas por dichos establecimientos deben ser restadas del total calculado anteriormente. Por ejemplo, si las emisiones de fuentes puntuales son:

- 500 kg GOT/año por el Establecimiento A (400 kg del diluyente, 100 kg de la combustión)

- 300 kg GOT/año por el Establecimiento B (250 kg del diluyente, 50 kg de la combustión)

Entonces:

Emisiones de Fuentes de Area = (Emisiones Totales) - (Emisiones Puntuales)
= 3,253 - (400 + 250)
= 2,603 kg GOT/año

6.9 Uso Comercial y Doméstico de Solventes

CODIGO DE FUENTE	DESCRIPCION
Doméstico	
24-65-000-000	Todos los Productos de Consumo
24-65-100-000	Productos de Cuidado Personal
24-65-200-000	Productos Domésticos
24-65-300-000	Productos en Aerosol
24-65-400-000	Productos de Cuidado Automotriz
24-65-600-000	Adhesivos y Selladores
24-65-800-000	Pesticidas Domésticos
24-65-900-000	Productos Misceláneos
Comercial	
24-61-000-000	Productos Comerciales Totales
24-61-600-000	Adhesivos y Selladores
24-61-800-000	Pesticidas Comerciales

DESCRIPCION:

Los hidrocarburos son ingredientes de los productos comerciales y de consumo que sirven como propulsores, agentes para el secado (a través de la evaporación), co-solventes y agentes limpiadores, y son emitidos durante el uso del producto. Típicamente estas fuentes de hidrocarburos son muy numerosas, altamente dispersas y a nivel individual emiten cantidades relativamente pequeñas de GOT. Los productos comerciales y de consumo que emiten GOT incluyen aerosoles, productos domésticos, productos de cuidado personal, de cuidado automotriz, adhesivos y selladores, así como pesticidas comerciales y domésticos.

Los solventes contenidos en los productos comerciales y de consumo son emitidos principalmente durante el uso del producto. Cantidades residuales de solvente pueden permanecer en el empaque desechado del producto, ingresar en la corriente municipal de residuos sólidos, y ser dispuestos en rellenos sanitarios, Los solventes de estos productos también pueden ingresar en el sistema de tratamiento de aguas residuales a través del uso y la disposición. La mayoría de los esfuerzos de inventario asumen que todo el GOT en los productos de consumo y comerciales se volatiliza al aire.

Los componentes típicos del GOT que son emitidos a la atmósfera a partir de esta categoría de fuente incluye a las naftas especiales, alcoholes y diversos cloro y fluorocarbonos. Aproximadamente 31% del GOT emitido por estos productos es considerado no fotoquímicamente reactivo (AP-42, 1995).

CONTAMINANTES: GOT

GOR: Se estima que las emisiones GOR constituyen 69% del GOT.

AJUSTES DE FUENTES PUNTUALES: Ninguno.

METODOLOGIA:

$$\text{Emisiones Anuales de GOT} = (\text{Población}) \times (\text{Factor de Emisión}) \tag{6.9-1}$$

DATOS NECESARIOS:

DATOS		FUENTES
Población		INEGI
Factores de Emisión GOR		
Productos en Aerosol	0.046 kg/persona/año	DDF, 1995b
Productos Domésticos	0.36 kg/persona/año	U.S. EPA, 1996a
Productos de Cuidado Personal	1.05 kg/persona/año	U.S. EPA, 1996a
Productos de Cuidado Automotriz	0.61 kg/persona/año	U.S. EPA, 1996a
Adhesivos y Selladores	0.26 kg/persona/año	U.S. EPA, 1996a
Pesticidas Comerciales y Domésticos	0.81 kg/persona/año	
Productos Misceláneos		
GOT TOTALES	0.03 kg/persona/año	U.S. EPA, 1996a
	3.17 kg/persona/año	U.S. EPA, 1996a
Factores de Emision GOT		
Productos en Aerosol	0.067 kg/persona/año	DDF, 1995b
Productos Domésticos	0.52 kg/persona/año	U.S. EPA, 1996a
Productos de Cuidado Personal	1.52 kg/persona/año	U.S. EPA, 1996a
Productos de Cuidado Automotriz	0.88 kg/persona/año	U.S. EPA, 1996a
Adhesivos y Selladores	0.38 kg/persona/año	U.S. EPA, 1996a
Pesticidas Comerciales y Domésticos	1.17 kg/persona/año	
Productos Misceláneos		
GOT TOTALES	0.04 kg/persona/año	U.S. EPA, 1996a
	4.58 kg/persona/año	U.S. EPA, 1996a

NOTAS:

1. Los Factores de emisión GOT han sido desarrollados a partir de los factores de emisión GOT de referencia, y se estima que las emisiones GOR constituyen el 69% de los GOT.

2. El factor de emisión mostrado para los productos en aerosol fue desarrollado por el DDF (1995b) con base en la información sobre contenido de solventes y ventas de productos (para 1993), proporcionada por la ANAFAPYT.

3. Los ajustes este factor de emisión per cápita podrían ser necesarios con el tiempo, debido a que la sustitución de los compuestos contenidos en los productos comerciales y de consumo puede alterar la fracción no reactiva.

EJEMPLO DE CALCULO:

Por ejemplo, las emisiones totales anuales de GOT de uso comercial y doméstico de solventes en el estado de Colima (población 428,510) son:

(428,510 personas) x (4.58 kg/persona/año) = 1,962.576 kg/año
= 1,963 Mg/año.

7.0 ALMACENAMIENTO Y TRANSPORTE DE DERIVADOS DE PETROLEO

Por lo general, los diversos puntos de emisión asociados con el almacenamiento y transporte de productos de petróleo se consideran demasiado numerosos para ser incluidos en el inventario de fuentes puntuales en una región de inventario determinada. Por lo tanto estas pequeñas fuentes de evaporación necesitan ser incluidas en un inventario de fuentes de área. La guía para hacer el inventario de estas fuentes se presenta en las siguientes subsecciones:

- Distribución de gasolina (incluye a las pipas de gasolina en tránsito, la descarga de pipas [Etapa 1], la respiración de los tanques subterráneos, la carga de los vehículos [Etapa II] y derrames durante la carga);
- Carga de combustible en aeronaves y
- Distribución de Gas Licuado de Petróleo (gas LP).

7.1 Distribución de Gasolina

CODIGO DE FUENTE	**DESCRIPCION**
25-01-060-000	Estaciones de Servicio: Todos los Procesos
25-01-060-050	Etapa I: Total
25-01-060-051	Etapa I: Llenado Sumergido
25-01-060-052	Etapa I: Llenado por barboteo
25-01-060-053	Etapa I: Llenado Sumergido Balanceado
25-01-060-100	Etapa II: Total
25-01-060-101	Etapa II: Pérdidas por Desplazamiento/No Controladas
25-01-060-102	Etapa II: Pérdidas por Desplazamiento/Controladas
25-01-060-103	Etapa II: Derrames
25-05-030-120	Transporte en Camiones: Gasolina
25-01-060-200	Tanque Subterráneo: Total
25-01-060-201	Tanque Subterráneo: Respiración y Vaciado

DESCRIPCIÓN:

En la industria de la distribución de gasolina ésta es transportado en pipas desde las refinerías hasta las plantas y terminales a granel y finalmente a las estaciones de servicio. Los procedimientos que se discuten a continuación se refieren directamente a las emisiones que ocurren durante el transporte y distribución de gasolina desde las plantas y terminales de almacenamiento de cuentas comerciales hasta las estaciones de servicio.

Las emisiones evaporativas se presentan en todos los puntos del proceso de distribución de gasolina. Las operaciones que generalmente se consideran como fuentes de área son las estaciones expendedoras de gasolina (estaciones de servicio o gasolinerías) y las pipas de gasolina en tránsito. Las plantas y terminales de almacenamiento que son los puntos intermedios de distribución entre las refinerías y los expendedores deben inventariarse como fuentes puntuales.

Todas las fuentes de área de GOT provenientes del transporte y distribución de gasolina incluyen los siguientes tipos de emisiones:

- Pérdidas por respiración:
    - Evaporación de la gasolina de las pipas durante su transporte desde la planta o terminal de almacenamiento hasta la estación de servicio u otro expendio;
    - Evaporación de la gasolina de la pipa vacía durante el viaje de regreso desde la estación de servicio dentro de un área de inventario hasta la planta o terminal de almacenamiento y
    - Evaporación de la gasolina desde el tanque o tanques de almacenamiento subterráneos o de las líneas que van hacia las bombas despachadoras cuando están paradas y fuera de uso.
- Pérdidas durante la operación
    - Evaporación de la gasolina durante la transferencia de la pipa al tanque subterráneo de almacenamiento en la estación de servicio (a menudo referida como “Etapa I”);
    - Evaporación de la gasolina durante la transferencia de la bomba a los vehículos (a menudo referida como “Etapa II”);
    - Derrames de gasolina (y su subsecuente evaporación) durante cualquiera de las actividades anteriores. Estas pérdidas están constituídas por los goteos de la boquilla antes y después del llenado y por el rebosamiento del tubo de llenado del tanque de gasolina del vehículo durante el llenado y
    - Evaporación de la gasolina del tanque subterráneo de almacenamiento o de las líneas que van hacia las bombas durante la transferencia de la gasolina.

CONTAMINANTES: GOT

GOR: En la gasolina la fracción de las emisiones totales que son metano o etano es despreciable. Por lo tanto, se estima que las emisiones de GOR constituyen el 100% de los GOT. Para los combustibles diesel, el metano y el etano constituyen el 15% de las emisiones evaporativas totales de GOT por lo que se estima que las emisiones de GOR constituyen el 85% de los GOT.

AJUSTES POR FUENTES PUNTUALES:

Las actividades de distribución de gasolina pueden presentarse en plantas grandes que se hayan inventariado como fuentes puntuales. Las emisiones que se han calculado para las plantas consideradas fuentes puntuales deben ser restadas de las emisiones totales para estimar las emisiones de fuentes de área.

METODOLOGIA:

El enfoque más exacto para estimar las emisiones de fuentes de área de la distribución de gasolina consiste en obtener los datos del consumo del gasolina que luego se multiplica por varios factores de emisión para determinar las pérdidas evaporativas. PEMEX recopila y mantiene las estadísticas sobre distribución y consumo de gasolina.

El flujo de gasolina en el área de inventario debe ser seguido hasta el consumo del combustible. El mejor enfoque consiste en hacer una gráfica que muestre el flujo global de gasolina dentro del área del inventario, desde el punto de entrada, a través del almacenamiento a granel hasta las operaciones en las estaciones de servicios y en la carga de los vehículos. La construcción de este diagrama de flujo de una vista global valiosa del sistema de distribución de gasolina y facilita la detección de anomalías grandes en los datos de distribución. Debe tenerse cuidado de contabilizar toda la gasolina que se consume en el área del inventario incluyendo la que se expende en marinas, aeropuertos, bases militares y sitios comunes del gobierno para vehículos motorizados.

Descarga de las Pipas

Las emisiones de la descarga de las pipas se ven afectadas por el hecho de que el tanque de la estación de servicio esté equipado para llenado sumergido, por barboteo o por balance. Por lo tanto se debe obtener información acerca de la fracción de estaciones que usa cada método de llenado. Por medio de una encuesta de varias estaciones de servicio en el área se puede hacer una estimación del número de estaciones que emplean cada método de llenado. PEMEX es otra fuente de información sobre las características de las estaciones.

Las pérdidas en la descarga de pipas ocurren cuando los vapores de hidrocarburos en los tanques “vacíos” son desplazados hacia la atmósfera por el líquido que se les está cargando. Estos vapores están compuestos de: (1) vapores formados en el tanque vacío por la evaporación del producto residual de cargas anteriores; (2) vapores transferidos al tanque en los sistemas de balance de vapor a medida que el producto se está descargando y (3) vapores generados en el tanque a medida que se carga el nuevo producto.

En el método de carga por barboteo se baja sólo una parte de la manguera de llenado para servir la gasolina dentro del tanque de carga. Durante la operación de carga por barboteo hay importante turbulencia y contacto entre el vapor y el líquido lo que resulta en altos niveles de generación y pérdida de vapor. Si la turbulencia es suficientemente grande, algunas gotitas de líquido serán arrastradas en los vapores venteados.

Un segundo método de carga es el de carga sumergida. De éste hay dos tipos: el método de manguera de llenado sumergida y el método de cargado por el fondo. En el primero, la manguera de llenado se extiende casi hasta el fondo del tanque. En el segundo, se une una manguera permanente de llenado al fondo del tanque. Durante la mayor parte de las cargas sumergidas por ambos métodos la apertura de la manguera queda debajo del nivel de la superficie del líquido. La turbulencia del líquido se controla en gran medida durante la carga sumergida lo que resulta en una generación de vapor mucho menor que la que se encuentra durante la carga por barboteo.

Una medida de control para los vapores desplazados durante la carga de gasolina se conoce como “balance de vapor” o control de vapor en la Etapa I, en la cual los vapores desplazados durante la descarga del producto regresan al compartimiento de carga de la pipa. La eficiencia de control de las unidades recuperadoras varía entre el 90 y el 99%.

Las emisiones de la carga de gasolina (o de cualquier líquido de petróleo) pueden estimarse (con un error probable de ±30%) usando la siguiente expresión:

$$PC = 12.46 \frac{SPM}{T} \tag{7.1-1}$$

donde:

PC = Pérdidas durante la carga, libras por 1,000 galones de líquido cargado;

S = Factor de saturación (ver Tabla 7.1-1). El factor de saturación, S, representa el enfoque en fracción del vapor expelido hasta la saturación y explica las variaciones observadas en las tasas de emisión de los diferentes métodos de carga y descarga;

P = Presión de vapor verdadera del líquido cargado, libras por pulgada cuadrada absoluta (psia) (ver Tabla 7.1-2);
M = Peso molecular de los vapores, (lb/lb-mol) (ver Tabla 7.1-2) y
T = Temperatura de la masa del líquido cargado, °R (°F + 460).

Para estimar las emisiones, se aplica el factor de emisión para la descarga de pipas al combustible total distribuido como se indica en la siguiente ecuación:

$$E_{dp} = FE_{dp} \text{ x } C \tag{7.1-2}$$

donde:
E_{dp} = Emisiones totales de la descarga de pipas (kg/año)
FE_{dp} = Factor de emisión para las pipas durante la carga de combustible (kg/litro)
C = Combustible distribuido (litros/año).

DATOS NECESARIOS:

Datos	Fuentes
Consumo de combustible distribuido	PEMEX
Factores de emisión de GOT[a] Calculados usando la Ecuación 7.1-1 ó Llenado sumergido: 880 mg/litro de combustible Llenado por barboteo: 1,380 mg/litro de combustible Llenado sumergido balanceado: 40 mg/litro de combustible	AP-42, 1995

[a] Los factores son tanto para GOT como para GOR debido a que el contenido de metano y etano en los vapores de gasolina es despreciable.

EJEMPLO DE CÁLCULO - DESCARGA DE LAS PIPAS:

Suponer que en la región del inventario se descargan 100,000 m^3 de gasolina (RVP = 10 psia) en las estaciones de servicio durante un año dado. Suponer que todos los tanques de las estaciones de servicio están equipados para un llenado sumergido y que las pipas se operan como servicio exclusivo normal. Finalmente, suponer que la temperatura promedio de carga es de 21°C.

1. Determinar el factor de saturación S.

   Usar la Tabla 7.1-1 para el servicio normal exclusivo de carga sumergida, S = 0.6.

2. Determinar la presión de vapor verdadera y el peso molecular del vapor.

   Usar la Tabla 7.1-2. Para una RVP = 10 psia, el valor por omisión para el peso molecular del vapor es de 66 lb/lb-mol.

   La temperatura promedio de carga es de 21°C ó 70°F. Por lo tanto, el valor por omisión para la presión de vapor verdadera es de 6.2 psia.

3. Determinar el factor de emisión usando la ecuación 7.1-1:

4. Determinar las emisiones de GOT de estas operaciones de descarga de pipas usando la ecuación 7.1-2:

$$E_{dp} = FE_{dp} \times C$$

$$E_{dp} = (0.69\ \text{kg/m}^3) \times (100{,}000\ \text{m}^3)$$
$$= 69{,}000\ \text{kg de GOT} = 69\ \text{Mg de GOT}$$

Pérdidas por Respiración de Tanques Subterráneos

Una segunda fuente de emisiones de vapor en las estaciones de servicio está en la respiración de los tanques subterráneos. Las pérdidas por respiración ocurren a diario y se atribuyen a la evaporación de la gasolina y a los cambios en la presión barométrica. La frecuencia con la que se retira gasolina del tanque, permitiendo la entrada de aire fresco que aumenta la evaporación, también tiene un efecto importante en estas emisiones. Una tasa promedio de emisiones por respiración es de 120 mg/litro de producto.

Para estimar las emisiones se aplica el factor de emisión para la respiración del tanque al combustible total distribuido como se indica en la siguiente ecuación:

$$E_r = FE_r \times C \tag{7.1-3}$$

donde:

E_r = Emisiones totales por respiración del tanque subterráneo (mg/año);
FE_r = Factor de emisión para la respiración del tanque (mg/litro) y
C = Combustible distribuido (litro/año).

DATOS NECESARIOS:

Datos	Fuentes
Combustible Distribuido	PEMEX
Factor de Emisión de GOT[a] 120 mg/litro de combustible distribuido	AP-42, 1995

[a] El factor es tanto para GOT como para GOR debido a que el contenido de metano y etano en los vapores de gasolina es despreciable.

EJEMPLO DE CÁLCULO - RESPIRACIÓN DEL TANQUE SUBTERRANEO:

Al igual que en el ejemplo de cálculo anterior suponer que se distribuyen 100,000 m^3 de gasolina en las estaciones de servicios en la región del inventario durante un año dado. Usar la ecuación 7.1-3 para determinar las emisiones de GOT de la respiración del tanque subterráneo:

E_r = $FE_r \times C$
FE_r = $(120 \text{ mg/litro}) \times (1 \text{ kg}/10^6 \text{ mg}) \times (1{,}000 \text{ litros/m}^3)$ = 0.120 kg/m^3
E_r = $(0.120 \text{ kg/m}^3) \times (100{,}000 \text{ m}^3)$
= 12,000 kg de GOT
= 12 Mg de GOT

Pipas de Gasolina en Tránsito

Las pérdidas de respiración de las pipas durante el transporte de gasolina son ocasionadas por camiones de reparto con fugas, presión en los tanques y efectos térmicos sobre el vapor y sobre el líquido. Una causa aún más grave proviene de que un tanque con mal sellado se haya cargado con gasolina y el aire puro se vuelve saturado. Durante el proceso de vaporización la presión aumenta y ocurre el venteo.

Debido a que una parte de la gasolina se entrega en las plantas de almacenamiento a granel en vez de que se entregue directamente a las estaciones de servicio desde las plantas, la cantidad de gasolina transferida en cualquier área puede exceder al consumo total de gasolina debido a los viajes adicionales que se incluyen. Por lo tanto, las emisiones en tránsito no sólo incluyen el consumo final sino también el transporte de gasolina desde fuera del área de inventario hacia las plantas intermedias de almacenamiento y deben estar basadas en la gasolina total transferida más que en el consumo. Por ejemplo, si las ventas de gasolina en un área son de 300 millones de litros anuales y 50 millones de litros de éstos van a las plantas de almacenamiento, la cantidad transportada por las pipas es de 350 millones de litros. Esta es la cifra apropiada que se debe usar para estimar las pérdidas en tránsito. En EU se aplica una suposición por omisión de 25% si no se pueden obtener datos específicos del lugar. En otras palabras, la distribución de gasolina en un área podría multiplicarse por 1.25 para estimar su transporte (AP-42, 1991a). Este valor por omisión de los EU es de aplicación limitada en México y sólo se debe usar cuando no hay otros datos disponibles.

Para estimar las emisiones el factor de emisión para pipas en tránsito se aplica al combustible total transferido como se indica en la siguiente ecuación:

$$E_{pt} = FE_{pt} \times C_t \tag{7.1-4}$$

donde:

E_{pt} = Emisiones totales de las pipas en tránsito (mg/año);
FE_{pt} = Factor de emisión para las pipas en tránsito (mg/litro) y
C_t = Combustible en tránsito en el área del inventario incluyendo a las plantas de almacenamiento (litro/año).

DATOS NECESARIOS:

Datos	Fuentes
Combustible transferido dentro y a través del área del inventario	PEMEX
Factores de Emisión de GOT[a] Pipas cargadas con producto: 0-1 mg/litro transportado Pipas que regresan con vapor: 0-13 mg/litro transportado	AP-42, 1995

[a] Los factores son tanto para GOT como para GOR debido a que el contenido de metano y etano en los vapores de gasolina es despreciable.

NOTAS:

1. El valor por omisión en EU (de 25%) que se usa para la gasolina en tránsito pasando por las plantas de almacenamiento sirve para hacer correcciones por el paso de la gasolina por estas terminales. Se puede hacer un ajuste más exacto usando los datos de las terminales de almacenamiento en el área del inventario.

EJEMPLO DE CALCULO - PIPAS DE GASOLINA EN TRÁNSITO:

Al igual que en los ejemplos de cálculo anteriores suponer que 100,000 m^3 de gasolina son distribuidos en las estaciones de servicios en la región del inventario durante un año dado. Suponer que se desconoce la cantidad entregada a las plantas de almacenamiento.

1. Determinar la cantidad total de gasolina en tránsito.

   Dado que se desconoce la cantidad entregada a las plantas de almacenamiento usar el valor por omisión de EU, de 25%.

$$
\begin{aligned}
C_t &= C_{\text{estación de servicio}} + C_{\text{plantas de almacenamiento}} \\
&= C_{\text{estacion es de servicio}} + 0.25C_{\text{estacion es de servicio}} \\
&= 1.25 \times 100{,}000 \text{ m}^3 \\
&= 125{,}000 \text{ m}^3 \text{ de gasolina}
\end{aligned}
$$

2. Determinar las emisiones de GOT de las pipas de gasolina en tránsito y cargadas con combustible usando la ecuación 7.1-4.

$$E_{pt} = FE_{pt} \times C_t$$

$$
\begin{aligned}
FE_{pt} &= (0.5 \text{ mg/litro}) \times (1 \text{ kg}/10^6 \text{ mg}) \times (1{,}000 \text{ litros/m}^3) \\
&= 0.0005 \text{ kg/m}^3 \\
E_{pt} &= (0.0005 \text{ kg/m}^3) \times (125{,}000 \text{ m}^3) \\
&= 62.5 \text{ kg de GOT}
\end{aligned}
$$

3. Determinar las emisiones de GOT de las pipas de gasolina en tránsito y que regresan con vapor.

$$E_{pt} = FE_{pt} \times C_t$$

FE_{pt} = (6.5 mg/litro) x (1 kg/10^6 mg) x (1,000 litros/m^3)
= 0.0605 kg/m^3
E_{pt} = (0.0065 kg/m^3) x (125,000 m^3)
= 812.5 kg de GOT

Carga de Combustible a Vehículos (Etapa II) y Derrames

Las emisiones producidas al cargar gasolina a los vehículos provienen de los vapores desplazados de sus tanques por la gasolina y de los derrames. La cantidad de vapores desplazados depende de la temperatura de la gasolina y de la temperatura del tanque, de la presión de vapor Reid de la gasolina (RVP) y de la tasa a la que se sirve la gasolina. Se puede usar la ecuación 7.1-5 para estimar las pérdidas no controladas por desplazamiento de los vehículos al cargar gasolina para un conjunto particular de condiciones.

$$FE_{cg} = 264.2 \, [(-5.909) - 0.0949(\Delta T) + 0.0884(T_S) + 0.485(RVP)] \tag{7.1-5}$$

donde:
FE_{cg} = Factor de emisión deGOT para un vehículo al cargar gasolina (mg/litro);
ΔT = Diferencia entre la temperatura del combustible en el tanque del vehículo y la temperatura del combustible que se está cargando, °F;
T_D = Temperatura del combustible que se está cargando, °F y
RVP = Presión de vapor Reid, psia.

Se estima que las emisiones no controladas de los vapores desplazados durante la carga de gasolina a un vehículo promedian 1,320 mg/litro de gasolina cargada (AP-42, 1995). Este valor promedio basado en datos de los EU tiene una aplicación limitada en México y sólo debe usarse cuando no hay otros datos disponibles.

Las pérdidas por derrames están integradas por los goteos de la boquilla antes y después del llenado y por el rebosamiento del tubo de llenado del tanque de gasolina del vehículo durante la carga. La cantidad de pérdidas por derrames puede depender de diversas variables que incluyen las características de la estación de servicio, la configuración del tanque y las técnicas de carga del operador. Una pérdida promedio por derrames es de 80 mg/litro de gasolina cargada (AP-42, 1995). El valor promedio basado en datos de los EU tiene una aplicación limitada en México y sólo debe usarse cuando no hay otros datos disponibles.
Para estimar las emisiones el factor de emisión para la carga de combustible a vehículos se aplica al combustible total servido como se indica en la siguiente ecuación:

$$E_{cd} = FE_{cd} \times C \tag{7.1-6}$$

donde:
E_{cd} = Emisiones asociadas con la carga de combustible de los vehículos y derrames (kg/año)
FE_{cd} = Factores de emisión para la carga de combustible de los vehículos y derrames (mg/litro)
C = Combustible distribuido (litro/año).

DATOS NECESARIOS:

Datos	Fuentes
Combustible Distribuido	PEMEX
Factores de Emisión de GOT[a] Emisiones de Carga de Combustible Ecuación 7.1-5 ó No Controladas: 1320 mg/litro de combustible Controladas: 132 mg/litro de combustible Derrames 80 mg/litro de combustible	AP-42, 1995

[a] Los factores son tanto para GOT como para GOR debido a que el contenido de metano y etano en los vapores de gasolina es despreciable.

EJEMPLO DE CÁLCULO - CARGA DE COMBUSTIBLES EN VEHÍCULOS Y DERRAMES

Suponer nuevamente que se distribuyen 100,000 m^3 de gasolina (RVP = 10 psia) en la región del inventario en un año dado. Suponer que la temperatura de los combustibles distribuidos es de 15°C y que la temperatura del combustible en el tanque del vehículo es de aproximadamente 21°C. Finalmente, suponer que el valor promedio basado en datos de EU para pérdidas por derrame es aplicable.

1. Determinar el factor de emisión de GOT para la carga de combustible en vehículos usando la ecuación 7.1-5.

$$FE_c = 264.2\ [(-5.909\ ) - 0.0949(\Delta T) + 0.0884(T_D\ ) + 0.485(RVP)]$$

$$EF_r = 264.2\ [(-5.909\ ) - 0.0949(70^{o}F - 59^{o}F) + 0.0884(59^{o}\ ) + 0.485(10)]$$

$$= 822 \text{ mg/litro}$$

$$= 0.822 \text{ kg/m}^3$$

2. Determinar el factor de emisión de GOT para derrames.

$FE_d = 80.0$ mg/litro

$= 0.080$ kg/ m^3

3. Determinar las emisiones de GOT para la carga de combustible de vehículos y derrames usando la ecuación 7.1-6.

$E_{cd} = FE_{cd} \times C$

$FE_{cd} = (0.822 \text{ kg/ m}^3) + (0.080 \text{ kg/m}^3)$

$= 0.902 \text{ kg/ m}^3$

$E_{cd} = (0.902 \text{ kg/ m}^3)\ (100{,}000 \text{ m}^3)$

$=$ 90,200 kg de GOT

$=$ 90.2 MG de GOT

Tabla 7.1-1

Factores de Saturación (S) para Calcular las Pérdidas al Cargar Líquidos de Petróleo

Transporte de Carga	Modo de Operación	Factor S
Pipas y vagones cisterna	Carga sumergida: tanque de carga limpio	0.50
	Carga sumergida: servicio exclusivo normal	0.60
	Carga sumergida: servicio exclusivo de balance de vapor	1.00
	Carga por barboteo: tanque de carga limpio	1.45
	Carga por barboteo: servicio exclusivo normal	1.45
	Carga por barboteo: servicio exclusivo de balance de vapor	1.00
Embarcaciones marítimas[a]	Carga sumergida: barcos	0.2
	Carga sumergida: barcazas	0.5

[a] Para productos que no sean gasolina ni petróleo crudo.

Fuente: AP-42, 1995a, Sección 5.2.

Nota: El factor de saturación refleja el grado en que se saturan los vapores venteados con relación a las condiciones de equilibrio. Es decir, S = 1.00 representa vapores venteados en condiciones de equilibrio. Si hay gotitas de líquido arrastradas en los vapores venteados, entonces, S > 1.0.

Tabla 7.1-2

Propiedades (PM_V y P_{VA}) de Derivados de Petróleo Líquidos Selectos

Líquido de Petróleo	**PM_V, Peso Molecular del Vapor a 60°F, (lb/lb-mol)**	**Presión de Vapor Verdadera, P_{VA} (psia)**						
		40°F	**50°F**	**60°F**	**70°F**	**80°F**	**90°F**	**100°F**
Gasolina RVP 13	62	4.7	5.7	6.9	8.3	9.9	11.7	13.8
Gasolina RVP 10	66	3.4	4.2	5.2	6.2	7.4	8.8	10.5
Gasolina RVP 7	68	2.3	2.9	3.5	4.3	5.2	6.2	7.4
Crudo RVP 5	50	1.8	2.3	2.8	3.4	4.0	4.8	5.7
Nafta para Jet (JP-4)	80	0.8	1.0	1.3	1.6	1.9	2.4	2.7
Queroseno para Jet	130	0.0041	0.0060	0.0085	0.011	0.015	0.021	0.029
Combustóleo Destilado No. 2	130	0.0031	0.0045	0.0074	0.0090	0.012	0.016	0.022
Aceite Residual No. 6	190	0.00002	0.00003	0.00004	0.00006	0.00009	0.00013	0.00019

Fuente: AP-42, 1995a, Sección 7.1. Cuando sea posible los valores de estas propiedades para los derivados de petróleo mexicanos deben obtenerse de PEMEX.

7.2 Carga de Combustible en Aeronaves

CODIGO DE FUENTE	**DESCRIPCIÓN**
22-75-900-000	Carga de Combustible: Todos los Combustibles

DESCRIPCIÓN:

El gas avión y la turbosina son los tipos más comunes de combustibles para avión usados en México. Las emisiones ocurren si el aire cargado de vapor en un tanque parcialmente vacío es desplazado hacia la atmósfera cuando se recarga el tanque. La cantidad de vapor desplazado depende de la temperatura y presión de vapor del combustible, de la temperatura del tanque de combustible del avión y de la tasa a la que se carga el combustible.

Es probable que la aviación comercial y la general no contribuyan con suficientes emisiones como para que se les trate como fuentes puntuales. Sus emisiones por carga de combustible muestran variaciones regionales, estacionales y temporales que son determinadas por la concentración del tránsito aéreo en los aeropuertos del área de estudio (que se localizan por lo general cerca de las áreas urbanas), por los horarios diarios de las aerolíneas y por las temporadas de viajes.

CONTAMINANTES: GOT

GOR: Se estima que las emisiones de GOR constituyen el 100% de los GOT dado que se supone que las fracciones de metano y de etano son despreciables.

FUENTES PUNTUALES:

Es posible que algunos aeropuertos grandes que son fuentes puntuales hayan reportado emisiones por carga de combustible. De ser así, las emisiones incluidas en el inventario de fuentes puntuales deben ser restadas de las emisiones totales para estimar las emisiones de área.

METODOLOGIA:

Las emisiones por carga de combustible en aviones pueden estimarse usando los datos de venta por tipo de combustible multiplicados por los factores de emisión del combustible correspondiente. Los datos de consumo de combustible regionales, estatales y nacionales están disponibles en PEMEX y en ASA. Los datos de las ventas locales de combustible también pueden obtenerse con los oficiales de los aeropuertos locales o repartiendo las ventas de combustible a los aeropuertos a nivel regional con base en las actividades de vuelo.

Se pueden calcular los factores de emisión usando la siguiente ecuación (AP-42, 1995):

$$FE_a = 12.46 \times \frac{SP(PM)}{T} \qquad (7.2\text{-}1)$$

$$EF_a = 12.46 \frac{SPM}{T}$$

donde :

FE_a= Factor de emisión en libras de GOT por 1,000 galones de combustible usado;
S = Factor de saturación de 1.45 (Tabla 7.1-1);
P = Presión de vapor verdadera del combustible en psia (Tabla 7.1-2);
PM = Peso molecular de los vapores en lb/lb mol (Tabla 7.1-2) y
T = Temperatura de la masa del líquido cargado °R.

Para estimar las emisiones producidas en la carga de combustible en aviones se aplica el factor de emisión del avión al total de combustible para aviones distribuido como se indica en la siguiente ecuación:

$$E_a = FE_a \times C_a \qquad (7.2\text{-}2)$$

donde:

E_a = Emisiones totales producidas en la carga de combustible en aviones (mg/año);
FE_a = Factor de emisión para la carga de combustible en aviones (mg/litro)
C_a = Combustible para aviones distribuido en las áreas de inventario (litro/año).

DATOS NECESARIOS:

Datos	Fuentes
Combustible para aviones distribuido en el área de inventario	PEMEX, ASA
Factor de Emisión de GOT Ecuación 7.2-1	AP-42, 1995

EJEMPLO DE CALCULO :

Suponer que se utilizan 100,000 m^3 de turbosina para cargar en los aviones en la región del inventario en un año dado. Suponer que las propiedades físicas de la turbosina son similares a las del queroseno para jet en los EU. Finalmente, suponer que la temperatura promedio de carga es de 21°C.

1. Determinar el peso molecular del vapor y la presión de vapor verdadera.

   Usar la Tabla 7.1-2. Para el queroseno de jet, el valor por omisión para el peso molecular del vapor es de 130 lb/lb-mol.
   La temperatura promedio de carga es de 21°C ó 70°F.
   Por lo tanto, el valor por omisión para la presión de vapor verdadera es de 0.011 psia.

2. Determinar el factor de emisión usando la ecuación 7.2-1:

$$FE_a = 12.46 \times \frac{SP(PM)}{T}$$

$$= 12.46 \times \left| \frac{(1.45)(0.011)(130)}{(70 + 460)} \right|$$

$$= 0.0487 \text{ lb/1000 gal}$$
$$= 0.0058 \text{ kg/1000 litros}$$
$$= 0.0058 \text{ kg/m}^3$$

3. Determinar las emisiones de GOT de estas operaciones de carga de combustible en aviones usando la ecuación 7.2-2:

$$E_a = FE_a \times C_a$$

$$= (0.0058 \text{ kg/m}^3) \times (100{,}000 \text{ m}^3)$$
$$= 580 \text{ kg de GOT}$$
$$= 0.58 \text{ mg de GOT}$$

7.3 Distribución de Gas Licuado de Petróleo

CÓDIGO DE FUENTE	DESCRIPCIÓN
25-01-210-210*	Almacenamiento de Gas LP
25-05-000-210*	Transporte de Gas LP

* Códigos específicos propuestos para México para una categoría de fuentes que por lo general no se inventaría en los EU.

DESCRIPCIÓN:

Además de las emisiones de la combustión del gas LP, las emisiones debidas a fugas o a evaporación de los sistemas de almacenamiento y distribución representan una importante fuente de contaminación que debe ser considerada cuando se desarrolla un inventario de emisiones de área. El Instituto Mexicano del Petróleo (IMP) y algunos investigadores de la Universidad de California han identificado a las fugas de gas LP como una fuente potencialmente significativa de emisiones de hidrocarburos. Si bien una parte del gas LP es usado por los sectores industriales, comerciales y de servicios, en México el gas LP se usa sobre todo a nivel doméstico, tanto para cocinar como para calentar agua. Esta categoría de fuente se refiere a las emisiones generadas en toda la distribución de gas LP.

La Zona Metropolitana del Valle de México (ZMVM) es el mayor mercado de gas LP en el mundo con un consumo de 70,000 diarios, casi la misma cantidad que de gasolina (DDF et al, 1996). El uso del gas LP para cocinar y calentar agua en México se extiende por todas las regiones y de acuerdo con los datos del INEGI, alrededor del 70% de las casas habitación en México lo usan para cocinar. Solamente Chiapas y Oaxaca tienen una cifra inferior al 50%, predominando el uso de leña y carbón.

En México, la distribución y almacenamiento del gas LP para uso doméstico se hace principalmente por medio de tanques portátiles de 20-40 kg que se venden en camiones distribuidores. Los tanques vacíos se recolectan y se rellenan en centros especializados. Otra forma de distribución del gas LP doméstico es por medio de tanques estacionarios, cuya capacidad es, por lo general, de 300 kg, Estos tanques se llenan a domicilio por camiones especiales equipados con mangueras. En la Ciudad de México, 32 empresas independientes hacen unas 200,000 entregas diarias. Hay instalados cinco millones de tanques de acero en los millones de viviendas urbanas, en donde son conectados con mangueras y tuberías que puede o no recibir un mantenimiento adecuado (Sacramento Bee, 1995a).

En los países altamente industrializados, el gas LP está formado principalmente por propano (cuando menos el 95%). En México se vende una mezcla en la que predomina el propano (60%) pero que también contiene una cantidad apreciable de butano, isobutano, propileno y butilenos (PEMEX, 1996). Dado que, desde el punto de vista fotoquímico, los butanos y las olefinas son más reactivos que el propano la alta reactividad fotoquímica del gas LP mexicano también contribuye a su importancia potencial como una fuente de emisión.

CONTAMINANTES: GOT

GOR: Las emisiones de GOR constituyen el 98.4% de los GOT (PEMEX, 1996).

AJUSTES POR FUENTES PUNTUALES:

Por lo general, las emisiones de esta categoría de fuente no se incluyen en un inventario de fuentes puntuales. Sin embargo, si algunos centros de distribución de gas a granel se inventarían como fuentes puntuales, estas emisiones deben restarse de las emisiones totales a fin de estimar las emisiones de fuentes de área.

METODOLOGÍA:

Es necesario determinar la cantidad de gas LP consumido en la región de inventario. Si las estadísticas de uso de gas LP no corresponden directamente a las necesidades del inventario (e. g., existen estadísticas a nivel estatal pero la región del inventario incluye partes de varios estados; existen estadísticas a nivel estatal pero el inventario requiere estimaciones de emisiones a nivel municipal) entonces los datos censales (e. g., de censos de población o de vivienda) pueden usarse para repartir los datos regionales entre las áreas geográficas mas pequeñas. El ejemplo de cálculo para la combustión doméstica (combustibles comerciales) ilustra este procedimiento.

La forma esperada del cálculo de emisiones es:

$$\text{Emisiones de GOT} = (\text{volumen de gas LP usado}) \times (\text{densidad del gas LP}) \times (\text{FE [expresado como \% de fugas]}) \tag{7.3-1}$$

DATOS NECESARIOS:

Datos	Fuentes
Uso total de gas LP en el área del inventario	PEMEX
Datos de Población o de Vivienda	INEGI
Factor de emisión de fugas de gas LP - 3.6%	PEMEX, 1996
Composición química del gas LP, densidad	PEMEX

NOTAS:

1. El factor de emisión se basa en un estudio llevado a cabo para la Zona Metropolitana de la Ciudad de México (ZMCM) (PEMEX, 1996):

   FE =emisiones totales de gas LP/uso total de gas LP
   = (76,414 ton/año) (2,136,000 ton(año)
   = 3.6%

2. Si los datos específicos sobre la densidad del gas LP no están disponibles se puede usar como valor por omisión el valor del AP-42, de 507 g/litro (incluido en el Apéndice V-B de este documento).

3. La alta reactividad fotoquímica del gas LP usado en México, combinada con su gran consumo, significa que se están tomando en cuenta dos tipos de cambios de proceso: la eliminación de una parte significativa de las fugas en las instalaciones domésticas y comerciales o el enriquecimiento del gas LP con propano. Sin embargo hay algún riesgo asociado con el propano. Debido a que este compuesto tiene una presión de envasado mas alta que la de los otros componentes del gas LP, el gas LP reformulado, enriquecido con propano tendría también una presión de envasado mas alta que la del gas LP que se usa por lo común. Como resultado, sería necesario verificar que los tanques están en buenas condiciones y que pueden soportar la presión de la nueva formulación (DDF, et al, 1996).

EJEMPLO DE CALCULO:

Este ejemplo muestra como calcular las emisiones de las fugas en la distribución de gas LP en la ZMCM y se basa en los datos de uso de combustible obtenidos para desarrollar las emisiones de combustión para el inventario de área de la Ciudad de México (DDF, 1995a). Si es posible, deben obtenerse los datos específicos por región. En lugar de los datos específicos de la región se puede usar la información que se presenta a continuación:

Las emisiones de GOT se calculan usando los siguientes pasos:

1. Determinar la cantidad del gas LP usado en la ZMCM:

En el Oficio GPASI-1511/93, PEMEX reportó que la cantidad total de gas LP consumido en la ZMCM en 1993 fue de 3830.31×10^3 m^3. Con base en las cifras de PEMEX para 1992 se estimó que el 13% del total de gas LP fue usado por la industrial, 7% por los comercios y servicios y 80% para propósitos domésticos.

2. Determinar el factor de emisión de la distribución de gas LP:

A partir del estudio de PEMEX el factor de emisión es de 3.6%.

3. Entonces, las emisiones de GOT se calculan como:

$$E_{TOG} = (3830.31 \times 10^6 \text{ litros/año}) \times (507 \text{ g/litro}) \times (3.6\%)$$
$$= 69{,}911 \text{ Mg/año.}$$

8.0 FUENTES INDUSTRIALES LIGERAS Y COMERCIALES

Algunas actividades industriales ligeras o comerciales pueden ser demasiado pequeñas o demasiado numerosas para ser incluidas en el inventario de fuentes puntuales de una región de inventario dada. Por lo tanto, estas fuentes mas pequeñas deben incluirse en el inventario de fuentes de área. La guía para estas fuentes se presenta en las siguientes subsecciones:

- Panaderías;
- Ladrilleras;
- Actividades de Construcción;
- Señales de Tránsito;
- Asados al carbón y
- Vendedores Ambulantes.

8.1 Panaderías

CÓDIGO DE FUENTE: 23-02-050-000

DESCRIPCIÓN:

La fermentación de la levadura en las panaderías produce emisiones de hidrocarburos. Otras emisiones de las panaderías que se deben a la combustión no se cubren en esta sección y se deben calcular como parte de la categoría de uso comercial de combustibles. Las panaderías que producen artículos horneados que no son leudados no generan ningunos gases orgánicos provenientes de la fermentación de levaduras.

Las emisiones de hidrocarburos de las panaderías consisten principalmente del etanol que se produce durante la fermentación de la levadura. El etanol se emite durante los procesos de fermentación y de levantado, así como en el horneado. Las emisiones provienen de un proceso biológico y, como es típico en estos procesos, dependen de un gran número de variables como la duración del tiempo de levantado para la levadura, la cantidad de azúcares fermentables en la masa y la temperatura de fermentación. Para un inventario de fuentes de área, el esfuerzo que se requiere para recopilar datos sobre estos detalles consume demasiado tiempo comparado con la magnitud de las emisiones.

CONTAMINANTES: GOT

GOR: Las emisiones de GOR constituyen el 100% de los GOT.

AJUSTES POR FUENTES PUNTUALES:

Debe identificarse cualquier panadería incluida en el inventario de fuentes puntuales y las emisiones provenientes de la fermentación de levaduras se deben restar de las emisiones calculadas con los métodos que se describen aquí.

METODOLOGÍA:

Las emisiones de esta fuente se calculan usando un factor de emisión per cápita desarrollado para los EU (Adams, 1992). Esta fuente contiene una amplia gama de factores de emisión para los procesos de leudado de masa sin mezcla y de masa esponjosa:

Proceso	Factor de Emisión (kg de GOT/Mg de Pan)	Fuente
Masa sin mezcla	0.5 kg/Mg	Adams, 1992
Masa esponjosa	5 a 8 kg/Mg	Adams, 1992

La mayor parte de las panaderías usan masa esponjosa para el leudado de las levaduras por lo que el factor de emisión fue tomado de esta categoría. Dado que las estimaciones de emisión serán más altas y por lo tanto más conservadoras con la masa esponjosa que con la masa sin mezcla, se escogió el límite inferior del intervalo de factores de emisión. Para determinar el siguiente factor de emisión per cápita se usó una tasa de consumo de pan de 28.02 kg de pan por persona (fuente: U.S. Department of Commerce, International Trade Administration).

$$\frac{5\ \text{kg de GOT}}{\text{Mg de pan}} \times \frac{1\ \text{Mg}}{1{,}000\ \text{kg}} \times \frac{28.02\ \text{kg de pan}}{\text{persona - año}} = 0.14\ \frac{\text{kg de GOT}}{\text{persona - año}}$$

Este factor de emisión basado en datos de los EU tiene aplicación limitada en México y sólo se debe usar si no hay otros datos disponibles.

El cálculo utilizando el factor de emisión per cápita es:

$$\text{Emisiones Anuales} = (\text{Población}) \times (\text{Factor de Emisión}) \qquad (8.1\text{-}1)$$

<u>DATOS NECESARIOS</u>:

Datos	Fuentes
Método Per Cápita:	
Población	INEGI
Factor de Emisión de GOT 0.14 kg/persona-año	Adams, 1992

<u>NOTAS</u>:

1. Si los datos nacionales de producción de artículos horneados con levadura están disponibles es posible desarrollar un factor de emisión mexicano para esta categoría de fuentes. Para hacer esto se podría usar una tasa de emisión por kilogramo de pan horneado (5 kg de GOT/Mg pan producido) para estimar las emisiones nacionales de esta categoría de fuente y después se repartirían las emisiones resultantes entre la población nacional total. Sin embargo, es importante recordar que el uso de factores de emisión per cápita no refleja las

variaciones locales y que los datos de producción de pan deberían corresponder al año del inventario o bien a un año semejante. La información sobre la producción podría estar disponible en la Cámara Nacional de la Industria Panificadora. Las emisiones deberían calcularse con los siguientes métodos:

$$\text{Emisiones de GOT} = \frac{\text{5 kg de GOT}}{\text{Mg de pan producido}} \times \frac{\text{Mg de pan producido}}{\text{año}} \tag{8.1-2}$$

2. Las estimaciones de emisiones calculados usando el método de la producción de pan deberán relacionarse correctamente con el SNIFF para facilitar su ajuste con el inventario de fuentes puntuales.

EJEMPLO DE CÁLCULO:

Por ejemplo, las emisiones de panaderías en un estado con una población de 1,250,000 habitantes son:

(1,250,000 personas) × (0.14 kg/persona-año) = 175,000 kg/año
= 175 Mg/año

Si hay panaderías grandes en el área del inventario que hayan sido inventariadas como fuentes puntuales, las emisiones asignadas a esas plantas deben restarse del total calculado anteriormente. Por ejemplo, si las emisiones de fuentes puntuales son:

- 32 Mg por año para la Planta A;
- 11.2 Mg por año para la Planta B y
- 23 Mg por año para la Planta C.

Entonces:

Emisiones de Fuentes de Area = 175 Mg - (32 Mg + 11.2 Mg + 23 Mg)
= 108.8 Mg/año

8.2 Ladrilleras

CÓDIGO DE FUENTE: 23-05-090-000* Fabricación de Ladrillos

* Código específico propuesto para México para una categoría de fuente que en general no se inventaría en EU.

DESCRIPCIÓN:

En algunas partes del norte de México existen numerosos hornos pequeños de ladrillos. Por ejemplo, se estima que en Ciudad Juárez hay unos 200-300 hornos. Muchas de estas unidades son operaciones domésticas lo que hace impráctica su inclusión en los inventarios de fuentes puntuales. La leña es el combustible predominante en los horno domésticos de ladrillos. También se ha reportado que algunos utilizan otros materiales derivados de residuos, tales como basura o solventes de desecho. Además, en el área de Ciudad Juárez se están haciendo esfuerzos para convencer a algunos operadores domésticos de que utilicen gas LP.

CONTAMINANTES: GOT, CO, NO_x, SO_x, PM

GOR: Los factores de ajuste para los GOR dependen del tipo de combustible. Ver las Secciones 4.1 y 4.2 para los factores de ajuste de GOR/GOT para la combustión.

AJUSTES POR FUENTES PUNTUALES:

Las ladrilleras industriales mas grandes pueden incluirse en un inventario de fuentes puntuales. Se debe tener cuidado de no hacer un conteo doble de las emisiones en el inventario de fuentes de área.

METODOLOGÍA:

Se debe determinar la cantidad de cada tipo de combustible usado en los hornos pequeños en la región del inventario. Se debe hacer un esfuerzo especial para realizar una encuesta destinada a obtener datos sobre el número de hornos, el número de ladrillos producido por horno, así como sobre los tipos y cantidades de combustibles que consumen.

Los factores de emisión se pueden encontrar en el Capítulo 1 del AP-42 (AP-42, 1995) y se incluyen en el Apéndice V-B de este volumen (Nota: en el AP-42, el término “COT” a menudo se refiere a “GOT”). Las secciones en el Capítulo 1 cubren las emisiones para combustibles comerciales, leña y aceite residual. La Sección 2.5 del AP-42 también incluye los factores de emisión para la quema de residuos agrícolas y de llantas a cielo abierto los que podrían usarse para estimar las emisiones de los hornos de ladrillo. Sin embargo, el uso de factores de misión de la quema a cielo abierto podría ser muy incierto debido a las condiciones de combustión diferentes.

Para cada tipo de combustible, después se multiplica la cantidad quemada por los hornos pequeños por los factores de emisión adecuados como se muestra a continuación:

$$\text{Emisiones} = \left(\begin{array}{l}\text{Combustible Quemado}\\ \text{por Equipos del Tipo A}\\ \text{en Fuentes de Área}\end{array}\right) \text{ x } \left(\begin{array}{l}\text{Factor de Emisión}\\ \text{para Equipos del}\\ \text{Tipo A}\end{array}\right) \qquad (8.2\text{-}1)$$

DATOS NECESARIOS:

Datos	Fuentes
Combustible usado en la región del inventario por tipo de combustible	Encuesta o juicio de ingeniería (por omisión)
Número de hornos de ladrillo en la región del inventario	Encuesta o juicio de ingeniería (por omisión)
Características del combustible (contenido de calor, contenido de humedad de la madera)	AP-42, 1995, Apéndice A; Manuales Técnicos (e. g., *Marks Mechanical Handbook* - ver los datos presentados en el ejemplo de calculo)
Factores de emisión por tipo de combustible	AP-42, 1995

NOTAS:

1. Si no están disponibles las cantidades de combustible usaso para una región específica se puede suponer que un horno promedio produce 16,000 ladrillos por día y que se requieren aproximadamente 5,000 Btu (1,260 kcal) para hornear un ladrillo de 2.2 kg (4.8 lb) (Valenzuela, 1996). Después se pueden estimar las cantidades usadas de cada combustible como se muestra a continuación:

$$\text{Cantidad de Combustible Quemado} = \frac{\text{(no. de hornos/día) x (16,000 ladrillos/ horno/día) x (5,000 kcal/ladrillo)}}{\text{(contenido de calor del combustible[kcal/unidad de combustible])}} \tag{8.2-2}$$

2. Para aquellas regiones en las que la fabricación de ladrillos es una actividad importante es muy recomendable que se haga una encuesta de una muestra representativa de las operaciones típicas. Los resultados de esta muestra se deben aumentar a la escala de toda el área de inventario. Ver el Manual de *Técnicas Básicas de Estimación de Emisiones* para tener una descripción del procedimiento de encuesta.

EJEMPLO DE CALCULO:

Este ejemplo se basa en los cálculos desarrollados para estimar las emisiones de la manufactura de ladrillos en el área de Ciudad Juárez (Valenzuela, 1996).

(1) Determinar la cantidad de cada combustible quemado en los hornos de ladrillo:

Para este ejemplo se supone que un horno promedio produce 16,000 ladrillos por día y que se requieren aproximadamente 5,000 Btu (1,260 kcal) para hornear un ladrillo de 2.2 kg (4.8 lb) (Valenzuela, 1996). Si se alimentan 10 hornos con pino amarillo la cantidad de combustible se puede estimar como se muestra a continuación:

$$\text{Cantidad de pino amarillo quemado} = \frac{\text{(\# hornos)} \times \text{(16,000 ladrillos/horno/día)} \times \text{(1,260 kcal/ladrillo)}}{\text{(contenido de calor del combustible [kcal/unidad del combustible]}}$$

$$= \frac{\text{(10 hornos/día)} \times \text{(16,000 ladrillos/horno/día) x (1260 kcal/ladrillo)}}{\text{(3720 kcal/kg)}}$$

$$= \text{54,194 kg/día de pino amarillo.}$$

Donde el contenido de calor del pino amarillo se calculó como se muestra a continuación *(usando datos del Marks Mechanical Handbook)*:

El pino amarillo (seco) con 12% de humedad pesa 3,240 lb/cuerda
El pino amarillo (verde) con 50% de humedad pesa 4,770 lb/cuerda
Pino amarillo (seco) con 12% humedad - 26×10^6 Btu/cuerda
Pino amarillo (verde) con 50% humedad - 23.7×10^6 Btu/cuerda
(Nota: 1 cuerda de leña = 3.62 m^3):
Suponer que el contenido promedio de humedad en la madera es de 25%. Entonces, por interpolación:

El pino con 25% de humedad pesa 3,764 lbs/cuerda
Pino con 25% de humedad - 25.2×10^6 Btu/cuerda

ó (25.2×10^6 Btu/cuerda)/(3764 lb/cuerda) = 6,695 Btu/lb de pino

(2) Identificar los factores de emisión apropiados:

Usar los factores de emisión del AP-42, Sección 1.9-4 desarrollados para chimeneas domésticas (i. e., quemado de leña):

PM_{10}	17.3 g/kg
CO	126.3 g/kg
SO_x	0.2 g/kg
NO_x	1.3 g/kg
GOT	114.5 g/kg

E_{PM10} = (54,194 kg/día de pino) × (17.3 g/kg) / (1,000 g/kg)
= 938 kg de PM_{10}/día

E_{CO} = (54,194 kg/día de pino) × (126.3 g/kg) / (1,000 g/kg)
= 6,845 kg de CO/día

E_{SO2} = (54,194 kg/día de pino) × (0.2 g/kg) / (1,000 g/kg)
= 11 kg de SO_x/día

E_{NOx} = (54,194 kg/día de pino) × (1.3 g/kg) / (1,000 g/kg)
= 70 kg de NO_x/día

E_{GOT} = (54,194 kg/día de pino) × (114.5 g/kg) / (1,000 g/kg)
= 6,205 kg de COVs/día

8.3 Actividades de Construcción

CÓDIGO DE FUENTE: 23-11-000-000

DESCRIPCIÓN:

La construcción de edificios, caminos y otras actividades relacionadas son una fuente potencialmente importante de emisiones de partículas fugitivas. Estas emisiones pueden generarse por una gran variedad de actividades incluyendo el desmonte, el barrenado y dinamitado, la excavación y el movimiento de tierra y la construcción del edificio en sí. Las emisiones debidas a las actividades de construcción varían en cada sitio debido a los diferentes niveles de actividad, de operaciones y a las condiciones meteorológicas.

Esta sección se enfoca solamente en las emisiones fugitivas de partículas generadas por las actividades de construcción. Las emisiones de los escapes y las emisiones evaporativas del equipo de construcción y de los vehículos se tratan en la Sección 5.4 de este manual.

CONTAMINANTES: PM_{10}

GOR: No es aplicable.

AJUSTES POR FUENTES PUNTUALES: Ninguno

METODOLOGIA:

Debido a las diferencias potencialmente significativas en las prácticas de construcción mexicanas es recomendable que se recopilen datos específicos para México por medio de encuestas. Después se pueden usar estos datos en el desarrollo de un modelo de variable múltiple para las actividades de construcción en México. Hasta que estos datos se recopilen se recomienda usar los factores de emisión de los EU para estimar las emisiones de las actividades de construcción.

Hasta que se pueda hacer un modelo de emisiones de variable múltiple usando datos específicos para México se puede usar la siguiente ecuación para estimar las emisiones de polvo fugitivo de las actividades globales de construcción de la región.

$$\text{Emisiones} = \text{Área} \times \text{Tiempo} \times \text{FE} \qquad (8.3\text{-}1)$$

donde:

Emisiones = Emisiones totales anuales de polvo fugitivo (PM_{10});
Área = Área total del sitio específico de construcción;
Tiempo = Duración total de las actividades de construcción y
FE = Factor de emisión de polvo fugitivo (PM_{10}).

La Tabla 8.3-1 presenta los factores globales de emisión de PM_{10} sin control para siete sitios de construcción localizados en California y Nevada, así como la media geométrica resultante. También se incluye la descripción del tipo y nivel de la actividad de construcción en cada uno de los siete sitios.

Se recomienda usar el factor de emisión de la media geométrica (0.25 Mg PM_{10}/hectárea-mes). Sin embargo, se pueden usar otros factores de emisión de la tabla si la actividad específica de construcción es similar a las que están incluidas en la tabla. Debido a que estos factores de emisión representan actividades de construcción en EU debe tenerse cuidado cuando sean aplicados en México. Las diferencias en las prácticas de construcción y en los niveles de mecanización en México podrían introducir una incertidumbre considerable en las estimaciones de emisiones.

La metodología de estimación de emisiones presentada anteriormente es muy aplicable para las emisiones regionales de la construcción. Si se necesita estimar las emisiones para sitios individuales el AP-42, Tabla 13.2.3-1 (resumido en el MRI, 1996 [pág. 2-3 a 2-5, Tabla 1]) se presenta una metodología alternativa. Esta metodología proporciona diferentes factores de emisión para diversas operaciones de construcción (i. e., nivelación, compactación, desmonte, etc.). Con estos factores de emisión se obtendrá una estimación de emisiones más exacta que con los que se presentan en la Tabla 8.4-1 pero se deben recopilar datos mas detallados que sean específicos para el sitio.

DATOS NECESARIOS:

Datos	Fuentes
Área de Construcción	Autoridades locales o la Cámara Nacional de la Industria de la Construcción
Duración de la Construcción	Autoridades locales o la Cámara Nacional de la Industria de la Construcción
Factor de Emisión	Tabla 8.3-1
Datos Específicos del Sitio (ver AP-42, Tabla 13.2.3-1)	Personal en el sitio de construcción

EJEMPLO DE CÁLCULO:

En 1995 los funcionarios locales indicaron que había 120 hectáreas de actividad de construcción. Estos funcionarios estimaron que la áreas estarían en construcción durante un periodo promedio de 2.5 meses. A continuación se calculan las emisiones anuales totales de PM_{10} estimadas para 1995:

1. Si se supone que hay una gran variedad de tipos de construcción parece que el factor de emisión de la media geométrica de 0.25 Mg/hectárea-mes es el más apropiado.

2. Emisiones totales de PM_{10} :

$$120 \text{ hectáreas} \times 2.5 \text{ meses} \times 0.25 \text{ Mg de } PM_{10}/\text{ hectárea-mes}$$
$$= 75 \text{ Mg } PM_{10}$$

Tabla 8.3-1

Resumen de las Tasas de Emisiones de PM_{10} sin Control Estimadas para Sitios de Construcción[a]

Sitio	Factor Global de Emisión de PM_{10} sin Control (Mg/hectárea/mes)	Tipo de Construcción y Nivel de Actividad
A	0.072	Industrial - Actividad Moderada (atrincherado, prepavimentación, movimiento de tierra a pequeña escala)
B	0.72	Residencial - Actividad Moderada a Pesada (atrincherado, movimiento de tierra, barrenado y dinamitado, compactación)
C	0.18	Residencial - Actividad Moderada a Pesada (atrincherado, prepavimentación, acarreo del material de base para caminos)
D	0.0087	Residencial - Actividad Baja a Moderada (planeación y modificación del terreno)
E	0.90	Residencial - Actividad Pesada (movimiento de tierra, arrastre, apilado)
F	0.96	Residencial - Actividad Pesada (movimiento de tierra)
G	0.76	Comercial - Actividad Moderada a Pesada (atrincherado, acarreo de material de relleno)
Media Geométrica	0.25	

[a] Tabla derivada del MRI, 1996 (pág. 3-2, Tabla 2; pág. 4-2, Tabla 3).

8.4 Asados al Carbón

CÓDIGO DE FUENTE: 23-02-002-000

DESCRIPCIÓN:

Carnes asadas se refiere al cocinado de carne (por lo general de res o de pollo) sobre una flama abierta en el que se permite que la grasa escurra hacia adentro de la flama abierta. Esta categoría se limita a la actividad comercial ya que se piensa que la de las carnes asadas caseras es muy limitada. En México la actividad comercial se limita a restaurantes en pequeña escala y a vendedores callejeros. Los primeros se presentan en esta sección y los segundos en la Sección 8.5. Con base en observaciones realizadas en Nogales, Sonora por lo general la carne de res se asa con gas LP y el pollo con carbón.

Los principales contaminantes de interés provenientes del asado de carne son las PM_{10}. Virtualmente todas estas PM_{10} son de tamaño submicrónico. Además, una cantidad significativa de éstas consisten de carbono orgánico.

Las emisiones de las carnes asadas dependen de un gran número de variables, tales como el tipo de combustible usado, el tipo de carne asado, el contenido de grasa de la carne y la temperatura de la flama. Sin embargo, hasta hace poco, los efectos de estas variables no estaban muy bien cuantificados. Los datos existentes sobre las emisiones limitaban sobre todo a las hamburguesas asadas sobre una flama de gas natural, lo que ocnstituye una fracción significativa de este tipo de cocina en los EU. Investigadores del Colegio del Centro de Ingeniería para la Investigación y Tecnología Ambiental CE-CERT (*College of Engineering Center for Environmental Research and Technology*) de la Universidad de California en Riverside terminaron recientemente un estudio para el Distrito de Gestión de la Calidad del Aire de la Costa Sur (*South Coast Air Quality Management District ,SCAQMD*) en el que se examinan los efectos del tipo de carne sobre el tipo de emisiones. Los resultados preliminares de estas investigaciones se presentan en la Tabla 8.4-1.

CONTAMINANTES: GOT y PM_{10}

GOR: Las emisiones de GOR constituyen aproximadamente el 100% de los GOT (Welch, 1997).

AJUSTES POR FUENTES PUNTUALES:

Con la excepción de alguna planta industrial de cocinado de carne las emisiones de esta categoría de fuentes no se incluirían en un inventario de fuentes puntuales. Por lo tanto, en general, los ajustes por fuentes puntuales no deberían ser necesarios.

METODOLOGÍA:

Se considera que los factores de emisión basados en la cantidad de carne asada son muy confiables por lo que necesario estimar ésta.

La ecuación usada para estimar las emisiones de la carne asada es:

$$\text{Emisiones}_{ca} = N_{ca} \ \text{x} \ CP_{ca} \ \text{x} \ FE_{ca}$$

donde:

Emisiones_{ca} = Emisiones para el tipo de carne ca;
N_{ca} = Número de operaciones de asado para el tipo de carne ca;
CP_{ca} = Cantidad promedio de carne asada para el tipo de carne ca en cada operación y
FE_{ca} = Factor de emisión para el tipo de carne ca.

El primer paso al estimar las emisiones de la carne asada consiste en determinar el número de asadores. Los funcionarios locales de sanidad pueden aportar alguna información sobre el número de restaurantes con asadores. Debido a que estos restaurantes se concentran por lo general en los distritos comerciales y de compras se pueden hacer conteos gruesos por medio de encuestas informales.

La cantidad de carne asada y alguna otra información relacionada (uso de combustible, prácticas de cocinado, características de la carne, etc.) se deben estimar por medio de encuestas locales. Las diferencias culturales y socioeconómicas entre las diferentes regiones hacen que la utilización de datos que hayan sido obtenidos en otra región sea sumamente incierta.

La Tabla 8.4-1 presenta factores de emisión para la carne asada que se calcularon recientemente. Estos pueden que no representen exactamente las operaciones reales pero los factores de emisión todavía son algo limitados. En el futuro se espera refinar los factores de emisión existentes así como desarrollar nuevos factores.

Tabla 8.4-1

Factores de Emisión para la Carne Asada[a]

Tipo de Carne	PM_{10}[b] (g/kg carne)	GOT[c] (g/kg carne)	Comentarios
Res	32.7	3.9	Hamburguesas con 25% de grasa
Pollo	10.4	1.8	Pollos enteros abiertos
Pescado	3.2	0.4	Filetes de salmón del Atlántico

[a] Todos los factores de emisión se basan en muestreos en la fuente de parrillas con calentamiento inferior que usan gas natural (SCAQMD, 1997).

[b] Virtualmente todo las PM_{10} tiene un diámetro aerodinámico <2.5 µm o menor (Welch, 1997).

[c] Los factores de emisión originales fueron para GOR. Sin embargo, el metano medido estaba cerca de los límites de detección por lo que los GOT son casi equivalentes a los GOR (Welch, 1997)

DATOS NECESARIOS:

Datos	Fuentes
Número de asadores	Funcionarios locales de sanidad o datos de encuestas
Cantidad promedio de carne asada	Datos de encuestas locales
Tipo y cantidad de combustible	Datos de encuestas locales
Factores de Emisión	Tabla 8.4-1 de esta Sección; ver también Nota 1

EJEMPLO DE CALCULO:

Un área metropolitana tiene 80 restaurantes cada uno de los cuales asa un promedio de 60 kg de carne de res al día. Se supone que hay operaciones de asado todos los días del año. Calcular las emisiones anuales de PM_{10}.

80 restaurantes × 60 kg de carne/día × 365 días/año × 32.7 g PM_{10}/kg de carne
= 57,290 kg de PM_{10}
= 57.3 Mg de PM_{10}/año

NOTAS:

1. Las emisiones del asado de carne dependen sobre todo de la temperatura de la

flama en la interfaz flama-carne. A mayores temperaturas de flama se tienen emisiones mas altas. Aunque en la investigación del CE-CERT no se examinaron los efectos de diferentes combustibles algunas investigaciones previas sobre carnes asadas caseras indican que los combustibles con temperaturas de flama más altas (i. e., gas natural o propano) generan emisiones más altas que los combustibles con temperaturas de flama mas bajas (i. e., carbón) (Welch, 1997).

8.5 Vendedores Callejeros 7.5 Street Vendors

CÓDIGO DE FUENTE: 23-02-002-005*

*Código específico propuesto para México para una categoría de fuente que por lo general no se inventaría en los EU.

DESCRIPCIÓN:

Los vendedores ambulantes venden una gran variedad de productos comestibles en los distritos comerciales y de compras. En general estos vendedores expenden sus alimentos en carritos portátiles que se desplazan de un lado a otro. Muchas de las operaciones de estos vendedores no producen emisiones. Sin embargo, algunos de estos vendedores asan carne lo que puede ser una fuente significativa de GOT y PM_{10} y parece que el gas LP es su combustible preferido. por Para ver comentarios más detallados sobre el asado de carne referirse a la Sección 8.4.

CONTAMINANTES: GOT y PM_{10}

GOR: Las emisiones de GOR constituyen aproximadamente el 100% de los GOT (Welch, 1997).

AJUSTES POR FUENTES PUNTUALES: Ninguno

METODOLOGÍA:

La metodología empleada para estimar las emisiones de los vendedores callejeros es idéntica a la de los restaurantes en general. Para mayores detalles ver la Sección 8.4.

DATOS NECESARIOS:

Datos	Fuentes
Número de asadores de vendedores callejeros	Funcionarios locales de sanidad o datos de encuestas
Cantidad promedio de carne asada	Datos de encuestas locales
Tipo y cantidad de combustible	Datos de encuestas locales
Factores de Emisión	Tabla 8.4-1 de la Sección 8.4; ver también la Nota 1 de la Sección 8.4

EJEMPLO DE CÁLCULO:

Un área metropolitana tiene 140 vendedores callejeros y cada uno asa un promedio de 25 kg de carne de res al día. Se supone que las operaciones de asado se hacen todos los días del año. Usando el factor de emisión de PM_{10} para la carne de res presentado en la Tabla 8.4-1 calcular las emisiones anuales de PM_{10}.

140 vendedores ambulantes × 25 kg de carne/día × 365 días/año × 32.7 g PM_{10}/kg de carne
= 41,774 kg de PM_{10}
= 41.8 Mg de PM_{10}/año

9.0 AGRICULTURA

La mayor parte de las fuentes de emisión agrícolas pueden ser demasiado pequeñas o demasiado numerosas como para ser incluidas en el inventario de fuentes puntuales de una región dada. Por lo tanto, estas fuentes necesitan incluirse en el inventario de fuentes de área. La guía para el inventario de estas fuentes se presenta en las siguientes subsecciones.

- Aplicación de Plaguicidas;
- Corrales de Engorda de Ganado;
- Quemas Agrícolas;
- Aplicación de Fertilizantes;
- Desechos de Animales y
- Labranza Agrícola.

9.1 Aplicación de Plaguicidas

CODIGO DE FUENTES: 24-61-850-000

DESCRIPCION:

Los plaguicidas se usan para matar insectos, malezas u otras plagas o para retardar su crecimiento. La mayor parte de las emisiones al aire provenientes del uso de plaguicidas ocurren sobre todo debido a la naturaleza volátil de los ingredientes activos, los solventes acarreadores y otras productos químicos en las formulaciones. La volatilización de los plaguicidas puede ocurrir tanto durante la aplicación como algún tiempo después. Algunas formulaciones secas son polvos o gránulos y pueden resultar en emisiones de partículas. Sin embargo, no se han desarrollado factores de emisión de partículas debido a la insuficiencia de datos. La siguiente presentación se limita a las emisiones debidas a la volatilización de los plaguicidas con base hidrocarburos.

Por lo general, los plaguicidas volátiles se aplican como formulaciones líquidas tales como soluciones, emulsiones o aerosoles. En general, estos compuestos consisten de un ingrediente “activo” y de varios ingredientes “inertes”. Los términos “activo” e “inerte” no se refieren a la actividad fotoquímica sino mas bien son una medida de la toxicidad del compuesto. Las fracciones activa e inerte pueden variar dependiendo del tipo específico de aplicación del plaguicida.

La volatilidad de los ingredientes activos también puede ser muy variable. Se supone a menudo que la volatilización ocurre durante los 30 días siguientes a la aplicación. Después de aproximadamente 30 días, la degradación y los escurrimientos superficiales se convierten en los principales mecanismos de remoción de plaguicidas. Investigaciones de laboratorio y de campo indican que aparentemente la volatilidad de los ingredientes activos depende de tres parámetros principales: las propiedades físicas y químicas del ingrediente activo, las condiciones meteorológicas locales y la adsorción del suelo. Una discusión adicional sobre los efectos de estos tres parámetros se puede encontrar en la Sección 9.2.2.3 del AP-42 (AP-42, 1995).

La mayor parte de los plaguicidas no se aplican a la concentración completa (i. e., la forma pura del ingrediente activo) sino más bien en una mezcla con un “acarreador” inerte. A veces se usa agua como acarreador en las formulaciones de plaguicidas líquidos. Sin embargo, muchos de los acarreadores usados son gases y líquidos orgánicos volátiles. Se supone que el 100% de los acarreadores inertes volátiles se volatilizan durante los 30 días siguientes a la aplicación. Además de los plaguicidas orgánicos sintéticos descritos anteriormente a veces se usan destilados de petróleo para el control de malezas, hongos e insectos. En estos casos, se supone que el100% de los destilados se volatiliza.

CONTAMINANTES: GOT

GOR: Las emisiones de GOR constituyen el 100% de los GOT.

AJUSTES POR FUENTES PUNTUALES: Ninguno

METODOLOGIA:

Para plaguicidas orgánicos sintéticos:

$$\text{Emisiones}_i = (\text{Uso}_i \text{ x } \% \text{ activo}_i \text{ x } \text{FE}_i) + (\text{Uso}_i \text{ x } \% \text{ inerte}_i \text{ x } \%\text{V}_i) \quad (9.1\text{-}2)$$

donde:
Emisiones_i = Emisiones totales anuales de GOT del plaguicida i,
Uso_i = Uso anual total del plaguicida i;
$\% \text{ activo}_i$ = Porciento de ingredientes activos en el plaguicida i;
FE_i = Factor de emisión de ingredientes activos en el plaguicida i;
$\% \text{ inerte}_i$ = Porciento de ingredientes inertes en el plaguicida i (100% - % activo_i) y
$\%\text{V}_i$ = Contenido volátil de la fracción inerte del plaguicida i.

El factor de emisión usado en la ecuación anterior depende de la presión de vapor de los ingredientes activos específicos y del método de aplicación del plaguicida. Los factores de emisión para la aplicación superficial y para la incorporación en el suelo se presentan en la Tabla 9.1-1. No hay factores de emisión disponibles para la aplicación aérea de plaguicidas. Algunas investigaciones en curso indican que la volatilización es pequeña comparada con los efectos del arrastre en las aplicaciones aéreas.

Para destilados de petróleo:

$$\text{Emisiones}_i = \text{Uso}_i \quad (9.1\text{-}2)$$

Tabla 9.1-1

Factores de Emisiones sin Control para los Ingredientes Activos de Plaguicidas[a]

Tipo de Aplicación	Intervalo de Presión de Vapor (mm de Hg a 20 - 25 °C)[b]	Factor de Emisión (kg/Mg)[c]
Aplicación Superficial	1×10^{-4} a 1×10^{-6}	350
	$>1 \times 10^{-4}$	580
Incorporación al Suelo	$<1 \times 10^{-6}$	2.7
	1×10^{-4} a 1×10^{-6}	21
	$>1 \times 10^{-4}$	52

[a] Tabla modificada del AP-42, Tabla 9.2.2-4.

[b] Las presiones de vapor de algunos ingredientes activos específicos se pueden encontrar en el AP-42, Tabla 9.2.2-1. Para otros ingredientes activos, se deben consultar las referencia sobre plaguicidas.

[c] Los factores de emisión expresan como el peso equivalente de ingredientes activos volatilizados por unidad de peso de los ingredientes activos aplicados.

El método anterior proporciona una estimación exacta de las emisiones de la aplicación de plaguicidas. Sin embargo, si los datos enlistados en la tabla siguiente no están disponibles se puede usar un método conservador, si bien menos preciso Éste consiste en suponer que el 100% del plaguicida aplicado se volatiliza. Esto dará como resultado una sobreestimación de las emisiones pero es un método alternativo razonable si no hay datos detallados disponibles.

DATOS NECESARIOS:

Datos	Fuentes
Uso anual de plaguicidas (por formulación específica)	Oficina Local de la (SAGAR)/CICOPLAFEST
Método de aplicación	Oficina Local de la SAGAR/CICOPLAFEST
Tipos de ingredientes activos en la formulación	Envase del plaguicida, fabricante, formulador del uso final o distribuidor local. Los ingredientes activos para los nombres comerciales comunes de los plaguicidas se presentan en el AP-42, Tabla 9.2.2-2. También, en *Farm Chemicals Handbook - 1992*. (Meister, 1992)
Presiones de vapor de los ingredientes activos	Algunas presiones de vapor se proporcionan en el AP-42, Tabla 9.2.2-1. Se presentan presiones de vapor adicionales en Wauchope *et al*., 1992.
Tipo de formulación (e. g., emulsión, solución, gránulos, etc.)	Envase del plaguicida, fabricante, formulador del uso final o distribuidor local.
Porciento de ingredientes activos e inertes	Envase del plaguicida, fabricante, formulador del uso final o distribuidor local.
Contenido de compuestos volátiles en los ingredientes inertes	Fabricante del plaguicida o formulador del uso final. También se dan estimaciones del contenido promedio de compuestos volátiles en el AP-42, Tabla 9.2.2-3.

EJEMPLO DE CÁLCULO:

Se han aplicado 5,000 kg de Lazo® en la superficie de unos terrenos de cultivo para el control de malezas y se desea una estimación de la cantidad total de emisiones dentro de los 30 días siguientes a la aplicación.

1. El ingrediente activo en el Lazo® es el alacloro (AP-42 [Tabla 9.2.2-2] ó *Farm Chemicals Handbook - 1992*). En el contenedor del plaguicida se estipula que la formulación es una emulsión que contiene 41% de ingrediente activo y 59% de ingrediente inerte.

2. Cantidad total de ingrediente activo aplicado:

   $0.41 \times 5,000$ kg = 2,050 kg de alacloro aplicado

3. Del AP-42, Tabla 9.2.2-1, se determina que la presión de vapor del alacloro es 1.4×10^{-5} mm de Hg entre los 20 y los 25 °C. A partir del AP-42, Tabla 9.2.2-4, esto corresponde a un factor de emisión de 350 kg de ingrediente activo volatilizado por Mg de ingrediente activo aplicado. Por lo tanto, la cantidad total de ingrediente activo volatilizado está dada por:

   2.05 Mg × (350 kg/Mg) = 718 kg de alacloro volatilizado dentro de los 30 días siguientes a la aplicación

4. En el AP-42, Tabla 9.2.2-3, se puede determinar que el contenido promedio de compuestos volátiles en la porción inerte de las emulsiones (concentrados emulsionables) es de 56%.

   Cantidad total de emisiones de los ingredientes inertes:

   5,000 kg × 0.59 × 0.56 = 1,652 kg de ingredientes inertes volátiles (se supone que el 100% de los ingredientes inertes volátiles se volatiliza durante los 30 días siguientes a la aplicación)

5. La cantidad total de emisiones durante los 30 días siguientes a la aplicación es la suma de las emisiones de los ingredientes activos y de los ingredientes inertes. En este ejemplo, las emisiones son:

   718 kg (ingredientes activos) + 1,652 kg (ingredientes inertes volátiles)
   = 2,370 kg

9.2 Corrales de Engorda de Ganad Vacuno

CÓDIGO DE FUENTES: 28-05-001-000

DESCRIPCIÓN:

Los corrales de engorda de ganado son áreas utilizadas para engordar o retener el ganado antes de comercializarlo o transferirlo a otro lugar. Por lo general el proceso de engorda consiste en alimentar al ganado con una ración de granos de alta energía por un periodo de cuatro a cinco meses. Los corrales pueden ser una fuente importante de partículas fugitivas. El principal mecanismo de generación es el movimiento del ganado sobre el polvo del suelo y el estiércol seco. El tránsito vehicular y la acción del viento en la vecindad del corral también pueden contribuir a las emisiones de partículas. No se espera que ocurran emisiones similares cuando el ganado pasta en el exterior porque habrá una acumulación mínima de estiércol concentrado y de área superficial perturbada.

Las emisiones de amoníaco también son generadas por el ganado a causa de la descomposición anaeróbica del estiércol sobre las superficies del patio así como por la volatilización desde la orina. Las emisiones de amoníaco producidas por el ganado se tratarán en la sección sobre desechos de animales (Sección 9.5).

CONTAMINANTES: PM_{10}

GOR: No es Aplicable.

AJUSTES POR FUENTES PUNTUALES: Ninguno.

METODOLOGÍA:

Las emisiones de los corrales de engorda pueden estimarse usando la siguiente ecuación basada en la producción del corral:

$$\text{Emisiones} = \text{Producción} \times FE_{\text{Producción}} \tag{9.2-1}$$

donde:

Emisiones = Emisiones anuales totales de PM_{10}

$\text{Producción}_{\text{Ganado}}$ = Producción anual de ganado

$FE_{\text{Producción}}$ =Factor de emisión de PM_{10} basado en la prpoducción anual.

De manera alternativa las emisiones de los corrales de engorda se pueden estimar usando la siguiente ecuación basada en la capacidad del corral:

$$\text{Emisiones} = \text{Ganado} \times \text{Días} \times FE_{Capacidad} \qquad (9.2\text{-}1)$$

donde:
Emisiones = Emisiones anuales totales de PM_{10} ;
Ganado = Número de cabezas promedio presentes en el corral;
Días = Número de días al año que el ganado permanece en el corral;
$FE_{Capacidad}$ = Factor de emisión de PM_{10} basado en la capacidad promedio.

DATOS NECESARIOS:

Datos	Fuentes
Factor de emisión[a] de PM_{10} ,12.0 Mg/producción de 1,000 cabezas (12.0 ton/ producción de 1,000 cabezas)	AP-42, 1985
Factor de emisión[a] de PM_{10} , 62.4 kg/día - capacidad de 1,000 cabezas (134.4 lb/día- capacidad de1,000 cabezas)	AP-42, 1985
Producción anual de ganado	SAGAR, INEGI o corrales de engorda locales
Número promedio de cabezas de ganado en el corral	SAGAR, INEGI o corrales de engorda locales
Número de días que el ganado permanece en el corral	SAGAR, INEGI o corrales de engorda locales

[a] En realidad, los factores de emisión del AP-42 están dados para Partículas. Documentos del Air Resource Board (ARB) indican que el 48% de las Partículas de los corrales de engorda de ganado vacuno son PM_{10} (ARB, 1995).

NOTAS:

1. Todos los factores de emisión suponen que no se ha instrumentado ninguna medida interna de control de la contaminación del aire. En la mayor parte de los corrales de engorda se usan medidas normales de mantenimiento para evitar cantidades inaceptables de estiércol.

2. Los factores de emisión vigentesson muy inciertos. La EPA está haciedo investigación sobre esta categoría de fuente. En un futuro se debe contar con factores de emisión mejorados pero hasta marzo de 1997 no había ninguno disponible. Cuando los haya, estos factores de emisión mejorados se presentarán en la Sección 9.4.1 del AP-42.

EJEMPLO DE CÁLCULO:

En un corral de engorda de ganado se indica que hay una producción anual de 23,200 cabezas de ganado.

1. Cantidad total de emisiones de PM_{10} para este corral de engorda:

23,200 cabezas × (12.0 Mg/producción de1,000 cabezas) = 278 Mg de PM_{10}

9.3 Quemas Agrícolas

CÓDIGO DE FUENTES: 28-01-500-000

DESCRIPCIÓN:

La quemas agrícolas se refieren a la quema de cultivos, madera y hojas asociadas con las actividades agrícolas. En México esta práctica se limita sobre todo a la quema de los restos de la cosecha para preparar los campos para nuevos cultivos. La quema agrícola se permite en México siempre y cuando primero se notifique a la SEMARNAP o a la SAGAR. Todas las quemas agrícolas deben cumplir con la NOM-EM-003-SEMARNAP/ SAGAR-1996.

Las emisiones de quemas agrícolas dependen de varios factores diferentes. Entre los factores principales está el tipo de cultivo, la carga de combustible (cantidad de material orgánico por unidad de área de terreno) y tipo de quemado (directo o a contracandela). Los fuegos directos se inician en el lado del campo contrario al viento y se deja que avancen en la dirección del viento. Los incendios a contracandela se inician en el lado del campo a favor del viento y se les obliga a avanzar en la dirección contraria. Entre otros factores que pueden afectar a las emisiones están el contenido de humedad y el arreglo del material orgánico que se va a quemar. Hay información adicional sobre estos factores en la Sección 2.5.2.3 del AP-42 (AP-42, 1995).

CONTAMINANTES: GOT, CO y partículas

GOR: Las emisiones de GOR constituyen el 72.2% de los GOT.

AJUSTES POR FUENTES PUNTUALES: Ninguno.

METODOLOGÍA:

$$\text{Emisiones}_c = \text{Área}_c \text{ x Carga de combustible}_c \text{ x FE}_c \tag{9.3-1}$$

donde:

Emisiones_c = Emisiones totales del tipo de cultivo c;
Área_c = Área total quemada del tipo de cultivo c;
$\text{Carga de combustible}_c$ = Carga de combustible promedio para el tipo de cultivo c y
FE_c = Factor de emisión para el tipo de cultivo c.

La SAGAR mantiene estadísticas de las áreas cultivadas para diversas cosechas. Esta información se puede obtener en sus oficinas en los Estados. El INEGI también recopila y publica parte de esta información agrícola. Sin embargo la SAGAR no cuenta por el momento con ninguna información sobre el número de quemas que se realizan ni cual es el método empleado. A medida que se aplique la NON-EM-003-SEMARNAP/SAGAR-1996 se espera que este tipo de información esté disponible en la SAGAR Mientras tanto, será necesario recopilarla a nivel local.

El factor de emisión usado en la ecuación anterior depende sobre todo del tipo de cultivo y del tipo de quema. Los factores de emisión para quemas agrícolas se pueden encontrar en la Tabla 2.5-5 del AP-42. Se dan los siguientes tipos de quema: de cultivos no especificados y de cultivos especificados (quemas directas, a contracandela y quemas independientes del tipo de encendido) , de enredadera, de malezas, de huertos y residuos forestales. A su vez, estos grupos se dividen en tipos específicos de cultivo (e. g., los huertos incluyen aguacates, cítricos, higos, aceitunas, etc.). La Tabla 2.5-5 del AP-42 incluye diferentes factores de carga de combustible para cada tipo de cultivo.

Debe señalarse que los factores de emisión para quemas agrícolay y los factores de carga de combustible presentados en el AP-42 fueron desarrollados en los EU. Las prácticas agrícolas mexicanas que son muy diferentes así como otros factores podrían dar como resultado factores de emisión y factores de carga de combustible diferentes. Un ejemplo de diferentes factores de carga de combustible en los EU pueden encontrarse en el pie de página “i” de la Tabla 2.5-5 del AP-42. El factor de carga de combustible de la caña de azúcar para Louisiana está dado como 8-13.6 Mg/hectárea, mientras que para Hawaii está dado como 30-48 Mg/hectárea. Estos factores de carga de combustible son sumamente distintos debido a las diferencias en clima y/o en las prácticas agrícolas. En vez de depender de los factores de carga de combustible presentados en el AP-42 siempre que sea posible se deben desarrollar factores de carga de combustible específicos para México. Esto requerirá estudios de campo para determinar la cantidad (i. e., el peso) de los residuos de cultivos que están presentes por área de terreno.

DATOS NECESARIOS:

Datos	Fuentes
Area agrícola quemada (por tipo de cultivo)	Recopilación de datos locales
Factor de carga de combustible	Recopilación de datos locales; valores de los EU presentados en el AP-42, Tabla 2.5-5
Factor de emisión	AP-42, Tabla 2.5-5

NOTAS:

1. Los factores de emisión de partículas están dados como partículas totales. Algunas investigaciones indican que las partículas de la mayor parte de quemas agrícolas están en el intervalo de los submicrómetros. Por lo tanto, se puede suponer que las partículas totales son equivalentes a las PM_{10}.

2. Los factores de emisión GOT se presentan separados como factores de GOT no metano y factores de GOT metano. El factor de emisión de GOT global se puede calcular sumando los factores de emisión no metano y metano.

EJEMPLO DE CÁLCULO:

Los funcionarios locales indican que aproximadamente el 75% de las 120 hectáreas de cultivos de melón se queman después de la cosecha. Calcular la cantidad de emisiones de CO de esta quema agrícola.

1. Área total quemada:

   120 hectáreas × 0.75 = 90 hectáreas de campos quemados.

2. De la Tabla 2.5-5 del AP-42 el factor de carga de combustible para melones (cultivo de enredadera) es 5.6 Mg/hectárea. Sin embargo, esta región agrícola practica un cultivo más concentrado. En consecuencia se usará un factor hipotético de carga de combustible específico para la región de 7.8 Mg/hectárea.

3. El factor de emisión de CO para los cultivos de enredadera de la Tabla 2.5-5 del AP-42 es 26 kg/Mg de residuos agrícolas.

4. Emisiones de CO totales:

   90 hectáreas × (7.8 Mg de residuos/hectárea) × (26 kg/Mg de residuos)
   = 18,252 kg de CO
   = 18.3 Mg de CO

9.4 Aplicación de Fertilizantes

CÓDIGO DE FUENTES	DESCRIPCIÓN
28-01-700-001	Amoníaco Anhidro
28-01-700-002	Amoníaco Acuoso (Amoníaco en Solución)
28-01-700-003	Soluciones de Nitrógeno
28-01-700-004	Urea
28-01-700-005	Nitrato de Amonio
28-01-700-006	Sulfato de Amonio
28-01-700-007	Tiosulfato de Amonio
28-01-700-008	Otro Nitrógeno sin combinar
28-01-700-009	Fosfatos de Amonio
28-01-700-010	Mezclas de N-P-K

DESCRIPCION:

Los fertilizantes se utilizados de manera extensiva para añadir o reabastecer nutrientes agotados o que de alguna otra manera faltan en el suelo agrícola. Debido a la gran variedad de suelos y de cultivos se han formulado muchos tipos diferentes de fertilizantes. Después de su aplicación, los fertilizantes con base nitrógeno emiten amoníaco a la atmósfera. La cantidad de emisiones de amoníaco depende del tipo de fertilizante aplicado y por lo general se expresa como un porcentaje del contenido de nitrógeno del fertilizante.

El desarrollo de factores de emisión de amoniaco de la aplicación de fertilizantes todavía está en las etapas iniciales. Sin embargo, a pesar de que se han calculado algunos factores de emisión generalizados, existen muchas variables que tienen influencia sobre estos factores y que no se han tratado de manera adecuada. Entre estas variables están las condiciones meteorológicas, las propiedades del suelo, la técnica de aplicación (superficial o bajo la superficie) y los ciclos de aplicación.

CONTAMINANTES: NH_3

GOR: No es Aplicable.

AJUSTES POR FUENTES PUNTUALES: Ninguno.

METODOLOGÍA:

Las emisiones de amoníaco provenientes de la aplicación de fertilizantes se pueden estimar usando la siguiente ecuación:

$$Emisiones_f = Uso_f \; x\%N_f \; x \; FE_f \qquad (9.4\text{-}1)$$

donde:
$Emisiones_f$ = Emisiones anuales totales de NH_3 para el fertilizante tipo f
Uso_f = Uso anual total del fertilizante tipo f
$\%N_f$ = Contenido de nitrógeno del fertilizante tipo f
FE_f = Factor de emisión para el fertilizante tipo f.

DATOS NECESARIOS:

Datos		Fuentes
Uso Anual de Fertilizante (por tipo de fertilizante)		Oficina Local SAGAR/CICOPLAFEST
Contenido de Nitrógeno (por tipo de fertilizante)		Oficina Local SAGAR/CICOPLAFEST
Factores de Emisión de NH_3		Battye *et al*., 1994
Amoniaco Anhidro	12 kg NH3/Mg N Total	
Amoniaco Acuoso	12 kg NH3/Mg N Total	
Soluciones de Nitrógeno	30 kg NH3/Mg N Total	
Urea	187 kg NH3/Mg N Total	
Nitrato de Amonio	25 kg NH3/Mg N Total	
Sulfato de Amonio	97 kg NH3/Mg N Total	
Tiosulfato de Amonio	30 kg NH3/Mg N Total	
Otro Nitrógeno Directo	30 kg NH3/Mg N Total	
Fosfatos de Amonio	48 kg NH3/Mg N Total	
N-P-K	48 kg NH3/Mg N Total	

NOTAS:

1. Actualmente, la EPA está desarrollando un factor de emisión de amoniaco para la aplicación de fertilizantes; sin embargo, para marzo de 1997, aún no estaba disponible, En un momento determinado, estos factores serán presentados en la Sección 9.2.1 del AP-42. Se espera que algunos de los factores de emisión presentados anteriormente sea incluido en la documentación del AP-42.

EJEMPLO DE CÁLCULO:

Se reporta que se han aplicado 42 Mg de N-P-K a los campos de melones en una región determinada. El fertilizante de N-P-K tiene un contenido total de nitrógeno del 32%. ¿Cuáles son las emisiones de NH_3 resultantes?

1. Emisiones totales de NH_3 del fertilizante de N-P-K:

   (42 Mg de N-P-K) × (0.32 Mg de N total /Mg de N-P-K) ×
   (48 kg de NH3/Mg de N total)
   = 645 kg de NH_3

9.5 Desechos de Animales

CÓDIGO DE FUENTES	DESCRIPCIÓN
Reses y Becerros	
28-05-020-001	Ganado vacuno
28-05-020-002	Vacas Lecheras
28-05-020-003	Vaquillas (Reemplazos del ganado vacuno)
28-05-020-004	Vaquillas (Reemplazos de vacas lecheras)
28-05-020-005	Vaquillas (Otras)
28-05-020-006	Novillos
28-05-020-007	Toros
28-05-020-008	Terneros
Cerdos	
28-05-025-011	Marranas de cría (> 50 kg)
28-05-025-011	Marranas de cría (20-50 kg)
28-05-025-021	Cerdos para la venta (< 27.2 kg)
28-05-025-022	Cerdos para la venta (27.2-54.0 kg)
28-05-025-023	Cerdos para la venta (54.1-81.2 kg)
28-05-025-024	Cerdos para la venta (> 81.3 kg)
Pollos	
28-05-030-001	Gallinas Criadoras (> 6 meses)
28-05-030-002	Gallinas Ponedoras (> 18 semanas)
28-05-030-003	Gallinas Criadoras (< 6 meses)
28-05-030-004	Gallinas Ponedoras (< 18 semanas)
28-05-030-005	Otros Pollos
28-05-030-006	Pollos para Asar
Otras Aves	
28-05-035-001	Patos
28-05-035-002	Pavos
28-05-035-003	Pavos (< 7 meses)
28-05-035-004	Pavos (> 7 meses)
28-05-035-005	Pavos (para freír o para hornear)
Animales Misceláneos de Granja	
28-05-040-000	Ovejas y Corderos
28-05-045-001	Cabras
28-05-045-004	Conejos
27-10-020-030	Caballos.

DESCRIPCIÓN:

El ganado y otros animales domésticos de granja son una fuente importante de emisiones de emisiones de amoníaco. En algunos lugares constituyen la fuente única mas grande de emisiones de amoníaco. Estas emisiones resultan de la conversión del nitrógeno excretado en amoniaco y su subsecuente volatilización. Se piensa que el nitrógeno contenido en la orina del ganado se convierte fácilmente en amoníaco y se emite como tal. En cambio, las emisiones de amoníaco del estiércol por lo general requieren considerable descomposición.

La magnitud de las emisiones de amoníaco del ganado dependen de muchos factores. Entre éstos se incluye el tipo de ganado, el tamaño y peso de los animales, las prácticas de almacenamiento del estiércol, el contenido de nitrógeno del alimento y la meteorología. Adicionalmente, hay un gran número de factores ambientales que rigen la tasa de descomposición del estiércol. Debido a que las emisiones de amoníaco del ganado dependen de una amplia gama de variables ambientales es bastante difícil establecer un conjunto exacto de factores de emisión. Los factores que se presentan a continuación son los que se recomiendan en la actualidad para los inventarios de emisión a escala regional.

Se han desarrollado factores de emisión adicionales para fuentes de ganado especializadas (i. e., lecherías, rastros, etc.). En las **NOTAS** se presentan dos referencias sobre estos factores.

CONTAMINANTES: NH_3

GOR: No es Aplicable.

AJUSTES POR FUENTES PUNTUALES: Ninguno.

METODOLOGIA:

Las emisiones de amoníaco del ganado y de otros animales domésticos de granja se pueden estimar usando la siguiente ecuación:

$$\text{Emisiones}_a = \text{Población}_a \times FE_a \times TR_a \tag{9.5-1}$$

donde:

Emisiones_a = Emisiones anuales totales de NH_3 para el animal tipo a;
Población_a = Población total del animal tipo a;
FE_a = Factor de emisión de NH_3 para el animal tipo a y
TR_a = Tiempo de residencia del ganado para el animal tipo a como una fracción de un año.

DATOS NECESARIOS:

Datos		Fuentes
Poblaciones de ganado		Oficina Local de SAGAR. Las estadísticas del INEGI también pueden ser útiles.
Tiempo de Residencia del Ganado		Oficina Local de SAGAR.
Factor de emisión		Battye *et. al*, 1994
Ganado vacuno	39.7 kg NH_3/cabeza-año	
Vacas Lecheras	39.7 kg NH_3/cabeza-año	
Vaquillas (Reemplazo de ganado vacuno)	15.2 kg NH_3/cabeza-año	
Vaquillas (Reemplazo de vacas lecheras)	13.0 kg NH_3/cabeza-año	
Vaquillas (Otras)	13.0 kg NH_3/cabeza-año	
Novillos	8.2 kg NH_3/cabeza-año	
Toros	27.9 kg NH_3/cabeza-año	
Terneros	5.2 kg NH_3/cabeza-año	
Marranas de cría (>50 kg)	16.1 kg NH_3/cabeza-año	
Marranas de cría (20-50 kg)	5.2 kg NH_3/cabeza-año	
Cerdos para la venta (<27.2 kg)	7.0 kg NH_3/cabeza-año	
Cerdos para la venta (27.2-54.0 kg)	7.0 kg NH_3/cabeza-año	
Cerdos para la venta (54.1-81.2 kg)	11.0 kg NH_3/cabeza-año	
Cerdos para la venta (>81.3 kg)	11.0 kg NH_3/cabeza-año	
Pollos (Gallinas Criadoras>6 meses)	0.60 kg NH_3/cabeza-año	
Pollos (Gallinas Ponedoras>18 semanas)	0.31 kg NH_3/cabeza-año	
Pollos (Gallinas Criadoras<6 meses)	0.27 kg NH_3/cabeza-año	
Pollos (Gallinas Ponedoras<18 semanas)	0.17 kg NH_3/cabeza-año	
Otros Pollos	0.18 kg NH_3/cabeza-año	
Pollos para Asar	0.17 kg NH_3/cabeza-año	
Patos	0.12 kg NH_3/cabeza-año	
Pavos	0.86 kg NH_3/cabeza-año	
Pavos (<7 meses)	0.89 kg NH_3/cabeza-año	
Pavos (>7 meses)	1.3 kg NH_3/cabeza-año	
Pavos (para freír o para hornear)	0.86 kg NH_3/cabeza-año	
Ovejas y Corderos	3.4 kg NH_3/cabeza-año	
Cabras	6.4 kg NH_3/cabeza-año	
Conejos	2.8 kg NH_3/cabeza-año	
Caballos	12.2 kg NH_3/cabeza-año	

NOTAS:

1. Se han desarrollado algunos factores de emisión de amoníaco especializados para las lecherías del sur de California (Schmidt and Winegar, 1996). Se calcularon factores de emisión por animal para procesos unitarios individuales así como promedios globales de las lecherías. Existe incertidumbre respecto a qué tan aplicables serían estos factores de emisión para las lecherías mexicanas.

s mexicanas.

2. Se han desarrollado algunos factores de emisión de amoníaco para las plantas procesadoras de carne y de pollo en los EU (Radian, 1995). Los factores de emisión están dados en términos del número de animales procesados por día, de la cantidad de carne procesada diariamente, de la cantidad de aguas residuales descargadas y de la cantidad de amoníaco en el efluente o de la DBO (demanda bioquímica de oxígeno). Existe incertidumbre respecto a qué tan aplicables serían estos factores de emisión para las plantas mexicanas procesadoras de carne.

EJEMPLO DE CÁLCULO:

Una determinada región tiene una población anual de ganado vacuno de 25,000 cabezas y de 5,000 toros. Durante tres meses del año se traen 15,000 ovejas a pastar en la región. Calcular las emisiones totales de NH_3.

1. Emisiones totales de las 25,000 cabezas de ganado vacuno:
   25,000 cabezas × (39.7 kg de NH_3/cabeza-año) × 1.0
   = 992,500 kg de NH_3/año

2. Emisiones totales de los 5,000 toros:
   5,000 toros × (27.9 kg de NH_3/cabeza-año) × 1.0
   = 139,500 kg de NH_3/año

3. Emisiones totales de las 15,000 ovejas:
   15,000 ovejas × (3.4 kg de NH_3/cabeza-año) × 0.25
   = 12,750 kg de NH_3/año

4. Emisiones totales del ganado:
   992,500 kg de NH_3/año + 139,500 kg de NH_3/año + 12,750 kg de NH_3/año
   = 1,144,750 kg de NH_3
   = 1,145 Mg de NH_3

9.6 Labranza Agrícola

CÓDIGO DE FUENTES: 28-01-000-003

DESCRIPCIÓN:

El polvo fugitivo de las operaciones agrícolas puede contribuir de manera significativa a las emisiones de PM_{10} en algunas áreas rurales. Por lo general las operaciones agrícolas se dividen en tres clasificaciones: preparación del suelo, mantenimiento del suelo y cosecha. La categoría de labranza agrícola se enfoca principalmente en la preparación del suelo. Ésta incluye operaciones tales como: arado, gradado, nivelado y cortado.

CONTAMINANTES: PM_{10}

GOR: No es Aplicable

AJUSTES POR FUENTES PUNTUALES: Ninguno.

METODOLOGÍA:

Para estimar la emisiones de la labranza agrícola se usa la siguiente ecuación derivada del AP-42 y del manual de la Air Resources Board: *Emission Inventory Procedural Manual* (ARB, 1995):

$$\text{Emisiones}_c = 5.38(s)^{0.6} \times k \times HP_c \times \text{Área}_c \tag{9.6-1}$$

donde:
Emisiones_c = Emisiones anuales de PM_{10} para el cultivo tipo c;
$5.38(s)^{0.6}$ = Factor de emisión de base (kg de partículas/ hectárea-pase);
k = Multiplicador del tamaño de partícula (0.21 para PM_{10} , del AP-42);
s = Contenido de sedimento (%) - (ver **NOTA** #2);
HP_c = Número de hectárea-pases por hectárea para el cultivo tipo c y
Área_c = Área total cultivada del cultivo tipo c.

El primer término de la ecuación es tomado de la Sección 11.2.2 de la Cuarta Edición del AP-42 (AP-42, 1993) y se usa para estimar las emisiones de una operación específica.

El segundo término de la ecuación (número de hectárea-pases por hectárea) se usa para dar razón de las operaciones de labranza múltiple que se usan para la mayor parte de los tipos de cultivo. Este término se calcula multiplicando el número de operaciones típicas de labranza por el porcentaje de suelo agrícola que en realidad es labrado. En la mayor parte de cultivos de campo se labra el 100% del terreno. Sin embargo para los cultivos de huerto se labra una fracción mas pequeña del área (5-20%). La Tabla II de la Sección 7.4 del manual de la Air Resources Board: *Emission Inventory Procedural Manual* presenta algunos valores típicos para el número de operaciones de labranza y para el porcentaje del área cultivada que se labra en realidad para varios tipos de cultivos. Estos valores, sin embargo, representan las prácticas agrícolas de California. Debido a que las prácticas agrícolas mexicanas pueden ser muy diferentes se recomienda el desarrollo de datos específicos para México.

Aunque hay disponible un valor por omisión (18%) para el contenido de sedimento serían muy deseables los datos específicos por región. Los Apéndices C.1 y C.2 del AP-42 contienen los procedimientos para determinar el contenido de sedimento.

DATOS NECESARIOS:

Datos	Fuentes
Contenido de sedimentos en el suelo	Mediciones específicas en sitio, INEGI o Instituto de Geología de la Universidad Nacional Autónoma de México (UNAM)
Area agrícola cultivada	SAGAR o funcionarios de agricultura
Número de operaciones anuales	SAGAR o funcionarios locales de agricultura ; valores de California presentados en el Emission Inventory Procedural Manual
Porcentaje del área labrada	SAGAR o funcionarios locales de agricultura ; valores de California presentados en el Emission Inventory Procedural Manual

NOTAS:

1. La metodología presentada anteriormente (en particular el factor $(5.38(s)^{0.6})$ se basa en datos limitados. Actualmente la EPA está revisando su metodología para estimar las emisiones de la labranza agrícola. Cuando ésta esté completa se presentará en la Sección 9.1 de la Quinta Edición del AP-42.

2. El valor por omisión para el contenido de sedimento es 18%. La ecuación 8.12-1 es válida para contenidos de sedimento entre 1.7 y 88%.

3. Algunos investigadores creen que las emisiones de la labranza no sólo son función del contenido de sedimento como se describió antes sino que hay otros parámetros que podrían explicar mejor los mecanismos de emisión para la labranza agrícola. En la actualidad el personal de investigación del Laboratorio Crocker Nuclear de la Universidad de California en Davis está recopilando datos y haciendo análisis estadísticos para calcular nuevos factores de emisión (Ashbaugh, 1996).

4. Se están llevando a cabo algunas investigaciones que indican que las emisiones de labranza agrícola varían dependiendo del tipo de cultivo y de los implementos de labranza usados. Por ejemplo, las concentraciones de polvo respirable muestreado al nivel del implemento (50% de las partículas tienen un diámetro aerodinámico igual o inferior a 4 micrómetros) revelaron que la rotura del suelo ocasiona concentraciones que son 31 veces más elevadas que las del cortado de los rastrojos de maíz. Además, las concentraciones del cortado de los rastrojos de trigo son 7.5 veces mayores que las del cortado de rastrojos de maíz. Las emisiones de la labranza agrícola también pueden ser influidas por varios factores ambientales como la humedad del suelo y la velocidad del viento. Se están haciendo mas investigaciones en un intento de probar y cuantificar estos factores (Clausnitzer y Singer, 1996).

EJEMPLO DE CÁLCULO:

Un área agrícola determinada tiene un contenido de sedimento de 20%. Los dos cultivos principales que se producen en esta región son algodón y naranjas. Hay 110 hectáreas de algodón y 35 hectáreas de naranjas. A partir de las prácticas agrícolas locales se determinó que el 100% de la tierra usada para el algodón es labrada cinco veces al año y que 15% de la tierra utilizada para las naranjas es labrada tres veces al año. ¿Cuáles son las emisiones anuales de PM_{10}?

1. Los pases hectárea por hectárea para el algodón son:

   $5 \times 100\% = 5$

2. Los pases hectárea por hectárea para las naranjas:

   $3 \times 15\% = 0.45$

3. Las emisiones anuales de PM_{10} del algodón son:

$5.38\ (20)^{0.6}$ (kg de PM_{10}/pase-hectárea) × 0.21 × 5 (pase-hectárea/hectárea) × 110 hectáreas

= 3,750 kg

4. Las emisiones anuales de PM_{10} de las naranjas son:

$5.38\ (20)^{0.6}$ (kg PM_{10}/pase-hectárea) × 0.21 × 0.45 (pase-hectárea/hectárea) × 35 hectáreas
= 107 kg

5. Las emisiones anuales totales de PM_{10} de la labranza agrícola son:

3,750 kg + 107 kg = 3,856 kg de PM_{10} = 3.86 Mg de PM_{10}

10.0 MANEJO DE RESIDUOS

Algunas fuentes de emisiones debidas al manejo de residuos pueden ser demasiado pequeñas o demasiado numerosas para ser incluidas en el inventario de fuentes puntuales para una región dada. Por lo tanto, estas fuentes deben incluirse en el inventario de fuentes de área. La guía para el inventario de estas fuentes se presenta en las siguientes subsecciones:

- Incineración en Sitio;
- Quema a Cielo Abierto;
- Tratamiento de Aguas Residuales y
- Aguas Negras y Aguas Residuales en Canales Abiertos.

10.1 Incineración en Sitio

CÓDIGO DE FUENTE	DESCRIPCIÓN
26-01-000-000	Todas las Categorías
26-01-020-000	Comercial e Institucional
26-01-030-000	Residencial

DESCRIPCIÓN

La incineración en sitio es la quema **confinada** de basura y otros desechos. La quema de estos materiales a cielo abierto se trata en la Sección 10.2 de este manual. Por lo general los incineradores de residuos municipales, peligrosos o industriales se clasifican como fuentes puntuales y caen dentro de la jurisdicción federal. Estos incineradores no serán tratados en esta sección. Aquí se tratarán solamente los dispositivos comerciales, institucionales y residenciales para la incineración en sitio. En México todavía no se dispone fácilmente de estadísticas directas relacionadas con esta incineración pues no se trata de una actividad muy extendida. Sin embargo, el método de balance de materiales que se describe a continuación puede usarse para estimar las emisiones.

CONTAMINANTES: GOT, CO, NO_x, SO_x y PM_{10}

GOR: Las emisiones de GOR constituyen 75% del GOT.

AJUSTES POR FUENTES PUNTUALES:

Las emisiones de la incineración en sitio deben ajustarse hacia abajo para tomar en cuenta cualquier fuente puntual de incineración (i e., incineradores municipales, etc.) en la región. Esto se hace restando los residuos que van a estas fuentes de la corriente global de residuos incinerados. El INE u otras dependencias gubernamentales deben tener información sobre las fuentes puntuales de incineración

METODOLOGÍA:

El primer paso para estimar las emisiones de la incineración en sitio consiste en hacer un balance de materiales de los residuos sólidos. En general, éste tiene la forma siguiente:

$$\Sigma \text{Residuos}_{\text{Generados}} = \Sigma\ \text{Residuos}_{\text{Eliminados}} \tag{10.1-1}$$

donde:

$\Sigma \text{Residuos}_{\text{Generados}}$ = Cantidad total de residuos generados y

$\Sigma\ \text{Residuos}_{\text{Eliminados}}$ = Cantidad total de residuos eliminados.

Por lo general, la cantidad total de residuos generados se calcula multiplicando una tasa de generación de residuos per cápita por la población del área del inventario. Esto se representa matemáticamente como:

$$\Sigma \text{Residuos}_{\text{Generados}} = \text{Población} \times \Sigma\ \text{Residuos}_{\text{per cápita}} \tag{10.1-2}$$

De acuerdo con el INE, la tasa de generación de residuos per cápita para 1994 para todo el país fue de 0.893 kg/persona-día (INE, 1994). Las diferencias socioeconómicas a nivel regional dan como resultado tasas de generación mas altas o mas bajas para diferentes regiones. Por ejemplo, se ha estimado que la tasa de generación en Nogales, Sonora es de aproximadamente 0.8 kg/persona-día (Monroy, 1996). Se recomienda ponerse en contacto con los funcionarios locales para obtener una tasa de generación de residuos apropiada.

La cantidad total de residuos elminados está dada por la siguiente ecuación:

$$\Sigma \text{Residuos}_{\text{Generados}} = \text{Residuos}_{\text{Relleno sanitario}} + \text{Residuos}_{\text{Reciclados}} + \text{Residuos}_{\text{Incineración}} + \text{Residuos}_{\text{Quema a cielo abierto}} + \text{Residuos}_{\text{Otros}} \tag{10.1-3}$$

donde:

$\text{Residuos}_{\text{Relleno sanitario}}$ = Cantidad total de residuos enviados a rellenos sanitarios;

$\text{Residuos}_{\text{Reciclados}}$ = Cantidad total de residuos reciclados;

$\text{Residuos}_{\text{Incineración}}$ = Cantidad total de residuos enviados a incineración;

$\text{Residuos}_{\text{Quema a cielo abierto}}$ = Cantidad total de residuos consumidos a través de la quema a cielo abierto

$\text{Residuos}_{\text{Otros}}$ = Cantidad total de residuo eliminados por otros medios (i. e., abandono, etc.)

El rearreglo de las ecuaciones 10.1-1, 10.1-2 y 10.1-3 da como resultado la siguiente ecuación que da la cantidad de residuos quemados en incineradores. Como se indicó antes, esta cantidad de residuos debe ajustarse todavía por los incineradores considerados fuentes puntuales.

$$\text{Residuos}_{\text{Incineració}} = (\text{Población x Residuos}_{\text{per cápita}}) - \text{Residuos}_{\text{Relleno sanitario}} + \text{Residuos}_{\text{Reciclados}} - \text{Residuos}_{\text{Quema a cielo abierto}} - \text{Residuos}_{\text{Otros}} \qquad (10.1\text{-}4)$$

El INE estima que alrededor del 70% de los residuos generados en las ciudades mexicanas termina siendo recolectado y enviado a los rellenos sanitarios. Otras áreas pueden enviar a rellenos sanitarios fracciones diferentes de la corriente global de residuos.

Es probable que la cantidad de residuos globales que se reciclan sea pequeña en la mayor parte de las áreas de México. Por ejemplo, se ha estimado que el 1.3% del total en Nogales, Sonora se recicló en 1990 (Monroy, 1996). Sin embargo, se espera que la cantidad de residuos reciclados aumente en el futuro a medida que la práctica del reciclaje se expanda a nivel mundial.

Será necesario consultar a los funcionarios locales para conocer la cantidad de residuos que se eliminan por quema a cielo abierto y por otros medios.

Después de estimar la cantidad de residuos enviados a incineración se le debe restar la cantidad enviada a los incineradores considerados fuentes puntuales. Después se pueden calcular las emisiones usando la siguiente ecuación:

$$\text{Emisiones}_i = \text{Residuos}_{\text{Incineración}} \text{ x } FE_i \qquad (10.1\text{-}5)$$

donde:

Emisiones_i = Emisiones anuales totales del contaminante i;

$\text{Residuos}_{\text{Incineración}}$ = Residuos totales incinerados (ajustado por incineradores considerados fuentes puntuales)

FE_i = Factor de emisión para el contaminante i.

En la Tabla 10.1-1 se presentan algunos factores de emisión para incineradores en sitio.

Tabla 10.1-1

Factores de Emisiones sin Control para Incineradores en Sitio que no sean para Residuos Municipales[a]

Tipo de Combustor		**COT[b] (kg/Mg)**	**CO (kg/Mg)**	**NO_x (kg/Mg)**	**Partículas (kg/Mg)**	**SO_2 (kg/Mg)**
Comercial / Institucional	Cámara Múltiple	1.5	5.0	1.5	3.5	1.25
	Una sola Cámara	75	10	1.0	7.5	1.25
Doméstico	Sin Quemador Primario	50	150	0.5	17.5	0.25
	Con Quemador Primario	1.0	≈0	1.0	3.5	0.25

[a] Factores de emisión tomados de la Tabla 2.1-12 del AP-42. Ahí se pueden encontrar factores de emisión adicionales para otros incineradores de residuos no municipales.

[b] Expresado como metano.

DATOS NECESARIOS:

Datos	**Fuentes**
Población	INEGI o funcionarios locales
Tasa de generación de residuos per cápita (por omisión - 0.893 kg/persona-día)	INE, INEGI o funcionarios locales
Cantidad de residuos elminados en rellenos sanitarios (por omisión - 70% de los residuos totales)	INE o funcionarios locales
Cantidad de residuos reciclados	Funcionarios locales
Cantidad de residuos eliminados por quema a cielo abierto	Funcionarios locales
Cantidad de residuos eliminados por otros medios (abandono, etc.)	Funcionarios locales
Cantidad de residuos eliminados en incineradores considerados fuentes puntuales	INE o plantas locales
Factores de emisión	Tabla 10.1-1 de este manual o Tabla 2.1-12 del AP-42

EJEMPLO DE CALCULO:

Cierto municipio tiene una población de 160,000 habitantes. Los funcionarios locales indican que el factor de generación de residuos per cápita es ligeramente inferior al promedio nacional (~0.85 kg/persona-día). También indican que el 65% de los residuos totales es enviado a rellenos sanitarios, el 3% es reciclado, el 10% es quemado a cielo abierto y el resto es incinerado. El 5% es abandonado o tirado a cielo abierto. Un incinerador de residuos de la municipalidad incinera 5,500 Mg de residuos anualmente. Calcular las emisiones anuales de CO provenientes de la incineración en sitio suponiendo que todo el residuo se quema en un incinerador comercial de una sola cámara.

1. Residuos totales anuales generados:

   160,000 habitantes × (0.85 kg/persona-día) × 365 días
   = 49,640,000 kg
   = 49,640 Mg

2. Residuos anuales totales que se envían a rellenos sanitarios:

   49,640 Mg × 0.65 = 32,266 Mg

3. Residuos anuales totales que se reciclan:

   49,640 Mg x 0.03 = 1,489 Mg

4. Residuos anuales totales que se queman a cielo abierto:

   49,640 Mg × 0.10 = 4,964 Mg

5. Residuos anuales totales que son abandonados o tirados a cielo abierto:

   49,640 Mg × 0.05 = 2,482 Mg

6. Residuos anuales totales que son incinerados:

   49,640 Mg - 32,266 Mg - 1,489 Mg - 4,964 Mg - 2,482 Mg = 8,439 Mg

7. Residuos anuales totales que son incinerados (ajustado por los incineradores considerados fuentes puntuales):

   8,439 Mg - 5,500 Mg = 2,939 Mg

8. Emisiones totales de CO:

   2,939 Mg residuos × (10 kg CO/Mg residuos)
   = 29,390 kg de CO/año
   = 29.4 Mg de CO/año

10.2 Manejo de Residuos - Quema a Cielo Abierto

CODIGO DE FUENTE	**DESCRIPCION**
26-10-000-000	Todas las Categorías
26-10-010-000	Industrial
26-10-020-000	Comercial / Institucional
26-10-030-000	Residencial

DESCRIPCION:

En algunas áreas la quema a cielo abierto es el método preferido para eliminar los residuos sólidos. La quema confinada de materiales de desecho se trata en la parte correspondiente a la incineración en sitio (Sección 10.1). La quema agrícola a gran escala no se incluye en esta sección. La metodología para efectuar quemas agrícolas se puede encontrar en la Sección 9.3. Los tiraderos grandes donde se hace quema a cielo abierto se clasifican, por lo general, como fuentes puntuales y no se tratarán en esta sección.

Las estadísticas directas relacionados con la quema de desechos a cielo abierto son limitadas. La ley mexicana establece que esta práctica sólo está permitida en zonas de jurisdicción federal, con la autorización de la SEMARNAP y sólo cuando se realice para el entrenamiento de bomberos. Al hacer la solicitud, se debe indicar la cantidad y tipo del combustible que va a quemarse. Sin embargo, también parece que la práctica de hacer quemas a cielo abierto de desechos en pequeña escala, sin permiso de SEMARNAP, sigue siendo común. Al estimar las emisiones de la quema a cielo abierto también deben tenerse en cuenta los efectos de las reglas y regulaciones locales. El método del balance de materiales, que se describe después, puede usarse para estimar las emisiones.

CONTAMINANTES: GOT, CO, NO_x, SO_x y PM_{10}

GOR: Las emisiones de GOR constituyen el 38.7% de los GOT.

AJUSTES POR FUENTES PUNTUALES:

Las emisiones de la quema de residuos a cielo abierto deben ajustarse hacia abajo para tomar en cuenta cualquier quema a cielo abierto considerada fuente puntual (i. e., grandes tiraderos donde se practica la quema a cielo abierto) dentro de la región. Esto se hace restando los residuos que van a estas fuentes desde la corriente global de residuos incinerados. Los funcionarios locales deben tener información sobre estas fuentes puntuales.

METODOLOGIA:

El primer paso al estimar las emisiones de la quema de residuos a cielo abierto consiste en hacer un balance de materiales de los residuos sólidos. En general, un balance de materiales de este tipo tiene la siguiente la forma:

$$\Sigma \text{Residuos}_{\text{Generados}} = \Sigma\ \text{Residuos}_{\text{Eliminados}} \tag{10.2-1}$$

donde:
$\Sigma \text{Residuos}_{\text{Generados}}$= Cantidad total de residuos generados y
$\Sigma\ \text{Residuos}_{\text{Eliminados}}$= Cantidad total de residuos eliminados.

Por lo general, la cantidad total de residuos generados se calcula multiplicando una tasa de generación de residuos per cápita por la población del área del inventario. Esto se representa matemáticamente como:

$$\Sigma \text{Residuos}_{\text{Generados}} = \text{Población x Residuos}_{\text{per cápita}} \tag{10.2-2}$$

De acuerdo con el INE la tasa per cápita de generación de residuos en 1994, para todo el país, era de 0.893 kg/persona-día (INE, 1994). Las diferencias socioeconómicas a nivel regional dan como resultado tasas de generación mas altas o mas bajas para diferentes regiones. Por ejemplo, se ha estimado que la tasa de generación de residuos en Nogales, Sonora es de aproximadamente 0.8 kg/persona-día (Monroy, 1996). Se recomienda ponerse en contacto con los funcionarios locales para obtener una tasa de generación de residuos apropiada.

La cantidad total de residuos eliminados está dada por la siguiente ecuación:

$$\Sigma \text{Residuos}_{\text{Eliminados}} = \text{Residuos}_{\text{Relleno sanitario}} + \text{Residuos}_{\text{Reciclados}} + \text{Residuos}_{\text{Incineración}} + \text{Residuos}_{\text{Quema a cielo abierto}} + \text{Residuos}_{\text{Otros}} \tag{10.2-3}$$

donde:
$\text{Residuos}_{\text{Relleno sanitario}}$ = Cantidad total de residuos enviados a rellenos sanitarios;
$\text{Residuos}_{\text{Reciclados}}$ = Cantidad total de residuos reciclados;
$\text{Residuos}_{\text{Incineración}}$ = Cantidad total de residuos enviados a incineración;
$\text{Residuos}_{\text{Quema a cielo abierto}}$ = Cantidad total de residuos consumidos por quema al aire libre y
$\text{Residuos}_{\text{Otros}}$ = Cantidad total de residuos eliminados por otros medios (i. e., abandono, etc.)

Rearreglando las ecuaciones 10.1-1, 10.1-2 y 10.1-3 se obtiene la siguiente ecuación que da la cantidad de residuos quemados a cielo abierto.

$$\text{Residuos}_{\text{Quema a cielo abierto}} = (\text{Población x Residuos}_{\text{per cápita}}) - \text{Residuos}_{\text{Relleno sanitario}} - \text{Residuos}_{\text{Reciclados}} - \text{Residuos}_{\text{Incineración}} - \text{Residuos}_{\text{Otros}} \qquad (10.2\text{-}4)$$

El INE ha estimado que aproximadamente el 70% de los residuos generados en las ciudades mexicanas termina siendo recolectado y enviado a los rellenos sanitarios. Otras áreas pueden enviar a los rellenos diferentes fracciones de su corriente general de residuos.

Es probable que la cantidad que se recicla de los residuos globales sea pequeña en la mayor parte de las áreas de México. Por ejemplo, se ha estimado que el 1.3% del total de residuos generados en Nogales, Sonora se reciclaron en 1990 (Monroy, 1996). Sin embargo, se espera que esta cantidad aumente en el futuro a medida que la práctica del reciclaje se expanda a nivel mundial.

Es necesario consultar a los funcionarios locales para conocer la cantidad de residuos que se eliminan por incineración y por otros medios.

Después de estimar la cantidad de residuos quemados a cielo abierto es posible calcular las emisiones usando la siguiente ecuación:

$$\text{Emisiones}_i = \text{Residuos}_{\text{Quema a cielo abierto}} \text{ x } \text{FE}_i \qquad (10.2\text{-}5)$$

donde: Emisiones_i = Emisiones anuales totales para el contaminante i;
$\text{Residuos}_{\text{Quema a cielo abierto}}$ = Residuos quemados totales (ajustado por incineradores considerados fuentes puntuales) y
FE_i = Factor de emisión para el contaminante i.

En la Tabla 10.2-1 se presentan factores de emisión para residuos municipales típicos. La quema a cielo abierto de desechos orgánicos o desechos agrícolas se trata en la Sección 9.3 de este manual. La quema a cielo abierto de partes de automóviles, llantas y películas agrícolas de plástico se trata en forma especializada en las secciones 2.5.2.2, 2.5.2.3, y 2.5.2.4 del AP-42 (AP-42, 1995).

Tabla 10.2-1

Factores de Emisión para la Quema a cielo abierto de Residuos Municipales[a]

Fuente	**GOT (kg/Mg)[b]**		**CO (kg/Mg)**	**NO_x (kg/Mg)**	**Partículas[c] (kg/Mg)**	**SO_2 (kg/Mg)**
	Metano	**No Metano**				
Desechos Municipales	6.5	15	42	3	8	0.5

[a] Factores de emisión tomados de la Tabla 2.5-1 del AP-42.

[b] Los factores de emisión de GOT se presentan separadamente como GOT no metano y factores de emisión de metano juntos.

[c] Los factores de emisión de partículas se presentan como partículas totales.Aunque no se estipula, parece razonable asumir que una fracción significativa de las partículas son PM_{10}.

DATOS NECESARIOS:

Datos	**Fuentes**
Población	INEGI o funcionarios locales
Tasa de generación de residuos per cápita (por omisión - 0.893 kg/persona-día)	INE, INEGI o funcionarios locales
Cantidad de residuos eliminados en rellenos sanitarios (por omisión - 70% de los residuos totales)	INE o funcionarios locales
Cantidad de residuos reciclados	Funcionarios locales
Cantidad de residuos eliminados por incineración	Funcionarios y plantas locales
Cantidad de residuos eliminados por otros medios (abandono, etc.)	Funcionarios locales
Factores de emisión	Tabla 10.2-1

EJEMPLO DE CÁLCULO:

Un cierto municipio tiene una población de 140,000 habitantes. Los funcionarios locales indican que el factor de generación de residuos per cápita es inferior al promedio nacional (~0.75 kg/persona-día). También indican que el 60% de los residuos totales es dispuesto en rellenos sanitarios, el 2% es reciclado, el 10% es eliminado por incineración (municipal y en sitio), el 5% es abandonado o arrojado en tiraderos y el resto es quemado a cielo abierto. Calcular las emisiones anuales de NO_x de la quema cielo abierto suponiendo que todos los residuos generados son residuos municipales típicos.

1. Residuos totales anuales generados:

   140,000 habitantes × (0.75 kg/persona-día) × 365 días
   = 38,325,000 kg
   = 38,325 Mg

2. Residuos anuales totales enviados a rellenos sanitarios:

   38,325 Mg × 0.60 = 22,995 Mg

3. Residuos anuales totales que son reciclados:

   38,325 Mg x 0.02 = 767 Mg

4. Residuos anuales totales que se eliminan por incineración:

   38,325 Mg × 0.10 = 3,833 Mg

5. Residuos anuales totales que son abandonados o tirados a cielo abierto:

   38,325 Mg × 0.05 = 1,916 Mg

6. Residuos anuales totales que son quemados a cielo abierto:

   38,325 Mg - 22,995 Mg - 767 Mg - 3,833 Mg - 1,916 Mg = 8,814 Mg

7. Emisiones totales de NO_x:

   8,814 Mg residuos × (3 kg NO_x/Mg residuos)
   = 26,442 kg NO_x/año
   = 26.4 Mg NO_x/año

10.3 Tratamiento de Aguas Residuales

CÓDIGO DE FUENTE	**DESCRIPCIÓN**
26-30-000-000	Todas las Categorías/**VALOR?**Compuesto
26-30-010-000	Industrial/**VALOR?** Compuesto
26-30-020-000	Propiedad Pública/ **VALOR?** Compuesto
26-30-030-000	Residencial o de Propiedad **subdividida** Mixta/ **VALOR?** Compuesto

DESCRIPCIÓN

Hay vaios procesos industriales que generan corrientes de aguas residuales que contienen compuestos orgánicos. Por lo general estas corrientes se recolectan, se someten a un tratamiento de sus contaminantes y a los pasos de almacenamiento antes de que sean descargadas, ya sea a un cuerpo receptor o a una planta municipal de tratamiento (también llamadas “obras públicas de tratamiento” [POTWs, por sus siglas en inglés], en EU) para recibir un tratamiento posterior. Durante algunas de estas operaciones las aguas residuales están expuestas al aire y se pueden emitir compuestos orgánicos a la atmósfera.

Además de las aguas residuales industriales, las plantas también pueden tratar aguas domésticas, institucionales o comerciales, así como aguas que ingresan al sistema de alcantarillado desde el suelo y desde los escurrimientos pluviales. En general, estos otros tipos de aguas residuales no contienen niveles significativos de GOT. En los EU, si se desconoce la contribución anual real de aguas residuales industriales a estas plantas en una región de inventario, se recomienda un valor por omisión del 16% del flujo total anual (i. e., el promedio nacional). Este valor por omisión basado en datos de los EU tiene una aplicación limitada en México y sólo debe usarse si no existen otros datos disponibles.

Los efluentes de las plantas de tratamiento de aguas residuales deben cumplir con las normas de calidad federales, estatales y municipales antes de ser descargados a un cuerpo receptor. El tamaño y grado del tratamiento de las corrientes de aguas residuales dependerá de su volumen y grado de contaminación, así como del grado de remoción de contaminantes que se desea.

CONTAMINANTES: GOT

GOR: La mayor parte de los hidrocarburos no reactivos que deben excluirse son compuestos orgánicos halogenados. Si hay datos de concentración en las aguas residuales de compuestos químicos específicos, las emisiones de GOT pueden ajustarse para excluir la parte correspondiente a compuestos orgánicos halogenados.

Por ejemplo, si las emisiones de GOT son de 100 Mg/año, la suma de las concentraciones de compuestos orgánicos halogenados es de 40 ppmp y la concentración de COT es de 500 ppmp, entonces:

Parte No Reactiva = (40 ppmp) / (500 ppmp) = 8%

Emisiones = (emisiones de GOT) x (fracción de GOR)
= (100 Mg/año) x (1 - 0.08)
= 92 Mg/año

AJUSTES POR FUENTES PUNTUALES:

El tratamiento de aguas residuales puede ocurrir en plantas grandes que se inventaríen como fuentes puntuales. De manera ideal, el volumen total de aguas residuales tratadas en las fuentes puntuales debería restarse del volumen total de aguas residuales tratadas en la región del inventario y el “volumen total de aguas residuales tratadas en fuentes de área” resultante debe usarse en los cálculos de las emisiones. Si sólo hay datos para las plantas consideradas fuentes puntuales, estas emisiones deben restarse de las emisiones totales calculadas utilizando los métodos aquí descritos para producir la estimación final de emisiones de las fuentes de área.

METODOLOGÍA:

Es necesario determinar la cantidad de aguas residuales industriales tratadas en la región del inventario. Si las estadísticas disponibles no corresponden directamente a las necesidades del inventario (e. g., existen estadísticas a nivel de todo el estado pero la región del inventario incluye porciones de diversos estados o el inventario requiere estimaciones de emisión a nivel municipal) se pueden usar datos de los censos (e.g., población o vivienda) o bien otras estadísticas disponibles para desagregar los totales para la región del inventario. Por ejemplo, los datos de población podrían usarse para el tratamiento de aguas residuales municipales y el número de plantas industriales o los ingresos industriales podrían usarse para el tratamiento de aguas residuales industriales. El ejemplo de calculo para la combustión residencial (combustibles comerciales) (Sección 4.2) ilustra este procedimiento.

El factor de emisión que se desarrolle debe relacionar la masa de contaminante emitido con la cantidad de aguas residuales tratadas (e. g., kg de GOT/litro). Entonces, la ecuación para las emisiones no controladas de GOT es simplemente:

$$\text{Emisiones}_{\text{GOT}} = (\text{volumen de aguas residuales tratadas}) \times \text{FE}_{\text{GOT}}$$

(10.3-1)

Como alternativa, puede aplicarse un enfoque mucho más riguroso usando un modelo de emisiones como el CHEMDAT8 ó el WATER8. Ver la Sección 4.1.4 del Manual de *Técnicas Básicas de Estimación de Emisiones* (Volumen III de esta serie) que contiene mayor información sobre estos modelos de cómputo, sobre las ecuaciones del modelo de emisión y los requerimientos de datos. También la Sección 4.2.8 (i. e., Tratamiento de Aguas Residuales) de los documentos para el desarrollo de un inventario de fuentes de área para el Area Metropolitana de la Ciudad de México (DDF, 1995a) dan información más detallada sobre la manera en que un modelo de emisiones mas antiguo (i. e., *the Surface Impoundment Modeling System* [SIMS] "Sistema de Modelado de Estanques Superficiales") se usó previamente en México para hacer estimaciones de las emisiones de fuentes de área del tratamiento de aguas residuales. Sin embargo, la EPA ya no apoya este modelo.

DATOS NECESARIOS:

Datos	Fuentes
Cantidad de aguas residuales industriales tratadas en la región del inventario	Dependencia Federal: Comisión Nacional del Agua Dependencia estatal o local: (e. g., Dirección General de Construcción y Operación Hidráulica, México, D. F.)
Factor de Emisión 1.3 x 10^{-5} kg de GOT/litro (1.1 x 10^{-4} GOT lb/gal)	U.S. EPA, 1991a

NOTAS:

1. La información sobre las plantas de tratamiento de aguas residuales por regiones en el país se puede encontrar en la Comisión Nacional del Agua, que es la dependencia federal que recopila la información sobre el uso y descarga en los cuerpos de agua federales y que es también una fuente de información sobre las plantas municipales de tratamiento de aguas.

2. El único factor de emisión que está publicado es de 1.3 x 10^{-5} kg/litro (1.1 x 10^{-4} lb/gal) (U.S. EPA, 1991a). Este factor se basa en el reporte sobre el flujo industrial total descargado a las plantas de tratamiento en los EU durante 1984, que fue de 1.6 x 10^{12} galones, y una estimación de emisiones de VOCs a nivel nacional proveniente de las plantas de 78,540 Mg/año. Esta estimación de las emisiones de COVs se basó en las cargas anuales de COVs reportadas para el influente crudo de las plantas, así como en una suposición, que ha sido apoyada por la investigación, de que en el caso de una gran carga química, el 85% de todos los contaminantes volátiles descargados en los sistemas de tratamiento de aguas residuales se emitirán al aire ambiente. Esto es:

   $FE_{COVs} = (78540 \text{ Mg/año}) (10^6 \text{ g/Mg}) / (453.6 \text{ g/lb}) / (1.6 \times 10^{12} \text{ gal/año})$

$= 1.1 \text{ x } 10^{-4}$ lbs COVs/gal

Este valor por omisión basado en datos de los EU tiene aplicación limitada en México y sólo debe usarse si no hay otros datos disponibles

EJEMPLO DE CÁLCULO:

1. Determinar la cantidad de aguas residuales tratadas. Suponer que la cantidad total de aguas residuales tratadas en la región del inventario es de $2{,}500 \times 10^6$ litros/año. Dado que se desconoce la cantidad de aguas residuales <u>industriales</u> tratadas, se usará el valor por omisión de los EU, de 16%.

   $(2{,}500 \times 10^6$ litros/año$) \times (16\%) = 400 \times 10^6$ litros/año

2. Determinar las emisiones de GOT

   Por ejemplo, las emisiones anuales totales de GOT de un estado que trata 400×10^6 litros/año de aguas residuales industriales son:

   $(400 \times 10^6$ litros/año$) \times (1.3 \times 10^{-5}$ kg de GOT/litro$)$ = 5200 kg/año
   = 5.2 Mg/año

3. En caso necesario restar las emisiones de las fuentes puntuales,.

Si hay plantas grandes de tratamiento de aguas residuales en la región del inventario que hayan sido inventariadas como fuentes puntuales entonces sería preferible que el volumen total de aguas residuales tratadas en las fuentes puntuales fuera restado del volumen total de aguas residuales tratadas en la región del inventario y el volumen total de aguas residuales tratadas en las fuentes de área se usara en los cálculos de las emisiones. Por ejemplo, si los gastos de las fuentes puntuales son:

- 10 millones de litros/año para la Planta A y
- 20 millones de litros/año para la Planta B;

Entonces:

$$[(400) - (10 + 20)] \times 10^{6} \text{ litros/año} \times (1.3 \times 10^{-5} \text{ kg de GOT/litro}) = 4810 \text{ kg/año}$$
$$= 4.8 \text{ Mg/año}$$

Si sólo estuvieran disponibles los datos de emisiones para las plantas consideradas fuentes puntuales las emisiones asignadas a éstas deben ser restadas del total calculado para la región del inventario. Por ejemplo, si las emisiones de las fuentes puntuales son:

- 100 kg/año para la Planta A y
- 150 kg/año para la Planta B;

Entonces:

$$\begin{aligned} \text{Emisiones de Fuentes de Área} &= (\text{Emisiones Totales}) - (\text{Emisiones Puntuales}) \\ &= 5200 - (100 + 150) \\ &= 4950 \text{ kg/año} \\ &= 4.95 \text{ Mg/año} \end{aligned}$$

10.4 Aguas Negras y Aguas Residuales en Canales Abiertos

CÓDIGO DE FUENTE:	**DESCRIPCIÓN:**
26-30-090-000*	Tratamiento de Aguas Residuales

*Código específico propuesto para México para una categoría de fuente que en general no se inventaría en los EU.

DESCRIPCIÓN

En algunas áreas de México se pueden usar canales abiertos para conducir aguas negras de origen humano y/o aguas residuales industriales. Por ejemplo, Ciudad Juárez con aproximadamente un millón de habitantes, no tiene sistema de drenaje y manda aproximadamente 55 millones de galones de auas negras crudas diarias hacia canales abiertos sin revestimiento que fluyen a lo largo del Río Bravo (*Sacramento Bee*, 1995b). Estos canales, corrientes, ríos y presas son fuentes de emisiones a la atmósfera por la descomposición del material orgánico y la evaporación de los hidrocarburos presentes en las descargas.

CONTAMINANTES: GOT y NH_3.

GOR: Las aguas residuales industriales pueden incluir clorofluorocarburos (CFCs) u otros compuestos orgánicos que no se consideran reactivos y que deben excluírse de los inventarios de GOR.

AJUSTES POR FUENTES PUNTUALES:

Por lo general, los canales abiertos de aguas negras y las fuentes de aguas residuales no se incluyen en un inventario de fuentes puntuales. Por lo tanto, los ajustes no son necesarios.

METODOLOGÍA:

Se requieren más estudios para desarrollar una metodología para estimar las emisiones de hidrocarburos volátiles provenientes de la descomposición del material orgánico y de las emisiones en canales abiertos. Ahora la EPA está financiando cuando menos una actiidad de este tipo a través del Centro de Información sobre Contaminación del Aire (CICA). El proyecto No. 2 del CICA, *Emission Estimation Techniques for Unique Source Categories in Mexicali, Mexico* (Técnicas de Estimación de Emisiones para Categorías Especiales de Fuentes en Mexicali, México) presentará y evaluará metodologías específicas para el desarrollo de factores de emisión para presas y canales abiertos de aguas residuales. Se espera que el borrador del reporte de este proyecto esté terminado en abril de 1997 y que esté disponible al público en la Página del CICA (*http://www.epa.gov/oar/oaqps/cica/*).

Es probable que en algunas regiones haya datos que sirvan para apoyar un enfoque simple de balance de materiales (e. g., cantidad total de aguas residuales, concentraciones de los contaminantes que se van a inventariar). Sin embargo, es seguro que la metodología deba tomar en cuenta los efectos de la descomposición, ya que esta reacción química puede, tanto destruir algunas especies químicas originalmente descargadas en los canales abiertos, como crear otros subprpoductos. Es interesante señalar que en un estudio de la Universidad Rice se sugiere que en algunos casos es posible que los residuos humanos no se descompongan debido a que los niveles de concentración de los productos químicos industriales matan a las bacterias en el agua (*http://www.rice.edu/projects/TELRC/Colonias/file5.html*).

DATOS NECESARIOS:

Datos	Fuentes
Información general sobre la longitud y condiciones de los canales abiertos.	Dependencias municipales (e. g., la Dirección General de Construcción y Operación Hidráulica del D.D.F.)
Número de viviendas y habitantes por disponibilidad y tipo de drenaje	INEGI (e. g., Reporte del censo de 1990)
Cantidad de aguas residuales generadas per cápita (desarrollada potencialmente a partir de la cantidad de aguas residuales tratadas y del número de habitantes atendidos por las plantas de tratamiento de aguas residuales existentes).	Plantas locales de tratamiento de aguas residuales.

NOTAS:

1. Por determinarse.

EJEMPLO DE CÁLCULO:

Por determinarse.

11.0 FUENTES DE ÁREA MISCELANEAS

Algunas fuentes diversas de emisiones pueden ser demasiado pequeñas o demasiado numerosas para ser incluidas en el inventario de fuentes puntuales de una región determinada. Por lo tanto, estas fuentes necesitan incluirse en el inventario de fuentes de área. La guía para esta fuentes se presenta en las siguientes subsecciones:

- Incendios Silvestres;
- Incendios de Construcciones;
- Polvo de Caminos Pavimentados;
- Polvo de Caminos sin Pavimentar;
- Erosión Del viento y
- Emisiones Domésticas de Amoníaco.

11.1 Incendios Silvestres10.1 Wildfires

CÓDIGO DE FUENTE: 28-10-001-000

DESCRIPCIÓN:

Los incendios silvestres ocurren de manera natural en México pero otras causas significativas de las emisiones de este tipo de incendios son aquellos provocados de manera intencional para promover el crecimiento de pastos para el pastoreo de ganado. El uso de incendios prescritos para el manejo de ecosistemas forestales no se practica en México. La mayor parte de los incendios ocurren en las regiones central y sur del país durante los meses que van de enero a mayo. Estos incendios no sólo ocurren en pastizales sino también en áreas forestales. En junio termina la estación de incendios cuando comienzan las lluvias de verano. Una excepción a esto se presenta en Baja California donde los incendios de matorrales ocurren de manera muy similar a como lo hacen en California.

Debido a que estos incendios tienden a presentarse durante la parte más fresca del año por lo general no arden con altas temperaturas. Esto da como resultado que la mayor parte sean incendios de superficie más que incendios de corona. Además, los incendios tienden a ser pequeños, aunque numerosos. Esto es particularmente cierto en los terrenos públicos, en los que se provocan más incendios que en los terrenos privados. Las estadísticas sobre la cantidad de acres quemados anualmente son conservadas por SEMARNAP.

CONTAMINANTES: GOT, CO y PM_{10}

GOR: La emisiones de GOT constituyen el 45% de los GOT.

AJUSTES POR FUENTES PUNTUALES: Ninguno.

METODOLOGÍA:

La ecuación básica para estimar las emisiones de incendios silvestres es:

$$\text{Emisiones}_i = FE_i \times L \times C \times A \qquad (11.1\text{-}1)$$

donde:
Emisiones_i = Emisiones totales del contaminante i
FE_i = Factor de emisión para el contaminante i (g/kg)
L = Carga de combustible (kg/ha)
C = Porcentaje de la carga de combustible que es consumido por el incendio
A = Superficie quemada (ha).

Los valores de la carga de combustible son estimaciones específicas para cada lugar de la masa secada al horno de los combustibles vegetales disponibles para ser consumidos por un incendio. De manera ideal, éstos se definen mejor en términos de la clase del tamaño del combustible, tales como combustibles finos (diámetro de 0-1”), combustibles pequeños (diámetro de 1-3”), combustibles leñosos grandes (diámetro mayor a 3”), vegetación viva y mantillo (humus parcialmente descompuesto). Cada componente del combustible tiene una propensión diferente a arder en un incendio y equilibra su contenido de humedad con el medio que lo rodea a una tasa diferente.
La cantidad de combustible disponible que realmente es consumido por un incendio es una función compleja de muchas variables, pero los principales parámetros son el contenido de humedad del combustible, la distribución de clase de tamaño y el arreglo del combustible, la velocidad del viento y la intensidad del fuego. Existen modelos de consumo, tales como el CONSUME para muchos combustibles en los EU (Ottmar *et al*., 1993). Si no se dispone de alguno de estos modelos se puede hacer la suposición conservadora de que el 100% del combustible disponible es consumido (i. e., C = 1.0).

De manera ideal, las estimaciones de consumo se calculan separadamente para el combustible consumido en las fases de la combustión, llameante y sin llama. Esta distinción es importante debido a que cada fase de la combustión ocurre con una eficiencia de combustión característica (η). La eficiencia de combustión completa ($\eta = 1.00$) produce solamente agua, dióxido de carbono y una pequeña cantidad de contaminantes inorgánicos. En la práctica, sin embargo, la combustión completa no ocurre nunca. La combustión sin llama es muy ineficiente y produce una mayor proporción de contaminantes en comparación con la combustión llameante. En general, los factores de emisión presentados en esta sección son función de la eficiencia de combustión. Para hacer las estimaciones detalladas de emisión, primero deben hacerse por separado las estimaciones para las emisiones llameantes y las emisiones sin llama porque las emisiones de la fase llameante, aunque son más “limpias”, pueden ser transportados a largas distancias cuando están contenidos en una pluma muy flotante proveniente de un gran incendio, mientras que las emisiones de la fase sin llama son más “sucias” y muy importantes para evaluar los impactos locales. El manejo de las emisiones puede hacerse limitando la combustión de la fase sin llama lo que puede lograrse: 1) programando las igniciones para aprovechar el contenido de humedad del combustible limitando así la duración de la combustión sin llama; y 2) limpiando muy bien después de la fase de llama para extinguir los rescoldos.

El consumo estimado total de combustible (después de sumar las fases llameante y sin llama) se presenta en la Tabla 11.1-1 para varios combustibles del oeste de los EU. Estos combustibles (o especies similares) también se extienden hasta México por lo que se espera que los valores de consumo sean representativos de las condiciones en este país. Los valores de consumo de combustible que se presentan en la Tabla 11.1-1 son en realidad producto de los términos L y C de la ecuación 11.1-1. Las estimaciones de consumo de combustible están dadas para un escenario de tiempo de incendio “seco” (usado para incendios silvestres en condiciones de sequía severa), para un escenario de tiempo de incendio “normal” (usado para las quemas por prescripción o para los incendios silvestres en condiciones moderadamente secas) y para un escenario de tiempo “húmedo” (usado para las quemas por prescripción o para los incendios silvestres en condiciones de mas humedad). Las estimaciones de quema de combustible de la Tabla 11.1-1 se obtuvieron asignando clasificaciones estándar de vegetación de la Society of American Foresters (SAF) *(Sociedad de Silvicultores Americanos)* y de la Society for Range

Management (SRM) *(Sociedad de Manejo de Praderas)* a uno de los modelos del sistema de combustibles de la National Fire Danger Rating (NFDR, por sus siglas en inglés) *(Clasificadora Nacional de los Peligros de Incendio)* (Deeming y Cohen, 1982). Para cada clasificación de vegetación presentada en la Tabla 11.1-1 se identifica el modelo NFDR específico (T, F, L, H ó C) usado en las estimaciones de quema de combustibles. Asimismo, para cada modelo específico, la carga de combustible y la intensidad del fuego resultante se ha identificado como baja, media o alta (Hardy et al., 1997). Los datos de la Tabla 11.1-1 representan sobre todo a una vegetación en un nivel de desarrollo maduro temprano. Si la vegetación se encuentra en etapas anteriores o posteriores de desarrollo las cargas serán diferentes.

Como se mencionó antes, las especies presentadas en la Tabla 11.1-1 son las que se encuentran tanto en EU como en México. Los datos deesta tabla no son apropiados para las especies nativas de México, sobre todo para aquellas que se encuentran en las áreas tropicales del país. La Tabla 11.1-1 también incluye factores promedio de emisión de $PM_{2.5}$ para cada escenario de combustible y tiempo, calculado a partir de los factores promedio de emisión de PM_{10} (Hardy *et al.*, 1997) por medio de un modelo de regresión desarrollado por Ward *et al.* (1993).

Algunos factores de emisión adicionales para combustibles de los páramos se presentan en la Tabla 11.1-2. Estos datos se basan en emisiones medidas de algunos combustibles representativos de los EU (Ward et al., 1993). Las interrelaciones entre los contaminantes emitidos permite calcular el factor de emisión a partir de la eficiencia de la combustión o de los datos de $PM_{2.5}$ data en la Tabla 11.1-1.

Tabla 11.1-1.

Consumo Total de Combustible, Factores de Emisión de $PM_{2.5}$ y Estimaciones de la Eficiencia de Combustión para Algunos Combustibles Representativos del Oeste de los EU

Combustible [a]	Escenario del Tiempo del Incendio	Consumo Total de Combustible (kg/ha)	Factor de Emisión de $PM_{2.5}$ (g/kg)	Eficiencia Promedio de la Combustión del Incendio h
Cola de antílope - Pasto empenachado: SRM104, T, M	Seco	2,317	6.99	0.90
	Normal	2,317	6.99	0.90
	Húmedo	2,317	6.78	0.90
Roble Azul - Pino Excavador: SAF250, F, H	Seco	2,317	6.95	0.90
	Normal	2,197	6.65	0.91
	Húmedo	1,877	5.55	0.93
Bosque de Roble Azul: SRM201, L, M	Seco	819	8.09	0.89
	Normal	799	8.09	0.89
	Húmedo	799	7.75	0.89
Chamizal: SRM206, F, M	Seco	2,317	6.99	0.90
	Normal	2,317	6.99	0.90
	Húmedo	2,317	6.78	0.91
Abeto Douglas Interior: SAF210, H, L	Seco	7,749	9.32	0.87
	Normal	7,050	9.36	0.87
	Húmedo	4,553	8.81	0.88
Pino Ponderosa Interior: SAF237, T, H	Seco	5,772	8.52	0.88
	Normal	5,292	8.52	0.88
	Húmedo	3,715	7.75	0.89
Bosque de Juníperos: SAF412, L, M	Seco	1,038	7.20	0.90
	Normal	1,038	7.20	0.90
	Húmedo	1,038	6.95	0.90

Tabla 11.1-1. (Continuación)

Combustible [a]	Escenario del Clima del Incendio	Consumo Total de Combustible (kg/ha)	Factor de Emisión de $PM_{2.5}$ (g/kg)	Eficiencia Promedio de la Combustión del Incendio h
Pino para Construcción: SAF218, H, H	Seco	4,993	7.46	0.90
	Normal	4,733	7.50	0.90
	Húmedo	4,074	7.58	0.90
Mezquite: SAF242, T, M	Seco	2,396	6.99	0.90
	Normal	1,358	5.81	0.92
	Húmedo	1,138	4.45	0.94
Pino Ponderosa - arbustos: SRM109, T, M	Seco	7,649	8.26	0.89
	Normal	7,130	8.43	0.88
	Húmedo	5,372	8.05	0.89
Pino Ponderosa - pastizal: SRM110, C, H	Seco	5,951	9.45	0.87
	Normal	5,432	9.41	0.87
	Húmedo	3,415	8.14	0.89
Abeto Blanco: SAF211, H, M	Seco	7,968	9.28	0.87
	Normal	7,269	9.36	0.87
	Húmedo	4,813	8.98	0.87

[a] Base para el consumo de combustible (clasificación vegetal, modelo NFR utilizado, suposición sobre la intensidad del fuego [alta, media o baja]).

Tabla 11.1-2.

Algoritmos de los Factores de Emisión

Contaminante (FE)	Algoritmo del Factor de Emisión	Unidades	Incertidumbre
Monóxido de carbono (CO)	$961 - (\eta \times 984)$	g/kg	±10%
Metano (CH_4)	$42.7 - (\eta \times 43.2)$	g/kg	±20%
Hidrocarburos no metano (NMHC)	$0.76 + (FE_{CH4} \times 0.616)$	g/kg	±25%
GOT	$FE_{CH4} + FE_{NMHC}$	g/kg	±25%
PM_{10}	$1.18 \times FE_{PM2.5}$	g/kg	±25%

DATOS NECESARIOS:

Datos	Fuentes
Superficie quemada	SEMARNAP
Carga de combustible y consumo	Datos específicos de México; Tabla 11.1-1
Factores de emisión	Datos específicos de México; Tabla 11.1-2

NOTAS:

1. La información presentada en las Tablas 11.1-1 y 11.1-2 no intenta ser exhaustiva, sino más bien contiene valores representativos. Si se requiere información adicional más detallada se deben consultar las referencias citadas en esta sección.

2. Todavía no se han calculado valores de carga de combustible para México. La carga de combustible depende de la edad y la distribución de las especies en cada sitio quemado por lo que se determina mejor a partir de inventarios de biomasa vegetal de los sitios representativos. Hasta que estos valores estén disponibles se pueden usar modelos de combustibles de otras regiones, tales como los EU, para estimar la carga de combustible mexicanas. Referirse a la Tabla 11.1-1 para obtener los datos de carga de combustibles de los EU que pueden ser usados en lugar de los datos específicos para México.

3. Los datos de consumo de combustible para México aún no han sido desarrollados. El consumo de combustible en las fases llameante y sin llama del incendio se determina mejor a partir de los inventarios de biomasa vegetal antes y después del incendio.

4. Todavía no se calculan los factores de emisión para la biomasa vegetal mexicana. Hasta que estos datos estén disponibles se pueden usar modelos de combustible de otras regiones, tales como los EU, para estimar los factores de emisión para los incendios mexicanos de vegetación. Referirse a las Tablas 11.1-1 para obtener los factores de emisión de los EU que pueden utilizados en lugar de los valores específicos de México

5. En la actualiad Radian está trabajando con Ernesto Alvarado y Roger Ottmar del USDA Forest Service, Pacific Northwest Research Station *(Servicio Forestal de EU, Estación de Investigación del Noroeste del Pacífico)* (206-553-7815) para desarrollar datos de carga de combustible y factores de emisión apropiados para usarse en México.

EJEMPLO DE CÁLCULO:

Estimar las emisiones de CO de un incendio por prescripción de 120 hectáreas de abeto Douglas interior a principios de la primavera.

1. Determinar el consumo de combustible para el incendio de 120 hectáreas (suponer que las condiciones a principios de la primavera están representadas por los datos de consumo "húmedo" en la Tabla 11.1-1):

   $A = 120$ ha
   $(L \times C) = 4{,}553$ kg/ha

   120 ha quemadas × 4,553 kg de combustible consumido/ha = 546,360 kg de combustible consumido

2. A continuación estimar el factor de emisión de CO a partir de la ecuación apropiada en la Tabla 11.1-2. Se usa la estimación de eficiencia de combustión (η) obtenida de la Tabla 11.1-1:

   $$EF_{CO} = 961 - (0.88 \times 984)$$
   $$= 95.08 \text{ g CO / kg de combustible consumido.}$$

3. Finalmente, estimar las emisiones totales del incendio utilizando el factor de emisión calculado para el CO y el consumo del combustible del paso 1:

   $$546{,}360 \text{ kg combustible} \times \left(\frac{95.08 \text{ g de CO}}{\text{kg combustible}} \right) = 51{,}948 \text{ kg de CO}$$
   $$= 51.9 \text{ Mg de CO}$$

11.2 Incendios de Construcciones

CODIGO DE FUENTE: 28-10-030-000

DESCRIPCIÓN:

Igual que otras fuentes de combustión, los incendios de construcciones generan emisiones de GOT, CO, NO_x y partículas. Sin embargo, a diferencia de otras fuentes de combustión, estos incendios no son intencionales y en consecuencia la cantidad de combustible quemado puede ser difícil de determinar.

Para estimar las emisiones de los incendios de construcciones primero es necesario determinar la cantidad de material quemado. Esto incluye tanto los materiales estructurales como el contenido del edificio. En esta sección se incluyen algunos valores típicos para los edificios de apartamentos en los EU. Sin embargo, se piensa que los valores en México pueden ser drásticamente diferentes debido a las diferencias en la construcción (i. e., en los EU las casas están construidas de madera de manera predominante, mientras que las mexicanas son de ladrillos o de otros materiales diferentes de la madera). Es deseable tener valores específicos para México por lo que éstos deben desarrollarse.

CONTAMINANTES: GOT, CO, NO_x y partículas

GOR: La emisiones de GOT constituyen el 69.9% de los GOT.

AJUSTES POR FUENTES PUNTUALES: Ninguno.

ECUACIONES:

$$\text{Emisiones}_p = \text{Incendios} \times \%\text{Pérdidas} \times (\text{MC}_{\text{Edificio}} + \text{MC}_{\text{Contenidos}} \times \text{FE}_p \qquad (11.2\text{-}1)$$

donde:
Emisiones_p = Emisiones totales anuales del contaminante p;
Incendios = Número total anual de incendios;
%Pérdidas = Porcentaje promedio pérdida de la construcción;
$\text{MC}_{\text{Edificio}}$ = Cantidad de material combustible del edificio mismo;
$\text{MC}_{\text{Contenidos}}$ = Cantidad de material combustible de los contenidos del edificio
FE_p = Factor de emisión para el contaminante p.

El porcentaje promedio de pérdida de la construcción se debe estimar porque los incendios de este tipo no consumen el 100% del material combustible disponible. Muchos de estos incendios son extinguidos antes de que la construcción se haya consumido por completo. En California, el porcentaje promedio de pérdida de la construcción se ha estimado en 7.3%.Éste podría usarse como valor por omisión para México pero es deseable tener una estimación específica para este país.

En EU, la casa habitación promedio tiene entre 111 y 139 m^2 (1,200-1,500 ft^2) de espacio de piso, con un peso de 9.1 a 10.9 Mg (10-12 tons) de materiales de construcción combustibles. Es probable que estas estadísticas no describan con exactitud las casas habitación en México. De manera específica, es probable que las casas de ladrillos, bloques de concreto y adobe, materiales tan extendidos en México, contengan menores cantidades de materiales combustibles.

En los EU se han determinado valores para el contenido de combustible por pie cuadrado para las diferentes áreas funcionales de la casa promedio. Estos valores se presentan en la Tabla 11.2-1 (CARB, 1995).

Tabla 11.2-1

Contenido de Materiales Combustibles para Diferentes Áreas Funcionales en los EU

Área Funcional	Origen de Incendios (%)	Combustibles (lbs/ft^2)	Combustibles (kg/m^2)	Promedio Ponderado (lbs/ft^2)
Recámara	28.96	10.4	50.8	3.01
Área de Dormitorios	0.20	10.4	50.8	0.02
Área del Comedor	2.20	7.2	35.2	0.16
Cocina	53.92	6.8	33.2	3.67
Baño	6.32	7.0	34.2	0.44
Lavandería	8.08	7.2	35.2	0.58
Estudio	0.17	7.9	38.6	0.01
Otro	0.13	9.6	46.9	0.01
Total	100.00	—	—	7.90

En los EU se ha estimado un promedio ponderado de 7.90 lbs/ft^2 (38.6 kg/m^2) de contenidos combustibles utilizando la distribución de ocurrencia de incendios para diferentes áreas funcionales multiplicada por el contenido de combustible en cada área funcional. Este valor puede no ser exacto para México en cuyo caso sería necesario estimar un contenido de combustible específico para el país.

DATOS NECESARIOS:

Datos	Fuentes
Número de Incendios	Departamento local de bomberos
Pérdida Porcentual Promedio de Construcción	Departamento local de bomberos o asociación nacional de protección contra incendios; valores por omisión para los EU.
Cantidad de Material de Construcción Combustible	INEGI, asociación nacional de protección contra incendios o asociación nacional de constructores; valores por omisión para los EU.
Cantidad de Contenidos Combustibles en el Edificio	INEGI, asociación nacional de protección contra incendios o asociación nacional de constructores; valores por omisión para los EU.
Factor de emisión de GOT[a] 6.95 kg/Mg (13.9 lbs/ton)	ARB, 1995
Factor de emisión de CO[a] 84 kg/Mg (168 lbs/ton)	ARB, 1995
Factor de emisión de NO_x [b] 2.0 kg/Mg (4.0 lbs/ton)	ARB, 1995
Factor de emisión de partículas[a] 5.4 kg/Mg (10.8 lbs/ton)	ARB, 1995

[a] Los factores de emisión de GOT, CO y partículas fueron obtenidos de pruebas realizadas durante los incendios de edificios de madera modelo.

[b] Se supone que el factor de emisión de NO_x es similar al que se presenta en el AP-42 para desechos municipales.

EJEMPLO DE CÁLCULO:

Un municipio reportó 1,100 incendios en 1995. Se estimó que la pérdida porcentual de construcción fue de aproximadamente 14%. La mayor parte de las casas en este municipio están construidas de ladrillos o de bloques de concreto por lo que se estima que el material combustible de la construcción era de sólo 2.5 Mg por casa. También se estimó que hay 25 kg de contenidos combustibles por metro cuadrado sabiendo que una casa típica mide 90 m^2. Los valores en este ejemplo sólo son para propósitos ilustrativos y no pretenden representar las condiciones en México, por lo que no deben usarse para hacer estimaciones de emisiones.

1. Cantidad total de contenidos combustibles por casa:

$$(25\ \text{kg/m}^2) \times 90\ \text{m}^2 = 2{,}250\ \text{kg}$$
$$= 2.25\ \text{Mg}$$

2. Emisiones totales de CO:

$$1{,}100\ \text{incendios} \times 0.14 \times (2.5\ \text{Mg} + 2.25\ \text{Mg}) \times (84\ \text{kg CO/Mg combustible quemado})$$
$$= 61{,}446\ \text{kg CO}$$
$$= 61.4\ \text{Mg CO}$$

11.3 Polvo de Caminos Pavimentados

CÓDIGO DE FUENTE	DESCRIPCIÓN
22-94-000-000	Todos los Caminos Pavimentados
22-94-005-000	Caminos Interestatales y Arterias
22-94-010-000	Todos los Demás Caminos Públicos
22-94-015-000	Caminos Industriales

DESCRIPCIÓN:

Cuando los vehículos circulan sobre las superficies de caminos pavimentados, el polvo que se ha depositado sobre la superficie pavimentada o que ha sido llevado a ésta es arrastrado por la estela turbulenta del vehículo y se emite como partículas. En la actualidad, las emisiones se calculan como una función de la carga de sedimentos de la superficie pavimentada y del peso promedio de los vehículos que circulan sobre ella. A su vez, la carga de sedimentos es función del tipo de camino. Por lo general, los caminos con altos volúmenes de tránsito tienen menores cargas de sedimentos que aquellos con bajos volúmenes. El sedimento se define como el material que atraviesa una criba de malla 200 usando el método ASTM-C-136.

Se están haciendo investigaciones adicionales para refinar el método usado actualmente para estimar emisiones. Esta sección se actualizará a medida que haya nueva información disponible. Se debe preguntar al INE cual es el método de estimación más reciente.

CONTAMINANTES: PM_{10}

GOR: No es aplicable.

AJUSTES POR FUENTES PUNTUALES: Ninguno.

METODOLOGÍA:

Para calcular un factor de emisión específico para la región se usa la siguiente ecuación empírica:

$$FE = k \left(\frac{Cs}{2} \right)^{0.65} \left(\frac{P}{3} \right)^{1.5} \qquad (11.3\text{-}1)$$

donde:
EF = factor de emisión de partículas
k = Multiplicador del tamaño de partícula (g/VKT)
Cs = Carga de sedimentos en la superficie del camino (g/m^2)
P = Peso promedio del vehículo (Mg).

Con base en datos recopilados en EU se ha encontrado que las cargas de sedimentos tienen importantes variaciones espaciales y temporales. Para los caminos que tienen un elevado tránsito promedio diario (ADT, por sus siglas en inglés) la distribución de frecuencia de los datos disponibles da un valor de carga del tamaño de 0.4 g/m^2 para el percentil 50 y de 7 g/m^2 para el percentil 90. Los datos correspondientes para los caminos con bajo ADT son 2.5 y 25 g/m^2 respectivamente. Para una autopista, la carga promedio de sedimentos baja hasta 0.02 g/m^2 (el valor para el percentil 90 no está disponible).

Además, esta ecuación es muy aplicable para las siguientes condiciones:

Carga de sedimentos:	0.02 a 400 g/m^2;
Peso promedio del vehículo:	1.8 a 38 Mg y
Velocidad promedio del vehículo:	16 a 88 km/hr.

Si se aplica esta ecuación en regiones con parámetros fuera de estos intervalos se obtendrán estimaciones muy inciertas. Las emisiones de polvo de caminos pavimentados se estiman usando la siguiente ecuación:

$$\text{Emisiones}_p = FE_p \times VKT_p \qquad (11.3\text{-}2)$$

donde:

Emisiones_p = Emisiones anuales de PM_{10} del polvo de caminos pavimentados;

FE_p = Factor de emisión de polvo de caminos pavimentados y

VKT_p = VKT anual de caminos pavimentados.

DATOS NECESARIOS:

Datos	Fuentes
Vehículos kilómetros Recorridos (VKT)	Obtenerlo de los cálculos para el modelado de emisiones de vehículos automotores. También ver el *Manual de Emisiones de Vehículos Automotores*.
Multiplicador del tamaño de partícula (k): 4.6 g/VKT para PM_{10}	U.S. EPA, 1995
Carga de sedimentos	Muestras locales (preferentemente por tipo de camino)
Peso promedio del vehículo	Análisis de la flotilla de vehículos automotores. Ver los datos de emisión de vehículos automotores para las características de la flotilla.

NOTAS:

1. En los Apéndices C.1 y C.2 del AP-42 se pueden encontrar métodos para determinar los datos de sedimentos específicos por región.

2. Si no es posible calcular los datos de carga de sedimentos específicos por región se pueden consultar las tablas del Apéndice V-D de este manual. Si es necesario, los datos apropiados de esta tabla se pueden extrapolar a otras regiones.

3. Si es necesario, se puede usar un valor por omisión para el peso promedio por vehículo de 2.2 Mg.

EJEMPLO DE CÁLCULO:

Las siguientes estimaciones de tránsito diario fueron calculados para una región geográfica definida: 1.1 millones VKT para autopistas; 500,000 VKT para caminos con alto ADT y 175,000 VKT para caminos con bajo ADT. Usando valores por omisión se tendría una primera aproximación de las emisiones de PM_{10} :

$$\text{Autopistas} = (1{,}1000{,}000)(4.6)\left(\frac{0.02}{2}\right)^{0.65}\left(\frac{2.2}{3}\right)^{1.5}(10^{-6})(365)$$

$$= 58.1 \text{ Mg/año}$$

$$\text{Caminos con Alto ADT} = (500{,}000)(4.6)\left(\frac{0.4}{2}\right)^{0.65}\left(\frac{2.2}{3}\right)^{1.5}(10^{-6})(365)$$

$$= 185.2 \text{ Mg/año}$$

$$\text{Caminos con Bajo ADT} = (175{,}000)(4.6)\left(\frac{2.5}{2}\right)^{0.65}\left(\frac{2.2}{3}\right)^{1.5}(10^{-6})(365)$$

$$= 213.3 \text{ Mg/año}$$

$$\text{Emisiones Totales} = 58.1 + 185.2 + 213.3$$

$$= 456.5 \text{ Mg/año}$$

11.4 Polvo de Caminos No Pavimentados

CÓDIGO DE FUENTE	DESCRIPCIÓN
22-96-000-000	Todos los caminos sin pavimentar
22-96-005-000	Caminos públicos sin pavimentar
22-96-010-000	Caminos industriales sin pavimentar

DESCRIPCIÓN:

Cuando los vehículos circulan sobre las superficies de los caminos sin pavimentar el polvo que contienen es arrastrado por la estela turbulenta del vehículo y es emitido como partículas. En el momento en que los vehículos pasan sobre la superficie la fuerza de las ruedas muele el material del camino en partículas más pequeñas reponiendo así parcialmente el contenido de sedimentos del camino.

Las emisiones se estiman como una función del volumen de tránsito, del contenido de sedimentos en la superficie sin pavimentar, de la velocidad de los vehículos, del número promedio de ruedas y del peso promedio de los vehículos que transitan sobre la superficie y del número de días con una precipitación superior a los 0.254 mm. El contenido de sedimentos, definido como partículas con un tamaño inferior a 75 micrómetros varía espacialmente y por tipo de camino (e. g., los caminos de grava tienen un contenido de sedimentos diferente al de los caminos de terracería). El contenido de sedimentos de un camino se determina midiendo la proporción de polvo superficial seco y suelto que pasa a través de una criba de malla 200 usando el método ASTM-C-136.

CONTAMINANTES: PM_{10}

GOR: No es Aplicable.

AJUSTES POR FUENTES PUNTUALES: Ninguno.

METODOLOGÍA:

La siguiente ecuación empírica se usa para calcular un factor de emisión específico para un sitio:

$$FE = k(1.7)\left(\frac{s}{12}\right)\left(\frac{v}{48}\right)\left(\frac{P}{2.7}\right)^{0.7}\left(\frac{r}{4}\right)^{0.5}\left(\frac{365 - p}{365}\right) \qquad (11.4\text{-}1)$$

donde:
FE = Factor de emisión (kg/VKT);
k = Multiplicador del tamaño de partícula (adimensional);
s = Contenido de sedimentos del material de la superficie del camino (%);
v = Velocidad promedio del vehículo (km/hr);
P = Peso promedio del vehículo (Mg);
r = Número promedio de ruedas y
p = Número de días con una precipitación > 0.25 mm.

En algunos estudios previos hechos en los EU se ha encontrado que la carga de sedimentos de caminos sin pavimentar varía significativamente. Por ejemplo, en los caminos de terracería se han observado valores del contenido de sedimentos del 1.6 al 68% con un valor medio de 12%. Siempre que sea posible es deseable obtener muestras locales y medirles el contenido de sedimentos.

Además, la ecuación empírica presentada anteriormente es muy aplicable en las siguientes condiciones:

Contenido de sedimentos:	4.3 a 20%;
Peso promedio del vehículo:	2.7 a 142 Mg;
Velocidad promedio del vehículo:	21 a 64 km/hr y
Número promedio de ruedas:	4 a 13.

Al aplicar esta ecuación en regiones con parámetros fuera de estos límites se obtendrán estimaciones sumamente inciertas. Las emisiones de polvo de caminos sin pavimentar se estiman usando las siguientes ecuaciones:

$$\text{Emisiones}_{sp} = FE_{sp} \times VKT_{sp} \tag{11.4-2}$$

donde:
Emisiones_{sp} = Emisiones anuales de PM_{10} del polvo de caminos sin pavimentar;
FE_{sp} = Factor de emisión de polvo de un camino sin pavimentar y
VKT_{sp} = VKT anual de un camino sin pavimentar.

DATOS NECESARIOS:

Datos	Fuentes
Vehículos Kilómetros Recorridos (VKT)	Datos locales de uso de vehículos. También ver el Manual de Emisiones de Vehículos Automotores
Multiplicador del tamaño de partícula(k): 0.36	U.S. EPA, 1995
Contenido de sedimentos	Muestras locales (de preferencia, por tipo de camino)

Datos	Fuentes
Peso promedio del vehículo	Análisis de la flotilla de vehículos automotores; ver los datos de modelado de emisiones de vehículos automotores para las características de la flotilla.
Velocidad promedio del vehículo	Observación de las velocidades locales
Número promedio de ruedas	Análisis de la flotilla de vehículos automotores; ver los datos de modelado de emisiones de vehículos automotores para las características de la flotilla.

NOTAS:

1. Los métodos para determinar los datos de sedimentos específicos para un sitio se pueden encontrar en los Apéndices C.1 y C.2 del AP-42.

2. Si no es posible calcular los datos de carga de sedimentos específicos para un sitio se pueden usar los siguientes valores por omisión. Camino rural de grava: de 5.0 a 13% con un valor promedio de 8.9%. Camino rural de terracería: de 1.6 a 68% con un valor promedio de 12%. Camino municipal sin pavimentar: de 0.4 a 13% con un valor promedio de 5.7%. En el AP-42 se pueden encontrar otros valores adicionales para caminos industriales.

3. Como valor por omisión se puede usar un peso promedio del vehículo de 2.2 Mg.

EJEMPLO DE CÁLCULO:

Para una región geográfica definida el VKT anual para caminos municipales sin pavimentar se estima en 2.3 millones VKT. Además, se estima que el 80% de este VKT ocurre en caminos de grava y el 20% en caminos rurales de terracería. La velocidad promedio en los caminos de grava es de 20 km/hr mientras que en los caminos rurales de terracería es de 10 km/hr. Anualmente hay 20 días con una precipitación superior a 0.25 mm. Usando los valores por omisión se obtiene una primera aproximación para las emisiones de PM_{10} de:

Caminos de Grava

$$= (2.3 \times 10^{6}\ \text{VKT})\ (0.80)\ (0.36)\ (1.7) \left(\frac{8.9}{12}\right) \left(\frac{20}{48}\right) \left(\frac{2.2}{2.7}\right)^{0.7} \left(\frac{5}{4}\right)^{0.5} \left(\frac{365 - 20}{365}\right) (10^{-3})$$

$$= 319\ \text{Mg}$$

Caminos de terracería

$$= (2.3 \times 10^{6})\ (0.20)\ (0.36)\ (1.7)\ \left(\frac{12}{12}\right)\left(\frac{10}{48}\right)\left(\frac{2.2}{2.7}\right)^{0.7}\left(\frac{4}{4}\right)^{0.5}\left(\frac{365 - 20}{365}\right)(10^{-3})$$

$$= 48\ \text{Mg}$$

Emisiones Totales = 319 + 48

= 367 Mg/año

11.5 Erosión Eólica

CODIGO DE FUENTE: 27-30-100-000

DESCRIPCIÓN:

Durante los periodos de vientos de alta velocidad, las partículas pequeñas de polvo pueden ser arrastradas por el viento y emitidas a la atmósfera como partículas. Por lo general, estas emisiones se asocian con suelos perturbados, como los campos agrícolas en cultivo o grandes sitios de construcción. Además, las emisiones pueden originarse en terrenos baldíos, en cunetas que contienen tierra suelta y en caminos sin pavimentar. Los suelos naturales que no han sido perturbados se consideran fuentes despreciables de polvo movido por el viento. De manera gradual, las fuentes que no se perturban de manera periódica pierden su capacidad para emitir polvo movido por el viento.

CONTAMINANTES: PM_{10}

GOR: No es Aplicable.

AJUSTES POR FUENTES PUNTUALES: Ninguno

METODOLOGÍA:

La técnica actual de estimación de emisiones para esta categoría se basa en una versión modificada de la ecuación de erosionabilidad del suelo desarrollada por el Departamento de Agricultura de los EU (USDA por sus siglas en inglés) (U.S. EPA, 1977). La siguiente ecuación presenta el enfoque modificado del USDA:

$$E_s = (FS)\ I\ C\ K\ L'\ V' \tag{11.5-1}$$

donde:
E_s = Factor de emisión de partículas suspendidas (ton/acre/año);
FS = Fracción de las pérdidas totales por erosión del viento medidas como partículas suspendidas;
I = Erosionabilidad del suelo (ton/acre/año)
C = Factor climático (adimensional);
K = Factor de rugosidad de la superficie (adimensional);
L' = Factor de amplitud del campo sin protección (adimensional) y
V' = Factor de cobertura vegetal (adimensional).

Fracción de la Pérdida por Erosión del Viento - FS

Este término representa la fracción de las pérdidas por erosión del viento que serían medidas como partículas suspendidas. Una determinada cantidad de suelo se "arrastra" sobre la superficie y no es suspendida en la atmósfera como una fuente de emisión. Por lo general se supone un valor de 2.5% para los suelos agrícolas y se usa un valor de 3.8% para los caminos sin pavimentar y para otras áreas. De la cantidad suspendida, alrededor del 50% son PM_{10}.

Erosionabilidad del Suelo - I

El factor de erosionabilidad del suelo es función de la textura o tipo de suelo. El tipo de suelo se obtiene de los mapas de suelos del área. En una región de inventario puede haber uno o más tipos de suelo por lo que habría diferentes grados de erosionabilidad en diferentes partes de la región. Debido a una falta de información sobre los límites correspondientes al área de cada tipo de suelo, por lo general el factor de erosionabilidad se basa en el tipo de suelo predominante en la región del inventario. La Tabla 11.5-1 enlista los factores de erosionabilidad (I) para 12 tipos predominantes de suelo.

Factor Climático - C

El factor climático C depende de la velocidad del viento y de la humedad de la superficie del suelo. La tasa de movimiento del suelo varía directamente con la velocidad del viento e inversamente con la humedad de la superficie y se calcula a partir de la siguiente ecuación:

$$C = \frac{(0.345)V^3}{\left[115\sum_{i=1}^{12}\left(\frac{PM_i}{TMi - 10}\right)^{10/9}\right]^2} \qquad (11.5\text{-}1)$$

donde: V = Velocidad media anual del viento (mph), corregida a 30 pies;
PM = Precipitación mensual en pulgadas y
TM = Temperatura promedio mensual en grados Fahrenheit (considerada igual a 28.4° si es inferior a 28.4°).

El factor climático, más que cualquier otro en la ecuación del polvo levantado por el viento, se hace menos exacto a medida que se aplica un valor promediado a las áreas más pequeñas y a períodos de tiempo más cortos. También es importante señalar que, a valores equivalentes para los otros parámetros, un viento de 100 mph arrastra 125 veces más partículas en una hora que un viento de 20 mph. De esta manera, un año con severas tormentas de viento puede tener emisiones de polvo arrastrado por el viento cuatro o cinco veces más grandes que las de un año sin dichas tormentas.

La velocidad del viento también es un parámetro importante para calcular estimaciones temporales de emisión. La velocidad promedio del viento no puede usarse con este propósito debido a que en la ecuación está elevada al cubo.

Este punto se demuestra en el siguiente ejemplo:

Area A: Velocidad del viento = 10 mph durante el 100% del tiempo
Area B: Velocidad del viento = 40 mph durante 25% del tiempo
0 mph durante 75% del tiempo

Ambas áreas tienen una velocidad numérica promedio del viento de 10 mph. En la ecuación 11.5-2 el término de la velocidad del viento para el Area A tiene el valor de:

(10 mph)^3 x 100% = 1,000

Mientras que el término de la velocidad del viento para el Area B es:

[(40 mph)^3 x 25%] + [(0 mph)^3 x 75%] = 16,000

Por lo tanto, si bien ambas áreas tienen la misma velocidad promedio de viento, en realidad el Area B sufriría 16 veces más erosión del viento que el Area A. Por esta razón el Servicio de Conservación de Suelos de los (*EU U.S. US Soil Conservation Service)* pondera sus factores C de corto plazo con la fracción de la velocidad de la energía media anual del viento durante el periodo de tiempo en cuestión. La velocidad de la energía media (V_e) para un periodo de tiempo en el que se tomaron “n” mediciones de la velocidad del viento (V) a intervalos iguales está dada por:

$$V_e = \left(\frac{\sum_{i=1}^{n} (vi)^3}{n} \right)^{1/3} \qquad (11.5\text{-}3)$$

Al calcular las emisiones de polvo levantado por el viento de la Cuenca Atmosférica del Desierto del Sureste de California, la EPA estimó por separado las emisiones resultantes de cada velocidad del viento medida (Ono y Bird, 1987). Este método es matemáticamente análogo a utilizar la velocidad de la energía media. La técnica de ponderar la velocidad de la energía media debe usarse sólo como lo hace el *U.S. Soil Conservation Service* si se requieren estimaciones calculadas en base temporal.

Además al despreciar los efectos de la irrigación en regiones áridas da como resultado un factor C de hasta un orden de magnitud más alto para algunos tipos de cultivo. El método preferido consiste en modificar el factor C de cada región para cada cultivo. Esto implica la recopilación de datos sobre la cantidad promedio de agua de riego que se requiere para hacer crecer cada cultivo en cada suelo y en cada área de temperatura. Esta agua de riego se suma al valor de la precipitación pluvial usado para calcular el factor C.

Factor de Rugosidad del Suelo - K

El factor de rugosidad de la superficie K toma en cuenta la resistencia al viento que sopla sobre los cerros, surcos o las grandes glebas en un campo. Para las áreas regionales, K es función del tipo de cultivo debido a que las técnicas de preparación del campo son relativamente uniformes para un cultivo específico. Algunos valores de K se presentan en la Tabla 11.5-2. Dado que esta Tabla enlista solamente un número limitado de cultivos, se debe asignar a algunos otros el mismo valor que tienen los que están en la lista basándose en el tipo de cultivo.

Para caminos sin pavimentar, el valor de K se toma como igual a 1.0 (i. e., existe un número mínimo de surcos y glebas en los caminos sin pavimentar).

Factor de amplitud del Campo sin Protección - L’

La erosión del suelo a través de un campo está directamente relacionada con la amplitud no protegida en la dirección del viento dominante. Conociendo esta amplitud (L) y la erosionabilidad de la superficie (IK) el factor L’ se obtiene usando la gráfica de la Figura 11.5-1 (U.S. EPA, 1977). Los valores de L para algunos cultivos comunes se enlistan en la Tabla 11.5-2.

Existe una situación similar para los caminos sin pavimentar. El valor real de L varía con el ángulo del viento respecto al camino. En el largo plazo, se puede suponer que la L’ para una superficie de camino dada en la dirección del viento dominante varía de manera continua. Para evaluar un factor promedio de la distancia efectiva se puede suponer que, en el largo plazo, la dirección del viento se distribuye de igual manera para todos los caminos. Cualquier error en esta suposición se compensa por la probable suposición de que todos los caminos están distribuidos en todas las diferentes direcciones. Con estas suposiciones L’ se velve función de IK como se muestra a continuación:

IK	**L’ Promedio**
40	0.29
60	0.32
80	0.34

Factor de Cobertura Vegetal - V’

La cubierta vegetal en los campos agrícolas, como por ejemplo los residuos del cultivo (rastrojos o el estiércol con paja) durante periodos que no sean la estación principal de cultivo reduce en gran medida la erosión del suelo por el viento. El factor V’ es la fracción de pérdida anual de suelo debida a que el campo tiene una cubierta vegetal. Ésta se estima a partir de la figura 11.5-2 (U.S. EPA, 1977). La cantidad de cubierta vegetal V es la cantidad en libras por acre de residuo secado al aire que queda en un campo. Los valores de V para algunos cultivos comunes se obtienen de la Tabla 11.5-2. El factor V’ se obtiene de la Figura 11.5-2 conociendo los valores de I, K, C, L, y V.

Para caminos sin pavimentar, V’ es igual a 1.0.

DATOS NECESARIOS:

Datos	Fuentes
Datos Meteorológicos	1. Instituto Nacional de Estadística, Geografía e Informática (INEGI) 2. Centro Meteorológico Nacional y Centro de Ciencias de la Atmósfera de la Universidad Nacional Autónoma de México (UNAM) 3. Servicio Meteorológico Nacional dependiente de la Comisión Nacional del Agua.
Area de cultivo en acres	SAGAR, INEGI

NOTAS:

1. Se piensa que la técnica de estimación de emisiones que se presenta aquí puede dar resultados muy inciertos y posiblemente engañosos. En la actualidad la EPA está auspiciando el desarrollo de una nueva metodología para esta fuente de emisiones.

EJEMPLO DE CÁLCULO:

Determinar las emisiones de polvo levantado por el viento de un área en la que se cultivan 1,000 acres de tomates. Se ha determinado que el suelo es de tierra negra arenosa. Se ha calculado que el factor climático (C) es de 0.30 (incluyendo la irrigación).

A partir de la Tabla 11.5-1 la erosionabilidad (I) es de 86 ton/acre/año. De la Tabla 11.5-2 se toman los valores de (K), (L) y (V) para verduras:

- K = 0.6;
- L = 500 pies y
- V = 100 lb/acre.

El producto de (IK) es 52. Usando este valor de (IK) y con (L) igual a 500 pies se obtiene un valor de (L') igual a 0.57 basado en la información presentada en la Figura 11.5-1.

Para determinar (V') primero hay que calcular el producto de (IKCL') que es igual a 8.9. En la Figura 11.5-2 se lee que V' es aproximadamente igual a 0.85. Con base en estos datos las emisiones anuales de partículas suspendidas por acre son:

$$
\begin{aligned}
E_s &= FS\ I\ CK\ L'\ V' \\
&= (0.025)\ (86)\ (0.30)\ (0.6)\ (0.57)\ (0.85) \\
&= 0.19 \text{ ton/acre/año}
\end{aligned}
$$

Las emisiones anuales de PM_{10} son:

$$
\begin{aligned}
EE &= (\text{Área})\ (E_s)\ (0.50) \\
&= (1{,}000)\ (0.19)\ (0.50) \\
&= 95 \text{ ton/año de } PM_{10}
\end{aligned}
$$

Tabla 11.5-1
Factores de Erosionabilidad para Varias Clases de Textura de Suelo

Clase de Textura de Suelo Predominante	Erosionabilidad I, ton/acre/año
Arena[a]	220
Arena con tierra negra[a]	134
Tierra negra arenosa[a]	86
Arcilla	86
Arcilla sedimentosa	86
Tierra negra	56
Tierra negra con arcilla arenosa[a]	56
Arcilla Arenosa[a]	56
Tierra negra con sedimentos	47
Tierra negra con arcilla	47
Tierra negra con arcilla sedimentosa	38
Sedimentos	38

[a] Arena muy fina, fina o mediana.

Fuente: U.S. EPA, 1977

Tabla 11.5-2

Valores de K, L y V para algunos Cultivos Comunes

Cultivo	K	L, ft	V, lb/acre
Alfalfa	1.0	1,000	3,000
Cebada	0.6	2,000	1,100
Frijoles	0.5	1,000	250
Maíz	0.6	2,000	500
Algodón	0.5	2,000	250
Heno de grano	0.8	2,000	1,250
Avena	0.8	2,000	1,250
Cacahuates	0.6	1,000	250
Papas	0.8	1,000	400
Arroz	0.8	1,000	1,000
Centeno	0.6	2,000	1,250
Cártamo	1.0	2,000	1,500
Sorgo	0.5	2,000	900
Soya	0.6	2,000	250
Betabel	0.6	1,000	100
Verduras	0.6	500	100
Trigo	0.6	2,000	1,350

Fuente: U.S. EPA, 1977

11.6 Emisiones Domésticas de Amoníaco

CODIGO DE FUENTE	**DESCRIPCIÓN**
27-10-020-020	Perros
27-10-020-010	Gatos
28-10-010-000	Respiración humana
28-10-010-000	Transpiración humana
28-10-010-000	Uso Doméstico de Amoníaco
28-10-060-000	Humo de Cigarrillos
28-10-010-000	Pañales
28-10-010-000	Desechos Humanos - Indigentes
28-10-010-000	Desechos Humanos - Otros

DESCRIPCIÓN:

Esta categoría consiste de diversas fuentes domésticas de amoníaco (NH_3) incluyendo los desechos de mascotas, la transpiración y la respiración humanas, el uso doméstico de amoníaco, el humo de cigarrillos y los desechos humanos sin tratar. A nivel individual, las emisiones de estas fuentes son relativamente pequeñas. Sin embargo, a nivel colectivo, podrían ser significativas.

CONTAMINANTES: NH_3

GOR: No es Aplicable.

AJUSTES POR FUENTES PUNTUALES: Ninguno.

METODOLOGÍA:

Las estimaciones de emisiones de amoníaco producidas por las mascotas (perros y gatos) se pueden hacer usando la siguiente ecuación:

$$\text{Emisiones}_p = \text{Población} \times PM_p \times FE_p \tag{11.6-1}$$

donde:
Emisiones_p = Emisiones anuales para el tipo de mascota p;
Población = Población total en la región;
PM_p = Proporción de mascotas (número de mascotas por 1,000 habitantes) para el tipo de mascota p y
FE_p = Factor de emisión para el tipo de mascota p.

En la Tabla 11.6-1 se presentan algunas proporciones de mascotas por habitante que son típicas para los EU. Estos son los únicos datos disponibles que existen. En la medida de lo posible se deben calcular datos específicos para México que se usen para reemplazar estos valores.

Tabla 11.6-1

Proporciones Típicas de Mascotas para Varias Regiones

Tipo de Región	Proporción - Perros (mascotas/1,000 habitantes)	Proporción - Gatos (mascotas/1,000 habitantes)	Referencia
Urbana (> 800,000 habitantes)	122	83	Coe *et al*, 1996
Suburbana (200,000-800,000 habitantes)	167	111	
Rural (< 200,000 habitantes)	220	133	

Las emisiones de amoníaco provenientes de cigarrillos se pueden estimar usando la siguiente ecuación:

$$\text{Emisiones} = \text{Cigarrillos} \times \text{FE} \qquad (11.6\text{-}2)$$

donde : Cigarrillos = Número de cigarrillos vendidos en la región.

Para todos los demás tipos de fuentes de amoníaco, las emisiones pueden estimarse usando la siguiente ecuación:

$$\text{Emisiones}_s = \text{Población}_s \times \text{FE}_s \qquad (11.6\text{-}3)$$

donde: Emisiones_s = Emisiones anuales de la fuente tipo s;

Población_s = Población aplicable dentro de la región para la fuente tipo s (población global para la transpiración y la respiración humanas, uso doméstico de amoníaco y para desechos humanos [otros]; población humana indigente para desechos humanos [indigentes] y niños menores de 3 años para pañales) y

FE_s = Factor de emisión para la fuente tipo s.

DATOS NECESARIOS:

Datos	Fuentes
Población Global	INEGI
Población Indigente	INEGI o funcionarios locales
Población (menor de 3 años)	INEGI
Proporción de Mascotas	Tabla 11.6-1
Número de cigarrillos vendidos	INEGI o funcionarios locales
Factores de emisión: Perros 2.49 kg/cabeza-año Gatos 0.82 kg/cabeza-año Cigarrillos 5.2 mg/cigarrillo Transpiración humana 0.25 kg/persona-año Respiración humana 0.0016 kg/persona-año Uso doméstico de amoníaco 0.023 kg/persona-año Pañales (tela) 3.13 kg/infante-año Pañales (desechables) 0.16 kg/infante-año Desechos Humanos (indigentes) 4.99 kg/persona-año Desechos Humanos (otros) 0.023 kg/persona-año	Radian, 1991

NOTAS:

1. Las proporciones de mascotas presentadas en la Tabla 11.6-1 se basan en los estudios de poblaciones de perros y gatos realizados en California durante los años 70. Estas proporciones podrían no ser aplicables para México. Se pueden obtener nuevas estadísticas para México en los consultorios veterinarios o a través de encuestas. Para revisar la metodología de encuestas ver el *Manual de Técnicas Básicas de Estimación de Emisiones.*

2. El uso de pañales desechables ha aumentado de manera significativa en las ciudades y áreas urbanas de México, mientras que los pañales de tela se usan todavía de manera considerable en las áreas rurales.

EJEMPLO DE CALCULO:

Estimar las emisiones anuales totales de amoníaco de un municipio con 175,000 habitantes (definido como un área rural en la Tabla 11.6-1).

Suponer que el 15% de la población fuma un promedio de 20 cigarrillos/día. Suponer que los niños representan el 3% de la población y que todos ellos usan pañales desechables. Finalmente, suponer que no hay indigentes.

Perros: La proporción de mascotas para las áreas rurales es de 220 perros por 1,000 habitantes

$$\text{Emisiones} = (175{,}000 \text{ hab.}) \left(\frac{220 \text{ perros}}{1{,}000 \text{ hab.}} \right) \left(\frac{2.49 \text{ kg de } NH3}{\text{Perros-año}} \right) = 95{,}865 \text{ kg}$$

Gatos: La proporción de mascotas para las áreas rurales es de 133 gatos por 1,000 habitantes.

$$\text{Emisiones} = (175{,}000 \text{ hab.}) \left(\frac{133 \text{ gatos}}{1{,}000 \text{ hab.}} \right) \left(\frac{0.82 \text{ kg}}{\text{gato-año}} \right) = 19{,}086 \text{ kg}$$

Cigarrillos:

$$\text{Emisiones} = (175{,}000 \text{ hab.})(0.15) \left(\frac{20 \text{ cigarrillos}}{\text{día}} \right) \left(\frac{365 \text{ días}}{\text{año}} \right) \left(\frac{5.2 \text{ mg}}{\text{cigarrillo}} \right) \quad 996 \text{ kg}$$

Transpiración Humana:

$$\text{Emisiones} = (175{,}000 \text{ hab.}) \left(\frac{0.25 \text{ kg}}{\text{persona-año}} \right) = 43{,}750 \text{ kg}$$

Respiración Humana:

$$\text{Emisiones} = (175{,}000 \text{ hab.}) \left(\frac{0.0016 \text{ kg}}{\text{persona-año}} \right) = 280 \text{ kg}$$

Uso Doméstico de Amoníaco:

$$\text{Emisiones} = (175{,}000 \text{ hab.}) \left(\frac{0.023 \text{ kg}}{\text{persona-año}} \right) = 4{,}045 \text{ kg}$$

Pañales (Desechables):

$$\text{Emisiones} = (175{,}000 \text{ hab.})\ (0.03) \left(\frac{0.16 \text{ kg}}{\text{persona-año}} \right) = 840 \text{ kg}$$

Residuos Humanos (Otros):

$$\text{Emisiones} = (175{,}000 \text{ hab.}) \left(\frac{0.023 \text{ kg}}{\text{persona-año}} \right) = 4{,}045 \text{ kg}$$

Emisiones de Amoniaco Totales
= 95,865 +19,086 +996 + 43,750 + 280 + 4,025 + 840 + 4,025
= 168,867 kg/año
= 168.9 Mg/año

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Secretaría de Medio Ambientes, Recursos Naturales, y Pesca (SEMARNAP)

Universidad Nacional Autónoma de Mexico (UNAM)

APENDICE V-A

CODIGOS DE CATEGORIA DE FUENTES DE AREA

APENDICE V-B

FACTORES DE EMISION DEL QUEMADO INDUSTRIAL, COMERCIAL E INSTITUCIONAL DE COMBUSTIBLE

(TOMADOS DEL AP-42)

APENDICE V-D

DATOS DE MUESTREO DE CAMINOS PAVIMENTADOS

(TOMADOS DEL AP-42)

APENDICE V-C

DATOS DE ACTIVIDAD Y FACTORES DE EMISION PARA EQUIPO MOVIL QUE NO CIRCULA POR CARRETERAS

670-017-51-02
Marzo 31, 1997

John T. Leary
Gerente de Proyecto
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Asunto: Entrega de la versión final del Manual para el Desarrollo de Inventarios de Emisiones de Fuentes de Area para el Proyecto de Metodología para el Inventario de Emisiones de México

Estimado John:

Anexa se encuentra una copia final del Volumen V de los Manuales para el Programa del Inventario de Emisiones de México, *Desarrollo de Inventarios de Emisiones de Fuentes Puntuales.* Este es el cuarto documento final que hemos desarrollado en nuestra serie de manuales de inventarios de emisiones Adicionalmente, estamos entregando al INE un “master” impreso por un lado y una versión electrónica (MS Word 6.0) de este documento para facilitar cualesquier esfuerzos posteriores de reproducción y traducción.

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MEXICO EMISSIONS INVENTORY PROGRAM MANUALS

VOLUME VI - MOTOR VEHICLE INVENTORY DEVELOPMENT

FINAL

Prepared for:

Western Governors' Association
Denver, Colorado

and

Binational Advisory Committee

Prepared by:

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May 17, 1996

PREFACE

Air pollution can negatively impact public health when present in the atmosphere in sufficient quantities. Most rural areas rarely experience air quality problems, while elevated concentrations of air pollution are commonly found in many urban environments. Recently, urbanization and industrial activity throughout Mexico has increased, resulting in air quality concerns for several regions.

Air pollution results from a complex mix of, literally, thousands of sources, from industrial smoke stacks and motor vehicles, to the individual use of grooming products, household cleaners, and paints. Even plant and animal life can play an important role in the air pollution problem. Due to the complex nature of air pollution, detailed regional plans are needed to identify the emission sources and to develop methods for reducing the health impact from exposure to air pollution. Examples of air quality planning activities include:

- Application of air quality models;
- Examination of the sources emitting air pollution for emissions control analysis, where necessary;
- Development of emission projections to examine possible changes in future air quality;
- Analysis of emission trends; and
- Analysis of emissions transport from one region to another.

Development of fundamentally sound emissions inventories is a key aspect for each of these air quality planning functions.

Developing emission estimates to meet air quality planning needs requires continual development and refinement; "one time" inventory efforts are not conducive to the air quality planning process. For lasting benefit, an *inventory program* must be implemented so that accurate emission estimates can be developed for all important geographic regions, refined over time, and effectively applied in the air quality planning and monitoring process. Therefore, a set of inventory manuals is being developed that can be used throughout the country to help coordinate the development of consistent emission estimates. These manuals are intended for use by local, state, and federal staff, as well as by industry and private consultants. The purpose of these manuals is to assist in implementing the inventory program and in maintaining that program over time so that emissions inventories can be developed in periodic cycles and continually improved.

The manuals cover inventory program elements such as estimating emissions, program planning, database management, emissions validation, and other important topics. Figure 1 shows the complete series of manuals that will be developed to support a comprehensive inventory program. The main purpose of each manual is summarized below.

Volume I—Emissions Inventory Program Planning. This manual addresses the important planning issues that must be considered in an air emissions inventory program. Program planning is discussed not as an "up-front" activity, but rather as an ongoing process to ensure the long-term growth and success of an emissions inventory program. *Key Topics*: program purpose, inventory end uses, regulatory requirements, coordination at federal/state/local levels, staff and data management requirements, identifying and selecting special studies.

Volume II—Emissions Inventory Fundamentals. This manual presents the basic fundamentals of emissions inventory development and discusses inventory elements that apply to multiple source types (e.g., point and area) to avoid the need for repetition in multiple volumes. *Key Topics*: applicable regulations, rule effectiveness, rule penetration, pollutant definitions (e.g., how to properly exclude nonreactive volatile compounds), point/area source delineation, point/area source reconciliation.

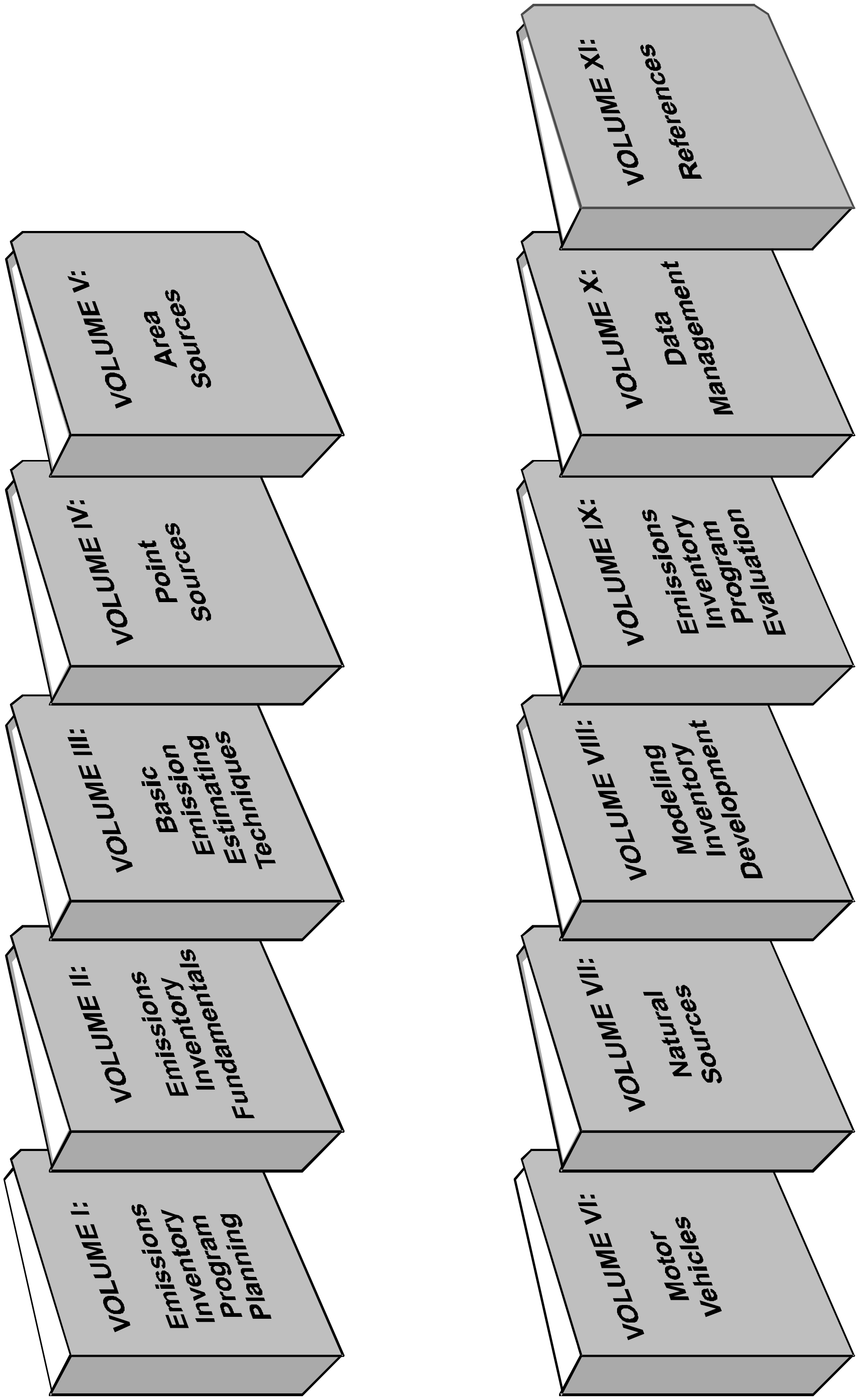

Figure 1. Mexico Emissions Inventory Program Manuals

Volume III—Emissions Inventory Development: Basic Emission Estimating Techniques (EETs). This manual presents the basic EETs used to develop emission estimates, including examples and sample calculations. Inventory tools associated with each methodology are identified and included in Volume XI (References). *Key Topics*: source sampling, emissions models, surveying, emission factors, material balance, extrapolation.

Volume IV—Point Sources. This manual provides guidance for developing the point source emissions inventory. A cross-reference table is provided for each industry/device type combination (e.g., petroleum refining/combustion devices) with one or more of the basic EETs presented in Volume III. *Key Topics*: cross-reference table, stack parameters, control devices, design/process considerations, geographic differences and variability in Mexico, quality assurance/quality control (QA/QC), overlooked processes, data references, data collection forms.

Volume V—Area Sources (includes non-road mobile). This manual provides guidance for developing the area source emissions inventory. After the presentation of general area source information, a table is provided to cross-reference each area source category (e.g., asphalt application) with one or more of the basic EETs presented in Volume III. Then, source category-specific information is discussed for each source category defined in the table. *Key Topics*: area source categorization and definition, cross-reference table, control factors, geographic differences and variability in Mexico, QA/QC, data references, data collection forms (questionnaires).

Volume VI—Motor Vehicles. Because motor vehicles are inherently different from point and area sources, the available estimation methods and required data are also different. To estimate emissions from these complex sources, models are the preferred estimation tool. Many of these models utilize extensive test data applicable to a given country or region. This manual focuses primarily on the data development phase of estimating motor vehicle emissions. *Key Topics*: available estimation methods, primary/secondary/tertiary data and information, source categorization, emission factor sources, geographic variability within Mexico, QA/QC.

Volume VII—Natural Sources. This manual provides guidance for developing a natural source emissions inventory (i.e., biogenic volatile organic compounds [VOC] and soil oxides of nitrogen [NO_x]). In addition, this manual includes the theoretical aspects of emission calculations and discussion of specific models. *Key Topics*: source categorization and definition, emission mechanisms, basic emission algorithms, biomass determination, land use/land cover data development, temporal and meteorological adjustments, emission calculation approaches.

Volume VIII—Modeling Inventory Development. This manual provides guidance for developing inventory data for use in air quality models and addresses issues such as temporal allocation, spatial allocation, speciation, and projection of emission estimates. *Key Topics*: definition of modeling terms, seasonal adjustment, temporal allocation, spatial allocation, chemical speciation, projections (growth and control factors).

Volume IX—Emissions Inventory Program Evaluation. This manual consists of three parts: QA/QC, uncertainty analysis, and emissions verification. The QA/QC portion defines the overall QA/QC program and is written to complement source specific QA/QC procedures written into other manuals. The uncertainty analysis includes not only methods of assessing uncertainty in emission estimates, but also for assessing uncertainty in modeling values such as speciation profiles and emission projection factors. The emissions verification section describes various analyses that can be performed to examine the accuracy of the emission estimates. Examples include receptor modeling and trajectory analysis combined with specific data analysis techniques. *Key Topics*: description of concepts and definition of terms, inventory review protocol, completeness review, accuracy review, consistency review, recommended uncertainty EETs, applicable emission verification EETs.

Volume X—Data Management. This manual addresses the important needs associated with the data management element of the Mexico national emission inventory program. *Key Topics*: general-purpose data management systems and tools, specific-purpose software systems and tools, coding system, confidentiality, electronic submittal, frequency of updates, recordkeeping, Mexico-specific databases, reports.

Volume XI—References. This manual is a compendium of tools that can be used in emission inventory program development. Inventory tools referenced in the other manuals are included (i.e., hardcopy documents, electronic documents, and computer models).

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APPENDIX A: SAMPLE MOTOR VEHICLE EMISSIONS CALCULATION

FIGURES AND TABLES

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ACRONYMS

ARB	Air Resources Board
ATP	anti-tampering program
ATPFLG	ATP flag
BEF	basic emission factor
BER	basic emission rate
CMB	Chemical Mass Balance Model
C_3H_8	propane
CO	carbon monoxide
CO_2	carbon dioxide
COEF	composite fleet emission factor
EGR	exhaust gas recirculation
FEAT	Fuel Efficiency Automobile Test
FID	flame ionization detector
g	gram
GVW	gross vehicle weight
HC	hydrocarbon
HDDV	heavy-duty diesel vehicle (>3,857 kg)
HDGV	heavy-duty gasoline vehicle (>3,857 kg)
I/M	inspection and maintenance
IMFLAG	I/M flag
INE	National Institute of Ecology

IR	infrared
kg	kilogram
km	kilometer
kph	kilometer per hour
LAP	local area parameter
LDDT	light-duty diesel truck (>3,857 kg)
LDDV	light-duty diesel vehicle
LDGT1	light-duty gasoline truck (<2,727 kg)
LDGT2	light-duty gasoline truck (2,727-3,857 kg)
LDGV	light-duty gasoline vehicle
LPG	liquefied petroleum gas
MARI	Mexico City Air Quality Research Initiative
MC	motorcycle
Mg	megagram
mph	miles per hour
NMHC	non-methane hydrocarbons
NMHFLG	hydrocarbon emission factor flag
NMOC	non-methane organic compounds
NMOG	non-methane organic gases
NO_x	nitrogen oxides
OMS	Office of Mobile Sources
OUTFMT	output format flag

OXYFLG	oxygenated fuel flag
PCV	positive crankcase ventilation
PEMEX	Petróleos Mexicanos
PM	particulate matter
$PM_{2.5}$	particulate matter of aerodynamic diameter of 2.5 microns or less
PM_{10}	particulate matter of aerodynamic diameter of 10 microns or less
ppm	parts per million
psi	pounds per square inch
QA	quality assurance
QC	quality control
RFG	reformulated gasoline
ROG	reactive organic gases
RSD	remote sensing and detection
RVP	Reid vapor pressure
SCAQS	South Coast Air Quality Study
SEMOS	Southeast Michigan Ozone Study
SO_x	sulfur oxides
TAMFLG	tampering flag
TDM	travel demand model
TEMFLG	temperature flag
THC	total hydrocarbons
TOG	total organic gases

TTI	Texas Transportation Institute
U.S.	United States
U.S. EPA	United States Environmental Protection Agency
VKT	vehicle kilometers traveled
VOC	volatile organic compounds
wt	weight

1.0 INTRODUCTION

This manual addresses the development of emission estimates for on-road motor vehicles. On-road motor vehicles are those vehicles, such as autos, trucks, and buses, designed to operate on public roads. In most urban areas, on-road motor vehicles are major contributors of emissions of total organic gases (TOG), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x), particulate matter (PM), air toxics, and visibility reducing species. Due to their large emissions magnitude and the special considerations required to develop emission estimates, on-road motor vehicles are addressed separately from other area sources.

Interest in obtaining estimates of the on-road motor vehicle contribution to regional emission inventories in Mexico has been increasing, leading to the development of motor vehicle emission inventories for Mexico City, Monterrey, Ciudad Juárez, and Leon (Espinosa, et al., 1996). The data available to develop these inventories have varied considerably. Through improved data collection techniques and estimation methodologies, future inventory efforts will increase in their accuracy and precision. The purpose of this manual is to present existing and near-term inventory methods as they could be applied in Mexico. In order to address the wide variations in the availability of emissions and activity data, a variety of methods are discussed.

This manual provides an overview of various inventory methods. Additional information can be obtained from the references that are extensively cited in this manual. Similarly, additional “hands-on” training with the motor vehicle emission factor models referenced in this manual (MOBILE and PART5) is essential for the creation of a quality motor vehicle emissions inventory.

This manual addresses only on-road motor vehicles. Non-road mobile sources (also referred to as off-road mobile sources) include vehicles designed for use off of public roads (e.g., aircraft, locomotives, marine vessels, forklifts, cranes, and construction equipment), and other mobile emission sources (e.g., portable electric generators). The estimation of emissions from non-road sources is addressed in *Volume V: Area Sources Inventory Development*. The remainder of this introduction summarizes the emission processes associated with on-road motor vehicles and discusses the classification of Mexican vehicles into the groups used for emission inventories. The manual is organized as follows:

- Section 2.0 presents an overview of the on-road motor vehicle emission inventory process, and discusses how emissions are calculated and how data development priorities are established;
- Section 3.0 discusses emission factor models and their application in Mexico;
- Section 4.0 discusses the development of activity data used in conjunction with emission factors to estimate emissions; and
- Section 5.0 presents quality assurance (QA) procedures that can be applied to check the reasonableness and accuracy of on-road motor vehicle emission estimates.

1.1 On-Road Motor Vehicle Emission Processes

Motor vehicle emissions consist of a large number of pollutants resulting from a number of different processes (see Figure 1-1). The most commonly considered are exhaust emissions, which result from fuel combustion and are emitted from the vehicle exhaust tailpipe. Key pollutants of concern from exhaust emissions include TOG, CO, NO_x, SO_x, PM, air toxics, (e.g., 1,3-butadiene, benzene, formaldehyde, etc.) and visibility reducing species (e.g., ammonia, sulfates, $PM_{2.5}$, etc.). In addition to exhaust emissions, there are a variety of evaporative emission processes from motor vehicles. Evaporative emission processes are solely limited to TOG emissions. These evaporative processes include:

- **Hot soak emissions -** Emissions occurring due to volatilization of fuel in the fuel delivery system following engine shut-off. Residual engine heat volatilizes the fuel.

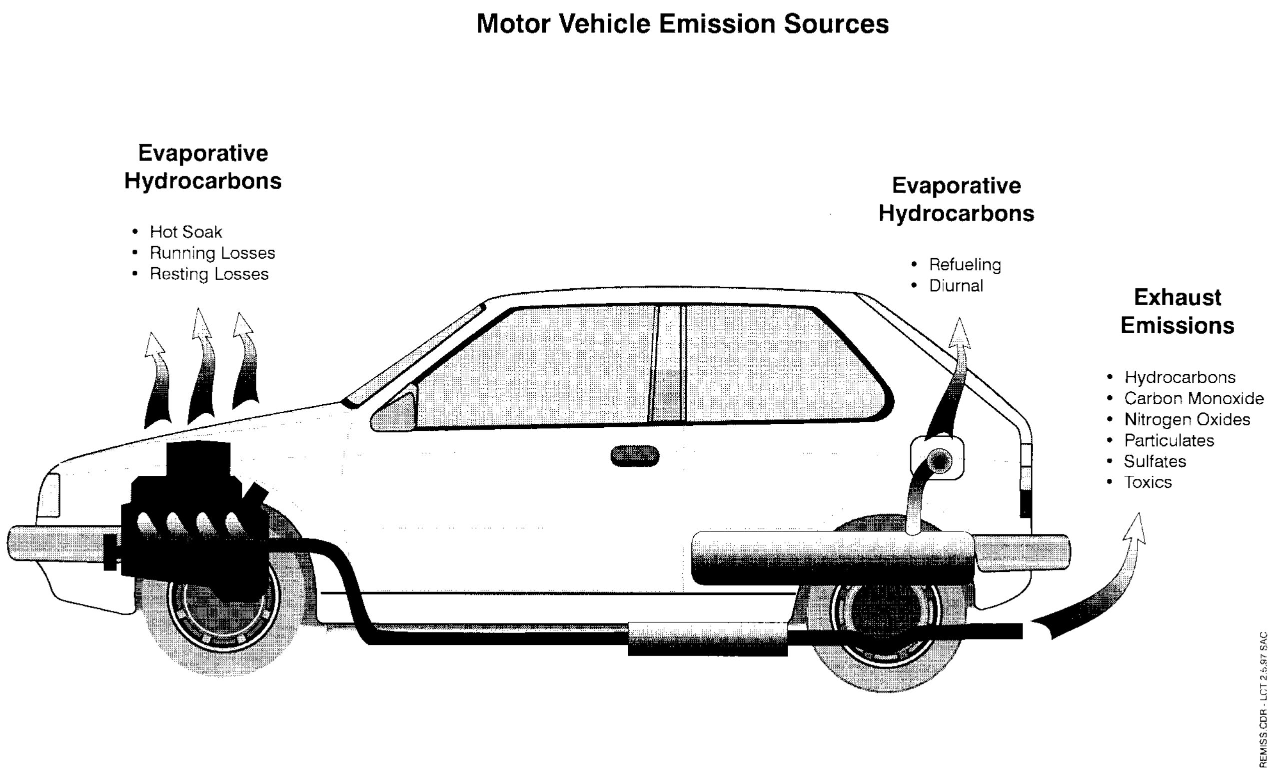


Figure 1-1. Motor Vehicle Emission Processes

- **Running evaporative emissions** - Evaporative emissions from liquid or vapor fuel leaks occurring while the engine is operating.
- **Refueling evaporative emissions** - Evaporative emissions displaced from the vehicle fuel tank during refueling. While the vehicle is the source of the emissions, they occur while the vehicle is stationary and at known locations, such as gasoline stations. Refueling is typically treated as an area source and discussed in *Volume V: Area Source Inventory Development*. Refueling emission factors can either be estimated using the MOBILE model or obtained from other sources such as AP-42.
- **Diurnal emissions** - Emissions from the vehicle fuel tank due to higher bulk liquid temperatures and fuel vapor pressure. These result from rising ambient temperatures heat input from the vehicle's exhaust system, or heat reflected from the road surface.
- **Resting evaporative emissions** - Evaporative emissions other than hot soak, diurnal, and refueling emissions that occur while the engine is not operating. Resting losses occur primarily from fuel leaks and permeation of vapor through fuel lines.

There are also additional sources of PM emissions from motor vehicles. The largest of these is entrained road dust, which is dust picked up by the vehicle tires and suspended in the air by the wake turbulence from the vehicle. Entrained road dust emissions are treated as an area source and are discussed in *Volume V: Area Source Inventory Development*. Other non-exhaust PM sources include tire wear and brake wear. These sources are typically insignificant compared to exhaust PM and entrained road dust and, therefore, are sometimes omitted from emission inventories. Emission factors for tire and brake wear, however, can be estimated using the PART5 model (see Section 3.2).

1.2 Mexican Vehicle Classes

The large number of vehicles in an inventory region make it impractical to measure the emissions of each individual vehicle. Consequently, the motor vehicle inventory methodology relies on organizing vehicles into categories with common emission characteristics, then attempting to quantify the emissions for each group. Key variables used in this initial grouping of vehicles are vehicle type (auto, truck, bus, etc.), fuel type (gasoline, diesel, liquefied fuels, etc.), gross vehicle weight (GVW), and the level of emission control technology on the vehicle. GVW is the vehicle weight when carrying the maximum cargo allowed by the manufacturer with a full tank of fuel.

Emissions from different motor vehicles can vary by multiple orders of magnitude, depending upon many factors. In particular, the level of emission control technology on a vehicle greatly influences the magnitude of emissions. The level of control technology is determined by the emission standards applicable to the vehicle. New vehicles meeting the same standards will tend to have similar emissions in actual use relative to vehicles produced to meet different standards. When estimating emission factors from vehicles, vehicles are grouped by emission standards that apply to the vehicles when they are first manufactured.

In Mexico, the following new vehicle emission standards have been established:

- NOM-042-ECOL-1993 - Applicable for vehicles (400-3,857 kg GVW) powered by gasoline, natural gas, or other alternative fuels;
- NOM-044-ECOL-1993 - Applicable for vehicles (greater than 3,857 kg) powered by diesel; and
- NOM-076-ECOL-1994 - Applicable for vehicles (greater than 3,857 kg) powered by gasoline.

In addition, the following standards have been established for vehicles in actual use:

- NOM-041-ECOL-1993 - Applicable for vehicles (greater than 400 kg) powered by gasoline;
- NOM-045-ECOL-1993 - Applicable for vehicles (greater than 400 kg) powered by diesel (smog opacity only);

- NOM-048-ECOL-1993 - Applicable for motorcycles powered by gasoline or gasoline-oil;
- NOM-050-ECOL-1993 - Applicable for vehicles (greater than 400 kg) powered by natural gas or other alternative fuels; and
- NOM-EM-102-ECOL-1995 - Applicable for vehicles in use in the Mexico City Valley (greater than 400 kg) powered by gasoline or other alternative fuels.

The “in-use” vehicle standards are primarily designed to detect high-emitting vehicles during inspection and maintenance (I/M) testing. The above vehicle standards and their associated vehicle classes are discussed in more detail in Section 3.4.2.

2.0 OVERVIEW OF THE INVENTORY DEVELOPMENT PROCESS

Development of an on-road motor vehicle emissions inventory is an attempt to quantify the emissions occurring from a large population of vehicles with diverse emission characteristics. The basic equation used for estimating motor vehicle emissions involves multiplying activity data by an appropriate emission factor. For motor vehicles, activity data consist of vehicle kilometers traveled (VKT) which is the total distance traveled by motor vehicles within the inventory domain, while emission factors are expressed in units of grams of pollutant emitted per VKT. Ideally, VKT estimates should be developed directly from local data, such as transportation models or roadway traffic counts. However, in many cases, these data are not available and it becomes necessary to rely on alternate measures of vehicle activity, such as regional fuel consumption statistics. Emission factors should be estimated using an existing emission factor model that has been adjusted for local conditions.

The basic steps in the on-road motor vehicle inventory development process are shown in Figure 2-1. This process can be divided into five key steps:

- Collection of local vehicle activity data (direct VKT or fuel consumption statistics);
- Collection of area-specific data (ambient temperature data, fuel characteristics, vehicle fleet composition, vehicle kilometer accumulation rates, etc.);
- Generation of emission factors using an emission factor model;
- Calculation of preliminary emission estimates; and

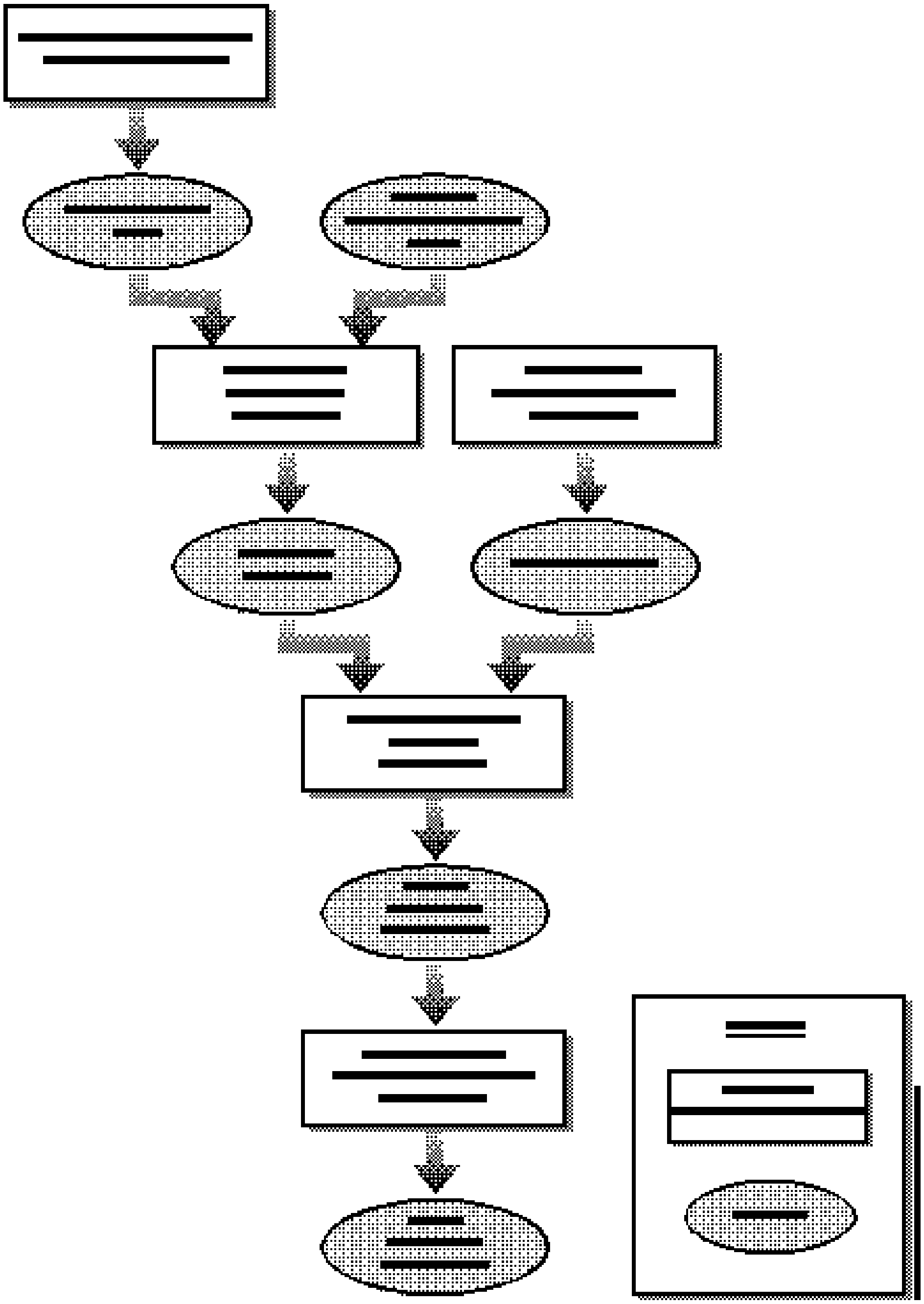


Figure 2-1. On-Road Motor Vehicle Inventory Development

- Implementation of quality assurance (QA) procedures to finalize the inventory estimates.

A typical motor vehicle emissions inventory for an urban area can include thousands, or even millions, of vehicles. The vehicle fleet includes a distribution of vehicles from each model year, and the level of emission controls varies significantly over the full span of model years currently in operation. Each vehicle is operated in a unique manner with different speeds and loads, under various driving conditions. In addition, vehicles are subject to varying levels of maintenance and tampering (e.g., disablement of emissions control systems). All of these elements can have significant impacts on the emission characteristics of a vehicle, resulting in large differences in emissions from otherwise similar vehicles.

Given present technology, it is not feasible to obtain emission measurements from each individual vehicle in a fleet. Consequently, other methods are needed to estimate motor vehicle emissions. Theoretical calculations, using fuel mass balances, for example, yield useful results for some pollutants such as SO_x and lead. For other pollutants, however, an emission factor model (such as MOBILE or PART5) is used to estimate emissions from various vehicle classifications. Emission factor models are based upon testing data collected from a statistically representative sample of the vehicle population. Input parameters are then adjusted to account for local conditions and variability.

Example calculations using both fuel mass balances and emission factor models are presented in Appendix A. These example calculations are based upon an actual emissions inventory conducted in Nogales, Sonora.

2.1 Basic Emission Estimation Methodology

The basic equation used for estimating motor vehicle emissions involves multiplying activity data by an appropriate emission factor. This is shown in Equation 2-1.

$$E_p = VKT \times EF_p \tag{2-1}$$

where:
E_p = Total emissions of pollutant p;
VKT = Vehicle kilometers traveled; and
EF_p = Emission factor of pollutant p.

For motor vehicles, activity data consist of vehicle kilometers traveled (VKT), while emission factors are expressed in units of grams of pollutant per VKT. VKT represents the total distance traveled by a vehicle population over a given period of time. VKT should preferably be estimated from transportation models or vehicle road counts. In some cases, however, VKT must be derived from fuel consumption statistics.

The basic emission estimation equation given above is applicable for most gaseous pollutants and particulate matter. For pollutants such as SO_x and lead, emissions are estimated using a fuel balance, assuming that all of the sulfur or lead contained in the fuel is emitted.

The equation describing the fuel balance for SO_x is:

$$E_{SO_x,f} = Fuel_f \times \rho_f \times S_f \times 2 \tag{2-2}$$

where:
$E_{SOx,f}$ = Emissions of SO_x for fuel f (gasoline or diesel);
$Fuel_f$ = Total fuel consumption of fuel f;
ρ_f = Fuel density of fuel f;
S_f = Fuel sulfur content (mass fraction) of fuel f; and
2 = Conversion factor from mass of sulfur to mass of SO_x (as SO_2).

A similar equation describing the fuel balance for lead is:

$$E_{Pb,f} = Fuel_f \times \rho_f \times Pb_f \tag{2-3}$$

where:
Pb_f = Fuel lead content (mass fraction) of fuel f.

2.2 Data Development Priorities

Many different data need to be collected to generate a motor vehicle emissions inventory. These include VKT, fuel consumption statistics, vehicle speeds, vehicle registration data, vehicle class mixes, and fuel characteristics. In some cases, the data are absolutely critical to the inventory process and must be obtained to generate even the most preliminary estimates. In other cases, the data are used to refine the modeling, often by replacing default data with local information. This section lists some of the key data to be gathered and prioritizes the various data needs. Additional information describing these data categories is available in Sections 3.0 and 4.0.

The importance of the different data for developing an inventory can be defined by grouping data into three categories: primary, secondary, and tertiary. Primary data are the minimum required to generate a basic inventory. Secondary data replace key default parameters with local data. Tertiary data are included as available to further refine the inventory to local conditions. An initial inventory can be generated using only primary data. However, as additional secondary and tertiary data are added to the inventory, the level of confidence in the resulting estimates is improved.

Primary data needs include:

- Vehicle activity data covering the entire inventory region (typically VKT or fuel consumption) grouped to match the available emission factor data;
- Vehicle emission standards by model year;
- Average vehicle speeds;
- Emission factors, by vehicle type, fuel type, model year, and speed;
- Fuel composition data for the inventory region, by season, including sulfur content, oxygen content, lead content, and Reid vapor pressure;
- Vehicle population distribution by model year, including the fraction of unregistered and foreign-registered vehicles;

- Local conditions of altitude and ambient temperature; and
- Annual vehicle kilometer accumulation rates, by vehicle class and model year.

Secondary data needs include:

- Local vehicle inspection and maintenance (I/M) program and anti-tampering program (ATP) information; and
- Local vehicle tampering and misfueling rate survey data.

Tertiary data needs include:

- Local driving behavior survey data to identify average trip lengths, and time between engine starts; and
- Driving pattern survey data to identify local patterns of vehicle speeds, engine loads and acceleration rates.

3.0 MOTOR VEHICLE EMISSION FACTOR MODELS

As described in Section 2.0, motor vehicle emissions are calculated by combining emission factors with VKT. Instead of simple published emission factors, however, motor vehicle emission factors are derived from emission factor models. The reason for this is that emissions from motor vehicles are more complex and dynamic than most other source types. For example, changes in fuel characteristics, vehicle operating speeds, emission control technology, ambient temperature, and altitude can all affect emission factors. In order to account for these and other impacts, an emission factor model is normally used that includes the effects of many parameters.

This section describes various aspects of the motor vehicle models (MOBILE and PART5) that should be used to estimate motor vehicle emissions in Mexico. The MOBILE model will be the central focus of this section, although the PART5 model will also be discussed. Section 3.1 briefly describes the history of the MOBILE and PART5 models in both the U.S. and Mexico. Section 3.2 provides a short theoretical description of the algorithms used to estimate motor vehicle emission factors. Section 3.3 briefly explains both the input and output files used by the MOBILE model. Finally, Section 3.4 presents a discussion of several fundamental area-specific characteristics that can greatly influence motor vehicle emissions.

3.1 Emission Factor Model Historical Background

This section presents some historical background about the MOBILE and PART5 emission factor models that have been developed within the U.S. A brief description of the use of these two models within Mexico is also provided.

MOBILE Emission Factor Model

The MOBILE model consists of an integrated set of FORTRAN routines that generate hydrocarbon (HC), carbon monoxide (CO), and nitrogen oxide (NO_x) emission factors for gasoline- and diesel-powered on-road motor vehicles. Hydrocarbon emission factors can be expressed either as total hydrocarbons (THC), non-methane hydrocarbons (NMHC), volatile organic compounds (VOC), total organic gases (TOG), or non-methane organic gases (NMOG). These are defined in Table 3-1. It is recommended that TOG emission factors be chosen for all emission inventory efforts. All references in this manual will be for TOG. To adjust for reactivity, the following reactive organic gas (ROG) fractions can be used (ARB, 1993):

- Non-catalyst gasoline vehicle exhaust emissions - 92.4%;
- Catalyst gasoline vehicle exhaust emissions - 85.2%;
- Diesel vehicle exhaust emissions - 95.8%; and
- Gasoline vehicle evaporative emissions - 100%.

The first generation of the MOBILE model was created in the mid-1970s. The MOBILE model has subsequently undergone several updates and revisions in order to account for changing environmental legislation and technological advances. These updated versions also incorporate large amounts of newly collected emissions data in an attempt to more accurately estimate motor vehicle emissions. The most recent version of the MOBILE model (MOBILE5b) was released in September 1996 and MOBILE6 is expected to be released in mid-1998. The MOBILE model and other related motor vehicle emission inventory information can be downloaded from the U.S. EPA Office of Mobile Sources (OMS) Internet web-site (http://134.67.104.12/html/oms/modeutil.htm).

Table 3-1

Definition of Hydrocarbons

	Compounds Included in Hydrocarbon Emission Factors			
	FID Hydrocarbons[a]	Methane	Ethane	Aldehydes
Total Hydrocarbons (THC)	✓	✓	✓	
Non-Methane Hydrocarbons (NMHC)	✓		✓	
Volatile Organic Compounds (VOC)	✓			✓
Total Organic Gases (TOG)	✓	✓	✓	✓
Non-Methane Organic Gases (NMOG)	✓		✓	✓

[a] FID hydrocarbons refer to hydrocarbon emissions as measured by the flame ionization detector (FID) used in motor vehicle testing.

Because the MOBILE model is based upon emissions testing of U.S. vehicles, its direct use in regions outside of the U.S. will likely produce uncertain results. In order to account for possibly different vehicle fleets and driving behavior in Mexico, the MOBILE model has been modified for the Mexico City, Monterrey, and Ciudad Juárez metropolitan areas. The modified models for Mexico City (MOBILE-MCMA) and Monterrey (MOBILE-MMAp) utilize an emission control technology equivalence matrix that maps basic MOBILE emission factors to vehicles within the Mexican vehicle fleet on the basis of vehicle age and level of emission controls. A sample technology equivalence matrix for exhaust and evaporative emission factors is presented in Table 3-2. From Table 3-2 it can be seen that a 1994 Mexican light-duty gasoline vehicle (LDGV) would be equivalent to a 1988 U.S. LDGV. In some instances, a certain Mexican model year might be equivalent to one U.S. model year for exhaust control technology and another for evaporative control technology. For example, a 1990 Mexican LDGV would be equivalent to a 1980 U.S. LDGV for exhaust emissions and a 1977 U.S. LDGV for evaporative emissions.

The most recent modified MOBILE model (MOBILE-Juárez) continues to assign evaporative emission factors using a technology equivalence matrix, but uses actual IM240 testing data of 206 Ciudad Juárez vehicles as the basis of the exhaust emission factors (Radian, 1996a). At the current time, this is the preferred emission factor model to use in Mexico. However, as research related to motor vehicles in Mexico continues, the Mexican MOBILE model will continue to evolve. INE should be contacted concerning the most appropriate version of the emission factor model to be used in any future motor vehicle inventory efforts.

PART5 Emission Factor Model

The U.S. EPA PART5 emission factor model also utilizes FORTRAN routines that are similar to MOBILE to estimate particulate matter (PM) and sulfur oxide (SO_x) emission factors for motor vehicles. However, it is recommended that Mexico SO_x emission factors not be estimated using the PART5 model, due to several reasons, including the inability to adjust the

Mexican	U.S. Equivalent Model Year (Exhaust)								U.S. Equivalent Model Year (Evaporative)							
Model Year	LDGV	LDGT1	LDGT2	HDGV	LDDV	LDDT	HDDV	MC	LDGV	LDGT1	LDGT2	HDGV	LDDV	LDDT	HDDV	MC
1971	1968	1968	1968	1968	1968	1968	1968	1971	1968	1968	1968	1968	1968	1968	1968	1968
1972	1968	1968	1968	1968	1968	1968	1968	1972	1968	1968	1968	1968	1968	1968	1968	1968
1973	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971
1974	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971
1975	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971
1976	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971
1977	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971
1978	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971
1979	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971
1980	1971	1971	1971	1971	1971	1971	1971	1971	1972	1972	1972	1972	1972	1972	1972	1972
1981	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972
1982	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972
1983	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972
1984	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972
1985	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972
1986	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972
1987	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972
1988	1975	1974	1974	1974	1974	1974	1974	1974	1975	1975	1975	1975	1975	1975	1975	1975
1989	1975	1974	1974	1974	1974	1974	1974	1974	1975	1975	1975	1975	1975	1975	1975	1975
1990	1980	1974	1974	1974	1974	1974	1974	1974	1977	1977	1977	1977	1977	1977	1977	1977
1991	1980	1974	1974	1974	1974	1974	1974	1974	1977	1977	1977	1977	1977	1977	1977	1977
1992	1981	1974	1974	1974	1974	1974	1974	1974	1980	1980	1980	1980	1980	1980	1980	1980
1993	1988	1977	1977	1977	1977	1977	1977	1977	1981	1981	1981	1981	1981	1981	1981	1981
1994	1988	1981	1981	1981	1981	1981	1981	1981	1988	1988	1988	1988	1988	1988	1988	1988
1995	1989	1981	1981	1981	1981	1981	1981	1981	1988	1988	1988	1988	1988	1988	1988	1988
1996	1990	1981	1981	1981	1981	1981	1981	1981	1988	1988	1988	1988	1988	1988	1988	1988
1997	1990	1981	1981	1981	1981	1981	1981	1981	1990	1990	1990	1990	1990	1990	1990	1990
1998	1994	1985	1985	1985	1985	1985	1985	1985	1990	1990	1990	1990	1990	1990	1990	1990
1999	1995	1985	1985	1985	1985	1985	1985	1985	1990	1990	1990	1990	1990	1990	1990	1990
2000	1996	1985	1985	1985	1985	1985	1985	1985	1990	1990	1990	1990	1990	1990	1990	1990
2001	1997	1993	1993	1990	1993	1993	1990	1993	1990	1990	1990	1990	1990	1990	1990	1990

LDGV = Light-duty gasoline vehicle
LDGT1 = Light-duty gasoline truck (< 2,727 kg)
LDGT2 = Light-duty gasoline truck (2,727-3,857 kg)
HDGV = Heavy-duty gasoline truck (> 3,857 kg)
LDDV = Light-duty diesel vehicle
LDDT = Light-duty diesel truck (< 3,857 kg)
HDDV = Heavy-duty diesel vehicle (>3,857 kg)
MC = Motorcycle

Table 3-2. Typical Emission Control Technology Equivalence Matrix

fuel sulfur content to reflect local conditions. Instead, SO_x emissions should be estimated using fuel balances as described in Section 2.1. The latest version of the PART5 model was released in February 1995 (U.S. EPA, 1995). Although the PART5 model resembles the MOBILE model in several respects, it is at an earlier stage of development because less particulate emission data have been collected. This is mainly the result of ozone precursors (TOG, CO, and NO_x) being given higher priority than PM in the U.S. Consequently, some parameters that affect motor vehicle particulate emissions (e.g., temperature, inspection and maintenance [I/M] programs, fuel impacts) have not been modeled in PART5. Also, several assumptions in the model (i.e., driving cycles, fuel specifications, emission control systems, engine system deterioration rates) are valid only for the U.S. Unless conditions in Mexico are similar to these assumptions, the resultant emission factors will not accurately represent particulate emissions from Mexican motor vehicles.

At the present time, the PART5 model has not been modified for use outside of the U.S. It is expected that the level of effort needed to modify the PART5 model for use in Mexico would be similar to that expended in modifying the MOBILE model for use in Mexico City or Monterrey. Until a modified PART5 model has been developed for Mexico, it is recommended that the U.S. PART5 model be used. This is not an ideal solution, however, the U.S. PART5 model will serve as an interim methodology until a Mexico-specific version is developed. INE should be contacted concerning the most appropriate version of this emission factor model to be used in any future motor vehicle inventory efforts.

3.2 Theoretical Description of Emission Factor Models

Within the MOBILE and PART5 models, the ultimate goal is to calculate an average emission factor for each vehicle type. This section outlines some of the basic theoretical equations that are used to calculate the average emission factor for each vehicle type. The emission factor calculation methodology given below is presented as general background information for the model user. These theoretical equations will be invisible to the actual user of the emission factor model; however, these equations and the resulting emission factors will be influenced by various input parameters that are described within Sections 3.3 and 3.4.

The calculation of average basic emission rates (BERs) for each vehicle type and model year is the first step in estimating motor vehicle emission factors. The foundation of BERs is emissions test data from in-use vehicles measured under standardized test conditions (i.e., standard temperature, fuel characteristics, and driving cycles). However, emissions vary with vehicle age, so linear regressions that relate emissions data to odometer readings are performed. These linear regressions result in BER equations which incorporate a zero mile emission rate (the y-intercept of the regression) and a deterioration rate (the slope). The zero mile emission rate represents emissions from a new vehicle, while the deterioration rate describes how emissions increase with increased vehicle mileage.

The MOBILE model, in fact, uses two BER equations to describe different deterioration rates in different mileage regimes for light-duty gasoline vehicles and newer light-duty gasoline trucks. Two hypothetical BER equations are presented below:

$$\text{For CUMMIL} \le 50{,}000 \text{ miles, BER} = \text{ZML} + \left(\text{DET1} \times \frac{\text{CUMMIL}}{10{,}000}\right); \qquad (3\text{-}1)$$

$$\text{For CUMMIL} > 50{,}000 \text{ miles, BER} = \text{ZML} + (\text{DET1} \times 5) + \left(\text{DET2} \times \frac{[\text{CUMMIL} - 50{,}000]}{10{,}000}\right) \qquad (3\text{-}2)$$

where:
BER = basic emission rate;
ZML = zero mile emissions level (intercept);
DET1 = deterioration rate per 10,000 miles (slope) for accumulated mileage up to 50,000 miles;
DET2 = deterioration rate per 10,000 miles (slope) for accumulated mileage over 50,000 miles; and
CUMMIL = accumulated odometer mileage.

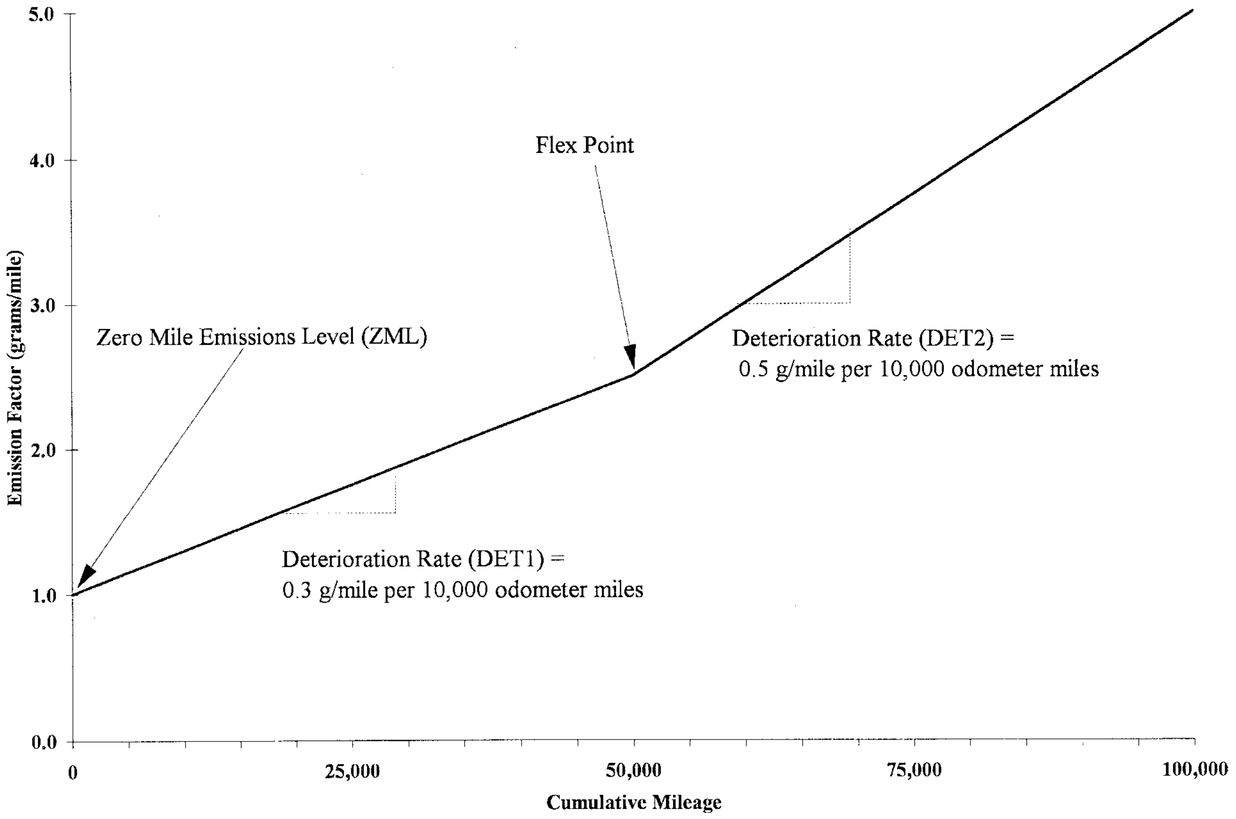


Figure 3-1. Hypothetical Basic Emission Rates (BERs)

These two hypothetical BER equations are plotted in Figure 3-1. In this figure, the zero mile emissions level and the two deterioration rates are indicated. Also, a hypothetical “flex-point” at 50,000 miles can clearly be seen where vehicles shift from one deterioration rate to another. In reality, the emissions test data from in-use vehicles might be extremely nonlinear. The MOBILE model utilizes one or two linear BER equations to keep the amount of calculations to a manageable level. Depending upon the distribution of emissions data in different data sets, the BER equations and the resulting flex-points might vary significantly. The convention of a 50,000 mile flex-point has been adopted in the MOBILE model for light-duty gasoline vehicles and trucks. For each vehicle type, a BER is assigned to 25 model years based upon the average mileage accumulation for each model year.

Base emission rates, however, do not exactly correspond to actual motor vehicle emissions. Rather, they represent emissions measured under highly controlled test conditions. To reconcile the differences that exist between test emissions and actual emissions, several adjustment factors must be applied to the actual emissions. In this way, a basic emission factor (BEF) for each vehicle type and model year can be calculated from the BER. This is shown below:

$$\text{BEF} = (\text{BER} \times \text{OMTCF} \times \text{PCLEFT}) + \text{OMTTAM} \tag{3-3}$$

where:

BEF = basic emission factor, by model year;

BER = basic emission rate, by model year;

OMTCF = adjustment factor for effects of different temperatures, fuel Reid vapor pressures, and operating modes;

PCLEFT = adjustment factor for effect of I/M program; and

OMTTAM = adjustment factor for effects of tampering and anti-tampering programs.

The above equation shows only major adjustment factors that are applicable for all pollutant types in most typical situations. There are additional adjustment factors in MOBILE that are only applicable for specialized circumstances or one pollutant (e.g., low temperature CO correction). Information concerning these other adjustment factors can be found in the MOBILE5a User's Guide (U.S. EPA, 1994) and other related documentation (U.S. EPA, 1992).

After the BEFs for each model year have been calculated with appropriate adjustments made, an average or composite fleet emission factor for each vehicle type is calculated with the inclusion of an additional adjustment factor. The composite fleet emission factor (COEF) is given by the following equation:

$$\text{COEF} = \sum_{\text{my}=1}^{25} (\text{TF} \times \text{SALHCF} \times \text{BEF}) \qquad (3\text{-}4)$$

where:
COEF = composite fleet emission factor;
my = model year;
TF = travel fraction (fraction of the overall VKT that each model year contributes);
SALHCF = adjustment factor for effects of speed, air conditioning use, extra load, and trailer towing; and
BEF = basic emission factor, by model year.

The additional adjustment factor (SALHCF) accounts for the effects of area-specific traffic speed characteristics, air conditioner use, extra load, and trailer towing. After this adjustment, each adjusted emission factor is weighted by the fraction of travel (in VKT) for that model year. Finally, the weighted emission factors for each of the 25 model years are summed together to produce a composite emission factor, which is the average emission factor for a specific vehicle type.

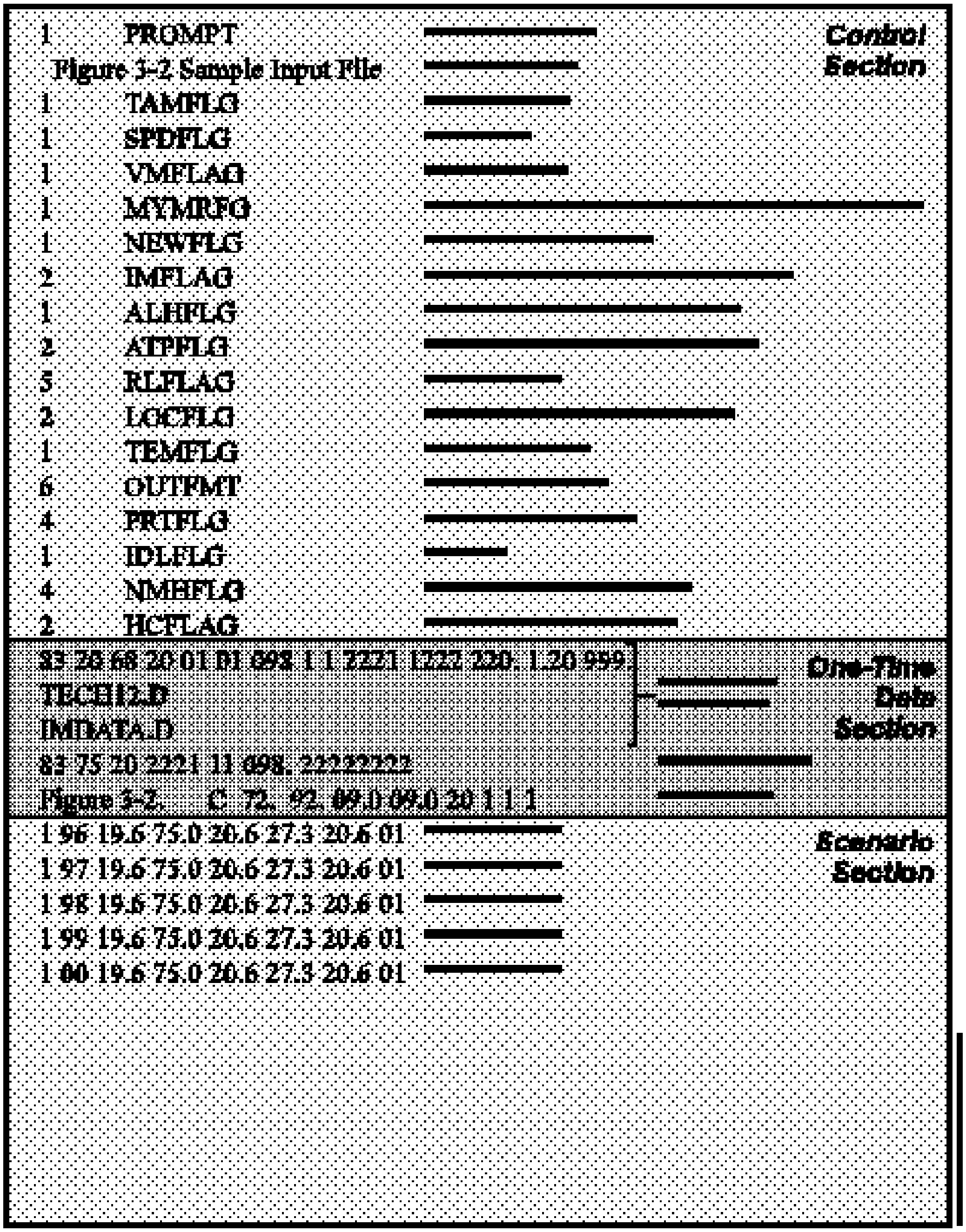
3.3 MOBILE Input and Output Formats

This section describes a sample MOBILE input file and its resultant output file. Actual MOBILE input and output files for an emissions inventory conducted in Nogales, Sonora are also presented in Appendix A. Once again, further information about MOBILE file formats can be found in the MOBILE User's Guide. Figure 3-2 presents a sample MOBILE5a input file and Figure 3-3 presents a portion of its resultant output file in spreadsheet format. The input file is an ASCII text file read by the MOBILE model's FORTRAN code. Because FORTRAN is extremely "sensitive" to errors, an extra space or misplaced character can have disastrous effects on the MOBILE run. For this reason, it is recommended that an existing MOBILE input file be modified, rather than creating an input file from scratch.

As indicated in Figure 3-2, the MOBILE input file consists of three separate sections: the Control section, the One-Time Data section, and the Scenario section. The Control section of the input file mainly consists of a number of flags that determine the content and format of the remainder of the input file, as well as the program's output file. The flags also affect how the MOBILE code is executed. All of these flags are necessary for the MOBILE model to run.

The One-Time Data section contains information that is area-specific. This detailed local information is entered only once into the input file and replaces default data that are built into the MOBILE model. The types of alternate information that can be entered into the One-Time Data section include:

- Tampering rates;
- VKT mixes;
- Annual mileage accumulation rates;



```
1       PROMPT
 Figure 3-2 Sample Input File
1       TAMFLG
1       SPDFLG
1       VMFLAG
1       MYMRFG
1       NEWFLG
2       IMFLAG
1       ALHFLG
2       ATPFLG
5       RLFLAG
2       LOCFLG
1       TEMFLG
6       OUTFMT
4       PRTFLG
1       IDLFLG
4       NMHFLG
2       HCFLAG
83 28 68 20 01 01 098 1 1 2221 1222 220. 1 20 999.
TECH12.D
IMDATA.D
83 75 20 2221 11 098. 22222222
Figure 3-2.    C  72.  92. 09.0 09.0 20 1 1 1
1 96 19.6 75.0 20.6 27.3 20.6 01
1 97 19.6 75.0 20.6 27.3 20.6 01
1 98 19.6 75.0 20.6 27.3 20.6 01
1 99 19.6 75.0 20.6 27.3 20.6 01
1 00 19.6 75.0 20.6 27.3 20.6 01
```

Figure 3-2. Sample MOBILE Input File

```
Figure 3-3 Sample Output File
 MOBILE5a (26-Mar-93)

I/M Program:          Yes          Anti-tam Program:     Yes         Reformulated Gas:    No
Minimum Temp:              72      Maximum Temp:               92    Period 1 RVP:              9
Gasoline Market Share:           1          Ether Blend Market Share:            0        Alcohol Blend Market S
                                            Ether Blend Oxygen Content:          0        Alcohol Blend Oxygen
                      Composite Emission Factors
Pollutant  Cal. Year  LDGV  ef  LDGT1 ef  LDGT2 ef  LDGT  ef  HDGV  ef  LDDV  ef  LDDT  ef  HDDV  ef  MC   ef    All Veh

Emission factors are as of      Jan.      1st of the indicated calendar year.
HC               1996     2.481     2.505     3.522     2.827    10.464     0.782      1.12     2.601     6.005     2.845
Exhaust          1996     1.396     1.576     2.234     1.784     5.255     0.782      1.12     2.601     2.172     1.697
Evap             1996     0.343      0.39     0.534     0.436     3.583                                   3.406     0.466
Refuel           1996         0         0         0         0         0                                                 0
Running          1996     0.661      0.46     0.679     0.529     1.496                                             0.603
Resting          1996     0.082     0.079     0.075     0.078      0.13                                   0.427     0.079
CO               1996    17.152    18.885    23.876    20.464   105.181     1.746     2.003    12.163    24.777    20.435
NOx              1996     1.551     1.675     2.107     1.812     5.172     1.618      1.88    13.577     0.773     2.475

I/M Program:          Yes          Anti-tam Program:     Yes         Reformulated Gas:    No
Minimum Temp:              72      Maximum Temp:               92    Period 1 RVP:              9
Gasoline Market Share:           1          Ether Blend Market Share:            0        Alcohol Blend Market S
                                            Ether Blend Oxygen Content:          0        Alcohol Blend Oxygen
                      Composite Emission Factors
Pollutant  Cal. Year  LDGV  ef  LDGT1 ef  LDGT2 ef  LDGT  ef  HDGV  ef  LDDV  ef  LDDT  ef  HDDV  ef  MC   ef    All Veh

Emission factors are as of      Jan.      1st of the indicated calendar year.
HC               1997     2.431     2.441     3.409     2.745     9.688     0.769     1.098     2.512         6     2.764
Exhaust          1997     1.369     1.546     2.203     1.752     4.853     0.769     1.098     2.512     2.167     1.656
Evap             1997     0.327     0.364      0.48     0.401       3.3                                   3.406     0.438
Refuel           1997         0         0         0         0         0                                                 0
Running          1997     0.656     0.454     0.654     0.516      1.41                                             0.593
Resting          1997     0.079     0.077     0.073     0.076     0.124                                   0.427     0.077
CO               1997    16.951    18.882    24.459    20.637    94.805      1.73     1.987    12.003    24.777    20.037
NOx              1997     1.511     1.638     2.171     1.806     5.118     1.581     1.827    12.847     0.773     2.418
```

Figure 3-3. Sample MOBILE Output File

- Registration distributions by vehicle type and age;
- Basic emission rates;
- Inspection and maintenance (I/M) programs; and
- Anti-tampering programs (ATPs).

The One-Time Data section also contains the local area parameter (LAP) record which includes several important local data. These include minimum and maximum ambient daily temperature, as well as fuel Reid vapor pressure (RVP). Also, flags regarding alternate fuel mixes (diesel, oxygenated fuels, and reformulated gasoline) can be included in the LAP. With the exception of the LAP, all data in the One-Time Data section are optional. At least one LAP must be included in each MOBILE run. If the One-Time Data section does not contain any optional inputted data, then the MOBILE model will run using various default data. The sample input file presented in Figure 3-2 only includes the LAP record and I/M program and ATP information.

The Scenario section contains variables that represent scenario-specific information. Each scenario to be evaluated is associated with a group of Scenario section records. At a minimum, each scenario is represented by a record which identifies whether the region is low-altitude or high-altitude, the calendar year of evaluation, average speed, ambient temperature, operating mode fractions, and month of evaluation. Additional scenario section records may be needed, depending on the setting of various flags in the Control section. Multiple scenarios may be calculated in each MOBILE run. For instance, the Figure 3-2 input file includes five scenarios representing the years from 1996 to 2000. Multiple scenarios can be used to model the effects of fleet turnover, I/M programs, and anti-tampering programs over time.

After running the MOBILE model, an output file is generated. The format of this file is controlled by the output format flag (OUTFMT) in the Control Flag Section. Depending upon the value selected for this flag, the output file will be generated in 140- or 222-column numerical format, 80- or 112-column descriptive format, “by-model year” format, or spreadsheet format. The spreadsheet format was incorporated into MOBILE5 and allows modeled emission factors to be transferred into various spreadsheet programs (e.g., Excel, Lotus 1-2-3). This format simplifies further data manipulation and is the preferred output format.

Figure 3-3 presents a portion of the output file generated from the Figure 3-2 sample input file. The values included in Figure 3-3 are strictly hypothetical results and should not be used in real-life applications. The 1996 and 1997 HC (total and by component), CO, and NO_x emission factors for each of the eight vehicle types are indicated in Figure 3-3. For example, the 1997 light duty gas vehicle (LDGV) emission factors for HC (selected as TOG in the input file), CO, and NO_x are 2.431, 16.951, and 1.511 grams per mile, respectively. Fleet average emission factors (assuming default vehicle registration distributions) have also been calculated. In Figure 3-3, the 1997 fleet average emission factors for HC, CO, and NO_x are 2.764, 20.037, and 2.418

grams per mile. Sections of the output file not included in Figure 3-3 contain emission factors for the years 1998 through 2000 as well as summaries of input file data.

3.4 Effect of Local Characteristics

As indicated previously, adjustment factors are widely used in emission factor models to correct for non-standard operating conditions. These non-standard operating conditions are the result of various area-specific characteristics. Section 3.4.1 will address regional characteristics, while Section 3.4.2 will discuss fleet characteristics. These sections will only provide an overview of the effects of these characteristics on motor vehicle emissions; specific details, as well as information concerning lesser characteristics, can be found in the MOBILE User’s Guide.

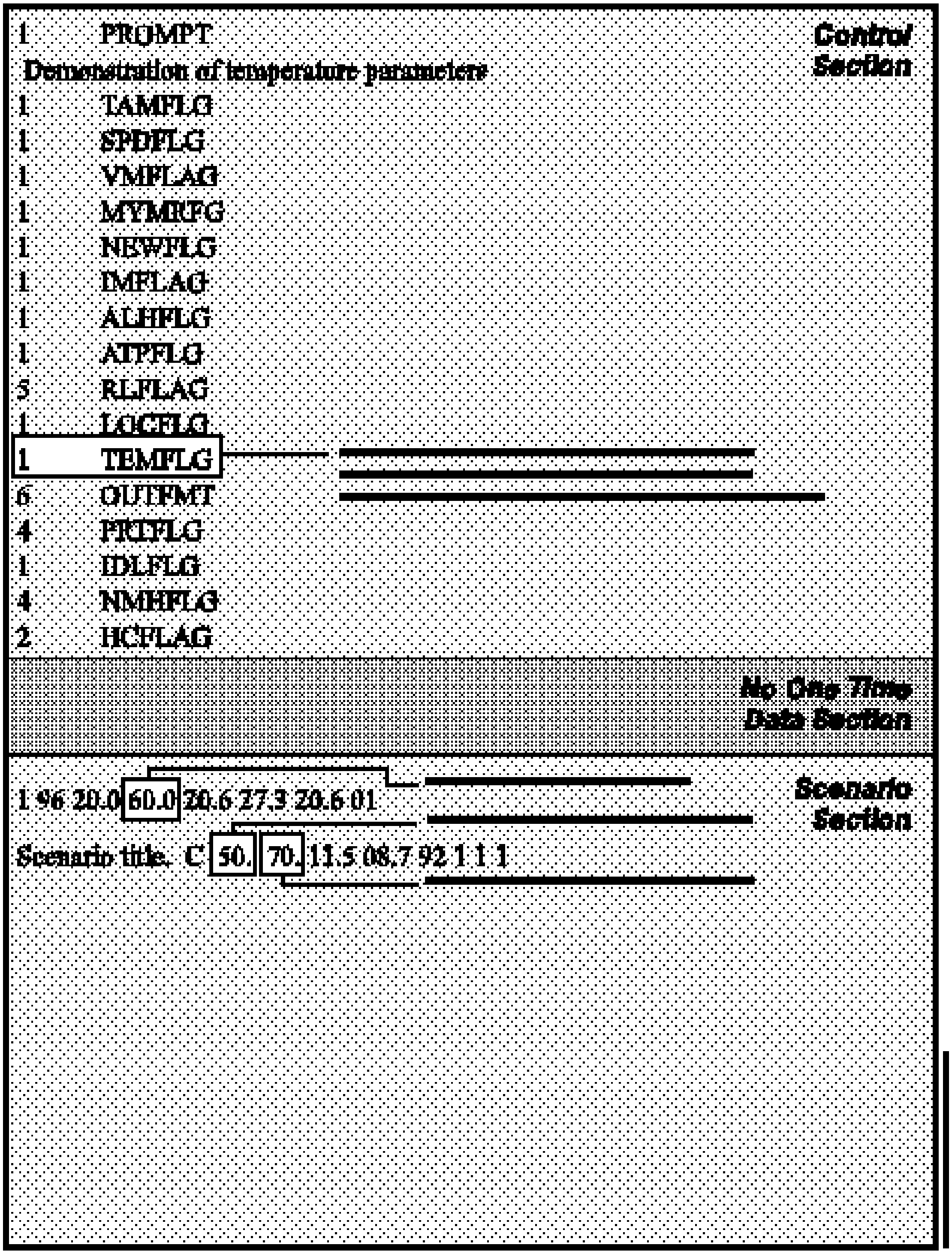
3.4.1 Regional Characteristics that Affect Emission Factors

Some of the regional characteristics that can effect motor vehicle emissions include physical characteristics (such as temperature or altitude), fuel characteristics, and regulatory programs (such as inspection and maintenance programs and anti-tampering programs). These are described below.

Temperature

Motor vehicle emissions (TOG, CO, and NO_x) are very dependent upon the surrounding air temperature. The standard operating temperature used in the determination of the MOBILE basic emission rates is 24 °C (75 °F); the modeling of emissions at any other temperature requires the use of temperature adjustment factors. In the MOBILE model, these temperature adjustment factors are determined by the temperature flag (TEMFLG) in the Control section, the minimum and maximum daily temperature in the local area parameter (LAP) record, and the ambient temperature in the scenario descriptive record. These data inputs are indicated on the sample MOBILE input file presented in Figure 3-4.

Depending upon the value chosen for TEMFLG, the adjustment factors for exhaust emissions, hot soak evaporative emissions, and resting and running loss emissions will be calculated using either the minimum and maximum daily temperature or ambient temperature. It is recommended that the minimum and maximum daily temperature option be used whenever possible. Regardless of the TEMFLG value, the adjustment factor for diurnal evaporative emissions will be calculated based on the minimum and maximum daily temperature. For some emission inventories, seasonal mobile source emissions are desirable. In these situations, a MOBILE run should be made for each season (spring, summer, fall, and winter) using average minimum and maximum daily temperature for each season.fects of high altitude should be considered carefully in regions such as Mexico City.



```
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Demonstration of temperature parameters
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1       SPDFLG
1       VMFLAG
1       MYMRFG
1       NEWFLG
1       IMFLAG
1       ALHFLG
1       ATPFLG
5       RLFLAG
1       LOCFLG
1       TEMFLG
6       OUTFMT
4       PRTFLG
1       IDLFLG
4       NMHFLG
2       HCFLAG
1 96 20.0 60.0 20.6 27.3 20.6 01
Scenario title. C 50. 70. 11.5 08.7 92 1 1 1
```

Figure 3-4. Sample Temperature Parameters in MOBILE

The temperature dependence of TOG (selected by setting the NMHFLG flag to “4”), CO, and NO_x emissions is shown in Figure 3-5, where the ambient temperature is varied and all other model parameters are held constant. From Figure 3-5, it is clear that TOG and CO emissions are greatly affected by ambient temperatures, while NO_x emissions are affected to a lesser degree.

Altitude

Another physical characteristic that has a significant effect on motor vehicle emissions is the altitude of the region. As altitude increases, the density of the ambient air decreases. The result of this decrease in air density is that vehicles calibrated to run at a stoichiometric air-to-fuel ratio will tend to run fuel-rich. This deviation from stoichiometry will result in additional pollutant emissions. Also, altitude can affect the mechanical efficiencies of motor vehicles, which in turn can change the amount of emissions. The effects of high altitude should be considered carefully in regions such as Mexico City.

Instead of using an adjustment factor to account for differences in altitude, the MOBILE model uses one set of BERs for low-altitude areas (representing conditions at approximately 150 meters above mean sea level) and another set of BERs for high-altitude areas (representing conditions at approximately 1,700 meters above mean sea level). The desired set of BERs is selected in the first data element of the scenario descriptive record (a “1” indicating low-altitude, and a “2” indicating high-altitude), as shown in Figure 3-6. The difference between low- and high-altitude emissions can be seen in the TOG, CO, and NO_x fleet average emission factors plotted in Figure 3-7, where all other model parameters are held constant. The TOG and CO fleet average emission factors at higher altitudes are approximately 15-20% higher than those at lower altitudes, while the NO_x fleet average emission factors decrease slightly.

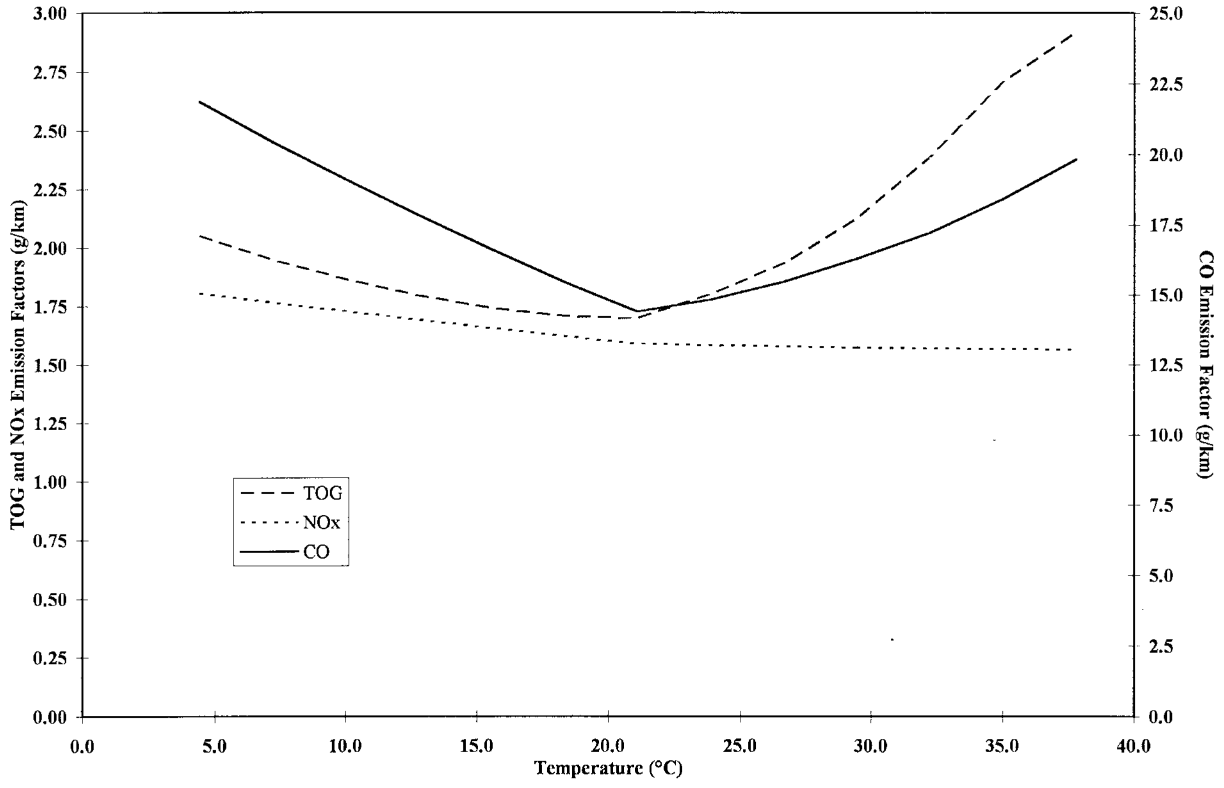
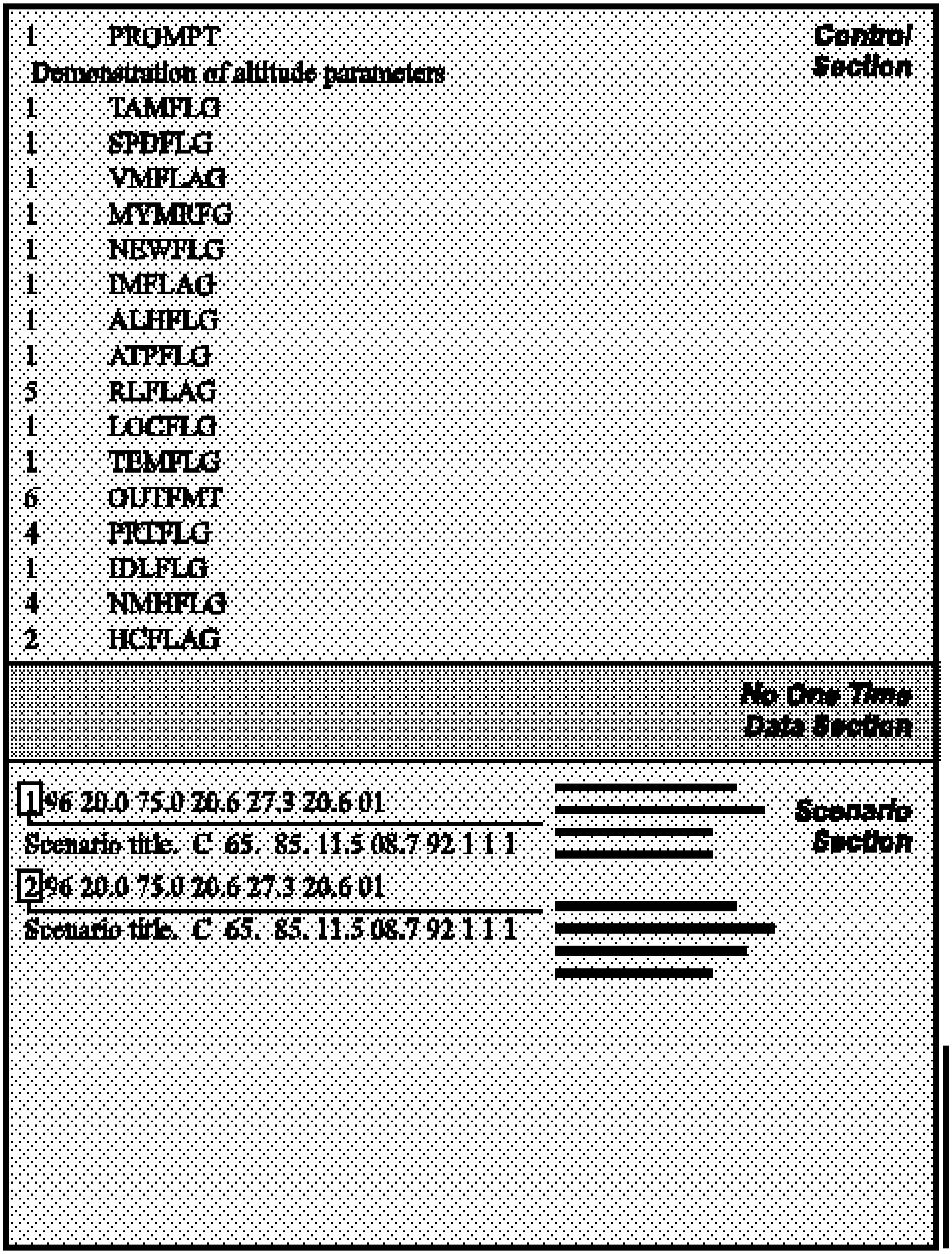


Figure 3-5. Fleet Average Emission Factors for TOG, CO, and NO_x with Varying Ambient Temperature



```
1       PROMPT
Demonstration of altitude parameters
1       TAMFLG
1       SPDFLG
1       VMFLAG
1       MYMRFG
1       NEWFLG
1       IMFLAG
1       ALHFLG
1       ATPFLG
5       RLFLAG
1       LOCFLG
1       TEMFLG
6       OUTFMT
4       PRTFLG
1       IDLFLG
4       NMHFLG
2       HCFLAG
```

```
1 96 20.0 75.0 20.6 27.3 20.6 01
Scenario title.  C  65.  85. 11.5 08.7 92 1 1 1
2 96 20.0 75.0 20.6 27.3 20.6 01
Scenario title.  C  65.  85. 11.5 08.7 92 1 1 1
```

Figure 3-6. Sample Altitude Parameters in MOBILE

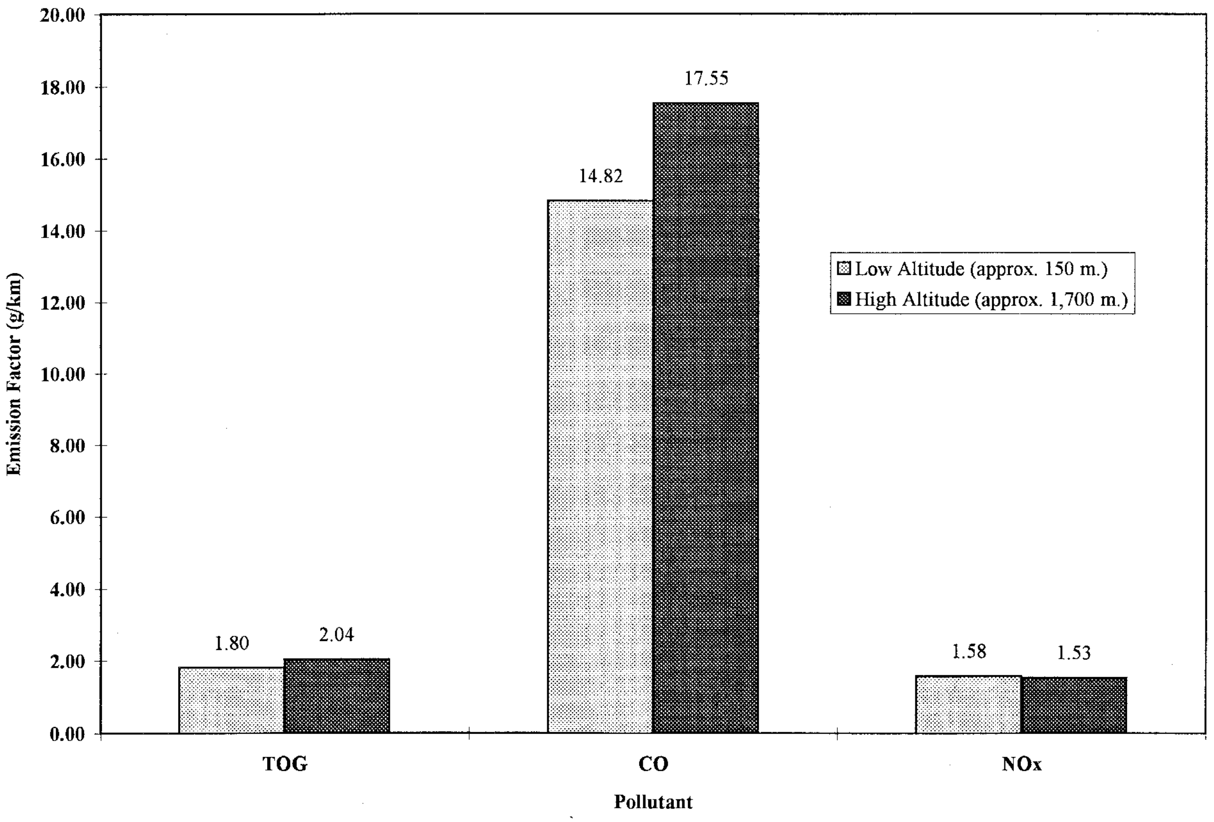
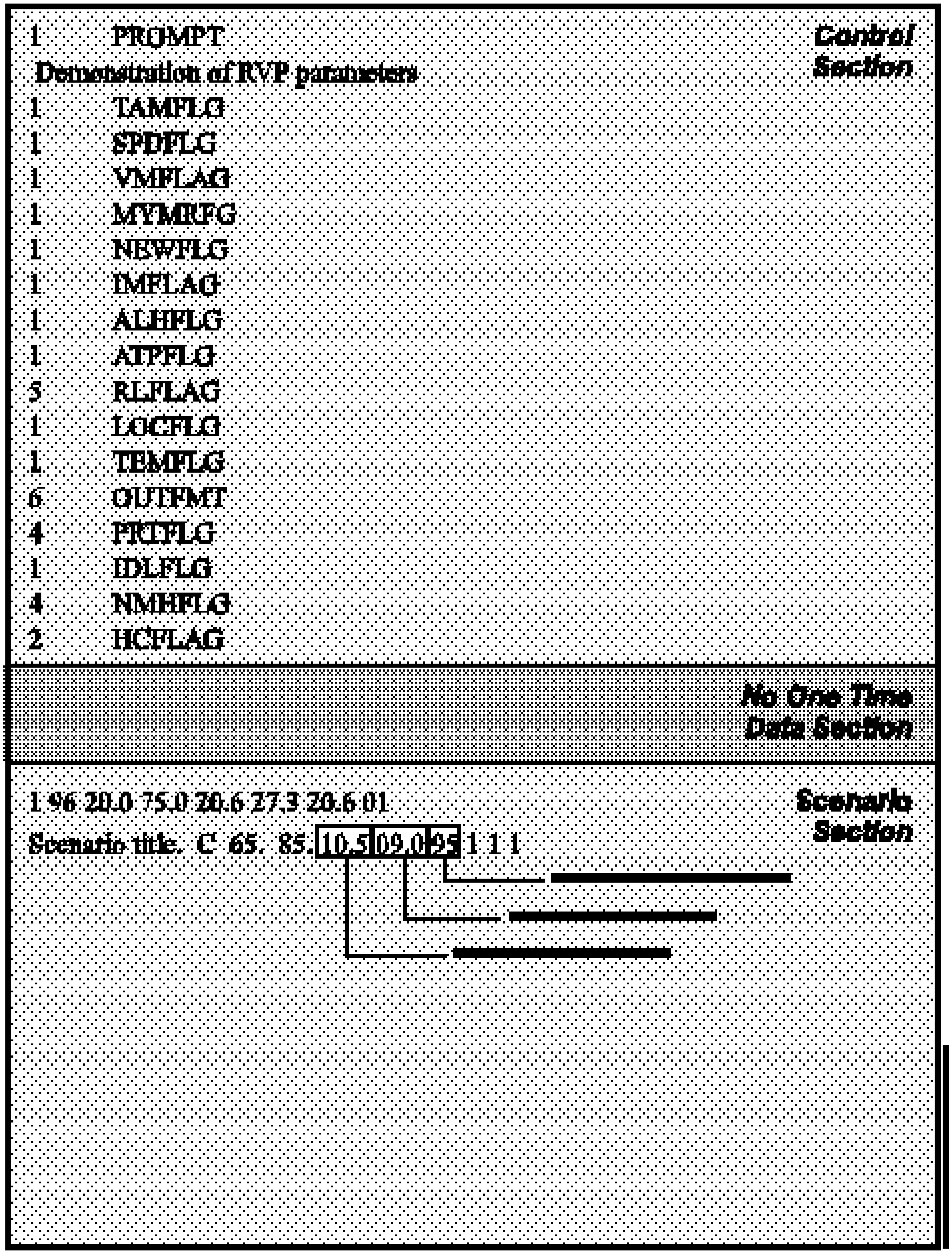


Figure 3-7. Fleet Average Emission Factors for TOG, CO, and NO_x at Low and High Altitude

Fuel Characteristics - RVP

Because motor vehicle emissions are the end result of the combustion and evaporation of gasoline and diesel fuel, fuel characteristics can significantly affect the amount of pollutants emitted. Fuel volatility, in particular, directly affects the amount of motor vehicle emissions. For the MOBILE model, as well as in many other applications, fuel volatility is expressed as a Reid vapor pressure (or RVP). The standard gasoline RVP used in the determination of basic emission rates for the MOBILE model is 9.0 pounds per square inch (psi); the use of any other gasoline RVP requires the use of RVP adjustment factors. Current fuel specifications require a fuel RVP of 6.5 to 8.5 in Mexico City and a fuel RVP of 6.5 to 9.5 in all other parts of Mexico. It is recommended that the area-specific RVP be requested from PEMEX. If this information is unavailable, then the upper end value of these fuel specification ranges should be used as the MOBILE input value. Because diesel has a very low volatility resulting in negligible evaporative emissions, a diesel RVP value is not used in MOBILE. The RVP adjustment factors are determined by three data inputs in the LAP record: Period 1 RVP (the RVP before a volatility control program takes effect), Period 2 RVP (the RVP after a volatility control program takes effect), and Period 2 start year (the year in which a volatility control program is implemented). Using these three data inputs, the MOBILE model can model an RVP control program or any other RVP-related change. If no volatility control program is to be modeled, then the Period 1 RVP and Period 2 RVP will be equal. These data inputs are indicated on the sample MOBILE input file presented in Figure 3-8.

In general, reduced volatility (or lower RVP values) will result in lower emissions. The dependence of emissions upon fuel RVP is shown in Figure 3-9, where the gasoline RVP is varied from 8.0 to 13.0 psi and all other model parameters are held constant. In Figure 3-9, the relationship between lower gasoline RVP and lower TOG and CO emissions is quite evident.



```
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Demonstration of RVP parameters
1       TAMFLG
1       SPDFLG
1       VMFLAG
1       MYMRFG
1       NEWFLG
1       IMFLAG
1       ALHFLG
1       ATPFLG
5       RLFLAG
1       LOCFLG
1       TEMFLG
6       OUTFMT
4       PRTFLG
1       IDLFLG
4       NMHFLG
2       HCFLAG
1 96 20.0 75.0 20.6 27.3 20.6 01
Scenario title. C 65. 85. 10.5 09.0 95 1 1 1
```

Figure 3-8. Sample Gasoline RVP Parameters in MOBILE

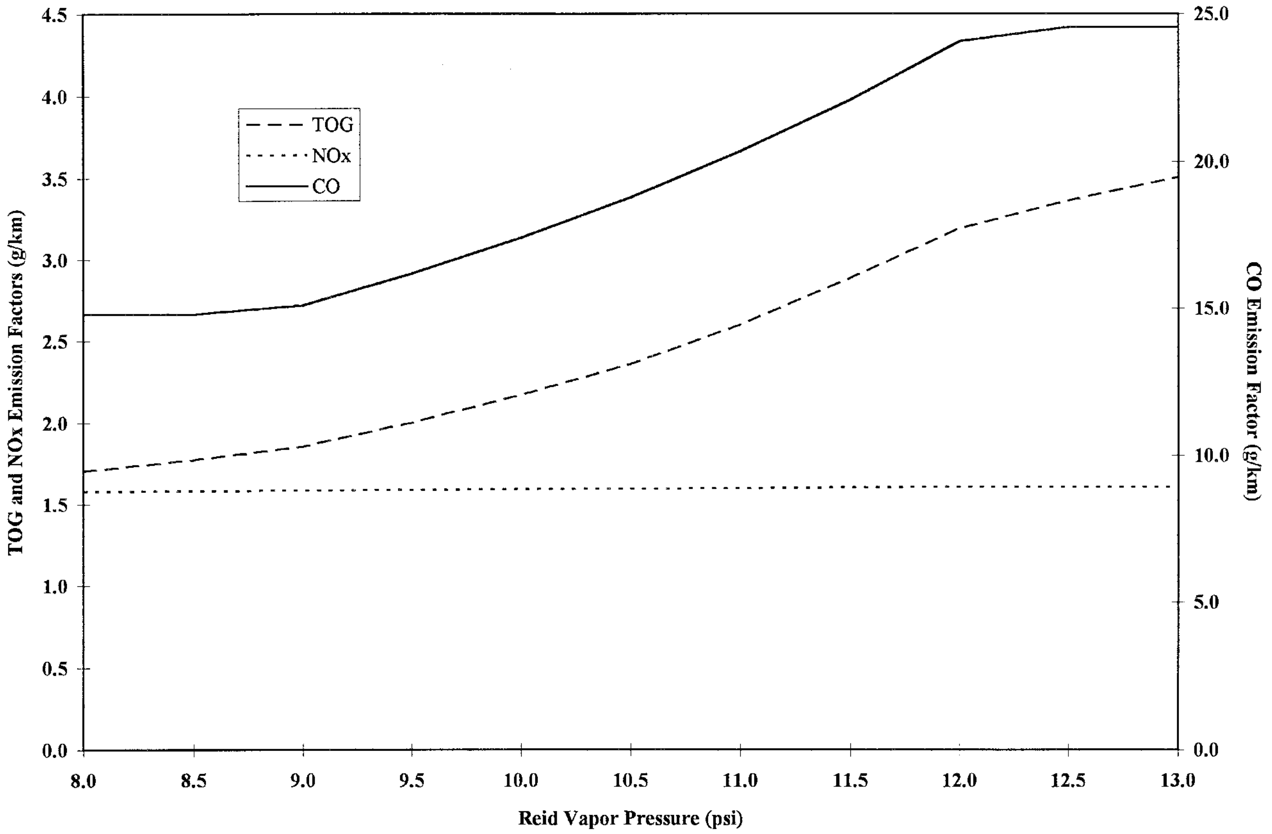


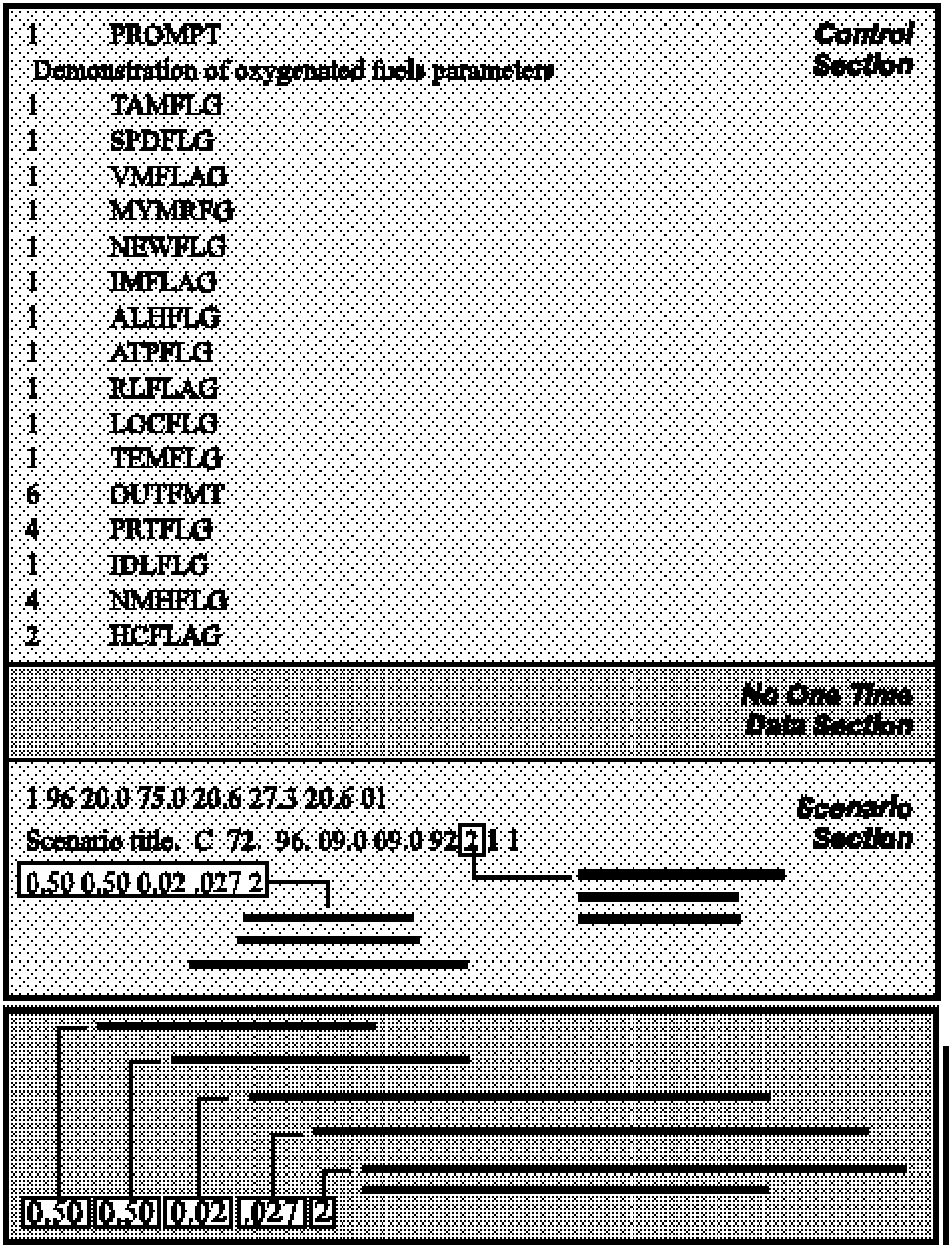
Figure 3-9. Fleet Average Emission Factors for TOG, CO, and NO$_x$ with Varying Reid Vapor Pressure

Fuel Characteristics - Oxygenated Fuels

Another fuel characteristic that can affect the amount of pollutants emitted by motor vehicles is the introduction of oxygenated fuels (either gasoline/alcohol blends or gasoline/ether blends) into the overall fuel mix. Oxygenated fuels are typically introduced to reduce CO emissions. The higher oxygen content of oxygenated fuels improves combustion efficiency, thereby reducing CO emissions. The adjustment for oxygenated fuels is controlled by the oxygenated fuel flag (OXYFLG) in the LAP record and an oxygenated fuels descriptive record which immediately follows the LAP record. The oxygenated fuels record includes market shares and oxygen contents of ether blend and alcohol blend fuels. These data inputs are indicated on the sample MOBILE input file presented in Figure 3-10.

The effects of oxygenated fuels can be seen in Figure 3-11. The emission factors plotted in Figure 3-11 represent a somewhat unrealistic scenario (i.e., 50% of all fuel used by motor vehicles is an alcohol blend with the other 50% being an ether blend). A more typical scenario would probably have a smaller amount of oxygenated fuel sales, but the overall effect of oxygenated fuel, namely significant reductions in CO emissions and virtually unchanged TOG and NO_x emissions, can be seen in this example.

In addition to the fuel characteristics described above, reformulated gasoline (RFG) may be introduced into Mexico in the future as an emissions control measure. Simply stated, RFG is similar to conventional gasoline, except that several fuel characteristics (e.g., RVP, benzene content, aromatics content, oxygen content, distillation points) have been adjusted. Because emissions are affected differently by changes in each of these fuel characteristics, the estimation of emissions from RFG is not a simple task. MOBILE5a does have an RFG flag; however, its estimation methodology is overly simplistic and does not accurately account for all of the effects of RFG. Information on the existing RFG flag can be found in the MOBILE5a User's Guide. MOBILE6 (to be released in mid-1998) is expected to provide a more complete representation of the effects of RFG. If Mexico plans to implement



```
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Demonstration of oxygenated fuels parameters
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1        SPDFLG
1        VMFLAG
1        MYMRFG
1        NEWFLG
1        IMFLAG
1        ALHFLG
1        ATPFLG
1        RLFLAG
1        LOCFLG
1        TEMFLG
6        OUTFMT
4        PRTFLG
1        IDLFLG
4        NMHFLG
2        HCFLAG
1 96 20.0 75.0 20.6 27.3 20.6 01
Scenario title.  C  72.  96. 09.0 09.0 92 2 1 1
0.50 0.50 0.02 .027 2
```

Figure 3-10. Sample Oxygenated Fuel Parameters in MOBILE

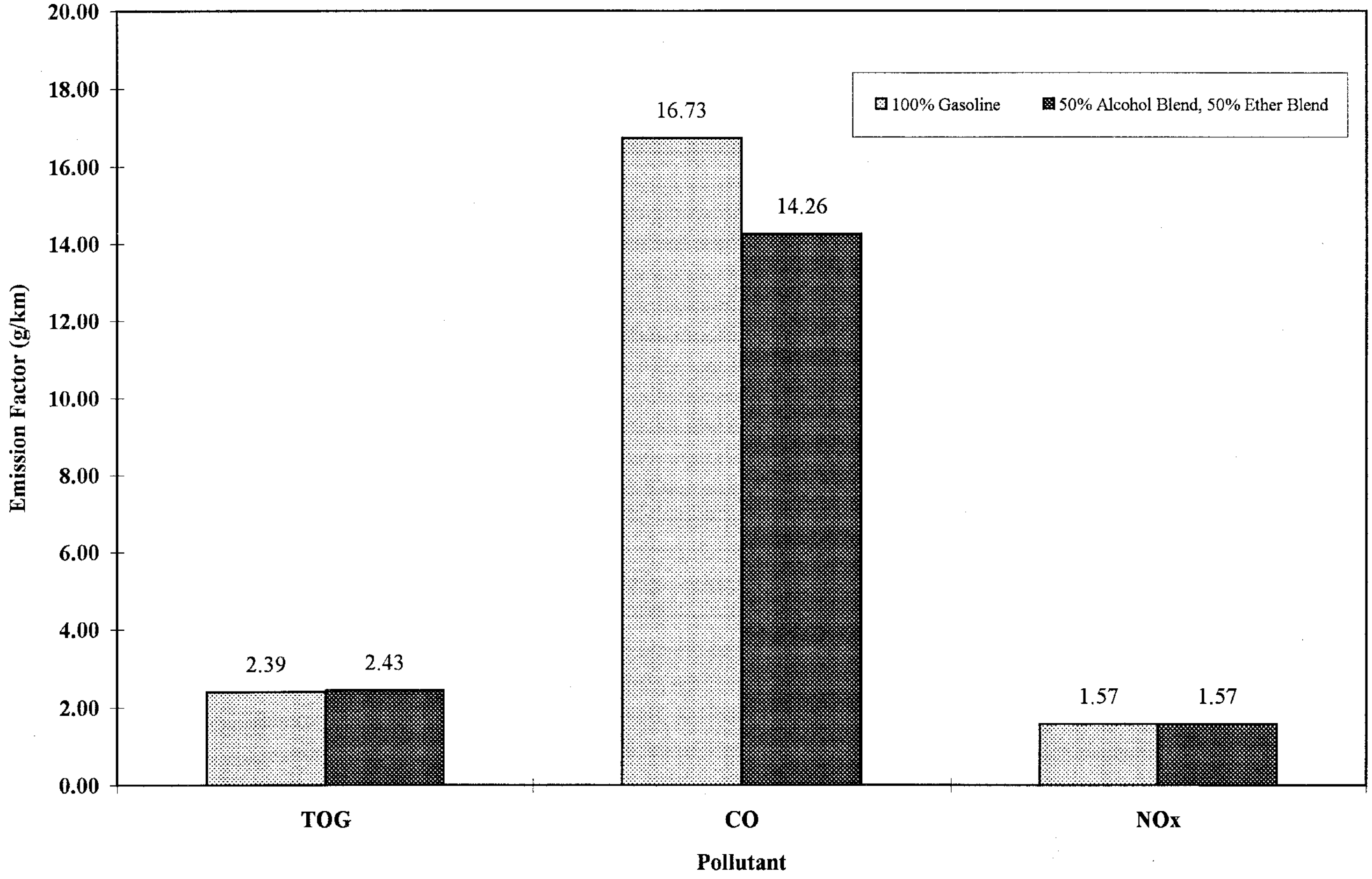


Figure 3-11. Fleet Average Emission Factors for TOG, CO, and NO_x With and Without Oxygentated Fuels

RFG as an emission control strategy in the future, then further detailed examination of the MOBILE models and other research is warranted.

In Mexico, fuel property data is compiled by Petróleos Mexicanos (PEMEX). Government agencies can request data from:

Unidad Central de Coordinación Operativa de PEMEX
Torre Ejecutiva Piso 40
Marina Nacional No. 329
Col. Huasteca
Telephone: 250-55-96, 531-97-00
Fax: 203-55-66

Inspection and Maintenance (I/M) Programs

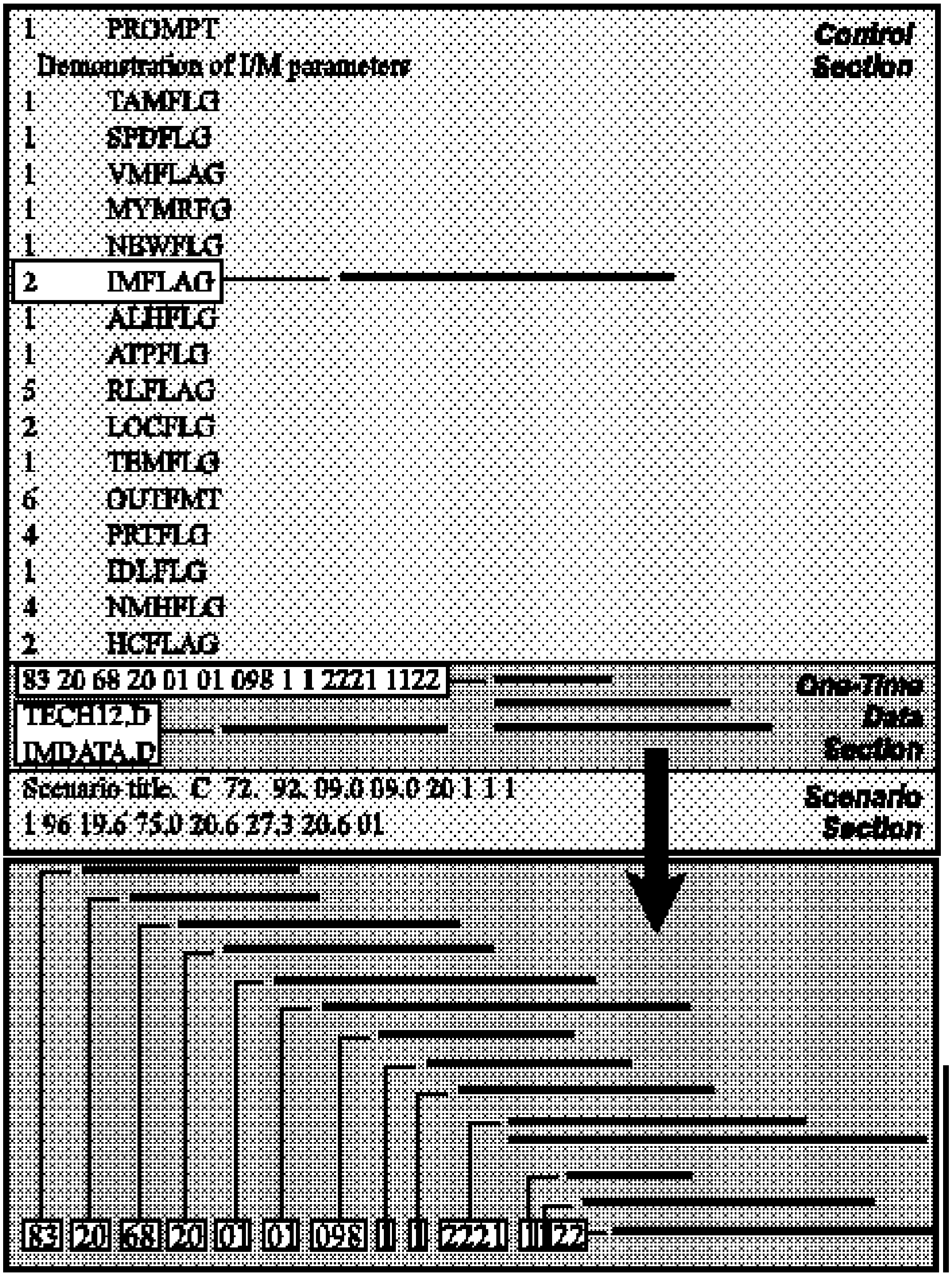
To reduce motor vehicle emissions, regional regulatory programs are often implemented. The most common regulatory program is an inspection and maintenance (I/M) program. As a vehicle's mileage increases, exhaust and evaporative emissions also increase due to the gradual degradation of the vehicle's emission control system. The purpose of I/M programs is to minimize these excess emissions by using emissions testing performed at regular time intervals. Emissions testing is sometimes used as a requirement for vehicle registration. Those vehicles whose emissions exceed established emission standards are required to be repaired. As explained in Section 3.2, BER data do not include the effects of I/M programs. Adjustment factors, based upon I/M-related input parameters, are used to adjust BER data.

Because the specific requirements for I/M programs vary from region to region, there are many possible I/M program variations. The I/M flag (IMFLAG) located in the Control section allows the effects of zero, one, or two I/M programs to be modeled. Although single I/M programs represent the most common situation, sometimes two I/M programs (e.g., a conventional program for some earlier model years and an "enhanced" program for later model years) are to be modeled concurrently. Each I/M program that is to be modeled requires an I/M program descriptive record which is located in the One-Time Data section. The I/M program descriptive record includes the following parameters:

- I/M program start year;
- Stringency level, or the percentage of vehicles failing the first test;
- First and last model years subject to I/M program;
- Waiver rates, or the percentage of vehicles granted an exemption from repairs;
- Compliance rate, or the percentage of the overall subject vehicle population participating in the program;
- Program type (inspection only, inspection and repair [manual], or inspection and repair [computerized]);
- Frequency of inspection (annual or biennial);
- Types of gasoline-fueled vehicles subject to the I/M program;
- Test type (idle, 2500/idle, loaded/idle, or transient); and
- Use of non-default emission cutpoints.

All of these data inputs are indicated on the sample MOBILE input file presented in Figure 3-12.

The effects of I/M programs are shown in Figure 3-13. The fleet average emission factors plotted in Figure 3-13 represent three typical I/M scenarios: no I/M program, one I/M program, and two I/M programs. The parameters for each of these scenarios do <u>not</u> represent the most stringent I/M programs possible, but instead represent typical I/M programs. Obviously, actual I/M programs will use different parameters that will alter the estimated emission factors somewhat, but the overall emissions reduction trend from I/M programs can be seen from this example. This example also demonstrates that some of the benefit derived from I/M programs is realized only over time. Currently, I/M programs have been implemented in Mexico City, Monterrey, and Ciudad Juárez.



```
1       PROMPT
 Demonstration of I/M parameters
1       TAMFLG
1       SPDFLG
1       VMFLAG
1       MYMRFG
1       NEWFLG
2       IMFLAG
1       ALHFLG
1       ATPFLG
5       RLFLAG
2       LOCFLG
1       TEMFLG
6       OUTFMT
4       PRTFLG
1       IDLFLG
4       NMHFLG
2       HCFLAG
83 20 68 20 01 01 098 1 1 2221 1122
TECH12.D
IMDATA.D
Scenario title.  C  72.  92. 09.0 09.0 20 1 1 1
1 96 19.6 75.0 20.6 27.3 20.6 01
```

Figure 3-12. Sample I/M Parameters in MOBILE

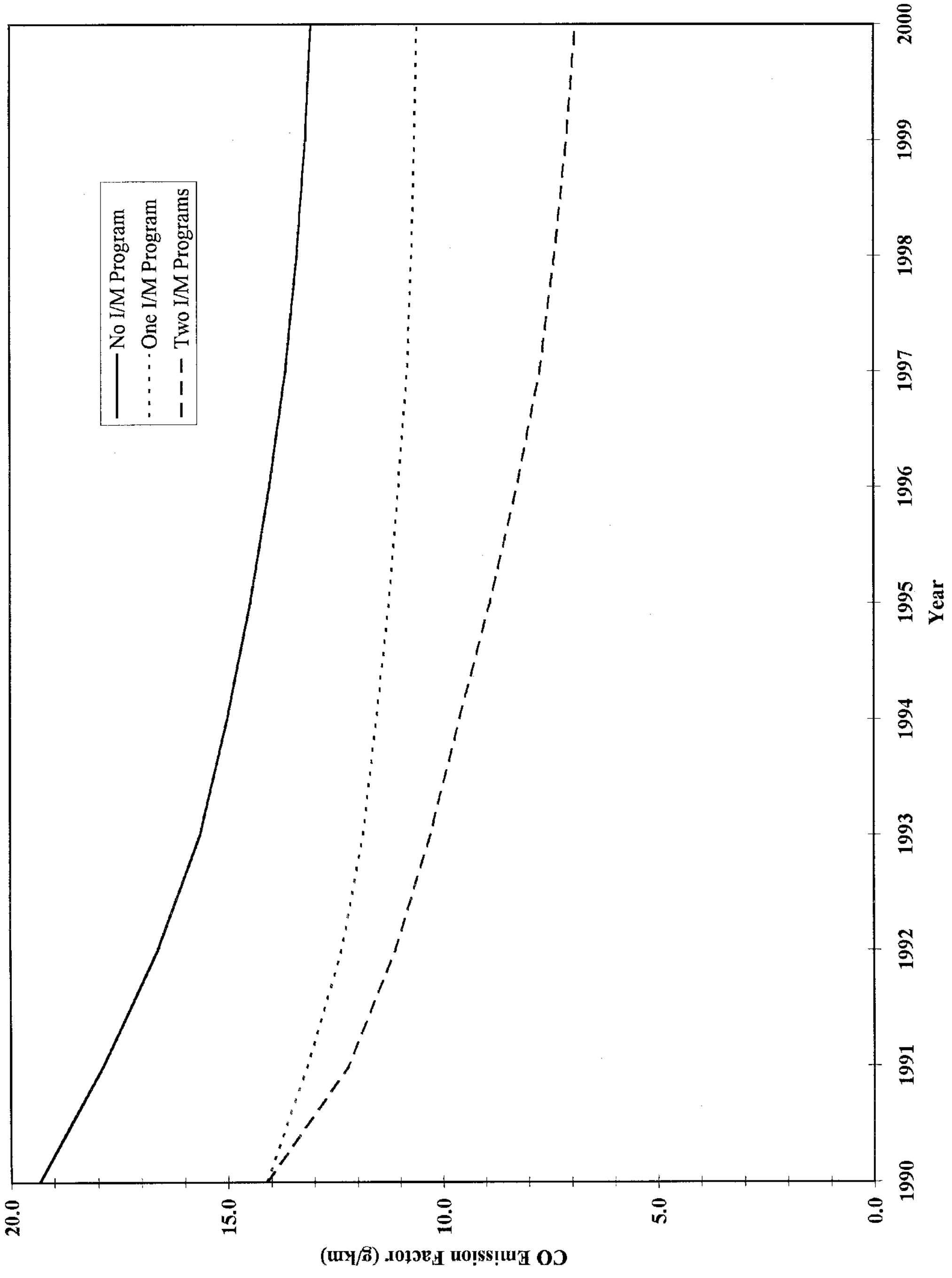


Figure 3-13. Light Duty Gasoline Vehicle CO Emission Factors Under Three Different I/M Scenarios

Anti-Tampering Programs

Another type of regulatory program that can be implemented is an anti-tampering program (ATP). Tampering refers to vehicle misfueling, removal or disablement of catalytic converters, or otherwise reducing the efficiency of a vehicle's emission control system. The reasons for tampering are varied, but the overall effect is to cancel out some of the emissions reductions achieved through I/M programs or other technological advances. Tampering can be intentional or unintentional. As the name suggests, ATPs are implemented to counter the effects of tampering. ATPs consist of inspections of various vehicle components that are used to control emissions. These vehicle components include the catalytic converter, fuel inlet restrictor, gas cap, and others. For purposes of convenience, ATP inspections are typically performed in conjunction with periodic I/M testing.

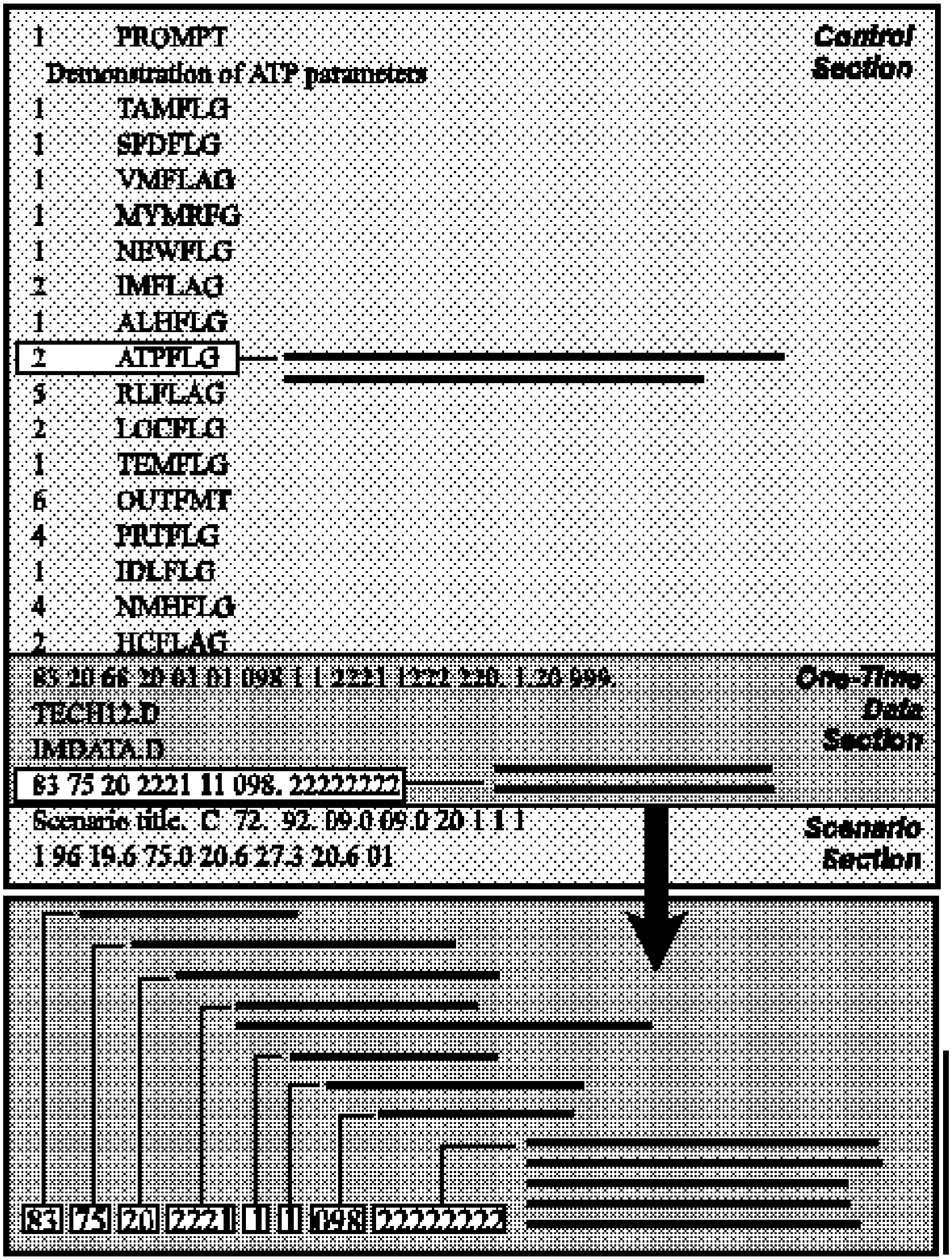
The necessity of an ATP is dependent upon the actual level of tampering within a specific region. In order to quantify actual tampering levels, a tampering survey should be performed. If tampering levels are found to be low, then an ATP might not be the appropriate regulatory program to reduce motor vehicle emissions. However, if tampering levels are determined to be high, then the implementation of an ATP might provide significant emission reductions. For example, previous studies have indicated that over 80 percent of Mexican vehicles with catalysts in Ciudad Juárez have been misfueled with leaded fuel, thereby "poisoning" the catalyst and eliminating virtually all possible emissions reductions.

Overall default tampering levels for U.S. vehicles are currently encoded into the MOBILE model. If tampering survey results indicate significantly different tampering levels in Mexico, then alternative tampering rates can be inserted into the MOBILE model by adjusting the tampering flag (TAMFLG) located in the Control section. For instance, a 1990 tampering rate survey of Ciudad Juárez vehicles was used in the development of MOBILE-Juárez. Additional details concerning the format of these alternative tampering rates can be found in the MOBILE User's Guide (U.S EPA, 1994).

If regional tampering levels warrant the implementation of an ATP, the effects of the ATP can be modeled using the MOBILE model. Much like I/M programs, there are many different possible ATPs that can be implemented. Consequently, there are many parameters that must be specified in order to define a particular ATP. The ATP flag (ATPFLG) located in the Control section allows the effects of an ATP to be modeled. In addition to ATPs, certain values of the ATPFLG allow functional purge and pressure checks of the evaporative emission control system to be modeled. These tests are not described in this document; additional information can be found in the MOBILE User's Guide. Each ATP that is to be modeled requires an ATP descriptive record which is located in the One-Time Data section. The ATP descriptive record includes the following parameters:

- ATP start year;
- First and last model years subject to ATP;
- Types of gasoline-fueled vehicles subject to ATP;
- Program type (inspection only or inspection and repair);
- Frequency of inspection (annual or biennial);
- Compliance rate; and
- Eight types of ATP inspections (Air pump system, catalytic converter, fuel inlet restrictor, tailpipe lead detection, exhaust gas recirculation [EGR] system, evaporative control system, positive crankcase ventilation [PCV] system, and gas cap).

All of these data inputs are indicated on the sample MOBILE input file presented in Figure 3-14. different result and emission reductions. However, the differential reduction of emissions due to an ATP added to an I/M program can be seen in this example.



```
1       PROMPT
  Demonstration of ATP parameters
1       TAMFLG
1       SPDFLG
1       VMFLAG
1       MYMRFG
1       NEWFLG
2       IMFLAG
1       ALHFLG
2       ATPFLG
5       RLFLAG
2       LOCFLG
1       TEMFLG
6       OUTFMT
4       PRTFLG
1       IDLFLG
4       NMHFLG
2       HCFLAG
85 20 68 20 01 01 098 1 1 2221 1222 220. 1.20 999.
TECH12.D
IMDATA.D
83 75 20 2221 11 098. 22222222
Scenario title.  C  72.  92. 09.0 09.0 20 1 1 1
1 96 19.6 75.0 20.6 27.3 20.6 01
```

Figure 3-14. Sample ATP Parameters in MOBILE

The effects of an ATP are shown in Figure 3-15. The fleet average emission factors plotted in Figure 3-15 represent a typical I/M program with and without an ATP. The ATP used in Figure 3-15 assumes that all eight equipment inspections listed above are performed. Obviously, ATPs characterized by different ATP input parameters will have different result and emission reductions. However, the differential reduction of emissions due to an ATP added to an I/M program can be seen in this example.

3.4.2 Fleet Characteristics

In order to use an emission factor model, it is necessary to estimate the travel characteristics of each vehicle type. These travel characteristics include:

- **Vehicle speed.** The average vehicle speed by vehicle class (and preferably by road type) must be determined because emission factors are affected by vehicle speed.
- **Vehicle class VKT distributions (or mixes).** Overall VKT data must be distinguished by vehicle class in order to assign appropriate emission factors.
- **Mileage accumulation rates and registration distributions (fraction of total registered vehicles) for each model year in a vehicle class.** This is used to determine the travel fraction of each model year within a vehicle class.

Vehicle Speed

Average vehicle speed estimates are an important data element for determining the appropriate emission factors for on-road motor vehicle emission inventories. In the MOBILE model, emission factors represent travel at an average speed. The emission factors are developed from test cycles where the vehicle speed is not constant but is varied around an

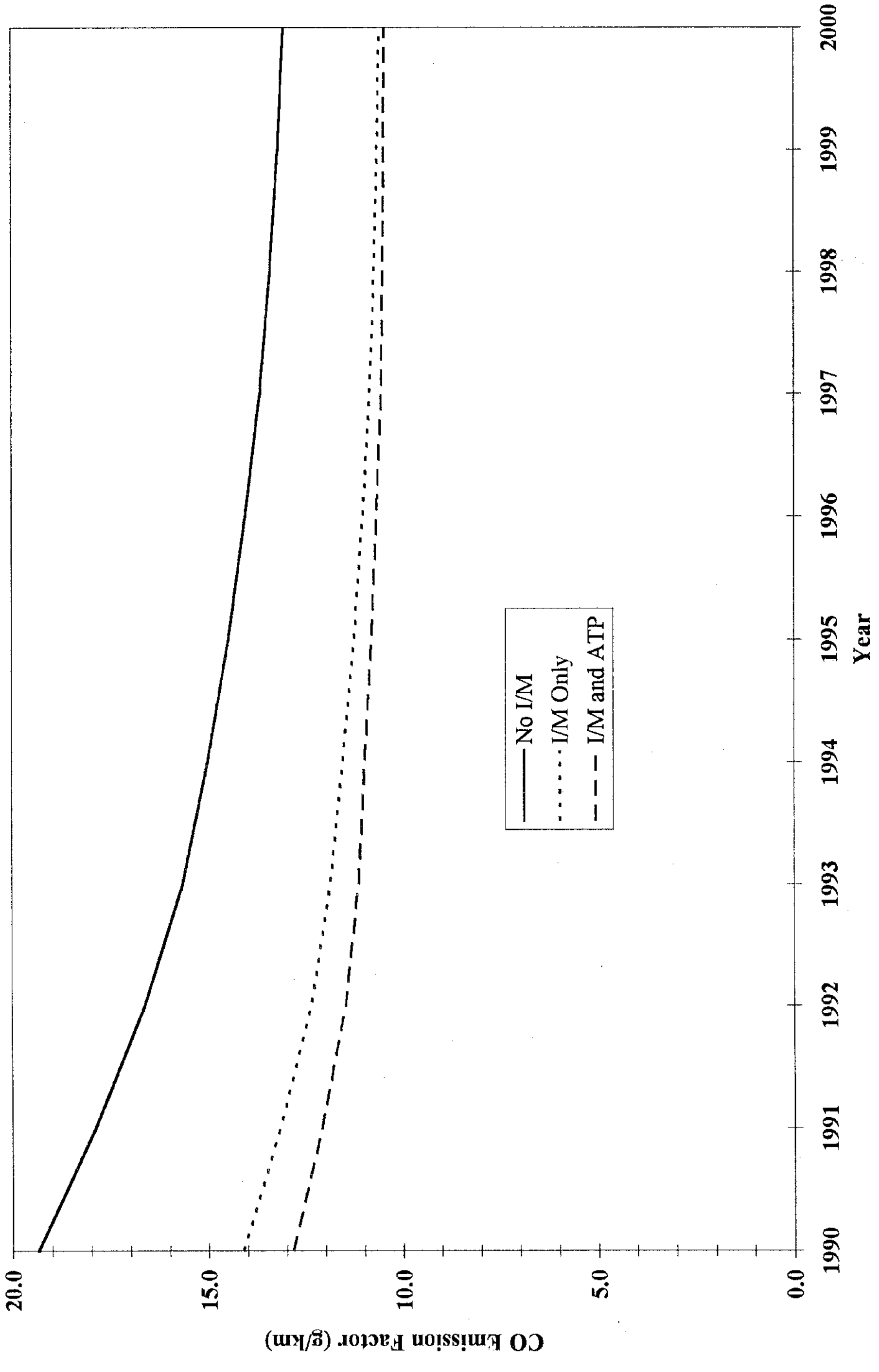


Figure 3-15. Light Duty Gasoline Vehicle CO Emission Factors Under Three Different ATP Scenarios

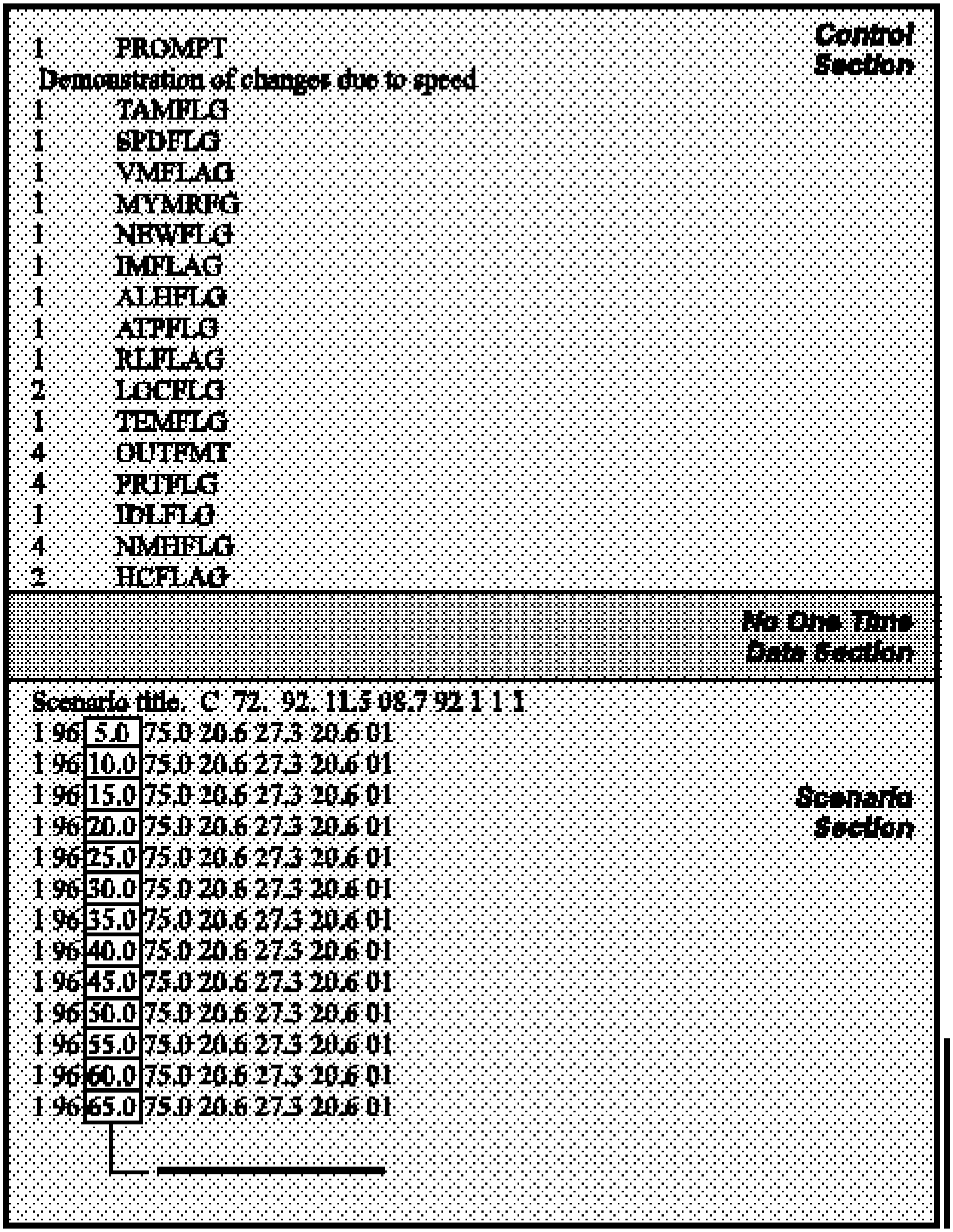
average. Consequently, the goal in developing speed estimates is to determine average vehicle speeds rather than instantaneous speeds. As mentioned in Section 3.2, a speed adjustment factor is applied to the basic emission factors to account for the variability of emissions at different speeds. Average speeds are entered into the scenario descriptive record of the MOBILE input file. These average speeds are indicated on the sample MOBILE input file presented in Figure 3-16. Figure 3-17 presents example emission factors versus average vehicle speed. Note that the emission rate changes significantly with variations in speed, particularly at low and high speeds. Consequently, knowledge of vehicle speeds is important for producing accurate emission inventories.

Estimating average vehicle speeds can be a challenging portion of the inventory data collection effort because many factors can affect speeds on a roadway at any given time. The key factors include:

- **Road type and characteristics -** Speeds vary significantly by road type. For example, freeways and expressways will have higher average speeds than boulevards and arterials, which have higher average speeds than local roads. Road conditions will also have an impact, with paved roads having higher average speeds than unpaved roads.

- **Road location -** The area surrounding a road impacts the average speeds. For example, urban expressways usually have lower average speeds than rural expressways due to higher levels of traffic congestion. In general, for two roads of the same type, average speeds in urban roads are lower than for rural roads.

- **Time of day and season -** In urban areas, variations in traffic congestion will significantly affect the average speeds on a road. Each road has a free-flow speed that is attained when congestion is low. As congestion increases, average speeds are reduced. Seasonal variations can occur in some areas as changes in weather alter road conditions and the average speeds.



```
1       PROMPT
Demonstration of changes due to speed
1       TAMFLG
1       SPDFLG
1       VMFLAG
1       MYMRFG
1       NEWFLG
1       IMFLAG
1       ALHFLG
1       ATPFLG
1       RLFLAG
2       LOCFLG
1       TEMFLG
4       OUTFMT
4       PRTFLG
1       IDLFLG
4       NMHFLG
2       HCFLAG
Scenario title.  C  72.  92. 11.5 08.7 92 1 1 1
1 96  5.0 75.0 20.6 27.3 20.6 01
1 96 10.0 75.0 20.6 27.3 20.6 01
1 96 15.0 75.0 20.6 27.3 20.6 01
1 96 20.0 75.0 20.6 27.3 20.6 01
1 96 25.0 75.0 20.6 27.3 20.6 01
1 96 30.0 75.0 20.6 27.3 20.6 01
1 96 35.0 75.0 20.6 27.3 20.6 01
1 96 40.0 75.0 20.6 27.3 20.6 01
1 96 45.0 75.0 20.6 27.3 20.6 01
1 96 50.0 75.0 20.6 27.3 20.6 01
1 96 55.0 75.0 20.6 27.3 20.6 01
1 96 60.0 75.0 20.6 27.3 20.6 01
1 96 65.0 75.0 20.6 27.3 20.6 01
```

Figure 3-16. Sample Average Speeds in MOBILE

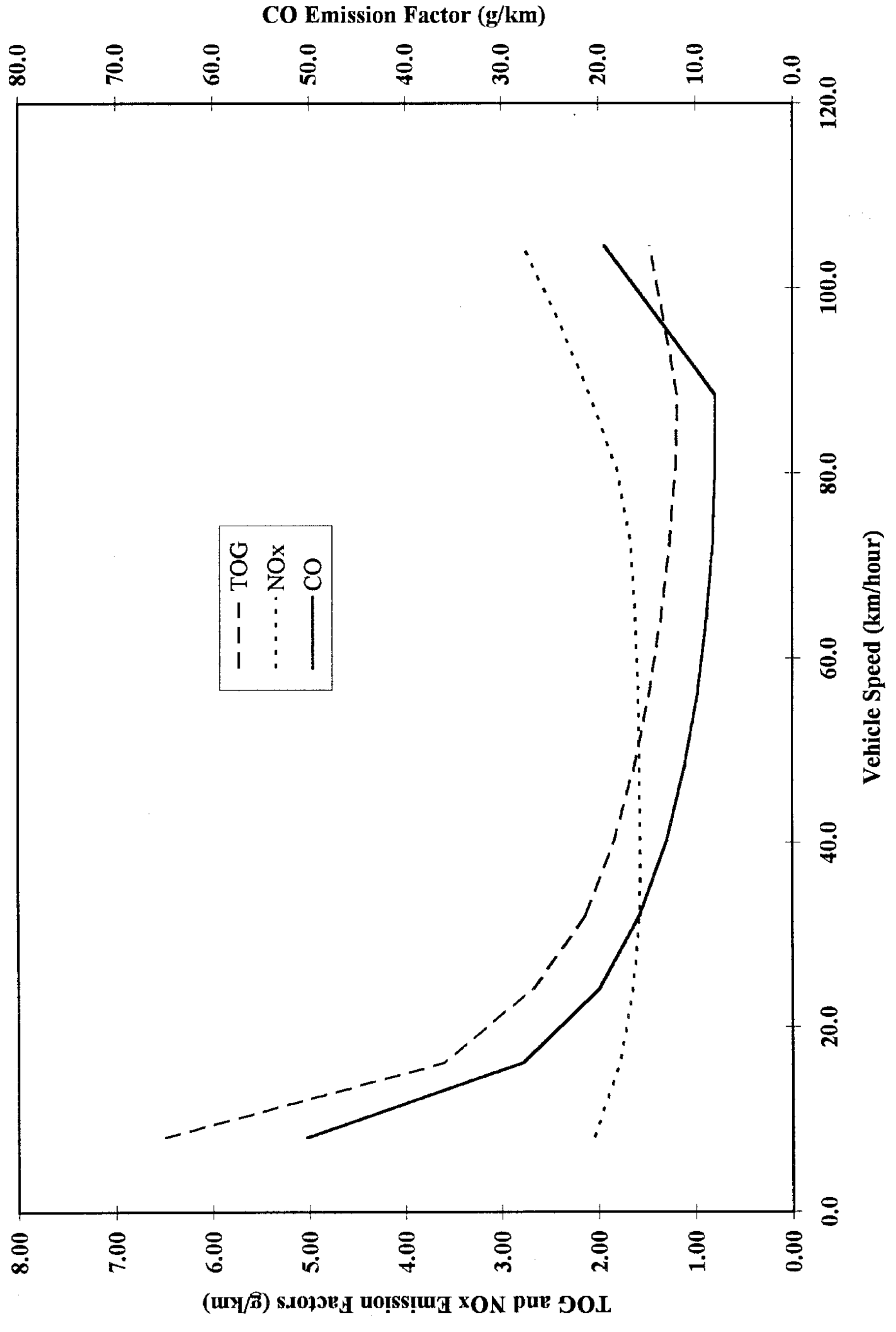


Figure 3-17. Fleet Average Emission Factors for TOG, CO, and NO_x with Varying Vehicle Speed

- **Vehicle type** - Average speeds are often different between different vehicle types. For example, passenger cars and light trucks often have higher speeds than heavy-duty trucks and buses. This is particularly true in urban environments involving stop-and-go traffic.

A variety of options are available for developing speed estimates. Many of these techniques are also useful for collecting vehicle travel information. Hence, if an effort is to be made to determine vehicle travel characteristics in a region, vehicle speed data can also be collected as part of the same study. More detailed information on speed data collection studies is available from the Institute of Transportation Engineers (ITE, 1994).

When such detailed speed estimates are not required, or not available, the goal is to divide VKT into appropriate average speed groupings. One common set of groupings is to classify VKT by road type (expressway, arterials, collector roads, and local roads) and area type (urban and rural), if sufficient data are available. One average speed is assigned for each class of road type and area type, based on survey data or other data sources. This classification assigns the same speed to all vehicle types and to all time periods of the day. Other classifications may be preferable depending upon the level of data available. For example, speed data could be collected as part of an instrumented vehicle study (described below). In this case, the amount of time spent at specific speeds would be known for individual vehicles. While such a study would not define speeds on specific roads, the range of speeds could be divided into groups and the amount of time spent within each group could be calculated.

For initial regional inventories when detailed speed data are not yet available, posted speed limits can be used as a first approximation. Posted speed limits, however, may not represent average vehicle speed under free-flowing conditions where vehicles often exceed posted speed limits. Conversely, areas with heavy congestion, traffic signals, or other intersection controls may have significantly lower average speeds than posted speed limits. These initial estimates can be supplemented with speed surveys collected from a sample of the roads in the inventory region. Speed surveys utilize a variety of measurement techniques.

These include the following:

- **Pneumatic traffic counters** - Pneumatic tubes are placed across traffic lanes and are connected to recorders, which time-stamp the passage of vehicles. These are commonly used to collect traffic flow data as part of traffic management studies. Multiple counters can also be used to measure vehicle speeds. However, this method only measures speeds at a defined point, not average speeds along a roadway.

- **Radar gun studies** - Similar to the pneumatic tube method, radar is used to measure instantaneous vehicle speeds. The radar can be operated in a manned or unmanned mode.

- **Observer or video studies** - Two observers or video cameras are placed at different locations a measured distance apart. A random selection of vehicles are selected and the time they pass each location is recorded. The distance between the locations is divided by the difference in the time marks to estimate average speed.

- **Floating car studies** - An observer car selects vehicles at random and follows the vehicle for a set period of time to measure their speed. In a similar method designed to measure the median speed, the observer car travels at a set speed and notes the fraction of vehicles being passed and the fraction of vehicles passing the observer car.

- **Instrumented car studies** - A random selection of vehicles are procured from the vehicle population. These vehicles are fitted with automated speed recorders which record the vehicle speed at regular intervals (i.e., once per second). The vehicles are released to the owner and returned after a period of operation, perhaps one week. The recorders are removed and the speed data are downloaded. The program can also include diaries to be completed by the vehicle owners where they record their driving activity during the survey period. This method does not provide information on speeds for specific locations, but can be used to estimate region-wide speed distributions.

VKT Mixes

The VKT mix describes the distribution of the total fleet VKT by each vehicle class. When estimating motor vehicle emissions, total VKT in a region or on an individual road is determined first. Then the VKT mix is used to disaggregate the total VKT into different vehicle classes to assist in calculating emissions. The VKT mix can be estimated if vehicle populations and mileage accumulation rates for each vehicle class are known. Both parameters are necessary because different vehicle classes tend to be driven at different rates. For example, commercial heavy-duty trucks generally have higher mileage accumulation rates than passenger cars. The publication *Techniques for Estimating MOBILE2 Variables* (EEA, 1980) outlines general methods for calculating the VKT mix.

If the vehicle populations and mileage accumulation rates are not available, then the next option is to estimate VKT mix from local surveys. In the survey method, observers are stationed at a number of locations in the inventory region. The observers classify a random sample of cars passing the location based on their vehicle class. Alternatively, photographs of vehicles and/or their license plates can be taken for later classification to distinguish fuel type (gasoline versus diesel). This technique provides an estimate of the VKT mix since the number of vehicles in a class passing a location should be proportional to the overall VKT contribution for that class. This data collection method was used to estimate the VKT mix for the 1993 Ciudad Juárez inventory (TTI, 1994).

The MOBILE model vehicle classes coincide with U.S. vehicle emission standard classifications. Fortunately, Mexico vehicle emission standards are also set up in similar classifications to the U.S., which simplifies the use of the existing MOBILE vehicle classes. A comparison of the Mexico new vehicle emission standard classifications and the MOBILE model vehicle classes is shown in Figure 3-18. Mexico has established new vehicle emission standards for six vehicle classes covering passenger cars, light-duty trucks, heavy-duty trucks, and buses. These classes map to five of the MOBILE vehicle classes. There are also other vehicles present in the Mexico fleet for which no new vehicle emission standards have been established, including light-duty diesel-powered cars and trucks, and gasoline-powered motorcycles. In addition to these new vehicle emission standards, Mexico has also established “in-use” vehicle emission standards, which are described in Section 1.2. Figure 3-19 shows an example distributions of VKT activity among the eight MOBILE classes from motor vehicle inventories in Monterrey and Ciudad Juárez. While the distribution of activity between the vehicle classes will vary, for most regions the activity is dominated by light-duty vehicles and light-duty trucks. Light-duty diesel-powered cars and trucks, and gasoline-powered motorcycles are present in the fleet, but as shown in Figure 3-19, they collectively constitute less than 2 percent of the total fleet VKT activity.

Registration Distributions

Registration distributions give the fraction of vehicles in a particular model year relative to the overall vehicle class population. Some uncertainty exists because the overall vehicle population includes both registered and unregistered vehicles, while any registration distribution, by definition, only includes registered vehicles. The registration distribution and mileage accumulation rates are used together to calculate the travel fraction in MOBILE. The travel fraction is the portion of VKT accumulated by one model year of vehicles in a vehicle class relative to the total VKT for the entire vehicle class. This calculation is performed using the following equation:

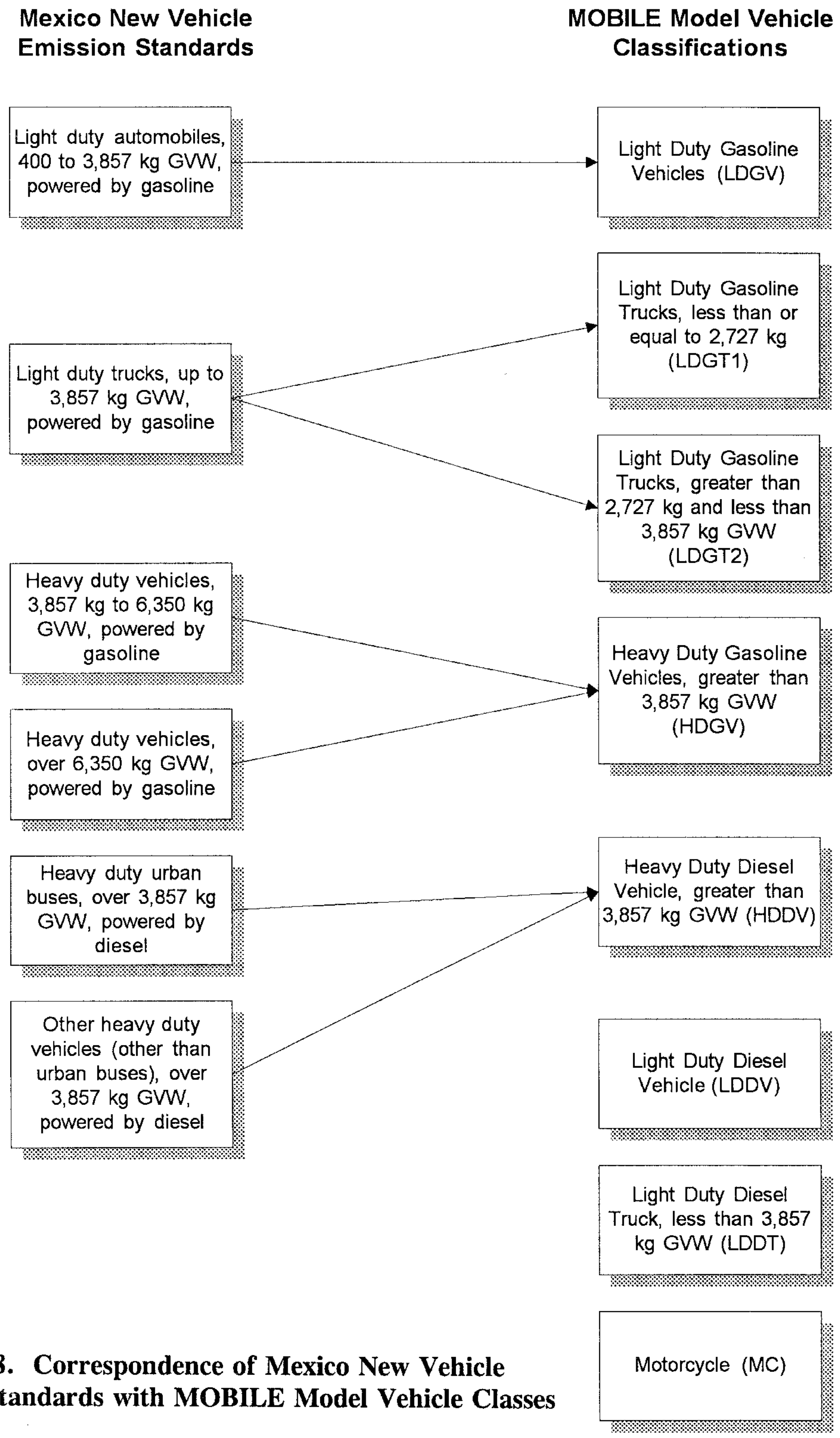


Figure 3-18. Correspondence of Mexico New Vehicle Emission Standards with MOBILE Model Vehicle Classes

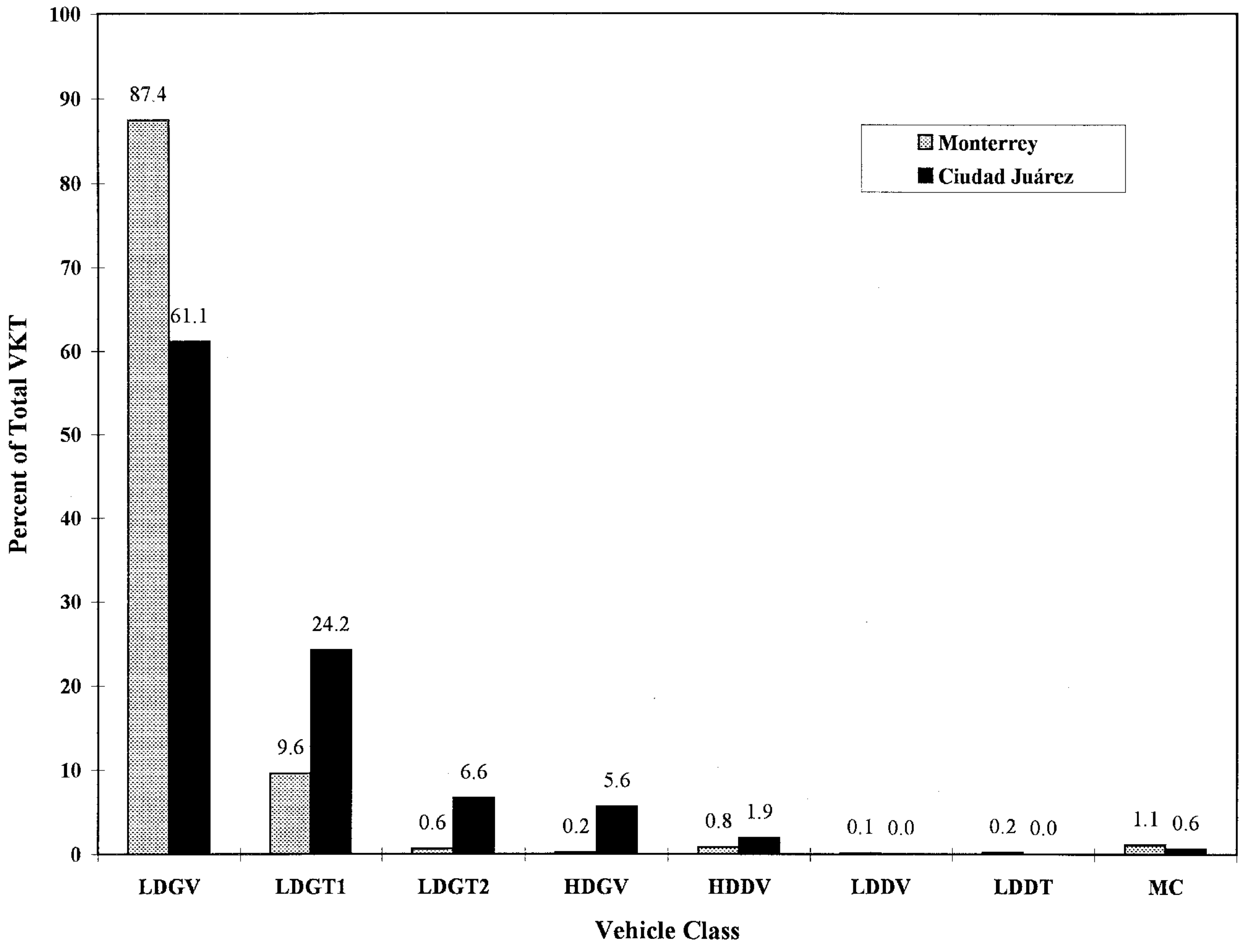


Figure 3-19. Monterrey and Ciudad Juárez Vehicle Kilometers Traveled (VKT) Distributions

where: TF_i = Travel fraction for model year, i, within a vehicle class;
RF_i = Fraction of total vehicle class registrations for model year, i; and
MAR_i = Mileage accumulation rate for vehicles in model year, i.

In Mexico, vehicle registration data are typically compiled by individual states or municipalities. Detailed vehicle registration data should provide the model year of each vehicle which then can be used to estimate registration distributions. However, in some areas vehicle registration data might be limited to the overall vehicle population and, possibly, the number of vehicles in each vehicle class. In such instances, surveys would need to be conducted in order to estimate registration distributions and mileage accumulation rates. Alternatively, information from other regions in Mexico could be used (subject to increased uncertainty) in similar regions. For example, some information used in the development of MOBILE-Juárez (Radian, 1996a) will be used to estimate motor vehicle emissions for an emissions inventory in Nogales, Sonora.

In some areas of Mexico, unregistered and/or U.S.-registered vehicles form a significant proportion of the vehicle population. In Ciudad Juárez, for example, 23% of the vehicles observed during vehicle surveys were unregistered and 15% were registered in the U.S. (TTI, 1994). In this case, registration distributions calculated from official registration records will be underestimated. A direct survey of vehicle populations may be more appropriate to improve the registration distribution estimate.

Mileage Accumulation Rates

Mileage accumulation rate is the annual amount of VKT accumulated by vehicles of one model year and one vehicle class. This parameter is one of the most difficult to determine since it cannot be estimated from traffic observations. The U.S. EPA document *Techniques for Estimating MOBILE2 Variables* (EEA, 1980) discusses methods for obtaining mileage accumulation rate estimates. However, the methods described in this document are dependent upon use of U.S.-specific information sources that may not apply to Mexico. Three options for estimating mileage accumulation rates are available:

- **Travel surveys of vehicle owners.** These can be home interview questionnaires taken of vehicle owners asking their annual mileage accumulation rates. In more detailed travel surveys, a sample of vehicle operators is solicited to complete a log of all travel made over a set period of time. From these results, annual mileage accumulation rates can be estimated.

- **Use of vehicle inspection data.** If the region has a vehicle I/M or safety inspection program in place where vehicle odometer readings are recorded, mileage accumulation rates could be calculated. This calculation is based on the difference in odometer readings for individual vehicles recorded over multiple inspections. A less accurate rate could be estimated from single odometer readings and the age of the vehicle, if the mileage is assumed to be accumulated at an even rate over the life of the vehicle.

- **Use of mileage accumulation rates from other regions.** U.S. mileage accumulation rates should not be used. Mileage accumulation rates from other similar regions in Mexico can be used if site-specific data cannot be obtained. The resultant emission estimates, however, will contain an additional amount of uncertainty because driving patterns are likely to vary from region to region.

4.0 DEVELOPMENT OF ACTIVITY DATA

As described in Section 2.0, vehicle kilometers traveled (VKT) estimates are combined with emission factors to yield emission estimates. In Mexico, there are two methods to derive VKT estimates. These two methods are:

- Direct traffic-based VKT estimates; and
- Fuel consumption statistics.

There are definite differences in the quality of the VKT estimates available through the use of these two methods. The choice of the activity data to be used will primarily be determined by which types of data are available and the overall quality of the data. In general, direct traffic-based VKT estimates tend to provide a better representation of vehicle activity than VKT estimates from fuel consumption statistics.

In major urban areas, some sort of traffic-based VKT estimate is often available. Outside of major urban areas, however, such VKT estimates are not likely to be available, leading to the use of fuel consumption data. Even if direct traffic-based VKT estimates are available, VKT estimates derived from fuel consumption statistics can be used as an effective quality assurance tool. Traffic-based VKT estimates are discussed in Section 4.1, while VKT estimates derived from fuel consumption statistics are presented in Section 4.2.

4.1 Traffic-Based VKT Estimates

There are two primary types of traffic-based VKT estimates: detailed estimates for specific roads obtained from travel demand models (TDMs), and regional VKT estimates developed from traffic measurement programs or other means.

4.1.1 VKT Estimates from Travel Demand Models

Travel demand models (TDMs) are computer model representations of the road network in an urban area. Currently, TDMs are only used in the larger urban areas (i.e., Mexico City and Monterrey). TDMs are used to model traffic flows for traffic improvement and congestion management studies. In TDMs, the region to be modeled is divided into zones of similar demographic characteristics. Roads or groups of roads are represented in the model as a network of connected links. These links provide the means to track traffic flow between zones. To model travel behavior, the number, origin, and destination of vehicle trips are assigned to appropriate zones. The travel on the links is then calculated to produce the shortest estimated travel times between zones. Outputs from TDMs provide estimated travel time and traffic flows on the individual links. TDMs are not created explicitly for use as emission inventory tools, but if they are comprehensive and up-to-date, the results can serve as a source of detailed vehicle travel and speed estimates for use in emission inventories. For a description of the TDM development process and the use of TDMs in emission inventories, see *Procedures for Emission Inventory Preparation, Volume IV: Mobile Sources*, Section 3.4.2 (U.S. EPA, 1992). Many texts are also available that discuss the TDM process in detail, including *Urban Travel Demand Modeling* (Oppenheim, 1995).

A considerable investment or resources and time is necessary to gather the data to support TDMs. Consequently, they are usually only developed for major urban areas where traffic improvement studies are frequently needed to maintain the transportation infrastructure. As mentioned above, only the largest urban areas in Mexico currently operate TDMs. Smaller urban areas must rely on other sources of VKT estimates.

From the estimates of distance and volume on TDM links, VKT on a single link can be estimated from the equation:

$$VKT = \frac{Volume}{Distance} \qquad (4\text{-}1)$$

where:
VKT = Vehicle kilometers traveled per time period;
Volume = Number of vehicles on a link for a given time period; and
Distance = ... Distance of the link, in kilometers.

Regional estimates of VKT can be developed by summing VKT over all links or links of a given type and area designation.

The data obtained from a TDM must be analyzed to determine how applicable they are to the emissions inventory being developed. Two key issues for emission inventories are the extent of coverage of the overall road network and the representativeness of the data to the inventory year. Frequently, TDMs are developed to model travel on the larger roads in the road network only, and do not include travel on smaller local roads and streets. It is important to determine the limits of the TDM coverage. In cases where the coverage is not complete, separate estimates must be developed for the local roads.

The TDM process depends on survey data of local travel behavior. These survey results are important because they help estimate the amount and location of trip generating activity. Therefore, the TDM inputs should be based on survey data taken as close to the inventory year as possible. Ideally, the survey should be conducted within five years of the inventory year. Survey results older than five years will introduce additional uncertainty to the inventory.

4.1.2 Regional VKT Estimates

Many urban areas are likely to have developed regional VKT estimates as part of the transportation planning process. While not as spatially detailed as VKT estimates from TDMs, these regional estimates can equal or exceed the precision of the TDM estimates on a regional level if they are based on a sufficient number of actual measurements.

Regional VKT estimates are normally based on direct measurements of vehicle volumes passing a single point on a road. VKT on the road is then estimated from the vehicle volumes and the length of the road. Ideally, direct measurement of traffic volumes would be made on a large sample of roads in the area. However, it is cost-prohibitive to frequently measure the traffic volumes on the large number of roads in an urban area. Measurements are instead taken from a sample or subset of the roads in the region and the results are extrapolated to estimate the regional VKT total. As part of this process, the road network is first classified into a system where roads of the same class are expected to have similar traffic volumes. Measurements are taken from a sample of the roads in each class. A regional estimate can then be developed by extrapolating the sample results based on the ratio of the length of roads in the class sampled to the total length of roads in the class. Additional adjustments may be necessary if measurements taken over a number of years are being combined to estimate regional VKT.

Further information on techniques for measurement of vehicle volumes can be obtained from *Manual of Transportation Engineering Studies* (ITE, 1994). For purposes of emission inventory development, spot measurements of vehicle volumes may be made to validate regional estimates or to supplement existing data. Sampling methods can include both automated and manual data collection. These studies can be designed to also collect speed data at the same time (see Section 3.4.2).

National estimates of traffic volumes for Mexico are available for paved roads and are compiled by road type (federal, toll, and state roads). These data are available in the publication *Anuario Estadístico del Sector Comunicaciones y Transportes* (SCT, 1993). It is uncertain whether these data have been disaggregated to the regional or sub-regional level.

4.2 VKT Estimates Derived from Fuel Consumption Data

In the absence of direct VKT estimates from TDMs and regional data collection programs, VKT may be estimated indirectly from fuel consumption data. If these other sources of direct VKT estimates are available, fuel consumption data can also be used to check the validity and accuracy of the estimates.

Fuel sales and consumption statistics typically are much more widely used and available than direct VKT estimates. These statistics are usually kept to track fuel sales and consumption because gasoline and diesel are valuable commodities. In Mexico, fuel consumption or local sales data can be obtained from Petróleos Mexicanos (PEMEX). For a smaller inventory region, fuel sales from individual service stations may also be requested.

Government agencies can request data from:

Unidad Central de Coordinación Operativa de PEMEX
Torre Ejecutiva Piso 40
Marina Nacional No. 329
Col. Huasteca
Telephone: 250-55-96, 531-97-00
Fax: 203-55-66

Using fuel consumption data, a regional estimate of VKT can be obtained that represents the entire fleet of vehicles using one type of fuel:

$$VKT_f = Sales_f \times KPL_f \tag{4-2}$$

where:
VKT = Vehicle kilometers traveled;
Sales = Total fuel sales (liters);
KPL = Fleet average fuel efficiency (kilometers/liter) (Mexico-specific values or U.S. default values); and
f = Fuel type (gasoline or diesel).

The use of VKT data from TDMs or regional estimates is preferred over the use of fuel data. In general, it is preferable to use fuel sales or fuel consumption data to check existing direct VKT estimates, but if needed, fuel sales or fuel consumption data can be used to estimate VKT. Several issues increase the uncertainty in VKT estimates derived from fuel statistics. These include:

- Fuel sold within the inventory region may not be consumed within the region. This may be particularly true where there are large differences in fuel prices between geographic areas or where there is a large amount of commuting traffic into an urban area.
- Fuel sales or consumption data may include off-road equipment, (particularly for diesel).

There are some inventory regions where the location of fuel purchases and fuel consumption could differ significantly. In other words, fuel purchased in one area might be used in a different area. Within small inventory regions, this can create major discrepancies between fuel purchases and fuel consumption. However, in larger inventory regions, these discrepancies tend to cancel each other out and become less significant.

It is also important to determine the end use of the fuel. Regional fuel consumption data will likely include consumption by both on-road motor vehicles and off-road equipment, particularly for diesel fuel. Inclusion of fuel consumed by off-road equipment will inflate the VKT estimate. If possible, off-road equipment fuel consumption should be subtracted from total fuel consumption.

5.0 QUALITY ASSURANCE/ QUALITY CONTROL PROCEDURES

The final necessary step in developing accurate and useful emission estimates is to assess the overall accuracy of the estimates. Historically, developing independent assessments of the accuracy of motor vehicles emission estimates has been a difficult process because of the large number of sources, the geographic scope of their operation, and the diversity of emissions from individual vehicles. In spite of this difficulty, motor vehicle emissions must receive proper quality assurance/quality control (QA/QC) review. Motor vehicles represent a major source of emissions and the procedures used to develop the emission estimates require the use of large and complex data sets. Because no single QA measure is available that can assess the accuracy and bias of motor vehicle emission estimates, successful QA programs attempt to assess the inventory through as many independent measures as possible. This section presents specific procedures that can be used to evaluate the accuracy of motor vehicle emission estimates. These procedures include:

- Comparison of motor vehicle emissions to overall emissions inventory;
- Comparison of per capita emissions;
- Comparison of emissions versus VKT;
- Comparison of motor vehicle activity data to fuel consumption statistics;
- Remote sensing surveys of exhaust emissions; and
- Use of ambient sampling data.

5.1 Comparison of Motor Vehicle Emissions to Overall Inventory

A useful QA check on an emission inventory is the comparison of emissions from motor vehicles to emissions from all anthropogenic sources. The motor vehicle fraction of total emissions will vary by pollutant and location. There is no one single fraction that applies globally. Ideally, inventory results can be compared to historical results for the same area, or compared to results from other areas believed to have similar motor vehicle and stationary source emissions. This check will only provide an approximate estimate of the reasonableness of the emissions estimates. Further investigation is warranted if the motor vehicle fractions are noticeably different than results from similar regions. Discrepancies may be due to errors in the inventory or unknown differences in the characteristics of the two regions.

An example of the use of relative percentage emission contributions for assessing the reasonableness of emission estimates is given in Table 5-1. In this table, the relative proportion of motor vehicle emissions as a percentage of total emissions is presented for six regions, two in the United States (Atlanta and Los Angeles), two in Mexico (Mexico City and Monterrey), and two in Asia (Bangkok and Hong Kong). Emission estimates from motor vehicles vary between the six locations. The relative proportion of the motor vehicle contribution to overall VOC emissions ranges from 35 percent for Atlanta to 80 percent for Mexico City. This amount of variation is reasonable given different vehicle fleet mixes, vehicle emission standards, and levels of industrialization in each area.

The comparisons for CO and NO_x highlight Bangkok as noticeably different from the other regions. In the other five locations, NO_x emissions range from 20 percent to 75 percent of the overall anthropogenic emissions inventory. Bangkok, on the other hand, is estimated to have only 1 percent of its NO_x emissions contributed by mobile sources. Likewise, the CO percentage for Bangkok appears to be a statistical outlier at 35 percent compared to the other four locations with percentages between 70 percent and 98 percent. Part of the difference

Table 5-1

Relative Contribution of Motor Vehicle Emissions to Overall Anthropogenic Emission Estimates in Selected Cities

Location	Inventory Year	Reference	Estimated Motor Vehicle Emissions as a Percentage of Anthropogenic Emissions		
			VOC	CO	NO_x
Bangkok, Thailand	1992	MSTE, 1994	55	35	1
Hong Kong	1991	EPD, 1994	N/A	80	25
Monterrey, Mexico	1995	Radian, 1996b	70	95	30
Mexico City, Mexico	1989	LANL and IMP, 1994	80	98	75
Atlanta, Georgia	1995	Georgia DNR, 1995	35	70	20
Los Angeles, California	1990	SCAQMD, 1994	50	80	60

CO = carbon monoxide
NO_x = nitrogen oxides
VOC = volatile organic compounds
N/A = not available

between Bangkok and the other regions may be due to different mixes of vehicles. The Bangkok vehicle fleet includes a large proportion of two-cycle engines which have lower NO_x emissions than comparable four-cycle engines that predominate in the other areas. However, this does not explain the total extent of the difference in NO_x emissions, or the difference in CO emissions.

The above percentages do not indicate whether the Bangkok motor vehicle or anthropogenic emission estimates are potentially faulty; only that one or both of the CO and NO_x emission estimates are likely to be biased. The conclusion from this example analysis is that more detailed review of the overall inventory for Bangkok is warranted to determine if there are indeed biases in the emission estimates. As more emission estimates are generated in Mexico, they can be used in a similar fashion to identify potential outliers such as the Bangkok data presented in Table 5-1.

5.2 Comparison of Per Capita Emissions

Motor vehicle emissions are usually developed from traffic-based VKT estimates or VKT estimates derived from fuel consumption statistics. Per capita motor vehicle emissions can be calculated and compared to results from other regions to check for reasonableness of the results.

To illustrate this process, Figure 5-1 presents estimates of per capita motor vehicle emission estimates for 12 western states in the United States. Emission estimates are aggregated at the state level and are compared to state-wide population estimates. Both emission estimates and population are for 1990.

There is not a clear relationship between population and per capita emissions. California, with the largest population, has one of the lowest per capita emission rates for each of the four pollutants presented. Texas, the next most populous state presented, has a per capita emission rate that is in the middle. Wyoming, the least populous state represented, has the highest per capita emission rates for all pollutants.

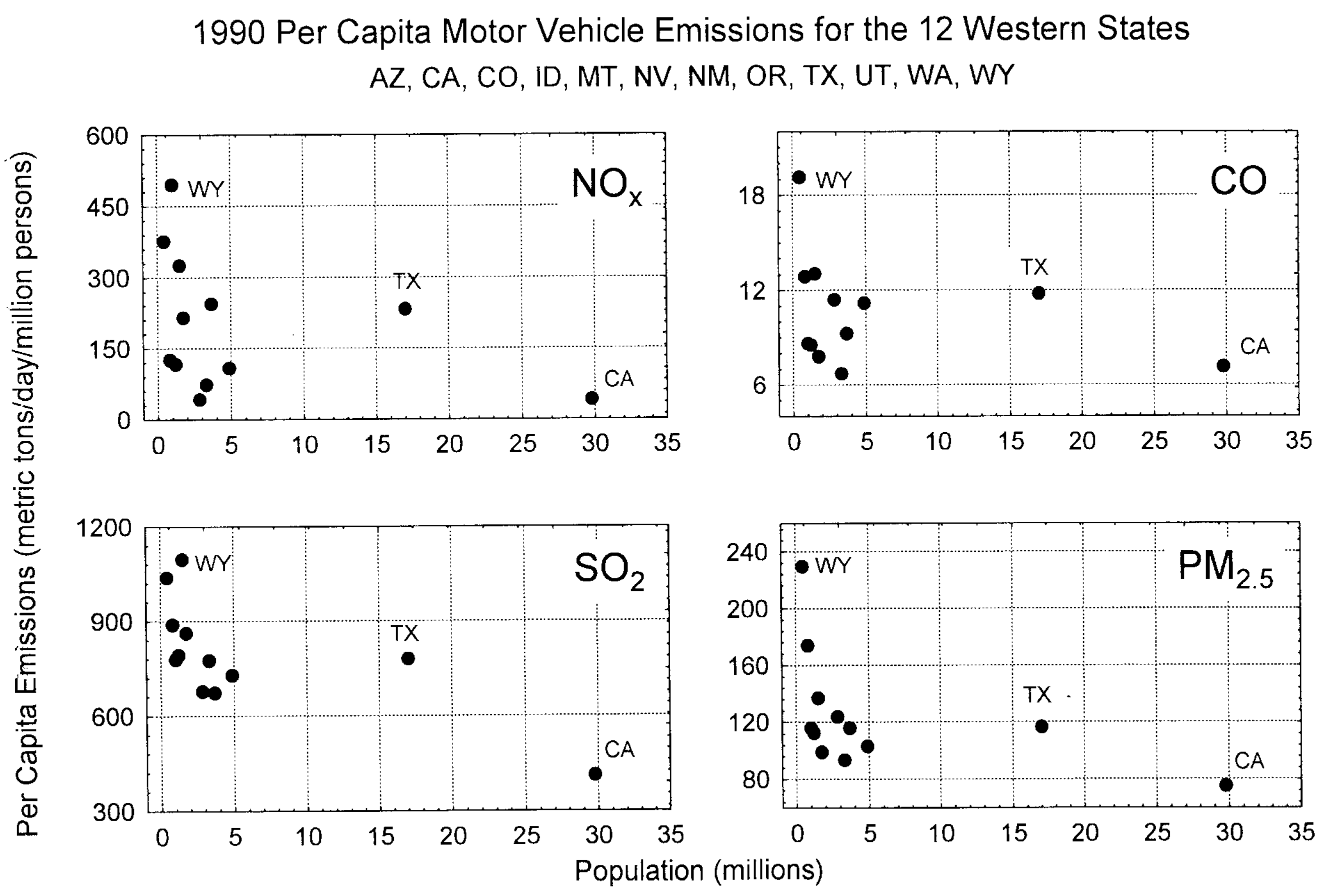


Figure 5-1. 990 Per Capita Motor Vehicle Emissions for the 12 Western States AZ, CA, CO, ID, MT, NV, NM, OR, TX, UT, WA, WY

Because of the large difference in the emission estimates between California and Wyoming, the natural question is what is the cause of the difference. Unless the reason for the observed differences can be readily explained, a potential bias in the emission estimates might be suspected. In the present example, the high per capita emissions rate in Wyoming is likely explained by the fact that Wyoming is a very rural state with large distances between urban areas. Average travel distances are large, resulting in more emissions per vehicle and relatively larger per capita emissions when compared to the other states. On the other hand, California has high traffic volumes and travel distances, but these factors are counterbalanced by the most stringent motor vehicle emission limits in the United States. As a result, there are relatively low per capita emissions from motor vehicles. This demonstrates the need to examine differences and provide reasonable explanations for these differences. If an explanation cannot be provided, then an error or bias might exist in the estimates.

Figure 5-2 presents plots of motor vehicle emissions and VKT for 43 counties in central Georgia, including metropolitan Atlanta and surrounding areas. Unlike the previous plot of per capita emissions, there appears to be a linear relationship between emissions and population and between VKT and population. In this plot, the four counties containing the bulk of the Atlanta area population appear to be outliers in the upper right corner of each plot. However, if these four counties were removed from the plot, the resulting plot of emissions versus population would be much less linear. This plot provides an example of the need to examine plots and data closely to ensure that initial impressions are correct and that no obvious systematic differences or errors are present in the data that may skew the conclusions.

5.3 Comparison of Emissions Versus VKT

Motor vehicle emission estimates are calculated by multiplying an emission factor by VKT. A simple comparison of estimated emissions to VKT can often identify computational errors.

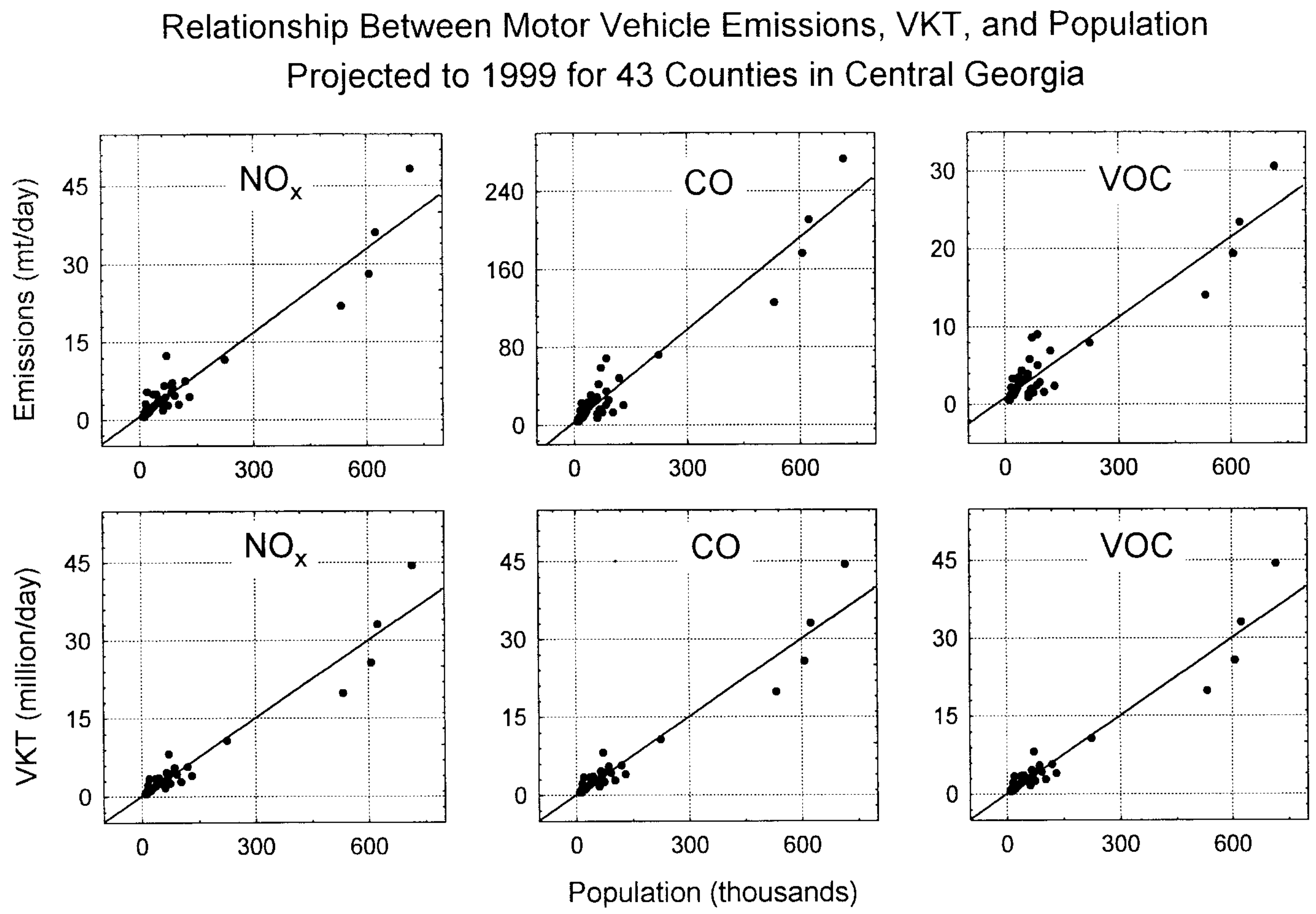


Figure 5-2. **Relationship Between Motor Vehicle Emissions, VKT, and Population Projected to 1999 for 43 Countries in Central Georgia**

Figure 5-3 presents a plot of motor vehicle emissions versus VKT for 43 counties in central Georgia. Since VKT was used to estimate Atlanta emissions, this does not qualify as an independent check of emissions. Given that emissions are linearly proportional to VKT, a linear relationship is expected in Figure 5-3. Some deviations away from an exact linear correlation are to be expected due to differences in fleet mix, fuel characteristics, inspection and maintenance (I/M) programs, and other factors. However, significant deviations from the linear relationship (beyond differences seen in Figure 5-3, for example) would indicate the need to recheck the accuracy of the inventory calculations.

5.4 Comparison of Motor Vehicle Activity Data to Fuel Consumption Statistics

Fuel consumption statistics can be used to check the reasonableness of motor vehicle emission estimates, unless the original VKT estimates were themselves derived from fuel consumption statistics. VKT estimates used for comparison should be derived using fuel statistics as described in Section 4.2. Also, the uncertainty described in Section 4.2 resulting from off-road mobile equipment use and other factors should also be considered when this QA method is utilized.

5.5 Remote Sensing Surveys of Exhaust Emissions

The basic data used in motor vehicle emission factor models (e.g., MOBILE or PART5) are collected from vehicles operating on dynamometers according to prescribed driving patterns. Even though large quantities of data can be generated under these test conditions, the data are limited in their ability to recreate “real world” driving conditions. To the extent that basic data used in an emission factor model do not match real world conditions, the predicted average emission factors from the emission factor model are biased. For example, the basic data used to populate previous versions of the MOBILE model have resulted in an underestimation of VOC and CO emissions. The current driving cycle used in the dynamometer tests does not account for all high speed driving as well as hard accelerations and decelerations. In addition,

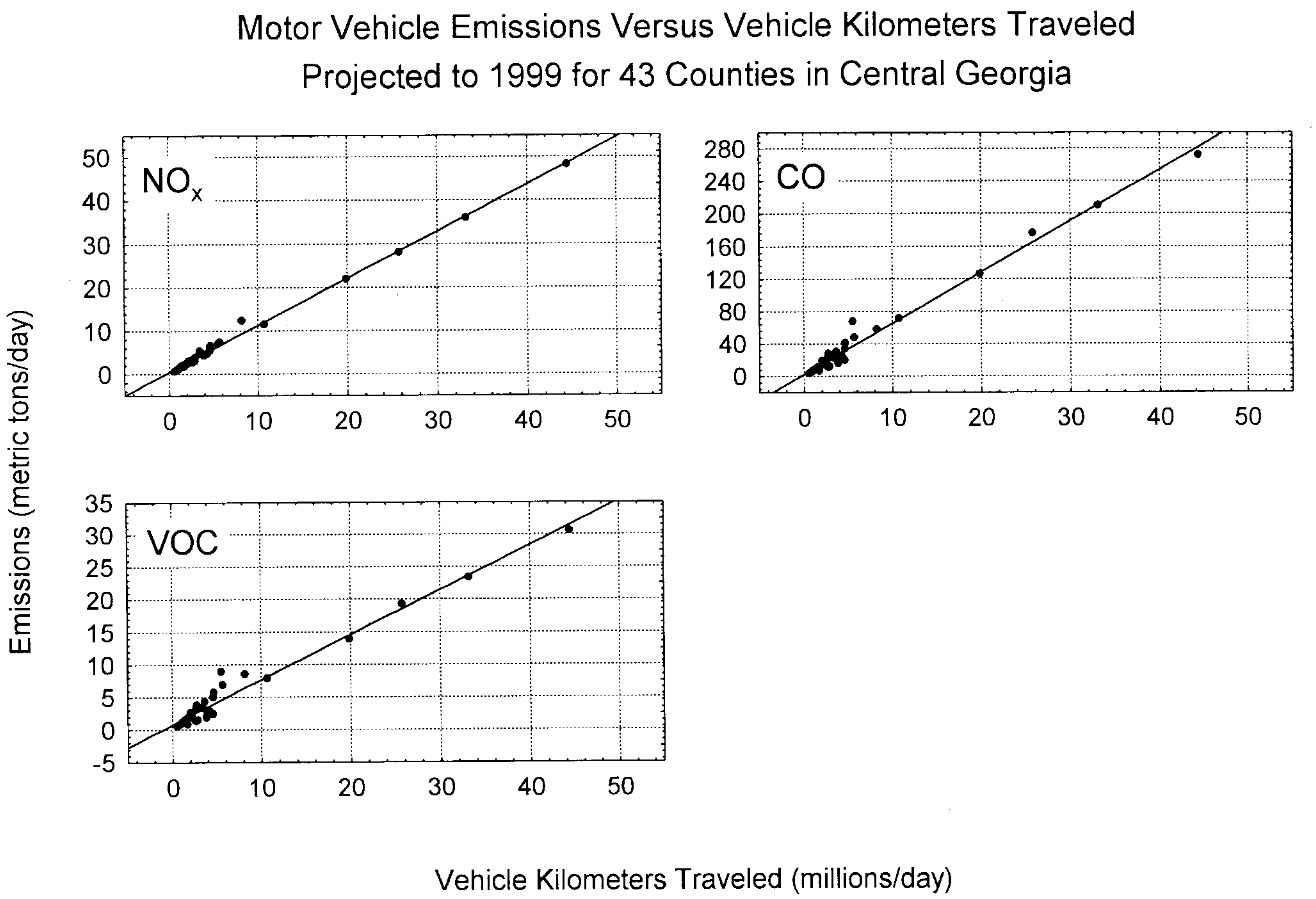


Figure 5-3. Motor Vehicle Emissions Versus Vehicle Kilometers Traveled Projected to 1999 for 43 Counties in Central Georgia

the basic data used in the MOBILE model do not always represent “super emitters” (i.e., vehicles that have much higher emission rates than are typically found within the vehicle fleet). U.S. EPA, California Air Resources Board (ARB), and other organizations are working to address these deficiencies in upcoming versions of MOBILE and EMFAC (ARB’s motor vehicle emission factor model) models. However, the presence of the deficiencies points to the continued need for independent measures of motor vehicle emissions.

The concept of remote sensing and detection (RSD) as a method to identify “super emitters” and to provide a check of the motor vehicle emissions inventory was developed in Denver, Colorado during 1987. While RSD technology and use are still developing, RSD has rapidly evolved into a relatively efficient QA tool for motor vehicle emission estimates. Although this is a relatively straightforward technology, special expertise and equipment are nonetheless required to obtain useable RSD results. The following material provides an overview of this technology and how it can be used as a QA tool for motor vehicle emission estimates. Additional detail can be found in Bishop et al. (1993 and 1994) and Cadle et al. (1993).

This technology applies an infrared (IR) remote monitoring system that measures the ratios of carbon monoxide (CO) and hydrocarbons (HC) to carbon dioxide (CO_2). This technology can identify improperly tuned or misfiring vehicles, which when repaired will result in improved fuel economy. Therefore, this technology has been termed the Fuel Efficiency Automobile Test (FEAT). An IR beam is transmitted across a single lane of traffic, approximately 25 centimeters above the road surface. A calibrated detector receives the beam and reports the CO, CO_2, and HC data on a percent basis.

In order to use RSD measurements for QA, additional steps are involved to convert the RSD measurements into a form that can be combined with fuel consumption data. RSD results provide ratios of exhaust concentrations (i.e., CO/CO_2 and HC/CO_2), rather than absolute measurements of pollutant concentrations. The derivation of emission factors in grams of pollutant per unit volume of fuel consumed from RSD measurements is detailed by Singer and Harley (1996). Using a carbon balance, estimates of the pollutant of interest can be derived from the equation below:

$$E_P = \frac{[P]}{[CO_2] + [CO] + 3[HC]} \times \frac{MW_P}{MW_C} \times WF_C \times \rho_f \qquad (5\text{-}1)$$

where: E_P = Emissions of pollutant P;
$[P]$ = Exhaust concentration of pollutant P;
MW_P = Molecular weight of pollutant P;
MW_C = Molecular weight of carbon;
WF_C = Weight fraction of carbon in the fuel; and
ρ_f = Density of fuel, f.

The sum of the concentrations of CO, CO_2, and HC in the denominator represents the concentration of carbon atoms in the exhaust. The equation assumes that hydrocarbons have been measured as propane, C_3H_8, hence the factor of 3 is applied to the exhaust HC concentration. If the RSD results are reported as ratios to CO_2, then the equations can be re-written as:

$$E_P = \frac{[Q_P]}{[1] + [Q_{CO}] + 3[Q_{HC}]} \times \frac{MW_P}{MW_C} \times WF_C \times \rho_f \qquad (5\text{-}2)$$

where: $[Q_P]$ = $[P]/[CO_2]$;
$[Q_{CO}]$ = $[CO]/[CO_2]$; and
$[Q_{HC}]$ = $[HC]/[CO_2]$.

In Equations 5-1 and 5-2, the HC term is usually ignored unless [HC] is high enough to influence desired accuracy (e.g., [HC]~1000 ppm).

The FEAT has been used to measure the emissions of more than 500,000 vehicles in Denver, Chicago, Los Angeles, Toronto, Sweden, and Mexico (Bishop et al., 1993). For Mexico, this technology was used to evaluate the motor vehicle emissions in Mexico City (Beaton et al., 1992). Results of the study indicate that the exhaust characteristics of the Mexico City vehicle fleet are very different than any other region ever tested with this technology. This QA tool, therefore, provides a warning that the indiscriminate application of the MOBILE model to areas vastly different from the United States might lead to highly biased emission estimates.

Results of the Mexico City analysis include measurements of over 30,000 vehicles. The data were then reduced to provide gram per gallon emission factors for HC and CO. These data can be combined with gasoline sales data and used to calculate alternative emission estimates that can be used as a QA check of the emission estimates calculated using the predicted emission factors from the MOBILE model.

It must be remembered that there may be significant uncertainty associated with emission estimates based upon the FEAT or other remote sensing devices. These devices only provide an instantaneous measurement of emissions and fail to capture the variations of emissions over time and various driving conditions. Consequently, these alternative emission estimates should be used for QA purposes only. It is not recommended that they be used directly for emission estimation in inventory efforts.

5.6 Use of Ambient Sampling Data

Ambient sampling data can also be used to validate and perform QA on emission inventory estimates. Ambient sampling data provide a measurement of reality that can be compared to predicted emissions estimates. Three of the more commonly used methods are receptor modeling, concentration ratios, and three-dimensional grid models. The major benefit of these QA methods is that they provide information independent from the methodology used to estimate motor vehicle emissions. A drawback of these methods is the generally limited nature of ambient monitoring data available for use in the analysis. The ambient data are only representative of the conditions and source types that were present during the field measurements. If the conditions for which the emission estimates are valid differ from those encountered during the field measurements, then there will be inherent uncertainty in the results of any comparison that is made between the ambient data and the emission estimates.

5.6.1 Receptor Modeling

Receptor modeling, also called source apportionment, uses statistical methods and ambient monitoring data to estimate the relative contribution of emissions from a series of source categories to the observed ambient concentrations in an area. It is a "top-down" QA method because it uses information about the entire inventory and modeling domain to estimate the relative contribution of emissions from each source category, rather than building up contribution estimates on a source-by-source basis. The Chemical Mass Balance Model (CMB) (Watson et al., 1984) is a widely used model for performing receptor modeling.

In receptor modeling, least squares estimation is used to obtain the best fit of emissions from each source modeled that reproduces the chemical composition of observed monitoring data at a given monitoring site. The two key input requirements for receptor modeling are the chemical composition of ambient monitoring data and the chemical composition ("fingerprints") of emissions from each source category that corresponds to the same level of detail as the monitoring data.

The model is only able to resolve contributions from source categories that have unique chemical compositions. In addition, only relative impacts are produced by the model indicating the relative contribution from each source class. Typical source categories used in receptor modeling may include motor vehicle exhaust, fuel combustion, electric utilities, construction activities, marine aerosol, and fugitive dust of geological origin.

Historically, receptor modeling has been used primarily for examining sources of relatively stable (or non-reactive) pollutants such as particulate matter. For example, Chow et al., (1992) used the CMB to examine PM_{10} source apportionment in the San Joaquin Valley in California. They concluded that fugitive dust of geological origin (e.g., fugitive dust from agricultural tilling, roadways, and construction activity) exceeded 50% of the observed PM_{10} at Bakersfield in the summer and fall. On-road motor vehicle exhaust, on the other hand, contributed only approximately 10% of the observed PM_{10}.

Much recent work has been performed to apply receptor modeling to reactive pollutants. For example, Scheff et al. (1995) applied the CMB to evaluate emissions of non-methane organic compounds (NMOC) for the Southeast Michigan Ozone Study (SEMOS). Based upon the assumption of relatively low travel times, and hence limited time for chemical reactions to occur, chemical species with relatively low reactivity were selected for use in the modeling. In this study, the relative proportion of the observed NMOC concentrations was found to be consistent with current estimates of emissions for some categories, such as architectural coating and coke oven sources. However, there were significant differences between the CMB results and the current inventory on the relative proportion of emissions from other categories, such as refineries and graphic arts.

As mentioned at the beginning of Section 5.5, a major strength of using the CMB approach for emissions inventory QA analysis is that it is completely independent of the methods used to estimate the emissions. These statistical methods rely on ambient monitoring data alone to estimate the relative contribution of emissions sources. Thus, this method provides the ability to independently verify the relative distribution of emissions estimated through the inventory process and to identify potential problem areas.

A potential limitation of the methodology is that the resolution available from the CMB model is limited by the quality of the available source emission composition profiles. Because of differences between sources (and, potentially, from test to test for a given source), these profiles are highly variable. Consequently, great care must be exercised to ensure that the most representative source profiles are used as input to the CMB model. In addition, the monitoring data used in CMB modeling must be representative of ambient concentrations in the area in which the emissions are occurring. These monitoring data cannot be dominated by local sources for which source profiles are not available.

5.6.2 Ambient Sample Ratios

Specific emission sources tend to have somewhat fixed ratios of the emissions of various pollutants. By analysis of these ratios, it is possible to derive information as to the probable contribution of specific emission sources to observed monitoring data. A good example of the use of ambient monitoring data in this manner is a study by Fujita et al. (1992) in Los Angeles, California. Similar analyses have been performed in the Chicago and Central California areas (Korc et al., 1995). Fujita et al. compared ratios of various pollutants developed from emission inventories and ambient monitoring data collected in 1987 during the South Coast Air Quality Study (SCAQS).

Table 5-2 presents the results of Fujita et al. in which ambient and emission inventory ratios of CO/NO_x and NMOG/NO_x were compared. Included on Table 5-2 are the adjustment factors to the motor vehicle exhaust portion of the emission inventory that would be required to bring the emission inventory ratios to equality with the observed ambient ratios (i.e., remove a potential bias). Because the NMOG/NO_x ratios require a larger motor vehicle adjustment factor compared to the CO/NO_x ratios, it appears that NMOG has been underestimated.

Conducting this type of analysis on a routine basis as part of the emissions inventory development process is not recommended. However, as Mexico emissions inventories continue to develop, the amount of ambient field measurements will increase, which will allow more widespread use of this analysis technique.

5.6.3 Three-Dimensional Grid Models

Three dimensional grid models are also being used more frequently to help evaluate the uncertainty in the emissions inventory process (Chang et al., 1993; Mulholland and Seinfeld, 1995). Current three-dimensional grid models include the effects of atmospheric chemistry and varying meteorological conditions. Emission inventory estimates are then used as data inputs for the three-dimensional grid models. After the model has been run, the predicted atmospheric concentrations are compared to actual measured concentrations at various monitoring sites. In this way, the inventory uncertainty can be ascertained. A recent example is the Mexico City Air Quality Research Initiative (MARI). In the MARI study, staff of Los Alamos National Laboratory and the Mexican Petroleum Institute concluded that the estimated VOC inventory for Mexico City is low by nearly a factor of four (LANL and IMP, 1994). This conclusion was reached through data analysis techniques, including trajectory analysis, as part of the model performance evaluation. As with receptor modeling and ambient sample ratios, the current applicability of three-dimensional grid models is somewhat limited. However, as emission inventories develop and mature in Mexico, advanced techniques such as three-dimensional grid models will see increased use.

Table 5-2

Comparison of Ambient and Inventory Ratios of CO/NO_x and $NMOG/NO_x$ for Los Angeles for 1987

Pollutant Ratio	Season	Time (Pacific Standard Time)	Ambient/Inventory Ratio[a]	Required Motor Vehicle Adjustment Factor[b]
CO/NO_x	Summer	06 - 08	1.4	1.5
		20 - 08	1.6	1.9
	Fall	06 - 08	1.1	1.2
		20 - 08	1.4	1.7
$NMOG/NO_x$	Summer	06 - 08	2.5	4.4
		20 - 08	3.0	5.5
	Fall	06 - 08	1.7	2.8
		20 - 08	2.3	4.0

[a] Ratio of the pollutant ratio estimated from ambient monitoring data to that estimated from the motor vehicle emissions inventory.

[b] Adjustment factor required to bring the hot exhaust motor vehicle emissions inventory ratio to equality with the ambient ratio.

Source: Fujita et al., 1992.

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APPENDIX A

SAMPLE MOTOR VEHICLE EMISSIONS CALCULATION

Appendix A - Sample Motor Vehicle Emissions Calculation

Objective - To demonstrate the calculation of motor vehicle emissions using both emission factor models and mass balances. Total organic gas (TOG) and sulfur oxide ($SO_{x)}$ emissions will be estimated in this sample calculation.

Description -This sample calculation is based upon actual emission calculations performed for an air toxics inventory in Nogales, Sonora, Mexico (Radian, 1997). Emissions will be estimated for four vehicle classifications using gasoline: light-duty gasoline vehicles (LDGV), light-duty gasoline trucks (LDGT), heavy-duty gasoline vehicles (HDGV), and motorcycles (MC).

TOG emissions were calculated as an intermediate step prior to air toxics speciation. The TOG emission factors were calculated using MOBILE-Juárez (a MOBILE5a model modified using data for Ciudad Juárez). SO_x emissions were not calculated as part of the air toxics inventory; however, they can be easily derived from fuel consumption statistics.

It has been assumed that the PEMEX fuel statistics presented below represent fuel that is used in Mexican cars in Nogales, Sonora. Though not entirely true, this assumption was a necessary simplification used in the air toxics inventory. The calculations of the average fleet fuel efficiency and vehicle kilometers traveled (VKT) distribution by road type are too complicated for this sample calculation and have not been included. Only the results for average fleet fuel efficiency and VKT distribution are included in this sample calculation.

TOG Emissions - Estimation of Emission Factors

Step 1: Construct MOBILE-Juárez input file. The input file prepared for the spring scenario in Nogales, Sonora is presented in Figure A-1. In order to account for temperature changes from season to season, four separate input files were prepared for spring, summer, fall, and winter. In general, seasonal scenarios are optional. Each line of the input file is briefly explained in Table A-1. The line numbers included in Figure A-1 are not part of the actual input file, but are used as a referencing aid.

Step 2: Run the MOBILE-Juárez model.

Step 3: Extract emission factors from the MOBILE-Juárez output file. The portion of the resulting output file containing emission factors for the spring scenario in Nogales, Sonora is shown in Figure A-2. The emission factors for each speed and vehicle classification are indicated.

Step 4: Calculate annual average emission factors. Annual average emission factors are calculated using the spring emission factors shown in Figure A-2, as well as similar emission factors for the other three seasons that are not shown here. This calculation is summarized in Table A-2.

TOG Emissions - Estimation of VKT

Step 1: Calculate total fuel consumption. Monthly 1994 fuel consumption statistics (both leaded and unleaded gasoline) were obtained from PEMEX. Yearly totals are calculated in Table A-3. Total unleaded gasoline consumption was 51,169,901 liters, while total leaded gasoline consumption was 10,571,891 liters. Overall total gasoline consumption was 61,741,792 liters.

Step 2: Calculate VKT. Using registration and mileage accumulation data (by model year) from the MOBILE-Juárez model and model year fuel efficiencies from the United States, it was determined that the 1994 average fleet fuel efficiency for Nogales was 6.788 kilometers per liter of gasoline. Dividing the overall total gasoline consumption by this fuel efficiency results in approximately 419,100,000 total VKT for Nogales, Sonora.

Step 3: Distribute VKT by vehicle classification. The overall Ciudad Juárez VKT mix indicated the following: LDGV - 61.1% of total VKT, LDGT - 30.8%, HDGV - 5.6%, and MC - 0.6%. However, this VKT mix includes diesel vehicle VKT as well. Normalizing for gasoline VKT results in the following: LDGV - 62.3% of gasoline VKT, LDGT - 31.4%, HDGV - 5.7%, and MC - 0.6%. After applying this normalized VKT fraction, total VKT is divided into vehicle classes as shown below:

LDGV	261,100,000 VKT
LDGT	131,600,000 VKT
HDGV	23,900,000 VKT
MC	2,500,000 VKT

Step 4: Distribute VKT by vehicle speed. Based upon a site visit in Nogales, Sonora and engineering judgment, it was estimated that 23.3% of all VKT occurred at 24.1 kilometers per hour (15 mph), 70.0% occurred at 40.2 kilometers per hour (25 mph), and 6.7% occurred at 56.3 kilometers per hour (35 mph). The VKT distribution by vehicle speed is shown in Table A-4.

TOG Emissions - Calculation of emissions

As indicated in Section 2.1 of this manual, TOG emissions are calculated by multiplying the MOBILE-Juárez emission factor by the VKT estimate. This is shown in Table A-4 for each vehicle classification and each of the three vehicle speeds. Total TOG emissions for gasoline-powered vehicles have also been summed at the bottom of Table A-4.

Total TOG emissions were estimated to be 2,866 Mg/yr or 7.85 Mg/day.

SO_x Emissions - Calculation of emissions

As indicated in Section 2.1 of this manual, SO_x emissions are estimated using a fuel balance.

Step 1: Obtain fuel consumption statistics. From the TOG emission calculation above, it was determined that 51,169,901 liters of unleaded gasoline and 10,571,891 liters of leaded gasoline were consumed.

Step 2: Obtain fuel sulfur contents. From PEMEX fuel specifications, the maximum fuel sulfur content for unleaded gasoline is 0.1% (wt) and for leaded gasoline is 0.15% (wt).

Step 3: Determine the density of gasoline. Based on previous experience, a typical density of gasoline is 0.731 kg/liter (6.09 lbs/gallon).

Using the fuel balance equation for SO_x (see Equation 2-2 of this manual):

$$E_{\text{Unleaded}} = (51{,}169{,}901\ \ell) \times (0.731\ \text{kg}/\ell) \times 0.001 \times 2 = 74{,}810\ \text{kg}\ SO_x = 74.8\ \text{Mg}\ SO_x$$

$$E_{\text{Leaded}} = (10{,}571{,}891\ \ell) \times (0.731\ \text{kg}/\ell) \times 0.0015 \times 2 = 23{,}184\ \text{kg}\ SO_x = 23.2\ \text{Mg}\ SO_x$$

Total SO_x emissions are 98 Mg/year or 0.268 Mg/day.

Table A-1
Explanation of MOBILE-Juárez Input File for Nogales, Sonora

Line Number	Data Element	Explanation	Comments
1	1	PROMPT flag - Input data entered without prompting in vertical format.	Also known as batch file input. This option is recommended.
2	Entire Line	PROJID - Input file identification.	None.
3	1	TAMFLG - MOBILE-Juarez default tampering rates used.	This option should be used unless local tampering survey performed.
4	1	SPDFLG - One average speed for all vehicle types (for each Scenario Descriptive Record).	This option should be used unless detailed transportation speed information is available.
5	3	VMFLAG - One VKT mix assigned for all scenarios.	VKT mix from Ciudad Juárez/El Paso assumed to be applicable for Nogales, Sonora.
6	1	MYMRFG - MOBILE-Juarez default mileage accumulation rates and registration distributions used.	This option should be used unless local mileage accumulation and registration distribution data are collected.
7	5	NEWFLG - MOBILE-Juarez BERs used with all new Clean Air Act requirements disabled.	This option should be used for all applications of the MOBILE-Juarez model.
8	1	IMFLAG - No inspection and maintenance (I/M) program to be modeled.	This option should be used unless an I/M program has been implemented.
9	1	ALHFLG - No corrections made for air conditioning usage, extra vehicle load, trailer towing, and humidity.	This option should normally be used.
10	1	ATPFLG - No anti-tampering program (ATP) to be modeled.	This option should be used unless an ATP has been implemented.

Table A-1

(continued)

Line Number	Data Element	Explanation	Comments
11	5	RLFLAG - No refueling emission factors calculated.	This option should be used unless refueling emissions are not estimated as an area source.
12	1	LOCFLG - One Local Area Parameter (LAP) record for each scenario.	This option is typically used.
13	1	TEMFLG - Emission factors adjusted using minimum and maximum daily temperatures.	This option should be used unless minimum and maximum daily temperatures are not available.
14	4	OUTFMT - 80-column descriptive output format.	The MOBILE-Juarez model has been customized to accept only this option.
15	1	PRTFLG - Only hydrocarbon emission factors included in output.	This option was selected to meet the requirements of the Nogales, Sonora air toxics inventory.
16	1	IDLFLG - No idle emission factors calculated.	This option should normally be used.
17	4	NMHFLG - Hydrocarbon emission factors given as total organic gases (TOG).	This option should normally be used.
18	3	HCFLAG - Total, component, and detailed evaporative emission factors included in output.	This option should normally be used.

Table A-1

(continued)

Line Number	Data Element	Explanation	Comments
19	.611	VKT fraction for light-duty gasoline vehicles (LDGV).	VKT fraction estimated for Ciudad Juárez assumed to be applicable for Nogales, Sonora.
	.242	VKT fraction for light-duty gasoline trucks <2,727 kg (LDGT1).	VKT fraction estimated for Ciudad Juárez assumed to be applicable for Nogales, Sonora.
	.066	VKT fraction for light-duty gasoline trucks >2,727 kg and <3,857 kg (LDGT2).	VKT fraction estimated for Ciudad Juárez assumed to be applicable for Nogales, Sonora.
	.056	VKT fraction for heavy-duty gasoline vehicles >3,857 kg (HDGV).	VKT fraction estimated for Ciudad Juárez assumed to be applicable for Nogales, Sonora.
	.000	VKT fraction for light-duty diesel vehicles (LDDV).	VKT fraction estimated for Ciudad Juárez assumed to be applicable for Nogales, Sonora.
	.000	VKT fraction for light-duty diesel trucks <3,857 kg (LDDT).	VKT fraction estimated for Ciudad Juárez assumed to be applicable for Nogales, Sonora.
	.019	VKT fraction for heavy-duty diesel vehicles >3,857 kg (HDDV).	VKT fraction estimated for Ciudad Juárez assumed to be applicable for Nogales, Sonora.
	.006	VKT fraction for motorcycles (MC).	VKT fraction estimated for Ciudad Juárez assumed to be applicable for Nogales, Sonora.
20	1	Low altitude region.	This option should be used except for high altitude regions (>1,676 meters).
	94	1994 inventory year.	The inventory year for the Nogales, Sonora inventory. This data will vary depending upon inventory year.

Table A-1

(continued)

Line Number	Data Element	Explanation	Comments
20 cont	24.1	Vehicle speed of 24.1 kilometers per hour (15 miles per hour).	One of the vehicle speeds estimated for Nogales, Sonora during a site visit. For MOBILE-Juarez, this value must be in units of kilometers per hour.
	25.0	Ambient temperature.	This temperature is typically not used because TEMFLG (see Line Number 13) is set to “1”. However, the ambient temperature must be set between the minimum and maximum daily temperatures. The value of 25.0 °C was arbitrarily chosen. For MOBILE-Juarez, this value must be in units of °C.
	19.6	PCCN operating mode variable.	Operating mode variables estimated for Ciudad Juarez assumed to be applicable for Nogales, Sonora.
	19.7	PCHC operating mode variable.	Operating mode variables estimated for Ciudad Juarez assumed to be applicable for Nogales, Sonora.
	30.0	PCCC operating mode variable.	Operating mode variables estimated for Ciudad Juarez assumed to be applicable for Nogales, Sonora.
	1	Emission factors calculated for January of inventory year.	This option should normally be used.

Table A-1
(continued)

Line Number	Data Element	Explanation	Comments
21	Nogales Spring	Scenario name.	None.
	A	Fuel volatility class.	This option should normally be used.
	3.6	Minimum daily temperature.	Average minimum daily temperature for March, April, and May derived from meteorological data for Nogales, Arizona. For MOBILE-Juarez, this value must be in units of °C.
	25.4	Maximum daily temperature.	Average maximum daily temperature for March, April, and May derived from meteorological data for Nogales, Arizona. For MOBILE-Juarez, this value must be in units of °C.
	09.5	Period 1 RVP.	Upper end of PEMEX RVP range assumed to be applicable for Nogales, Sonora.
	09.5	Period 2 RVP.	Upper end of PEMEX RVP range assumed to be applicable for Nogales, Sonora.
	93	Period 2 start year.	Because the Period 1 and Period 2 RVPs are identical, the Period 2 start year is not used. The entered 93 value is arbitrary.
	1	Oxygenated fuel flag.	This option should be used unless oxygenated fuels are to be modeled in the region.
	1	Diesel sales fraction flag.	This option should be used unless alternate diesel sales fractions are to be used.
	1	Reformulated gasoline flag.	This option should be used unless the effects of reformulated gasoline are to be modeled.

Table A-1

(continued)

Line Number	Data Element	Explanation	Comments
22	Entire Line	Identical to the Scenario Descriptive Record presented in Line 20 except that vehicle speed has been changed to 40.2 kilometers per hour.	None.
23	Entire Line	Identical to the Local Area Parameter Record presented in Line 21.	None.
24	Entire Line	Identical to the Scenario Descriptive Record presented in Line 20 except that vehicle speed has been changed to 56.3 kilometers per hour.	None.
25	Entire Line	Identical to the Local Area Parameter Record presented in Line 21.	None.

Table A-2
Calculation of Annual TOG Emission Factors (g/km) for Nogales, Sonora

Vehicle Class	Speed (kph)	Spring	Summer	Fall	Winter	Average
LDGV	24.1	8.17	9.93	8.20	8.45	8.69
	40.2	5.79	7.35	5.90	5.84	6.22
	56.3	4.65	6.15	4.80	4.57	5.04
LDGT	24.1	8.04	9.54	8.07	8.28	8.48
	40.2	5.80	7.20	5.89	5.87	6.19
	56.3	4.71	6.08	4.84	4.68	5.08
HDGV	24.1	11.50	16.36	12.10	10.58	12.64
	40.2	7.41	11.76	8.05	6.45	8.42
	56.3	5.68	9.82	6.34	4.70	6.64
MC	24.1	6.92	8.91	7.32	6.03	7.30
	40.2	5.60	7.65	6.03	4.58	5.97
	56.3	4.92	7.02	5.37	3.85	5.29

Table A-3
1994 Fuel Consumption Statistics for Nogales, Sonora

Month	Magna Sin (Unleaded) (liters)	Nova Plus (Leaded) (liters)
January	3,510,000	1,348,600
February	3,464,800	1,246,800
March	3,990,000	1,461,500
April	3,830,000	932,500
May	4,180,000	992,500
June	4,141,930	751,645
July	4,238,970	689,935
August	4,724,500	719,761
September	4,575,179	607,200
October	4,489,828	621,450
November	4,794,593	615,000
December	5,230,101	585,000
Total	**51,169,901**	**10,571,891**

Table A-4
Calculation of Annual TOG Emissions (Mg) for Nogales, Sonora

Vehicle Class	Speed (kph)	Emission Factor (g/km)	VKT	Emissions (Mg/yr)
LDGV	24.1	8.69	60,836,300	528.7
	40.2	6.22	182,770,000	1136.8
	56.3	5.04	17,493,700	88.2
LDGT	24.1	8.48	30,662,800	260.0
	40.2	6.19	92,120,000	570.2
	56.3	5.08	8,817,200	44.8
HDGV	24.1	12.64	5,568,700	70.4
	40.2	8.42	16,730,000	140.9
	56.3	6.64	1,601,300	10.6
MC	24.1	7.30	582,500	4.3
	40.2	5.97	1,750,000	10.4
	56.3	5.29	167,500	0.9
Total	**-**	**-**	**419,100,000**	**2866.2**

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MANUALES DEL PROGRAMA DE INVENTARIOS DE EMISIONES DE MEXICO

VOLUMEN VI - DESARROLLO DE INVENTARIOS DE EMISIONES DE VEHICULOS AUTOMOTORES

FINAL

Elaborado para:

La Asociación de Gobernadores del Oeste
Denver, Colorado

y

El Comité Asesor Binacional

Elaborado por:

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Febrero 19, 1997

PREFACIO

La contaminación del aire puede tener impactos negativos sobre la salud pública cuando su concentración en la atmósfera alcanza niveles significativos. En la mayor parte de las áreas rurales los problemas de calidad del aire se dejan sentir sólo en raras ocasiones, mientras que muchos ambientes urbanos con frecuencia registran elevadas concentraciones de contaminantes. Durante los últimos años, México ha tenido un gran crecimiento en la urbanización y en la actividad industrial, lo que ha generado serias preocupaciones acerca de la calidad del aire en diversas regiones del país.

La contaminación del aire resulta de una compleja mezcla de miles de fuentes, desde las chimeneas industriales y los vehículos automotores, hasta el uso individual de productos de aseo, limpiadores domésticos y pinturas; incluso la vida animal y vegetal puede jugar un papel importante en el problema de la contaminación. Debido a la compleja naturaleza de la contaminación del aire, se requieren planes regionales detallados para identificar las fuentes de emisión, así como el desarrollo de métodos para reducir el impacto sobre la salud ocasionado por la exposición a los contaminantes. Entre algunos ejemplos de las actividades para la gestión de la calidad del aire destacan:

- La aplicación de modelos de calidad del aire
- El estudio de las fuentes emisoras de contaminantes para analizar el control de emisiones, cuando así se requiera
- El desarrollo de proyecciones de las emisiones para identificar cambios potenciales en la futura calidad del aire
- El análisis de las tendencias de emisión
- El análisis del transporte de las emisiones de una región a otra.

El desarrollo de inventarios de emisión bien fundamentados es un aspecto clave en cada una de estas funciones de la gestión de la calidad del aire.

El cálculo de estimaciones de emisión que cumplan con las necesidades de la gestión de la calidad del aire requiere de un desarrollo y refinamiento continuos; por lo tanto, los esfuerzos para elaborar inventarios "a un tiempo" no son adecuados para dicho proceso de gestión. Con el objetivo de tener un beneficio de larga duración, es necesario instrumentar un *programa de inventarios* que haga posible el desarrollo de estimaciones exactas de las emisiones para todas las regiones geográficas de importancia; que tenga la capacidad de ser refinado con el paso del tiempo, y que pueda aplicarse efectivamente en los procesos de gestión y monitoreo de la calidad del aire. Es por estas razones que se está desarrollando un conjunto de manuales de inventarios de emisiones que puedan ser aplicados en todo el país, para ayudar a coordinar la generación de estimaciones de emisión consistentes. Estos manuales se han diseñado para ser utilizados por las autoridades locales, estatales y federales, así como por la industria y los consultores privados. El propósito de estos manuales consiste en apoyar el proceso de instrumentación del programa de inventarios y su mantenimiento a lo largo del tiempo, de manera tal que los inventarios de emisiones puedan ser desarrollados periódicamente y mejorados de manera continua.

Los manuales comprenden elementos del programa de inventarios tales como la estimación de emisiones, la planeación del programa, manejo de bases de datos, validación de emisiones y otros temas relevantes. La Figura 1 muestra la serie completa de manuales que serán desarrollados para apoyar la instrumentación de un programa de inventarios de largo alcance. A continuación se resume el propósito principal de cada manual.

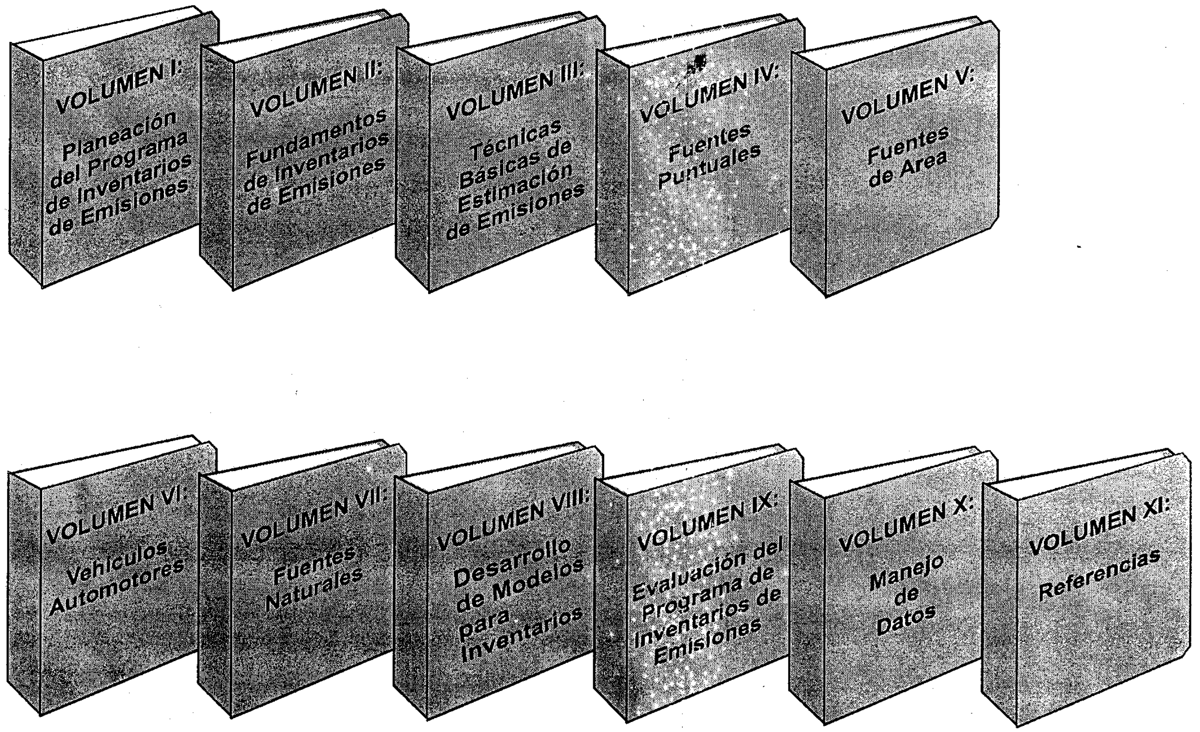

Figura 1. Manuales del Programa de Inventarios de Emisiones de México

Volumen I - Planeación del Programa de Inventarios de Emisiones. Este manual presenta los aspectos de gestión que deben ser considerados en un programa de inventario de emisiones al aire. La planeación del programa no se presenta como una actividad “terminal”, sino más bien como un proceso continuo para asegurar tanto el crecimiento en el largo plazo como el éxito del programa de inventarios. *Temas Clave:* propósito del programa; usos finales del inventario; requerimientos regulatorios; coordinación en los niveles federal, estatal y local; requerimientos de personal y de manejo de datos; identificación y selección de estudios especiales.

Volumen II - Fundamentos de los Inventarios de Emisiones. Este manual presenta los fundamentos básicos para el desarrollo de inventarios de emisiones, así como los elementos que son aplicables a los diversos tipos de fuentes (e. g., puntuales y de área), para evitar la necesidad de que sean repetidos en varios volúmenes. *Temas Clave*: regulaciones aplicables; efectividad de la regla; penetración de la regla; definiciones sobre contaminantes (exclusión de compuestos volátiles no reactivos); delimitación de las fuentes puntuales y de área; reconciliación de las fuentes puntuales y de área.

Volumen III - Técnicas Básicas de Estimación de Emisiones (TBEEs). Este manual presenta las metodologías básicas utilizadas para hacer estimaciones de emisiones, incluyendo ejemplos y cálculos. Por otro lado las herramientas para la elaboración de inventarios asociadas con cada metodología se identifican e incluyen en el Volumen XI (Referencias). *Temas Clave*: muestreo en la fuente, modelos de emisiones, encuestas, factores de emisión, balance de materiales y extrapolación.

Volumen IV - Fuentes Puntuales. Este manual contiene las guías para elaborar inventarios de emisiones de fuentes puntuales. Incluye una tabla de referencias cruzadas para cada combinación de industria y tipo de dispositivo (e. g., refinación de petróleo y dispositivos de combustión), con una o más de las metodologías básicas presentadas en el Volumen III. *Temas Clave:* tabla de referencias cruzadas; parámetros de chimenea; dispositivos de control; consideraciones de diseño y de proceso; diferencias geográficas y variabilidad en México; aseguramiento y control de calidad (AC/CC); procesos omitidos; referencias de datos y formas para recopilación de datos.

Volumen V - Fuentes de Area (incluyendo fuentes móviles que no circulan por carreteras). Este manual contiene los lineamientos para el desarrollo de inventarios de emisiones de fuentes de área. Además de presentar información general sobre las fuentes de área, contiene una tabla de referencias cruzadas entre cada categoría de fuente de área (e. g., aplicación de asfalto) con una o más de las metodologías básicas incluidas en el Volumen III. Posteriormente, se discute la información específica para cada categoría de fuente definida en la tabla. *Temas Clave:* clasificación y definición de fuentes de área; tabla de referencias cruzadas; factores de control; diferencias geográficas y variabilidad en México; AC/CC; referencias de datos y formas para recopilación de datos (cuestionarios).

Volumen VI - Vehículos Automotores. Debido a que los vehículos automotores son intrínsecamente diferentes a las fuentes puntuales y a las de área, tanto los métodos de estimación disponibles como los datos requeridos son también diferentes. Los modelos son las herramientas preferidas para estimar las emisiones de estas complejas fuentes. Muchos de estos modelos utilizan datos de largas pruebas aplicables a un país o a una región determinados. Este manual se enfoca principalmente en la fase de levantamiento de datos para la estimación de emisiones de vehículos automotores. *Temas Clave:* métodos de estimación disponibles; datos e información primarios, secundarios y terciarios; clasificación de fuentes; fuentes de emisión; variabilidad geográfica dentro de México y AC/CC.

Volumen VII - Fuentes Naturales. Este manual proporciona los lineamientos para el desarrollo de inventarios de emisiones de fuentes naturales (e. g., compuestos orgánicos volátiles biogénicos [COVs] y óxidos de nitrógeno [NO_x]) en suelos. Además, incluye los aspectos teóricos de los cálculos de emisiones y la discusión de modelos específicos. *Temas Clave:* clasificación y definición de fuentes; mecanismos de emisión; algoritmos básicos de emisión; determinación de biomasa; desarrollo de datos de uso y cobertura del suelo; ajustes temporales y meteorológicos, y enfoques para el cálculo de emisiones.

Volumen VIII - Desarrollo de Modelos para Inventarios. Este manual proporciona los lineamientos para el desarrollo de datos de inventarios que serán utilizados en modelos de calidad del aire, y trata aspectos tales como la localización temporal y espacial, la especiación y proyección de estimaciones de emisiones. *Temas Clave:* definición de términos de modelado; ajuste estacional; localización temporal y espacial; especiación química y proyecciones (factores de crecimiento y control).

Volumen IX - Evaluación del Programa de Inventarios de Emisiones. Este manual consta de tres partes: AC y CC, análisis de incertidumbre y verificación de emisiones. La parte de AC y CC define el programa global de aseguramiento y control de calidad, y ha sido escrito para complementar los procedimientos de AC y CC para las fuentes específicas que se presentan en otros manuales. El análisis de incertidumbre no sólo incluye los métodos para evaluar la incertidumbre en las estimaciones de emisiones, sino también para evaluarla en los valores de modelado tales como los perfiles de especiación y los factores de proyección de emisiones. La sección de verificación de emisiones describe varios análisis para evaluar la exactitud de las estimaciones. Los ejemplos incluyen modelos de receptor y análisis de trayectoria, combinados con técnicas específicas para el análisis de datos. *Temas Clave:* descripción de conceptos y definición de términos; protocolo de revisión de inventarios; evaluación de integridad, exactitud y consistencia; metodologías recomendadas para el manejo de la incertidumbre, y metodologías aplicables para la verificación de emisiones.

Volumen X - Manejo de Datos. Este manual trata de las necesidades asociadas con los aspectos del manejo de datos del programa nacional de inventarios de emisiones de México. *Temas Clave:* sistemas y herramientas generales para el manejo de datos; sistemas y herramientas de software específicos; sistemas de programación; confidencialidad; presentación electrónica; frecuencia de actualizaciones, mantenimiento de registros; bases de datos específicas de México y elaboración de informes.

Volumen XI - Referencias. Este manual es un compendio de las herramientas que pueden utilizarse en el desarrollo de un programa de inventarios de emisiones. Se incluyen las herramientas citadas en los otros manuales para hacer inventarios (e. g., documentos impresos y electrónicos, así como modelos de computadora).

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APENDICE A: EJEMPLO DEL CALCULO DE EMISIONES DE VEHICULOS AUTOMOTORES

FIGURAS Y TABLAS

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ACRONIMOS

AC	Aseguramiento de calidad
ATPFLG	Bandera del Programa Anti-Alteraciones
C_3H_8	Propano
CARB	California Air Resources Board *(Consejo de Recursos del Aire de California)*
CC	Control de calidad
CO	Monóxido de carbono
CO_2	Bióxido de carbono
CONM	Compuestos orgánicos no metánicos
COVs	Compuestos orgánicos volátiles
DIF	Detector por ionización de flama (*Flame Ionization Detector*)
FECO	Factor de emisión del parque vehicular compuesto
EU	Estados Unidos
FEAT	*Fuel Efficiency Automobile Test* (Prueba de Rendimiento del Combustible en Automóviles)
FEB	Factor de emisión básica
g	Gramo
GLP	Gas licuado de petróleo (gas LP)
GOR	Gases orgánicos reactivos
GONM	Gases orgánicos no metánicos

GOT	Gases orgánicos totales
GRF	Gasolina reformulada
HC	Hidrocarburo
HCNM	Hidrocarburos no metánicos
HCT	Hidrocarburos totales
HDDV	Vehículos pesados a diesel (>3,857 kg) (*Heavy Duty Diesel Vehicle*)
HDGV	Vehículos pesados a gasolina (>3,857 kg) (*Heavy Duty Gasoline Vehicle*)
I/M	Inspección y mantenimiento
IMFLAG	Bandera de I/M
INE	Instituto Nacional de Ecología
IR	Infrarrojo
kg	Kilogramo
km	Kilómetro
kph	Kilómetro por hora
KRV	Kilómetros recorridos por vehículo
LDDT	Camión ligero a diesel (<3,857 kg) (*Light Duty Diesel Truck*)
LDDV	Vehículo ligero a diesel (*Light Duty Diesel Vehicle*)
LDGT1	Camión ligero a gasolina (<2,727 kg) (*Light Duty Gasoline Truck*)
LDGT2	Camión ligero a gasolina (2,727 - 3,857 kg)
LDGV	Vehículo ligero a gasolina (*Light Duty Gasoline Vehicle*)

MBMQ	Modelo de Balance de Masa Química
MARI	*Mexico City Air Quality Research Initiative* (Iniciativa de Investigación de la Calidad del Aire en la Ciudad de México)
MC	Motocicleta
MDR	Modelo de demanda de recorrido
Mg	Megagramo
mph	Millas por hora
NMHFLG	Bandera del factor de emisión de hidrocarburos
NO_x	Oxidos de nitrógeno
OMS	*Office of Mobile Sources* (Oficina de Fuentes Móviles)
OUTFMT	Bandera del formato de salida
OXYFLG	Bandera de combustible oxigenado
PAA	Programa Anti-Alteraciones *(Anti-Tampering Program)*
PAL	Parámetro de área local
PBV	Peso Bruto Vehicular (*Gross Vehicle Weight)*
Pemex	Petróleos Mexicanos
PM	Material particulado (partículas)
PM_{10}	Partículas de diámetro aereodinámico menor o igual a 10 micras
$PM_{2.5}$	Partículas de diámetro aereodinámico menor o igual a 2.5 micras
ppm	Partes por millón

psi	Libras por pulgada cuadrada
SDR	Sensibilidad y detección remota
PVP	Presión de vapor de Reid
RGE	Recirculación del gas del escape
SCAQS	*South Coast Air Quality* Study (Estudio de la Calidad del Aire de la Costa Sur)
SEMOS	*Southeast Michigan Ozone Study* (Estudio del Ozono del Sureste de Michigan)
SO_x	Oxidos de azufre
TAMFLG	Bandera de alteración
TBE	Tasa básica de emisión
TEMFLG	Bandera de temperatura
TTI	*Texas Transportation Institute* (Instituto del Transporte de Texas)
US EPA	*United States Environmental Protection Agency* (Agencia para la Protección Ambiental de EU)
VPC	Ventilación positiva del cárter
wt	Peso (*weight*)

1.0 INTRODUCCION

Este manual abarca el desarrollo de estimaciones de emisión para vehículos automotores en circulación, tales como autos, camiones y autobuses. En la mayoría de las áreas urbanas, los vehículos automotores participan de manera significativa en las emisión de gases orgánicos totales (GOTs), monóxido de carbono (CO), óxidos de nitrógeno, (NO_x), óxidos de azufre (SO_x), partículas (PM), gases tóxicos del aire y especies reductoras de la visibilidad. Debido a la gran magnitud de sus emisiones y a las consideraciones especiales que se requieren para el desarrollo de estimaciones de emisión, los vehículos automotores son manejados de manera independiente a otras fuentes de área.

El creciente interés en generar estimaciones de la contribución de los vehículos automotores a los inventarios regionales de emisión en México, ha conducido al desarrollo de inventarios de emisión para las ciudades de México, Monterrey, Ciudad Juárez y León (Espinosa, et al., 1996). Los datos disponibles para desarrollar estos inventarios han variado de manera considerable; sin embargo, través de las técnicas mejoradas para la recopilación de datos y las metodologías de estimación, los futuros esfuerzos de inventario incrementarán su precisión y confiabilidad. El propósito de este manual consiste en presentar los métodos de inventario existentes y de corto plazo, en la medida en que podrían ser aplicados en México. Por otro lado, con el objetivo de compensar las amplias variaciones en la disponibilidad de datos de emisiones y actividad vehicular, aquí se analiza una amplia variedad de procedimientos.

Este manual proporciona un panorama general de diversos métodos de inventario, y las numerosas referencias citadas dan acceso a valiosa información adicional. Cabe señalar que la capacitación “práctica” adicional en los modelos de factores de emisión de vehículos automotores referidos en este manual (MOBILE y PART5), es un factor esencial para la creación de un inventario de alta calidad.

Este manual se refiere sólo a vehículos automotores en circulación. Las fuentes móviles que no circulan por carreteras incluyen a los vehículos diseñados para ser utilizados fuera de caminos públicos (i. e., aeronaves, locomotoras, embarcaciones, palas mecánicas, grúas y equipo de construcción), así como otras fuentes de emisión móviles (e. g., generadores eléctricos portátiles). La estimación de emisiones de fuentes que no circulan por carreteras se presenta en el *Volumen V: Desarrollo de Inventarios de Fuentes de Area*. El resto de esta introducción resume los procesos de emisión asociados con los vehículos automotores que circulan por carreteras, y discute la clasificación de los vehículos mexicanos dentro de los grupos utilizados en los inventarios de emisión. El manual está estructurado como se muestra a continuación:

- La Sección 2.0 contiene un panorama general del proceso de inventario de emisiones de vehículos automotores que circulan por carreteras, discute la manera en que las emisiones son calculadas, y analiza la forma en que se establecen las prioridades para el desarrollo de los datos

- La Sección 3.0 discute los modelos de factores de emisión y su aplicación en México

- La Sección 4.0 presenta el desarrollo de los datos de actividad vehicular que se utilizan en conjunto con los factores de emisión para estimar las emisiones.

- La Sección 5.0 presenta los procedimientos de aseguramiento de calidad (AC) que pueden aplicarse para verificar la racionalidad y precisión de la estimación de las emisiones de los vehículos automotores que circulan por carreteras.

1.1 Procesos de Emisión en los Vehículos que Circulan por Carretera

Las emisiones de vehículos automotores están integradas por un gran número de contaminantes que provienen de muchos procesos diferentes (Figura 1-1). Las más comúnmente consideradas son las emisiones del escape, que resultan de la combustión del combustible y que son liberadas por el escape del vehículo. Los contaminantes de interés clave en este tipo de emisiones incluyen GOTs, CO, NO_x, SO_x, PM, gases tóxicos del aire (e. g., 1, 3-butadieno, benceno, formaldehído, etc.), y las especies reductoras de visibilidad (e. g., amoniaco, sulfatos, $PM_{2.5}$, etc.). Además de las emisiones del escape, los vehículos automotores registran una gran variedad de procesos de emisión evaporativa que se limitan a emisiones de GOTs, y que incluyen:

- **Emisiones Evaporativas del Motor Caliente**: Son aquellas que se presentan debido a la volatilización del combustible en el sistema de alimentación después de que el motor se ha apagado. El calor residual del motor volatiliza el combustible.

- **Emisiones Evaporativas de Operación**: Son las emisiones ocasionadas por las fugas de combustible, como líquido o vapor, que se presentan mientras el motor está en funcionamiento.

- **Emisiones Evaporativas Durante la Recarga de Combustible**: Son las emisiones evaporativas desplazadas del tanque de combustible del vehículo durante la recarga. Estas pueden ocurrir mientras el vehículo está en reposo y en puntos conocidos, como las gasolineras. La recarga de combustible es manejada típicamente como fuente de área y se discute en el *Volumen V: Desarrollo de Inventarios de Fuentes de Area*. Los factores de emisión para la carga de combustible también pueden estimarse a través del modelo MOBILE o bien, obtenerse de otras fuentes tales como el AP-42.

- **Emisiones Diurnas**: Son las emisiones del tanque de combustible del vehículo debidas a una mayor temperatura del combustible y a la presión de vapor del mismo. Estas emisiones se deben al incremento de la temperatura ambiente ocasionado por el sistema de escape del vehículo o por el calor reflejado en la superficie del camino.

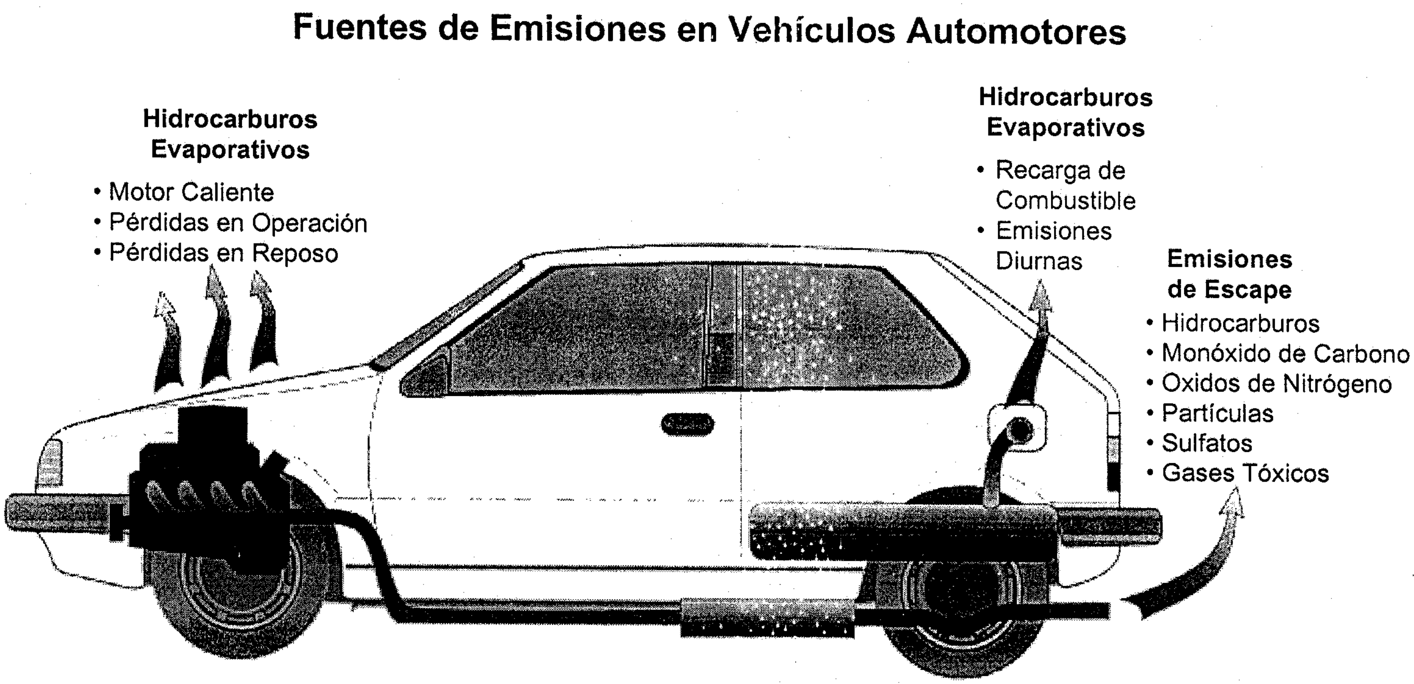


Figura 1-1 Procesos de Emisión en Vehículos Automotores

- **Emisiones Evaporativas en Reposo**: Son emisiones evaporativas diferentes a las anteriores, que se presentan cuando el motor no está en funcionamiento. Las pérdidas en reposo se deben principalmente a fugas de combustible y de la permeación del vapor a través de las líneas de alimentación del combustible.

Existen fuentes adicionales de emisiones de partículas (PM) de los vehículos automotores. Entre éstas, la de mayor magnitud es el levantamiento de polvo del camino, polvo recogido por las llantas del vehículo y suspendido en el aire por la turbulencia ocasionada por el movimiento. Las emisiones de polvo son manejadas como fuente de área y se discuten en el *Volumen V; Desarrollo de Inventarios de Fuentes de Area*. Otras fuentes de PM no originadas en el escape incluyen el desgaste de las llantas y frenos. En general, estas fuentes son insignificantes cuando se comparan con las del escape y el polvo levantado y, por lo tanto, en algunas ocasiones son omitidas de los inventarios de emisiones. Los factores de emisiones para llantas y frenos, sin embargo, pueden ser estimados utilizando el modelo PART5 (ver Sección 3.2).

1.2 Tipos de Vehículos en México

El gran número de vehículos en una región de aplicación del inventario hace que la medición de las emisiones de cada vehículo individual sea impráctica. En consecuencia, la metodología para el inventario de vehículos automotores se basa en distribuir a los vehículos en categorías con características de emisión similares y, posteriormente, tratar de cuantificar las emisiones para cada grupo. Las variables clave que se utilizan en esta clasificación inicial de los vehículos son el tipo de vehículo (automóvil, camión, autobús, etc.), el tipo de combustible (gasolina, diesel, combustibles licuados, etc.), el peso bruto vehicular (PBV), y el nivel de la tecnología de control de emisiones del vehículo. El PBV es el peso del vehículo cuando transporta la carga máxima permitida por el fabricante con el tanque de combustible lleno.

Las emisiones de los diferentes vehículos automotores pueden variar en múltiples órdenes de magnitud, dependiendo de numerosos factores. En particular, el nivel de la tecnología de control de emisiones en un vehículo ejerce una influencia significativa sobre la magnitud de las emisiones, y es determinado por las normas de emisión aplicables al vehículo. Los vehículos nuevos que cumplen con los mismos estándares tenderán a generar emisiones similares en el uso real con respecto a los vehículos producidos para cumplir estándares diferentes. Cuando se estiman los factores de emisión de los vehículos, éstos son agrupados con base en los estándares de emisión que aplican a los vehículos cuando fueron fabricados.

En México se han establecido las nuevas normas de emisión para vehículos que se muestran a continuación:

- NOM-042-ECOL-1999 – Aplicable a vehículos nuevos en planta (PBV 400-3,857 kg) alimentados con gasolina, gas natural u otros combustibles

- NOM-044-ECOL-1993 – Aplicable a vehículos nuevos que usan diesel (PBV >3,857 kg) alimentados con diesel

- NOM-076-ECOL-1995 – Aplicable a vehículos (PBV >3,857 kg) alimentados con gasolina, gas LP, gas natural y otros combustibles alternos.

Adicionalmente, se han establecido las siguientes normas aplicables a vehículos en circulación:

- NOM-041-ECOL-1999 - Aplicable a vehículos (PBV >400 kg) alimentados con gasolina

- NOM-045-ECOL-1996 - Aplicable a vehículos (PBV >400 kg) alimentados con diesel (sólo opacidad de smog)

- NOM-048-ECOL-1993 – Aplicable para motocicletas alimentadas con gasolina o con una mezcla de gasolina y aceite

- NOM-050-ECOL-1993 – Aplicable a vehículos (PBV >400 kg) alimentados con gas LP, gas natural y otros combustibles alternos

- NOM-EM-102-ECOL-1995 - Aplicable a vehículos utilizados en el Valle de México (PBV >400 kg) alimentados con gasolina u otros combustibles.

Las normas para los vehículos en circulación están diseñadas principalmente para detectar a los vehículos con altas emisiones durante las pruebas de inspección y mantenimiento (I/M). Estas normas y sus clases asociadas se discuten con mayor detalle en la Sección 3.4.2.

2.0 PANORAMA GENERAL DEL PROCESO DE DESARROLLO DEL INVENTARIO

El desarrollo de un inventario de emisiones de vehículos automotores tiene el objetivo de cuantificar las emisiones generadas por una gran flota vehicular con diversas características de emisión. La ecuación básica utilizada para estimar dichas emisiones consiste en multiplicar los datos de actividad vehicular por un factor de emisión adecuado. Para los vehículos automotores, los datos de actividad son representados por los kilómetros recorridos por vehículo (KRV), que es la distancia total recorrida por los vehículos automotores dentro del dominio espacial del inventario; mientras que los factores de emisión se expresan en unidades de gramos de contaminante emitido por KRV. De manera ideal, las estimaciones de KRVs deben ser desarrolladas directamente a partir de datos locales tales como modelos de transporte o conteos de tráfico en circulación. Sin embargo, en muchos casos, estos datos no están disponibles y surge la necesidad de estimar la actividad vehicular con base en parámetros alternos, tales como las estadísticas del consumo regional de combustible. Los factores de emisión deben estimarse utilizando un modelo de factor de emisión que haya sido ajustado para las condiciones locales.

La Figura 2-1 muestra las etapas básicas del proceso de desarrollo de un inventario de vehículos automotores que circulan por carretera. Este proceso puede ser dividido en cinco pasos clave:

- Recopilación de los datos de la actividad vehicular (KRV directos o estadísticas de consumo de combustible)
- Recopilación de los datos específicos de área (datos de temperatura ambiente, composición del parque vehicular, tasas de acumulación de kilómetros por vehículo, etc.)
- Generación de los factores de emisión utilizando un modelo de factor de emisión

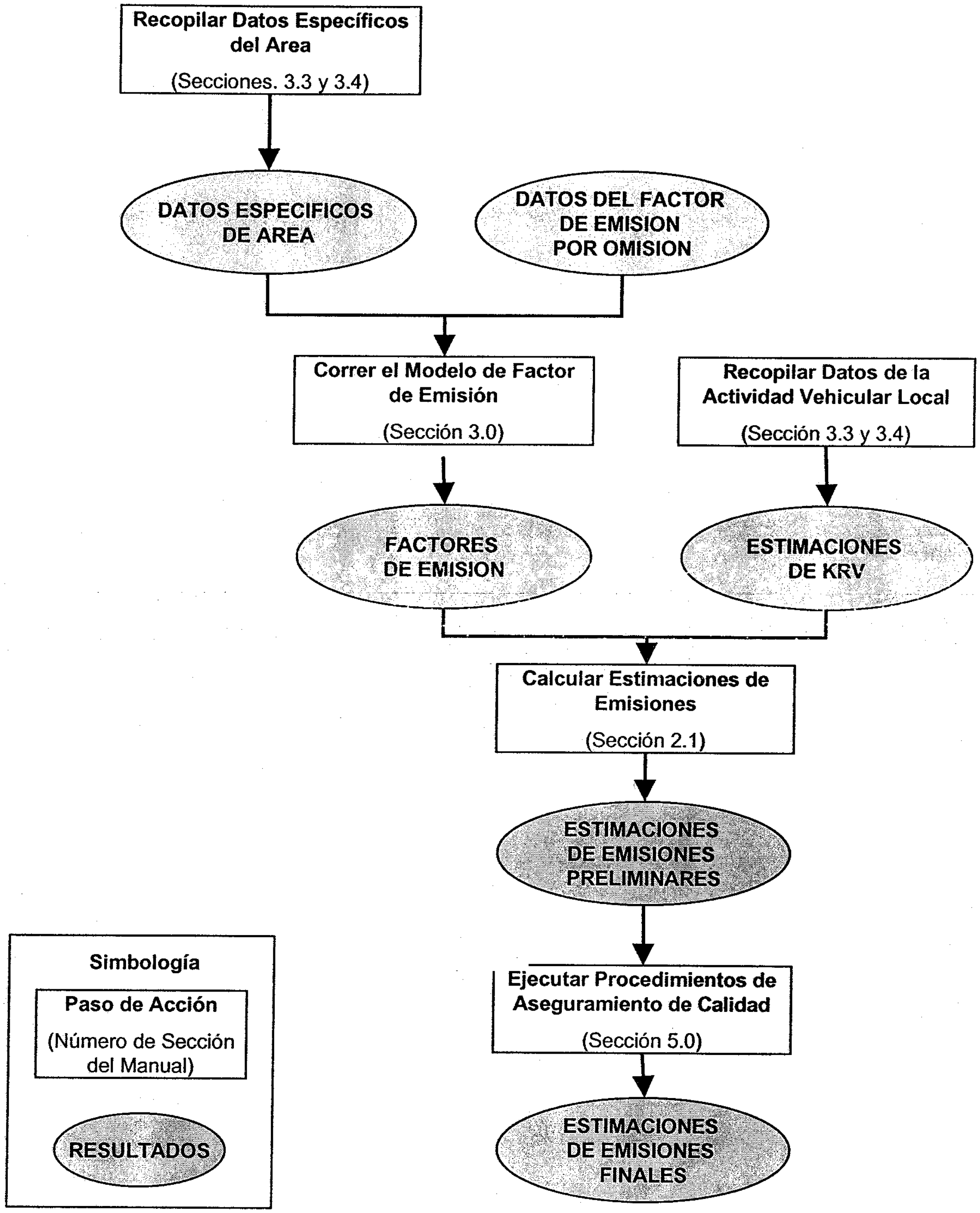


Figura 2-1. **Desarrollo del Inventario de Emisiones de Vehículos Automotores que Circulan por Carretera**

- Cálculo de las estimaciones de emisión preliminares
- Implantación de los procedimientos de aseguramiento de calidad (AC) para finalizar las estimaciones del inventario.

Un inventario de emisiones de vehículos automotores para un área urbana puede incluir miles, o hasta millones, de unidades. El parque vehicular está integrado por un conjunto de vehículos de todos los modelos y años, y el nivel de los controles de emisión instalados varía significativamente dentro de todo el espectro que están en operación en un momento determinado. Cada vehículo es conducido de manera individual, a diferentes velocidades y cargas, en diversas condiciones de manejo. Adicionalmente, los vehículos están sujetos a niveles variables de mantenimiento y alteraciones (e. g., desconexión de los sistemas de control de emisiones). Todos estos elementos pueden tener impactos significativos en las características de emisión de un vehículo, que se reflejarán como grandes diferencias en las emisiones de vehículos que de, otro modo, serían similares.

Con la tecnología actual no es factible medir las emisiones de cada vehículo individual del parque; por lo tanto, su estimación necesita de otros métodos. Los cálculos teóricos, utilizando balances de masa de combustible, por ejemplo, permiten obtener resultados útiles para estimar las emisiones de algunos contaminantes tales como el SO_x y el plomo. Para otros contaminantes, sin embargo, se debe utilizar un modelo de factores de emisión (como el MOBILE ó PART5). Los modelos de factores de emisión se basan en el tratamiento de los datos recopilados a partir de una muestra estadísticamente representativa de la flota vehicular. Posteriormente, los parámetros de entrada son ajustados para tomar en cuenta las condiciones locales y la variabilidad.

El Apéndice A presenta un ejemplo de los cálculos aplicando modelos tanto de balances de masa de combustible como de factores de emisión. Estos cálculos se basan en un inventario de emisiones real llevado a cabo en Nogales, Sonora.

2.1 Metodología Básica para la Estimación de Emisiones

La ecuación básica utilizada para la estimación de las emisiones de los vehículos automotores requiere la multiplicación de los datos de actividad vehicular por un factor de emisión apropiado, como se muestra en la Ecuación 2-1.

$$E_p = KRV \times FE_p \tag{2-1}$$

donde:

E_p = Emisiones totales del contaminante p

KRV = Kilómetros recorridos por vehículo

FE_p = Factor de emisión del contaminante p

Para los vehículos automotores, los datos de actividad se refieren a los kilómetros recorridos por vehículo (KRV), mientras que los factores de emisión se expresan en unidades de gramo de contaminante por KRV. Los KRV representan la distancia total recorrida por una población de vehículos en un periodo de tiempo determinado. Es preferible que los KRV sean estimados a partir de modelos de transporte o de conteos de vehículos en circulación. En algunos casos, sin embargo, los KRV deben ser obtenidos a partir de las estadísticas de consumo de combustible.

La ecuación básica de estimación presentada anteriormente es aplicable para la mayoría de los contaminantes gaseosos y partículas. Para otros contaminantes tales como SO_x y el plomo, las emisiones se calculan utilizando un balance de combustible, suponiendo que se emite la totalidad del azufre o plomo contenido en el combustible.

La ecuación que describe el balance de combustible para SO_x es:

(2-2)

$$E_{SO_x,f} = Comb_f \text{ x } \rho_f \text{ x } S_f \text{ x } 2$$

donde:

$E_{SOx,f}$ = emisiones de SO_x del combustible f (gasolina o diesel)
$Comb_f$ = Consumo total del combustible f
ρ_f = Densidad del combustible f
S_f = Contenido de azufre (fracción de masa) del combustible f
2 = Factor de conversión de masa de azufre a masa de SO_x (como SO_2).

Una ecuación similar describe el balance de combustible para el plomo:

(2-3)

$$E_{Pb,f} = Comb_f \text{ x } \rho_f \text{ x } Pb_f$$

donde:

Pb_f = Contenido de plomo (fracción de masa) del combustible f

2.2 Prioridades en el Desarrollo de Datos

Para generar un inventario de emisiones de vehículos automotores es necesario recopilar una gran variedad de datos que incluyen KRVs; estadísticas de consumo de combustible; velocidades de manejo, datos del registro vehicular y clases de vehículos; así como las características del combustible. En algunos casos, los datos son absolutamente indispensables para el proceso del inventario y deben obtenerse para generar incluso las estimaciones más preliminares. En otros casos, los datos se utilizan para refinar el modelado, a menudo reemplazando los datos por omisión con la información local. Esta sección presenta algunos de los datos clave que deben ser obtenidos, y jerarquiza las diversas necesidades de datos. La información adicional que describe estas categorías de datos está disponible en las Secciones 3.0 y 4.0.

La importancia de los diferentes datos para el desarrollo de un inventario puede ser definida al agruparlos en tres categorías: primarios, secundarios y terciarios. Los datos primarios son los mínimos requeridos para generar un inventario básico; los datos secundarios reemplazan a los parámetros clave por omisión con datos locales; los datos terciarios se incluyen en la medida en que estén disponibles para refinar el inventario con respecto a las condiciones locales. Un inventario inicial puede generarse sólo con datos primarios; sin embargo, la adición de datos secundarios y terciarios mejora sustancialmente el nivel de confianza de las estimaciones realizadas.

Los datos primarios para un inventario incluyen:

- Datos de actividad vehicular que cubran la región del inventario en su totalidad (típicamente KRV o consumo de combustible), agrupados para coincidir con los datos del factor de emisión disponibles
- Estándares de emisión vehicular por año y modelo
- Velocidades vehiculares promedio
- Factores de emisión por tipo de vehículo, tipo de combustible, año, modelo y velocidad de manejo
- Datos de la composición del combustible para la región del inventario, por estación, incluyendo contenido de azufre, oxígeno y plomo, y presión de vapor Reid (PVR)
- Distribución del parque vehicular por año y modelo, incluyendo la fracción de vehículos no registrados y extranjeros
- Condiciones locales de altitud y temperatura ambiente
- Tasas de acumulación anual de kilómetros por vehículo, por clase vehicular, modelo y año

Los datos secundarios necesarios incluyen:

- Información sobre el programa local de inspección y mantenimiento de vehículos (I/M), y del programa anti-alteraciones (PAA)
- Datos de las encuestas locales de alteración de vehículos y tasas de uso del combustible no adecuado

Los datos terciarios incluyen:

- Datos de las encuestas locales de hábitos de manejo para identificar las longitudes de recorrido promedio y el tiempo transcurrido entre los arranques de motor
- Datos de la encuesta del patrón de manejo para identificar los patrones locales de velocidades vehiculares, peso transportado y tasas de aceleración.

3.0 MODELOS DE FACTORES DE EMISIÓN PARA VEHÍCULOS AUTOMOTORES

Como se describió en la Sección 2.0, las emisiones de vehículos automotores se calculan combinando los factores de emisión con los KRV. En lugar de ser simples factores de emisión que pudieran encontrarse en una publicación, los factores de emisión de los vehículos automotores se derivan a partir de modelos. La razón de esto es que las emisiones de los vehículos automotores son más complejas y dinámicas que la mayoría de los otros tipos de fuentes. Por ejemplo, los cambios en las características del combustible, las velocidades de operación del vehículo, la tecnología para el control de emisiones, la temperatura ambiente y la altitud pueden afectar los factores de emisión. Con el objeto de incorporar éstos y otros factores, generalmente se utiliza un modelo de factor de emisión que incluye los efectos de numerosos parámetros.

Esta sección describe diversos aspectos de los modelos para vehículos automotores (MOBILE y PART5) que pueden utilizarse para estimar las emisiones de vehículos automotores en México. El modelo MOBILE será el tema central, si bien también se discutirá el modelo PART5. La Sección 3.1 describe brevemente la historia de ambos modelos en EU y en México. La Sección 3.2 presenta una breve descripción teórica de los algoritmos utilizados para estimar los factores de emisión para vehículos automotores. La Sección 3.3 analiza los archivos tanto de entrada como de salida utilizados por el modelo MOBILE. Finalmente, la Sección 3.4 discute diversas características específicas que pueden tener una gran influencia sobre las emisiones de los vehículos automotores.

3.1 Antecedentes Históricos de los Modelos de Factores de Emisión

Esta sección resume los antecedentes históricos de los modelos de factores de emisión MOBILE y PART5 en EU, así como una breve descripción del uso de ambos modelos en México.

Modelo de Factor de Emisión MOBILE

El modelo MOBILE está formado por un conjunto de rutinas codificadas en lenguaje FORTRAN que generan factores de emisión de hidrocarburos (HC), monóxido de carbono (CO) y óxidos de nitrógeno (NO_x), para vehículos automotores alimentados con gasolina y diesel que circulan por carreteras. Los factores de emisión para hidrocarburos pueden ser expresados como hidrocarburos totales (HCT), hidrocarburos no metánicos (HCNM), compuestos orgánicos volátiles (COV), gases orgánicos totales (GOT), o gases orgánicos no metánicos (GONM). Estas categorías se definen en la Tabla 3-1. Se recomienda que los factores de emisión de GOTs sean seleccionados en todos los esfuerzos de inventario de emisiones. Todas las referencias de este manual serán para GOTs. Para ajustar la reactividad, es posible utilizar las siguientes fracciones para gases orgánicos reactivos (GOR) (ARB, 1993):

Tabla 3-1

Definición de Hidrocarburos

	Compuestos Incluidos en los Factores de Emisión de Hidrocarburos			
	Hidrocarburos DIF[a]	**Metano**	**Etano**	**Aldehídos**
Hidrocarburos Totales (HCT)	✓	✓	✓	
Hidrocarburos No Metánicos (HCNM)	✓		✓	
Compuestos Orgánicos Volátiles (COV)	✓			✓
Gases Orgánicos Totales (GOT)	✓	✓	✓	✓
Gases Orgánicos No Metánicos (GONM)	✓		✓	✓

[a] Los Hidrocarburos FID se refieren a las emisiones de hidrocarburos como son medidas en el detector de ionización de flama (DIF) utilizado en las pruebas de vehículos automotores.

- Emisiones del escape de vehículos de gasolina sin catalizador - 92.4%

- Emisiones del escape de vehículos de gasolina con catalizador - 85.2%
- Emisiones del escape de vehículos a diesel - 95.8%
- Emisiones evaporativas de vehículos a gasolina - 100%.

La primera generación del modelo MOBILE fue creada a mediados de los años 70 y, desde entonces, ha tenido numerosas actualizaciones y revisiones para incorporar los cambios de la legislación ambiental y los avances tecnológicos. Estas versiones actualizadas también incluyen grandes cantidades de datos de emisiones recientemente recopilados, como parte de un esfuerzo para estimar las emisiones de los vehículos automotores con mayor precisión. La versión más reciente del modelo MOBILE (MOBILE5b) fue emitida en septiembre de 1996, y se espera que el MOBILE6 sea emitido a mediados o finales del año 2000. El modelo MOBILE y otra información relacionada con los inventarios de emisiones de vehículos automotores puede ser obtenida en la página electrónica de la U.S. EPA en Internet, *Office of Mobile Sources - OMS* (Oficina de Fuentes Móviles*)*: http://www.epa.gov/oms/models.htm.

Debido a que el modelo MOBILE se basa en pruebas de emisión de vehículos estadounidenses, es probable que su uso directo en regiones fuera de EU genere resultados inciertos. Con el objeto de tomar en cuenta las posibles diferencias en el parque vehicular y los hábitos para conducir en México, el modelo MOBILE ha sido modificado para las áreas metropolitanas de las ciudades de México, Monterrey y Ciudad Juárez. Los modelos modificados para la Ciudad de México (MOBILE-MCMA) y Monterrey (MOBILE-MMAp) utilizan una matriz de equivalencia para la tecnología de control que identifica los factores de emisión básicos de MOBILE para los vehículos del parque vehicular mexicano con base en la edad del vehículo y sus controles de emisión. La Tabla 3-2 presenta un ejemplo de la matriz de equivalencia de tecnología para los factores de emisión del escape y evaporativos, donde puede observarse que un vehículo mexicano ligero a gasolina (LDGV) de 1994, sería equivalente a un LDGV

Tabla 3-2
Matriz de Equivalencia de la Tecnología de Control de Emisiones Típica

Año Modelo Mexi-cano	**Modelo Año Equivalente Estadounidense (Escape)**								**Modelo Año Equivalente Estadounidense (Evaporativo)**							
	LDGV	**LDGT1**	**LDGT2**	**HDGV**	**LDDV**	**LDDT**	**HDDV**	**MC**	**LDGV**	**LDGT1**	**LDGT2**	**HDGV**	**LDDV**	**LDDT**	**HDDV**	**MC**
1971	1968	1968	1968	1968	1968	1968	1968	1971	1968	1968	1968	1968	1968	1968	1968	1968
1972	1968	1968	1968	1968	1968	1968	1968	1972	1968	1968	1968	1968	1968	1968	1968	1968
1973	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971
1974	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971
1975	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971
1976	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971
1977	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971
1978	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971
1979	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971
1980	1971	1971	1971	1971	1971	1971	1971	1971	1972	1972	1972	1972	1972	1972	1972	1972
1981	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972
1982	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972
1983	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972
1984	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972
1985	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972
1986	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972
1987	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972	1972
1988	1975	1974	1974	1974	1974	1974	1974	1974	1975	1975	1975	1975	1975	1975	1975	1975
1989	1975	1974	1974	1974	1974	1974	1974	1974	1975	1975	1975	1975	1975	1975	1975	1975
1990	1980	1974	1974	1974	1974	1974	1974	1974	1977	1977	1977	1977	1977	1977	1977	1977
1991	1980	1974	1974	1974	1974	1974	1974	1974	1977	1977	1977	1977	1977	1977	1977	1977
1992	1981	1974	1974	1974	1974	1974	1974	1974	1980	1980	1980	1980	1980	1980	1980	1980
1993	1988	1977	1977	1977	1977	1977	1977	1977	1981	1981	1981	1981	1981	1981	1981	1981
1994	1988	1981	1981	1981	1981	1981	1981	1981	1988	1988	1988	1988	1988	1988	1988	1988
1995	1989	1981	1981	1981	1981	1981	1981	1981	1988	1988	1988	1988	1988	1988	1988	1988
1996	1990	1981	1981	1981	1981	1981	1981	1981	1988	1988	1988	1988	1988	1988	1988	1988
1997	1990	1981	1981	1981	1981	1981	1981	1981	1990	1990	1990	1990	1990	1990	1990	1990
1998	1994	1985	1985	1985	1985	1985	1985	1985	1990	1990	1990	1990	1990	1990	1990	1990
1999	1995	1985	1985	1985	1985	1985	1985	1985	1990	1990	1990	1990	1990	1990	1990	1990
2000	1996	1985	1985	1985	1985	1985	1985	1985	1990	1990	1990	1990	1990	1990	1990	1990
2001	1997	1993	1993	1990	1993	1993	1990	1993	1990	1990	1990	1990	1990	1990	1990	1990

LDGV = vehículo ligero a gasolina
LDGT1 = camión ligero a gasolina (<2,727 kg)
LDGT2 = camión ligero a gasolina (2,727 – 3,857 kg)
HDGV = Camión pesado a gasolina (>3,857 kg)
LDDV = Vehículo ligero a diesel
LDDT = Camión ligero a diesel (<3,857 kg)
HDDV = Vehículo pesado a diesel (>3,857 kg)
MC = Motocicleta

estadounidense de 1988. En algunos casos, un determinado modelo y año mexicano podría ser equivalente a un modelo y año estadounidense para la tecnología de control del escape, y otro para la tecnología de control de evaporaciones. Por ejemplo, un LDGV mexicano de 1990 sería equivalente a un LDGV estadounidense de 1980 para las emisiones del escape, y a uno de 1977 para las evaporativas.

El modelo MOBILE modificado más reciente (MOBILE-Juárez) sigue asignando factores de emisiones evaporativas a partir de una matriz de equivalencia de tecnología, pero aplica los datos reales de la prueba IM240 de 206 vehículos de Ciudad Juárez como base para los factores de emisión del escape (Radian, 1996a). Hoy en día, este es el modelo de factores de emisión más recomendable para ser utilizado en México; sin embargo, a medida en que la investigación relacionada con los vehículos automotores en México continúe, el modelo MOBILE mexicano también seguirá evolucionando. El INE es la referencia a contactar con relación a la versión más adecuada del modelo de factores de emisión a ser utilizado en cualesquier esfuerzos de inventario de emisiones en el futuro.

Modelo de Factor de Emisión PART5

El modelo de factor de emisión PART5 de la U.S. EPA también utiliza rutinas codificadas en lenguaje FORTRAN similares a las de MOBILE para estimar los factores de emisión de partículas (PM) y óxidos de azufre (SO_x) de vehículos automotores. Sin embargo, se recomienda que los factores de emisión de SO_x en México **NO** sean estimados con el modelo PART5, por diversas razones, entre las que se incluye la incapacidad del modelo para ajustar el contenido de azufre de manera tal que refleje las condiciones locales. En su lugar, las emisiones de SO_x deben estimarse utilizando balances de combustible, como se describe en la Sección 2.1. La última versión del modelo PART5 fue emitida en febrero de 1995 (U.S. EPA, 1995). Si bien el modelo PART5 se asemeja al MOBILE en varios aspectos, el primero se encuentra en una etapa de desarrollo más temprana debido a que se han recopilado menos datos sobre la emisión de PM. Esto es, en gran medida, el resultado de que en EU los precursores de ozono (GOT, CO y NO_x) han recibido una mayor prioridad que las PM. En consecuencia, algunos de los parámetros que afectan las emisiones de partículas en los vehículos automotores (e. g., temperatura, programas de inspección y mantenimiento [I/M], etc.), aún no hayan sido modelados en el PART5. Por otro lado, varios supuestos en este modelo (i. e., ciclos de manejo, especificaciones de combustible, sistemas de control de emisiones, tasas de deterioro de los sistemas del motor, etc.), son válidos sólo para EU. A menos que las condiciones en México sean similares a estos supuestos, los factores de emisión resultantes no representarán de manera precisa las emisiones de PM de los vehículos automotores mexicanos.

Hasta este momento, el modelo PART5 **NO** ha sido modificado para ser utilizado fuera de EU. Se espera que el nivel de esfuerzo necesario para su adaptación para México sea similar al aplicado en la modificación del MOBILE para las ciudades de México y Monterrey. Se recomienda que el modelo PART5 sea utilizado sólo hasta que haya sido adaptado al caso de México. Esta no es una solución ideal, sin embargo, el modelo PART5 de EU servirá como metodología provisional hasta que se genere la versión específica para México. El INE es la referencia a contactar con relación a la versión más adecuada del modelo de factores de emisión a ser utilizado en cualesquier esfuerzos de inventario de emisiones en el futuro.

3.2 Descripción Teórica de los Modelos de Factores de Emisión

En los modelos MOBILE y PART5, la meta final consiste en calcular un factor de emisión **promedio** para cada tipo de vehículo. Esta sección describe algunas de las ecuaciones teóricas básicas utilizadas, que se presentan como parte de los antecedentes generales para el usuario del modelo. Estas ecuaciones teóricas no serán visibles para el usuario real del modelo de factores de emisión; sin embargo, tanto éstas como los factores de emisión resultantes serán influenciados por los diversos parámetros de entrada del modelo que se describen en las secciones 3.3 y 3.4.

El cálculo de las tasas básicas de emisión promedio (TBEs) para cada tipo de vehículo, modelo y año es el primer paso para estimar los factores de emisión de vehículos automotores. El fundamento de las TBEs son los datos sobre las emisiones de vehículos en uso obtenidos en condiciones de prueba normalizadas (i. e., temperatura, características del combustible y ciclos de manejo normalizados). Ahora bien, las emisiones varían con la edad del vehículo, de manera que es posible aplicar regresiones lineales que relacionan los datos de las emisiones con las lecturas del odómetro. Estas regresiones dan como resultado ecuaciones TBEs que incorporan una tasa de emisión de cero millas (la interseción "y" de la regresión) y una tasa de deterioro (pendiente). La primera representa las emisiones de un vehículo nuevo, mientras que la segunda describe la manera en que las emisiones se incrementan con el kilometraje (millaje) del vehículo.

El modelo MOBILE utiliza dos ecuaciones TBEs para describir las diferentes tasas de deterioro en diferentes regímenes de kilometraje (millaje) para los LDGV y los camiones ligeros a gasolina nuevos. A continuación se presentan las dos ecuaciones TBE hipotéticas:

$$\text{Para } MILAC \leq 50{,}000 \text{ millas}, TBE = ECM + \left(\text{DET}\,1 \text{ x } \frac{MILAC}{10{,}000}\right) \qquad \textbf{(3-1)}$$

$$\text{Para } MILAC > 50{,}000 \text{ millas}, TBE = ECM + (\text{DET}\,1 \text{ x } 5) + \left(\text{DET } 2 \text{ x } \frac{[MILAC - 50{,}000]}{10{,}000}\right) \qquad (3\text{-}2)$$

donde:

TBE = tasa básica de emisión
ECM = nivel de emisión cero millas (intersección)
DET1 = tasa de deterioro por cada 10,000 millas (pendiente) para el millaje acumulado hasta 50,000 millas
DET2 = tasa de deterioro por cada 10,000 millas (pendiente) para el millaje acumulado por más de 50,000 millas
MILAC = millaje acumulado en el odómetro

Estas dos ecuaciones TBE hipotéticas han sido graficadas en la Figura 3-1, donde aparecen el nivel de emisión cero millas y las dos tasas de deterioro. Un punto de inflexión hipotético a las 50,000 millas puede observarse claramente en el momento en que los vehículos pasan de una tasa de deterioro a otra. En realidad, los datos de la prueba de emisiones de los vehículos en uso podría ser no linear en extremo. El modelo MOBILE utiliza una o dos ecuaciones TBEs para mantener el volumen de los cálculos en un nivel manejable. Dependiendo de la distribución de los datos de emisión en los diferentes conjuntos de datos, las ecuaciones TBEs y los puntos de inflexión resultantes podrían variar significativamente. El punto de inflexión de 50,000 millas en el modelo MOBILE ha sido adoptado por convención para los vehículos y camiones ligeros a gasolina. A cada tipo de vehículo se le ha asignado una TBE por cada 25 años de antigüedad, con base en la acumulación de kilometraje (millaje) para cada modelo y año vehicular.

Las tasas básicas de emisión no corresponden exactamente con las emisiones reales de un vehículo automotor; dado que más bien representan las emisiones medidas en condiciones de prueba sumamente controladas. Para reconciliar las diferencias que existen entre las emisiones de prueba y las reales, se deben aplicar diversos factores de ajuste a las emisiones reales. De esta manera, a partir de la TBE es posible calcular un factor de emisión básico (BEF) para cada tipo de vehículo, modelo y año.

Esto se muestra a continuación:

$$FEB = (TBE \text{ x } FA \text{ x } FAim) + FAaa \qquad (3\text{-}3)$$

donde:

FEB = factor de emisión básico, por modelo y año
TBE = tasa básica de emisión, por modelo y año
FA = factor de ajuste para los efectos de diferentes temperaturas, presiones de vapor de Reid y modos de operación
FAim = factor de ajuste para el efecto del programa de I/M
FAaa = factor de ajuste para los efectos de la alteración de los controles de emisión y los programas anti-alteración

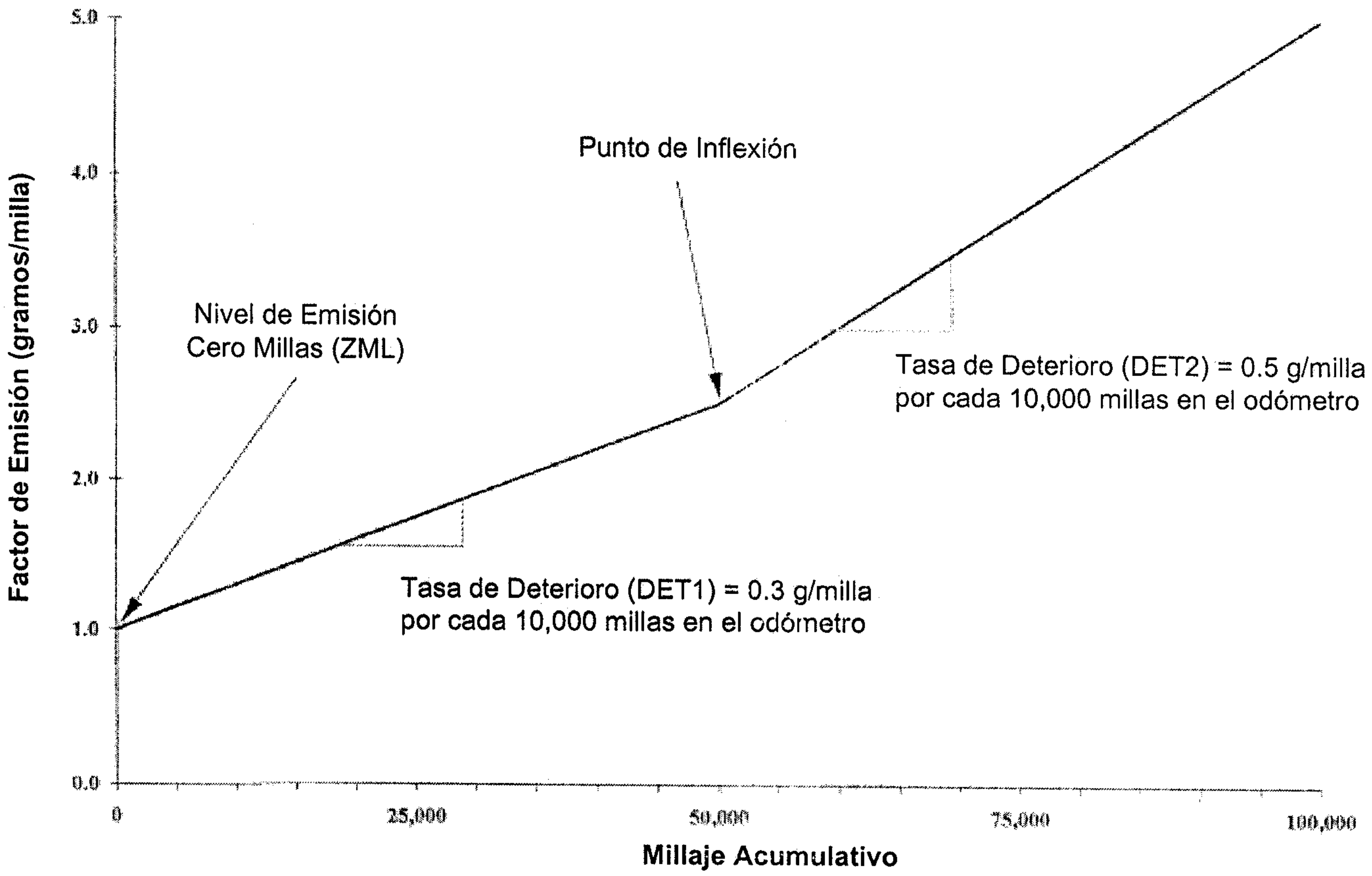


Figura 3-1. Tasas de Emisión Básicas Hipotéticas (BERs)

La ecuación anterior sólo muestra los principales factores de ajuste que son aplicables para todos los tipos de contaminantes en las situaciones más típicas. En el modelo MOBILE existen factores de ajuste adicionales que son aplicables sólo en circunstancias especializadas o para un contaminante (e. g., corrección para CO a baja temperatura). La información sobre estos factores de ajuste específicos puede encontrarse en la *MOBILE User's Guide* (Guía del Usuario del MOBILE5*)* (U.S. EPA, 1994), y otra documentación relacionada (U.S. EPA, 1992).

Después de que los FEBs para cada modelo y año han sido calculados con los ajustes pertinentes, se calcula un factor de emisión promedio o compuesto para el parque vehicular para cada tipo de vehículo con un factor de ajuste adicional. El factor de emisión compuesto para el parque vehicular (FECO) está dado por la siguiente ecuación:

$$FECA = \sum_{\mathrm{m}a = 1}^{25} (FR \times Fa \times TBE) \qquad (3\text{-}4)$$

donde:

FECA = factor de emisión compuesto del parque vehicular
ma = modelo y año
FR = fracción del recorrido (fracción de los KRV totales con los que contribuye cada modelo y año)
Fa = factor de ajuste para los efectos de la velocidad, uso del aire acondicionado, carga extra y remolque de trailers
TBE = factor de emisión básico por modelo y año

El factor de ajuste adicional (Fa) toma en cuenta los efectos de las características específicas del área de estudio con respecto a velocidad del tráfico, uso del aire acondicionado, carga extra y remolque de trailers. Después de este ajuste, cada factor de emisión ajustado es ponderado por la fracción del recorrido (en KRV) para ese modelo y año. Finalmente, los factores de emisión ponderados para cada uno de los 25 años de antigüedad se suman para generar un factor de emisión compuesto, que es el factor de emisión promedio para un tipo de vehículo específico.

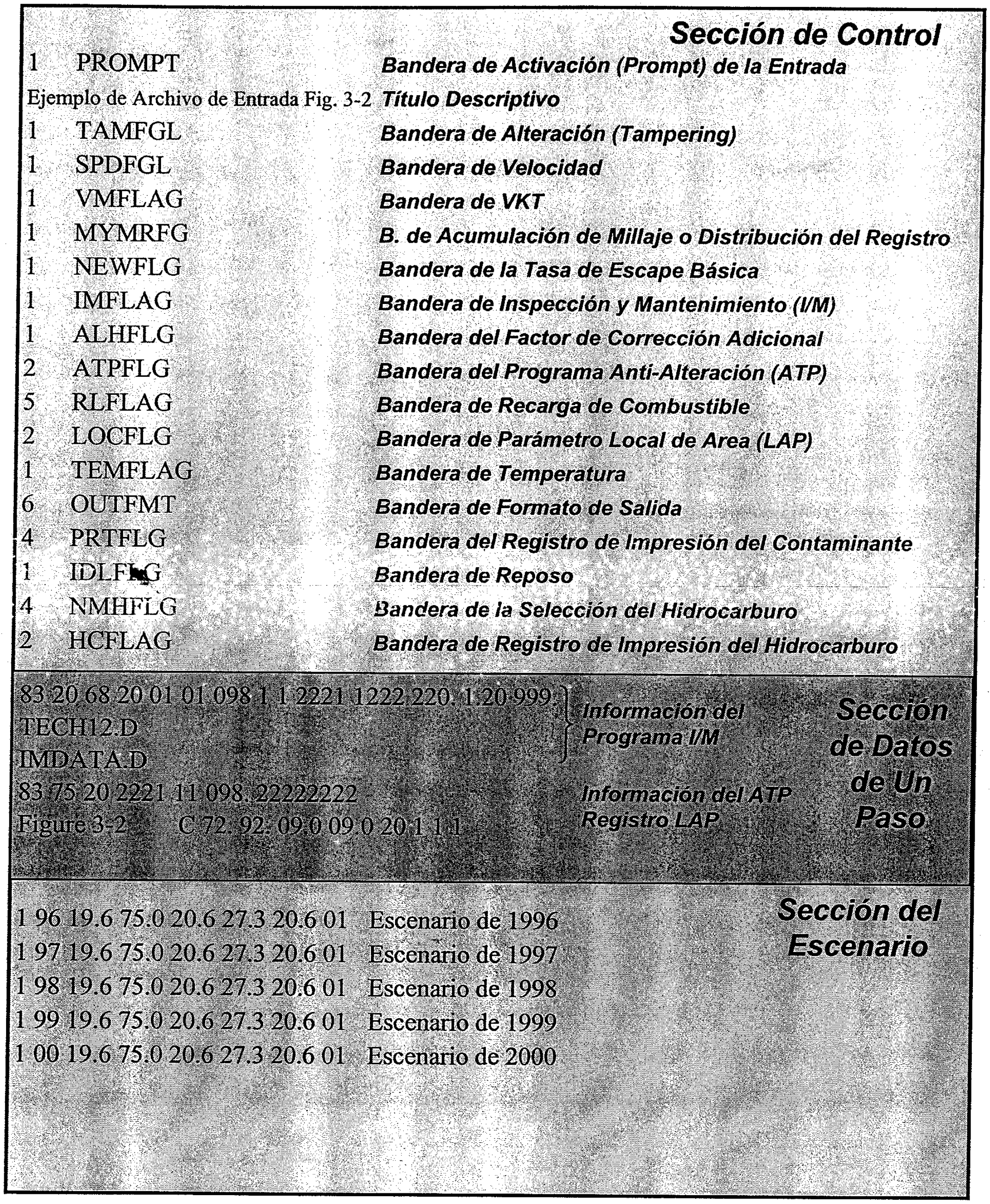
3.3 Formatos de Entrada y Salida de MOBILE

Esta sección describe un ejemplo de un archivo de entrada de MOBILE y el archivo de salida resultante. El Apéndice A presenta los archivos MOBILE reales para un inventario de emisiones realizado en Nogales, Sonora. Recuerde el lector que es posible encontrar mayor información sobre los formatos de archivo del MOBILE en la Guía del Usuario del MOBILE. La Figura 3-2 presenta un ejemplo del archivo de entrada del MOBILE5a, y la Figura 3-3 contiene una parte del archivo de salida resultante en el formato de hoja de cálculo. El archivo de entrada es un texto en formato ASCII leído por el código FORTRAN del modelo. Dado que FORTRAN es extremadamente "sensible" a errores, un espacio extra o un carácter mal ubicado pueden tener efectos desastrosos en la corrida del modelo. Por esta razón se recomienda más la modificación de un archivo de entrada de MOBILE existente, que la creación de uno nuevo.

Como se indica en la Figura 3-2, el archivo de entrada MOBILE está formado por tres secciones separadas: la sección de Control, la de Datos de Un Paso y la del Escenario. La primera sección consiste principalmente de un número de banderas que determinan el contenido y el formato del resto del archivo de entrada, así como del archivo de salida del programa. Las banderas también definen la forma en que el código MOBILE es ejecutado. Todas estas banderas son necesarias para que el modelo MOBILE corra correctamente.

La sección Datos de Un Paso contiene información que es específica del área. Esta información local detallada se captura sólo una vez en el archivo de entrada y reemplaza los datos por omisión que están cargados en el modelo MOBILE. Los tipos de información alterna que pueden ser capturados en esta sección incluyen:

- Tasas de alteración de los dispositivos de control de emisiones
- Combinaciones de KRV
- Tasas anuales de acumulación de kilometraje (millaje)



Sección de Control

1	PROMPT	***Bandera de Activación (Prompt) de la Entrada***
Ejemplo de Archivo de Entrada Fig. 3-2		***Título Descriptivo***
1	TAMFGL	***Bandera de Alteración (Tampering)***
1	SPDFGL	***Bandera de Velocidad***
1	VMFLAG	***Bandera de VKT***
1	MYMRFG	***B. de Acumulación de Millaje o Distribución del Registro***
1	NEWFLG	***Bandera de la Tasa de Escape Básica***
1	IMFLAG	***Bandera de Inspección y Mantenimiento (I/M)***
1	ALHFLG	***Bandera del Factor de Corrección Adicional***
2	ATPFLG	***Bandera del Programa Anti-Alteración (ATP)***
5	RLFLAG	***Bandera de Recarga de Combustible***
2	LOCFLG	***Bandera de Parámetro Local de Area (LAP)***
1	TEMFLAG	***Bandera de Temperatura***
6	OUTFMT	***Bandera de Formato de Salida***
4	PRTFLG	***Bandera del Registro de Impresión del Contaminante***
1	IDLFLG	***Bandera de Reposo***
4	NMHFLG	***Bandera de la Selección del Hidrocarburo***
2	HCFLAG	***Bandera de Registro de Impresión del Hidrocarburo***

Sección de Datos de Un Paso

83 20 68 20 01 01 098 1 1 2221 1222 220. 1 20 999.
TECH12.D
IMDATA.D

Información del Programa I/M

83 75 20 2221 11 098. 22222222

Información del ATP

Figure 3-2   C 72. 92. 09.0 09.0 20 1 1 1

Registro LAP

Sección del Escenario

1 96 19.6 75.0 20.6 27.3 20.6 01   Escenario de 1996
1 97 19.6 75.0 20.6 27.3 20.6 01   Escenario de 1997
1 98 19.6 75.0 20.6 27.3 20.6 01   Escenario de 1998
1 99 19.6 75.0 20.6 27.3 20.6 01   Escenario de 1999
1 00 19.6 75.0 20.6 27.3 20.6 01   Escenario de 2000

Figura 3-2. Ejemplo del Archivo de Entrada de MOBILE

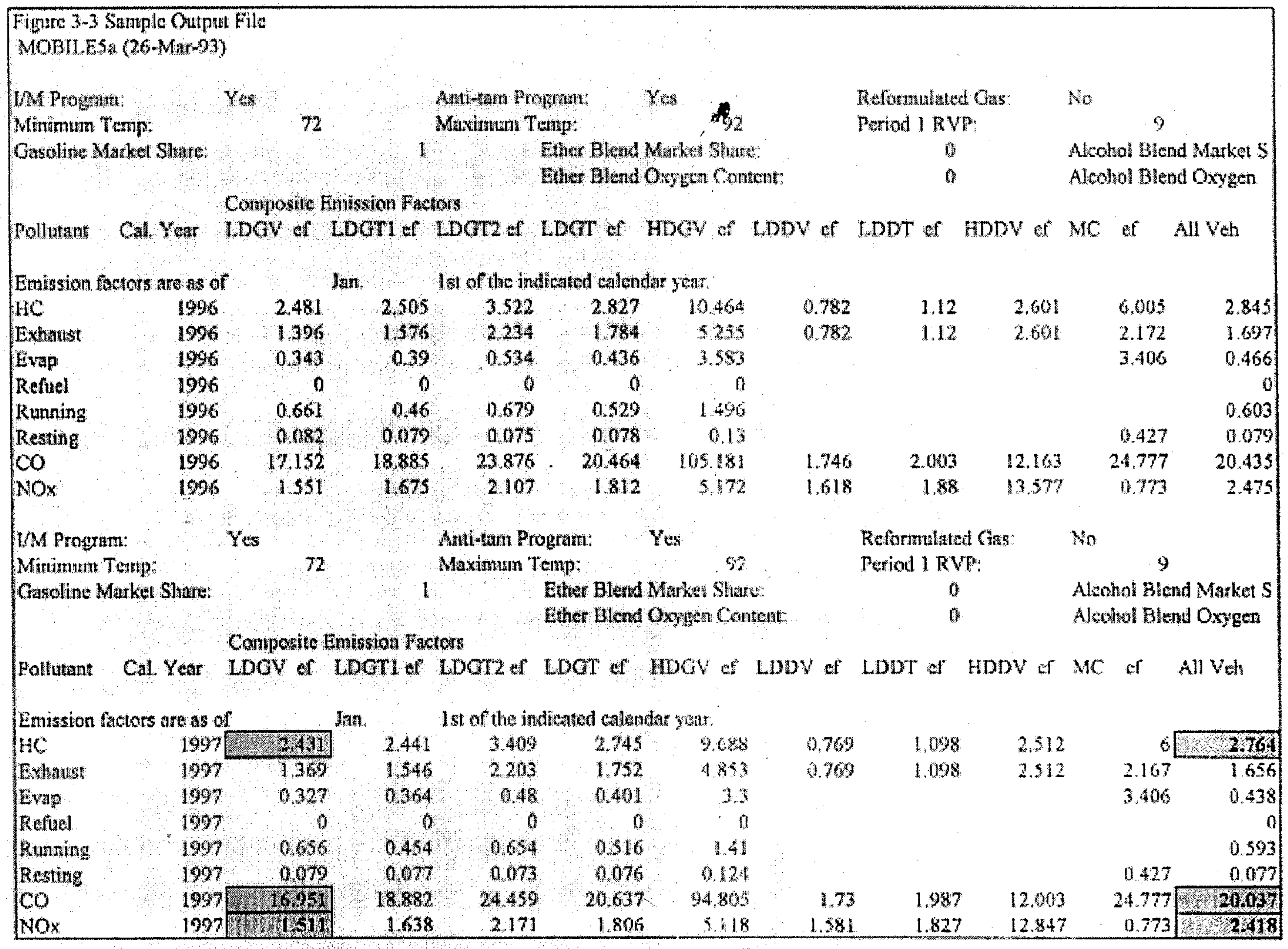


Figure 3-3 Sample Output File
MOBILE5a (26-Mar-93)

I/M Program: Yes Anti-tam Program: Yes Reformulated Gas: No
Minimum Temp: 72 Maximum Temp: 92 Period 1 RVP: 9
Gasoline Market Share: 1 Ether Blend Market Share: 0 Alcohol Blend Market S
Ether Blend Oxygen Content: 0 Alcohol Blend Oxygen

Composite Emission Factors

Pollutant	Cal. Year	LDGV ef	LDGT1 ef	LDGT2 ef	LDGT ef	HDGV ef	LDDV ef	LDDT ef	HDDV ef	MC ef	All Veh
Emission factors are as of			Jan.	1st of the indicated calendar year.							
HC	1996	2.481	2.505	3.522	2.827	10.464	0.782	1.12	2.601	6.005	2.845
Exhaust	1996	1.396	1.576	2.234	1.784	5.255	0.782	1.12	2.601	2.172	1.697
Evap	1996	0.343	0.39	0.534	0.436	3.583				3.406	0.466
Refuel	1996	0	0	0	0	0					0
Running	1996	0.661	0.46	0.679	0.529	1.496					0.603
Resting	1996	0.082	0.079	0.075	0.078	0.13				0.427	0.079
CO	1996	17.152	18.885	23.876	20.464	105.181	1.746	2.003	12.163	24.777	20.435
NOx	1996	1.551	1.675	2.107	1.812	5.172	1.618	1.88	13.577	0.773	2.475

I/M Program: Yes Anti-tam Program: Yes Reformulated Gas: No
Minimum Temp: 72 Maximum Temp: 92 Period 1 RVP: 9
Gasoline Market Share: 1 Ether Blend Market Share: 0 Alcohol Blend Market S
Ether Blend Oxygen Content: 0 Alcohol Blend Oxygen

Composite Emission Factors

Pollutant	Cal. Year	LDGV ef	LDGT1 ef	LDGT2 ef	LDGT ef	HDGV ef	LDDV ef	LDDT ef	HDDV ef	MC ef	All Veh
Emission factors are as of			Jan.	1st of the indicated calendar year.							
HC	1997	2.431	2.441	3.409	2.745	9.688	0.769	1.098	2.512	6	2.764
Exhaust	1997	1.369	1.546	2.203	1.752	4.853	0.769	1.098	2.512	2.167	1.656
Evap	1997	0.327	0.364	0.48	0.401	3.3				3.406	0.438
Refuel	1997	0	0	0	0	0					0
Running	1997	0.656	0.454	0.654	0.516	1.41					0.593
Resting	1997	0.079	0.077	0.073	0.076	0.124				0.427	0.077
CO	1997	16.951	18.882	24.459	20.637	94.805	1.73	1.987	12.003	24.777	20.037
NOx	1997	1.511	1.638	2.171	1.806	5.118	1.581	1.827	12.847	0.773	2.418

Figura 3-3. Ejemplo de Archivo de Salida de MOBILE

- Distribuciones del registro por tipo de vehículo y edad (modelo y año)
- Tasas básicas de emisión
- Programas de inspección y mantenimiento (I/M)
- Programas Anti-alteración (PAAs).

La sección de Datos de Un Paso también contiene el registro de los parámetros de área local (PAL), que incluyen diversos datos locales de importancia, entre los que destacan las temperaturas ambiente diarias mínimas y máximas, así como la presión de vapor de Reid (PVR) del combustible. Por otro lado, las banderas relacionadas con las mezclas de combustibles alternos (diesel, combustibles oxigenados y gasolina reformulada) también pueden ser incluidas en los PAL. Con excepción de los PAL, todos los datos en la sección Datos de Un Paso son opcionales. Cada corrida de MOBILE debe incluir cuando menos un PAL. Si esta sección no contiene ningún parámetro opcional, entonces el modelo correrá utilizando diversos datos cargados por omisión. El archivo ejemplificado en la Figura 3-2 sólo incluye el registro PAL, el programa I/M y la información PAA.

La sección de Escenario contiene variables que representan información específica. Cada escenario a ser evaluado está asociado con un grupo de los registros de la sección Escenario. Como mínimo, cada escenario está representado por un registro que identifica si la región está localizada a una altitud alta o baja, el año calendario de la evaluación, la velocidad promedio, la temperatura ambiente, las fracciones del modo de operación, y el mes de la evaluación. Los registros adicionales de esta sección pueden ser necesarios, dependiendo de la selección de las diversas banderas en la sección de Control. En cada corrida de MOBILE es posible calcular múltiples escenarios. Por ejemplo, el archivo de entrada de la Figura 3-2 incluye cinco escenarios que representan los años de 1996 a 2000. Los escenarios múltiples pueden ser utilizados para modelar los efectos de la rotación del parque vehicular, los programas I/M y los programas anti-alteraciones en el tiempo.

Después de correr, el modelo MOBILE genera un archivo de salida cuyo formato es controlado por la bandera de formato de salida (OUTFMT) en la Sección de Control de Banderas. Dependiendo del valor seleccionado para esta bandera, el archivo de salida será generado en un formato descriptivo de 80 ó 112 columnas; un formato de 140 ó 222 columnas, “por modelo y año” o como hoja de cálculo. Este último formato fue incorporado en el MOBILE5 y permite que los factores de emisión modelados sean transferidos a diversos programas de hojas de cálculo (e. g., Excel, Lotus 1-2-3). Este formato simplifica la manipulación posterior de los datos y es el más utilizado.

La Figura 3-3 presenta una porción del archivo de salida generado a partir del archivo de entrada ejemplificado en la Figura 3-2. Los valores de la Figura 3-3 son resultados estrictamente hipotéticos y no deben ser utilizados en aplicaciones reales. Esta figura indica los factores de emisión de los modelos 1996 y 1997 para HC (totales y por componente), CO y NO_x para cada uno de los ocho tipos de vehículos. Por ejemplo, los factores de emisión de 1997 para los vehículos ligeros a gasolina (LDGV) para HC (seleccionados como GOT en el archivo de entrada), CO y NO_x son 2.431, 16.951 y 1.511 gramos por milla, respectivamente. Los factores de emisión promedio del parque vehicular (asumiendo las distribuciones por omisión del registro de vehículos) también han sido calculados. En la Figura 3-3, los factores de emisión del parque vehicular en 1997 para HC, CO y NO_x son de 2.764, 20.037 y 2.418 gramos por milla, respectivamente. Las secciones del archivo de salida no incluidas en la Figura 3.3 contienen los factores de emisión para el periodo 1998-2000, así como los resúmenes de los datos del archivo de entrada.

3.4 Efecto de las Características Locales

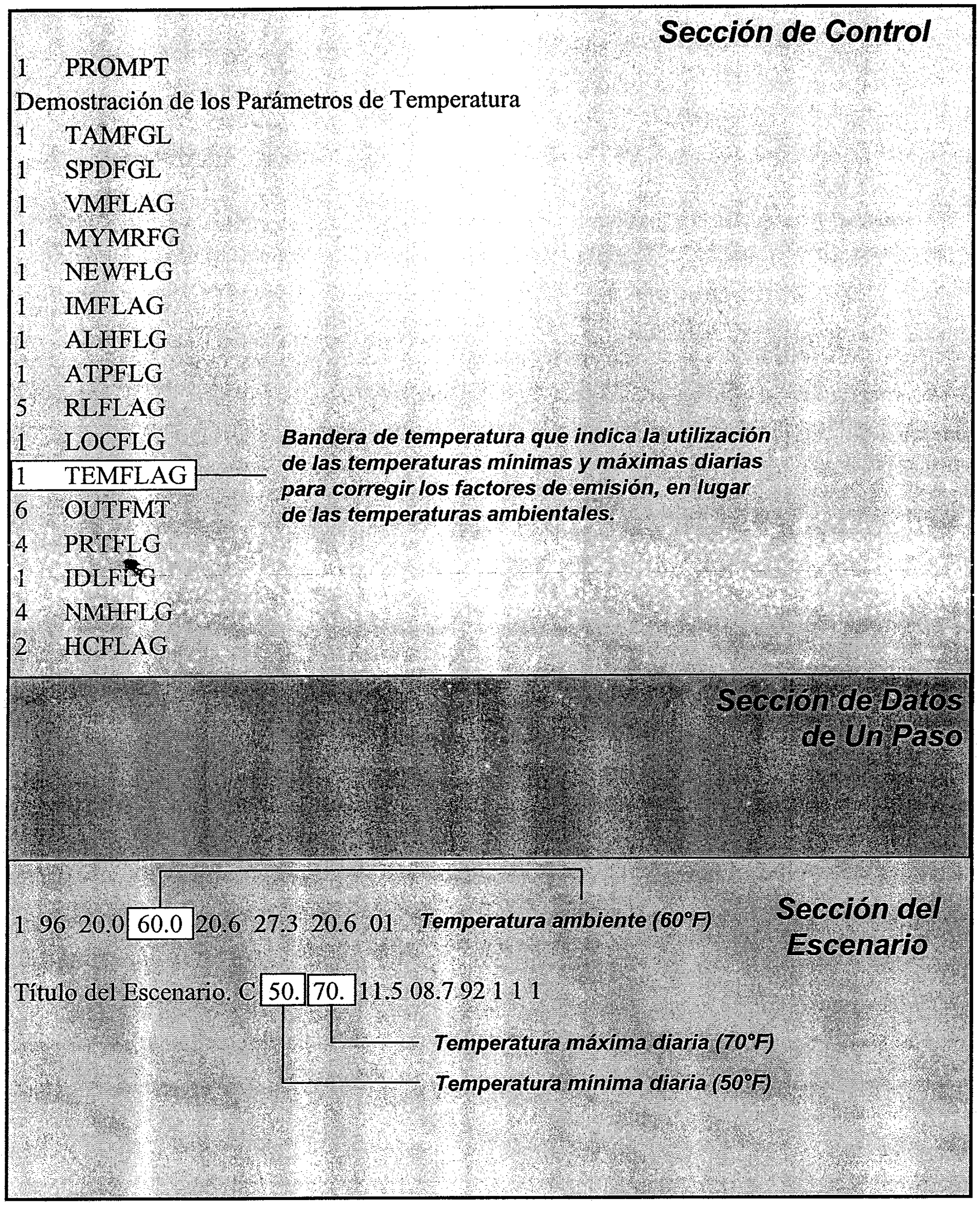
Como se indicó anteriormente, los factores de ajuste son ampliamente utilizados en los modelos de factores de emisión para corregir las condiciones de operación particulares, que son el resultado de diversas características específicas del área. La Sección 3.4.1 hará referencia a las características regionales, mientras que la Sección 3.4.2 discutirá las características del parque vehicular. Estas secciones sólo presentan un panorama general de los efectos de dichas características en las emisiones de los vehículos automotores; los detalles específicos, así como la información relacionada con las características menos importantes, pueden encontrarse en la Guía del Usuario del Modelo MOBILE.

3.4.1 Características Regionales que Afectan a los Factores de Emisión

Algunas de las características regionales que pueden afectar las emisiones de los vehículos automotores incluyen las características físicas (temperatura o altitud), características del combustible, y programas de verificación (programas I/M y anti-alteración PAA). A continuación se presenta una breve descripción de cada una de ellas.

Temperatura

Las emisiones de vehículos automotores (GOT, CO y NO_x) tienen una gran dependencia de la temperatura del aire circundante. La temperatura de operación estándar utilizada en la determinación de las tasas básicas de emisión del MOBILE es de 24°C (75°F); por lo tanto, el modelado de emisiones a cualquier otra temperatura requiere el uso de factores de ajuste para este parámetro. En el modelo MOBILE, estos factores de ajuste son determinados por la bandera de temperatura (TEMFLG) en la sección de Control, el registro de la temperatura diaria mínima y máxima en el parámetro de área local (PAL), y la temperatura ambiente en el registro descriptivo del escenario. Estas entradas de datos se indican en el ejemplo del archivo de entrada de MOBILE que se presenta en la Figura 3-4.



```
1   PROMPT
Demostración de los Parámetros de Temperatura
1   TAMFGL
1   SPDFGL
1   VMFLAG
1   MYMRFG
1   NEWFLG
1   IMFLAG
1   ALHFLG
1   ATPFLG
5   RLFLAG
1   LOCFLG
1   TEMFLAG
6   OUTFMT
4   PRTFLG
1   IDLFLG
4   NMHFLG
2   HCFLAG
```

Bandera de temperatura que indica la utilización de las temperaturas mínimas y máximas diarias para corregir los factores de emisión, en lugar de las temperaturas ambientales.

```
1 96 20.0 60.0 20.6 27.3 20.6 01
Título del Escenario. C 50. 70. 11.5 08.7 92 1 1 1
```

Temperatura ambiente (60°F)

Temperatura máxima diaria (70°F)

Temperatura mínima diaria (50°F)

Figura 3-4. Ejemplo de los Parámetros de Temperatura en MOBILE

Dependiendo del valor elegido para TEMFLG, los factores de ajuste para las emisiones de escape, emisiones evaporativas del motor recién apagado y las emisiones en reposo y en operación serán calculadas utilizando la temperatura mínima y máxima diaria, o la temperatura ambiente. Se recomienda que siempre que sea posible se utilice la opción de la temperatura mínima y máxima diaria. Independientemente del valor de la TEMFLG, el factor de ajuste para las emisiones evaporativas diurnas será calculado con base en la temperatura mínima y máxima diaria. En algunos inventarios, las emisiones estacionales de fuentes móviles son deseables. En estos casos, debe realizarse una corrida del MOBILE para cada estación (primavera, verano, otoño e invierno), utilizando la temperatura mínima y máxima diaria promedio para cada una.

La dependencia de las emisiones de GOT (seleccionada ajustando la bandera NMHFLG a “4”), CO y NO_x de la temperatura, se muestra en la Figura 3-5, donde la temperatura ambiente es variable y todos los demás parámetros del modelo se mantienen constantes. A partir de la Figura 3-5, queda claro que las emisiones de GOT y CO son afectadas en gran medida por las temperaturas ambientales, mientras que las emisiones de NO_x son afectadas en menor grado.

Altitud

Otra característica física que tiene un efecto significativo sobre las emisiones de los vehículos automotores es la altitud de la región. A medida en que la altitud se incrementa, la densidad del aire ambiente disminuye. El resultado de esta disminución en la densidad del aire es que los vehículos afinados para funcionar en una relación aire-combustible estequiométrica, tienden a funcionar en una relación más rica en combustible. Esta desviación de la estequiometría resultará en mayores emisiones de contaminantes. Por otro lado, la altitud también puede afectar la eficiencia mecánica de los vehículos que, a su vez, pueden modificar la cantidad de las emisiones. Los efectos de una altitud elevada deben ser cuidadosamente analizados en regiones tales como la Zona Metropolitana de la Ciudad de México.

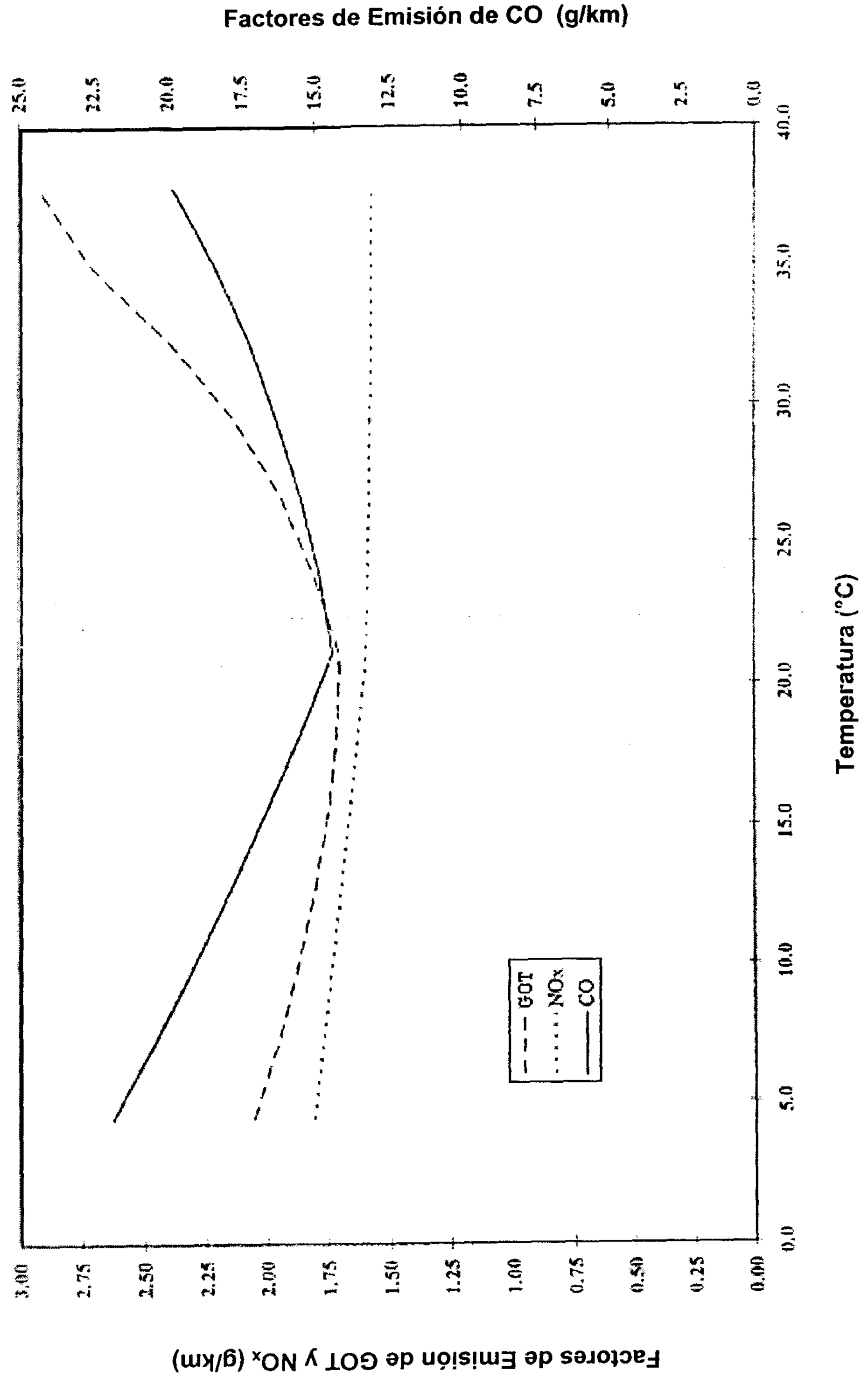
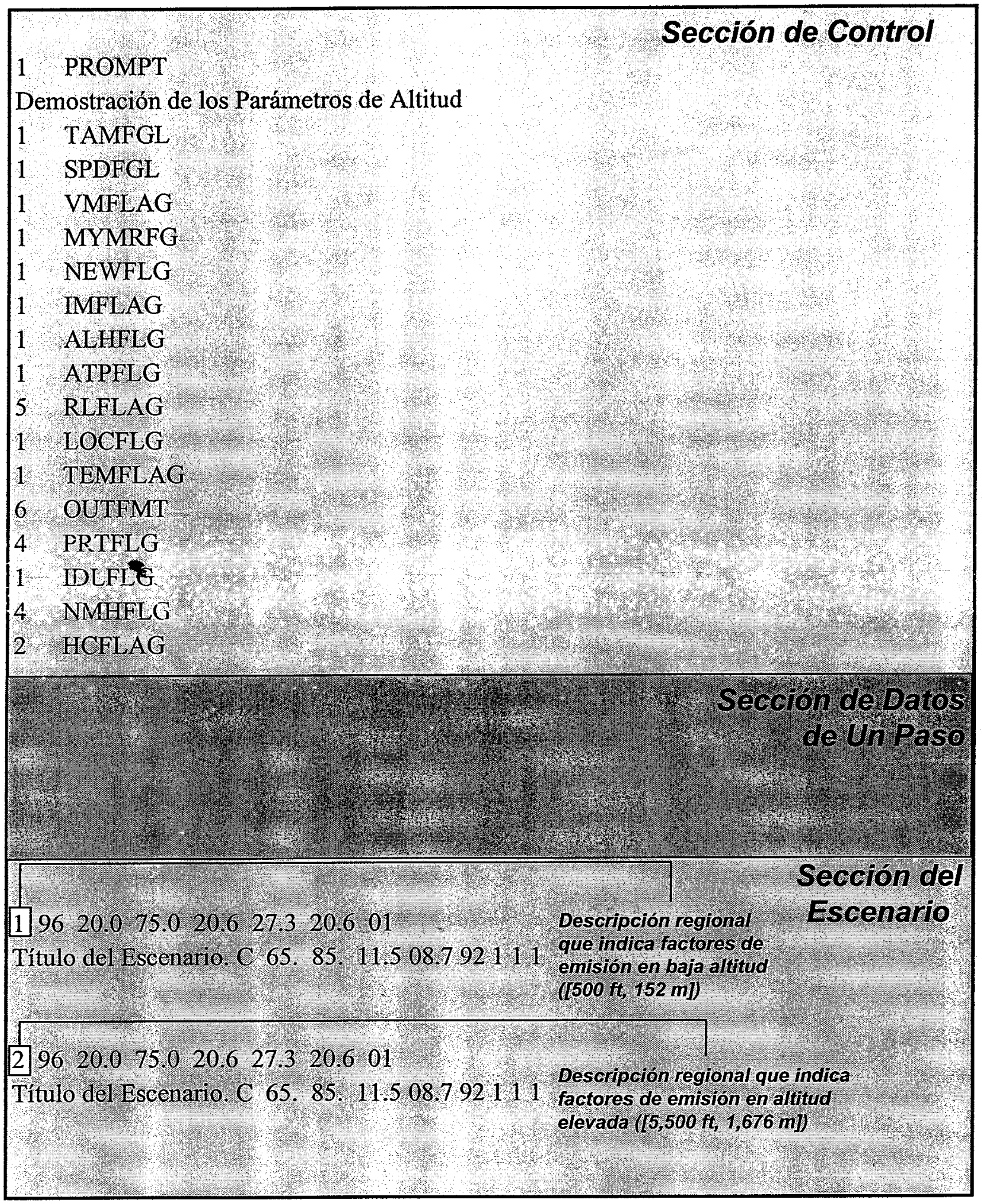


Figura 3-5. Factores de Emisión Promedio del Parque Vehicular para GOTs, NO$_x$ y CO con Temperatura Ambiente Variable

En lugar de usar un factor de ajuste para tomar en cuenta las diferencias de altitud, el modelo MOBILE utiliza un conjunto de TBEs para áreas de baja altitud (representando las condiciones aproximadamente a 150 metros sobre el nivel medio del mar), y otro conjunto de TBEs para áreas de altitud elevada (representando las condiciones aproximadamente a 1,700 metros sobre el nivel medio del mar. El conjunto de TBEs deseado se selecciona en el primer elemento de los datos del registro descriptivo del escenario (“1” para indicar baja altitud, y “2” para alta), como se muestra en la Figura 3-6. La diferencia entre las emisiones en alta y baja altitud pueden observarse en los factores de emisión promedio del parque vehicular para GOT, CO y NO_x graficados en la Figura 3-7, donde los demás parámetros del modelo se mantienen constantes. Los factores de emisión promedio del parque vehicular para GOT y CO en altitudes elevadas son entre 15 y 20% mayores que en altitudes bajas, mientras que los de NO_x disminuyen ligeramente.

Características del Combustible - PVR

Dado que las emisiones de los vehículos automotores son el resultado final de la combustión de la gasolina y el diesel, las características del combustible pueden afectar de manera significativa la cantidad de contaminantes emitidos. La volatilidad del combustible, en particular, afecta directamente la cantidad de las emisiones de un vehículo automotor. Para el modelo MOBILE, así como para otras muchas aplicaciones, la volatilidad del combustible se expresa como presión de vapor de Reid (ó PVR). La PVR estándar para gasolina utilizada en la determinación de las tasas básicas de emisión para el modelo MOBILE es 9.0 libras por pulgada cuadrada (psi); el uso de cualquier otra PVR para gasolina requiere la aplicación de factores de ajuste. Las especificaciones del combustible actual requieren una PVR de combustible de 6.5 a 8.5 en la Zona Metropolitana de la Ciudad de México, y de 6.5 a 9.5 en el resto del país. Se recomienda que las PVR específicas del área sean solicitadas a Petróleos Mexicanos (Pemex). Si esta información no estuviera disponible, entonces debe utilizarse la cifra superior de estos límites de especificación para el combustible como valor de entrada para MOBILE. Debido a que el diesel tiene una volatilidad muy baja que resulta en emisiones evaporativas despreciables, el MOBILE no utiliza un valor PVR para este combustible. Los factores de ajuste para la PVR son determinados por tres entradas de datos en el registro PAL: PVR del Periodo 1 *(Period 1 PVR)*



```
1    PROMPT
Demostración de los Parámetros de Altitud
1    TAMFGL
1    SPDFGL
1    VMFLAG
1    MYMRFG
1    NEWFLG
1    IMFLAG
1    ALHFLG
1    ATPFLG
5    RLFLAG
1    LOCFLG
1    TEMFLAG
6    OUTFMT
4    PRTFLG
1    IDLFLG
4    NMHFLG
2    HCFLAG
```

```
1 96  20.0  75.0  20.6  27.3  20.6  01
Título del Escenario. C  65.  85.  11.5 08.7 92 1 1 1
```

Descripción regional que indica factores de emisión en baja altitud ([500 ft, 152 m])

```
2 96  20.0  75.0  20.6  27.3  20.6  01
Título del Escenario. C  65.  85.  11.5 08.7 92 1 1 1
```

Descripción regional que indica factores de emisión en altitud elevada ([5,500 ft, 1,676 m])

Figura 3-6. Ejemplo de los Parámetros de Altitud en MOBILE

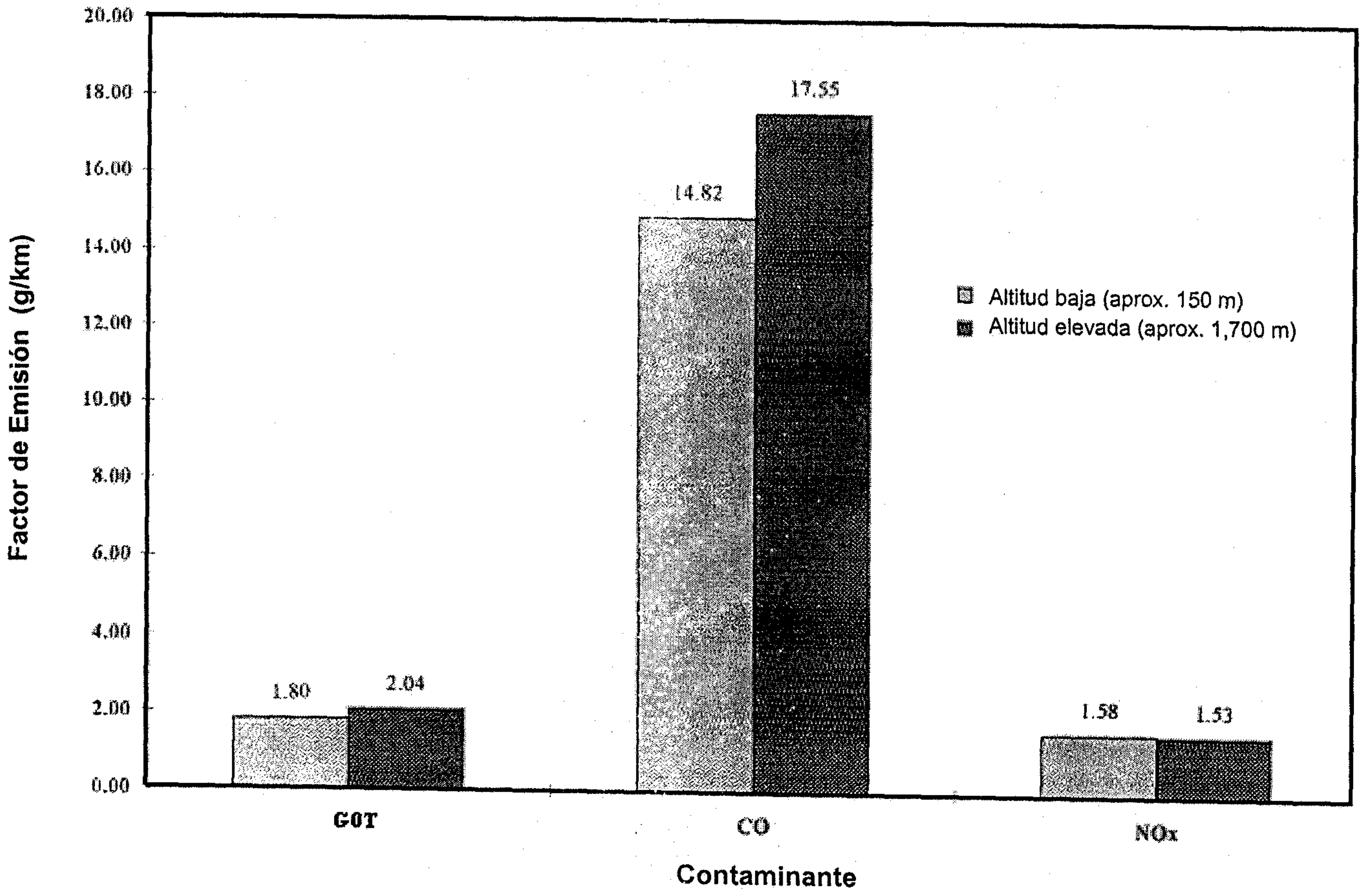


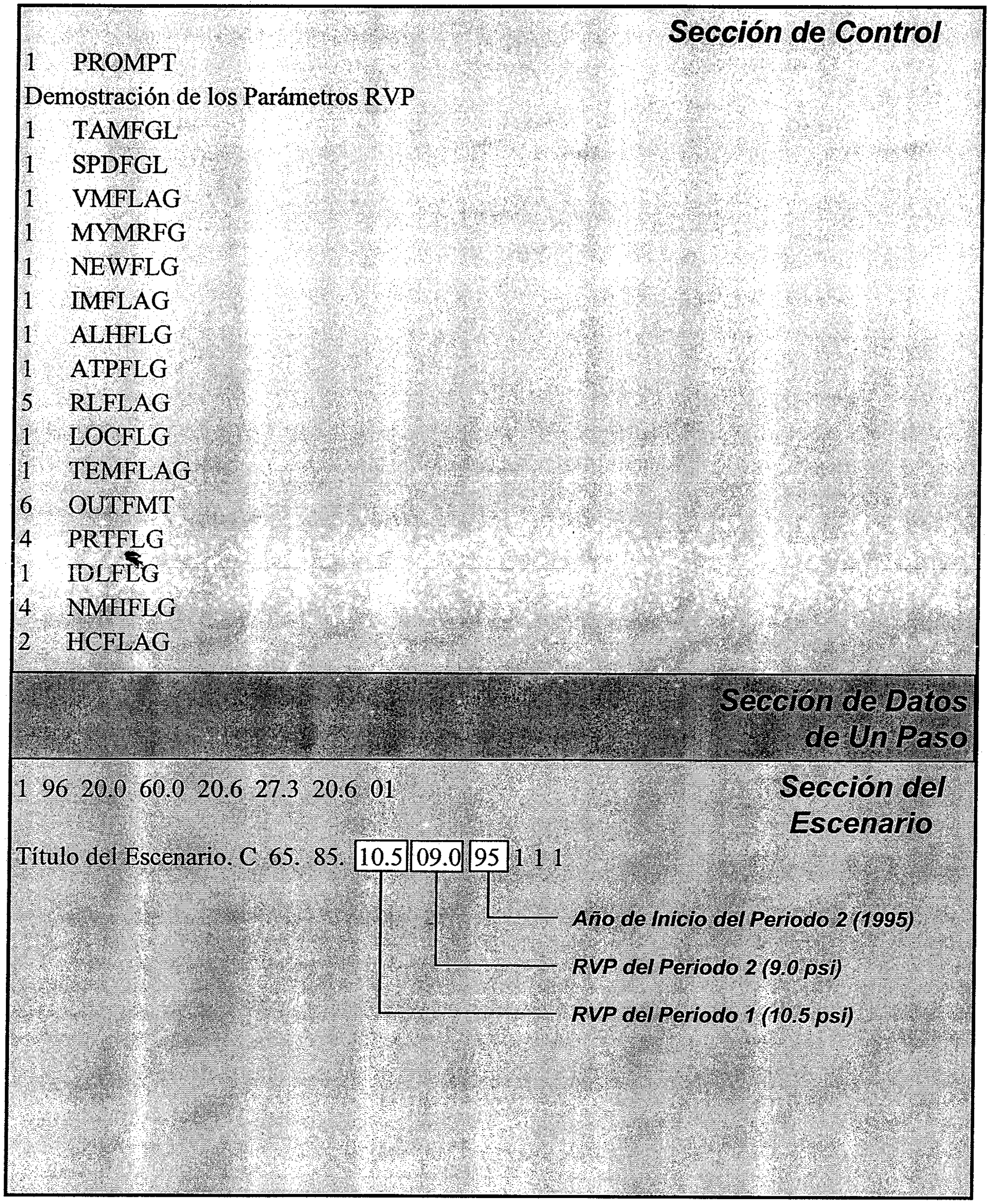
Figura 3-7. Factores de Emisión Promedio del Parque Vehicular para GOTs, NO_x y CO en Altitudes Bajas y Altas

(PVR antes de que un programa de control de la volatilidad entre en vigor); PVR del Periodo 2 *(Period 2 PVR)* (PVR después de que un programa de control de la volatilidad ha entrado en vigor); y año de inicio del Periodo 2 *(Period 2 start year)* (el año en que el programa de control de la volatilidad fue instrumentado). Utilizando estas tres entradas de datos, el MOBILE puede modelar un programa de control de la PVR o cualquier otro cambio relacionado con este parámetro. Si no hay un programa de control de la volatilidad que deba ser modelado, entonces las PVR del Periodo 1 y del Periodo 2 serán iguales. Estas entradas de datos son indicadas en el ejemplo del archivo de entrada de MOBILE que se presenta en la Figura 3-8.

En general, una volatilidad reducida (o valores de PVR bajos) ocasionarán emisiones más bajas. La dependencia de las emisiones con relación a la PVR del combustible se muestra en la Figura 3-9, donde la PVR de la gasolina varía de 8.0 a 13.0 psi y los demás parámetros del modelo se mantienen constantes. En esta Figura, la relación entre la PVR más baja de la gasolina y las menores emisiones de GOT y CO es sumamente evidente.

Características del Combustible – Combustibles Oxigenados

Otra característica del combustible que puede afectar la cantidad de contaminantes emitidos por los vehículos automotores, es la introducción de combustibles oxigenados (ya sea mezclas de gasolina y alcohol, o de gasolina y éter), dentro de la mezcla general de combustibles. Los combustibles oxigenados típicamente son introducidos para reducir las emisiones de CO. El mayor contenido de oxígeno en los combustibles oxigenados mejora la eficiencia de la combustión, reduciendo así las emisiones de CO. El ajuste para los combustibles oxigenados es controlado en el registro PAL por la bandera de combustible oxigenado (OXYFLG), y por un registro descriptivo de los combustibles oxigenados que sigue inmediatamente al registro PAL. Este registro incluye la participación de mercado y el contenido de oxígeno en las mezclas de combustible con alcohol y éter. Estas entradas de datos se indican en el ejemplo del archivo de entrada de MOBILE que se presenta en la Figura 3-10.



```
1    PROMPT
Demostración de los Parámetros RVP
1    TAMFGL
1    SPDFGL
1    VMFLAG
1    MYMRFG
1    NEWFLG
1    IMFLAG
1    ALHFLG
1    ATPFLG
5    RLFLAG
1    LOCFLG
1    TEMFLAG
6    OUTFMT
4    PRTFLG
1    IDLFLG
4    NMHFLG
2    HCFLAG
1 96 20.0 60.0 20.6 27.3 20.6 01
Título del Escenario. C 65. 85. 10.5 09.0 95 1 1 1
```

Año de Inicio del Periodo 2 (1995)

RVP del Periodo 2 (9.0 psi)

RVP del Periodo 1 (10.5 psi)

Figura 3-8. Ejemplo de los Parámetros PVR de la Gasolina en MOBILE

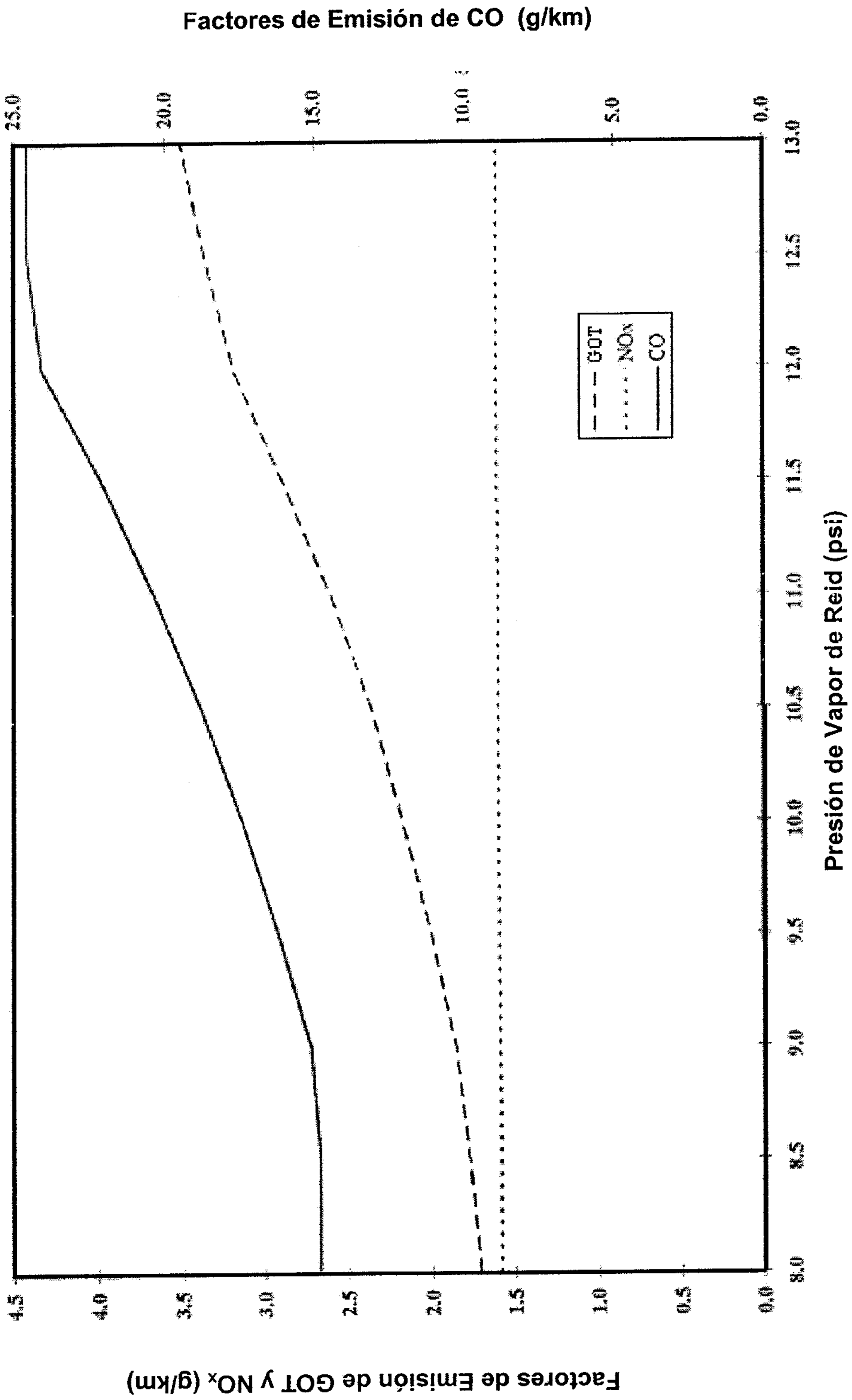
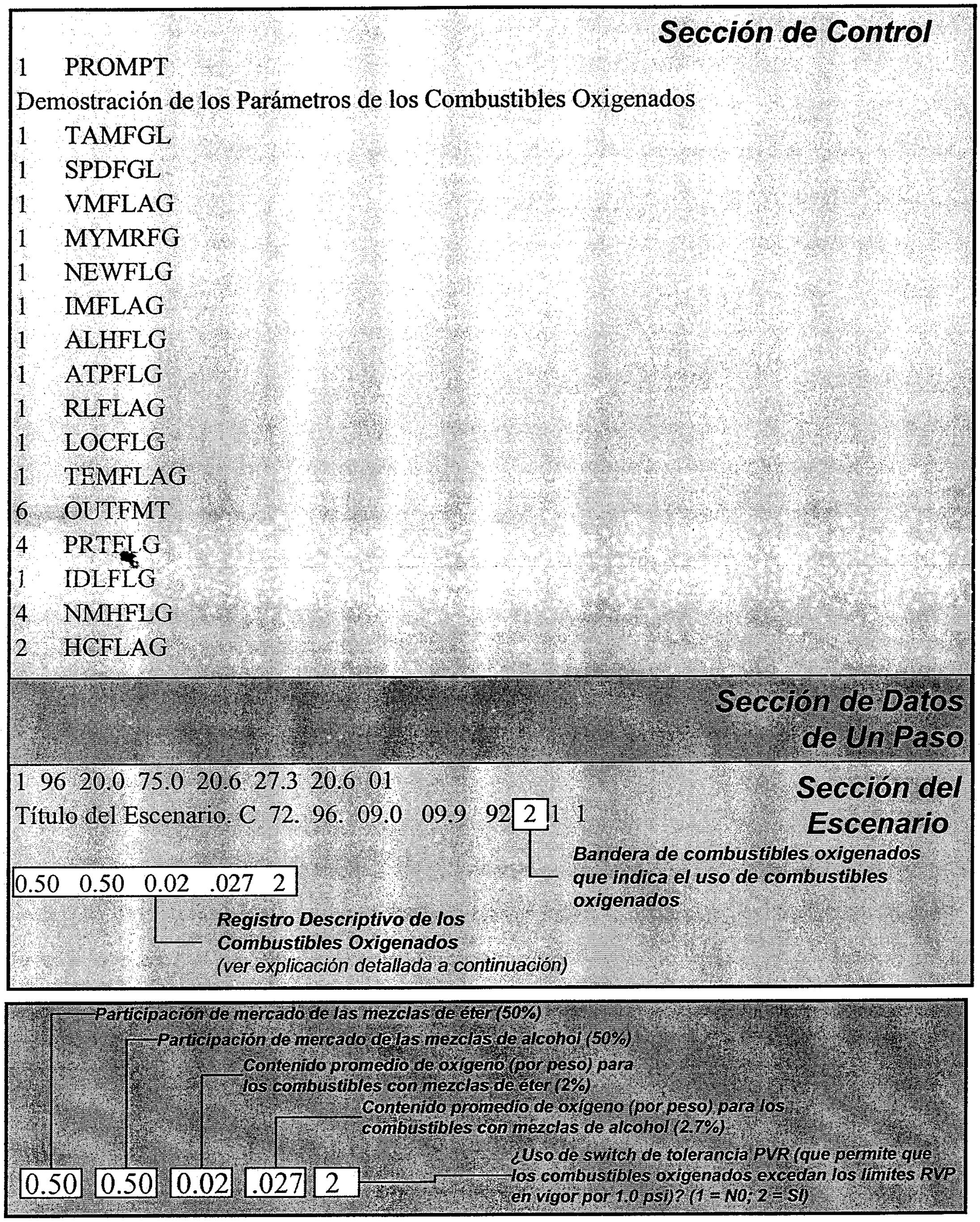


Figura 3-9. Factores de Emisión Promedio del Parque Vehicular para GOT, NO_x y CO con RVPs Variables



Sección de Control

```
1   PROMPT
Demostración de los Parámetros de los Combustibles Oxigenados
1   TAMFGL
1   SPDFGL
1   VMFLAG
1   MYMRFG
1   NEWFLG
1   IMFLAG
1   ALHFLG
1   ATPFLG
1   RLFLAG
1   LOCFLG
1   TEMFLAG
6   OUTFMT
4   PRTFLG
1   IDLFLG
4   NMHFLG
2   HCFLAG
```

Sección de Datos de Un Paso

Sección del Escenario

```
1 96 20.0 75.0 20.6 27.3 20.6 01
Título del Escenario. C 72. 96. 09.0 09.9 92 2 1 1
0.50 0.50 0.02 .027 2
```

Bandera de combustibles oxigenados que indica el uso de combustibles oxigenados

Registro Descriptivo de los Combustibles Oxigenados
(ver explicación detallada a continuación)

`0.50` *Participación de mercado de las mezclas de éter (50%)*

`0.50` *Participación de mercado de las mezclas de alcohol (50%)*

`0.02` *Contenido promedio de oxígeno (por peso) para los combustibles con mezclas de éter (2%)*

`.027` *Contenido promedio de oxígeno (por peso) para los combustibles con mezclas de alcohol (2.7%)*

`2` *¿Uso de switch de tolerancia PVR (que permite que los combustibles oxigenados excedan los límites RVP en vigor por 1.0 psi)? (1 = N0; 2 = SI)*

Figura 3-10. Ejemplo de los Parámetros del Combustible Oxigenado en MOBILE

Los efectos de los combustibles oxigenados puede observarse en la Figura 3-11. Los factores de emisión graficados en esta Figura representan un escenario poco realista (e. g., 50% de todo el combustible utilizado en vehículos automotores es una mezcla de alcohol, mientras que el otro 50% es una mezcla de éter). Un escenario más típico probablemente tendría una cantidad de ventas de combustibles oxigenados más baja, pero en este ejemplo se pueden observar los efectos generales, es decir, reducciones significativas en las emisiones de CO y emisiones de GOT y NO_x virtualmente sin cambios.

Además de las características de los combustibles descritos anteriormente, la gasolina reformulada (GRF) puede ser introducida a México en el futuro, como medida para el control de emisiones. Puesto de manera simple, la GRF es similar a la gasolina convencional, excepto en que algunas de sus características (e. g., PVR, contenido de benceno, de aromáticos y de oxígeno, y puntos de destilación) han sido ajustadas. Dado que las emisiones son afectadas de manera diferente por los cambios en cada una de estas características del combustible, la estimación de las emisiones de la GRF no es una tarea sencilla. El MOBILE5a tiene una bandera GRF; sin embargo, su metodología de estimación es demasiado simplista y no puede reflejar con precisión todos los efectos de la GRF. La información existente sobre la bandera GRF puede encontrarse en la Guía del Usuario del MOBILE5a. Se espera que la versión MOBILE6 (que será emitida a mediados de 1998) permita una representación más completa de los efectos de la GRF. Si México planea implementar la GRF como estrategia para el control de emisiones en el futuro, entonces será necesario llevar a cabo un análisis más detallado de los modelos MOBILE, así como otras investigaciones.

En México, los datos de las propiedades de los combustibles son manejados por Pemex. Las entidades gubernamentales pueden solicitar esta información a:

Subdirección de producción
Torre Ejecutiva, Piso 13
Marina Nacional No. 329
Col. Huasteca
Teléfono: 5722 2500 exts. 22691 y 22521
Fax: 5722 2500 ext. 23135

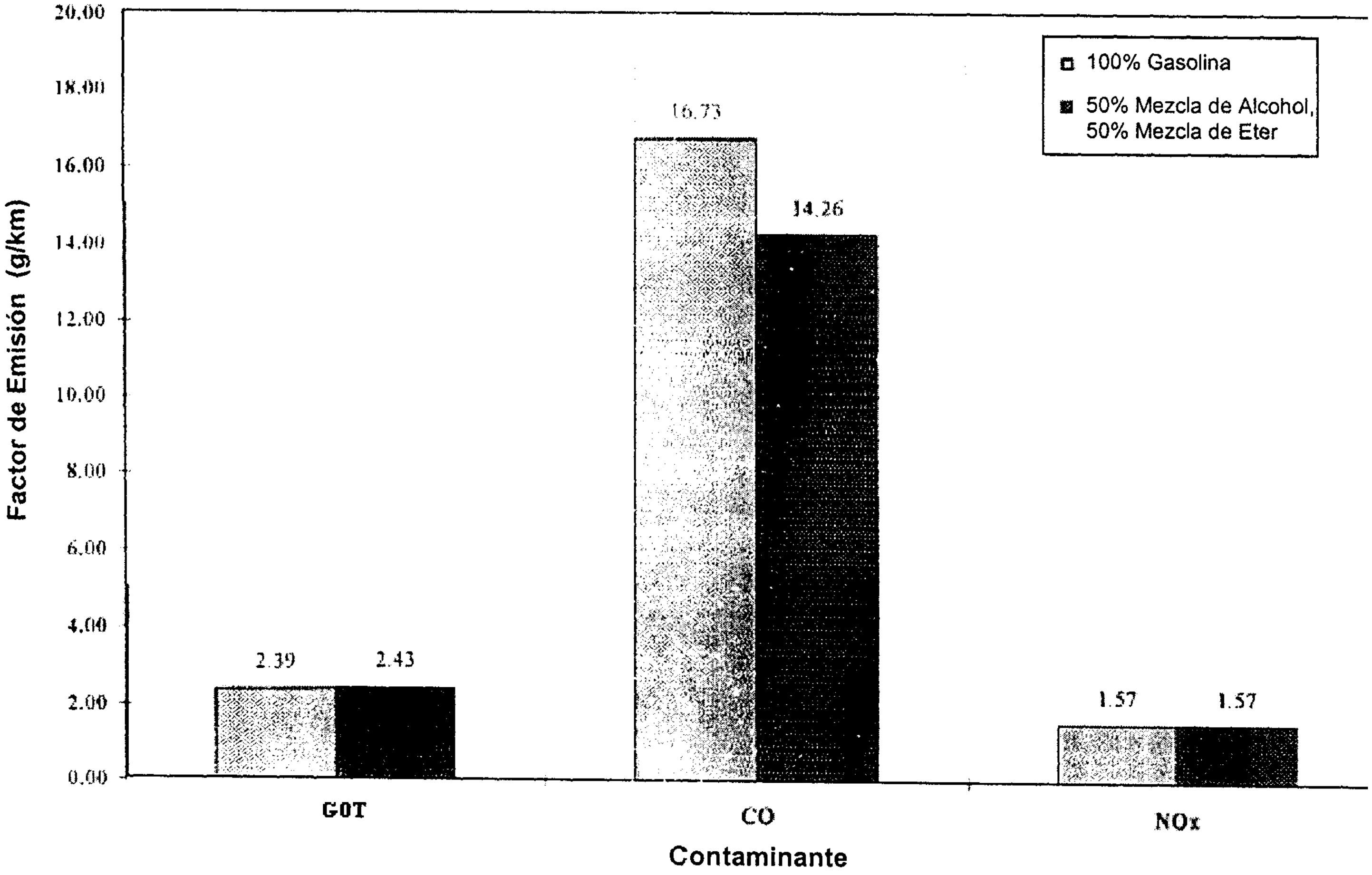


Figura 3-11. Factores de Emisión Promedio del Parque Vehicular para GOT, NO_x y CO con y sin Combustibles Oxigenados

Programas de Inspección y Mantenimiento (I/M)

Con el objetivo de reducir las emisiones de los vehículos automotores, con frecuencia se instrumentan programas de verificación regionales, de los cuales el más común es el programa de inspección y mantenimiento (I/M). A medida en que el kilometraje (millaje) de un vehículo aumenta, las emisiones evaporativas y del escape también aumentan, debido a la degradación continua del sistema de control de emisiones del vehículo. El propósito de los programas I/M consiste en minimizar este exceso de emisiones aplicando pruebas en intervalos de tiempo regulares. En algunas ocasiones, esta prueba de emisiones es aplicada como un requerimiento para el registro y licenciamiento de los vehículos; aquellas unidades cuyas emisiones excedan los estándares establecidos son obligados a ser reparados. Como se explica en la Sección 3.2, los datos TBE no incluyen los efectos de los programas I/M, por lo tanto, los factores de ajuste, basados en los parámetros de entrada relacionados con los I/M, son usados para ajustar los datos TBE.

Debido a que los requerimientos específicos de los programas I/M pueden ser distintos de una región a otra, existen muchas variaciones posibles. La bandera I/M (IMFLAG), ubicada en la sección de Control, permite la modelación de los efectos de cero, uno o dos programas I/M. Si bien los programas I/M individuales representan la situación más común, en algunas ocasiones es necesario modelar dos programas I/M de manera simultánea (e. g., uno convencional para algunos modelos y años anteriores, y uno “mejorado” para modelos y años posteriores). Cada programa I/M que deba ser modelado requiere un registro descriptivo que se ubica en la sección Datos de Un Paso, y requiere la definición de los siguientes parámetros:

- Año de inicio del programa I/M
- Nivel de exigencia, o porcentaje de los vehículos que reprueban el primer año
- Primer y último modelo y año sujetos al programa I/M
- Tasas de tolerancia *(waiver rates)*, o porcentaje de vehículos a los que se les otorga una exención de reparaciones

- Tasa de cumplimiento, o porcentaje del parque vehicular sujeto a la participación en el programa

- Tipo de programa (sólo inspección, inspección y reparación [manual], o inspección y reparación [computarizada])

- Frecuencia de la inspección (anual o bienal)

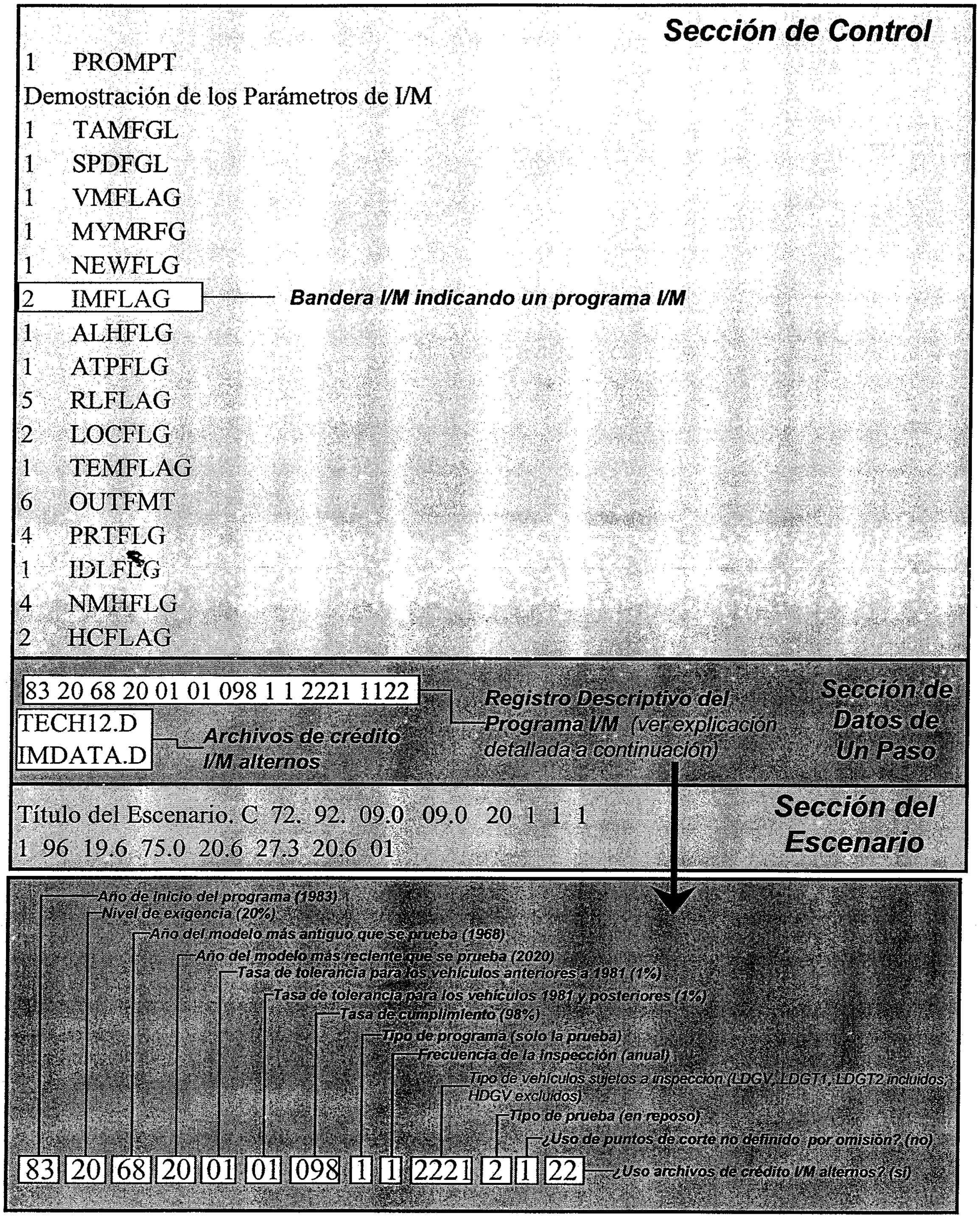
- Tipos de vehículos a gasolina sujetos al programa I/M

- Tipo de prueba (reposo, 2500/idle *(2500 rpm/reposo),* cargado/reposo ó transitorio *(transient)*)

- Uso de puntos de corte de emisión no definidos por omisión *(non-default emission cutpoints).*

Todos estos datos de entrada se indican en el ejemplo del archivo de entrada de MOBILE que se presenta en la Figura 3-12.

Los efectos de los programas I/M se muestran en la Figura 3-13. Los factores de emisión promedio del parque vehicular graficados representan tres escenarios I/M típicos: sin programa I/M, con un programa I/M y con dos programas I/M. Los parámetros para cada uno de estos escenarios **NO** representan los programas I/M más estrictos posibles, sino programas I/M típicos. Obviamente, los programas I/M reales utilizarán parámetros diferentes que alterarán en cierta medida los factores de emisión estimados, pero la tendencia hacia la reducción de las emisiones generales de los programas I/M puede observarse en este ejemplo. Por otro lado, el ejemplo también demuestra que algunos de los beneficios derivados de los programas I/M se observan solamente con el transcurso del tiempo. Actualmente, se han instrumentado programas I/M en las ciudades de México, Monterrey y Ciudad Juárez.



```
1     PROMPT
Demostración de los Parámetros de I/M
1     TAMFGL
1     SPDFGL
1     VMFLAG
1     MYMRFG
1     NEWFLG
2     IMFLAG
1     ALHFLG
1     ATPFLG
5     RLFLAG
2     LOCFLG
1     TEMFLAG
6     OUTFMT
4     PRTFLG
1     IDLFLG
4     NMHFLG
2     HCFLAG
83 20 68 20 01 01 098 1 1 2221 1122
TECH12.D
IMDATA.D
Título del Escenario. C  72.  92.  09.0  09.0  20  1  1  1
1  96  19.6  75.0  20.6  27.3  20.6  01
```

Figura 3-12. Ejemplo de los Parámetros I/M en MOBILE

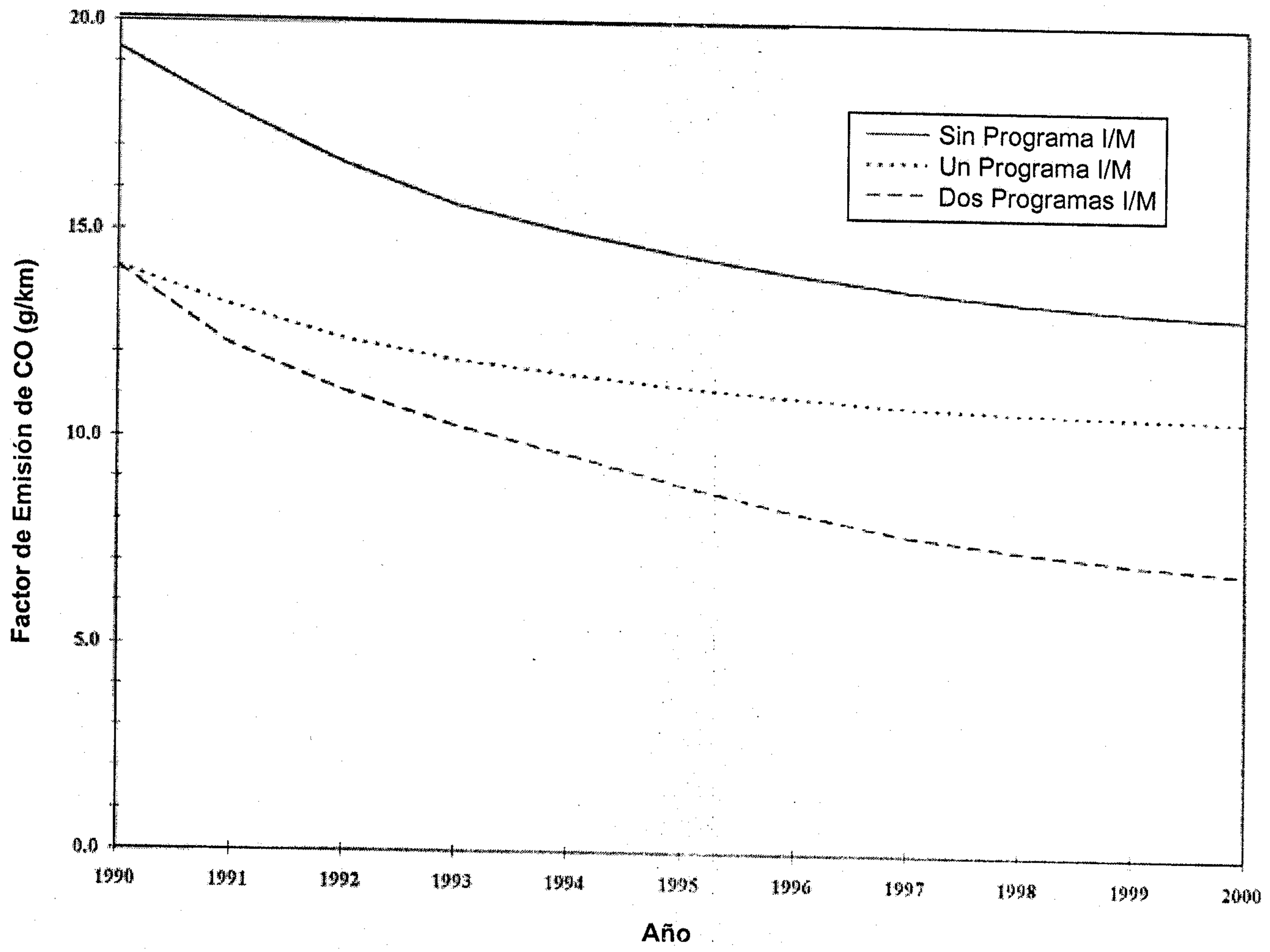


Figura 3-13. **Factores de Emisión de CO para Vehículos Ligeros a Gasolina en Tres Escenarios de I/M**

Programas Anti-Alteraciones

Otro tipo de estrategia regulatoria que puede ser instrumentada es el programa anti-alteraciones (PAA). La alteración se refiere a la alimentación del vehículo con el combustible inapropiado, la eliminación o desconexión de los convertidores catalíticos, o la reducción, por algún otro medio, de la eficiencia del sistema de control de emisiones del vehículo. Las razones para la alteración son diversas, pero su efecto general es la anulación de algunas de las reducciones en las emisiones logradas a través de los programas I/M u otros avances tecnológicos. La alteración puede ser intencional o no. Como su nombre lo sugiere, los PAAs son instrumentados para compensar los efectos de la alteración, y consisten en inspecciones a los diversos componentes del vehículo que son utilizados para el control de emisiones, entre los que se incluyen: los convertidores catalíticos, el limitador de entrada de combustible, y el tapón de gasolina, entre otros. Para facilitar su administración, las inspecciones PAA normalmente se realizan de manera simultánea con las pruebas I/M periódicas.

La necesidad de un PAA depende del nivel real de alteración dentro de una región específica. Para cuantificar los niveles reales de alteración, es necesario realizar un estudio. Si se encuentra que dichos niveles son bajos, entonces un PAA podría no ser la estrategia normativa adecuada para reducir las emisiones de los vehículos automotores. Sin embargo, si se determina que los niveles de alteración son altos, la instrumentación de un PAA podría permitir reducciones significativas en las emisiones. Por ejemplo, algunos estudios previos indican que más del 80% de los vehículos mexicanos con catalizadores en Ciudad Juárez han sido alimentados inadecuadamente con combustibles con plomo, "envenenando" el catalizador y eliminando virtualmente cualesquier reducciones posibles en las emisiones.

Actualmente, el modelo MOBILE incorpora los niveles de alteración generales por omisión para los vehículos estadounidenses. Si los resultados del estudio de alteración indican niveles significativamente diferentes en México, entonces las tasas de alteración alternativas pueden ser insertadas en el modelo MOBILE ajustando la bandera de alteración

(TAMFLG) ubicada en la sección de Control. Por ejemplo, se llevó a cabo un estudio de la tasa de alteración de los vehículos de Ciudad Juárez para el desarrollo del modelo MOBILE-Juárez. Los detalles adicionales con respecto al formato para estas tasas de alteración alternativas pueden encontrarse en la Guía del Usuario del MOBILE (U.S EPA, 1994).

Si los niveles regionales de alteración ameritan la instrumentación de un PAA, los efectos de éste pueden ser modelados con MOBILE. Existen diversos PAAs, muy similares a los programas I/M, que pueden ser instrumentados. En consecuencia, son numerosos los parámetros que deben ser especificados para definir un PAA particular. La bandera PAA (ATPFLG), ubicada en la sección de Control, permite que la modelación de los efectos de un PAA sean modelados. Además de los PAAs, hay ciertos valores de la ATPFLG que permiten el modelado de las purgas y las revisiones de presión del sistema de control de emisiones evaporativas. Estas pruebas no se describen en este documento, sin embargo, puede encontrarse información adicional en la Guía del Usuario del MOBILE. Cada PAA que deba ser modelado necesita un registro descriptivo, localizado en la sección Datos de Un Paso y que incluye los siguientes parámetros:

- Año de inicio del PAA
- Primero y último modelo y año sujeto al PAA
- Tipos de vehículos a gasolina sujetos al PAA
- Tipo de programa (sólo de inspección, o de inspección y reparación)
- Frecuencia de la inspección (anual o bienal)
- Tasa de cumplimiento
- Ocho tipos de inspecciones PAA (sistemas de la bomba de aire, convertidor catalítico, limitador de entrada de combustible, detección de plomo en el mofle, sistema de recirculación del gas del escape [RGE], sistema de control evaporativo, ventilación positiva del cárter [VPC] y tapón de gasolina).

Todas estas entradas de datos se indican en el ejemplo del archivo de entrada de MOBILE que se presenta en la Figura 3-14.

La Figura 3-15 muestra los efectos de un PAA. Los factores de emisión promedio del parque vehicular graficados en esta Figura, representan un programa I/M típico con y sin PAA. El PAA utilizado en la Figura 3-15 presupone que se realizan las ocho inspecciones de equipo antes enlistadas. Obviamente, los PAAs caracterizados por parámetros diferentes tendrán diferentes resultados y reducciones de las emisiones. Sin embargo, la reducción diferencial de emisiones debidas a un PAA adicionado a un programa I/M puede observarse en este ejemplo.

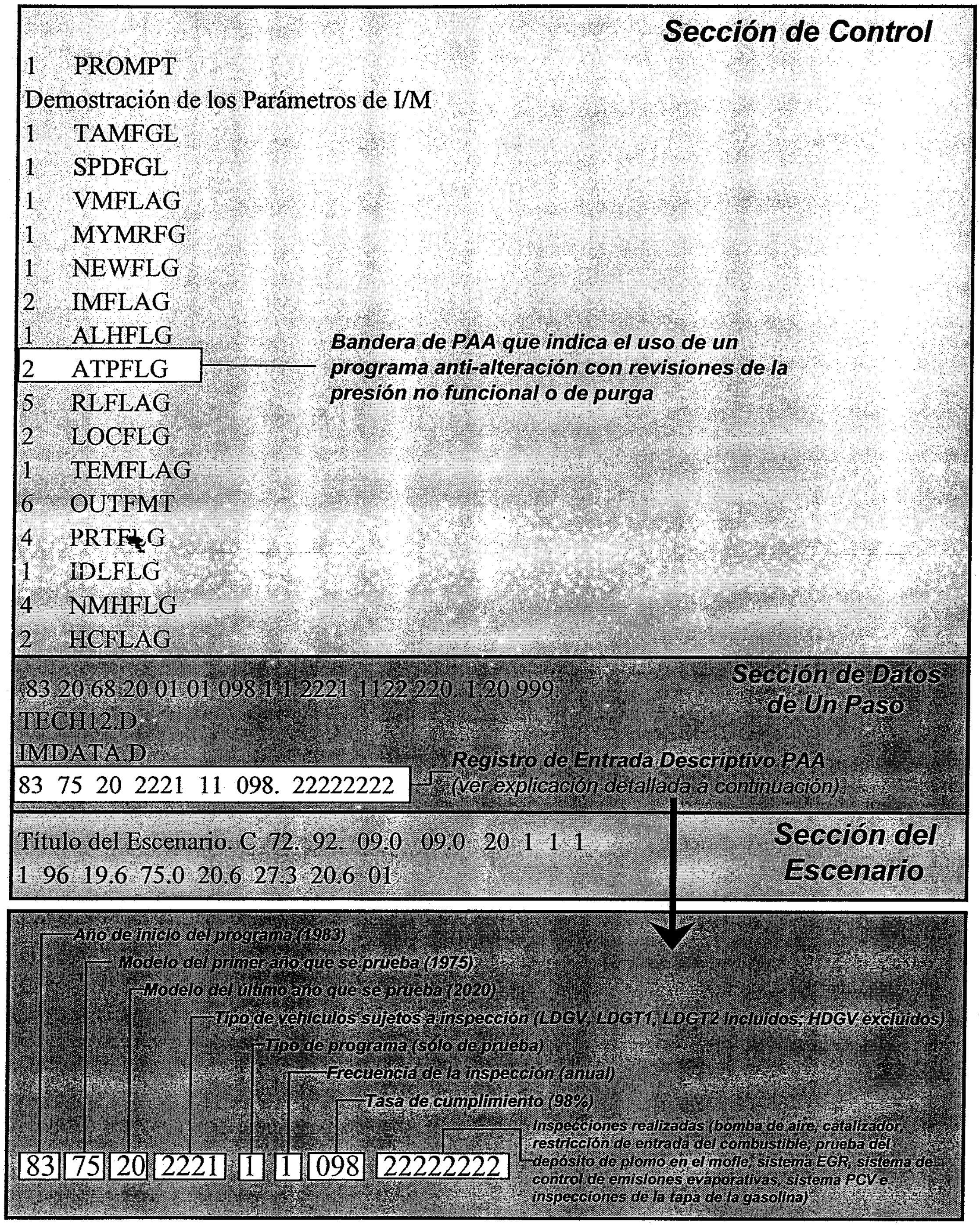
3.4.2 Características del Parque Vehicular

Para utilizar un modelo de factor de emisión, es necesario estimar las características del recorrido de cada tipo de vehículo, entre las que destacan:

- **Velocidad del vehículo:** Debe determinarse la velocidad promedio del vehículo por clase vehicular (y de preferencia por tipo de camino), debido a que este parámetro afecta los factores de emisión.

- **Distribuciones KRV por clase vehicular (o combinaciones)**: los datos KRV generales deben ser segregados por clase vehicular para asignar los factores de emisión adecuados.

- **Tasas de acumulación de kilometraje (millaje) y distribución del registro (fracción del total de vehículos registrados) para cada modelo y año) en una clase vehicular**: Estas se utilizan para determinar la fracción del recorrido de cada modelo y año dentro de una clase vehicular.



```
1    PROMPT
Demostración de los Parámetros de I/M
1    TAMFGL
1    SPDFGL
1    VMFLAG
1    MYMRFG
1    NEWFLG
2    IMFLAG
1    ALHFLG
2    ATPFLG
5    RLFLAG
2    LOCFLG
1    TEMFLAG
6    OUTFMT
4    PRTFLG
1    IDLFLG
4    NMHFLG
2    HCFLAG
83 20 68 20 01 01 098 1 1 2221 1122 220. 1 20 999.
TECH12.D
IMDATA.D
83  75  20  2221  11  098.  22222222
Título del Escenario. C  72.  92.  09.0   09.0   20  1  1  1
1  96  19.6  75.0  20.6  27.3  20.6  01
```

```
83  75  20  2221  1  1  098  22222222
```

Figura 3-14. Ejemplo de los Parámetros PAA en MOBILE

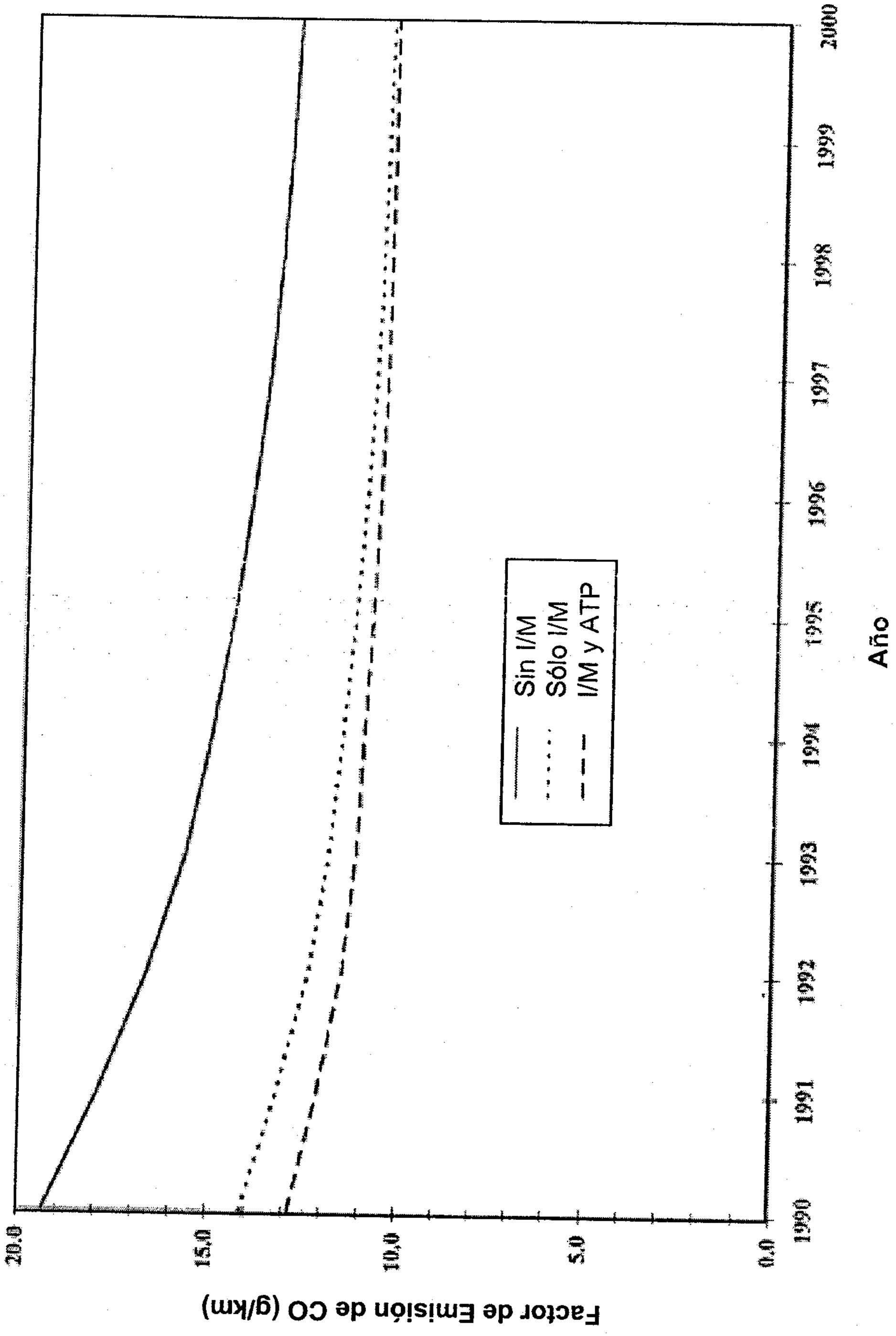


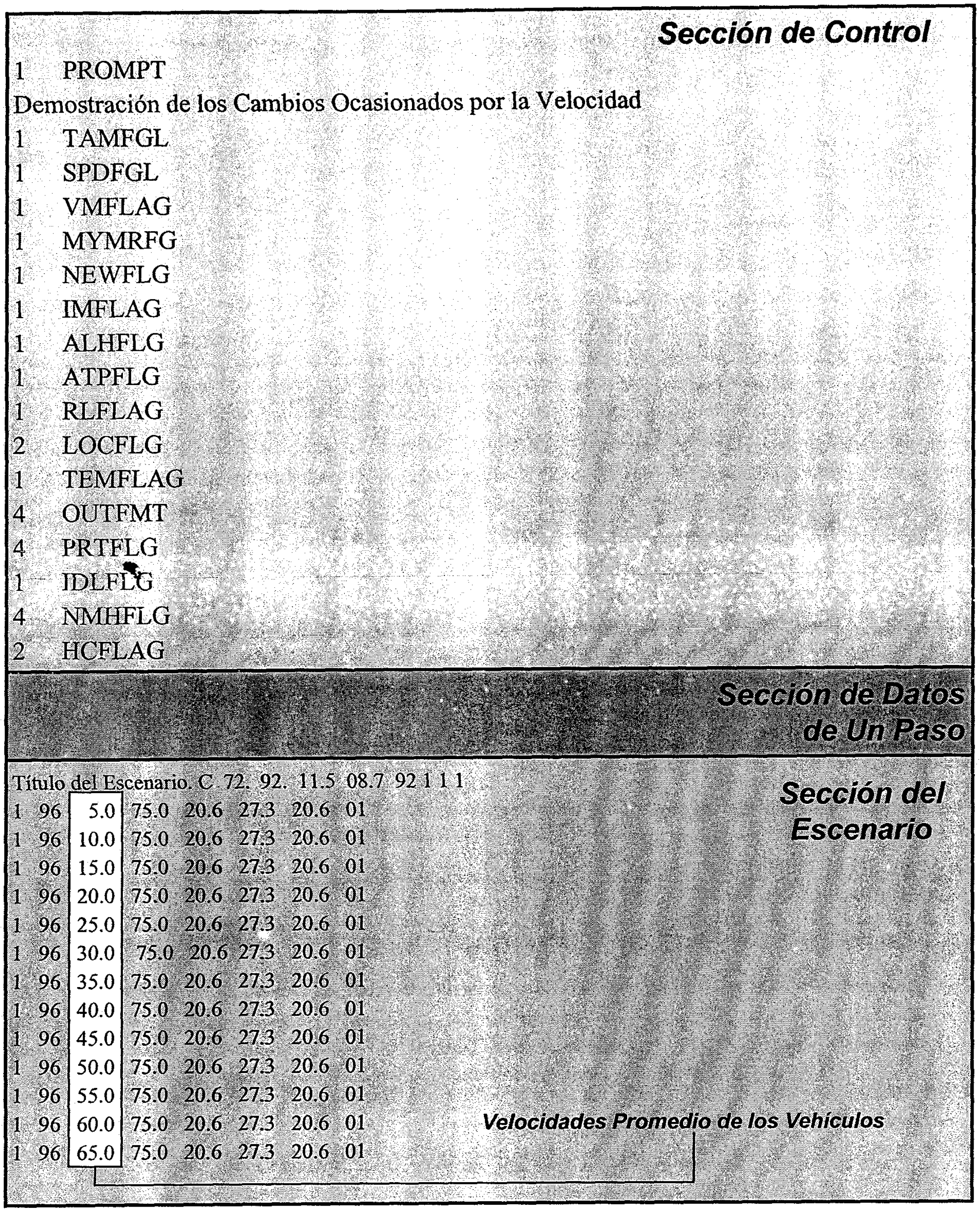
Figura 3-15. Factores de Emisión de CO para Vehículos Ligeros a Gasolina en Tres Escenarios ATP

Velocidad del Vehículo

Las estimaciones de la velocidad promedio del vehículo son un elemento importante de los datos para determinar los factores de emisión apropiados para los inventarios de emisiones de vehículos automotores que circulan por carreteras. En el modelo MOBILE, los factores de emisión representan el recorrido a una velocidad promedio. Los factores de emisión son desarrollados a partir de ciclos de prueba en los que la velocidad del vehículo no es constante, sino que varía alrededor de un promedio. En consecuencia, la meta al desarrollar estimaciones de la velocidad consiste en determinar velocidades promedio del vehículo, en lugar de velocidades instantáneas. Como se mencionó en la Sección 3.2, un factor de ajuste de velocidad se aplica a los factores de emisión para tomar en cuenta la variabilidad de las emisiones a diferentes velocidades. Las velocidades promedio son capturadas en el registro descriptivo del escenario del archivo de entrada de MOBILE. Estas velocidades promedio se indican en el ejemplo del archivo de entrada presentado en la Figura 3-16. La Figura 3-17 contiene un ejemplo de los factores de emisión con respecto a la velocidad promedio del vehículo. Nótese que la tasa de emisión cambia significativamente con las variaciones en la velocidad, en particular a bajas y altas velocidades. En consecuencia, es importante conocer las velocidades de los vehículos para la generación de inventarios de emisiones precisos.

La estimación de las velocidades vehiculares promedio puede ser una parte desafiante del esfuerzo de recopilación de los datos del inventario, debido a que son muchos los factores que pueden afectar las velocidades en una carretera en un momento determinado. Entre los factores clave se incluyen:

- **Características del tipo de camino**: Las velocidades varían significativamente con el tipo de camino. Por ejemplo, las autopistas y vías rápidas tienen velocidades promedio superiores a los bulevares y arterias, que a su vez tienen velocidades promedio mayores que los caminos locales. Las condiciones del camino también tendrán un impacto: los caminos pavimentados registrarán velocidades más altas que los no pavimentados.



```
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Demostración de los Cambios Ocasionados por la Velocidad
1   TAMFGL
1   SPDFGL
1   VMFLAG
1   MYMRFG
1   NEWFLG
1   IMFLAG
1   ALHFLG
1   ATPFLG
1   RLFLAG
2   LOCFLG
1   TEMFLAG
4   OUTFMT
4   PRTFLG
1   IDLFLG
4   NMHFLG
2   HCFLAG
```

```
Título del Escenario. C  72.  92.  11.5  08.7  92 1 1 1
1  96   5.0  75.0  20.6  27.3  20.6  01
1  96  10.0  75.0  20.6  27.3  20.6  01
1  96  15.0  75.0  20.6  27.3  20.6  01
1  96  20.0  75.0  20.6  27.3  20.6  01
1  96  25.0  75.0  20.6  27.3  20.6  01
1  96  30.0  75.0  20.6  27.3  20.6  01
1  96  35.0  75.0  20.6  27.3  20.6  01
1  96  40.0  75.0  20.6  27.3  20.6  01
1  96  45.0  75.0  20.6  27.3  20.6  01
1  96  50.0  75.0  20.6  27.3  20.6  01
1  96  55.0  75.0  20.6  27.3  20.6  01
1  96  60.0  75.0  20.6  27.3  20.6  01
1  96  65.0  75.0  20.6  27.3  20.6  01
```

Figura 3-16. Ejemplo de las Velocidades Promedio en MOBILE

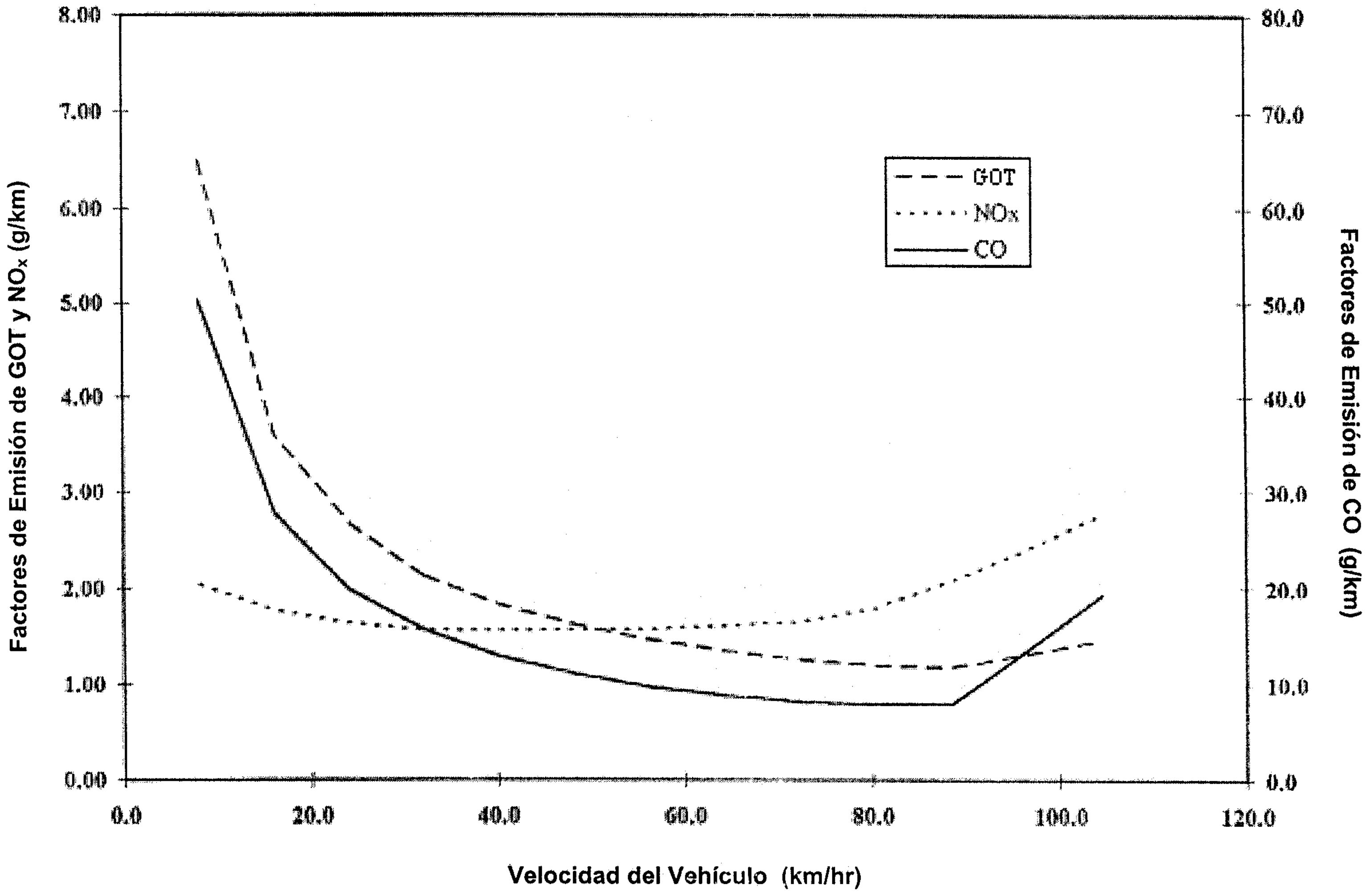

Figura 3-17. Factores de Emisión Promedio del Parque Vehicular para GOT, NO_x y CO con Velocidades Vehiculares Variables

- **Ubicación del camino**: El área que rodea al camino afecta las velocidades promedio. Por ejemplo, las vías rápidas urbanas generalmente tienen velocidades promedio más bajas que las rurales, debido a los mayores niveles de congestionamiento del tráfico. En general, para dos caminos del mismo tipo, las velocidades en los caminos urbanos son más bajas que para los rurales.

- **Hora del día y estación**: En las áreas urbanas, las variaciones en el congestionamiento del tráfico afectará de manera significativa las velocidades promedio en un camino. Cada camino tiene una velocidad de flujo libre que se alcanza cuando el congestionamiento es bajo. A medida en que el congestionamiento aumenta, las velocidades promedio se reducen. En algunas áreas en las que el clima altera las condiciones del camino y las velocidades promedio, pueden presentarse variaciones estacionales.

- **Tipo de vehículo**: Las velocidades promedio con frecuencia son diferentes entre los distintos tipos de vehículo. Por ejemplo, los autos de pasajeros y los camiones ligeros a menudo tienen velocidades más altas que los camiones pesados y los autobuses. Esto es particularmente cierto en los medios urbanos que representan un tráfico que se detiene y avanza.

Existe una gran variedad de opciones disponibles para desarrollar estimaciones de velocidad. Muchas de estas técnicas también son útiles para recopilar información sobre el recorrido de los vehículos. Por lo tanto, si se va a realizar un esfuerzo para determinar las características del recorrido vehicular en una región, los datos de velocidad pueden ser obtenidos como parte del mismo estudio. Información más detallada sobre los estudios de recopilación de datos de velocidad está disponible en el *Institute of Transportation Engineers* (Instituto de Ingenieros del Transporte) (ITE, 1994).

Cuando las estimaciones de velocidad con este nivel de detalle no son requeridas o no están disponibles, la meta es dividir los KRV en los grupos de velocidad promedio adecuados. Un tipo de agrupamiento común consiste en clasificar los KRV por tipo de camino (vía rápida, arterias, caminos colectores y caminos locales), y tipo de área (urbana o rural), si existen datos suficientes. Esta clasificación asigna la misma velocidad a todos los tipos de vehículos y todas las horas del día. Otras clasificaciones podrían ser más recomendables dependiendo del nivel de los datos disponibles. Por ejemplo, los datos de velocidad pueden ser recopilados como parte de un estudio vehicular instrumentado (que se describe a continuación). En este caso, se conocería el tiempo que vehículos individuales han transitado a velocidades específicas. Este tipo de estudio no definiría las velocidades en caminos específicos, sin embargo, el espectro de velocidades podría ser dividido en grupos, y podría calcularse el tiempo transcurrido dentro de cada grupo.

Para los inventarios regionales iniciales, cuando los datos detallados de la velocidad no están disponibles todavía, los límites de velocidad máxima señalados en los caminos podrían utilizarse como primera aproximación. Estos, sin embargo, pueden no representar la velocidad vehicular promedio en condiciones de flujo libre, en la que los vehículos con frecuencia exceden estos límites. Por el contrario, las áreas con un fuerte congestionamiento vehicular, con señalamientos u otros controles de tráfico en las intersecciones, pueden tener velocidades promedio significativamente menores que los límites de velocidad máxima establecidos. Estas estimaciones iniciales pueden ser complementadas con estudios de velocidad realizados en una muestra de los caminos en la región del inventario. Dichos estudios utilizan una gran variedad de técnicas de medición, entre las que se incluyen:

- **Contadores neumáticos de tráfico**: Son tubos neumáticos colocados a través de los carriles, que están conectados a registradores que detectan una estampa de tiempo del paso de los vehículos. Este equipo se utiliza comúnmente para recopilar datos del flujo del tráfico como parte de los estudios de administración del tráfico. Diversos contadores también pueden ser utilizados para medir las velocidades de los vehículos; sin embargo, este método sólo mide la velocidad instantánea en un punto definido, no las velocidades promedio a lo largo de una carretera.

- **Estudios con radar de pistola**: De manera similar al método de los contadores neumáticos, el radar es utilizado para medir la velocidad instantánea del vehículo, y puede ser operado en modo manual o automático.

- **Estudios con observador o con video**: Dos observadores o cámaras de video se colocan en diferentes puntos a una distancia conocida entre ellos. Se hace una selección aleatoria de vehículos y se registra el tiempo que tardan en pasar entre ambos puntos. La distancia entre los puntos se divide entre la diferencia de las marcas de tiempo para estimar la velocidad promedio.

- **Estudios de autos flotantes**: Un carro observador selecciona aleatoriamente algunos vehículos y sigue a uno de ellos durante un periodo de tiempo establecido para calcular su velocidad. En un método similar diseñado para medir la mediana de la velocidad, el auto observador puede viajar a una velocidad definida registrando tanto la fracción de vehículos que él rebasa, como la que le rebasan.

- **Estudios con autos adaptados con instrumentos**: Se hace una selección aleatoria de vehículos del parque vehicular. Estos vehículos son equipados con registradores de velocidad automatizados, que registran la velocidad del vehículo en intervalos regulares (i. e., una vez por segundo). Los vehículos son entregados a sus propietarios, y el equipo de registro se recupera después de un periodo de operación, por ejemplo, una semana. Los registradores son retirados y se descargan los datos de velocidad capturados. El programa puede incluir bitácoras que deberán ser llenadas por los propietarios del vehículo, donde registrarán su actividad de manejo durante el periodo del estudio. Este método no aporta información sobre las velocidades en localidades específicas, pero puede ser utilizado para estimar las distribuciones de la velocidad en una región.

Combinaciones de KRV

La combinación de KRV describe la distribución de los KRVs del parque vehicular total para cada clase vehicular. Cuando se estiman las emisiones de los vehículos automotores, primero deben determinarse los KRVs totales en una región o en un camino individual. Posteriormente, la combinación es utilizada para disgregar los KRVs totales en diferentes clases vehiculares para ayudar en el cálculo de las emisiones. La combinación KRV puede ser estimada si se conocen las poblaciones vehiculares y las tasas de acumulación de kilometraje (millaje) para cada clase vehicular. Ambos parámetros son necesarios debido a que las diferentes clases vehiculares tienden a ser manejadas a diferentes tasas. Por ejemplo, los camiones comerciales pesados generalmente tienen tasas de acumulación de kilometraje (millaje) superiores a los vehículos de pasajeros. La publicación *Techniques for Estimating MOBILE2 Variables* (Técnicas para Estimar las Variables del MOBILE2) (EEA, 1980) describe los métodos generales para calcular la combinación de KRV.

Si las poblaciones vehiculares y las tasas de acumulación de kilometraje (millaje) no están disponibles, la siguiente opción consiste en estimar la combinación de KRV a partir de estudios locales en los que se colocan observadores en diversos puntos de la región de inventario, quienes clasifican una muestra aleatoria de unidades que pasan por dichos puntos con base en su clase vehicular. De manera alternativa, es posible tomar fotografías de los vehículos y/o registrar sus placas para una clasificación posterior con el objetivo de identificar el tipo de combustible (gasolina vs. diesel). Esta técnica permite hacer una estimación de la combinación de KRV dado que el número de vehículos de una clase que pasa por un punto debe ser proporcional a la contribución de dicha clase en el KRV general. Este método de recopilación de datos fue utilizado para estimar la combinación de KRV para el inventario de Ciudad Juárez de 1993 (TTI, 1994).

Las clases vehiculares del modelo MOBILE coinciden con las clasificaciones de los estándares de emisión vehicular estadounidenses. Afortunadamente, los estándares de emisiones vehiculares en México también están definidos a partir de una clasificación similar a la estadounidense, lo que simplifica el uso de las clases vehiculares existentes en el MOBILE. La Figura 3-18 presenta una comparación de las clasificaciones de los nuevos estándares de emisiones vehiculares de México y las clases vehiculares del modelo MOBILE. México ha establecido nuevos estándares de emisión para seis clases de vehículos, que cubren autos de pasajeros, camiones ligeros, camiones pesados y autobuses. Estas clases se relacionan con cinco clases vehiculares del MOBILE. En el parque vehicular mexicano también existen otros vehículos para los que no se han definido nuevos estándares de emisión, entre los que se incluyen autos y camiones ligeros a diesel, y motocicletas a gasolina. Además de estos nuevos estándares de emisión vehicular, México también ha establecido estándares de emisión “en uso”, que se describen en la Sección 1.2. La Figura 3-19 muestra un ejemplo de las distribución de la actividad KRV entre las ocho clases del MOBILE de los inventario de vehículos

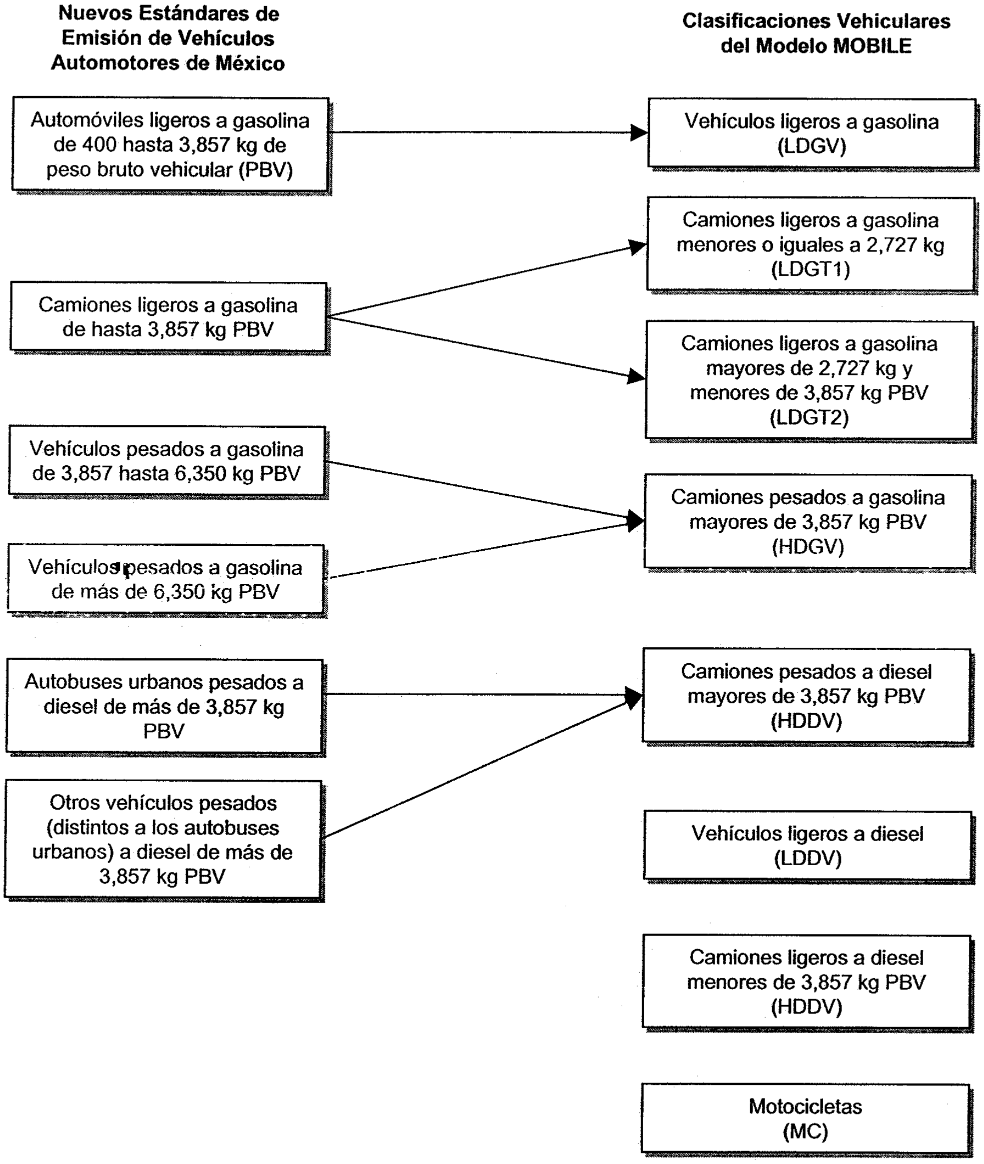

Figura 3-18. Correspondencia de los Nuevos Estándares de Emisión de México con las Clases Vehiculares del Modelo MOBILE

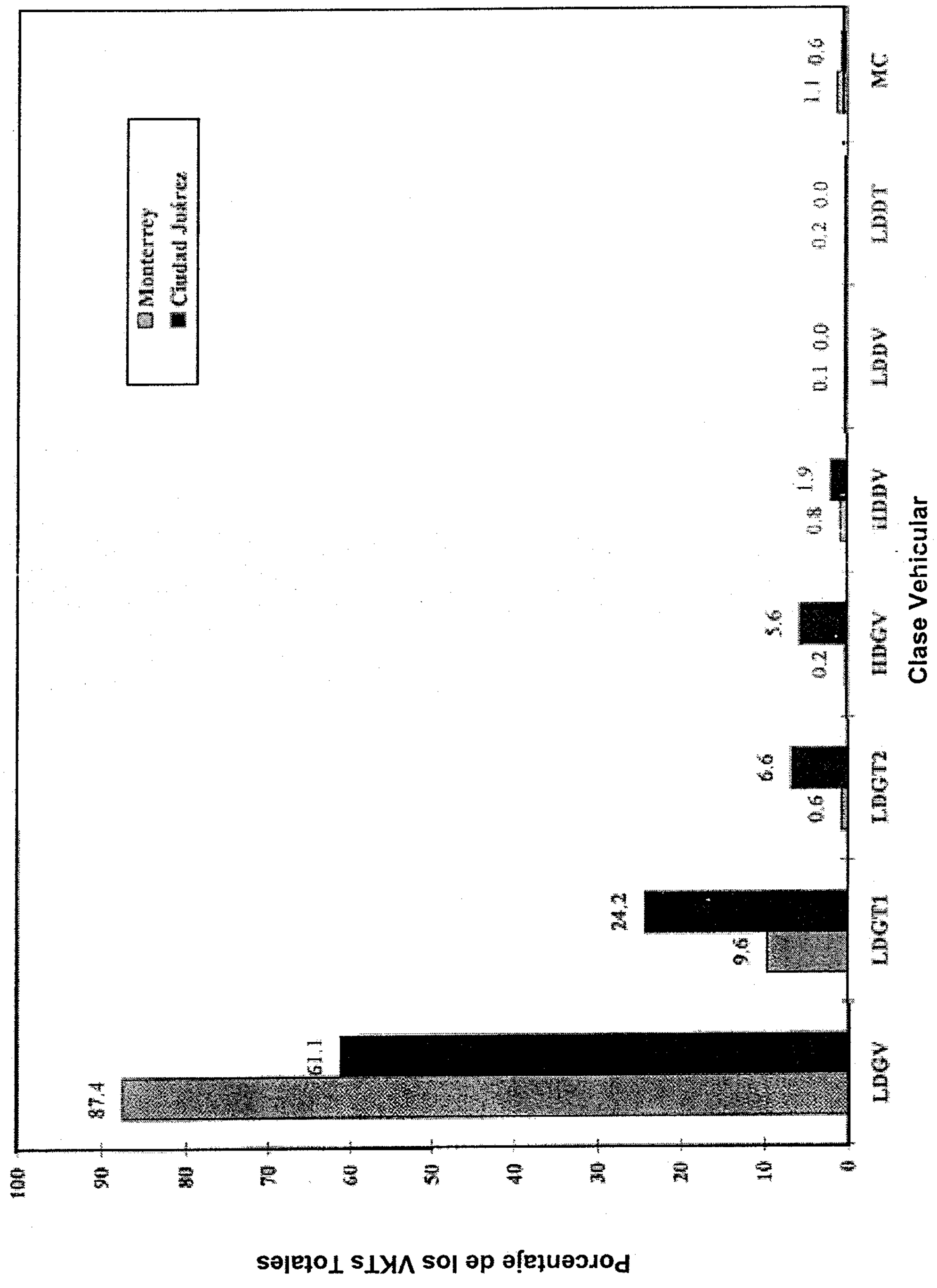

Figura 3-19. Distribuciones de los KRVs en Monterrey y Ciudad Juárez

automotores en Monterrey y Ciudad Juárez. Si bien la distribución de la actividad entre las clases vehiculares varía, en la mayoría de las regiones está dominada por los vehículos y camiones ligeros. Los autos y camiones ligeros a diesel y motocicletas a gasolina están presentes en el parque vehicular pero, como se muestra en la Figura 3-19, en conjunto constituyen menos del 2% de la actividad KRV del parque vehicular total.

Distribuciones del Registro

Las distribuciones del registro permiten conocer la fracción de vehículos de un modelo y año particular con relación a la población general de clases vehiculares. Existe cierto grado de incertidumbre debido a que la población vehicular está compuesta tanto por vehículos registrados como por no registrados, mientras que cualquier distribución del registro, por definición, sólo incluirá a los vehículos registrados. La distribución del registro y las tasas de acumulación de kilometraje (millaje) son utilizadas en conjunto para calcular la fracción del recorrido en el modelo MOBILE. Esta fracción del recorrido es la porción de KRV acumulados por un modelo y año de vehículos en una clase vehicular, con respecto a los KRV totales para la clase vehicular completa. Este cálculo se realiza utilizando la siguiente ecuación:

(3-5)

$$FR_i = \frac{Frt_i \text{ x } TAM_i}{\sum_{i=1}^{25}(Frt_i \text{ x } TAM_i)}$$

donde:

FR_i = Fracción recorrida para el modelo y año i, dentro de una clase vehicular

Frt_i = Fracción de los registros totales de la clase vehicular para el modelo y año, i

TAM_i = Tasa de acumulación de kilometraje (millaje) para los vehículos en el modelo y año, i

En México, los datos del registro vehicular en general son recopilados por los estados o municipios individualmente. De manera detallada, estos datos deben proporcionar el modelo y año de cada vehículo que, entonces, puede ser utilizado para estimar las distribuciones del registro. Sin embargo, en algunas áreas los datos del registro vehicular pueden estar limitados a la población vehicular total y, posiblemente, al número de vehículos de cada clase vehicular. En tales casos, sería necesario realizar estudios para estimar las distribuciones del registro y las tasas de acumulación de kilometraje (millaje). Como alternativa podría usarse la información generada en otras regiones similares de México (sujeto a un incremento en la incertidumbre). Por ejemplo, una parte de la información utilizada para el desarrollo del MOBILE-Juárez (Radian, 1996a), será aplicada para estimar las emisiones de vehículos automotores en un inventario de emisiones en Nogales, Sonora.

En algunas áreas de México, los vehículos no registrados y/o registrados en EU representan una proporción significativa de la población vehicular. En Ciudad Juárez, por ejemplo, 23% de los vehículos observados durante los estudios vehiculares no estaban registrados, y 15% estaba registrado en EU (TTI, 1994). En este caso, las distribuciones del registro calculadas a partir de los registros oficiales estarán sub-estimadas. Un estudio directo de las poblaciones vehiculares sería más adecuado para mejorar la estimación de la distribución del registro.

Tasas de Acumulación de Kilometraje (Millaje)

La tasa de acumulación de kilometraje (millaje) es la cantidad anual de KRVs acumulados por los vehículos de un modelo, año y una clase vehicular. Esta parámetro es uno de los más difíciles de determinar, dado que no puede ser estimado a partir de las observaciones del tráfico. El documento de la U.S. EPA *Techniques for Estimating MOBILE2 Variables* (Técnicas para Estimar las Variables del MOBILE2) (EEA, 1980), discute los métodos para obtener las estimaciones de la tasa de acumulación de kilometraje (millaje). Sin embargo, los métodos descritos en este documento dependen del uso de las fuentes de información específicas para EU que podrían no ser aplicables en México. Existen tres opciones para estimar las tasas de acumulación de kilometraje (millaje):

- **Encuestas de recorrido aplicadas a los propietarios de los vehículos**: Estos pueden ser cuestionarios y entrevistas a domicilio a los propietarios de los vehículos, para conocer sus tasas de acumulación de kilometraje (millaje) anuales. En encuestas de recorrido más detalladas, se solicita que una muestra de conductores llene una bitácora con todos los recorridos realizados durante un periodo determinado de tiempo. A partir de estos resultados, las tasas anuales de acumulación de kilometraje (millaje) pueden ser estimadas.

- **Uso de los datos de la inspección vehicular**: Si la región tiene un programa I/M o de inspección de seguridad vehicular vigente en el que se registren las lecturas del odómetro del vehículo, las tasas de acumulación de kilometraje (millaje) pueden ser calculadas a partir de estos datos. Este cálculo se basa en la diferencia en las lecturas del odómetro para los vehículos individuales, que fueron registradas en múltiples inspecciones. Una tasa menos precisa podría estimarse a partir de una sola lectura al odómetro y la edad del vehículo, si se supone una tasa de acumulación de kilometraje (millaje) constante a lo largo de la vida del vehículo.

- **Uso de las tasas de acumulación de kilometraje (millaje) de otras regiones**: No deben utilizarse las tasas de acumulación de kilometraje (millaje) estadounidenses. En caso de que los datos específicos no puedan ser obtenidos, es posible utilizar las tasas de acumulación de kilometraje (millaje) de otras regiones similares en México. Las estimaciones de emisiones resultante, sin embargo, tendrán una incertidumbre adicional debido a que es probable que los patrones de manejo varíen de una región a otra.

4.0 DESARROLLO DE LOS DATOS DE ACTIVIDAD

Como se describió en la Sección 2.0, las estimaciones de los kilómetros recorridos por vehículo (KRV) se combinan con los factores de emisión para obtener las estimaciones de emisión. En México existen dos métodos para realizar las estimaciones de KRV:

- Estimaciones de KRVs directas basadas en el tráfico
- Estadísticas del consumo de combustible.

Existen diferencias evidentes en la calidad de las estimaciones de los KRVs realizadas a través de estos dos métodos. La elección de los datos de actividad que serán utilizados estará determinada principalmente por los tipos de datos disponibles y por la calidad de éstos. En general, las estimaciones de KRVs directas basadas en el tráfico tienden a hacer una mejor representación de la actividad vehicular, que las estimaciones hechas a partir de las estadísticas de consumo de combustible.

En las principales áreas urbanas, con frecuencia está disponible cierto tipo de estimaciones de KRV basadas en el tráfico. Fuera de estas áreas urbanas, sin embargo, es poco probable que tales estimaciones existan, lo que conduce al uso de los datos de consumo de combustible. Incluso si las estimaciones de KRVs directas basadas en el tráfico están disponibles, las estimaciones de KRVs derivadas de las estadísticas de consumo de combustible pueden ser utilizadas como una efectiva herramienta de aseguramiento de calidad. Las estimaciones KRV basadas en el tráfico se discuten en la Sección 4.1, mientras que aquellas derivadas de las estadísticas de consumo de combustible se presentan en la Sección 4.2.

4.1 Estimaciones de KRV Basadas en el Tráfico

Existen dos tipos principales de estimación de KRVs basadas en el tráfico: las estimaciones detalladas para caminos específicos obtenidos a partir de los modelos de demanda de recorrido (MDRs), y las estimaciones de KRVs regionales desarrolladas a partir de los programas de medición del tráfico u otros medios.

4.1.1 Estimaciones de los KRV a Partir de los Modelos de Demanda de Recorrido

Los modelos de demanda de recorrido (MDRs) son representaciones de la red de caminos en un área urbana modeladas en computadora. Actualmente, los MDRs son utilizados solamente en las grandes áreas urbanas (i. e., la Zona Metropolitana de la Ciudad de México y de Monterrey). Los MDRs son usados para modelar los flujos de tráfico a fin de mejorarlos, y en los estudios de administración de congestionamientos. En los MDRs, la región a ser modelada se divide en zonas con características demográficas similares. Los caminos o grupos de caminos se representan en el modelo como una red de enlaces conectados que constituyen los medios para rastrear el flujo de tráfico entre zonas. Para modelar la conducta del recorrido, se asigna a las zonas adecuadas el número, origen y destino de los recorridos vehiculares. El recorrido en los enlaces es entonces calculado para generar los tiempos de recorrido estimados más cortos entre las zonas. Los resultados de los MDRs hacen una estimación del tiempo de recorrido y de los flujos de tráfico en los enlaces individuales. Los MDRs no son creados de manera explícita para ser utilizados como herramientas en un inventario de emisiones, pero si son extensos y están actualizados, sus resultados son una fuente información de recorridos vehiculares detallados y estimaciones de la velocidad que pueden ser utilizados en los inventarios de emisiones. Para una descripción del proceso de desarrollo de los MDRs y su uso en los inventarios de emisiones, ver el documento *Procedures for Emission Inventory Preparation*, *Volume IV: Mobile Sources*, (Procedimientos para la Preparación de un Inventario de Emisiones) Sección 3.4.2 (U.S. EPA, 1992). Existen diversos textos que discuten el proceso de un MDR en detalle, incluyendo el *Urban Travel Demand Modeling* (Modelado de la Demanda de Recorrido Urbana) (Oppenheim, 1995).

La generación de los datos necesarios para soportar un MDR requiere una cantidad considerable de recursos y tiempo. En consecuencia, éstos son desarrollados solamente para las principales áreas urbanas en las que los estudios para el mejoramiento del tráfico son requeridos con frecuencia para mantener la infraestructura del transporte. Como se mencionó anteriormente, hoy en día sólo las grandes áreas urbanas en México operan MDRs. Las pequeñas áreas urbanas deben depender de otras fuentes para la estimación de los KRV.

A partir de las estimaciones de la distancia y el volumen de los enlaces MDR, los KRVs en un enlace individual pueden ser estimados a partir de la ecuación:

$$KRV = \frac{\text{Volumen}}{\text{Distancia}} \qquad (4\text{-}1)$$

donde:

KRV = Kilómetros recorridos por vehículo en un periodo de tiempo dado
Volumen = Número de vehículos en un enlace para un periodo de tiempo dado
Distancia = Distancia del enlace, en kilómetros

Las estimaciones regionales de KRVs pueden desarrollarse sumando los KRVs de todos los enlaces de un tipo determinado en un área definida.

Los datos obtenidos a partir de los MDRs deben ser analizados para determinar la manera en que serán aplicados al inventario de emisiones que se está desarrollando. Dos aspectos clave para los inventarios de emisiones son el alcance de la cobertura de la red general de caminos, y qué tan representativos son los datos para el año de inventario. Con frecuencia, los MDRs son desarrollados para modelar solamente los mayores recorridos de la red, y no incluyen los recorridos en los caminos y calles locales más pequeños. Es importante determinar los límites de la cobertura del MDR. En los casos en que la cobertura no es completa, deben desarrollarse estimaciones independientes para los caminos locales.

El proceso MDR depende de los datos del estudio de la conducta de los recorridos locales. Estos resultados son importantes porque ayudan a estimar la cantidad y ubicación de la actividad generadora de recorridos. Por lo tanto, las entradas del MDR deben estar basadas en los datos del estudio que hayan sido tomados lo más próximos posible al año de inventario. De manera ideal, el estudio debe ser conducido en un máximo de cinco años con respecto al año de inventario, porque los resultados con mayor antigüedad van a introducir una incertidumbre adicional.

4.1.2 Estimación de KRV Regionales

Es probable que muchas áreas urbanas hayan desarrollado estimaciones de KRVs regionales como parte del proceso de planeación del transporte. Si bien no son tan espacialmente detalladas como las estimaciones de KRVs hechas a partir de MDRs, éstas pueden igualar o exceder la precisión de las estimaciones MDR a nivel regional, si se basan en un número suficiente de mediciones reales.

Las estimaciones de KRVs regionales normalmente se basan en mediciones directas de los volúmenes vehiculares que pasan por un punto individual de un camino. Los KRVs del camino son entonces estimados a partir de los volúmenes vehiculares y la longitud de camino. De manera ideal, las mediciones directas de los volúmenes de tráfico deberían ser hechas en una gran muestra de caminos en el área; sin embargo, el costo de una medición frecuente de los volúmenes de tráfico en una gran cantidad de caminos en un área urbana, es prohibitivo. En su lugar, las mediciones son hechas en una muestra o subconjunto de caminos en la región y los resultados son extrapolados para estimar los KRVs regionales totales. Como parte de este proceso, la red de caminos primero es clasificada en un sistema en el que se espera que los caminos de la misma clase tengan volúmenes de tráfico similares. Las mediciones son hechas a partir de una muestra de los caminos en cada clase. Una estimación regional puede entonces ser desarrollada extrapolando los resultados de la muestra con base en la relación de la longitud de los caminos de la clase muestreada con respecto a la longitud total de los caminos de dicha clase. Si las mediciones tomadas durante cierto número de años son combinadas para estimar los KRV regionales, podrían requerirse ajustes adicionales.

Otra información sobre las técnicas de medición de los volúmenes vehiculares puede obtenerse en el *Manual of Transportation Engineering Studies* (Manual del Estudio de Ingeniería del Transporte) (ITE, 1994). Para los propósitos de desarrollo de un inventario de emisiones, sería posible realizar mediciones puntuales de los volúmenes vehiculares para validar las estimaciones regionales o para complementar los datos existentes. Los métodos de muestreo pueden incluir la recopilación de datos manual o automatizada, y también pueden diseñarse estudios para recopilar datos sobre la velocidad de manera simultánea (ver Sección 3.4.2).

Las estimaciones nacionales de los volúmenes de tráfico en México están disponibles para los caminos pavimentados, y están compilados por tipo de camino (federal, estatal y de cuota). Estos datos se encuentran en el *Anuario Estadístico del Sector Comunicaciones y Transportes* (SCT, 1993). No hay una certeza con respecto a que si estos datos han sido desagregados a nivel regional o subregional.

4.2 Estimaciones de los KRVs Derivadas de los Datos de Consumo de Combustible

En ausencia de estimaciones de KRVs directas a partir de MDRs y de programas regionales para la recopilación de datos, los KRVs pueden ser estimados indirectamente a partir de los datos de consumo de combustible. Si las fuentes para la estimación de KRVs directa están disponibles, los datos de consumo de combustible también pueden ser utilizados para verificar la validez y precisión de las estimaciones.

Las estadísticas de ventas y consumo de combustible son típicamente mucho más utilizadas y accesibles que las estimaciones de KRVs directas. En general, estas estadísticas son calculadas para evaluar las ventas y consumo de combustible, dado que la gasolina y el diesel son artículos de consumo de gran valor. En México, los datos de consumo o ventas locales pueden obtenerse de Pemex. Para un inventario regional más pequeño también se pueden obtener los datos las ventas de combustible de las gasolinerías individuales.

Las entidades gubernamentales pueden solicitar esta información a:

Subdirección de producción
Torre Ejecutiva, Piso 13
Marina Nacional No. 329
Col. Huasteca
Teléfono: 5722 2500 exts. 22691 y 22521
Fax: 5722 2500 ext. 23135

Al utilizar los datos de consumo de combustible, es posible obtener una estimación regional de los KRV que represente el total del parque vehicular que utiliza un solo tipo de combustible.

(4-2)

$$KRV_f = Ventas_f \text{ x } KPL_f$$

donde:

KRV = Kilómetros recorridos por vehículo
Ventas = Ventas totales de combustible (litros)
KPL = Rendimiento promedio del parque vehicular (kilómetros/litro) (valores específicos para México, o valores estadounidenses por omisión)
f = Tipo de combustible (gasolina o diesel).

El uso de los datos KRV a partir de MDRs o de estimaciones regionales es preferible al uso de los datos de consumo de combustible. En general, es más conveniente utilizar los datos de las ventas o consumo de combustible para verificar las estimaciones directas de KRVs existentes, pero en caso necesario estos datos pueden ser utilizados para estimar los KRVs. Algunos aspectos que incrementan la incertidumbre en las estimaciones de KRVs derivadas de las estadísticas de combustible son los siguientes:

- El combustible vendido dentro de la región del inventario puede no ser consumido dentro de la misma región. Esto puede ser particularmente cierto en áreas geográficas donde existen grandes diferencias en los precios del combustible, o en un área urbana donde circula una gran cantidad de tráfico de paso.

- Los datos de venta o consumo de combustible incluyen equipo que no circula por carreteras (particularmente de diesel).

Existen algunas regiones de inventario en las que el punto de compra del combustible y el punto de consumo pueden diferir de manera significativa. En otras palabras, el combustible adquirido en un área puede ser utilizado en otra. En regiones de inventario pequeñas, esto puede crear grandes discrepancias entre las compras y el consumo de combustible; sin embargo, en regiones de inventario grandes, estas diferencias tienden a anularse entre sí y se hacen menos significativas.

También es importante determinar el uso final del combustible. Es probable que los datos regionales incluyan el consumo de los vehículos automotores que circulan por carreteras y del equipo que no circula por carreteras, en particular para diesel. La adición del combustible consumido por este último va a incrementar el KRV estimado. Si es posible, el consumo de combustible del equipo que no circula por carreteras debe ser restado del consumo de combustible total.

5.0 PROCEDIMIENTOS DE ASEGURAMIENTO Y CONTROL DE CALIDAD

El paso final necesario para el desarrollo de estimaciones de emisión exactas y útiles consiste en evaluar su precisión general. Históricamente, el desarrollo de evaluaciones independientes de la precisión de las estimaciones de las emisiones de vehículos automotores, ha sido un proceso difícil debido a la gran cantidad de fuentes, el alcance geográfico de su operación y la diversidad de sus emisiones. A pesar de esta dificultad, las estimaciones deben ser sometidas a un proceso de aseguramiento y control de la calidad (AC/CC) adecuado. Los vehículos automotores representan una fuente importante de emisiones y los procedimientos utilizados para desarrollar las estimaciones requieren el uso de grandes y complejos conjuntos de datos. Debido a que no existe un parámetro de AC individual que pueda medir la precisión y sesgo de las estimaciones, los programas de AC exitosos buscan evaluar el inventario a través de todas las mediciones independientes que sean posibles. Esta sección presenta los procedimientos específicos que pueden ser utilizados para evaluar la precisión de las estimaciones de las emisiones de los vehículos automotores, que incluyen:

- Comparación de las emisiones de vehículos automotores con las emisiones generales del inventario.
- Comparación de las emisiones per cápita
- Comparación de las emisiones contra KRVs
- Comparación de los datos de actividad vehicular contra las estadísticas de consumo de combustible
- Estudios de detección remota de las emisiones del escape
- Uso de los datos de muestreos ambientales.

5.1 Comparación de las Emisiones de Vehículos Automotores con el Inventario General

Una verificación de AC adecuada para un inventario de emisiones consiste en la comparación de las emisiones de los vehículos automotores con las emisiones de todas las fuentes antropogénicas. La fracción de las emisiones totales representada por los vehículos automotores va a variar por contaminante y localidad. No existe una sola fracción que aplique globalmente. De manera ideal, los resultados del inventario pueden ser comparados con los resultados históricos de la misma área, o con los resultados de otras áreas que tengan fuentes de emisión, móviles y estacionarias, similares. Esta revisión sólo dará una estimación aproximada de la racionalidad de las estimaciones de las emisiones. Una investigación más profunda será necesaria si los resultados de las fracciones de vehículos automotores son notablemente diferentes a los de otras regiones similares. Las discrepancias pueden deberse a errores en el inventario o a diferencias desconocidas en las características de las regiones.

La Tabla 5-1 presenta un ejemplo del uso del porcentaje de contribución relativo de las emisiones para evaluar la racionalidad de las estimaciones de las emisiones de vehículos automotores. En esta Tabla, la proporción relativa de las emisiones de vehículos automotores se presenta como un porcentaje de las emisiones totales en seis regiones, dos en EU (Atlanta y Los Angeles), dos en México (las zonas metropolitanas de las ciudades de México y Monterrey), y dos en Asia (Bangkok y Hong Kong). Las estimaciones de emisión de vehículos automotores varían entre estas localidades. La contribución relativa de los vehículos automotores a las emisiones generales de COVs fluctúa desde un 35% para Atlanta hasta un 80% para la Zona Metropolitana de la Ciudad de México. Esta variación es razonable, dadas las diferentes mezclas del parque vehicular, los estándares de emisión y los niveles de industrialización de cada área.

Tabla 5-1
Contribución Relativa de las Emisiones de Vehículos Automotores en las Estimaciones de Emisiones Antropogénicas Generales en Ciudades Seleccionadas

Localidad	**Año de Inventario**	**Referencia**	**Emisiones de Vehículos Automotores Estimadas como Porcentaje de las Emisiones Antropogénicas**		
			COV	**CO**	**NOx**
Bangkok, Thailandia	1992	MSTE, 1994	55	35	1
Hong Kong	1991	EPD, 1994	N/A	80	25
Monterrey, México	1995	Radian, 1996b	70	95	30
Ciudad de México, México	1989	LANL y IMP, 1994	80	98	75
Atlanta, Georgia	1995	Georgia DNR, 1995	35	70	20
Los Angeles, California	1990	SCAQMD, 1994	50	80	60

CO = monóxido de carbono
NOx = óxidos de nitrógeno
COV = compuestos orgánicos volátiles
N/A = no disponible

Las comparaciones de CO y NO_x indican que Bangkok es notablemente diferente a las demás regiones. En las cinco regiones restantes, las emisiones de NO_x representan desde el 20 hasta el 75% para el inventario de emisiones antropogénicas generales. Se estima que en Bangkok, por otro lado, sólo el 1% de sus emisiones de NO_x es generado por fuentes móviles. De manera similar, el 35% de CO para Bangkok parece estadísticamente ajeno comparado con las otras cinco localidades, que tienen porcentajes que van del 70 al 98%. Una parte de la discrepancia entre Bangkok y las otras regiones puede deberse a las diferencias en la mezcla de vehículos. El parque vehicular de Bangkok incluye una gran proporción de motores de dos ciclos, que tienen emisiones de NO_x más bajas que los motores de cuatro ciclos comparables que predominan en otras áreas. Sin embargo, esto no explica la magnitud total de las diferencias en las emisiones de NO_x ni de CO.

Los porcentajes anteriores no indican que las estimaciones de las emisiones de vehículos automotores o antropogénicas en Bangkok sean potencialmente erróneas, sólo que es posible que una o ambas estimaciones de la emisión de CO y NO_x estén sesgadas. La conclusión de este ejemplo de análisis es que se necesita una revisión más detallada del inventario general de Bangkok, para determinar si las estimaciones realmente están sesgadas. A medida en que más estimaciones de emisión se generen en México, sus resultados podrán ser utilizados de manera similar para identificar discrepancias potenciales, como en el caso de los datos de Bangkok presentados en la Tabla 5-1.

5.2 Comparación de las Emisiones Per Cápita

Las emisiones de vehículos automotores se desarrollan generalmente a partir de estimaciones de KRVs basadas en el tráfico o derivadas de las estadísticas de consumo de combustible. Las emisiones de vehículos automotores per cápita pueden ser calculadas y comparadas con los resultados de otras regiones, con el objetivo de verificar la racionalidad de los resultados.

Para ilustrar este proceso, la Figura 5-1 presenta las estimaciones de las emisiones per cápita de vehículos automotores para 12 estados del oeste en EU. Las estimaciones están agregadas a nivel estatal, y son comparadas con las estimaciones de la población en todo el estado; ambas series de datos son para 1990.

En este ejemplo, no existe una relación directa entre la población y las emisiones per cápita. California, con la mayor población, tiene una de las tasas de emisión per cápita más bajas para cada uno de los contaminantes presentados. Texas, el siguiente estado más poblado, tiene una tasa de emisión per cápita que está a la mitad de la escala, mientras que Wyoming, el estado menos poblado, tiene las tasas de emisión per cápita más altas para todos los contaminantes.

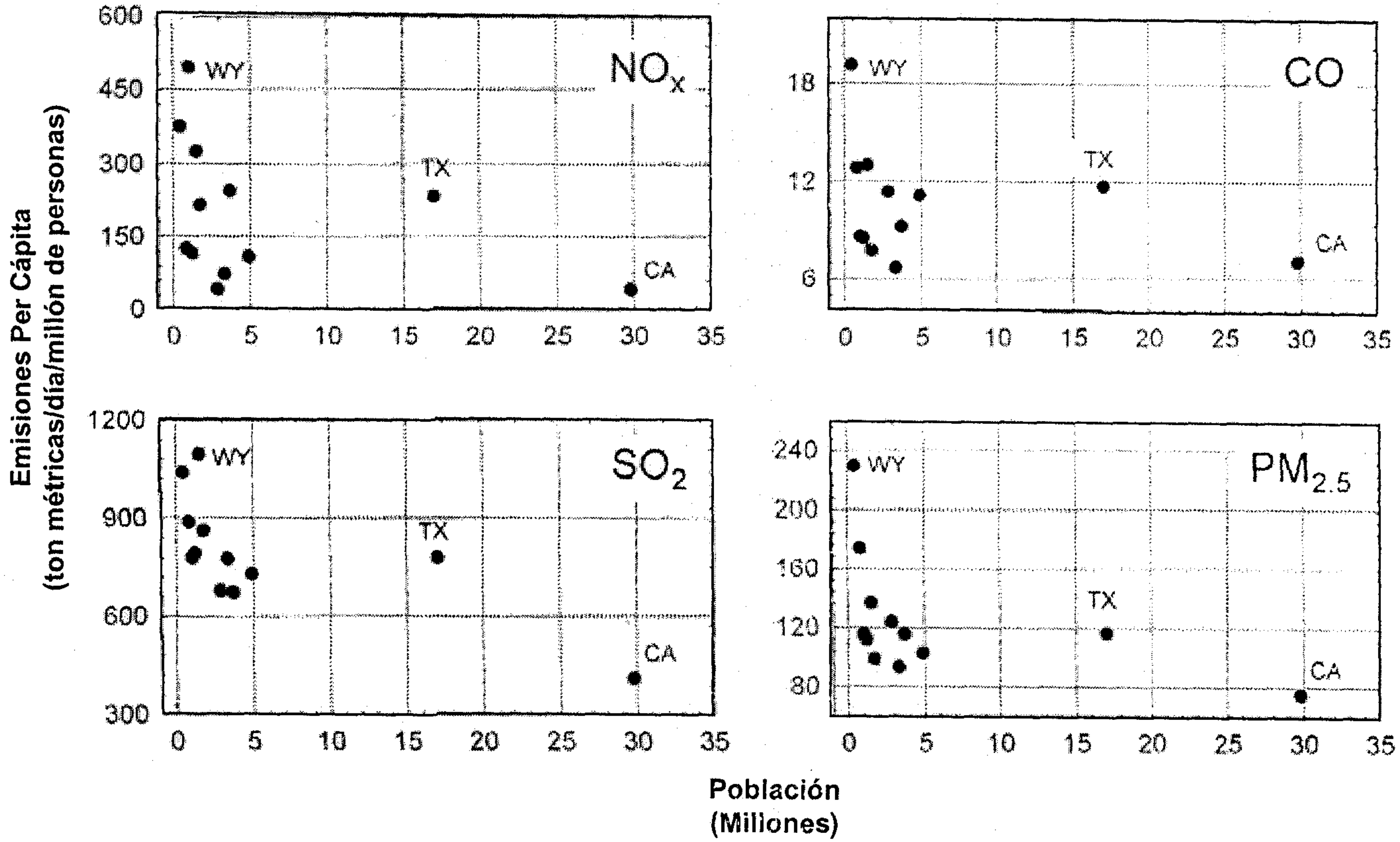

Figura 5-1. Emisiones de Vehículos Automotores Per Cápita en 12 Estados del Oeste de EU para 1990: AZ, CA, CO, ID, MT NV, NM, OR, TX, UT, WA, WY

Dada la gran diferencia en las estimaciones de emisión entre California y Wyoming, la pregunta lógica sería ¿cuál es la causa? A menos que la razón para las diferencias observadas pueda explicarse de manera inmediata, existe la sospecha de un sesgo potencial en las estimaciones. En este ejemplo, la elevada tasa de emisiones per cápita en Wyoming podría ser explicada por el hecho de que éste es un estado sumamente rural, con grandes distancias entre las áreas urbanas. Las distancias de recorrido promedio son grandes, lo que resulta en emisiones por vehículo y per cápita relativamente más altas, cuando se compara con otros estados. Por otro lado, California tiene altos volúmenes de tráfico y grandes distancias de recorrido, pero estos factores son equilibrados por los límites de emisiones para vehículos automotores más estrictos en EU. Como resultado, las emisiones per cápita son relativamente bajas. Esto demuestra la necesidad de analizar las diferencias y darles una explicación razonable. En caso de que ésta no sea posible, entonces debe existir un error o sesgo en las estimaciones.

La Figura 5-2 presenta seis gráficas de las emisiones de vehículos automotores y KRVs para 43 condados en la parte central de Georgia, incluyendo el área metropolitana de Atlanta y sus zonas circundantes. A diferencia de la gráfica de emisiones per cápita previa, aquí parece haber una relación lineal entre las emisiones y la población, y entre los KRV y la población. En esta gráfica, los cuatro condados que contienen la mayor población en el área de Atlanta parecen quedar fuera, en la esquina superior derecha de cada gráfica. Sin embargo, si estos cuatro condados se eliminan, la gráfica de emisiones contra la población resultante sería mucho menos lineal. Esta figura constituye un ejemplo de la necesidad de analizar las gráficas y datos detalladamente para asegurar que las impresiones iniciales sean correctas, y que no haya errores o diferencias sistemáticas obvias en los datos que puedan llevar a conclusiones equivocadas.

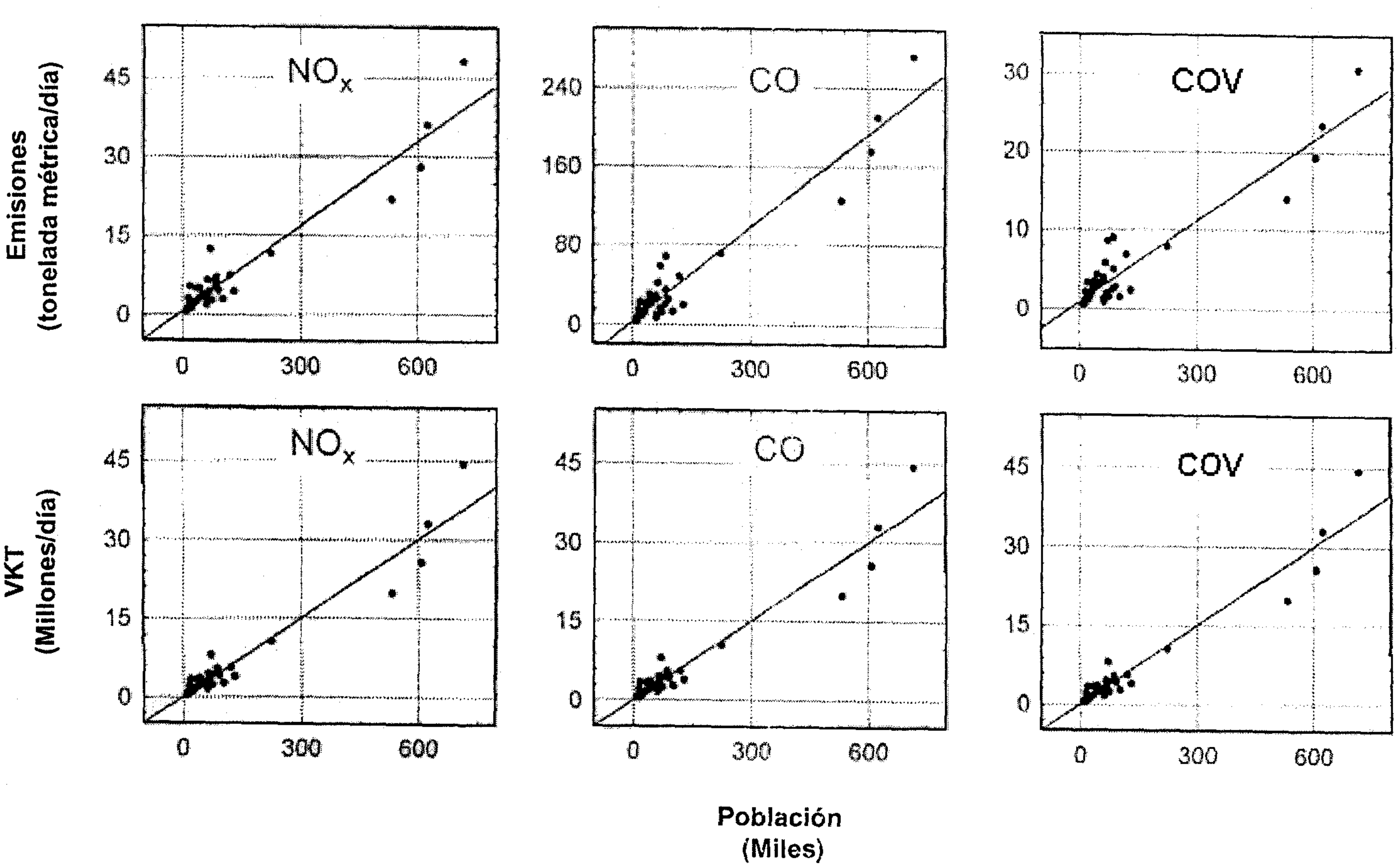

Figura 5-2. Relaciones entre las Emisiones de Vehículos Automotores, KRVs y Población, Proyectadas para 1999 en 43 Condados de la Parte Central de Georgia

5.3 Comparación de las Emisiones *vs.* KRV

Las estimaciones de las emisiones de vehículos automotores se calculan multiplicando un factor de emisión por los KRVs. Una simple comparación de las emisiones estimadas con los KRVs puede, con frecuencia, identificar errores en el cómputo.

La Figura 5-3 presenta una gráfica de las emisiones de vehículos automotores contra los KRVs en 43 condados en la parte central de Georgia. Debido a que los KRVs fueron utilizados para estimar las emisiones de Atlanta, esto no se puede calificar como una revisión independiente de las emisiones. Dado que las emisiones son linealmente proporcionales a los KRVs, en la Figura 5-3 se esperaría una relación lineal. Algunas desviaciones de una correlación lineal perfecta podrían anticiparse debido a las diferencias en la mezcla del parque vehicular, en las características del combustible, los programas de inspección y mantenimiento (I/M) en vigor y otros factores. Sin embargo, las desviaciones significativas con respecto a la relación lineal (más allá de las diferencias observadas en la Figura 5.3, por ejemplo), indicarían la necesidad de revisar nuevamente la precisión de los cálculos del inventario.

5.4 Comparación de los Datos de Actividad de los Vehículos Automotores contra las Estadísticas de Consumo de Combustible

Las estadísticas de consumo de combustible pueden ser utilizadas para verificar la racionalidad de las estimaciones de las emisiones de los vehículos automotores, a menos que las estimaciones de los KRVs originales hayan sido derivadas de esas mismas estadísticas. Las estimaciones de los KRVs utilizadas para la comparación deben ser calculadas utilizando las estadísticas de consumo de combustible como se describe en la Sección 4.2. Por otro lado, la incertidumbre descrita en la misma sección, y que resulta del uso de equipo móvil que no circula por carreteras y otros factores, también debe ser considerada cuando se aplique este método de AC.

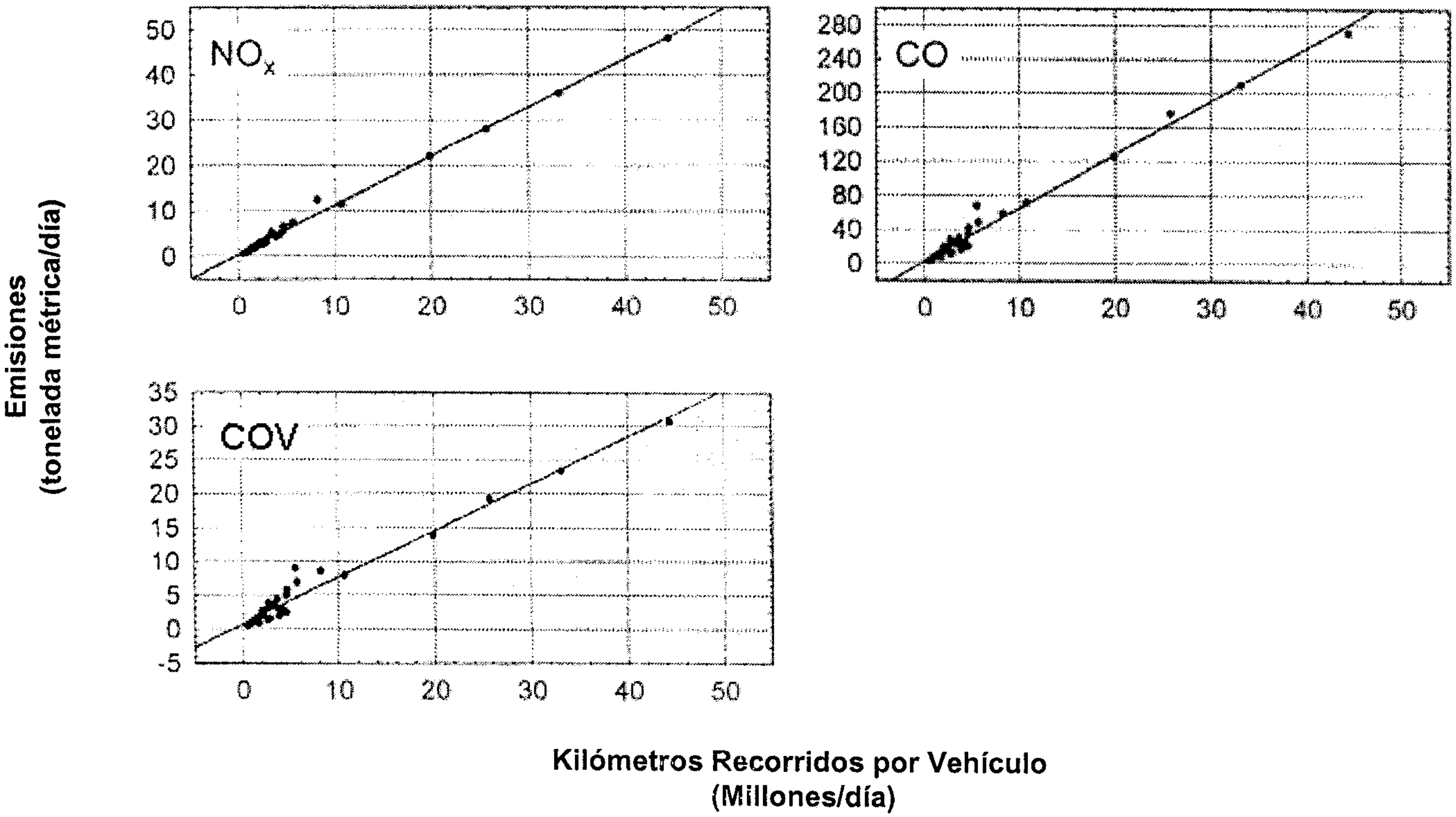

Figura 5-3. **Emisiones de Vehículos Automotores vs. KRVs Proyectadas para 1999 en 43 Condados de la Parte Central de Georgia**

5.5 Estudios de Detección Remota de las Emisiones del Escape

Los datos básicos utilizados en los modelos de factores de emisión de vehículos automotores (e. g., MOBILE o PART5) se obtienen con vehículos que operan sobre dinamómetros, de conformidad con patrones de manejo definidos. Si bien estas condiciones de prueba pueden generar grandes cantidades de datos, éstos están limitados por el grado en que reproduzcan las condiciones de manejo del "mundo real". Si los datos básicos utilizados en un modelo de factor de emisión no reflejan las condiciones del mundo real en cierta medida, cabe esperar que los factores de emisión promedio proyectados por el modelo estén sesgados en un grado equivalente. Por ejemplo, los datos básicos utilizados para alimentar las versiones previas del modelo MOBILE han resultado en una subestimación de las emisiones de COVs y CO. El ciclo de manejo actual utilizado en las pruebas de dinamómetro no toma en cuenta la totalidad del manejo a alta velocidad, ni las aceleraciones o desaceleraciones repentinas. Adicionalmente, los datos básicos utilizados en el modelo MOBILE no siempre representan a los "super emisores" (i. e., vehículos que tienen tasas de emisión mucho más altas y que, típicamente, forman parte del parque vehicular). La U.S. EPA, el *California Air Resources Board* (CARB) (Consejo de Recursos del Aire de California), y otras organizaciones están trabajando para resolver estas deficiencias en las futuras versiones del MOBILE y el EMFAC (el modelo de factores de emisión de vehículos automotores del CARB). Es un hecho que estas deficiencias indican la necesidad continua de mediciones independientes de las emisiones de vehículos automotores.

El concepto de Sensibilidad y Detección Remota (SDR) - *Remote Sensing and Detection* - como método para identificar "super emisores" y para revisar el inventario de emisiones de vehículos automotores, surgió en Denver, Colorado durante 1987. A pesar de que el uso de la tecnología SDR aún está en desarrollo, ha evolucionado con rapidez como una herramienta de

AC de eficiencia relativa para las estimaciones de las emisiones en vehículos automotores. Si bien ésta es una tecnología relativamente sencilla, se requiere, sin embargo, de experiencia y equipo especial para obtener resultados que sean útiles. A continuación se presenta un panorama general de esta tecnología, y de la manera en que puede ser utilizada como herramienta de AC. Es posible encontrar información adicional en Bishop, *et al.* (1993 y 1994) y Cadle, *et al.* (1993).

Esta tecnología aplica un sistema de monitoreo infrarrojo (IR) remoto que mide las relaciones del monóxido de carbono (CO) e hidrocarburos (HC) con el dióxido de carbono (CO_2). El SDR puede identificar vehículos mal carburados o con problemas en el encendido que, al ser reparados, permiten un ahorro de combustible. Por lo tanto, esta tecnología ha sido denominada Prueba del Rendimiento del Combustible del Automóvil (PRCA) - *Fuel Efficiency Automobile Test* -. El principio de funcionamiento consiste en un haz de energía IR que es transmitido a través de un solo carril de tránsito, aproximadamente a 25 centímetros sobre la superficie del camino, y un detector calibrado recibe el rayo y reporta los datos de CO, CO_2 y HC en una base porcentual.

Para usar las mediciones SDR en AC, se requieren pasos adicionales para convertirlas en una forma que pueda ser combinada con los datos de consumo de combustible. Los resultados SDR aportan relaciones de concentración del escape (i. e., CO/CO_2 y HC/CO_2), más que mediciones absolutas de las concentraciones del contaminante. La conversión a los factores de emisión en gramos de contaminante por unidad de volumen o combustible consumido a partir de las mediciones SDR, es detallada por Singer y Harley (1996). Utilizando el balance de carbón, las estimaciones del contaminante de interés pueden ser obtenidas a partir de la siguiente ecuación:

$$E_P = \frac{[P]}{[CO_2] + [CO] + 3[HC]} \; x \; \frac{PM_P}{PM_C} \; x \; F_C \; x \; \boldsymbol{r}_f \tag{5-1}$$

donde:

E_P = Emisiones del contaminante P
$[P]$ = Concentración en el escape del contaminante P
PM_P = Peso molecular del contaminante P
PM_C = Peso molecular del carbón
F_C = Fracción en peso del carbón en el combustible
ρ_f = Densidad del combustible f.

La suma de las concentraciones de CO, CO_2 y HC en el denominador representa la concentración de átomos de carbono en el escape. La ecuación presupone que los hidrocarburos han sido medidos como propano, C_3H_8, de aquí que el factor 3 sea aplicado a la concentración de HC del escape. Si los resultados SDR se reportan como relaciones con el CO_2, entonces la ecuación puede ser replanteada como:

$$E_P = \frac{[Q_P]}{[1] + [Q_{CO}] + 3[Q_{HC}]} \; x \; \frac{PM_P}{PM_C} \; x \; F_C \; x \; \boldsymbol{r}_f \tag{5-2}$$

donde:

$[Q_P]$ = $[P]/[CO_2]$
$[Q_{CO}]$ = $[CO]/[CO_2]$
$[Q_{HC}]$ = $[HC]/[CO_2]$

En las ecuaciones 5-1 y 5-2, el término HC es generalmente ignorado, a menos que la [HC] sea lo suficientemente elevada como para influenciar la precisión deseada (e. g., [HC]~1000 ppm).

El PRCA ha sido utilizado para medir las emisiones de más de 500,000 vehículos en Denver, Chicago, Los Angeles, Toronto, Suecia y México (Bishop et al., 1993). México aplicó esta tecnología para evaluar las emisiones de vehículos automotores en la Zona Metropolitana de la Ciudad de México (Beaton, et al., 1992). Los resultados de este estudio indican que las características del escape del parque vehicular en esta zona son muy diferentes a las de cualquier otra región antes evaluada con dicha tecnología. Por lo tanto, los resultados obtenidos con esta herramienta de AC advierten de manera explícita que la aplicación indiscriminada del modelo MOBILE en regiones diferentes a EU puede conducir a la estimación de emisiones sumamente sesgadas.

Los resultados del análisis en la Zona Metropolitana de la Ciudad de México incluyen las mediciones de más de 30,000 vehículos. Los datos fueron reducidos posteriormente para generar factores de emisión para HC y CO en gramos por galón. Estos datos pueden ser combinados con los datos de venta de gasolina, y utilizarse en el cálculo de estimaciones de emisión alternativas que pueden servir como una verificación de AC de las estimaciones calculadas con los factores de emisión proyectados por el modelo MOBILE.

Debe recordarse que puede haber una incertidumbre significativa asociada con las estimaciones de emisión basadas en el PRCA u otros aditamentos de sensibilidad remota. Estos equipos sólo pueden proporcionar una medición instantánea de las emisiones, y no son útiles para capturar las variaciones en el tiempo ni las diversas condiciones de manejo. En consecuencia, estas estimaciones de emisión alternativas deben ser utilizadas sólo para los propósitos de AC. No se recomienda que se apliquen directamente para la estimación de emisiones en ningún esfuerzo de inventario.

5.6 Uso de los Datos del Muestreo Ambiental

Los datos del muestreo ambiental también pueden ser utilizados en los procesos de validación y AC de las estimaciones de un inventario de emisiones. Estos datos proporcionan una medición de la realidad que puede ser comparada con las estimaciones proyectadas. Tres de los métodos de AC más comúnmente utilizados son el modelado para determinar la exposición del receptor, las relaciones de concentración, y los modelos tridimensionales. La ventaja principal de estos procedimientos es que generan la información de manera independiente a la metodología utilizada para estimar las emisiones de los vehículos automotores. Una desventaja para su aplicación es la naturaleza generalmente limitada de los datos del monitoreo ambiental disponibles para ser utilizados en el análisis. Los datos ambientales sólo representan las condiciones y tipos de fuente presentes durante las mediciones de campo. Si las condiciones que son válidas para las estimaciones difieren de aquellas encontradas durante en el trabajo de campo, entonces habrá una incertidumbre inherente en los resultados de cualquier comparación que sea hecha entre los datos ambientales y la estimación de emisiones de los vehículos automotores.

5.6.1 Modelado para Determinar la Exposición del Receptor

El modelado para determinar la exposición del receptor, también denominado contribución de fuentes *(source apportionment)*, utiliza métodos estadísticos y datos del monitoreo ambiental para estimar la contribución relativa de las emisiones generadas por una serie de categorías de fuentes a las concentraciones ambientales observadas en un área. Es un método AC de “arriba hacia abajo” debido a que usa la información del inventario completo y el dominio del modelado para estimar la contribución relativa de las emisiones de cada categoría de fuente, en lugar de sumar las estimaciones de la contribución en una base fuente por fuente. El Modelo de Balance de Masa Química (MBMQ) - *Chemical Mass Balance Model* - (Watson, et al., 1984) es ampliamente utilizado en la realización de modelados para determinar la exposición del receptor.

En el modelado para determinar la exposición del receptor se utiliza una estimación de mínimos cuadrados para obtener el mejor ajuste de las emisiones de cada fuente modelada, misma que reproduce la composición química de los datos observados en el monitoreo en un sitio determinado.

Los dos requerimientos clave de las entradas para este modelado son la composición química de los datos del monitoreo ambiental, y la composición química (“huellas dactilares”) de las emisiones de cada categoría de fuente que tenga el mismo nivel de detalle que los datos del monitoreo.

El modelo sólo es capaz de identificar las contribuciones de las categorías de fuente que tienen composiciones químicas únicas. Por otro lado, el modelo únicamente genera los impactos relativos, indicando la contribución relativa de cada clase de fuente. Las categorías de fuente típicas utilizadas en el modelado para determinar la exposición del receptor pueden incluir escapes de vehículos automotores, combustión de combustibles, plantas de generación eléctrica, actividades de construcción, aerosoles marinos y polvo fugitivo de origen geológico.

A nivel histórico, el modelado del receptor ha sido utilizado principalmente para analizar las fuentes de contaminantes relativamente estables (o no reactivos), tales como material particulado. Por ejemplo, Chow et al., (1992) utilizó el MBMQ para analizar la contribución de las fuentes de PM_{10} en el Valle de San Joaquín en California. Ellos concluyeron que el polvo fugitivo de origen geológico (e. g., polvo fugitivo del arado agrícola, carreteras y actividades de construcción), representaba más del 50% de las PM_{10} observadas en Bakersfield durante el verano y el otoño. Por otro lado, los escapes de los vehículos automotores contribuyeron sólo con aproximadamente el 10% de las PM_{10} observadas.

Gran parte del trabajo reciente ha sido realizado con el objetivo de aplicar el modelado para determinar la exposición del receptor a los contaminantes reactivos. Por ejemplo, Scheff et al. (1995), aplicaron el MBMQ para evaluar las emisiones de compuestos orgánicos no metánicos (CONM) en el *Southeast Michigan Ozone Study* (Estudio del Ozono del Sureste de Michigan). Con base en el supuesto de tiempos de recorrido relativamente cortos y, por lo tanto, un tiempo limitado para que se presenten reacciones químicas, las especies químicas con reactividad relativamente baja fueron seleccionadas para utilizarse en el modelado. En este estudio se encontró que la proporción relativa de las concentraciones de CONMs observadas era consistente con las estimaciones de emisión actuales para algunas categorías, tales como las fuentes de recubrimiento arquitectónico y hornos de coque. Sin embargo, entre los resultados del MBMQ y el inventario actual hubo diferencias significativas en la proporción relativa de emisiones de otras categorías, tales como refinerías y artes gráficas.

Como se mencionó al inicio de la Sección 5.5, una de las principales ventajas del MBMQ como parte del proceso de AC del inventario de emisiones, es que es completamente independiente de los métodos utilizados para estimar las emisiones. Los métodos estadísticos de este tipo dependen sólo de los datos del monitoreo ambiental para estimar las contribuciones relativas de las fuentes de emisiones. Por lo tanto, el MBMQ brinda la capacidad para verificar independientemente las distribuciones relativas de las emisiones estimadas a través del proceso de inventario, y para identificar las áreas potencialmente problemáticas.

Un inconveniente de esta metodología es que la resolución actual del modelo MBMQ está limitada por la calidad de los perfiles de la composición de la fuente de emisión disponibles. Debido a las diferencias entre las fuentes (y, potencialmente, entre una prueba y otra para una fuente determinada), estos perfiles son sumamente variables. En consecuencia, debe tenerse gran cuidado para asegurar que sólo los perfiles más representativos sean

utilizados como entrada para el modelo MBMQ. Adicionalmente, los datos de monitoreo aplicados en el MBMQ deben ser representativos de las concentraciones ambientales en el área de estudio. Estos datos no pueden estar dominados por fuentes locales para las que no existan perfiles disponibles.

5.6.2 Relaciones de las Muestras Ambientales

Las fuentes de emisión específicas tienden a tener relaciones de emisión de diversos contaminantes prácticamente fijas. Al analizar estas relaciones, es posible derivar la información con respecto a la contribución probable de las fuentes de emisión específicas en los datos de monitoreo observados. Un buen ejemplo del uso de los datos del monitoreo ambiental en esta forma es un estudio de Fujita et al. (1992) en Los Angeles, California. Análisis similares han sido realizados en las áreas de Chicago y el centro de California (Korc et al., 1995). Fujita et al., compararon las relaciones de diversos contaminantes desarrolladas a partir de los inventarios de emisiones y de los datos de monitoreo ambiental recopilados en 1987 durante el Estudio de la Calidad del Aire de la Costa Sur *(South Coast Air Quality Study*).

La Tabla 5-2 presenta los resultados de Fujita et al., que comparan las relaciones ambientales y de los inventarios de emisiones para CO/NO_x y $GONM/NO_x$. En esta tabla se incluyen los factores de ajuste para la porción del escape de los vehículos automotores del inventario de emisiones necesarios para hacer que las relaciones del inventario de emisiones igualen las relaciones ambientales observadas (i. e., eliminación de un sesgo potencial). Debido a que las relaciones $GONM/NO_x$ requieren un factor de ajuste mayor comparado con las relaciones CO/NO_x, podría parecer que los GONM han sido subestimados.

No se recomienda que este tipo de análisis sea realizado de manera rutinaria como parte del proceso de desarrollo de un inventario de emisiones. Sin embargo, a medida en que los inventarios de emisiones mexicanos sigan evolucionando, la cantidad de mediciones ambientales en campo también se va a incrementar, lo que permitirá la difusión del uso de esta técnica.

Tabla 5-2
Comparación de las Relaciones Ambientales y del Inventario de CO/NO$_x$ y GONM/NO$_x$ para Los Angeles, Datos de 1987

Relación del Contaminante	Estación	Hora (Hora Estándar del Pacífico)	Relación Ambiente/Inventario[a]	Factor de Ajuste Requerido para el Motor del Vehículo[b]
CO/NO$_x$	Verano	06-08	1.4	1.5
		20-08	1.6	1.9
	Otoño	06-08	1.1	1.2
		20-08	1.4	1.7
GONM/NO$_x$	Verano	06-08	2.5	4.4
		20-08	3.0	5.5
	Otoño	06-08	1.7	2.8
		20-08	2.3	4.0

a Relación de la relación del contaminante estimada a partir de los datos de monitoreo ambiental con respecto a la estimada a partir del inventario de emisiones de vehículos automotores.
b Factor de ajuste requerido para igualar la relación de las emisiones de escape caliente de vehículos automotores con la relación ambiente.

5.6.3 Modelos Tridimensionales

Los modelos tridimensionales también están siendo utilizados con mayor frecuencia para ayudar a evaluar la incertidumbre en el proceso de inventario de emisiones (Chang et al., 1993; Mulholland y Seinfeld, 1995). Los modelos tridimensionales actuales incluyen los efectos de la química atmosférica y de la variación de las condiciones meteorológicas. Las estimaciones del inventario de emisiones son utilizadas como entradas de datos para los modelos tridimensionales. Después de correr el modelo, las concentraciones atmosféricas proyectadas se comparan con las concentraciones reales medidas en diversos sitios
con monitoreo. De esta manera, es posible calcular la incertidumbre del inventario. Un ejemplo reciente es la Iniciativa de Investigación de la Calidad del Aire en la Ciudad de México (MARI), en la que los equipos del Laboratorio Nacional Los Alamos y del Instituto Mexicano del Petróleo concluyeron que el inventario de COVs estimado para la Ciudad de México tiene un error de

cálculo de aproximadamente un factor de cuatro (LANL y IMP, 1994). Esta conclusión fue alcanzada a través de técnicas de análisis de datos, que incluyen análisis de trayectoria, como parte de la evaluación del desempeño del modelo. Al igual que con el modelado para determinar la exposición del receptor y las relaciones de la muestra ambiental, el uso actual de los modelos tridimensionales es limitado. Sin embargo, a medida en que los inventarios de emisiones se desarrollen y maduren en México, también se incrementará el uso de técnicas avanzadas, tales como los modelos tridimensionales.

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Apéndice A – Ejemplo del Cálculo de Emisiones de Vehículos Automotores

Apéndice A – Ejemplo del Cálculo de Emisiones de Vehículos Automotores

Objetivo – Ejemplificar la estimación de las emisiones de los vehículos automotores utilizando modelos de factor de emisión y balances de masa. En este ejemplo se estimarán las emisiones de gas orgánico total (GOT) y óxidos de azufre (SO_x).

Descripción – Este ejemplo de cálculo se basa en las estimaciones de emisión reales efectuadas para un inventario de tóxicos del aire en la ciudad de Nogales, Sonora, México (Radian, 1997). Se estimaron las emisiones para cuatro clases de vehículos a gasolina: vehículos ligeros (LDGV), camiones ligeros (LDGT), vehículos pesados (HDGV) y motocicletas (MC).

Las emisiones de GOT fueron calculadas como paso intermedio previo a la especiación de tóxicos del aire. Los factores de emisión de GOT se calcularon utilizando el modelo MOBILE-Juárez (que es un modelo MOBILE5a modificado desarrollado con los datos para Ciudad Juárez). Las emisiones de SO_x no fueron calculadas como parte del inventario de tóxicos del aire, sin embargo, pueden ser derivados fácilmente a partir de las estadísticas de consumo de combustible.

Se ha supuesto que las estadísticas de combustible de Pemex que se manejaron representan el combustible que es utilizado por los vehículos mexicanos en Nogales, Sonora. Si bien no es totalmente cierto, este supuesto fue una simplificación necesaria para el inventario de tóxicos del aire. Los cálculos del rendimiento promedio de combustible del parque vehicular y la distribución de los kilómetros recorridos por vehículo (KRVs) por tipo de camino son demasiado complejos para este ejemplo de cálculo y no han sido incorporados. Este ejemplo sólo incluye los resultados del rendimiento promedio de combustible del parque vehicular y la distribución de los KRVs.

Emisiones de GOT – Estimación de los Factores de Emisión

Paso 1: Construcción del archivo de entrada del MOBILE-Juárez.
La Figura A-1 presenta el archivo elaborado para el escenario de primavera en Nogales, Sonora. Con el objetivo de tomar en cuenta los cambios de temperatura de una estación a otra, se generaron cuatro archivos de entrada separados para la primavera, verano, otoño e invierno. En general, los escenarios estacionales son opcionales. Cada renglón del archivo de entrada se explica brevemente en la Tabla A-1. Los números de renglones incluidos en la Figura A-1 no son parte del archivo de entrada real, sino que son utilizados como referencia.

Paso 2: Correr el modelo MOBILE-Juárez.

Paso 3: Extraer los factores de emisión del archivo de salida del MOBILE-Juárez. La parte del archivo de salida resultante que contiene los factores de emisión para el escenario de primavera en Nogales, Sonora se muestra en la Figura A-2, que indica los factores de emisión para cada velocidad y clase vehicular.

LINEA #		***Sección de Control***
1	1 PROMPT	
2	MOBILE-Juárez - Nogales, Sonora - Spring *(primavera)*	
3	1 TAMFGL	
4	1 SPDFGL	
5	3 VMFLAG	
6	1 MYMRFG	
7	5 NEWFLG	
8	1 IMFLAG	
9	1 ALHFLG	
10	1 ATPFLG	
11	5 RLFLAG	
12	1 LOCFLG	
13	1 TEMFLAG	
14	4 OUTFMT	
15	1 PRTFLG	
16	1 IDLFLG	
17	4 NMHFLG	
18	3 HCFLAG	
19	.611.242.066.056.000.000.019.006	***Sección de Datos de Un Paso***
20	1 94 24.1 25.0 19.6 19.7 30.0 1	***Sección del Escenario***
21	Nogales Spring A 3.6 25.4 09.5 09.5 93 1 1 1	
22	1 94 40.2 25.0 19.6 19.7 30.0 1	
23	Nogales Spring A 3.6 25.4 09.5 09.5 93 1 1 1	
24	1 94 56.3 25.0 19.6 19.7 30.0 1	
25	Nogales Spring A 3.6 25.4 09.5 09.5 93 1 1 1	

Figura A-1. Archivo de Entrada en el Modelo MOBILE-Juárez para Nogales, Sonora

Paso 4: Calcular los factores de emisión promedio anuales. Estos se calculan utilizando los factores de emisión de primavera mostrados en la Figura A-2, así como los factores de emisión para las otras tres estaciones, que no se muestran aquí. Este cálculo se resume en la Tabla A-2.

Emisiones de GOT – Estimación de los KRV

Paso 1: Calcular el consumo total de combustible. Las estadísticas mensuales de consumo de combustible para 1994 fueron obtenidas de Pemex. Los totales anuales se calculan en la Tabla A-3. El consumo total de gasolina sin plomo fue de 51,169,901 litros, mientras que el de gasolina con plomo fue de 10,571,891 litros. El consumo general total de gasolina fue de 61,741,792 litros.

Paso 2: Calcular los KRV. Utilizando los datos del registro, la acumulación de millaje (por modelo y año) del modelo MOBILE-Juárez y los rendimientos del combustible del modelo (año) estadounidenses, se determinó que el rendimiento del combustible del parque vehicular de 1994 en el área de estudio fue de 6.788 kilómetros por litro de gasolina. Al dividir el consumo general total de gasolina entre esta cifra se obtiene un KRV total de aproximadamente 419,100,000 para Nogales, Sonora.

Paso 3: Distribuir el KRV por clase vehicular. La mezcla KRV general de Ciudad Juárez indica lo siguiente: LDGV - 61.1% del KRV total; LDGT - 30.8%, HDGV - 5.6%, y MC - 0.6%. Sin embargo, esta mezcla también incluye el KRV de los vehículos a diesel. Al hacer la normalización para gasolina, los resultados son los siguientes: LDGV - 62.3% del KRV de gasolina; LDGT - 31.4%, HDGV - 5.7% y MC - 0.6%. Después de aplicar esta fracción KRV normializada, el KRV total se divide en las clases vehiculares como se muestra a continuación:

LDGV	261,100,000 KRV
LDGT	131,600,000 KRV
HDGV	23,900,000 KRV
MC	2,500,000 KRV

Paso 4: Distribuir el KRV por la velocidad vehicular. Basado en una visita al sitio en Nogales, Sonora y en el juicio ingenieril, se estimó que 23.3% de todos los KRV se presentaron a 24.1 kilómetros por hora (15 mph), 70.0% a 40.2 kilómetros por hora (25 mph), y 6.7% a 56.3 kilómetros por hora (35 mph). La distribución de KRV por velocidad vehicular se muestra en la Tabla A-4.

Emisiones de GOT – Cálculo de las Emisiones

Como se indicó en la Sección 2.1 de este manual, las emisiones de GOTs son calculadas multiplicando el factor de emisión MOBILE-Juárez por el KRV estimado. Esto se muestra en la Tabla A-4 para cada clase vehicular y para cada una de las tres velocidades vehiculares. Las emisiones GOT totales para vehículos a gasolina también han sido sumadas en la parte inferior de la Tabla A-4.

Las emisiones de GOT totales se estimaron en 2,866 Mg/año ó 7.85 Mg/día.

Emisiones de SO_x – Cálculo de las Emisiones

Como se indicó en la Sección 2.1 de este manual, las emisiones de SO_x son estimadas utilizando el balance de combustible.

Paso 1: Obtener las estadísticas del consumo de combustible. A partir del cálculo de las emisiones de GOTs anteriores, se determinó el consumo de 51,169,901 litros de gasolina sin plomo, y 10,571,891 litros de gasolina con plomo.

Paso 2: Obtener el contenido de azufre del combustible. A partir de las especificaciones para combustibles de Pemex, el máximo contenido de azufre para la gasolina sin plomo es de 0.1% (en peso), y para la gasolina con plomo es 0.15% (en peso).

Paso 3: Determinar la densidad de la gasolina. Con base en la experiencia previa, una densidad típica de la gasolina es de 0.731 kg/litro (6.09 lbs/galón).

Aplicando la ecuación de balance de combustible para el SO_x (ver Ecuación 2-2 de este manual):

$$E_{SinPlomo} = (51{,}169{,}901\ \text{litro})\ \text{x}\ (0.731\ \text{kg/ litro})\ \text{x}\ 0.001\ \text{x}\ 2 = 74{,}810\ \text{kg}\ SO_x = 74.8\ \text{Mg}\ SO_x$$

$$E_{ConPlomo} = (10{,}571{,}891\ \text{litro})\ \text{x}\ (0.731\ \text{kg/ litro})\ \text{x}\ 0.0015\ \text{x}\ 2 = 23{,}184\ \text{kg}\ SO_x = 23.2\ \text{Mg}\ SO_x$$

Las emisiones totales de SO_x son de 98 Mg/año ó 0.268 Mg/día.

Tabla A-1
Explicación del Archivo de Entrada del MOBILE-Juárez para Nogales, Sonora

Número de Renglón	Elemento de los Datos	Explicación	Comentarios
1	1	Bandera PROMPT – Entrada de datos capturada sin activar el formato vertical.	También conocida como entrada del lote del archivo. Se recomienda incluir esta opción.
2	Renglón Completo	PROJID – Identificación del archivo de entrada.	Ninguno.
3	1	TAMFLG – Tasas de alteración por omisión usadas en el MOBILE-Juarez.	Esta opción debe ser utilizada a menos que se haya realizado un estudio de alteración local.
4	1	SPDFLG – Una velocidad promedio para todos los tipos de vehículos para cada Registro Descriptivo del Escenario *(Scenario Descriptive Record).*	Esta opción debe ser utilizada a menos que exista información detallada sobre la velocidad de transporte
5	3	VMFLAG – Una mezcla KRV asignada a todos los escenarios.	Se supone que la mezcla de KRVs de Ciudad Juárez/El Paso es aplicable para Nogales, Sonora.
6	1	MYMRFG – Tasas de acumulación de millaje por omisión y distribuciones del registro utilizadas para el MOBILE-Juarez.	Esta opción debe ser utilizada a menos que se tengan recopilados los datos locales de acumulación de millaje y distribución del registro.
7	5	NEWFLG – BERs del MOBILE-Juarez utilizadas con todos los nuevos requerimientos de la Clean Air Act *(Ley de Aire Limpio)* desactivados.	Esta opción debe ser utilizada para todas las aplicaciones del modelo MOBILE-Juarez.

Tabla A-1 (Cont.)
Explicación del Archivo de Entrada del MOBILE-Juárez para Nogales, Sonora

Número de Renglón	**Elemento de los Datos**	**Explicación**	**Comentarios**
8	1	IMFLAG – No hay programas de inspección y mantenimiento (I/M) que deban ser modelados.	Esta opción debe ser utilizada a menos que se haya instrumentado un programa I/M.
9	1	ALHFLG – No se hicieron correcciones para el uso de aire acondicionado, carga extra del vehículo, arrastre de trailers y humedad.	Esta opción debe ser usada normalmente.
10	1	ATPFLG – No hay programa anti-alteración (ATP) que deba ser modelado.	Esta opción debe ser utilizada a menos que un programa ATP haya sido instrumentado.
11	5	RLFLAG – No se calcularon los factores de emisión de carga de combustible	Esta opción debe ser utilizada a menos que las emisiones por carga de combustible no hayan sido estimadas como fuente de área.
12	1	LOCFLG – Un registro de Parámetro Local de Area *(Local Area Parameter)* (LAP) para cada escenario.	Esta opción es utilizada típicamente.
13	1	TEMFLG – Factores de emisión ajustados utilizando las temperaturas diarias mínimas y máximas.	Esta opción debe ser utilizada a menos que las temperaturas mínimas y máximas diarias no estén disponibles.
14	4	OUTFMT – Formato de salida descriptivo de 80 columnas.	El modelo MOBILE-Juarez ha sido adaptado para aceptar sólo esta opción.
15	1	PRTFLG – Sólo los factores de emisión de hidrocarburos han sido incluidos en la salida.	Esta opción fue seleccionada para cumplir con los requerimientos del inventario de tóxicos del aire de Nogales.

Tabla A-1 (Cont.)
Explicación del Archivo de Entrada del MOBILE-Juárez para Nogales, Sonora

Número de Renglón	Elemento de los Datos	Explicación	Comentarios
16	1	IDLFLG – No se calcularon factores de emisión en reposo.	Esta opción debe ser utilizada normalmente.
17	4	NMHFLG – Factores de emisión de hidrocarburos como gases orgánicos totales (GOTs).	Esta opción debe ser utilizada normalmente.
18	3	HCFLAG – Los factores de emisiones evaporativas totales, por componente y detallados, han sido incluidos en la salida.	Esta opción debe ser utilizada normalmente.
19	.611	Fracción de los KRVs para vehículos ligeros a gasolina (LDGV).	Fracción de los KRVs estimada para Ciudad Juárez y supuestamente aplicable para Nogales, Sonora.
	.242	Fracción de los KRVs para camiones ligeros a gasolina <2,727 kg (LDGT1).	Fracción de los KRVs estimada para Ciudad Juárez y supuestamente aplicable para Nogales, Sonora.
	.066	Fracción de los KRVs para camiones ligeros a gasolina >2,727 kg y <3,857 kg (LDGT2).	Fracción de los KRVs estimada para Ciudad Juárez y supuestamente aplicable para Nogales, Sonora.
	.056	Fracción de los KRVs para vehículos pesados a gasolina >3,857 kg (HDGV).	Fracción de los KRVs estimada para Ciudad Juárez y supuestamente aplicable para Nogales, Sonora.
	.000	Fracción de los KRVs para vehículos ligeros a diesel (LDDV).	Fracción de los KRVs estimada para Ciudad Juárez y supuestamente aplicable para Nogales, Sonora.

Tabla A-1 (Cont.)
Explicación del Archivo de Entrada del MOBILE-Juárez para Nogales, Sonora

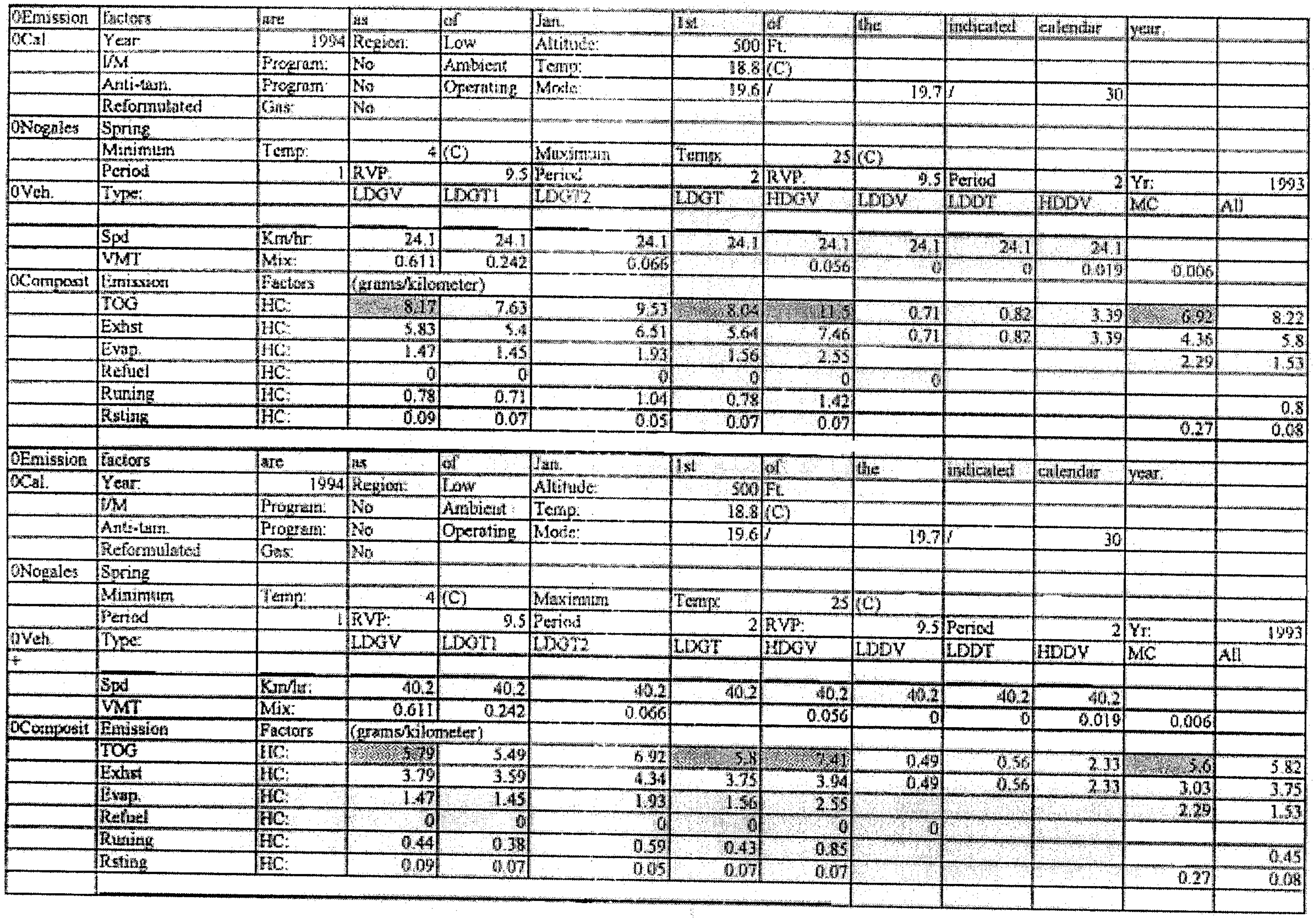
Número de Renglón	Elemento de los Datos	Explicación	Comentarios
19 (Cont.)	.000	Fracción de los KRVs para camiones ligeros a diesel <3,857 kg (LDDT).	Fracción de los KRVs estimada para Ciudad Juárez y supuestamente aplicable para Nogales, Sonora.
	.019	Fracción de los KRVs para vehículos pesados a diesel >3,857 kg (HDDV).	Fracción de los KRVs estimada para Ciudad Juárez y supuestamente aplicable para Nogales, Sonora.
	.006	Fracción de los KRVs para motocicletas (MC).	Fracción de los KRVs estimada para Ciudad Juárez y supuestamente aplicable para Nogales, Sonora.
20	1	Región de baja altitud.	Esta opción debe ser utilizada excepto para regiones de altitud elevada (>1,676 metros sobre el nivel del mar).
	94	Año de inventario 1994.	El año de inventario para el inventario de Nogales, Sonora. Este dato variará dependiendo del año de inventario.
	24.1	Velocidad vehicular de 24.1 kilómetros por hora (15 millas por hora).	Una de las velocidades vehiculares estimadas para Nogales, Sonora durante una visita al sitio. Para el MOBILE-Juarez, este valor debe estar en unidades de kilómetros por hora.
	25.0	Temperatura ambiente.	Típicamente esta temperatura no es utilizada, debido a que la TEMFLG (ver renglón número 13) está ajustada a “1”. Sin embargo, la temperatura ambiente debe estar ajustada entre las temperaturas diarias mínima y máxima. El valor de 25.0 °C fue elegido arbitrariamente. Para el MOBILE-Juarez, este valor debe estar en °C.

Tabla A-1 (Cont.)
Explicación del Archivo de Entrada del MOBILE-Juárez para Nogales, Sonora

Número de Renglón	Elemento de los Datos	Explicación	Comentarios
20 (Cont.)	19.6	Variable del modo de operación PCCN.	Variables de los modos de operación estimadas para Ciudad Juárez supuestamente aplicables para Nogales, Sonora.
	19.7	Variable del modo de operación PCHC.	Variables de los modos de operación estimadas para Ciudad Juárez supuestamente aplicables para Nogales, Sonora.
	30.0	Variable del modo de operación PCCC.	Variables de los modos de operación estimadas para Ciudad Juárez supuestamente aplicables para Nogales, Sonora.
	1	Factores de emisión calculados para el mes de enero del año de inventario.	Esta opción debe ser utilizada normalmente.
21	Primavera de Nogales	Nombre del escenario.	Ninguno.
	A	Clase de volatilidad del combustible.	Esta opción debe ser utilizada normalmente.
	3.6	Temperatura diaria mínima.	Temperatura mínima promedio para marzo, abril y mayo, obtenida de los datos meteorológicos de Nogales, Arizona. Para el MOBILE-Juarez, este valor debe estar en °C.
	25.4	Temperatura diaria máxima.	Temperatura máxima promedio para marzo, abril y mayo, obtenida de los datos meteorológicos de Nogales, Arizona. Para el MOBILE-Juarez, este valor debe estar en °C.
	09.5	PVR Periodo 1.	Límite superior del espectro PVR de Pemex que se supone aplicable para Nogales, Sonora.
	09.5	PVR Periodo 2.	Límite superior del espectro PVR de Pemex que se supone aplicable para Nogales, Sonora.

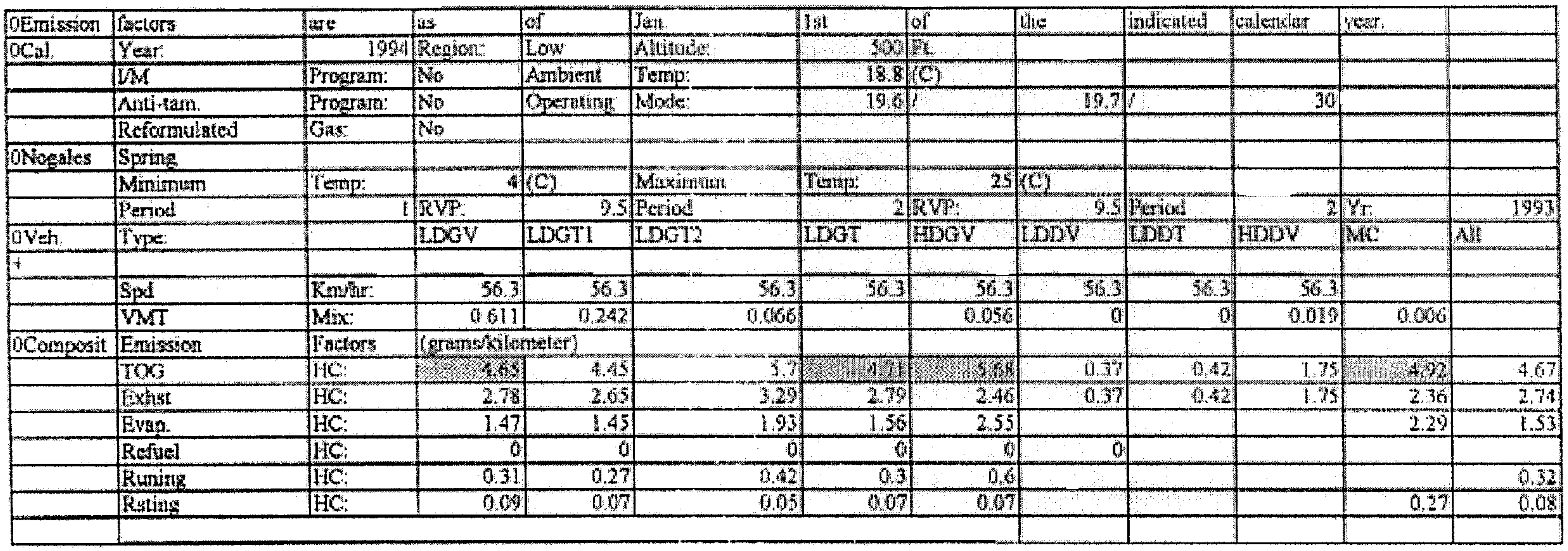
Tabla A-1 (Cont.)
Explicación del Archivo de Entrada del MOBILE-Juárez para Nogales, Sonora

Número de Renglón	Elemento de los Datos	Explicación	Comentarios
21 (Cont.)	93	Año de inicio del Periodo 2.	Debido a que los PVRs de los periodos 1 y 2 son idénticos, no se utilizó el año de inicio del Periodo 2. El valor capturado 93 es arbitrario.
	1	Bandera de combustible oxigenado.	Esta opción debe ser utilizada a menos que los combustibles oxigenados deban ser modelados en la región.
	1	Bandera de la fracción de ventas de diesel.	Esta opción debe ser utilizada a menos que se apliquen fracciones alternas a la venta de diesel.
	1	Bandera de gasolina reformulada.	Esta opción debe ser utilizada a menos que los efectos de la gasolina reformulada deban ser modelados.
22	Renglón completo	Idéntico al Registro Descriptivo del Escenario presentado en el Renglón 20, excepto que la velocidad del vehículo ha sido cambiada a 40.2 kilómetros por hora.	Ninguno.
23	Renglón completo	Idéntico al Registro de Parámetro de Area Local presentado en el Renglón 21.	Ninguno.
24	Renglón completo	Idéntico al Registro Descriptivo del Escenario presentado en el Renglón 20, excepto que la velocidad del vehículo ha sido cambiada a 56.3 kilómetros por hora.	Ninguno.
25	Renglón completo	Idéntico al Registro de Parámetro de Area Local presentado en el Renglón 21.	Ninguno.



0Emission	factors	are	as	of	Jan.	1st	of	the	indicated	calendar	year.	
0Cal	Year:	1994	Region:	Low	Altitude:	500	Ft.					
	I/M	Program:	No	Ambient	Temp:	18.8	(C)					
	Anti-tam.	Program:	No	Operating	Mode:	19.6	/	19.7	/	30		
	Reformulated	Gas:	No									
0Nogales	Spring											
	Minimum	Temp:	4	(C)	Maximum	Temp:	25	(C)				
	Period	1	RVP:	9.5	Period	2	RVP:	9.5	Period	2	Yr:	1993
0Veh.	Type:		LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC	All
	Spd	Km/hr:	24.1	24.1	24.1	24.1	24.1	24.1	24.1	24.1		
	VMT	Mix:	0.611	0.242	0.066		0.056	0	0	0.019	0.006	
0Compost	Emission	Factors	(grams/kilometer)									
	TOG	HC:	8.17	7.63	9.53	8.04	11.5	0.71	0.82	3.39	6.92	8.22
	Exhst	HC:	5.83	5.4	6.51	5.64	7.46	0.71	0.82	3.39	4.36	5.8
	Evap.	HC:	1.47	1.45	1.93	1.56	2.55				2.29	1.53
	Refuel	HC:	0	0	0	0	0	0				
	Runing	HC:	0.78	0.71	1.04	0.78	1.42					0.8
	Rsting	HC:	0.09	0.07	0.05	0.07	0.07				0.27	0.08
0Emission	factors	are	as	of	Jan.	1st	of	the	indicated	calendar	year.	
0Cal.	Year:	1994	Region:	Low	Altitude:	500	Ft.					
	I/M	Program:	No	Ambient	Temp:	18.8	(C)					
	Anti-tam.	Program:	No	Operating	Mode:	19.6	/	19.7	/	30		
	Reformulated	Gas:	No									
0Nogales	Spring											
	Minimum	Temp:	4	(C)	Maximum	Temp:	25	(C)				
	Period	1	RVP:	9.5	Period	2	RVP:	9.5	Period	2	Yr:	1993
0Veh.	Type:		LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC	All
+												
	Spd	Km/hr:	40.2	40.2	40.2	40.2	40.2	40.2	40.2	40.2		
	VMT	Mix:	0.611	0.242	0.066		0.056	0	0	0.019	0.006	
0Composit	Emission	Factors	(grams/kilometer)									
	TOG	HC:	5.79	5.49	6.92	5.8	7.41	0.49	0.56	2.33	5.6	5.82
	Exhst	HC:	3.79	3.59	4.34	3.75	3.94	0.49	0.56	2.33	3.03	3.75
	Evap.	HC:	1.47	1.45	1.93	1.56	2.55				2.29	1.53
	Refuel	HC:	0	0	0	0	0	0				
	Running	HC:	0.44	0.38	0.59	0.43	0.85					0.45
	Rsting	HC:	0.09	0.07	0.05	0.07	0.07				0.27	0.08

Figura A-2Archivo de Salida del Modelo MOBILE-Juarez para Nogales, Sonora



0Emission	factors	are	as	of	Jan.	1st	of	the	indicated	calendar	year.	
0Cal.	Year:	1994	Region:	Low	Altitude:	500	Ft.					
	I/M	Program:	No	Ambient	Temp:	18.8	(C)					
	Anti-tam.	Program:	No	Operating	Mode:	19.6	/	19.7	/	30		
	Reformulated	Gas:	No									
0Nogales	Spring											
	Minimum	Temp:	4	(C)	Maximum	Temp:	25	(C)				
	Period	1	RVP:	9.5	Period	2	RVP:	9.5	Period	2	Yr:	1993
0Veh.	Type:		LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC	All
+												
	Spd	Km/hr:	56.3	56.3	56.3	56.3	56.3	56.3	56.3	56.3		
	VMT	Mix:	0.611	0.242	0.066		0.056	0	0	0.019	0.006	
0Composit	Emission	Factors	(grams/kilometer)									
	TOG	HC:	4.65	4.45	5.7	4.71	5.68	0.37	0.42	1.75	4.92	4.67
	Exhst	HC:	2.78	2.65	3.29	2.79	2.46	0.37	0.42	1.75	2.36	2.74
	Evap.	HC:	1.47	1.45	1.93	1.56	2.55				2.29	1.53
	Refuel	HC:	0	0	0	0	0	0				
	Runing	HC:	0.31	0.27	0.42	0.3	0.6					0.32
	Rsting	HC:	0.09	0.07	0.05	0.07	0.07				0.27	0.08

Figura A-2Archivo de Salida del Modelo MOBILE-Juarez para Nogales, Sonora (Cont.)

Tabla A-2
Cálculo de los Factores de Emisión de GOT Anuales (g/km) para, Sonora

Clase Vehicular	Velocidad (kph)	Primavera	Verano	Otoño	Invierno	Promedio
LDGV	24.1	8.17	9.93	8.20	8.45	8.69
	40.2	5.79	7.35	5.90	5.84	6.22
	56.3	4.65	6.15	4.80	4.57	5.04
LDGT	24.1	8.04	9.54	8.07	8.28	8.48
	40.2	5.80	7.20	5.89	5.87	6.19
	56.3	4.71	6.08	4.84	4.68	5.08
HDGV	24.1	11.50	16.36	12.10	10.58	12.64
	40.2	7.41	11.76	8.05	6.45	8.42
	56.3	5.68	9.82	6.34	4.70	6.64
MC	24.1	6.92	8.91	7.32	6.03	7.30
	40.2	5.60	7.65	6.03	4.58	5.97
	56.3	4.92	7.02	5.37	3.85	5.29

Tabla A-3
Estadísticas del Consumo de Combustible en Nogales, Sonora para 1994

Mes	Magna Sin (Sin Plomo) (Litros)	Nova Plus (Con Plomo) (Litros)
Enero	3,510,000	1,348,600
Febrero	3,464,800	1,246,800
Marzo	3,990,000	1,461,500
Abril	3,830,000	932,500
Mayo	4,180,000	992,500
Junio	4,141,930	751,645
Julio	4,238,970	689,935
Agosto	4,724,500	719,761
Septiembre	4,575,179	607,200
Octubre	4,489,828	621,450
Noviembre	4,794,593	615,000
Diciembre	5,230,101	585,000
Total	**51,169,901**	**10,571,891**

Tabla A-4
Cálculo de las Emisiones Anuales de GOTs (Mg) para Nogales, Sonora

Clase Vehicular	Velocidad (kph)	Factor de Emisión (g/km)	KRV	Emisiones (Mg/yr)
LDGV	24.1	8.69	60,836,300	528.7
	40.2	6.22	182,770,000	1136.8
	56.3	5.04	17,493,700	88.2
LDGT	24.1	8.48	30,662,800	260.0
	40.2	6.19	92,120,000	570.2
	56.3	5.08	8,817,200	44.8
HDGV	24.1	12.64	5,568,700	70.4
	40.2	8.42	16,730,000	140.9
	56.3	6.64	1,601,300	10.6
MC	24.1	7.30	582,500	4.3
	40.2	5.97	1,750,000	10.4
	56.3	5.29	167,500	0.9
Total	**-**	**-**	**419,100,000**	**2,866.2**

670-017-51-01
Febrero 19, 1997

John T. Leary
Gerente de Proyecto
Asociación de Gobernadores del Oeste
600 17th Street
Suite 1705, South Tower
Denver, CO 80202

Asunto: Entrega de la versión final del Manual para el Desarrollo de Inventarios de Emisiones de Vehículos Automotores para el Proyecto de Metodología para el Inventario de Emisiones de México

Estimado John:

Anexa se encuentra una copia final del Volumen VI de los Manuales para el Programa del Inventario de Emisiones de México, *Desarrollo de Inventarios de Emisiones de Vehículos Automotores*. Este es el tercer documento final que hemos desarrollado en nuestra serie de manuales de inventarios de emisiones Adicionalmente, estamos entregando al INE un “master” impreso por un lado y una versión electrónica (MS Word 6.0) de este documento para facilitar los esfuerzos de reproducción y traducción posteriores.

En caso de que existieran dudas o comentarios acerca del material que se anexa, por favor comuníquese conmigo al (916) 857-7467.

Atentamente

Ronald J. Dickson
Ingeniero Senior

cc: Víctor Hugo Páramo, INE (cinco copias)
Comité Asesor Binacional
José Ortega, Corporación Radian
Jim Yarbrough, U.S. EPA Región VI
Archivo del Proyecto.

RCN 670017.6210

MEXICO EMISSIONS INVENTORY PROGRAM MANUALS

VOLUME VIII – MODELING INVENTORY DEVELOPMENT

FINAL

Prepared for:

Western Governors' Association
Denver, Colorado

and

Binational Advisory Committee

Prepared by:

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10389 Old Placerville Road
Sacramento, CA 95827

February 16, 2000

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The *Mexico Emissions Inventory Program Manuals* were the result of efforts by several participants. The Binational Advisory Committee (BAC) guided the development of these manuals. The members of the BAC were:

Dr. John R. Holmes, State of California Air Resources Board
Mr. William B. Kuykendal, U.S. Environmental Protection Agency
Mr. Mike George, Arizona Department of Environmental Quality
Dr. Victor Hugo Páramo, Instituto Nacional de Ecología
Mr. Gerardo Rios, U.S. Environmental Protection Agency
Mr. Carl Snow, Texas Natural Resource Conservation Commission

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PREFACE

Air pollution can negatively impact public health when present in the atmosphere in sufficient quantities. Most rural areas rarely experience air quality problems, while elevated concentrations of air pollution are found in many urban environments. Recently, there has been an increasingly larger degree of urbanization and industrial activity throughout Mexico, resulting in air quality impairment for several regions.

Air pollution results from a complex mix of literally thousands of sources ranging from industrial smoke stacks and motor vehicles to the individual use of grooming products, household cleaners, and paints. Even plant and animal life can play an important role in the air pollution problem. The complex nature of air pollution requires the development of detailed plans on a regional level that provide a full understanding of the emission sources and methods for reducing the health impacts associated with exposure to air pollution. Example air quality planning activities include:

- Application of air quality models;
- Examination of source attribution for emissions control where deemed necessary;
- Development of emission projections to examine possible changes in future air quality;
- Analysis of emission trends; and
- Analysis of emissions transport from one region to another.

Development of fundamentally sound emissions inventories is a key need for each of these air quality management and planning functions.

Developing emission estimates to meet air quality planning needs requires continual development and refinement; “one time” inventory efforts are not conducive to the air quality planning process. For lasting benefit, an *inventory program* must be implemented so that accurate emission estimates can be developed for all important geographic regions, refined over time, and effectively applied in the air quality planning and monitoring process. Consequently, a set of inventory manuals will be developed that can be used throughout the country to help coordinate the development of consistent emission estimates. These manuals are intended for use by local, state, and federal agencies, as well as by industry and private consultants. The purpose of these manuals is to assist in implementing the inventory program and in maintaining that program over time so that emissions inventories can be developed in periodic cycles and continually improved.

The manuals cover inventory program elements such as estimating emissions, program planning, database management, emissions validation, and other important topics. Figure 1 shows the series of manuals that will be developed to support a complete inventory program. The main purpose of each manual or volume is summarized below.

Volume I — Emissions Inventory Program Planning. This manual addresses the important planning issues that must be considered in an air emissions inventory program. Program planning is discussed not as an "up-front" activity, but rather as an ongoing process to ensure the long-term growth and success of an emissions inventory program. *Key Topics*: program purpose, inventory end uses, regulatory requirements, coordination at federal/state/local levels, staff and data management requirements, identifying and selecting special studies.

Volume II — Emissions Inventory Fundamentals. This manual presents the basic fundamentals of emissions inventory development and discusses inventory elements that apply to multiple source types (e.g., point and area) to avoid the need for repetition in multiple volumes. *Key Topics*: applicable regulations, rule effectiveness, rule penetration, pollutant definitions (excluding nonreactive volatile), point/area source delineation, point/area source reconciliation.

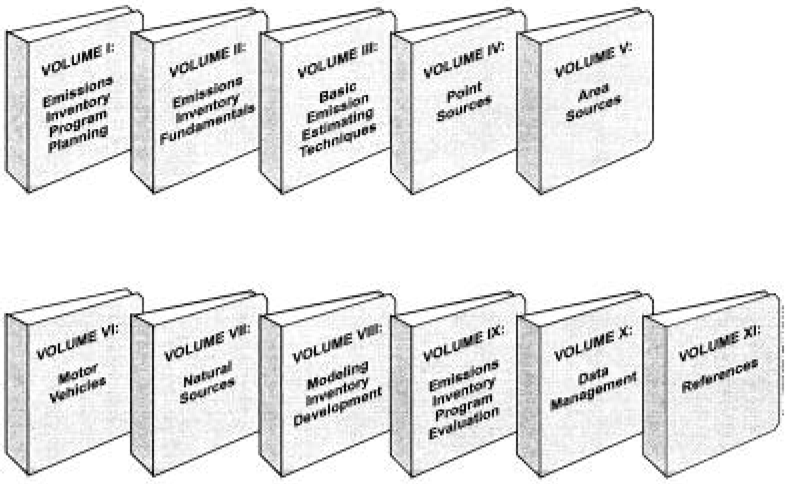

Figure 1. Mexico Emissions Inventory Program Manuals

Volume III — Basic Emission Estimating Techniques. This manual presents the basic methodologies used to develop emission estimates, including examples and sample calculations. Inventory tools associated with each methodology are identified and included in Volume XI (References). *Key Topics*: source sampling, emissions models, surveying, emission factors, material balance, and extrapolation.

Volume IV — Emissions Inventory Development: Point Sources. This manual provides guidance for developing the point source emissions inventory. A cross-reference table is provided for each industry/device type combination (e.g., petroleum refining/combustion devices) with one or more of the basic methodologies presented in Volume III. *Key Topics*: cross-reference table, stack parameters, control devices, design/process considerations, geographic differences and variability in Mexico, quality assurance/quality control (QA/QC), overlooked processes, data references, and data collection forms.

Volume V — Emissions Inventory Development: Area Sources (includes non-road mobile). This manual provides guidance for developing the area source emissions inventory. After the presentation of general area source information, a table is provided to cross-reference each area source category (e.g., asphalt application) with one or more of the basic methodologies presented in Volume III. Then, source category-specific information is discussed for each source category defined in the table. *Key Topics*: area source categorization and definition, cross-reference table, control factors, geographic differences and variability in Mexico, QA/QC, data references, and data collection forms (questionnaires).

Volume VI — Emissions Inventory Development: Motor Vehicles. Because motor vehicles are inherently different from point and area sources, the available estimation methods and required data are also different. To estimate emissions from these complex sources, models are the preferred estimation tool. Many of these models utilize extensive test data applicable to a given country or region. This manual focuses primarily on the data development phase of estimating motor vehicle emissions. *Key Topics*: available estimation methods, primary/secondary/tertiary data and information, source categorization, emission factor sources, geographic variability within Mexico, and QA/QC.

Volume VII — Emissions Inventory Development: Natural Sources. This manual provides guidance for developing a natural source emissions inventory (i.e., biogenic volatile organic compound [VOC] and soil nitrogen oxide [NO_x]). In addition, this manual includes the theoretical aspects of emission calculations and discussion of specific models. *Key Topics*: source categorization and definition, emission mechanisms, basic emission algorithms, biomass determination, land use/land cover data development, temporal and meteorological adjustments, and emission calculation approaches.

Volume VIII — Modeling Inventory Development. This manual provides guidance for developing inventory data for use in air quality models and addresses issues such as temporal allocation, spatial allocation, speciation, and projection of emission estimates. *Key Topics*: definition of modeling terms, seasonal adjustment, temporal allocation, spatial allocation, chemical speciation, and projections (growth and control factors).

Volume IX — Emissions Inventory Program Evaluation. This manual consists of three parts: QA/QC, uncertainty analysis, and emissions verification. The QA/QC portion defines the overall QA/QC program and is written to complement source-specific QA/QC procedures written into other manuals. The uncertainty analysis includes not only methods of assessing uncertainty in emission estimates, but also for assessing uncertainty in modeling values such as speciation profiles and emission projection factors. The emissions verification section describes various analyses that can be performed to examine the accuracy of the emission estimates. Examples include receptor modeling and trajectory analysis combined with specific data analysis techniques. *Key Topics*: description of concepts and definition of terms, inventory review protocol, completeness review, accuracy review, consistency review, recommended uncertainty methodologies, and applicable emission verification methodologies.

Volume X — Data Management. This manual addresses the important needs associated with the data management element of the Mexico national emissions inventory program. *Key Topics*: general-purpose data management systems and tools, specific-purpose software systems and tools, coding system, confidentiality, electronic submittal, frequency of updates, recordkeeping, Mexico-specific databases, and reports.

Volume XI — References. This manual is a compendium of tools that can be used in emissions inventory program development. Inventory tools referenced in the other manuals are included (i.e., hard-copy documents, electronic documents, and computer models).

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FIGURES AND TABLES

Figures **Page**

Tables **Page**

ACRONYMS

AMS	Area and Mobile Source
ARB	California Air Resources Board
BAC	Binational Advisory Committee
CAS	Chemical Abstract System
CB-IV	Carbon Bond IV
CC	crankcase emissions
CE	control efficiency
CEIDARS	California Emission Inventory Development and Reporting System
CFC	chlorofluorocarbon
CMAP	Mexican Classification of Activities and Products
CO	carbon monoxide
CST	cold start emissions
DNL	diurnal emissions
EC	elemental carbon
EMS-95	Emissions Modeling System - 95
FIRE	Factor Information Retrieval Data System
g	gram
GEMAP	Geocoded Emissions Modeling and Projections System
GCVTC	Grand Canyon Visibility and Transport Commission
GIS	geographic information system
GPS	global positioning systems
HAP	hazardous air pollutant
HC	hydrocarbon
HCFC	hydrochlorofluorocarbon
HFC	hydrofluorocarbon
hr	hour
HSK	hot soak emissions
HST	hot start emissions

H_2SO_4	sulfuric acid
ID	identification number
IFU	Fraunhofer-Institut für Atmosphärische Umweltforschung (Fraunhoter Institute for Atmospheric Environmental Research)
I/M	inspection and maintenance
INE	Instituto Nacional de Ecología (National Institute of Ecology)
km	kilometer
m	meter
m^2	square meter
MCCM	IFU's regional scale air quality model
Mg	megagram (10^6 grams; 1 metric ton)
MOBILE	U.S. Environmental Protection Agency's motor vehicle emission factor model
N/A	not applicable
NAICS	North American Industry Classification System
NH_3	ammonia
NMHC	non-methane hydrocarbon
NMOG	non-methane organic gas
NO	nitric oxide
NO_x	nitrogen oxides
NO_2	nitrogen dioxide
OC	organic carbon
OH^-	hydroxyl radical
O_3	ozone
PCBEIS	U.S. Environmental Protection Agency's biogenic emissions model
PFC	perfluorocarbon
PM	particulate matter
$PM_{2.5}$	particulate matter less than 2.5 micrometers in aerodynamic diameter
PM_{10}	particulate matter less than 10 micrometers in aerodynamic diameter
QA	quality assurance

QC	quality control
RACM	Regional Atmospheric Chemistry Mechanism
RADM2	Regional Atmospheric Deposition Model Mechanism, Version 2
RE	rule effectiveness
REV	running evaporative emissions
REX	running exhaust emissions
ROG	reactive organic gas
RP	rule penetration
SAPRC	California Statewide Air Pollution Research Center
SCC	Source Classification Code
SIC	Standard Industrial Classification
SNIFF	Sistema Nacional de Información de Fuentes Fijas (National Information System of Point Sources)
SO_x	sulfur oxides
SO_2	sulfur dioxide
SO_3	sulfur trioxide
SO_4^{2-}	sulfate ion
SPECIATE	U.S. Environmental Protection Agency’s speciation profile database
TDM	travel demand models
THC	total hydrocarbon
TNRCC	Texas Natural Resource Conservation Commission
TOG	total organic gas
TSP	total suspended particulate
UAM	Urban Airshed Model
U.S.	United States
U.S. EPA	United States Environmental Protection Agency
UTM	Universal Transverse Mercator
VKT	vehicle kilometers traveled
VOC	volatile organic compounds
WGA	Western Governors’ Association

yr	year
µg	microgram

1.0 INTRODUCTION

Over the past 25 years, numerous studies have been performed to address air quality problems. More recently, many of these investigations have relied upon the use of advanced air quality models. Air quality modeling is often used to show compliance with ambient air quality standards for criteria pollutants (e.g., ozone [O_3], carbon monoxide [CO], nitrogen oxides [NO_x], etc.) or to analyze the effectiveness of various control strategies. Though photochemical modeling has traditionally been used to demonstrate attainment with ozone standards, regional modeling is expected to also be used in the future as a tool for demonstrating attainment with particulate matter and regional haze standards. Also, regional modeling is sometimes used to examine the health and/or environmental risk associated with hazardous air pollutant (HAP) emissions. Pollutant emission rates are a key input to these models. A modeling emissions inventory is a compilation of these pollutant emission rates, which are then utilized by an air quality model.

The purpose of this manual is to educate the reader on the steps that are involved in developing a modeling inventory. It is intended to be an introductory "bridge" document between Volume IV *(Point Source Inventory Development)*, Volume V *(Area Source Inventory Development)*, and Volume VI *(Motor Vehicle Inventory Development)* of this manual series and the user's guides for specific emissions modeling tools (e.g., Geocoded Emissions Modeling and Projections System [GEMAP] [Radian, 1993], Emissions Modeling System-95 [EMS-95] [U.S. EPA, 1999a], etc.). As such, the content of this document is not model-specific, but presents the general concepts of modeling inventory development and illustrates them through the use of figures and numerical examples.

A number of papers that describe the use of GEMAP and EMS-95 for developing modeling inventories were identified in the technical literature (Beidler et al., 1996; Benjey and Moghari, 1995; Bruckman, 1993; Bruckman and Oliver, 1993; Dickson and Oliver, 1991; Dickson et al., 1992; Dickson et al., 1993; Dickson et al., 1994; Janssen, 1996; Janssen, 1998; Koerber, 1992; Mayenkar et al., 1992; and Oliver et al., 1998); these references are provided in

Section 10.0. It should be noted that GEMAP and EMS-95 are two widely used emissions modeling tools; other useful emissions modeling tools may exist. The specific inventory and modeling objectives should be examined in order to select the appropriate emissions modeling tool. Selection of an emissions model is often made on the basis of:

- Familiarity with existing emissions models; and
- Compatibility of emissions model formats with both existing input data and requirements of the air quality model.

The availability of input data for the emissions model is essential to the success of emissions modeling, but usually does not significantly affect the selection of a particular emissions model. All such models require a great amount of site-specific and source-specific input data.

The technical steps conducted during modeling inventory development to process the inventories for input to air quality models are as follows:

1. Temporal allocation – breaking down the annual emission estimates in the base year inventory into smaller time increments (usually hourly);
2. Spatial allocation – distributing the base year emission estimates into individual grid cells defined over the inventory domain;
3. Speciation – breaking down total organic gas (TOG)/reactive organic gas (ROG) emissions into reactivity groups and/or individual chemical species, total NO_x into nitric oxide (NO) and nitrogen dioxide (NO_2), and total particulate matter (PM) by particle size and/or individual chemical species; and
4. Projections – combining base year emission estimates with growth and control factors to estimate emissions for future years.

To implement these technical steps, many different data sets are required. These data need to be specifically tailored to the geographic modeling region and to the operating conditions of the source types within that region. For example, site-specific data are needed for spatial allocation profiles and seasonal operating rates. Source-specific data are needed for temporal allocation profiles (seasonal, weekly, hourly), emissions chemical speciation, and growth/control factors. Thus, each modeling domain and each source category requires specific data sets for temporal and spatial allocation, speciation, and emission projections.

Many of the required data sets should not be generalized. For example, hourly vehicle traffic patterns in Mexico City are likely to be different than in metropolitan areas along the Mexico-U.S. border (e.g., Ciudad Juárez, Mexicali, etc.). The appropriate data needed for the emissions model are specific, in many cases, to prevailing conditions in each region and for each source type. In such cases, these data cannot simply be assumed without affecting the validity of the emissions model results. Examples include the required spatial allocation profiles, temporal profiles for motor vehicles and airports, and emission projections.

For those data sets in which assumptions or generalizations will not compromise the results, Mexico-specific data are preferred. However, it is expected that U.S.-derived data sets will be used in selected cases until the Mexico- or site-specific information can be developed. Examples of these types of data include emissions, chemical speciation profiles for most source types, and some temporal allocation profiles (e.g., operating patterns for solvent usage, etc.).

Nevertheless, a large amount of data is required to implement the temporal, spatial, speciation, and projection steps in an emissions modeling system. These data sets must be obtained for the modeling domain so that the emissions modeling methods described in this manual can be reliably applied.

In order to clearly explain the four modeling inventory development steps listed above, an easy-to-understand modeling inventory example is used throughout this document and is presented in shaded boxes. The example is based upon the hypothetical modeling inventory community presented in Figure 1-1. The community contains the following six emission sources:

- A point source (i.e., a large factory) with a boiler for seasonal heating and a surface coating process (counted as two separate emission sources);
- On-road motor vehicles (i.e. light-duty passenger automobiles);
- Gasoline stations;
- Residential consumer solvent use; and
- Agricultural pesticide application.

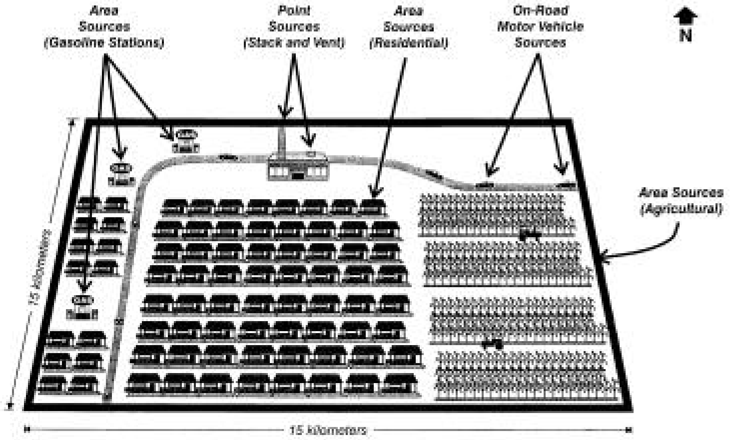

Figure 1-1. Hypothetical Modeling Inventory Community

All six emission sources emit TOG, while CO and NO_x emissions are limited to the two combustion sources (i.e., the factory boiler and light-duty automobiles). Assumed annual emissions for these six emission sources are presented in Table 1-1.

Table 1-1. Assumed Annual Emissions for Emission Sources in Hypothetical Modeling Inventory Community

Emission Source	TOG (Mg/yr)	CO (Mg/yr)	NO_x (Mg/yr)
Factory (Boiler)	200	600	400
Factory (Surface Coating)	300	N/A	N/A
Light-Duty Automobiles	400	800	600
Gasoline Stations	150	N/A	N/A
Residential Consumer Solvent Use	200	N/A	N/A
Agricultural Pesticide Application	100	N/A	N/A

Mg/yr = megagrams (10^6 grams or 1 metric ton) per year
N/A = not applicable

The number of emission sources has been limited to six, so that the various modeling inventory development steps can be adequately demonstrated without the number of associated calculations becoming too large. An actual modeling inventory will contain many more emission sources and will require more sophisticated data manipulation tools than the simple calculations presented in this manual. In addition, only TOG, CO, and NO_x emissions will be directly addressed in the model. There will be some discussion of PM and other pollutants, but the main focus of the example will be on TOG, CO, and NO_x. Finally, it should be noted that all values used in the hypothetical modeling inventory are for demonstration purposes only and should not be used in actual modeling inventories.

The remainder of this manual is organized as follows:

- Section 2.0 presents the data and computing requirements for a modeling inventory;
- Section 3.0 explains temporal allocation;
- Section 4.0 describes spatial allocation;
- Section 5.0 explains speciation;
- Section 6.0 discusses emission projections;

- Section 7.0 presents the modeling inventory development example for one source category;
- Section 8.0 contains some analyses of the entire hypothetical modeling inventory;
- Section 9.0 presents a conclusion for this manual;
- Section 10.0 contains references used in development of this manual;
- Appendix A contains the calculation spreadsheets used for the hypothetical modeling inventory;
- Appendix B presents the TOG speciation profiles associated with the source categories used in the hypothetical modeling inventory; and
- Appendix C presents the PM speciation profiles associated with the source categories used in the hypothetical modeling inventory.

2.0 MODELING INVENTORY REQUIREMENTS

The starting point for development of a modeling inventory is a database of emissions-related data, often referred to as the *base year inventory*. It is important to understand that a spreadsheet containing only the annual emission estimates for the base year would not be a sufficiently robust enough data set to support modeling inventory development. Examples of other emissions-related data that would need to be included in the base year inventory are facility information, material types and throughputs, stack parameters, etc. An extensive, but not comprehensive, list of needed base year inventory data for point sources is provided in Table 2-1. Similar data for area, motor vehicle, and biogenic sources are presented in Tables 2-2 through 2-4.

Table 2-1. Typical Base Year Inventory Data – Point Sources

Data Type	Data Element
Facility Data	Facility ID Facility Name Facility Industrial Code – SIC, NAICS, CMAP Facility UTMs (Easting, Northing, Zone)
Stack Data	Stack ID Stack Inside Diameter Stack Height (above ground surface) Stack Exit Temperature Stack Exit Velocity Stack Exit Flow Rate Stack UTM Coordinates (Easting, Northing, Zone) Stack Elevation (of base above sea level)
Device Data	Device ID Operation Schedule Data – Fractional Monthly Throughputs Fractional Seasonal Throughputs Operation Weeks/Year Operation Days/Week Operation Hours/Day
Process Data	Process ID SCC Annual Process Rate/Throughput

Table 2-1. (Continued)

Data Type	Data Element
Emissions Data	Pollutant ID Actual Emission Factors Actual Annual Emissions Primary Control Equipment Code Secondary Control Equipment Code Overall Control Equipment Efficiency

CMAP = Mexican Classification of Activities and Products
ID = identification number
NAICS = North American Industry Classification System
SCC = Source Classification Code
SIC = Standard Industrial Classification
UTM = Universal Transverse Mercator

Table 2-2. Typical Base Year Inventory Data – Area Sources

Data Type	Data Element
Location Data	State Code County/Municipality Code
Source Data	Area Category Code
Emissions Data	Pollutant ID Actual Emission Factor Allowable Emission Factor Actual Emission Estimate Allowable Emission Estimate Primary Control Equipment Secondary Control Equipment Control Efficiency Temporal Basis (Average Annual or Average Day)

ID = identification number

Table 2-3. Typical Base Year Inventory Data – Motor Vehicle Sources

Data Type	Data Element
Location Data	State Code County/Municipality Code
Source Data	Vehicle Class Vehicle Technology Type
Emissions Data	Pollutant ID Motor Vehicle Emission Process Code (i.e., REX, CST, HST, REV, HSK, DNL, CC) Total Daily County-Wide Emission Estimate

CC = crankcase emissions
CST = cold start emissions
DNL = diurnal emissions
HSK = hot soak emissions
HST = hot start emissions
ID = identification
REV = running evaporative emissions
REX = running exhaust emissions

Table 2-4. Typical Base Year Inventory Data – Biogenic Sources

Data Type	Data Element
Location Data	State Code County/Municipality Code
Source Data	Plant Community Code (i.e., Vegetation Type)
Emissions Data	Pollutant ID Canopy Type Biogenic Emission Flux (µg/m^2-hr)

hr = hour
ID = identification number
m^2 = square meter
µg = microgram

These additional data are needed to support the modeling and its end-uses such as analyzing source impacts and assessing the effectiveness of air pollution control strategies. For example, facility information can help identify which industrial sectors are the major contributors to air pollution in the inventory region and focus the development of control measures. Material types and throughputs may also be used to refine the control strategy (e.g., which fuel types are responsible for most of the combustion emissions). Stack parameters are used together with meteorological data to model the dispersion and transport of the pollutants from their release point. If accurate, inventory-specific data are not available, appropriate assumptions should be made for these missing data.

The base year inventory data also typically include fields for coding the emissions-related data. Coding systems are usually keyed to source types and facilitate the extensive manipulation of modeling inventory data. Without coding systems, data manipulation becomes difficult, if not impossible. Some examples of commonly used coding systems include state and municipality abbreviations, industrial classifications, and emission category codes. Coding systems are used to assign appropriate temporal profiles, spatial surrogates, and/or speciation profiles to emission estimates. An example of this assignment is provided in Table 2-5.

Table 2-5. Sample Coding System Assignment of Temporal Profiles, Spatial Surrogates, and Speciation Profiles

Source Category	SCC	AMS	Temporal Profile ID[a]	Spatial Surrogate ID[b]	Speciation Profile ID[c]
Factory Boiler	10200601	N/A	024	N/A	0002
Gasoline Stations	N/A	25-01-060-000	075	99	1190
Light-Duty Automobiles	N/A	22-01-001-000	051	47	1101

[a] The temporal profile ID is a numerical code that identifies a specific temporal profile; in this table, the temporal profile IDs are fictitious.

[b] The spatial surrogate ID is a numerical code that identifies a specific spatial surrogate; in this table the spatial surrogate IDs are fictitious.

[c] The speciation profile ID is a numerical code that identifies a specific speciation profile; in this table the speciation profile IDs were obtained from U.S. EPA's SPECIATE database (U.S. EPA, 1999c).

ID = identification number
N/A = not applicable
SCC = Source Classification Code

The existing industrial classification system in Mexico is the 1999 Mexican Classification of Activities and Products (CMAP), while the 1987 Standard Industrial Classification (SIC) system (OMB, 1987) is widely used in the United States (U.S.). The CMAP classification system is somewhat similar to the SIC system. However, the North American Industry Classification System (OMB, 1997; U.S. Census, 1999), a tri-national industrial classification system, is starting to be implemented in Mexico, the U.S., and Canada. Another example of codes are industrial location data codes that are used in the UBICIND database file within Mexico's National Information System of Point Sources (SNIFF).

The U.S. currently employs Source Classification Codes (SCC) for point sources and Area and Mobile Source (AMS) category codes for area and mobile sources. Listings of SCC codes are provided in Appendix E of Volume IV (*Point Source Inventory Development*) and listings of AMS codes are provided in Appendix A of Volume V (*Area Source Inventory Development*). Mexico currently does not have a comprehensive system of emission category codes, but such a coding system is needed before modeling inventories can be developed.

Due to the volume of data involved, an electronic emissions modeling system is a necessity for modeling inventory development. An emissions modeling system is a group of emissions models executed in a specific sequence that processes annual emission estimates to generate speciated, spatially and temporally resolved values for input to photochemical and other regional air quality models. Each emissions model is an integrated collection of calculational procedures, or algorithms, properly encoded for computer-based computation. For example, GEMAP and EMS-95 have distinct emissions models for point, area, motor vehicle, and biogenic sources. Figure 2-1 identifies the distinct emission models within the overall GEMAP structure. Emissions modeling systems also include a geographic information system (GIS) tool to process the various spatial data sets or “coverages” (e.g., the definition of the inventory domain, political boundaries, population, vegetation type, etc.). The GIS tool can be used to visualize various aspects of the modeling inventory that may not be readily apparent by simply looking at the numerical data in the inventory database.

Modeling inventories will have large quantities of data associated with them. This is not surprising given that inventory domains can be on the order of thousands of square kilometers with a required spatial resolution as fine as 500 meters. This is further compounded by the need for hourly estimates of potentially hundreds of chemical species for the large number of source categories that comprise a comprehensive modeling emissions inventory. A Mexico-specific example of the large volume of data generated with modeling inventories is conceptually illustrated in Figure 2-2.

An air toxics inventory was previously performed for Ambos Nogales (i.e., Nogales, Sonora; and Nogales, Arizona) (Radian, 1997). The characteristics of the inventory included:

- Domain evenly divided between Mexico and the U.S.;
- Domain measuring 19 kilometers (km) (north-south) by 12 km (east-west);
- 500-meter grid cells (total number of grid cells – 912);
- Four different seasons (total of 96 different hours);
- 113 individual air toxic species; and
- 103 different area and motor vehicle sources.

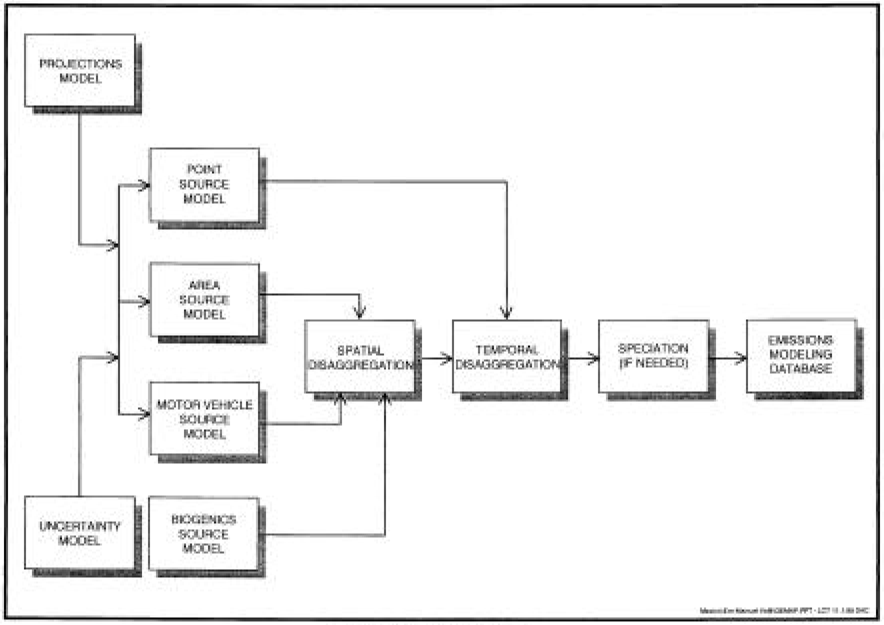

Figure 2-1. GEMAP Structure

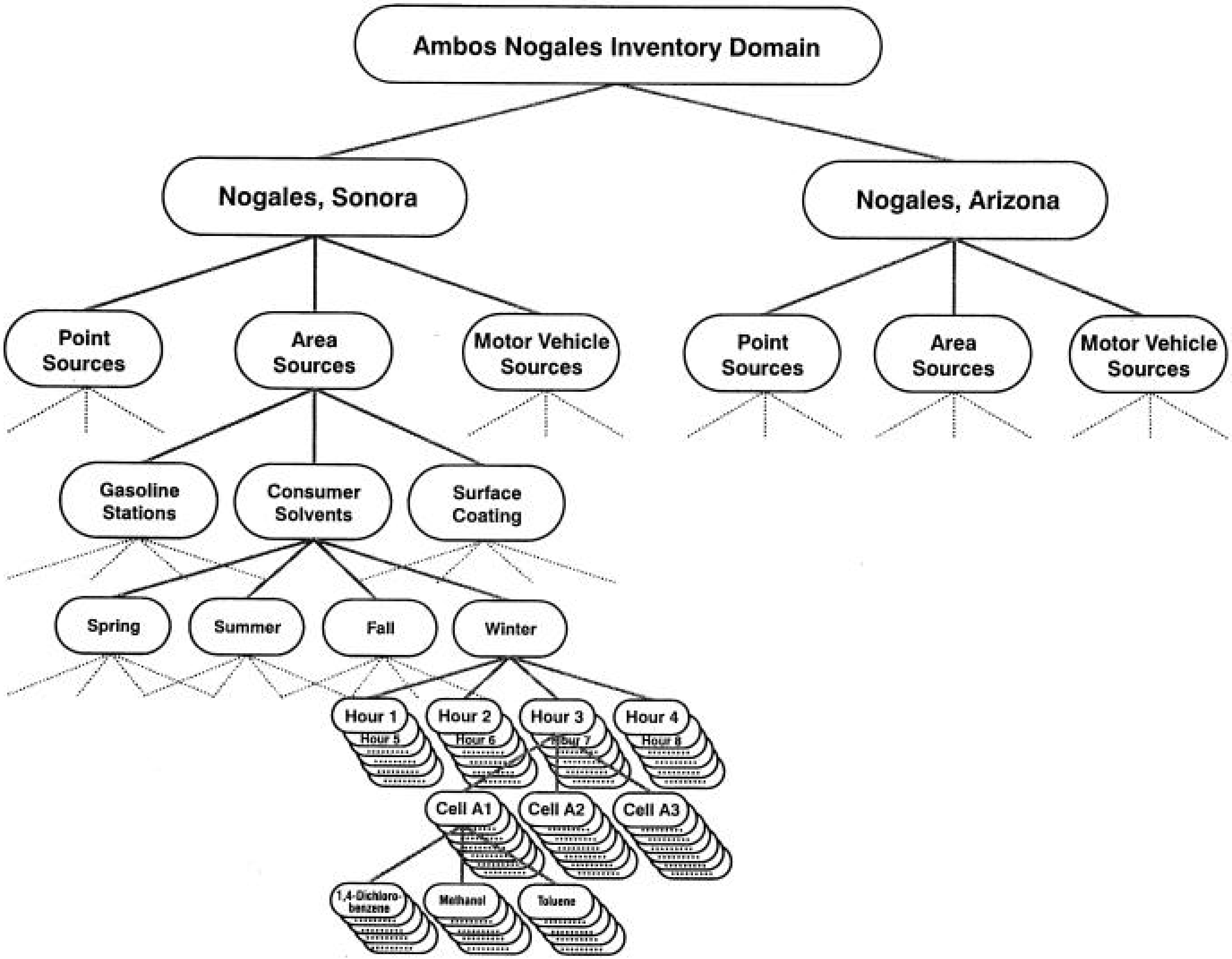

Figure 2-2. Conceptual Diagram of Ambos Nogales Hazardous Air Pollutant Modeling Inventory

Although not all air toxics were emitted from every source category and not all source categories were located in every grid cell for the Ambos Nogales air toxics inventory, the total potential number of speciated, spatially and temporally resolved emission values exceeded one billion (1 x 10^9). The actual number of emission values was somewhat less. In Figure 2-2, only some of the speciated consumer solvent emissions in Cell A1 for Nogales, Sonora during Hour 3 of an average winter day are represented. The entire inventory was much larger than this, but it could not be clearly represented in one figure; the other emissions were not presented in the figure in order to preserve conceptual clarity.

3.0 TEMPORAL ALLOCATION

The first step of modeling inventory development is the temporal allocation of emissions. Because air quality modeling attempts to represent the actual physical and chemical processes as they occur over a specific duration of time, it is important that the temporal allocation of emissions be as accurate as possible. Temporal allocation can be thought of as an accounting of emissions variation over time. The simplest temporal allocation is for a steady-state emissions source that continually releases emissions at the same rate all the time. Under actual conditions, however, steady-state emission sources are quite rare. Instead, under actual conditions, emission sources may operate only in the winter (e.g., space heating), not operate on Sundays (e.g., many commercial or industrial sources), or their activity may peak during certain hours of the day (e.g., motor vehicle commute traffic). Temporal allocations allow emissions variability to be correctly modeled during the desired modeling periods. The desired modeling periods will vary depending upon the purpose of the inventory. For instance, some inventories will need only average day emissions for each season, while other inventories will require more specific data to reproduce a historical multi-day ozone episode.

In general, the starting point for temporal allocation in modeling inventories is annual emission estimates. Temporal allocation is then performed using *temporal allocation profiles.* Temporal allocation profiles indicate the distribution of emissions over the selected period of disaggregation (e.g., season, week, day). The annual emission estimates are first disaggregated using seasonal (spring/summer/fall/winter) allocation profiles. Weekly allocation profiles are then used to account for differences in typical weekday, Saturday, and Sunday activity levels. Finally, hourly allocation profiles are used to estimate the hour-by-hour differences in emissions.

Default seasonal, weekly, and hourly temporal allocation profiles are often included in electronic emissions modeling systems. However, for each modeling inventory being developed, it should be determined whether or not it is appropriate to use the default allocation profiles. For some source categories, default allocation profiles do not accurately characterize the actual temporal distribution of emissions. If the use of default allocation profiles is not appropriate, some inventory-specific allocation profiles will need to be developed.

It should also be noted that “day-specific” emission estimates are required for some specialized modeling applications. The use of day-specific emission estimates, however, is not widespread because of typical inventory resource constraints and lack of day-specific data. Instead of estimating hourly emissions using temporal allocations in a “top-down” approach, day-specific emissions are estimated using a “bottom-up” approach that incorporates activity data (e.g., material throughput, hours of operation, etc.) from a specific designated day. Day-specific emissions are typically limited to a few significant point sources. In general, the disperse nature of other source types usually prevents activity data from being collected for a specific day. However, day-specific emissions are sometimes estimated for episodic source categories (e.g., wildfires, prescribed burning, agricultural pesticide application, etc.). Additional discussion of day-specific emissions can be found in Section 3.4.

3.1 Seasonal Allocation Profiles

The first step of temporal allocation is to disaggregate annual emissions into four seasonal emissions subtotals using seasonal temporal profiles. In some cases, seasonal temporal profiles are readily available, but in other situations they must be derived from monthly emissions or activity data. This is done by summing the monthly portion of emissions or activity data for three months into a single season. In general, modeling inventory seasons are conventionally defined as follows:

- Spring (March, April, May);
- Summer (June, July, August);
- Fall (September, October, November); and
- Winter (December, January, February).

However, local circumstances may dictate that different seasonal groupings be used. Monthly temporal allocation is sometimes, but not often, performed as part of modeling inventory development.

Some emission sources release emissions at the same rate throughout the year, while other emission sources have significant seasonal variations. Figure 3-1 shows assumed seasonal allocation profiles for two of the sources in the hypothetical modeling inventory. The first assumed seasonal profile shows an emission source that is constant throughout the year (i.e., the factory coating process); the second assumed seasonal profile shows a seasonally variable emission source (i.e., the factory boiler used for heating). The boiler shows high emissions during the winter, which is a period of high space-heating demand, while no emissions are assigned to the summer because the boiler is not used during that period of time. Other examples of seasonally variable emission sources include motor vehicles (due to possible increased usage during vacation and holiday periods) and agricultural activities (due to seasonal crop requirements). Regardless of the seasonal variability, all seasonal (or monthly) allocations should add to 1.00 (or 100 percent).

3.2 Weekly Allocation Profiles

After seasonal allocation has been completed, emissions must be allocated on a weekly basis (i.e., typical weekday, Saturday, and Sunday). For many sources, emissions are not constant throughout the week. For instance, operation of many industrial facilities will be limited to a five- or six-day workweek. Likewise, urban motor vehicle activity and emissions will be somewhat different during the weekend, which is strongly influenced by recreational activities, compared to weekdays, which are dominated by commute traffic. Unlike the seasonal allocation profiles, which sum to 1.00 and are easy to estimate from monthly allocations, the determination of weekly profiles is more complex. The steps for determining weekly profiles are outlined as follows:

- The average daily factor (F_{ad}) for any season is 0.011 of the seasonal emissions (100 percent divided by 91 days in a season).
- The average daily factor is converted to an average weekday factor (F_{wd}) by multiplying the average daily factor by the ratio of the actual weekday fraction of weekly emissions (A_{wd}) divided by the average day fraction of weekly emissions (i.e., 1 day divided by 7 days, or approximately 0.1429).

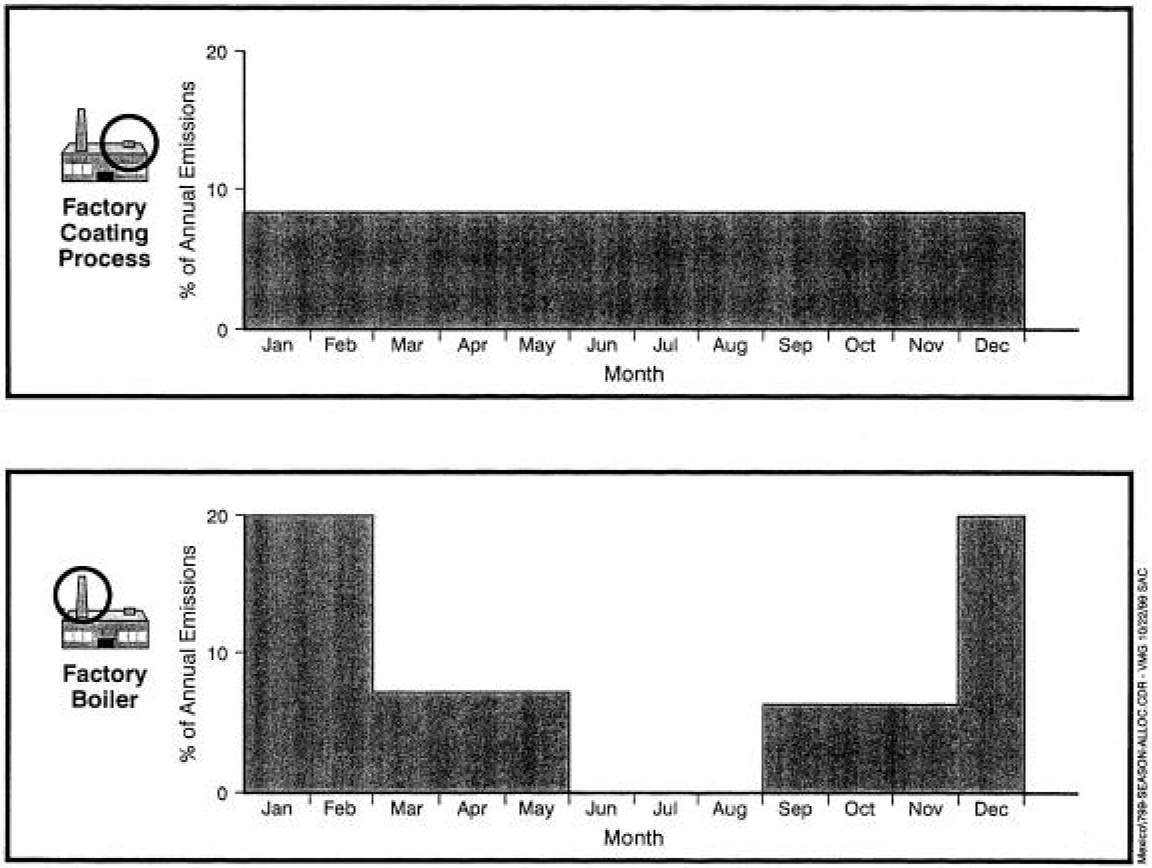

Figure 3-1. Examples of Assumed Constant and Variable Seasonal Allocation Profiles for the Hypothetical Modeling Inventory

- Average Saturday and Sunday factors (F_{sat}; F_{sun}) are estimated in a similar manner; the average daily factor is multiplied by the ratio of the actual Saturday and Sunday fractions of weekly emissions (A_{sat}; A_{sun}) divided by the average day fraction.

For example, assume that a source category operates on Monday through Friday with equal activity on each day and with no operation on Saturday or Sunday. As mentioned above, the average daily emissions are 1.1% of the total seasonal emissions. The actual average weekday fraction of weekly emissions is 0.200 (i.e., 1.00 divided by 5 weekdays), while the actual Saturday and Sunday fractions of weekly emissions are both 0.000. The calculation of the average weekday, Saturday, and Sunday factors is shown as follows:

$$F_{wd} = 1.1\% \times (0.200/0.1429) = 1.54\%$$
$$F_{sat} = 1.1\% \times (0.000/0.1429) = 0.00\%$$
$$F_{sun} = 1.1\% \times (0.000/0.1429) = 0.00\%$$

The weekly allocation factors can be verified by applying the following equation (where 65 is the number of weekdays in a season and 13 is the number of Saturdays or Sundays in a season):

$$(65 \times F_{wd}) + (13 \times F_{sat}) + (13 \times F_{sun}) = 1.00$$
$$(65 \times 0.0154) + (13 \times 0.0000) + (13 \times 0.0000) = 1.001 \approx 1.000 \text{ ⁙}$$

If this equation is not correctly satisfied, an error has been made in the calculation of the weekly allocation factors.

3.3 Hourly Allocation Profiles

The final step of temporal allocation is the disaggregation of daily emissions (i.e., average weekday, Saturday, or Sunday) into hourly emissions. Except for some industrial facilities that may operate at the same level “around-the-clock,” most emission sources will undergo some sort of operational variation during the day. For instance, motor vehicle emissions will typically have distinct peak values during the morning and evening commutes, but will drop to very low levels in the early morning (i.e., 2 or 3 a.m.). Emissions from some industrial facilities will be limited to an 8-hour shift. Assumed hourly allocation profiles for both of these examples are shown in Figure 3-2. The hourly allocation profiles indicate the fraction of daily emissions that occur in each hour. Regardless of the hourly variability, the 24 hourly fractions in the hourly allocation profile should add up to 1.00 (or 100 percent).

3.4 Day-specific Emissions

For most modeling inventories, the "top-down" temporal allocation of annual emissions into progressively smaller time periods as described in Section 3.1 through Section 3.3 can be used. However, there may be some situations where day-specific emissions are desired. In particular, day-specific emissions are often used to model high-ozone (or other pollutant) events. Day-specific emissions are used in an effort to approximate a specific day's emissions as closely as possible; day-specific emissions will be more accurate than temporally allocated emissions which often rely on default temporal profiles. Day-specific emissions are generated using activity data collected for a particular day or even a specific hour. In general, day-specific emissions are usually only estimated from point sources with known operating schedules and parameters, but it may be feasible to estimate day-specific emissions from certain types of episodic area sources (e.g., wildfires, prescribed fires, agricultural pesticide application, etc.). Day-specific emissions also can be estimated for sources that are affected by extraordinary events (e.g., air quality alerts, sporting events, etc.). However, it will usually be too resource-intensive to collect day-specific activity data for all sources in an entire inventory.

3.5 Source Type Considerations

In addition to the general temporal allocation process discussed above, there are some issues that should be considered for certain source types. These issues are addressed as follows:

Point Sources

Ideally, temporal profiles will be assigned to the process level for all point sources. However, data availability and/or resource limitations may force temporal profiles to be assigned at a less refined level (i.e., device level or facility level). In order to determine

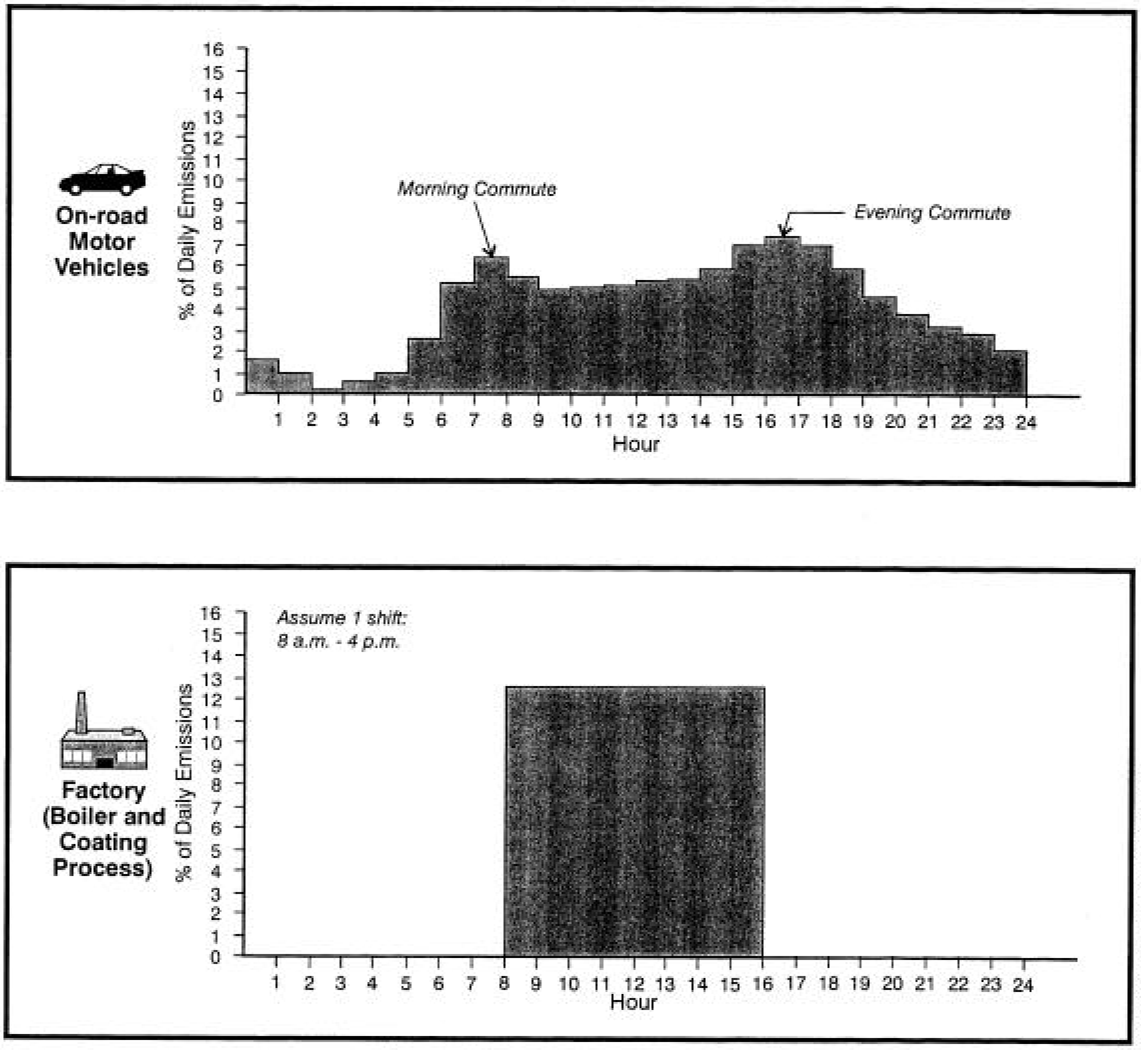

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Figure 3-2. Examples of Assumed Hourly Allocation Profiles for the Hypothetical Modeling Inventory

appropriate temporal profiles, actual point source operating schedules should be obtained wherever possible. These schedules will typically be obtained from surveys. Depending upon the selected air quality modeling requirements, temporal profiles for point sources may need to be adjusted for holiday operating schedules. Different temporal profiles should be considered for weekday and weekend activity levels for most sources.

Area Sources

Each area source category typically has a default temporal profile assigned to it by emissions modeling tools. However, the emission processes and temporal distribution for each inventory region varies (e.g., agricultural emissions will vary across different climatic regions due to different crop types and cultivation practices, cutback asphalt paving may be prohibited in summer months in some regions, etc.). Where possible, temporal profiles should be customized for each emissions inventory. If it is necessary to use default temporal profiles, these profiles should be assessed prior to the actual temporal allocation process to determine whether or not they are appropriate for a particular emissions inventory. Accurate temporal profiles will certainly improve the quality of hourly emissions.

Motor Vehicle Sources

Motor vehicles typically have considerable temporal variation. The amount of motor vehicle travel may vary significantly from season-to-season or month-to-month. Also, depending upon the inventory region, weekday travel patterns may be quite dissimilar to weekend travel patterns. Holiday motor vehicle activity levels may also be different from non-holiday activity levels. It is crucial that the temporal allocation profiles for motor vehicles accurately reflect actual motor vehicle activity for the specific time periods of interest.

Natural Sources

If computer models (e.g., PCBEIS [U.S. EPA's biogenic emissions model]) (U.S. EPA, 1998) are used to develop biogenic or other natural source emissions, temporal allocation normally is not needed because the temporal allocation has already been accounted for in the models.

3.6 Temporal Allocation Example

This portion of the example will focus on the temporal allocation of annual emissions to hourly emissions only; other modeling inventory development steps are demonstrated elsewhere in this document. In order to provide a clear example, the calculation of one hourly emission estimate (i.e., hourly emissions for the eighth hour [between 7 a.m. and 8 a.m.] on an average summer weekday) is shown for one emission source (i.e. on-road motor vehicles). A more detailed example sequentially showing all modeling inventory development steps for one source category is presented in Section 7.0; the emission calculations associated with the entire example are presented in Appendix A.

The assumed temporal allocations that are associated with the six sources in the hypothetical inventory grid are graphically shown in Figure 3-3 (monthly profiles), Figure 3-4 (weekly profiles), and Figure 3-5 (daily profiles). The numerical data for these profiles are provided in Appendix A. The temporal profiles shown in these figures are hypothetical and should not be used in the development of actual modeling inventories.

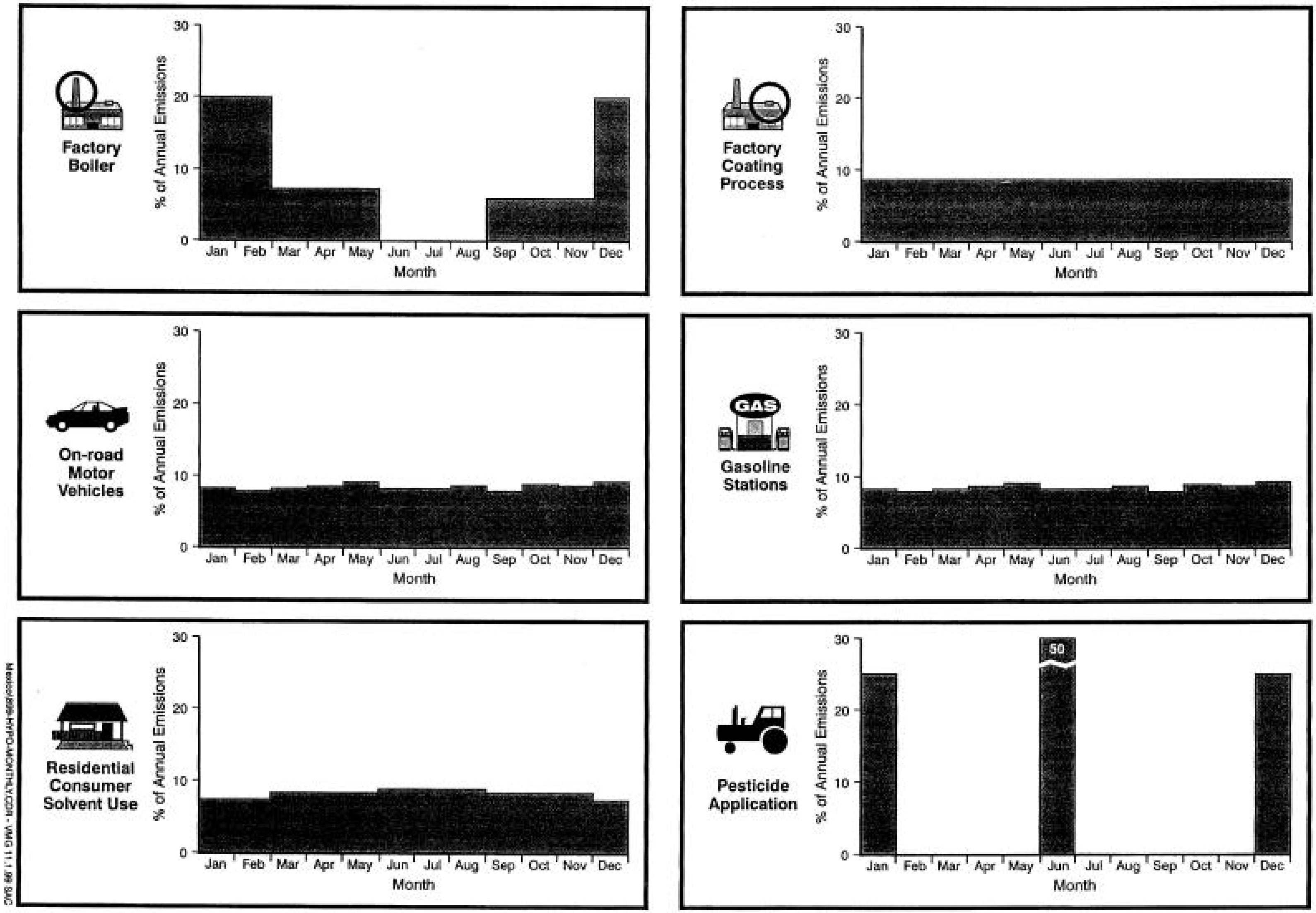

Figure 3-3. Assumed Monthly Temporal Allocation Profiles for the Hypothetical Modeling Inventory

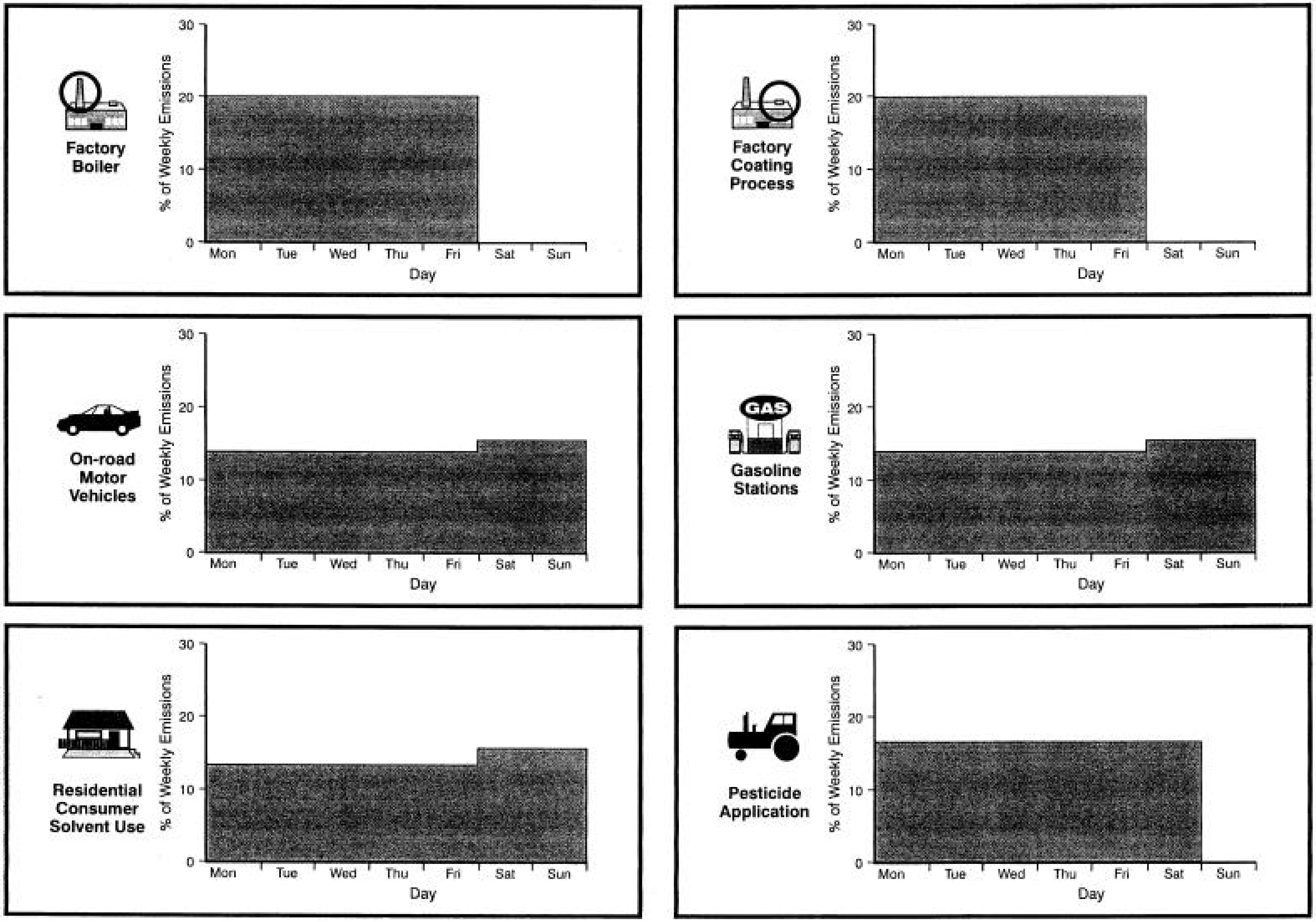

Figure 3-4. Assumed Weekly Temporal Allocation Profiles for the Hypothetical Modeling Inventory

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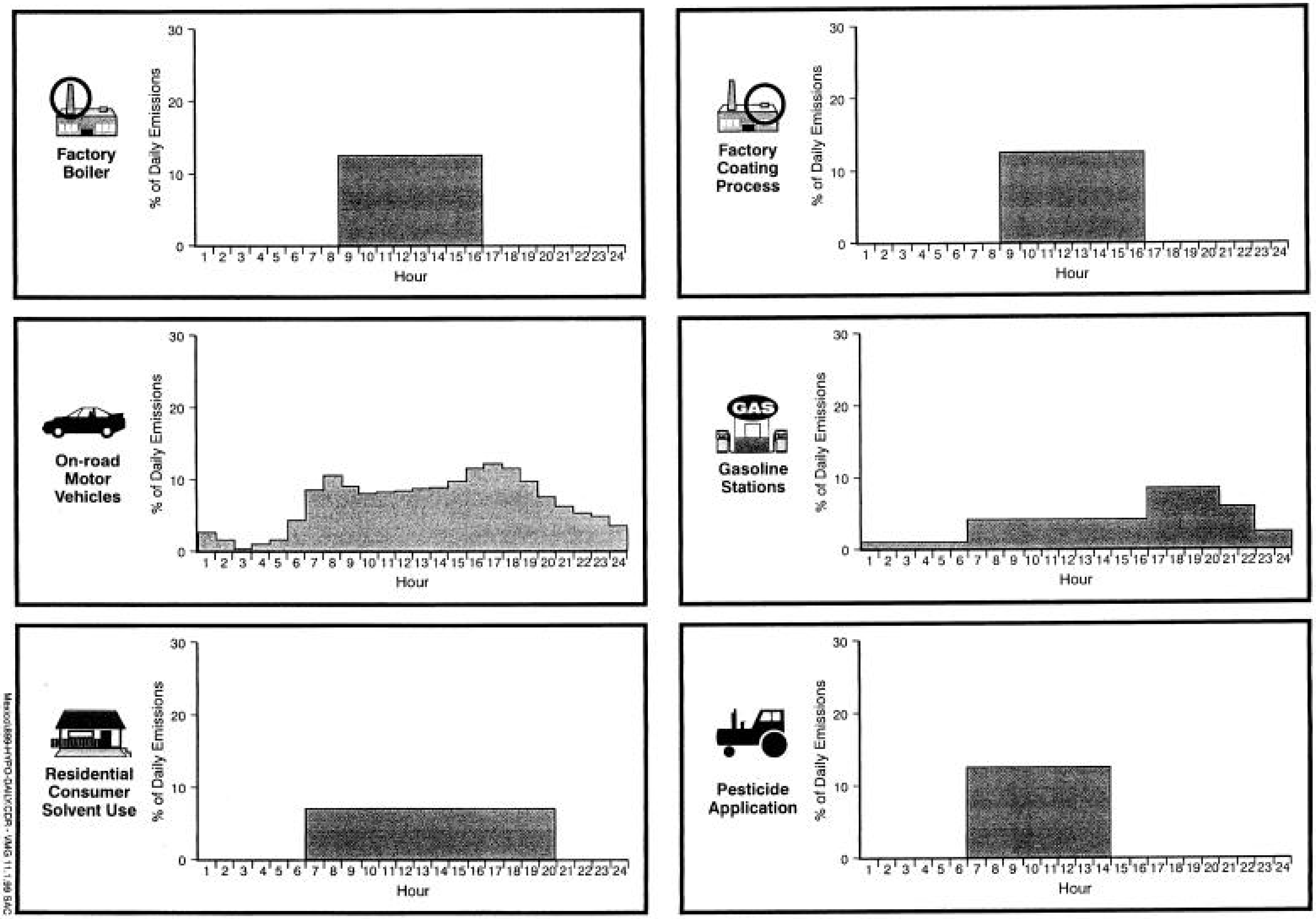

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Figure 3-5. Assumed Hourly Temporal Allocation Profiles for the Hypothetical Modeling Inventory

Example Calculation

Although the calculations presented in this example are quite straightforward, it should be pointed out that these calculations were limited to one season, day, hour, and source category. If all seasons, days, hours, and source categories are to be addressed, a large number of calculations will need to be performed. The number of calculations would further expand if the other modeling inventory steps (i.e., spatial allocation, speciation, and projections) are considered. This large volume of calculations will need to be performed with a computer modeling tool, rather than by hand, in order to reduce calculation time and minimize the number of potential errors

Step 1 – Seasonal Temporal Allocation

Motor vehicle activity is distributed throughout the year as shown in Table 3-1.

Table 3-1. Assumed Monthly Motor Vehicle Temporal Allocation Profile for the Hypothetical Modeling Inventory

Month	Fraction of Annual Activity
January	0.081
February	0.078
March	0.080
April	0.084
May	0.089
June	0.081
July	0.082
August	0.083
September	0.079
October	0.088
November	0.084
December	0.091
Total	**1.000**

The equation for converting monthly temporal allocations into seasonal temporal allocations is as follows:

$$TA_s = TA_{m1} + TA_{m2} + TA_{m3}$$

Where TA_s = Seasonal temporal allocation for season “s”;

TA_{m1} = Monthly temporal allocation for month 1 of season “s”;

TA_{m2} = Monthly temporal allocation for month 2 of season “s”; and

TA_{m3} = Monthly temporal allocation for month 3 of season “s.”

The four seasonal temporal allocations are calculated as follows (only the summer seasonal temporal allocation will be used throughout this example):

$$\begin{aligned}
TA_{win} &= TA_{Dec} + TA_{Jan} + TA_{Feb} &&= 0.091 + 0.081 + 0.078 = 0.250\\
TA_{spr} &= TA_{Mar} + TA_{Apr} + TA_{May} &&= 0.080 + 0.084 + 0.089 = 0.253\\
TA_{sum} &= TA_{Jun} + TA_{Jul} + TA_{Aug} &&= 0.081 + 0.082 + 0.083 = 0.246\\
TA_{fal} &= TA_{Sep} + TA_{Oct} + TA_{Nov} &&= 0.079 + 0.088 + 0.084 = 0.251
\end{aligned}$$

The calculation of the seasonal temporal allocations also should be checked, as shown below, to make sure it was performed correctly.

$$TA_{win} + TA_{spr} + TA_{sum} + TA_{fal} = 0.250 + 0.253 + 0.246 + 0.251 = 1.000 \checkmark$$

Assuming annual on-road motor vehicle emissions of 400 Mg/yr of TOG, 800 Mg/yr of CO, and 600 Mg/yr of NO_x (as previously defined in Table 1-1), the summer seasonal emissions are calculated as follows:

$$\begin{aligned}
E_{TOG,sum} &= Annual_{TOG} \times TA_{sum} &&= 400\ \text{Mg/yr} \times 0.246 = 98.4\ \text{Mg/yr}\\
E_{CO,sum} &= Annual_{CO} \times TA_{sum} &&= 800\ \text{Mg/yr} \times 0.246 = 196.8\ \text{Mg/yr}\\
E_{NOx,sum} &= Annual_{NOx} \times TA_{sum} &&= 600\ \text{Mg/yr} \times 0.246 = 147.6\ \text{Mg/yr}
\end{aligned}$$

STEP 2 – Weekly Temporal Allocation

Weekly motor vehicle activity is distributed as shown in Table 3-2.

Table 3-2. Assumed Weekly Motor Vehicle Temporal Allocation Profile for the Hypothetical Modeling Inventory

Day	Fraction of Weekly Activity
Monday	0.138
Tuesday	0.138
Wednesday	0.138
Thursday	0.138
Friday	0.138
Saturday	0.155
Sunday	0.155
Total	**1.000**

The equations for converting weekly temporal allocation into average weekday, Saturday, and Sunday factors are shown as follows (only the average weekday temporal allocation will be used throughout the example).

$$F_{wd} = F_{ad} \times (A_{wd}/0.1429) = 0.0110 \times (0.138/0.1429) = 0.0106 = 1.06\%$$
$$F_{sat} = F_{ad} \times (A_{sat}/0.1429) = 0.0110 \times (0.155/0.1429) = 0.0119 = 1.19\%$$
$$F_{sun} = F_{ad} \times (A_{sun}/0.1429) = 0.0110 \times (0.155/0.1429) = 0.0119 = 1.19\%$$

Where F_{wd} = weekday factor;
F_{sat} = Saturday factor;
F_{sun} = Sunday factor;
A_{wd} = Average weekday activity;
A_{sat} = Saturday activity;
A_{sun} = Sunday activity;
F_{ad} = average daily factor (1.00/91 days per season); and
0.1429 = average day fraction of weekly emissions (see page 3-3).

The calculation of the weekly temporal allocations also should be checked, as shown below, to make sure it was performed correctly (when 65 is the number of weekdays in a season and 13 is the number of Saturdays or Sundays in a season; see page 3-5).

$$(65 \times F_{wd}) + (13 \times F_{sat}) + (13 \times F_{sun}) = (65 \times 0.0106) + (13 \times 0.0119) + (13 \times 0.0119)$$
$$= 0.689 + 0.1547 + 0.1547 = 0.9984 \approx 1.00$$ ⌘

Using the calculated summer on-road motor vehicle emissions (98.4 Mg/yr of TOG, 196.8 Mg/yr of CO, and 147.6 Mg/yr of NO_x) and the calculated weekday factor of 0.0106, the average summer weekday emissions are calculated as follows:

$$
\begin{aligned}
E_{TOG,sumwd} &= E_{TOG,sum} \times F_{wd} = 98.4 \text{ Mg/yr} \times 0.0106 = 1.043 \text{ Mg/day} \\
E_{CO,sumwd} &= E_{CO,sum} \times F_{wd} = 196.8 \text{ Mg/yr} \times 0.0106 = 2.086 \text{ Mg/day} \\
E_{NOx,sumwd} &= E_{NOx,sum} \times F_{wd} = 147.6 \text{ Mg/yr} \times 0.0106 = 1.565 \text{ Mg/day}
\end{aligned}
$$

Step 3 – Hourly Temporal Allocation

Assumed hourly motor vehicle activity is distributed as shown in Table 3-3 below. As a convention, Hour 1 refers to the first hour of the day (midnight to 1 a.m.), Hour 2 refers to the second hour of the day (1 a.m. to 2 a.m.), and so on. Therefore, Hour 8 refers to the eighth hour of the day (7 a.m. to 8 a.m.).

Table 3-3. Assumed Hourly Motor Vehicle Temporal Allocation Profile for the Hypothetical Modeling Inventory

Hour	Fraction of Daily Activity
1	0.016
2	0.010
3	0.003
4	0.006
5	0.010
6	0.026
7	0.053
8	0.064
9	0.055
10	0.048
11	0.050
12	0.052
13	0.054
14	0.055
15	0.059
16	0.070
17	0.074
18	0.070
19	0.058
20	0.046
21	0.037
22	0.033
23	0.028
24	0.022
Total	**1.000**

The hourly emissions for Hour 8 of an average summer weekday emissions are given below:

$$E_{TOG,sum,wd,8} = E_{TOG,sum,wd} \times F_8 = 1.043 \text{ Mg/day} \times 0.064 = 0.067 \text{ Mg/hr}$$
$$E_{CO,sum,wd,8} = E_{CO,sum,wd} \times F_8 = 2.086 \text{ Mg/day} \times 0.064 = 0.134 \text{ Mg/hr}$$
$$E_{NOx,sum,wd,8} = E_{NOx,sum,wd} \times F_8 = 1.565 \text{ Mg/day} \times 0.064 = 0.100 \text{ Mg/hr}$$

Hourly emission calculations for the other hours are performed in the same manner.

4.0 SPATIAL ALLOCATION

After performing the temporal allocation of emissions, the second step of modeling inventory development is the spatial allocation of emissions. Because air quality modeling strives to replicate the actual physical and chemical processes that occur in an inventory domain, it is important that the physical location of emissions be determined as accurately as possible. In an ideal situation, the physical location of all emissions would be known exactly. In reality, however, the spatial allocation of emissions in a modeling inventory only approximates the actual location of emissions.

Before any spatial allocation can be performed, several characteristics of the inventory must be identified. First, the modeling grid domain must be established. The grid domain of the hypothetical community is shown in Figure 4-1 as thick black perimeter line. The dimensions of the grid domain measure 15 km by 15 km. A modeling grid domain is a rectangular area that encompasses all the desired emission sources to be modeled. In this manual's hypothetical example, the modeling grid domain corresponds exactly with the community boundaries. In real life, however, rectangular modeling grids will be assigned to irregularly-shaped areas.

The modeling objectives and purposes often will determine the modeling grid domain used. For example, a hazardous air pollutant (HAP) inventory conducted for Ambos Nogales (Nogales, Sonora; and Nogales, Arizona) used a relatively small grid domain (12 km by 19 km) (Radian, 1997). This grid domain size was determined by the actual limits of urban development. In contrast, the emissions inventory developed in support of the Grand Canyon Visibility and Transport Commission (GCVTC) extended from southern Canada to northern Mexico in the north-south direction and from the Mississippi River to the Pacific Ocean in the east-west direction (Radian, 1995). A large domain size was selected to address the issues of long-distance transport and visibility impairment. The choice of modeling grid domain may also be influenced by local topography and/or meteorology. For instance, topography often determines the size and shape of air basins which may affect grid domain selection. In addition,

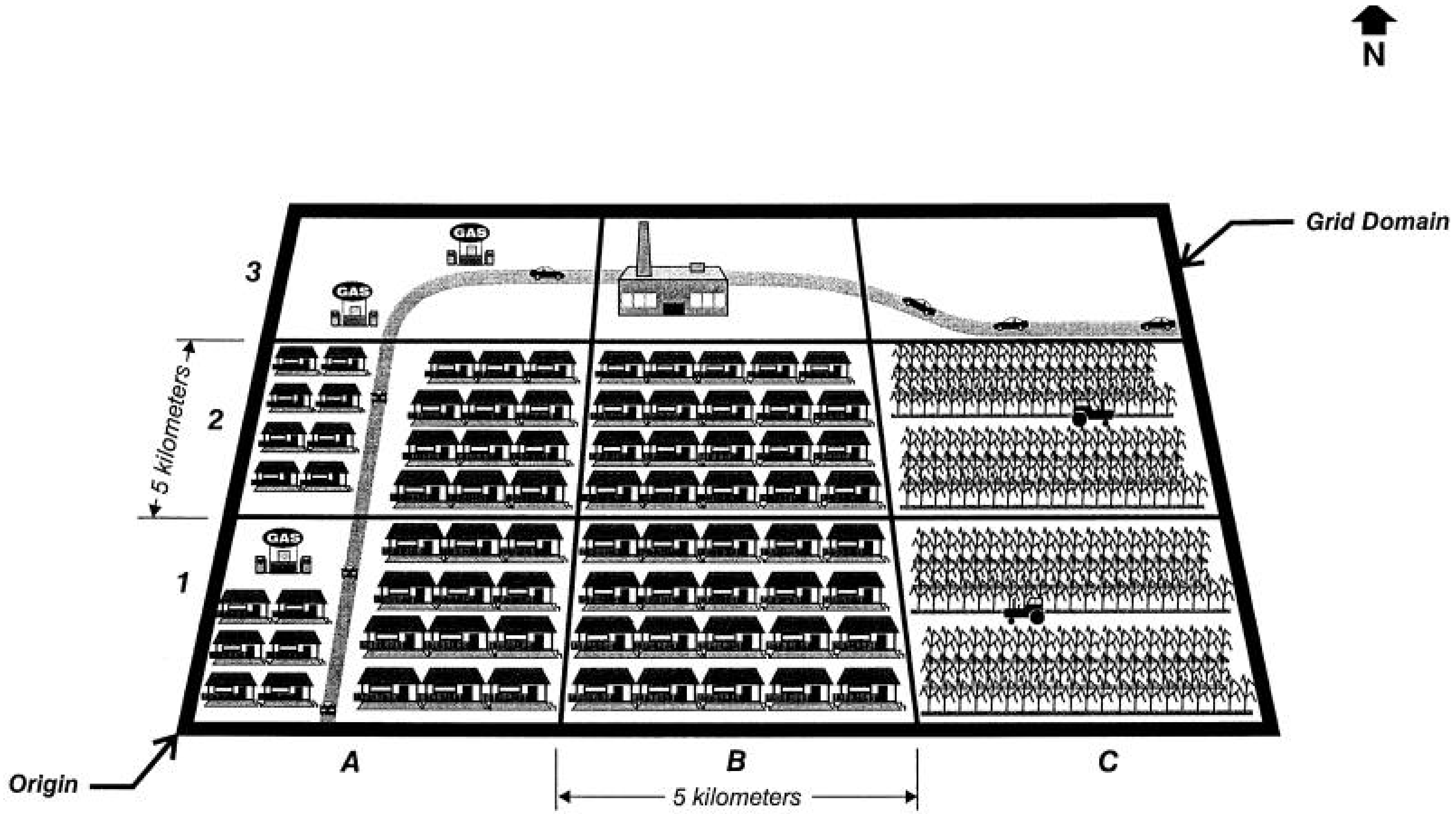

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Figure 4-1. Hypothetical Modeling Inventory Community and Modeling Grid meteorology (e.g., prevailing wind direction) may cause a particular grid domain to include certain emission sources.

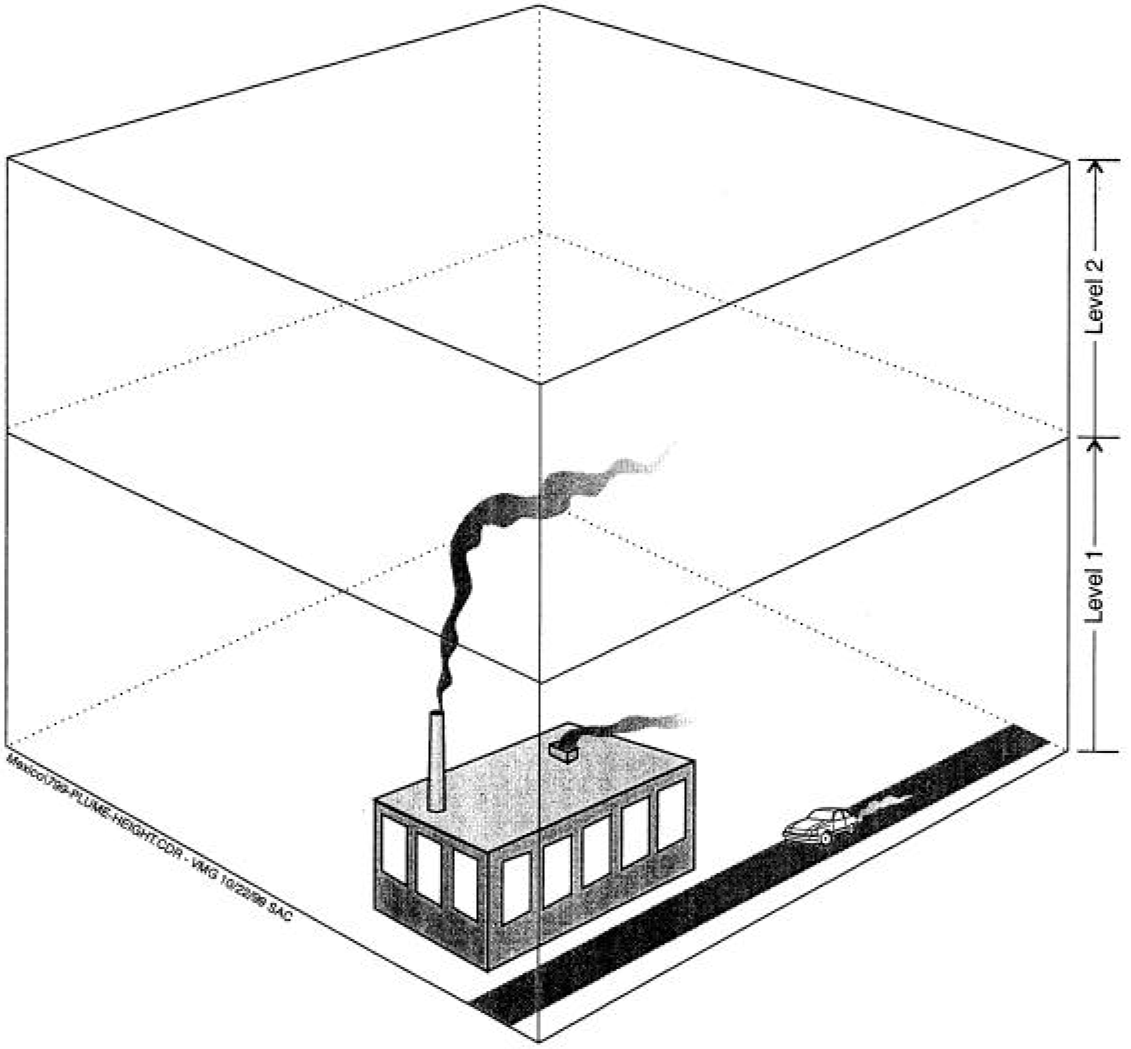
The next step after establishing the extent of the grid domain is to determine the size of the smaller grid cells within the grid domain. The nine grid cells shown in Figure 4-1 each measure 5 km by 5 km. Grid cells always will be square and nearly always will be of equal size. Smaller grid cells are occasionally nested inside other grid cells in order to effectively model local effects, but this is generally not done. Once again, selected modeling objectives and purposes may influence the grid cell size to be used. Large regional inventories may have grid cells 5 km by 5 km or larger; smaller inventories for a single metropolitan area may have grid cells 1 km by 1 km or smaller. The Ambos Nogales inventory mentioned above used grid cells that measured 500 meters (m) by 500 m. In this inventory, several of the ambient air monitors were located very close together. In order to have these monitors located in their own grid cells, a small grid cell size was required. On the other hand, the Grand Canyon inventory used 50 km by 50 km grid cells. Using smaller grid cells for this inventory might have adversely impacted resources needed for data management.

The advantages and disadvantages of specific grid cell sizes should be assessed prior to actual selection. For example, smaller grid cells will reduce modeling uncertainty; however, they may adversely affect inventory resources (e.g., insufficient computer memory, overly long modeling run times, unwieldy data outputs, etc.). Reducing the size of grid cells from 2 km by 2 km to 1 km by 1 km will increase the total number of cells in the grid by a factor of four. Inventory resources will likely be affected in a similar manner. Finally, if three-dimensional grid models are to be employed, cell heights will need to be established. A three-dimensional grid model will have two to five cell layers representing different heights in the atmosphere; however, most emissions will occur in the bottom layer (i.e., ground level).

The final step in establishing grid characteristics is fixing the grid origin and associated cell-naming convention. Without a cell-naming convention, describing a certain cell as “the eighth cell in the sixth row” does not refer to a unique cell (i.e., is this the sixth row from the top or from the bottom? Is this the eighth cell from the left or from the right?). In the U.S. and elsewhere, the southwest corner of the grid domain conventionally has been designated as the grid origin. In Figure 4-1, the southwest (i.e., bottom left) corner of the grid domain is the origin and all the grid cells are numbered from there. The grid cells are identified from west to east (i.e., left to right) using letters of the alphabet and from south to north (i.e., bottom to top) using numbers. As an example, in Figure 4-1, “the second cell in the third row” uniquely refers to cell B3.

After defining the necessary grid characteristics, the spatial allocation of emissions can be performed. Spatial allocation can refer to both horizontal and vertical allocation. (Most of the discussion in this manual relative to spatial allocation focuses on horizontal allocation because it is applicable for all emission sources. Vertical allocation will be addressed to a lesser degree because it is applicable for only a few types of emission sources.) Horizontal spatial allocation refers to assigning emissions to their proper grid cell prior to modeling activities. The specific method of allocation will vary depending upon the source type emissions being allocated. Vertical spatial allocation refers to assigning emissions to their proper layer in the atmosphere prior to modeling activities.

Vertical allocation is limited to those emissions that are released from an elevated height with a significant upward velocity and/or buoyancy. It is most important for specific air quality episodes that are characterized by low mixing heights. For all practical purposes, vertical allocation is limited to significant point sources with elevated stacks. An example of vertical allocation is shown in Figure 4-2. The emissions from the elevated point source stack are shown rising into Level 2, which indicates a relatively high upward release velocity and/or buoyancy. The emissions from the rooftop vent of the same point source, however, stay within Level 1; these emissions likely have a lower upward release velocity and/or buoyancy than the point source stack emissions. Also, as shown in Figure 4-2, emissions from motor vehicles (and area sources) are assumed to remain within Level 1. In general, vertical spatial allocation is a step performed automatically by the emissions modeling system (or in some cases by the air quality model) based upon the stack parameters listed in Table 2-1.



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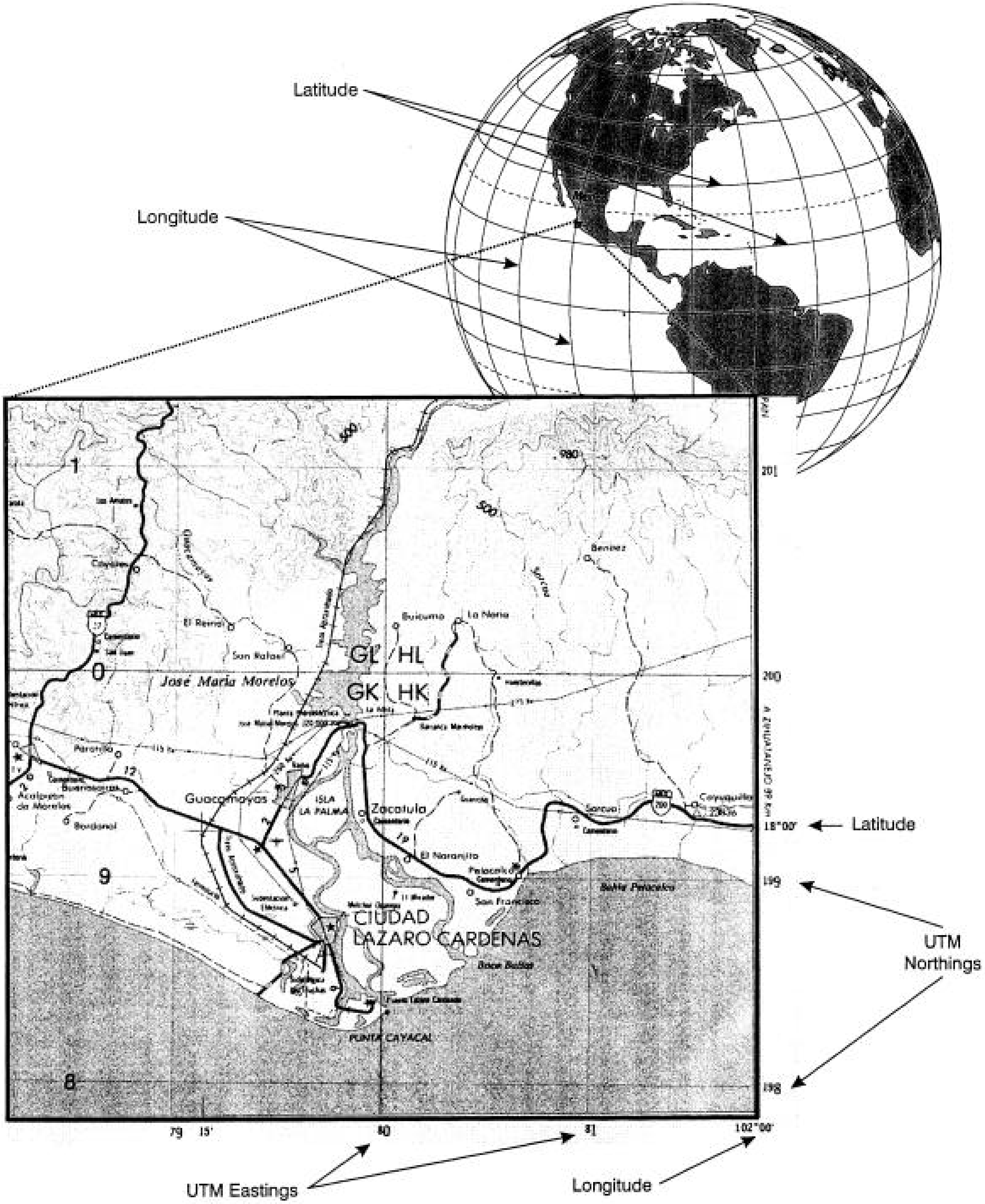
4.1 Points (Point Sources)

Point sources are spatially allocated to a modeling grid based upon precise location information and stack parameters. Point sources are, by definition, emission sources that have a specific, identifiable point of release.

Point source emissions are typically spatially allocated to the modeling grid using Universal Transverse Mercator (UTM) projection coordinates. Emission locations identified by latitude-longitude coordinates or other geographic coordinate systems should be transformed into UTM coordinates. The transformation of latitude-longitude coordinates to UTM coordinates is typically performed using a GIS-type application with this built-in capability (e.g., ArcInfo™), rather than by hand. An example of UTM and latitude-longitude coordinates in Lázaro Cárdenas, State of Michoacan, Mexico, is presented in Figure 4-3. Specific geographic coordinate information should be collected for those point sources that are only identified by census tracts, postal codes, or physical addresses; these types of location identifiers are insufficient for use in a modeling inventory. Some maps can provide UTM coordinates. More recently, however, global positioning systems (GPS) have become an economical way to identify UTM coordinates. Ideally, each individual point source (e.g., stacks, vents, etc.) would be precisely identified on a device level and allocated to the modeling grid. However, this level of detail is sometimes not available. In such circumstances, emissions are allocated on a less refined basis (i.e., process level or facility level).

The vertical spatial allocation of point source emissions is determined by the stack parameters associated with each point source. Stack parameters (i.e., stack height, stack diameter, flowrate, exit velocity, and gas exit temperature) are used by air quality models to estimate the plume rise and trajectory of emissions. Emissions from stacks with higher exit velocities and/or gas exit temperatures will tend to rise to a higher altitude than emissions from stacks with lower exit velocities and/or gas exit temperatures.



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It is important that these stack parameters be collected at the same time that point source emissions are estimated. Also, stack parameters should be screened for "reasonableness"; incorrect stack parameters may lead to suspect air quality modeling results. Experience in the U.S. indicates that approximately 20% to 30% of the stacks have one or more incorrect stack parameters (U.S. EPA, 1999b). Some examples of questionable stack parameters include stack heights greater than 400 meters, supersonic exit velocities, and gas exit temperatures cooler than ambient temperature. Such stack parameters should not automatically be discarded, but further research should be conducted to assess their validity.

4.2 Areas (Area and Natural Sources)

The major difference between point source emissions and area and natural source emissions is that point source emissions are released from an individual discrete location while area and natural source emissions are released from a large number of disperse locations. It is impractical, if not impossible, to identify all the release points associated with area and natural source emissions; thus, a more indirect method of spatial allocation is used for area and natural source emissions. This spatial allocation method involves the use of "spatial surrogates." Some examples of spatial surrogates include population, housing, land use, etc. The spatial surrogates are thought to approximately represent the spatial distribution of emissions throughout the grid domain. For example, population is typically thought to be an appropriate spatial surrogate for allocating consumer solvent emissions because consumer solvent users are the population in general. On the other hand, population would probably not be an appropriate spatial surrogate for allocating agricultural emissions because the entire population is not involved in agricultural activities.

A short example demonstrating how spatial surrogates are developed is provided here. There is a hypothetical inventory domain (unrelated to the other hypothetical inventory domain presented in this document) that contains only four grid cells (e.g., A, B, C, and D). It is assumed that consumer solvent emissions are proportionally related to population. The population of the four grid cells is provided in Table 4-1.

Table 4-1. Population for a Hypothetical Four Grid Cell Inventory Domain

Cell	Population
A	103,800
B	26,900
C	57,200
D	71,500
Total	**259,400**

The spatial allocation factor for Cell A is calculated by dividing the population for Cell A by the total population for the four grid cells (103,800/259,400 = 0.4002). The spatial allocation factors for the other three cells are calculated in a similar manner. These spatial allocation factors are presented in Table 4-2.

Table 4-2. Calculated Consumer Solvent Spatial Surrogates for a Hypothetical Four Grid Cell Inventory Domain

Cell	Spatial Surrogates
A	0.4002
B	0.1037
C	0.2205
D	0.2756
Total	**1.0000**

In order to spatially allocate an entire inventory, a unique spatial surrogate will need to be assigned to each area source category which is typically defined using source codes (some recommended source codes are provided in Volume V of this manual series [*Area Source Inventory Development*]). It should be noted that all area and natural source emissions are assumed to be ground-level releases. Thus, spatial allocation for area and natural source emissions is usually limited to horizontal allocation. Some natural source emissions (e.g., biogenic emissions) may often be estimated using an emissions model (e.g., PCBEIS) which often include spatial allocation in the calculation process. Such emissions models typically use land use and vegetative cover information to estimate emissions on an individual county basis.

4.3 Lines (Motor Vehicles, Railroads, and Shipping Lanes)

Although mobile sources (including on-road motor vehicles and nonroad mobile sources) are sometimes grouped with area sources in an inventory, their spatial allocation is somewhat different. Specifically, many mobile sources are limited to operation on linear transportation networks (e.g., on-road motor vehicles to road networks, locomotives to railroad systems, and commercial marine vessels to specific shipping lanes). On-road motor vehicle activity (e.g., vehicle kilometers traveled [VKT], trips, starts, etc.) is often modeled on the road network using travel demand models (TDM) or other transportation models; simpler models may also exist for other types of mobile sources. These transportation models can be used to allocate activity data (e.g., VKT) to individual network segments. Activity data can then be adjusted for any special conditions that exist at the individual network segment level. For example, the effects of higher vehicle speeds or more traffic congestion can be assigned to individual segments.

The modeling inventory ultimately needs to have emissions assigned to either specific UTM coordinates (for point sources) or specific grid cells (all other sources). As a result, motor vehicle emissions are spatially allocated to specific grid cells depending upon the relevant activity occurring within those grid cells. Activity data may be fractionally split into multiple grid cells based upon the fraction of activity within each grid cell. For instance, a road segment that crosses three grid cells and has equally distributed motor vehicle activity along its entire length would have one-third of its emissions assigned to each one of the three relevant grid cells.

4.4 Spatial Allocation Example

This portion of the example focuses on the spatial allocation of annual emissions to individual grid cells only; other modeling inventory development steps are demonstrated elsewhere in this document. In an actual modeling inventory, temporal allocation of annual emissions to hourly emissions would be performed first. However, in order to provide a clear illustration of the spatial allocation process, spatial surrogates are applied directly to annual emissions. This example is limited to spatial allocation of annual emissions for one source category only. A more detailed example sequentially showing all modeling inventory development steps for one source category is presented in Section 7.0; the emission calculations associated with the entire example are presented in Appendix A.

Figure 4-4 presents the six spatial surrogates that are associated with the hypothetical inventory grid. The fraction of emissions assigned to each grid cell is indicated as a decimal number. If emissions are not present in a particular grid cell, then a zero is indicated in the spatial surrogates. It should be noted that this example does not include UTM coordinates or other geographic coordinates for the factory stack and vent. All the emissions from the factory stack and vent are simply allocated to the cell where the factory is located (i.e., Cell B3). Also, this example does not include vertical allocation of the factory stack emissions; all emissions are assumed to occur at or near ground level.

Example Calculation

One road segment is assumed to pass through the inventory grid as shown in Figure 4-1. The road segment passes through five grid cells (A1, A2, A3, B3, and C3). It is assumed that the fractional road segment distance and motor vehicle activity is equally distributed among these five grid cells. The motor vehicle spatial surrogate, therefore, has 20% of the total emissions assigned to each grid cell. The equation for spatially allocating emissions is as follows:

$$E_{xy} = \text{Annual} \times SS_{x,y}$$

Where E_{xy} = Annual emissions in grid cell x,y (Mg/yr);

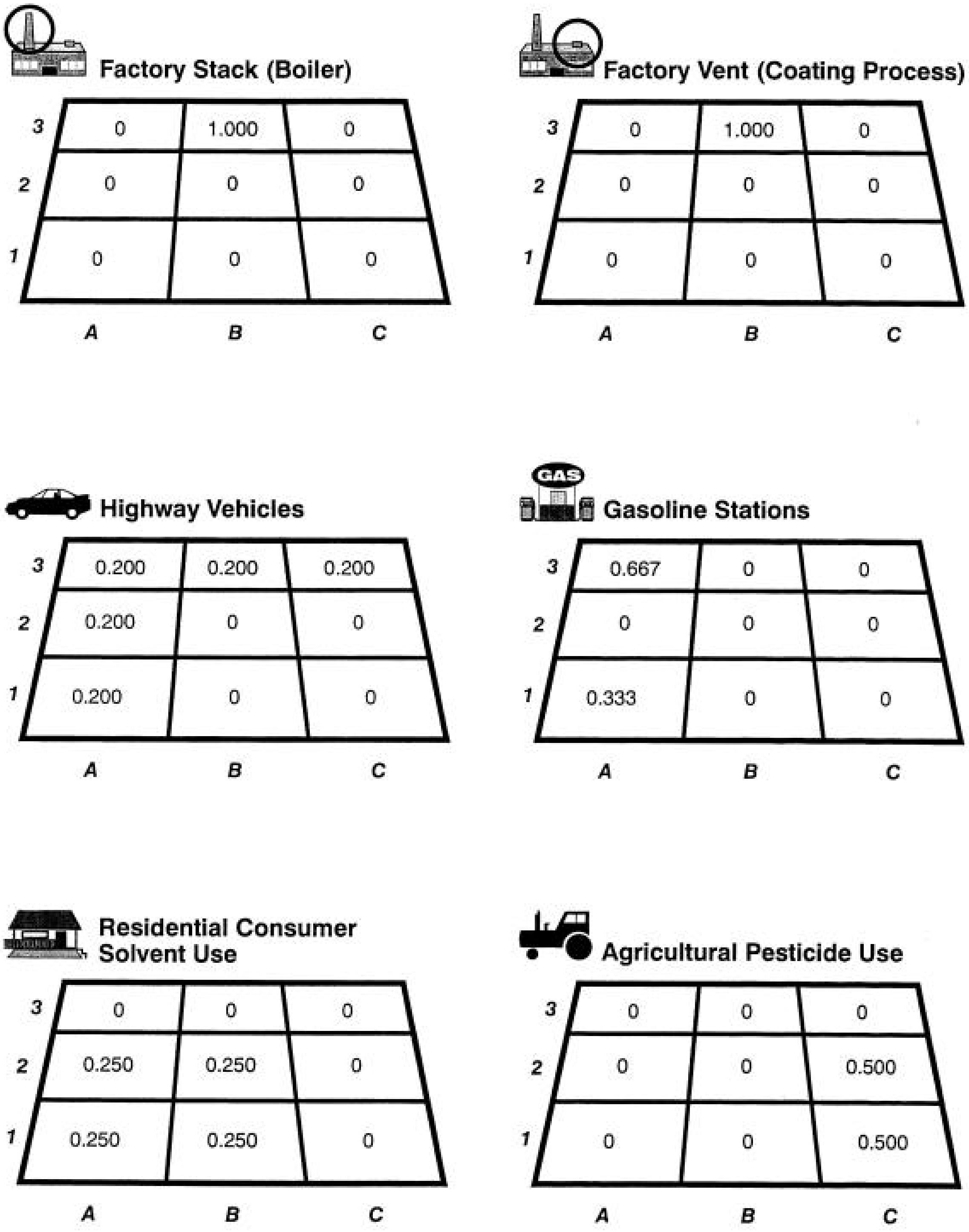
Annual = Annual emissions for entire domain (Mg/yr); and

$SS_{x,y}$ = Spatial surrogate fraction for grid cell x,y.

Using this equation, the TOG, CO, and NO_x emissions for motor vehicles in Cell A1 are calculated as follows using the emission values previously defined in Table 1-1.

$$E_{TOG,A1} = \text{Annual}_{TOG} \times SS_{A1} = 400 \text{ Mg/yr} \times 0.200 = 80 \text{ Mg/yr}$$
$$E_{CO,A1} = \text{Annual}_{CO} \times SS_{A1} = 800 \text{ Mg/yr} \times 0.200 = 160 \text{ Mg/yr}$$
$$E_{NOx,A1} = \text{Annual}_{NOx} \times SS_{A1} = 600 \text{ Mg/yr} \times 0.200 = 120 \text{ Mg/yr}$$

Emission calculations for the other four grid cells that contain motor vehicle emissions (i.e., Cells A2, A3, B3, and C3) are identical to these.



Factory Stack (Boiler)

	A	B	C
3	0	1.000	0
2	0	0	0
1	0	0	0

Factory Vent (Coating Process)

	A	B	C
3	0	1.000	0
2	0	0	0
1	0	0	0

Highway Vehicles

	A	B	C
3	0.200	0.200	0.200
2	0.200	0	0
1	0.200	0	0

Gasoline Stations

	A	B	C
3	0.667	0	0
2	0	0	0
1	0.333	0	0

Residential Consumer Solvent Use

	A	B	C
3	0	0	0
2	0.250	0.250	0
1	0.250	0.250	0

Agricultural Pesticide Use

	A	B	C
3	0	0	0
2	0	0	0.500
1	0	0	0.500

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Figure 4-4. Spatial Surrogates for the Hypothetical Modeling Inventory

5.0 SPECIATION

The third step in modeling inventory development is speciation. This is the process of disaggregating inventory pollutants (e.g., TOG, NO_x) into individual chemical species components (e.g., toluene, NO_2) or groups of species. The need for speciation is determined by the inventory purpose. Inventory applications that require detailed speciation include photochemical modeling, air toxics inventories, chemical mass balance modeling, and visibility modeling. This section describes different speciation procedures for a variety of pollutants and source types.

Depending on the purpose of a particular emissions inventory, the inventory may include TOG, NO_x, sulfur oxides (SO_x), CO, total suspended particulate matter (TSP), particulate matter less than 10 micrometers in aerodynamic diameter (PM_{10}), or ammonia (NH_3). However, modeling inventories may require these emissions to be expressed in terms of other pollutants. For example, most photochemical models require that hydrocarbon emissions are expressed in terms of designated reactivity groups or “classes” of compounds. Additionally, for some models, NO_x emissions may need to be specified as NO and NO_2. Also, PM may need to be separated into various size fractions, such as PM_{10} and PM less than 2.5 micrometers in aerodynamic diameter ($PM_{2.5}$).

Modeling inventories can be developed using either discrete speciation (e.g., for air toxics) or lumped-model speciation (e.g., for photochemical modeling). The specific required speciation mechanism will typically be specified by the modeling software that is used. The following definitions of these two speciation methods are from the U.S. EPA (U.S. EPA, 1999b):

- **Discrete speciation –** refers to splitting emissions for a pollutant into individual chemical compounds or size classifications. For example, TOG emissions from automobile exhaust may consist of 50 or more identified organic compounds (e.g., benzene, hexane, formaldehyde). Discrete speciation is performed using speciation profiles containing weight fractions for each chemical compound; and

- **Lumped-model speciation –** refers to splitting emissions for a pollutant into groups of components that represent numerous discrete compounds. The groups of components are referred to as lumped-model species. The lumped-model species for TOG are developed using split factors that are specific to the type of chemical mechanism employed by the photochemical model to be used.

5.1 TOG and PM Speciation Profiles

Discrete speciation profiles are available for TOG and PM emissions for many source types. Prior to applying speciation profiles, it may be necessary to adjust emissions to account for any components not included in the emissions inventory. For example, ROG may be adjusted to TOG (ROG-to-TOG conversion). This adjustment is necessary because emission factors for certain source categories exclude methane and formaldehyde, and therefore, represent only the reactive components, or ROG; however, most speciation profiles are applied assuming the emissions represent TOG.

The U.S. EPA has identified the following compounds that have negligible, or no, photochemical reactivity:

- Methane;
- Ethane;
- Acetone;
- Perchloroethylene (tetrachloroethylene);
- Methylene chloride (dichloromethane);
- Methyl chloroform (1,1,1-trichloroethane);
- Various chlorofluorocarbons (CFCs);
- Various hydrochlorofluorocarbons (HCFCs);
- Various hydrofluorocarbons (HFCs); and
- Various perfluorocarbons (PFCs).

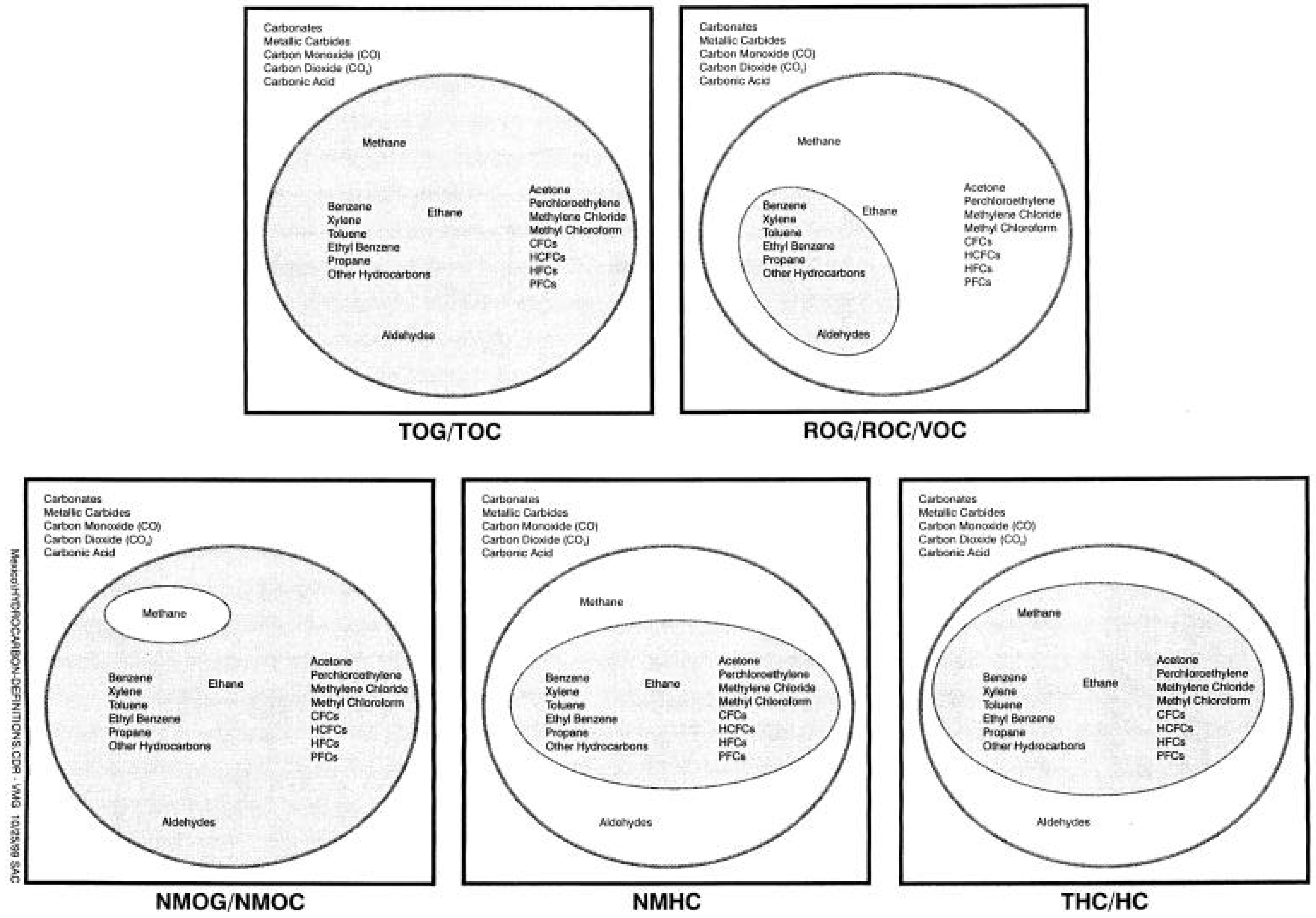
Additional information on these compounds, and a listing of a few more uncommon non-photochemically reactive compounds, can be found in the *U.S. Code of Federal Regulations* (CFR, 1997). This listing of nonreactive compounds is updated periodically as U.S. EPA designates new nonreactive compounds.

Chemicals considered to be photochemically reactive are termed ROG. By definition, therefore, ROG is a subset of TOG. ROG are photochemically reactive chemical gases composed of hydrocarbons that may contribute to the formation of smog.

ROG are also sometimes referred to as VOC. Emission factors published in U.S. EPA's AP-42 (U.S. EPA, 1995) are presented both as TOG and ROG/VOC. Other hydrocarbon definitions that occasionally appear in air quality and emission factor literature include: non-methane organic gases (NMOG), non-methane hydrocarbons (NMHC), total hydrocarbons (THC), and hydrocarbons (HC). Figure 5-1 graphically illustrates the relationship between these various hydrocarbon definitions. The shaded areas in Figure 5-1 indicate the compounds included in each definition. The definitions for NMOG, NMHC, THC, and HC are generally used for combustion processes only.

Chemical speciation and particle size distribution information is available through U.S. EPA's SPECIATE database. SPECIATE contains TOG and PM speciation profiles for more than 300 source types. The most recent release of SPECIATE (Version 3.0) was developed as a Windows® application (U.S. EPA, 1999c). U.S. EPA is also considering development of an interactive Internet application. An Internet application would allow researchers to add new profiles to the system. The speciation profiles attempt to distribute the total TOG or PM emissions from a particular source into the individual compounds (in the case of TOG) or elements and size fractions (for PM). Such a breakdown has been developed for use in some photochemical models and source-receptor models (primarily for PM). These profiles were not developed for, and are not recommended for use in, speciating TOG or PM emissions for air toxics inventories. The Factor Information Retrieval (FIRE) Data System contains U.S. EPA's recommended emission factors for both toxic and criteria pollutants. The most recent version of FIRE (Version 6.22) was also developed as a Windows® application (U.S. EPA, 1999d).

Speciation data may also be developed for site-specific applications or by other regulatory agencies. For example, the California Air Resources Board (ARB) has compiled speciation profiles for TOG and PM (ARB, 1991a; ARB, 1991b) and has an ongoing effort to



TOG/TOC

ROG/ROC/VOC

NMOG/NMOC

NMHC

THC/HC

Figure 5-1. Description of Hydrocarbon Definitions update estimates of the size fractions and chemical composition of PM profiles for a variety of emission source categories. The ARB has recently proposed new or revised TOG profiles for motor vehicle exhaust and evaporation, utility equipment exhaust, diesel exhaust, and jet engine exhaust. Speciation profiles (both TOG and PM) for the six source categories in the overall example have been provided in Appendix B and Appendix C, respectively. Although PM emissions were not considered in the hypothetical modeling inventory example, the PM speciation profiles in Appendix C are provided for informational purposes.

5.2 Photochemical Reactivity Groups

Speciating chemicals into reactivity groups is important for photochemical modeling applications because some species of TOG are far more reactive than others. Researchers have identified differences among TOG species in their contributions to ozone formation in the atmosphere and have developed chemical mechanisms for models that predict transformation of pollutants in the atmosphere. These mechanisms have been evaluated using laboratory experiments. Many chemical mechanisms have been developed, but the following two are most commonly used in photochemical modeling today:

- Carbon Bond IV (CB-IV); and
- California Statewide Air Pollution Research Center (SAPRC).

The CB-IV mechanism requires that TOG emissions be disaggregrated into emissions of lumped species based on the species' carbon bond structure. In the SAPRC mechanism, discrete compounds are lumped together based on their relative reactivity with the hydroxyl radical (OH^-). The CB-IV and SAPRC lumped species are provided in Table 5-1 and 5-2, respectively

Other mechanisms that may be of interest to Mexico are the Regional Acid Deposition Model Mechanism, Version 2 (RADM2) and the Regional Atmospheric Chemistry Mechanism (RACM). These mechanisms are used within the MCCM regional scale air quality model developed by the Fraunhofer-Institut für Atmosphärische Umweltforschung (Fraunhofer Institute for Atmospheric Environmental Research) (IFU). The RADM2 gas phase mechanism utilizes 61 species, while the RACM gas phase mechanism uses 71 species in their respective reactivity groups. Mexico's Instituto Nacional de Ecología (INE) has indicated that some of their staff are currently receiving training on the MCCM model in Germany.

Table 5-1. Carbon Bond IV Organic Species

Organic Species	Organic Species ID
Olefins	OLE
Paraffins	PAR
Toluene	TOL
Xylene	XYL
Formaldehyde	FORM
High Molecular Weight Aldehydes	ALD2
Ethene	ETH
Methanol	MEOH
Ethanol	ETOH
Isoprene	ISOP
Nonreactive	Not Applicable

Table 5-2. SAPRC Organic Species

Organic Species	Organic Species ID
Formaldehyde	HCHO
Higher Aldehydes	CCHO
Ketones	MEK
Alkyl Nitrites	RNO3
PAN Analogues	PAN
Phenols	CRES
Glyoxal	GLY
Methyl Glyoxal	MGLY
Uncharacterized Aromatic Fragmentation Product #1	AFG1
Uncharacterized Aromatic Fragmentation Product #2	AFG2

Emissions of lumped-model species are calculated using split factors, which represent the amount (in moles) of lumped-model species per gram of TOG. For each source or source category emitting TOG, two or more percentages (totaling 100 percent) must be defined, each one corresponding to the fraction of TOG emitted as the lumped-model species.

5.3 NO_x Speciation

Some photochemical models do not require that nitrogen oxides be distinguished as either NO or NO_2. Instead, these models assume that all NO_x is NO, which is the predominant form of NO_x emitted from combustion processes (the primary source of NO_x emissions). For models requiring that a distinction between NO or NO_2 be made, split factors must be applied. For each source or source category emitting NO_x, two percentages (totaling 100 percent) need to be defined: one corresponding to the fraction of NO_x emitted as NO and the other corresponding to the fraction emitted as NO_2.

It is important to indicate how NO_x is reported in an inventory. NO_x emissions are commonly expressed "as NO_2," which means that a molecular weight of 46 is attributed to NO as well as NO_2, even though the true molecular weight of NO is 30. The actual value for NO emissions by weight is 30/46 (or 0.65) times the value of NO reported "as NO_2."

At present, few references are available that define split factors for allocating NO_x into NO and NO_2 (Milligan et al., 1997). As a rough average, 97% (by weight as NO_2) of the NO_x emitted from most boilers will be NO. Default split factors for all sources (including motor vehicles) are often given as 90% by weight of NO (as NO_2) and 10% by weight of NO_2.

5.4 PM Size Distribution

Size distribution information, which is used for PM_{10}, $PM_{2.5}$, or visibility-related modeling inventories, is available through U.S. EPA's SPECIATE database. Size fractions are also available from the California Emission Inventory Development and Reporting System (CEIDARS). PM_{10} and $PM_{2.5}$ emissions are estimated by multiplying total PM emissions by the desired partical size mass fraction.

A potentially significant portion of fine particulate matter (i.e., $PM_{2.5}$) is comprised of elemental carbon (EC) and organic carbon (OC). These two types of particulate matter are especially important for visibility-related modeling inventories because of their light scattering and extinction properties. Information on EC and OC is quite limited; virtually all available information is related to speciation profiles with hardly any emission factor data. Some sources of EC and OC information are U.S. EPA's SPECIATE database, California ARB's VOC and PM speciation profiles, and an EC/OC emissions inventory developed for California's South Coast Air Basin by the California Institute of Technology (Hildemann et al., 1991).

5.5 Other Pollutants

Although speciation is primarily a concern for hydrocarbons, NO_x, and PM, speciation may also be relevant for SO_x in some limited cases. Sulfur oxides are typically released as sulfur dioxide (SO_2). Emitted SO_2 may oxidize to sulfur trioxide (SO_3) and then to sulfuric acid (H_2SO_4) or sulfate (SO_4^{2-}) aerosols. However, SO_x emissions are generally reported on a SO_2 basis. Some photochemical models such as the Urban Airshed Model (UAM) require speciated SO_x emissions, which are disaggregated into SO_2 and SO_4^{2-}.

Finally, speciation is not a relevant issue for the other two commonly inventoried pollutants (CO and NH_3).

5.6 Source Type Considerations

The unique characteristics of each source have to be considered when speciating emissions. The Texas Natural Resource Conservation Commission (TNRCC) has summarized the following considerations for the various source types (TNRCC, 1999):

- **Point sources –** To accurately identify the chemicals in point source emissions, a special study of each specific process is necessary. Since this is not usually economically feasible, a speciation profile is generally used for each SCC. Individual industries emit different VOCs. The SCC-specific profiles are needed because each process emits different combinations of chemicals.

- **Area sources –** Similar to point sources, chemical speciation consists of assigning the correct proportion of different chemicals to different activities. For example, the emissions from lawn mowers are mapped to one chemical profile, while emissions from dry cleaners or asphalt road paving are mapped to others.

- **Motor vehicle sources** – Because the chemical composition of vehicular emissions differs among classes of vehicles (e.g., automobiles vs. 18-wheel diesels), separate chemical speciation profiles are used for different vehicle types. Similarly, each type of vehicle can emit hydrocarbons in different ways (e.g., gas tank vapor vs. tailpipe exhaust), so the chemical composition of each loss mode must be addressed as well.

- **Natural sources –** Species composition, or the type of vegetation in the area to be modeled, is significant because different types of vegetation emit different types and vastly different quantities of VOCs.

5.7 Speciation Example

To illustrate the concepts described in this section, the emissions of TOG, NO_x, and PM emissions from the hypothetical boiler introduced in Section 1.0 are speciated using different methods. In modeling inventory development, both temporal allocation and spatial allocation would normally be performed prior to speciation. However, in order to clearly demonstrate the speciation process, speciation is applied in this example directly to ungridded, annual emission estimates. Due to space considerations, speciation was not included in the more detailed example sequentially showing all modeling inventory development steps in Section 7.0 or the emission calculations associated with the entire example in Appendix A.

Example Calculation

This example calculation focuses on lumped–model speciation; an example of discrete speciation can be found in Section 6.4 of Volume II of this manual series (*Emissions Inventory Fundamentals*).

It should also be noted that emissions calculated using lumped–model speciation (i.e., for photochemical modeling) are usually presented on a molar basis, rather than a weight basis. As a result, emission estimates in this example calculation will be shown on a molar basis.

First, SPECIATE is used to determine or identify the species profile and discrete VOC species for the boiler. Assume that the boiler is classified as SCC 10500105 (External Combustion Boilers – Space Heaters – Industrial – Distillate Oil). The profile number assocated with this source category, as given in SPECIATE, is 0002.

Next, TOG emissions are assigned to lumped-species categories of the CB-IV mechanism using split factors from the UAM Emissions Processing System (EPS 2.0) split factors file (Table B-35 in EPS 2.0) and the following equation:

$$\text{Emissions}_I = \text{TOG emissions} \times \text{SF}_I / \text{Divisor}_I$$

Where

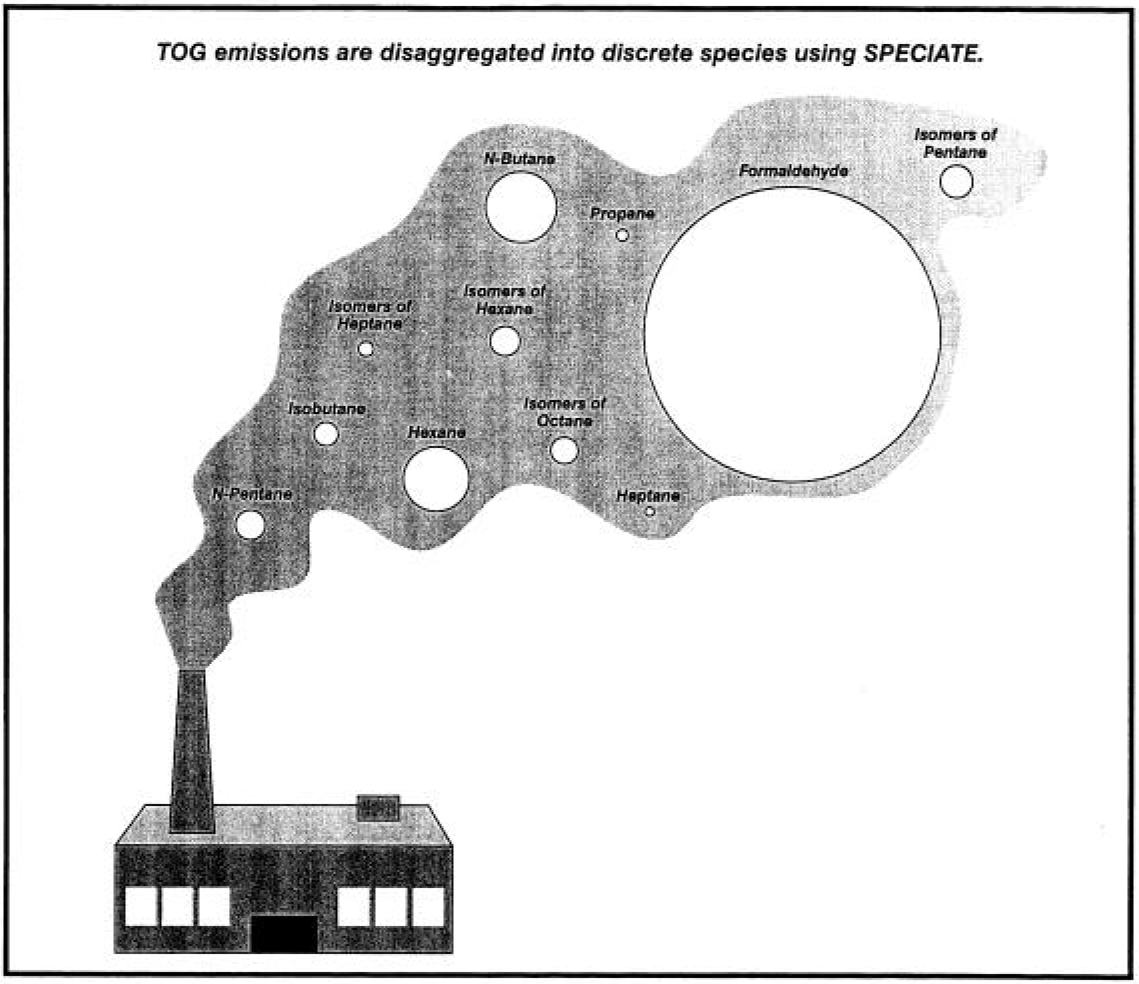
Emissions_I = Emissions of lumped-model species I (10^6 moles/yr);

TOG = TOG emissions (Mg/yr);

SF_I = Split factor for lumped-model species I (g-mole/g); and

Divisor_I = Secondary conversion factor for lumped-model species I.

Total organic gas boiler emissions were presented in Section 1.0 as 200 Mg/yr. Emissions of the Carbon Bond IV lumped-model species were calculated using the above equation and are listed in the Table 5-3. Figure 5-2 shows the discrete species and lumped-model species for the boiler.



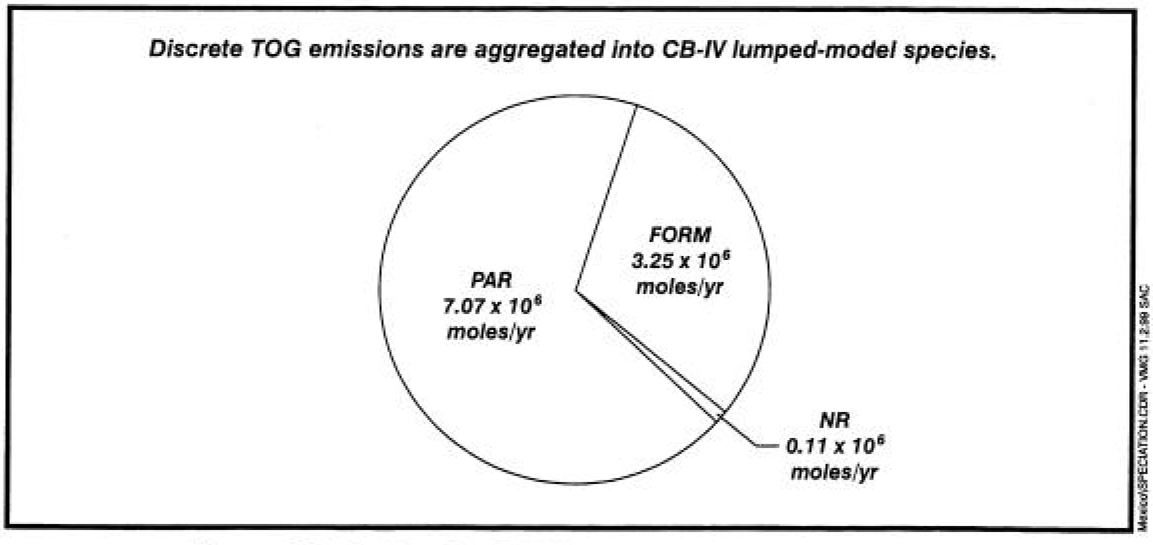


Figure 5-2. Carbon Bond IV Speciation for the Hypothetical Modeling Inventory Point Source

Table 5-3. Carbon Bond IV Lumped–Model Species Emission Estimates for the Hypothetical Modeling Inventory Boiler

Species I	SF_I (g-mole/g)	$Divisor_I$	$Emissions_I$ (10^6 moles/yr)
FORM	0.0162333333	1	3.25
NR	0.0005454545	1	0.11
PAR	0.0353612035	1	7.07

The hypothetical boiler emits 400 Mg/yr NO_x as NO_2. Given split factors of 90% and 10% by weight for NO and NO_2, respectively, the emissions would be equivalent to 360 Mg NO per year and 40 Mg NO_2 per year; however, the actual emissions of NO would be only 30/46 of 360, or 235 Mg per year. The annual molar NO and NO_2 emissions for the hypothetical boiler are estimated by dividing the annual mass emissions by the molecular weight of NO and NO_2 (30 g/mole and 46 g/mole, respectively). This results in emission estimates of 7.83 x 10^6 moles NO per year and 0.87 x 10^6 moles NO_2 per year.

6.0 PROJECTIONS

Emission projections refers to extrapolating baseline emission estimates to predict future emissions based upon expected future activity levels and emission controls. Projected emission estimates are often used for planning, evaluation of potential control measures, analysis of new source impacts, modeling of future air quality, and assessment of the effectiveness of air pollution control strategies. A baseline emissions inventory is important because it represents a snapshot of emissions for a given baseline year. However, because sources and their associated air emissions are not static over time, baseline emission estimates may not accurately represent emissions for a future year. Emission projections are an attempt to account for the effects of future growth and emission controls. Because projections attempt to quantify the unknown future, there will always be some uncertainty associated with any estimate of projected emissions. This uncertainty can be minimized by using source-specific growth factors and control factors that most nearly approximate future year emissions.

Projections are usually not considered to be a modeling inventory development step. Modeling inventory development steps are typically considered to be limited to temporal allocation, spatial allocation, and speciation. In fact, modeling inventory emissions that have been temporally allocated, gridded, and speciated are usually not projected into the future. Instead, the annual baseline emissions data are projected. These projected emissions can then be temporally allocated, spatially allocated, and speciated to create modeling inventories of the projected emissions.

6.1 Growth Factors

The first component of emission projections is growth. Growth is represented in terms of growth factors, which are expressed either in terms of annual percent change or percent change for a certain number of years. For most areas where air quality is a concern, growth will represent increasing activity and will be expressed as a positive number. However, negative growth rates can exist (e.g., transitioning from primary industries such as farming to industrial or high-tech industries may cause the agricultural growth rate to be negative). Two equations for projecting growth only are given below.

$$E_{proj} = E_{base} \times (1 + \%_{ann}/100)^{y}$$

OR

$$E_{proj} = E_{base} \times (1 + \%_{per}/100)$$

Where E_{proj} = Projected year emissions (Mg/yr);
E_{base} = Base year emissions (Mg/yr);
$\%_{ann}$ = Annual growth (%);
y = Number of years between base and projected year; and
$\%_{per}$ = Period growth.

Usually, emission projection growth factors are based upon forecasts of industrial growth, population growth, transportation growth, and land use changes. Air quality agencies generally should not need to develop their own growth forecasts; appropriate forecasts should be available from other agencies. Relying upon growth indicator forecasts from other agencies allows air quality agencies to conserve resources and maintain consistency with the other agencies. However, care should also be exercised to ensure that forecasts from other agencies do not contain inherent biases that misrepresent the growth of emissions.

Industrial growth forecasts are often used to project point source emissions and some area source emissions. There are four primary indicators of industrial economic growth. In descending order of typical data availability, these four indicators are employment, earnings, value added, and product output. The four indicators are discussed below:

- **Employment** — Employment forecasts are usually the most readily available type of forecasts. However, employment forecasts do not account for production efficiencies due to technological improvements.
- **Earnings** — Earnings data incorporate the effects of production efficiencies, which may not be apparent in employment forecasts. For example, a particular industry may have a 15% earnings increase, even though employment rose only by 3%.
- **Value Added** — Value added (i.e., the value of a product sold by a firm less the value of the goods purchased and used by the firm to produce the product; equal to the revenue which can be used for wages, rent, interest,

and profits) is considered to be more accurate than employment or earnings forecasts because it addresses both production efficiencies and production factor substitution. However, value added information is less readily available than employment and earnings statistics.

- **Product Output** — Product output is probably the most direct indicator of future emissions activity. Product output most accurately represents the level of employment, resource availability, capital growth, and technology use. In addition, product output is a direct measure of industrial activity; whereas, employment, earnings, and value added are economic surrogates which may or may not accurately represent the amount of industrial activity. Unfortunately, product output information may not easily be obtained.

These four industrial growth indicators (employment, earnings, value added, and product output) are often used for regional projections of entire industrial sectors. More specific projection information can be obtained from surveying individual facilities. However, extensive surveying for projection information may be too resource-intensive. In addition, many industrial facilities may be unwilling to provide the necessary projection information, which is sometimes considered to be proprietary or confidential. In general, point source projection surveys should be used only for those instances where there is a dominant industry or facility whose emission growth is not likely to be characterized correctly in regional industrial projections.

Population growth is used less widely than industrial growth indicators to project future activity and emissions, but it is still used for some types of very disperse area sources (e.g., architectural surface coating, graphic arts, commercial/consumer solvent use, etc.). These area sources are typically those that are estimated using per capita emission factors. Besides these limited uses, population growth should typically not be used to project emissions. However, in the case of extremely limited forecast data, it may be the only viable alternative.

Ideally, transportation growth indicators should be used to project motor vehicle emissions. In general, as the population of a metropolitan area grows, the motor vehicle activity (i.e., VKT) increases. In fact, it tends to increase at a greater rate than population growth. This is because incremental growth usually occurs at the edge of the metropolitan area, which typically requires more vehicular travel than if the growth occurred in the center of the metropolitan area. Thus, population growth will almost always underestimate transportation growth. Transportation growth indicators must usually be derived from travel demand models; instructions for using travel demand models are beyond the scope of this manual.

Finally, changes in land use should be considered in the estimation of growth factors. Biogenic sources and a few area sources are the only sources that are directly affected by changes in land use. In general, biogenic sources should be kept constant between the baseline inventory and the project inventory, unless there are land use changes that dramatically alter the biologic nature of an area (e.g., transformation of a heavily wooded forest into a large shopping center or residential development). Even these dramatic changes will tend to be limited to a few grid cells out of the entire inventory.

6.2 Control Factors

In addition to growth, emissions control is the other component of emission projections. Control factors are usually expressed as a percent of controlled emissions relative to uncontrolled emissions. There are several aspects of control factors that are discussed below.

Baseline emissions will include the effects of any control devices that have already been installed, as well as any existing regulations that have already been implemented as of the baseline year. Baseline emissions, however, will <u>not</u> include the effects of current regulations that have not been fully implemented as of the baseline year. These effects will need to be included in the future year projections. Although the emission reductions due to these regulations have not actually occurred, reasonable estimates of the expected reductions can usually be made because the associated regulation has already been established. The future emission reductions due to the adoption of a control strategy in a future year that has not been clearly defined in the base year, however, is much more difficult to quantify. In spite of this, these reductions need to be included in projection control factors. The basic equation for showing control factors only in any given year is given as follows:

$$E_c = E_u \times [1 - (CE/100)]$$

Where E_c = Controlled emissions (Mg/yr);

E_u = Uncontrolled emissions (Mg/yr); and

CE = Control efficiency (%).

Although the previous equation demonstrates the general control factor equation, past experience in emissions inventory development has shown that actual levels of control effectiveness fall short of expected levels. As a result, the concepts of rule effectiveness (RE) and rule penetration (RP) need to be incorporated into inventories.

RE attempts to quantify the relative ability of regulations to achieve the full amount of emission reductions expected from complete compliance with regulations. Regulations that have full compliance by all sources at all times would have an RE of 100%. Conversely, owners/operators of sources that ignore relevant regulations would cause the relevant source category to have an RE of 0%. It is often difficult to quantify the actual RE value; this value depends upon many factors, including the nature of the regulation, the nature of the compliance procedures, and the performance of the source in maintaining and assuring compliance over time. In the U.S., a default RE value of 80% has typically been used by U.S. EPA and other agencies responsible for air quality. However, where possible, source-specific RE values should be developed.

RP is a measure of the extent to which a regulation covers emissions from all sources within a source category. In situations where a regulation covers all sources within a source category, an RP value of 100% should be used. However, if a regulation is only applicable for larger facilities, or facilities with certain characteristics (e.g., exceeding certain emissions quantities, operating in excess of a certain number of hours per year, using certain types of fuel, etc.), the RP value would be somewhat less than 100%.

If RE and RP are incorporated into the basic control factor equation shown on page 6-4, the control factor equation becomes:

$$E_c = E_u \times [1 - (CE/100) \times RE \times RP]$$

Where E_c = Controlled emissions (Mg/yr);
E_u = Uncontrolled emissions (Mg/yr);
CE = Control efficiency (%);
RE = Rule effectiveness; and
RP = Rule penetration.

In general, it is desirable that projections incorporate the effects of both growth and control. As a result, the growth factor equation and control factor equations need to be combined into one overall equation. This equation is given below:

$$E_{proj} = E_u \times [1 - (CE/100) \times RE \times RP] \times (1 + \%_{ann}/100)^y$$

Where E_{proj} = Projected year emissions with controls (Mg/yr);
E_u = Uncontrolled base year emissions (Mg/yr);
CE = Control efficiency (%);
RE = Rule effectiveness;
RP = Rule penetration;
$\%_{ann}$ = Annual growth (%); and
y = Number of years between base and projected year.

6.3 Source Type Considerations

Since projections are developed from base year emission estimates, several source type-specific considerations should be examined. First, some point sources possess operating permits issued by regulatory agencies. These operating permits often specify daily or annual emission limits as conditions of device operation. When base year emission estimates from this type of permitted point source are projected to a future year, future year emission estimates should be increased only up to the permitted level. To project emissions above the permitted level would represent a permit violation by the facility possessing the permit.

Although not widely used in Mexico at the present time, the possible effects of emission offsets, banking, trading, and other market-based control strategies should be addressed in future year projections. A detailed discussion of these control strategies is beyond the scope of this manual, but it is expected that these types of control strategies will play a greater role in air quality in the future.

For motor vehicles, a significant source type in most emissions inventories, it is important that future control measures be properly incorporated into future year emission estimates. For example, new vehicle emission standards, inspection and maintenance (I/M) programs, and fuel reformulations will have a significant effect on future year emissions. These controls can be included in emission factor model input files (e.g., MOBILE-type models), but some consideration should be given to which classes of the vehicle fleet will be affected by these controls.

6.4 Projection Example

This portion of the example focuses on the projection of annual emissions to future years. As mentioned earlier, projections may not be considered to be a modeling inventory development step. However, annual base year emissions data are often projected and then temporally allocated, spatially allocated, and speciated to create modeling inventories of the projected emissions. In order to provide a clear illustration of future year projections, growth and control factors will be applied to annual emissions for one source category. A simplified projection calculation is included in the more detailed example showing all modeling inventory development steps presented in Section 7.0. Projected emissions, however, are not included in the Appendix A spreadsheets due to the large number of calculations.

Example Calculation

The emissions from the residential consumer solvent use category are to be projected from a base year of 1999 to the year 2010. The annual base year emissions from this category have been estimated to be 200 Mg/yr. Residential consumer solvent use emissions are typically increased using population forecasts; the local planning agency has estimated that the population in the hypothetical modeling inventory community will grow at an annual rate of 2.3%. A regulation that limits the amount of TOG contained in personal products (a portion of the residential consumer solvent use category) will be implemented in the year 2003. The regulation will reduce the TOG content by 50%. However, due to expected implementation problems, rule effectiveness is expected to be low initially. Rule effectiveness is only expected to be 10% in the first year of the regulation (2003), increasing 10% for each subsequent year until a maximum rule effectiveness of 80% is reached in the eighth year of the regulation (2010). Emissions from personal products use comprise 35% of the total emissions from residential consumer solvent use.

If growth factors alone are considered, the consumer solvent use emissions would increase to 256.8 Mg/yr in the year 2010 as shown by Curve A in Figure 6-1. The calculation for projecting growth only to the year 2005 is provided as follows:

$$E_{proj} = E_{base} \times (1 + \%_{ann}/100)^{y}$$
$$E_{2005} = E_{1999} \times (1 + 2.3/100)^{(2005\text{-}1999)}$$
$$E_{2005} = (200\ \text{Mg/yr}) \times (1.023)^{6} = 229.2\ \text{Mg/yr}$$

If control factors alone are considered, the consumer solvent use emissions would decrease to 172.0 Mg/year in the year 2010 as shown by Curve B in Figure 6-1. The calculation for projecting controls only to the year 2005 is provided as follows:

$$E_{c} = E_{u} \times [1 - (CE/100) \times RE \times RP]$$
$$E_{c,2005} = Eu,_{2005} \times [1 - (50/100) \times 0.3 \times 0.35]$$
$$E_{c,2005} = (200\ \text{Mg/yr}) \times [1 - 0.0525] = 189.5\ \text{Mg/yr}$$

If both growth factors and control factors are considered together, the consumer solvent use emissions would increase to 220.9 Mg/year in the year 2010 as shown by Curve C in Figure 6-1. It should be noted that these emissions are 14% less than if VOC limits had not been implemented. The calculation for projecting both growth and controls to the year 2005 is provided as follows:

$$E_{proj} = E_{u} \times [1 - (CE/100) \times RE \times RP] \times (1 + \%_{ann}/100)^{y}$$
$$E_{proj} = (200\ \text{Mg/yr}) \times [1 - (50/100) \times 0.3 \times 0.35] \times (1 + 2.3/100)^{6}$$
$$E_{proj} = (200\ \text{Mg/yr}) \times (0.9475) \times (1.1462) = 217.2\ \text{Mg/yr}$$

This example illustrates that future year emission projections may be significantly influenced by growth. As shown in this example, the effects of growth may negate any emission reductions brought about by controls. Although the reduction of emissions for personal products due to VOC limits is significant (i.e., 50%), the overall effect of this within the entire consumer solvent use category is much less due to the slow eight-year implementation and somewhat narrow focus (i.e., only 35% of the consumer solvent use category was affected). A real-life example which shows the influence of growth on future year emissions can be seen with motor vehicles in the U.S. Significant technological advances have reduced motor vehicle emissions (on a per-mile basis) by an order of magnitude or more compared to 20 or 30 years ago, but ever-increasing growth of vehicle travel (which typically exceeds population growth) has offset much of the realized emission reductions.

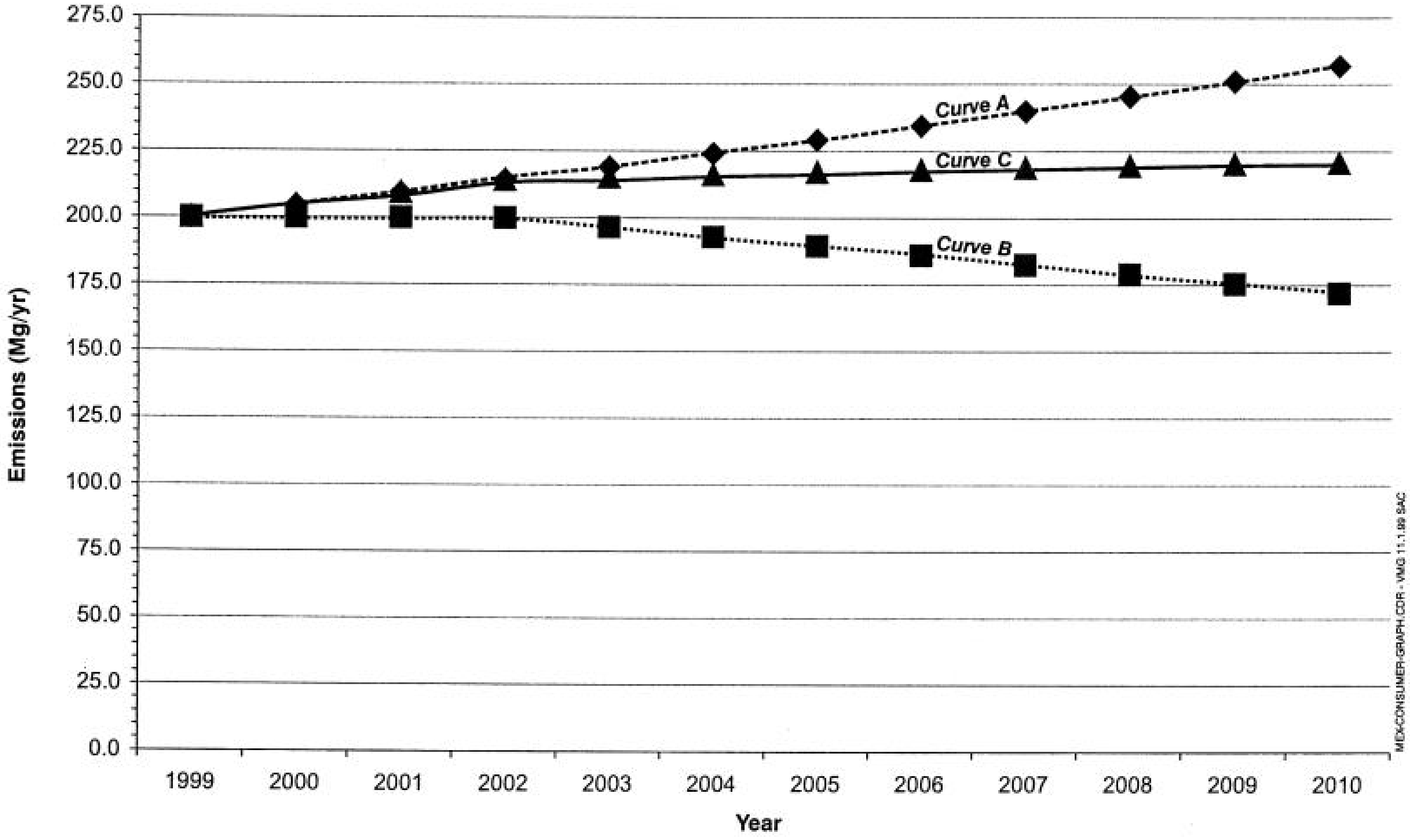


Figure 6-1. Estimated Projections of Consumer Product Use Source Category for Hypothetical Modeling Inventory

7.0 MODELING INVENTORY DEVELOPMENT EXAMPLE

This section presents a comprehensive example for one source category and illustrates temporal allocation, spatial allocation, speciation, and projection performed sequentially. The gasoline station source category was selected for this example. Detailed calculation spreadsheets for this category and the other categories in this hypothetical modeling inventory can be found in Appendix A. The numbers calculated in this example are identified in the Appendix A spreadsheets by a bold font and highlighted cells. For actual modeling inventories, an electronic emissions modeling system will need to be utilized. The calculation spreadsheets presented in this document were included for demonstration purposes only; spreadsheets should not be used for actual modeling inventories.

7.1 Temporal Allocation

The assumed gasoline station temporal profiles were presented in Figure 3-3 (seasonal), Figure 3-4 (weekly), and Figure 3-5 (hourly).

The first step in temporal allocation is to determine seasonal allocation factors. Monthly gasoline station activity assumed for this example is presented in Table 7-1 (this monthly distribution is identical to the assumed motor vehicle activity distribution presented in Section 3.6).

Table 7-1. Assumed Monthly Gasoline Station Temporal Allocation Profile for the Hypothetical Modeling Inventory

Month	Fraction of Annual Activity
January	0.081
February	0.078
March	0.080
April	0.084
May	0.089
June	0.081
July	0.082
August	0.083
September	0.079
October	0.088
November	0.084
December	0.091
Total	**1.000**

Seasonal temporal allocations are estimated as follows:

$$
\begin{aligned}
TA_{s} &= TA_{m1} + TA_{m2} + TA_{m3} \\
TA_{win} &= TA_{Dec} + TA_{Jan} + TA_{Feb} = 0.091 + 0.081 + 0.078 = 0.250 \\
TA_{spr} &= TA_{Mar} + TA_{Apr} + TA_{May} = 0.080 + 0.084 + 0.089 = 0.253 \\
TA_{sum} &= TA_{Jun} + TA_{Jul} + TA_{Aug} = 0.081 + 0.082 + 0.083 = 0.246 \\
TA_{fal} &= TA_{Sep} + TA_{Oct} + TA_{Nov} = 0.079 + 0.088 + 0.084 = 0.251
\end{aligned}
$$

The check of seasonal temporal allocations calculations is also shown.

$$TA_{win} + TA_{spr} + TA_{sum} + TA_{fal} = 0.250 + 0.253 + 0.246 + 0.251 = 1.000$$ ⁙

Given annual TOG emissions of 150 Mg/yr (previously shown in Table 1-1), the seasonal emissions are calculated as follows:

$$
\begin{aligned}
E_{TOG,win} &= Annual_{TOG} \times TA_{win} = 150 \text{ Mg/yr} \times 0.250 = 37.50 \text{ Mg} \\
E_{TOG,spr} &= Annual_{TOG} \times TA_{spr} = 150 \text{ Mg/yr} \times 0.253 = 37.95 \text{ Mg} \\
E_{TOG,sum} &= Annual_{TOG} \times TA_{sum} = 150 \text{ Mg/yr} \times 0.246 = 36.90 \text{ Mg} \\
E_{TOG,fal} &= Annual_{TOG} \times TA_{fal} = 150 \text{ Mg/yr} \times 0.251 = 37.65 \text{ Mg}
\end{aligned}
$$

After calculating seasonal emissions, the next step is to estimate emissions on a weekly basis. The assumed weekly gasoline station activity is shown in Table 7-2 (this weekly distribution is also identical to the assumed motor vehicle activity distribution presented in Section 3.6).

Table 7-2. Assumed Weekly Gasoline Station Temporal Allocation Profile for the Hypothetical Modeling Inventory

Day	Fraction of Weekly Activity
Monday	0.138
Tuesday	0.138
Wednesday	0.138
Thursday	0.138
Friday	0.138
Saturday	0.155
Sunday	0.155
Total	**1.000**

The equations for converting weekly temporal allocation into average weekday, Saturday, and Sunday factors are shown below.

$$\begin{aligned}
F_{wd} &= F_{ad} \times (A_{wd}/0.1429) = 0.0110 \times (0.138/0.1429) = 0.0106 = 1.06\% \\
F_{sat} &= F_{ad} \times (A_{sat}/0.1429) = 0.0110 \times (0.155/0.1429) = 0.0119 = 1.19\% \\
F_{sun} &= F_{ad} \times (A_{sun}/0.1429) = 0.0110 \times (0.155/0.1429) = 0.0119 = 1.19\%
\end{aligned}$$

The check of the weekly temporal allocation calculations is also shown.

$$\begin{aligned}
(65 \times F_{wd}) + (13 \times F_{sat}) + (13 \times F_{sun}) &= (65 \times 0.0106) + (13 \times 0.0119) + (13 \times 0.0119) \\
&= 0.689 + 0.1547 + 0.1547 = 0.9984 \approx 1.00 \text{ ⁙}
\end{aligned}$$

Using the calculated seasonal gasoline station emissions (spring – 37.95 Mg, summer – 36.90 Mg, fall – 37.65 Mg, and winter – 37.50 Mg) and the calculated weekly temporal allocations ($F_{wd} = 0.0106$, $F_{sat} = 0.0119$, and $F_{sun} = 0.0119$) , the weekly allocated emissions are calculated as shown below. The calculation shown below is for summer weekdays only; the other allocated emissions are calculated in a similar manner with the results shown in Table 7-3.

$$E_{TOG,sum,wd} = E_{TOG,sum} \times F_{wd} = 36.90 \text{ Mg} \times 0.0106 = 0.392 \text{ Mg/day}$$

Table 7-3. Estimated Weekly Allocated Gasoline Station Emissions for the Hypothetical Modeling Inventory

	Weekday (Mg/day)	Saturday (Mg/day)	Sunday (Mg/day)
Spring	0.403	0.452	0.452
Summer	0.392	0.440	0.440
Fall	0.400	0.449	0.449
Winter	0.398	0.447	0.447

After determining average weekday, Saturday, and Sunday emissions for each of the four seasons, the next step is to distribute daily gasoline station activity to an individual hourly basis. The assumed hourly gasoline station activity is distributed as shown in the Table 7-4; the distribution is assumed to be equally applicable for average weekdays, Saturdays, and Sundays. Note that Hour 1 refers to the first hour of the day (midnight to 1 a.m.), Hour 2 refers to the second hour of the day (1 a.m. to 2 a.m.), and so on. A check to confirm that the daily activity fractions total to 1.000 is also provided.

Table 7-4. Assumed Hourly Gasoline Station Temporal Allocation Profile for the Hypothetical Modeling Inventory

Hour	Fraction of Daily Activity
1	0.009
2	0.009
3	0.009
4	0.009
5	0.009
6	0.009
7	0.043
8	0.043
9	0.043
10	0.043
11	0.043
12	0.043
13	0.043
14	0.043
15	0.043
16	0.043
17	0.086
18	0.086
19	0.086
20	0.086
21	0.060
22	0.060
23	0.026
24	0.026
Total	**1.000 ⁙**

The hourly emissions for Hour 18 on an average summer weekday are given below:

$$E_{TOG,sum,wd,18} = E_{TOG,sum,wd} \times F_{18} = 0.392 \text{ Mg/day} \times 0.086 = 0.034 \text{ Mg/hr}$$

All other hourly emission calculations are performed in an identical manner. The results for average weekday (wd), Saturday (Sat), and Sunday (Sun) in Mg per hour rounded to three decimal places are provided in Table 7-5.

Table 7-5. Estimated Temporally Allocated Gasoline Station Emissions for the Hypothetical Modeling Inventory

	Spring (Mg/hr)			**Summer (Mg/hr)**			**Fall (Mg/hr)**			**Winter (Mg/hr)**		
Hr	**Wk**	**Sat**	**Sun**	**Wk**	**Sat**	**Sun**	**Wk**	**Sat**	**Sun**	**Wk**	**Sat**	**Sun**
1	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
2	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
3	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
4	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
5	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
6	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
7	0.017	0.019	0.019	0.017	0.019	0.019	0.017	0.019	0.019	0.017	0.019	0.019
8	0.017	0.019	0.019	0.017	0.019	0.019	0.017	0.019	0.019	0.017	0.019	0.019
9	0.017	0.019	0.019	0.017	0.019	0.019	0.017	0.019	0.019	0.017	0.019	0.019
10	0.017	0.019	0.019	0.017	0.019	0.019	0.017	0.019	0.019	0.017	0.019	0.019
11	0.017	0.019	0.019	0.017	0.019	0.019	0.017	0.019	0.019	0.017	0.019	0.019
12	0.017	0.019	0.019	0.017	0.019	0.019	0.017	0.019	0.019	0.017	0.019	0.019
13	0.017	0.019	0.019	0.017	0.019	0.019	0.017	0.019	0.019	0.017	0.019	0.019
14	0.017	0.019	0.019	0.017	0.019	0.019	0.017	0.019	0.019	0.017	0.019	0.019
15	0.017	0.019	0.019	0.017	0.019	0.019	0.017	0.019	0.019	0.017	0.019	0.019
16	0.017	0.019	0.019	0.017	0.019	0.019	0.017	0.019	0.019	0.017	0.019	0.019
17	0.035	0.039	0.039	0.034	0.038	0.038	0.034	0.039	0.039	0.034	0.038	0.038
18	0.035	0.039	0.039	0.034	0.038	0.038	0.034	0.039	0.039	0.034	0.038	0.038
19	0.035	0.039	0.039	0.034	0.038	0.038	0.034	0.039	0.039	0.034	0.038	0.038
20	0.035	0.039	0.039	0.034	0.038	0.038	0.034	0.039	0.039	0.034	0.038	0.038
21	0.024	0.027	0.027	0.024	0.026	0.026	0.024	0.027	0.027	0.024	0.027	0.027
22	0.024	0.027	0.027	0.024	0.026	0.026	0.024	0.027	0.027	0.024	0.027	0.027
23	0.010	0.012	0.012	0.010	0.011	0.011	0.010	0.012	0.012	0.010	0.012	0.012
24	0.010	0.012	0.012	0.010	0.011	0.011	0.010	0.012	0.012	0.010	0.012	0.012

7.2 Spatial Allocation

After temporal allocation of emissions has been completed, then spatial allocation is performed. The gasoline station spatial allocation was presented in Figure 4-4. It should be noted that the spatial allocation indicates that one-third of the gasoline station emissions are located in Cell A1 and two-thirds of the gasoline station emissions are located in Cell A3. Gasoline station emissions in the other seven cells (i.e., Cell A2, B1, B2, B3, C1, C2, and C3) will be zero. However, when an emissions modeling system is used, all potential values will be calculated.

Using the calculated hourly emissions shown in Table 7-5 and the spatial allocations shown in Figure 4-4 (Cell A1 = 0.333, Cell A3 = 0.667, and all other cells = 0.000), then the spatially allocated hourly emissions are calculated as follows:

$$E_{TOG,sum,wd,18,A1} = E_{TOG,sum,wd,18} \times SS_{A1} = 0.034\ \text{Mg} \times 0.333 = 0.011\ \text{Mg}$$

This calculation is for Cell A1 and Hour 18 of an average summer weekday, only. Other allocated emissions are calculated in a similar manner, and the results are shown in Table 7-6 and Table 7-7. All emission values are rounded to three decimal places.

Table 7-6. Estimated Spatially Allocated Gasoline Station Emissions (Cell A1) for the Hypothetical Modeling Inventory

Cell A1	**Spring (Mg/hr)**			**Summer (Mg/hr)**			**Fall (Mg/hr)**			**Winter (Mg/hr)**		
Hr	**Wk**	**Sat**	**Sun**	**Wk**	**Sat**	**Sun**	**Wk**	**Sat**	**Sun**	**Wk**	**Sat**	**Sun**
1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
2	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
3	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
4	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
5	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
6	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
7	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
8	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
9	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
10	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
11	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
12	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
13	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
14	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
15	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
16	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
17	0.012	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013
18	0.012	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013
19	0.012	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013
20	0.012	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013
21	0.008	0.009	0.009	0.008	0.009	0.009	0.008	0.009	0.009	0.008	0.009	0.009
22	0.008	0.009	0.009	0.008	0.009	0.009	0.008	0.009	0.009	0.008	0.009	0.009
23	0.003	0.004	0.004	0.003	0.004	0.004	0.003	0.004	0.004	0.003	0.004	0.004
24	0.003	0.004	0.004	0.003	0.004	0.004	0.003	0.004	0.004	0.003	0.004	0.004

Table 7-7. Estimated Spatially Allocated Gasoline Station Emissions (Cell A3) for the Hypothetical Modeling Inventory

Cell A3	Spring (Mg/hr)			Summer (Mg/hr)			Fall (Mg/hr)			Winter (Mg/hr)		
Hr	**Wk**	**Sat**	**Sun**	**Wk**	**Sat**	**Sun**	**Wk**	**Sat**	**Sun**	**Wk**	**Sat**	**Sun**
1	0.002	0.003	0.003	0.002	0.003	0.003	0.002	0.003	0.003	0.002	0.003	0.003
2	0.002	0.003	0.003	0.002	0.003	0.003	0.002	0.003	0.003	0.002	0.003	0.003
3	0.002	0.003	0.003	0.002	0.003	0.003	0.002	0.003	0.003	0.002	0.003	0.003
4	0.002	0.003	0.003	0.002	0.003	0.003	0.002	0.003	0.003	0.002	0.003	0.003
5	0.002	0.003	0.003	0.002	0.003	0.003	0.002	0.003	0.003	0.002	0.003	0.003
6	0.002	0.003	0.003	0.002	0.003	0.003	0.002	0.003	0.003	0.002	0.003	0.003
7	0.012	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013
8	0.012	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013
9	0.012	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013
10	0.012	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013
11	0.012	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013
12	0.012	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013
13	0.012	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013
14	0.012	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013
15	0.012	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013
16	0.012	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013	0.011	0.013	0.013
17	0.023	0.026	0.026	0.022	0.025	0.025	0.023	0.026	0.026	0.023	0.026	0.026
18	0.023	0.026	0.026	0.022	0.025	0.025	0.023	0.026	0.026	0.023	0.026	0.026
19	0.023	0.026	0.026	0.022	0.025	0.025	0.023	0.026	0.026	0.023	0.026	0.026
20	0.023	0.026	0.026	0.022	0.025	0.025	0.023	0.026	0.026	0.023	0.026	0.026
21	0.016	0.018	0.018	0.016	0.018	0.018	0.016	0.018	0.018	0.016	0.018	0.018
22	0.016	0.018	0.018	0.016	0.018	0.018	0.016	0.018	0.018	0.016	0.018	0.018
23	0.007	0.008	0.008	0.007	0.008	0.008	0.007	0.008	0.008	0.007	0.008	0.008
24	0.007	0.008	0.008	0.007	0.008	0.008	0.007	0.008	0.008	0.007	0.008	0.008

7.3 Speciation

After spatial allocation of emissions has been completed, then speciation is performed. The TOG speciation profile for gasoline stations is presented in Appendix B. Because of the large number of calculations that would be required to speciate each of the hourly, gridded emission estimates, these calculations are not included in this section or in Appendix A. Examples of speciation have been provided in Section 5.0.

7.4 Projections

As part of this example, a hypothetical projection factor will be calculated that could be applied to the previously estimated temporally and spatially allocated emissions. In general, projections are needed when an estimate of future emissions which include the effects of growth and controls are desired.

The projection scenario used here is for a projected year 10 years from the base year. The base year emissions from gasoline stations will be used (i.e., 150 Mg/yr). During the 10 years between the base year and the projected year, it is estimated that the population in the inventory domain will increase by an annual growth rate of 1.3%. As a rough estimate, it is assumed that gasoline throughput at the gasoline stations will grow at a similar annual growth rate. Also, various control strategies to be implemented during the 10 years between the base year and the projected year are estimated to provide a 40% control efficiency relative to uncontrolled emissions. Rule effectiveness (RE) and rule penetration (RP) are both assumed to be 90%.

The calculation for estimating the projected emissions is provided as follows:

$$E_{proj} = E_u \times [1 - (CE/100) \times RE \times RP] \times (1 + \%_{ann}/100)^y$$

$$E_{proj} = (150\ \text{Mg/yr}) \times [1 - (40/100) \times 0.9 \times 0.9)] \times (1 + 1.3/100)^{10}$$

$$E_{proj} = (150\ \text{Mg/yr}) \times [0.676] \times (1.1379) = 115.4\ \text{Mg/yr}$$

The projection factor is then calculated by dividing the projected emissions by the base year emissions as shown below:

$$F_{proj} = E_{proj}/E_{u} = (115.4 \text{ Mg/yr})/(150 \text{ Mg/yr}) = 0.769$$

Assuming that the effects of growth and control are evenly distributed over the entire modeling grid domain and during all time periods, then the temporally and spatially allocated base year emissions can be multiplied by a factor of 0.769 to obtain the temporally and spatially allocated projected year emissions. If the assumption that the effects of growth and control are evenly distributed over the entire modeling grid domain is not valid, then the entire modeling inventory development process should be performed with annual emission estimates from the projected year inventory.

8.0 SUMMARY OF HYPOTHETICAL MODELING INVENTORY

A major benefit of a modeling inventory is that a large body of complex data can be developed for input into air quality models. In addition, this data set can be analyzed to determine if the modeling inventory adequately represents the actual emission processes. A few representative analyses from the complete hypothetical modeling inventory are presented below; similar analyses can be derived from actual modeling inventories.

Figure 8-1 presents the hourly distribution of summer weekday TOG emissions (total and by individual source category) for the hypothetical inventory domain. Table 8-1 shows the source-specific emissions that are allocated to Hour 12.

Table 8-1. Hour 12 Summer Weekday TOG Emissions for the Hypothetical Modeling Inventory

Source Category	Emissions (Mg/hr)
Point – Boiler	0.000
Point – Process	0.144
Highway Vehicles	0.054
Gasoline Stations	0.017
Residential Consumer Solvents	0.041
Pesticides	0.080
Total	**0.336**

As expected, the hourly distribution peaks during the daytime hours. The daytime peak is affected primarily by the emissions from the coating process at the factory and, to a lesser extent, by agricultural pesticide use. Highway vehicle emissions occur throughout the day and are the predominant emission source during nighttime hours. Given the temporal profiles that were assumed for this inventory, these results are reasonable.

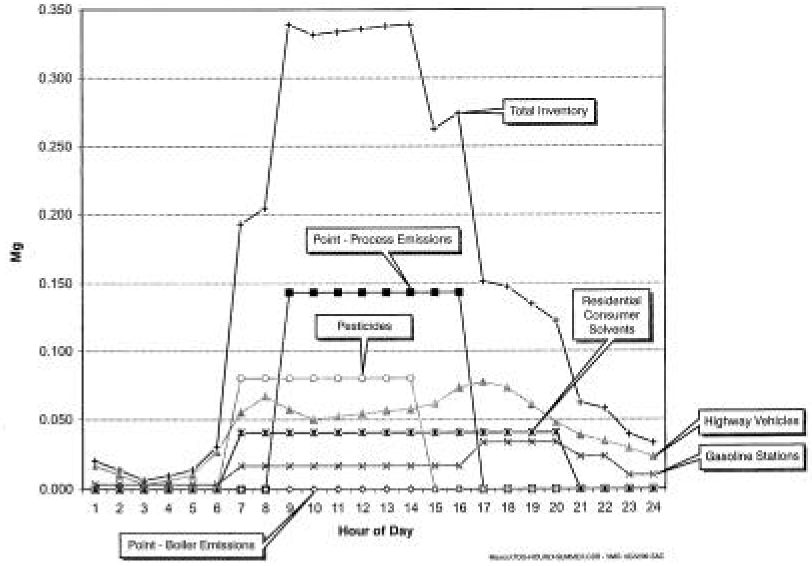


Figure 8-1. Hourly Distribution of Summer Weekday TOG Emissions for the Hypothetical Modeling Inventory

Figure 8-2 presents the hourly distribution of total summer and winter weekday TOG emissions for the entire hypothetical inventory domain. The summer curve is identical to the total curve in Figure 8-1; the scale, however, is different. The summer and winter curves "trace" each other very well from the evening to early morning hours. However, the winter emissions are considerably higher than the summer emissions. The main reason for this difference is that the factory boiler is assumed to be operating at a significant level during the winter and not during the summer. Once again, these results seem to agree with the temporal profiles that were assumed for this inventory.

Figure 8-3 shows the summer weekday TOG emissions for the hypothetical modeling inventory by grid cell. The stacked bar columns show the relative emissions contribution by each source category. The coating process emissions from the factory are the largest source located in Cell B3. Significant emissions from gasoline stations and highway vehicles are also located in Cells A1 and A3. Although pesticides are the only emitting source category in Cells C1 and C2, their contribution could be significant.

The relative distribution of total emissions in Figure 8-3 will be different if specific hours are analyzed. Also, the distribution of emissions would be different if different pollutants, seasons, or days were analyzed. For instance, if the distribution of summer weekday CO emissions was examined, there would be no emissions located in Cells B1, B2, C1, and C2. Only those cells with combustion sources (e.g., highway vehicles) would have any CO emissions. Likewise, the peak value of weekday TOG emissions located in Cell B3 (relative to other grid cells) would be even more pronounced in the winter because the factory boiler would be operating in addition to the coating process, which operates year-round. Finally, if weekend emissions were examined, instead of weekday emissions, there would be no peak value for TOG emissions in Cell B3 (relative to other grid cells) because the factory does not operate on Saturday or Sunday; TOG emissions in that grid cell would be at comparable levels to other grid cells.

The analyses presented in Figures 8-1, 8-2, and 8-3 are more straightforward than those associated with a typical modeling inventory. However, they demonstrate the analytical capabilities that are available through the use of modeling inventories.

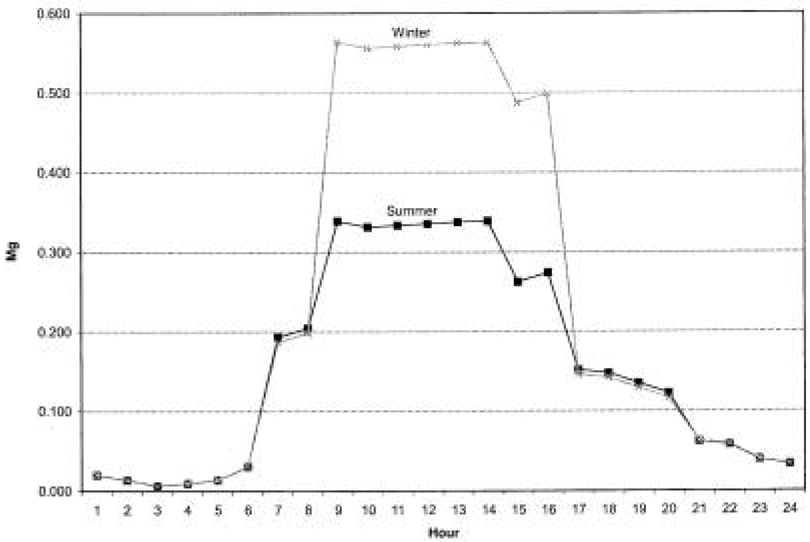


Figure 8-2. Comparison of Hourly Summer and Winter TOG Emissions for the Hypothetical Modeling Inventory

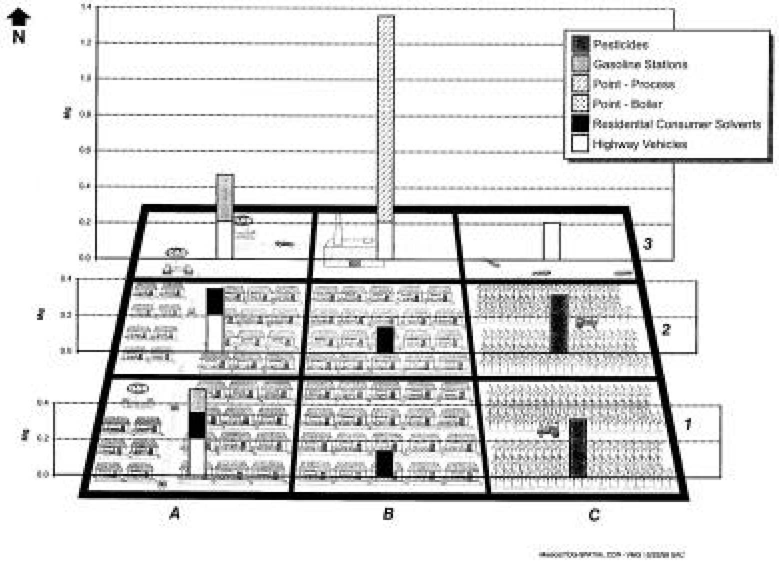


Figure 8-3. Spatial Distribution of Summer Weekday TOG Emissions for the Hypothetical Modeling Inventory

9.0 CONCLUSION

As mentioned previously, the spreadsheets located in Appendix A contain all the calculations used to temporally and spatially distribute emissions in this document’s modeling inventory example. Due to the large number of computations, speciation calculations were not included in Appendix A. Likewise, projection calculations were also not included in Appendix A. The 66 pages contained in Appendix A address only temporal and spatial allocation for the six source categories and nine grid cells that were included in the hypothetical modeling inventory example used.

Although the modeling inventory example presented in this document was simplified compared to an actual modeling inventory, the four steps of modeling inventory development (i.e., temporal allocation, spatial allocation, speciation, and projection) are the fundamental methods used in all emissions modeling systems. In general, an electronic emissions modeling system, rather than spreadsheets such as those presented in Appendix A, is needed to develop modeling inventories. Furthermore, this manual should be used along with emissions model user’s guides for developing modeling inventories and their required data sets.

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APPENDIX A
Hypothetical Modeling Inventory Calculation Spreadsheets

This appendix presents the calculation spreadsheets used for the hypothetical modeling inventory example contained in this manual. The calculation spreadsheets for each of the six emission sources are presented in this appendix as follows:

- Factory boiler – pages A-1 through A-11;
- Factory coating process – pages A-12 through A-22;
- On-road motor vehicles – pages A-23 through A-33;
- Gasoline stations – pages A-34 through A-44;
- Residential consumer solvent use – pages A-45 through A-55; and
- Pesticide application – pages A-56 through A-66.

The format of each 11 page emission source spreadsheet is as follows:

- Page #1 – Presentation of annual emissions; presentation of monthly, weekly, and hourly temporal allocation profiles; calculation of seasonal profiles, weekly activity profiles, and weekly allocation factors; and calculation of seasonal, average weekday, average Saturday, and average Sunday emissions;
- Page #2 – Temporally allocated emissions;
- Page #3 – Gridded and temporally allocated emissions for Cell A1;
- Page #4 – Gridded and temporally allocated emissions for Cell A2;
- Page #5 – Gridded and temporally allocated emissions for Cell A3;
- Page #6 – Gridded and temporally allocated emissions for Cell B1;
- Page #7 – Gridded and temporally allocated emissions for Cell B2;
- Page #8 – Gridded and temporally allocated emissions for Cell B3;
- Page #9 – Gridded and temporally allocated emissions for Cell C1;
- Page #10 – Gridded and temporally allocated emissions for Cell C2; and
- Page #11 – Gridded and temporally allocated emissions for Cell C3.

APPENDIX B
Hypothetical Modeling Inventory TOG Speciation Profiles

This appendix presents TOG speciation profiles that might be used for each of the six emission sources presented in this manual. All of the speciation profiles presented were obtained from U.S. EPA's SPECIATE database (U.S. EPA, 1999c). Each profile is labeled with the SPECIATE database profile number. The five columns for each profile identify the SPECIATE compound number, CAS number, species name, molecular weight, and weight percent for each compound in the speciation profile.

APPENDIX C
Hypothetical Modeling Inventory PM Speciation Profiles

This appendix presents PM speciation profiles that might be used for the two of the six emission sources presented in this manual that would have PM emissions (i.e., factory boiler and on-road motor vehicles). Both speciation profiles presented were obtained from U.S. EPA's SPECIATE database (U.S. EPA, 1999c). Each profile is labeled with the SPECIATE database profile number. The three columns in each profile identify the CAS number, species name, and weight percent for each compound in the speciation profile. It should be noted that these speciation profiles were not actually used in this manual and are presented for informational purposes only.

Factory Boiler

Factory Coating Process

On-road Motor Vehicles

Gasoline Stations

Residential Consumer Solvent Use

Pesticide Application

Prototipo
Cuestionario e Instrucciones para Fuentes Puntuales en México

El Cuestionario anexo está diseñado para recopilar datos sobre las emisiones de contaminantes al aire y la operación de los establecimientos industriales en México. Estos datos son necesarios para una mejor comprensión de las fuentes y magnitud de dichas emisiones.

El cuestionario existente para establecimientos en México ha sido rediseñado y fortalecido para facilitar la recopilación de los datos y perfeccionar la planeación de la calidad del aire. A continuación se presenta un panorama general del Cuestionario y sus formas, así como las instrucciones específicas para su llenado.

DEFINICIONES

El concepto clave para organizar los datos dentro del Cuestionario es la aplicación de los principios básicos del flujo y balance de materiales. Este enfoque ha sido utilizado para simplificar la comprensión de los datos y sus interrelaciones, dado que es el más familiar para los profesionales técnicos. Las siguientes son definiciones generales relacionadas con estos principios:

- Material: Materia o energía en cualquiera de sus formas. Un material puede ser cualquier sustancia, incluyendo contaminantes atmosféricos, combustibles, solventes, recubrimientos, químicos manufacturados, energía eléctrica y calor, y artículos tales como partes manufacturadas. Un material puede estar en cualquier estado físico (i. e., gas, líquido o sólido, o bien una mezcla de estados).

- Proceso: Un mecanismo químico o físico que origine, destruya o transforme un material de cualquier manera. Con respecto a la contaminación del aire, los procesos típicos incluyen a la combustión, evaporación, manejo de materiales y reacciones químicas.

Para determinar la ubicación de un proceso, son necesarias tres definiciones adicionales:

- Equipo: El sistema, máquina o instrumento en el que ocurre un proceso. Un equipo puede tener más de un proceso, y puede ser de cualquier tipo industrial, incluyendo: calderas, desengrasadores con solventes, pilas de almacenamiento, estanques de residuos, vehículos de motor, y equipos de control tales como casas de bolsas y chimeneas para la descarga de contaminantes.

- Equipo/Proceso: Es un proceso específico en un equipo específico (e. g., caldera y combustión, desengrasador y evaporación).

- Establecimiento: Es el sitio geográfico en el que se ubican los equipos. Típicamente, un establecimiento es el predio que el Operador del Establecimiento posee u opera.

Las relaciones lógicas entre Establecimiento, Equipo, Proceso y Material son las siguientes:

- Un establecimiento está integrado por uno o más equipos, cada uno de los cuales debe estar ubicado en el establecimiento

- Un Equipo tiene uno o más Procesos (normalmente sólo uno), y cada Proceso debe estar asociado con un Equipo

- Un Proceso tiene uno o más Materiales de entrada y/o salida (que entran o salen como una corriente), y cada Material debe estar asociado con uno o más Procesos.

Por otro lado, también existen las siguientes relaciones lógicas:

- Un material puede fluir de un Proceso (como salida) y fluir dentro de otro Proceso (como entrada)

- Dos Equipos pueden estar conectados para indicar que el Material puede fluir entre los Procesos y los Equipos.

La Figura 1 muestra de manera gráfica el concepto de un proceso. El círculo representa el proceso, y las flechas muestran los materiales que entran y salen de éste. En algunas ocasiones, el flujo de materiales hacia dentro y fuera del proceso que es representado por las flechas es conocido como una corriente.

IDENTIFICADORES UNICOS

Los identificadores únicos deben ser utilizados para identificar cada acontecimiento en un Establecimiento o Equipo. A continuación se presentan los procedimientos a ser utilizados para estos conceptos:

- Identificación (ID) del Establecimiento: Es el identificador único creado y utilizado por la Dependencia Normativa

- Identificación (ID) del Equipo - Es el identificador único creado y utilizado por el Operador del Establecimiento (o por la Dependencia Normativa si ninguno está disponible por parte del Operador del Establecimiento). Por ejemplo, si un establecimiento tiene tres calderas, sus identificaciones podrían ser asignadas simplemente como Equipo 1, 2, y 3. La ID del equipo puede ser cualquier combinación de caracteres con una longitud máxima de [XXX] (e. g., “A-42/1”).

PAQUETE DEL CUESTIONARIO

El Cuestionario está integrado por una serie de Formas, y está estructurado de una manera jerárquica consistente para organizar efectivamente la información de su establecimiento. El Anexo A contiene una lista de las formas disponibles y da las instrucciones para llenar cada una de ellas.

Este paquete incluye la siguiente información para facilitar el llenado del Cuestionario:

- Una carta dirigida al Operador del Establecimiento, donde se identifica el Establecimiento al que se le están solicitando los datos y la fecha en que debe entregarlos

- Un juego de instrucciones para llenar el Cuestionario, incluyendo una definición de términos

- Ejemplos de formas llenas para niveles variables de complejidad (Anexo B)

- Las formas del Cuestionario que deben ser llenadas (Anexo C)

- Una forma para la firma de la persona responsable, donde ratifique que los datos que se están entregando a la Entidad son precisos y están completos

- Un sobre con porte pagado.

REQUERIMIENTOS GENERALES

Formas de Presentación para los Establecimientos Individuales

Una empresa puede tener más de una localización o sitio con equipo que genere emisiones atmosféricas. Se requiere formas independientes para cada sitio.

Reporte de los Datos para el Año Calendario

Los datos deben representar un año calendario. Cualquier información que haya variado durante el año calendario debe ser reportada, ya sea como el valor más reciente (i. e., el valor al final del año calendario), o el valor típico. Los ejemplos de los casos en que el valor más reciente es de mayor utilidad son el nombre del operador del establecimiento y el nombre del contacto; mientras que los casos en que el valor típico es de mayor utilidad son el color de un tanque de almacenamiento y el calendario de operación del establecimiento o equipo.

Cálculo de Sus Emisiones

Los establecimientos son responsables del cálculo y la presentación de sus propias estimaciones de emisión. Comuníquese con la Oficina de SEMARNAP de su localidad para obtener los métodos específicos y los factores de emisión que pueden ser utilizados para ayudarle en sus cálculos. Si cuenta con datos confiables específicos para el proceso que describan las emisiones, tales como los datos de mediciones en chimeneas, entonces deben éstos ser utilizados para calcular las emisiones, en sustitución de los factores de emisión genéricos.

Proporcionar Estimados de Emisión para Contaminantes Específicos

Los estimados de emisión de los siguientes contaminantes deben ser calculados y reportados: gases orgánicos totales (GOT); óxidos de nitrógeno (NO_x); óxidos de azufre (SO_x); monóxido de carbono (CO); y material particulado total (MP).

Proporcionar Información Detallada

El Cuestionario anexo está diseñado para que el operador del establecimiento calcule y reporte las emisiones de cada equipo emisor (e. g., una caldera). Por favor, proporcione toda la información posible acerca del equipo específico, así como de todos sus procesos. Deben entregarse detalles suficientes junto con los estimados de emisión para permitir la revisión independiente de las emisiones.

Reportar las Emisiones de Todos los Equipos

Deben reportarse todas las emisiones de los equipos fijos en su establecimiento; las emisiones de equipo móvil (e. g., autos y camiones) no requieren ser reportadas. Los equipos estacionarios incluyen:

- Equipos de combustión tales como calderas y motores estacionarios de combustión interna

- Equipo con uso de solventes, tales como aquellos que aplican o utilizan materiales para el recubrimiento de superficies y desengrasado

- Equipos de evaporación, tales como tanques de almacenamiento a granel

- Equipo para el manejo de materiales, tales como transportadores, pilas de almacenamiento y equipo de trituración y molienda

- Equipos utilizados en diversos procesos industriales tales como la fundición de cobre.

Esta lista proporciona sólo algunos ejemplos; las emisiones deben ser reportadas para estos tipos de equipo y otras operaciones similares.

Agrupación de Equipos

En algunos casos, puede no haber información suficiente para calcular las emisiones de los equipos individuales, pero sí para un grupo de equipos. En este caso, varios equipos pueden ser agrupados de manera tal que la cantidad de material consumido o procesado sea reportada para el conjunto como un todo. Existen dos casos en los que esto ocurre y que requieren ser manejados por separado: los equipos en paralelo y los equipos en serie.

Equipos en Paralelo

Los equipos en paralelo son aquellos de tipo equivalente y que tienen las mismas características de operación. Típicamente serán asociados con el mismo factor de emisión. Por ejemplo, varias calderas con el mismo tipo, tamaño, equipo de control y combustible quemado. La razón por la que estos equipos en paralelo deben ser agrupados es que la cantidad de combustible utilizado por cada caldera individual es desconocido, y sólo se tiene el total del combustible consumido por todo el grupo. Si no puede demostrarse que los elementos de un conjunto de equipos en paralelo es equivalente y posee las mismas características de operación, deberán ser reportados de manera individual. En este caso, debe aplicarse el juicio ingenieril para asignar los valores del parámetro de operación (e. g., uso de combustible), y calcular las emisiones.

Para incluir los datos de un grupo de equipos en paralelo, las formas relacionadas con el equipo deben ser llenadas como se indica a continuación:

- Una forma para el “grupo” de equipos, al que se le asignara su propia ID de equipo. El campo para la “ID del Grupo de Equipos del que este equipo es miembro” se deja en blanco.

- Una forma para cada equipo individual que integra al grupo. A cada equipo se le asigna su propia ID, y la ID del Grupo de Equipos al que éste pertenece es registrada en el campo para la “ID del Grupo de Equipos de los que este equipo es miembro”

Equipos en Serie

Los equipos en serie son aquellos que pueden operar únicamente como una sola unidad, por ejemplo, una unidad de procesamiento químico (con válvulas, compresores, respiraderos, etc.), o una línea de recubrimiento (con una cabina de asperjado de recubrimiento, horno de secado y operación de limpieza). La razón por la que estos equipos en serie son agrupados se debe a que las emisiones son desconocidas para cada elemento, sin embargo, pueden ser calculadas para el grupo. Por ejemplo, el solvente evaporado de una línea de recubrimiento puede ser calculado para todo el proceso, pero no así la cantidad emitida en cada paso. Para incluir datos de grupos de equipos en serie, sólo es necesario llenar una forma para el grupo como un todo.

REQUERIMIENTOS ADICIONALES DE INFORMACION

La siguiente documentación debe ser entregada para complementar la información contenida en sus formas. Esta información requiere ser presentada sólo una vez, y debe ser actualizada anualmente si la configuración del establecimiento ha cambiado a partir de los reportes previos.

1. Mapa tamaño carta del establecimiento donde se muestre: [1.14]
   - Límites del establecimiento [1.14.1];
   - Calles adyacentes [1.14.4.2];
   - Ubicación de la zona residencial o sitios de reunión más próximos [1.14.4];
   - Norte de referencia [1.14]
   - Distribución del establecimiento y predios adyacentes [1.14.4].
2. Diagrama de flujo que muestre:
   - Cada equipo (máquina, instrumento, etc.), con la ID de Equipo asignada
   - Una lista de los diferentes procesos que pueden darse en cada equipo (e. g., qué combustibles son quemados, qué solventes son utilizados, etc.)
   - La dirección del flujo de materiales hacia dentro y fuera de cada equipo, incluyendo el flujo entre equipos conectados y el nombre de los materiales involucrados
   - El equipo que descarga a la atmósfera, incluyendo equipo de control de emisiones y chimeneas.
3. Diagrama de ingeniería del establecimiento que muestre:
   - La ubicación real de cada equipo (incluyendo equipo de control y chimeneas) que haya sido identificado en el Diagrama de Flujo del Proceso, incluyendo la ID del equipo [3.13]
   - Cada Grupo de Equipo, incluyendo su correspondiente ID de grupo.
4. Copia de la licencia de uso de suelo [1.14.3].
5. Copia de la autorización para el uso de equipo sujeto a presión, emitido por la Secretaría del Trabajo y Previsión Social [3.1.4].

FECHA DE ENTREGA

[Insertar instrucciones para la adecuada presentación de la fecha. Esto debe ser estandarizado para cada aplicación de este Cuestionario.]

INSTRUCCIONES DE ENTREGA

[Insertar instrucciones para los procedimientos de presentación adecuados. Esta lista debe ser estandarizada para cada aplicación de este Cuestionario.]

AYUDA

Soporte Telefónico
El soporte telefónico está disponible en la oficina de SEMARNAP de su localidad. [El Anexo B contiene una lista de los números telefónicos de la SEMARNAP].

Taller de Información
El personal de distrito de SEMARNAP efectuará talleres de trabajo anuales para responder preguntas y ayudar a los representantes de la industria en el llenado de las formas del Cuestionario. Comuníquese con su oficina regional de SEMARNAP para obtener información acerca de las fechas, horas y sedes de los talleres programados en su zona.

EJEMPLOS

El Anexo B contiene ejemplos de Formas de Cuestionario llenadas. Por favor, revise estos ejemplos antes de llenar el Cuestionario.

ANEXO A

LISTA DE FORMAS E INSTRUCCIONES

Anexo A
Lista de Formas e Instrucciones

Las siguientes formas fueron desarrolladas para facilitar el reporte de emisiones:

Claves	Descripción
Formas Generales	
PPT1	Portada para Remisión
EST1	Establecimiento
EQG1	Equipo General
CTL1	Equipo de Control de la Contaminación Atmosférica
CHM1	Chimeneas de Descarga
Formas para Equipo Específico	
CYC1	Calderas y Calentadores
EDS1	Equipo de Desengrasado con Solventes
MCI1	Motores de Combustión Interna
INC1	Incineradores
TAP1	Tanques Abiertos de Proceso
HOR1	Hornos
IMP1	Equipo de Impresión
SOL1	Equipo General de Uso de Solventes
ASP1	Cabinas de Aspersión y Aspersión Abierta
PDA1	Pilas de Almacenamiento
TNQ1	Tanques de Almacenamiento de Techo Fijo y Flotante

La relación entre las formas y el flujo de datos entre éstas se muestra en la Figura A-1.

Instrucciones
Forma para Establecimiento
[EST1]

Proporcione la información requerida acerca de la propiedad del establecimiento, los productos elaborados y la ubicación.

Información acerca del Propietario: Proporcione la información solicitada sobre la empresa que es responsable de la operación del establecimiento. El Nombre de la Empresa es la razón social registrada ante la Secretaría de Comercio y Fomento Industrial. La Asociación Industrial es el sector o asociación a la que la empresa pertenece o está afiliada. El Registro Federal de Causantes es la clave con la que la empresa está registrada ante la Secretaría de Hacienda y Crédito Público (SHCP).

Contacto: Proporcione el nombre, título o puesto, dirección y número telefónico de la persona responsable de la información contenida en el cuestionario, y que puede responder a las preguntas sobre cualquier información que haya sido presentada en éste.

Descripción del Establecimiento: Proporcione el nombre del establecimiento (no el nombre de la empresa) y los otros campos de datos solicitados.

Ubicación del Establecimiento: Proporcione la ubicación del establecimiento para los campos de datos solicitados.

Licencias: Proporcione los números de las licencias solicitadas.

Ubicación Geográfica: Proporcione la longitud y latitud del centroide del establecimiento y su elevación sobre el nivel del mar.

Datos Meteorológicos del Establecimiento: Obtener los datos meteorológicos locales a través del aeropuerto local, la oficina regional de la Comisión Nacional del Agua (CNA) o el INEGI. Los días de sequía por año son definidos como los días con una precipitación menor que 0.254 mm.

Calendario de Operación del Establecimiento: Registre el calendario general de operación para el establecimiento. Por ejemplo, el establecimiento típicamente opera 10 horas diarias, 5 días a la semana, 50 semanas al año.

Porcentaje Mensual Utilizado: Describa la actividad relativa mensual para las operaciones estacionales. Por ejemplo, las calderas utilizadas para calefacción pueden tener periodos inactivos durante el año, en los que su porcentaje de uso será 0%. Registre los valores en los espacios indicados y asegúrese de que sumen 100%.

Emisiones Totales: Se deberá llenar una forma para cada equipo que realmente descargue emisiones a la atmósfera (incluyendo los equipos de control y las chimeneas). Deben sumarse las emisiones descargadas a la atmósfera reportadas en cada una de estas formas y reportarlas en esta sección.

Instrucciones
Forma para Equipo General [EQG1]

Definición de Equipo: Un Equipo General es cualquier equipo para el que no existe una forma específica.

Identificación del Equipo: Registre la clave de identificación de equipo asignada a esta pieza particular. Si varias piezas similares de equipo han sido agrupadas para propósitos de reporte, registre el número de identificación del equipo en el espacio para grupo de equipo. Registre el nombre que usted utiliza para este equipo, por ejemplo, “caldera oeste” u “horno del Edificio 2”.

Si las emisiones del equipo de control son enviadas a la atmósfera, marque la caja apropiada. Si las emisiones del equipo son descargadas a un equipo de control o chimenea, registre la identificación de la chimenea o del equipo de control.

Características del Equipo: En los espacios indicados, registre el fabricante, modelo y número de serie del equipo.

Describa brevemente para qué se utiliza el equipo. Por ejemplo, “calefacción” u “horno de recalentamiento de aluminio”.

Calendario de Operación por Proceso: Si el calendario de operación es el mismo que se reporta en la Forma de Establecimiento (EST1), este dato no es requerido; sin embargo, si fuera diferente, registre el calendario típico de operación para cada material de entrada en el proceso. Por ejemplo, el propano podría ser utilizado en los meses de verano y el aceite destilado, para el resto del año. Cada uno de estos materiales debe ser registrado en la forma con el porcentaje de uso mensual correspondiente.

Emisiones por Proceso: En el espacio para “Material de Entrada”, registre cada material utilizado en el equipo. En la columna titulada “Uso Anual del Material” registre la cantidad de material utilizada para el año de reporte. Las unidades para esta cifra son registradas en la columna “Unidades de Uso”, y pueden ser expresadas como unidades de masa (e. g., kg) o de volumen (e. g., kl). Por ejemplo, los 32,400 litros de propano consumidos en una caldera serían registrados en estas columnas como: (1) Material de Entrada: “Propano”; (2) Uso anual: “32.4”; y (3) unidades: “kl”.

Las emisiones pueden ser calculadas y registradas en esta forma utilizando diversos métodos, como se describe a continuación.

Si bien sólo un método puede ser utilizado para calcular cualquier emisión, pueden utilizarse métodos diferentes para cálculos de diferentes emisiones, para cada parámetro de cualquier proceso.

Los métodos disponibles para la estimación de las emisiones se presentan a continuación, así como su código de letras:

- Factor de Emisión Genérico (Método Código G): Cualquier cálculo que use un solo factor genérico de emisión que sea multiplicado por un solo valor de uso o rendimiento. Un factor genérico de emisión es un factor de emisión publicado por una autoridad reconocida, que es representativo del equipo y proceso en cuestión

- Factor de Emisión Específico de Fuente (Método Código E): Cualquier cálculo que use un solo factor de emisión específico de fuente que sea multiplicado por un solo valor de uso o rendimiento. Un factor de emisión específico de fuente es un factor de emisión desarrollado específicamente para el equipo y proceso en cuestión, típicamente utilizando datos de mediciones

- Datos de Mediciones en Fuente (Método Código M): Cualquier cálculo que use mediciones de la corriente de gas descargada. Los datos utilizados deben ser representativos de las condiciones típicas de la operación real.

- Balances de Masa (Método Código B): Cualquier cálculo que use la ley de conservación de masa para estimar las cantidades de material fugados a la atmósfera, después de haber contabilizado todas las otras entradas y salidas de dicho material para un proceso determinado.

- Cálculos de Ingeniería (Método Código I): Cualquier cálculo basado en las características físicas del equipo y las operativas del proceso. Un ejemplo son las ecuaciones empíricas que han sido desarrolladas para los tanques de techo flotante.

- Otros (Método Código O): Cualquier otro método que sea explicado por escrito y anexado a la forma.

En la forma, el método de cálculo, la emisión calculada y el factor de emisión (si es utilizado) son registrados en la caja correspondiente. El factor de emisión es capturado en la esquina superior izquierda de cada caja en el campo mostrado como [____]. El código del método es registrado en la caja (?) debajo del factor de emisión. La emisión calculada es registrada en la mitad inferior de la caja.

Los métodos de cálculo de emisión generalmente calculan las “emisiones no controladas”, es decir, las emisiones que serían descargadas a la atmósfera si no hubiera un equipo de control corriente abajo (las formas están diseñadas para contabilizar los equipos de control corriente abajo utilizando formas adicionales para calcular cualquier reducción por parte de estos equipos). En algunos casos, el método de cálculo de emisiones cuantificará las “emisiones controladas”, es decir, aquellas que son descargadas a la atmósfera después de pasar a través de un equipo de control. En general, las emisiones controladas son calculadas directamente cuando:

- El factor de emisión utilizado incluye el efecto de un equipo de control corriente abajo (i. e., es un “factor de emisión controlada”)

- La medición en fuente se realiza en el punto de descarga a la atmósfera, y no en la salida del equipo generador.

Cuando el cálculo de emisiones genere emisiones controladas y se incluya una forma para el equipo de control, registre en la forma “emisiones controladas” en lugar del valor de emisión.

Instrucciones
Equipo de Control de la Contaminación Atmosférica
[Forma CTL1]

Identificación del Equipo: Registre la clave de identificación asignada a este equipo de control de la contaminación atmosférica particular. Si varias piezas similares de equipo han sido agrupadas para propósitos de reporte, registre el número de identificación del equipo en el espacio para grupo de equipo, y descríbalo brevemente.

Si las emisiones del equipo de control son enviadas a la atmósfera, marque la caja apropiada. Si las emisiones del equipo son descargadas a otro equipo de control o chimenea, registre la identificación de dicha chimenea o equipo de control.

Características del Equipo: En los espacios indicados, registre el fabricante, modelo y número de serie del equipo. Si el equipo no estuviera disponible con el fabricante, sino que hubiera sido diseñado y construido específicamente para este establecimiento, registre al fabricante como “propio”.

Marque la caja que mejor describa el equipo de control y registre cualquier información adicional requerida para la opción seleccionada.

Características Operativas del Proceso: A partir de los registros operativos, registre la máxima tasa de flujo de emisiones de escape que son procesadas por el equipo de control. Registre la temperatura tanto de entrada como de salida de la corriente de gas que ingresa y sale del equipo de control. Asimismo, registre el tiempo de paro (i. e., la cantidad de tiempo que las emisiones no estuvieron controladas por este equipo debido a reparaciones, mal funcionamiento, no uso, etc.).

Emisiones de Entrada: En otras formas, las emisiones fueron calculadas para los equipos y procesos individuales. En el espacio asignado para “Entrada Totales” en la tabla de Emisiones, enliste cada equipo que envíe una corriente de emisión a este equipo de control (las emisiones pueden venir de cualquier otro equipo y/o equipo de control).

Registre la eficiencia de captura para cada corriente de entrada de este equipo de control. La eficiencia de captura es la fracción de las emisiones en la corriente que llegan a este equipo. Si todas las emisiones corriente arriba alcanzaran este equipo de control, la eficiencia de captura sería del 100% (i.e., el 100% de las emisiones fueron “capturadas” por este equipo de control).

Registre las Emisiones Corriente Arriba, i. e., las emisiones que representaron “Salidas” del equipo corriente arriba. Calcule las Emisiones de Entrada, i. e., las emisiones que realmente entraron en este equipo de control, y las Emisiones Fugitivas, utilizando las ecuaciones en la parte inferior de la tabla que incluye la eficiencia de captura. Sume las Emisiones de Entrada (i. e., aquellas que fueron “capturadas” por este equipo de control”) y las Emisiones Fugitivas, y registre dichos valores en la parte inferior de la tabla.

Emisiones de Salida: En la tabla de Emisiones de Entrada, se calcularon las emisiones totales “capturadas” por el equipo para determinar las emisiones de entrada totales que fueron procesadas por éste. En la tabla de Emisiones de Salida Totales registre estas emisiones de entrada (i.e., “capturadas”).

Registre la eficiencia de control del equipo. Esta es la fracción del contaminante eliminado de la corriente de gas (por ejemplo, un equipo de control de la contaminación del aire que elimine el 90% del material particulado en una corriente de aire, tendrá una eficiencia de control del 90%).

Las emisiones de salida de este equipo de control (también identificado como las emisiones “controladas”) se calculan utilizando la eficiencia de captura a través de la ecuación que se presenta en la parte inferior de la tabla.

Instrucciones
Chimeneas de Descarga
[Forma CHM1]

Identificación del Equipo: Registre la clave de identificación de equipo asignada a la chimenea. Si varias piezas similares de equipo han sido agrupadas para propósitos de reporte, registre el número de identificación del equipo en el espacio para grupo de equipo

Características del Equipo: Proporcione la información acerca de la altura física total de la chimenea sobre el suelo, el diámetro interno de la chimenea en el punto en que el gas de escape es descargado a la atmósfera, y la altura de la chimenea sobre el techo, en el caso de que estuviera ubicada sobre un techo. Si se conocen, proporcionar las coordenadas de latitud y longitud donde se localiza la chimenea.

Si el punto de descarga de la chimenea es rectangular, el diámetro efectivo de la chimenea *(diámetro)* puede calcularse con la siguiente fórmula:

$$diámetro = 2\sqrt{longitud \text{ x } anchura/\pi}$$

donde: *longitud* y *anchura* son la longitud y anchura internos del rectángulo, respectivamente.

Características de Operación: Proporcione la temperatura y tasa de flujo de escape del gas en el punto en el que es descargado a la atmósfera. La tasa de flujo de escape (*flujo*) puede ser calculada con la siguiente fórmula:

$$flujo = \frac{\pi}{4}\,(diámetro)^2 \text{ x } velocidad$$

donde *diámetro* es el diámetro efectivo en el punto de descarga y *velocidad* es la velocidad de salida en el mismo punto.

Emisiones: En otras formas, las emisiones fueron calculadas para los equipos y procesos individuales. En el espacio proporcionado en la tabla de Emisiones, enliste cada equipo que envíe una corriente de emisión a este equipo de chimenea de descarga.

Registre la eficiencia de captura para cada corriente de entrada de la chimenea de descarga. La eficiencia de captura es la fracción de las emisiones en la corriente que llegan a este equipo. Si todas las emisiones corriente arriba alcanzaran este equipo de control, la eficiencia de captura sería del 100% (i. e., el 100% de las emisiones fueron “capturadas” por este equipo de control).

Registre las Emisiones Corriente Arriba, i. e., las emisiones que representaron “Salidas” del equipo corriente arriba. Calcule las Emisiones de Entrada, i. e., las emisiones que realmente entraron y se descargaron a través de este equipo de chimenea utilizando las ecuaciones en la parte inferior de la tabla que incluye la eficiencia de captura. Sume las Emisiones de Descarga (i. e., aquellas que fueron “capturadas” por la chimenea de descarga”) y las Emisiones Fugitivas, y registre dichos valores en la parte inferior de la tabla.

Instrucciones
Calderas y Calentadores
[Forma CYC1]

Las instrucciones son idénticas a las de la forma de Equipo General [EQG1], excepto por las instrucciones adicionales que se presentan a continuación.

Características del Equipo: Identifique el tipo (e. g., tangencial, de bajo NOx, etc.) y el número de quemadores en el equipo. Asimismo, registre la máxima tasa de calor y el método de arranque del equipo.

Emisiones por Proceso: Para cada combustible de entrada, registre su uso anual y las siguientes características: contenido de azufre, nitrógeno y cenizas, contenido calorífico y densidad.

Instrucciones
Equipo de Desengrasado con Solventes
[Forma EDS1]

Las instrucciones son idénticas a las de la forma de Equipo General [EQG1], excepto por las instrucciones adicionales que se presentan a continuación.

Definición de Equipo: Cualquier equipo utilizado para remover la grasa de partes que utilice un solvente orgánico.

Características del Equipo: Registre la longitud y anchura del área de superficie del solvente y la altura del borde libre. Identifique si el equipo es de limpieza fría por lotes o de vapor o desengrasador en línea.

Emisiones por Proceso: En el campo "Tipo de Solvente", registre cada solvente utilizado en el equipo. En las columnas tituladas "Uso Anual" y "Cantidad Anual Dispuesta", registre la cantidad de material utilizado y dispuesto durante el año de reporte. Registre la densidad del solvente.

Instrucciones
Motores de Combustión Interna
[Forma MCI1]

Las instrucciones son idénticas a las de la forma de Equipo General [EQG1], excepto por las instrucciones adicionales que se presentan a continuación.

Definición de Equipo: Cualquier equipo que queme combustible a presión para generar energía mecánica. Esto incluye motores de pistones y de turbina.

Características del Equipo: Identifique si el motor es de tipo turbina o de pistones.

Proporcionar la máxima capacidad tasada y el factor de carga promedio del motor.

Emisiones por Proceso: El porcentaje de azufre requerido para calcular las emisiones SOx debe registrarse en la caja ubicada en la esquina superior derecha, dentro del campo mostrado como [_____S%].

Instrucciones
Incineradores
[Forma INC1]

Las instrucciones son idénticas a las de la forma de Equipo General [EQG1], excepto por las instrucciones adicionales que se presentan a continuación.

Características del Equipo: Identifique el tipo de residuos que es incinerado, y registre el número de cámaras de incineración.

Emisiones por Proceso: En el campo “Material de Entrada”, registrar cada tipo de residuo incinerado, el rendimiento anual y las unidades de rendimiento.

Instrucciones
Tanques Abiertos de Proceso
[Forma TAP1]

Las instrucciones son idénticas a las de la forma de Equipo General [EQG1], excepto por las instrucciones adicionales que se presentan a continuación.

Características del Equipo: Registre las dimensiones del tanque abierto de proceso (longitud, anchura y altura). Indique el tipo de tanque y método de agitación. Adicionalmente, describa cualesquier métodos anti-niebla o inhibidores de niebla que se utilicen.

Emisiones por Proceso: Para cada material de entrada, registre la solución y tipo de plateado.

Instrucciones
Hornos
[Forma HOR1]

Las instrucciones son idénticas a las de la forma de Equipo General [EQG1], excepto por las instrucciones adicionales que se presentan a continuación.

Emisiones por Proceso: Para cada combustible de entrada, registre el uso anual de combustible.

Instrucciones
Equipo de Impresión
[Forma IMP1]

Las instrucciones son idénticas a las de la forma de Equipo General [EQG1], excepto por las instrucciones adicionales que se presentan a continuación.

Características del Equipo: Identifique el tipo de impresión, sustrato utilizado (i. e., el tipo de material sobre el que se hace la impresión, e. g., papel), el producto elaborado (e. g., periódico, carteles, etc.), y el método de secado.

Emisiones por Proceso: Para cada solvente de tinta de entrada, registre su uso anual y densidad (si son necesarios para calcular la masa de las emisiones).

Instrucciones
Equipo General de Uso de Solventes
[Forma SOL1]

Las instrucciones son idénticas a las de la forma de Equipo General [EQG1], excepto por las instrucciones adicionales que se presentan a continuación.

Definición de Equipo: Cualquier equipo que use solventes para el que no exista una forma de Equipo específica. Las formas específicas existen para el equipo de desengrasado con solventes e impresión.

Emisiones por Proceso: En el campo “Material de Entrada”, registre cada material utilizado en el equipo. En las columnas intituladas “Uso Anual” y “Cantidad Anual Dispuesta”, registre la cantidad de material utilizado y dispuesto durante el año de reporte. Registre la densidad del solvente, el nombre del solvente contenido en el material de entrada, el contenido del solvente en el material y la densidad del solvente. Si un material determinado contiene diversos solventes, debe incluirse un renglón de datos para cada uno de ellos.

Instrucciones
Cabinas de Aspersión y Equipo de Aspersión Abierta
[Forma ASP1]

Las instrucciones son idénticas a las de la forma de Equipo General [EQG1], excepto por las instrucciones adicionales que se presentan a continuación.

Características del Equipo: Identifique si el equipo de aspersión es de cabina o abierta. Describa el tipo de artículos que son asperjados. Identifique el método de aplicación (e. g., latas de aerosol, equipo de spray sin aire, equipo de spray convencional o spray de alto volumen y baja presión [AVBP]). Registre la eficiencia de transferencia del equipo de aspersión. Identifique si los artículos asperjados son secados al aire o en hornos.

Emisiones por Proceso: Para cada tipo de recubrimiento, registre su solvente y contenido de sólidos, así como el uso anual del solvente.

Instrucciones
Pilas de Almacenamiento
[Forma PDA1]

Las instrucciones son idénticas a las de la forma de Equipo General [EQG1], excepto por las instrucciones adicionales que se presentan a continuación.

Emisiones por Proceso: Registre cada material almacenado, su rendimiento anual, área y duración de almacenamiento. Asimismo, registre las siguientes características del material en la pila de almacenamiento: contenido de humedad y de sedimento.

Instrucciones
Tanques de Almacenamiento de Techo Fijo y Flotante
[Forma TNQ1]

Las instrucciones son idénticas a las de la forma de Equipo General [EQG1], excepto por las instrucciones adicionales que se presentan a continuación.

Definición de Equipo: Cualquier tanque superficial de almacenamiento con paredes verticales circulares utilizado para almacenar derivados del petróleo o productos químicos.

Características del Equipo: Identifique si el tanque tiene techo flotante interno o externo, o bien, techo fijo. Registre las siguientes dimensiones del tanque: volumen, diámetro y altura. Dependiendo del método de cálculo especificado por la Dependencia, las características restantes pueden o no ser requeridas. Algunas características típicas incluirían el color de la pintura del casco y el techo, las condiciones de la pintura, tipo de techo y tipo de sello de los pilotes primario y secundario.

Emisiones por Proceso: Para cada material de entrada al proceso, registre su Presión de Vapor, ya sea presión de vapor verdadera (PVV) o presión de vapor Reid (PVR), temperatura de almacenamiento promedio y rendimiento anual. Las emisiones deben ser calculadas de acuerdo con el método de cálculo de emisión especificado por la Dependencia.

ANEXO B

EJEMPLO DE LAS FORMAS DEL CUESTIONARIO LLENAS

Anexo B
Ejemplos de las Formas del Cuestionario Llenas

Esta sección contiene ejemplos de las formas del cuestionario llenas para el establecimiento ABC. La Figura B1 muestra un diagrama de flujo del proceso para cada uno de los equipos en este establecimiento.

FORMAS DEL CUESTIONARIO

G **SEMARNAP / INE**

FORMA: PPT1 [1]	Portada para Remisión	**Año:** [2]
Pág: 1 de 1		**Licencia SEMARNAP:** [3]

De acuerdo con los Artículos 17, 18, 19 y 21 del Reglamento de la Ley General del Equilibrio Ecológico y Protección al Ambiente en materia de Prevención y Control de la Contaminación Atmosférica, a través de este conducto se presenta un inventario de emisiones al aire, para la Licencia de SEMARNAP y el año que se indican.

Aquí hacemos constar que la información que se anexa es verdadera y que puede ser verificada por SEMARNAP / INE, quienes en caso de encontrar cualquier información falsa procederán a aplicar las sanciones pertinentes conforme a lo estipulado por la legislación vigente.

Representante Legal de la Empresa:

Nombre:____

Firma:____

Dirección:____

Persona Responsable de la Información:

Nombre:____

Título:____

Firma:____

Lugar:____________________________________ Fecha:_________________

Anexas a esta forma de presentación se encuentran TODAS las formas necesarias para describir y cuantificar las emisiones descargadas por el Establecimiento identificado con la Licencia SEMARNAP que se indica previamente.

G **SEMARNAP / INE**

FORMA: EST1 [1]	Establecimiento	**Año:** [2]
Pág: 1 de 2		**Licencia SEMARNAP:** [3]

INFORMACIÓN DEL PROPIETARIO

Nombre de la Empresa:______________________________[1.2][1.4.1]

Nombre o Razón Social: ______________________________[1.4.1]

Asociación Industrial:______________________________[1.8]

Actividades de la Empresa:______________________________[1.12]

Registro Federal de Causantes (RFC-SHCP):______________________________[1.6]

CONTACTO EN EL ESTABLECIMIENTO/RESPONSABLE

Nombre de la Persona:______________________________[1.1]

Título o Puesto:______________________________[1.1]

Dirección:______________________________[1.3]

Colonia:______________________________[1.3]

Municipio o Delegación:______________________[1.3] Estado:______________________[1.3]

Código Postal:____________________[1.3] Teléfono: ____________________[1.1]

DESCRIPCION DEL ESTABLECIMIENTO

Nombre del Establecimiento:______________________________

Número de empleados que trabajan en el establecimiento:

Administrativos, técnicos y ejecutivos ___ [1.11.1] Obreros, auxiliares y otros:____ [1.11.2]

Descripción de los productos elaborados (CMAP):______________________________

Fecha de inicio de operaciones:__________________[1.9]

UBICACIÓN DEL ESTABLECIMIENTO [1.4.2]

Calle y Número del Establecimiento: ______________________________

Entre calles:______________________y______________________

Colonia:______________________ Delegación o Municipio: ______________________

Estado:______________________ Código Postal:_____________

Continúa en Pág. 2 de 2

G **SEMARNAP / INE**

FORMA: EST1 [1]	Establecimiento	**Año:** [2]
Pág: 2 de 2		**Licencia SEMARNAP:** [3]

LICENCIAS DEL ESTABLECIMIENTO

Número de Licencia Sanitaria: _________________ Fecha:____________[1.7.1]

Número de Licencia de SEMARNAPL:______________ Fecha:____________[1.7.2]

UBICACIÓN GEOGRAFICA[1.5]

Coordenadas del Centroide del Establecimiento:

Longitud:_____:____:____ (grados: minutos: segundos Oeste)

Latitud: _____:____:____ (grados: minutos: segundos Norte)

Elevación sobre el Nivel del Mar: _____m

DATOS METEOROLOGICOS DEL ESTABLECIMIENTO

Velocidad promedio del viento: ________km/hr Número de días de sequía/año:________

Temperatura promedio: ____°C

Fracción de tiempo en el que la velocidad del viento es mayor que 19.3 km/hr:___%

CALENDARIO DE OPERACIÓN DEL ESTABLECIMIENTO *Obtener de los registros operativos*

Horas/Dïa	Días/Sem	Sems/Año	Porcentaje Mensual Usado											
			Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic

EMISIONES TOTALES *Sumar las emisiones de cada descarga registrada en otras formas*

Emisiones (kg) en el año especificado				
Gas Orgánico Total (GOT)	**Oxidos de Nitrógeno (NOx)**	**Oxidos de Azufre (SOx)**	**Monóxido de Carbono (CO)**	**Material Particulado (MP)**

Fin de Forma EST1

G **SEMARNAP / INE**

FORMA: EQG1 [1]	Forma General de Equipo	**Año:** [2]
Pág: 1 de 2		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO *Por Diagrama de Flujo del Proceso y Esquema de Ingeniería*

ID de este equipo:___________ [4] ID del Grupo de Equipos del que este equipo es miembro: ___________ [5]

Su nombre para este equipo: ____ [6]

El material de salida de este equipo va para:

La atmósfera [7] **ó** ID Equipo de Chimenea:________ [8] **ó** ID del Equipo de Control:______ [9]

CARACTERISTICAS DEL EQUIPO *Obtener de las especificaciones del fabricante*

Fabricante del Equipo:____

Modelo del Equipo:______________________________ No. de Serie del Equipo:_____________________

Describir para qué se utiliza este equipo: ____

____

____

CALENDARIO DE OPERACIÓN POR PROCESO *Obtener de los registros operativos*

Material de Entrada del Proceso* ***(Enlistar)***	Horas/ Día	Días/ Sem.	Sems./ Año	Porcentaje Utilizado Mensualmente											
				Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic

*Nombre común del material

Continuar en la Pág. 2 de 2

G **SEMARNAP / INE**

FORMA: EQG1 [1]	Forma General de Equipo	**Año:** [2]
Pág: 2 de 2		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO ***De la página anterior*** ID de este equipo:__________

EMISIONES POR PROCESO: ***Registrar datos del material de entrada para cada proceso y calcular emisiones de salida.***

Material de Entrada *(Enlistar)**	Uso Anual del Material	Unidades de Uso**	Emisiones (kg) - Ver ecuaciones posteriores para el método por omisión				
			Gas Orgánico Total (GOT)	Oxidos de Nitrógeno (NOx)	Oxidos de Azufre (SOx)	Monóxido de Carbono (CO)	Material Particulado (MP)
			[____]	[____]	[____]	[____]	[____]
			[____]	[____]	[____]	[____]	[____]
			[____]	[____]	[____]	[____]	[____]
			[____]	[____]	[____]	[____]	[____]
			[____]	[____]	[____]	[____]	[____]
			[____]	[____]	[____]	[____]	[____]
			[____]	[____]	[____]	[____]	[____]
Total							

*Nombre común del material

**Unidades asociadas con el uso anual del material

Para todos los parámetros: Emisiones (kg) = Uso de Material x [Factor de Emisión]

Si estas emisiones son descargadas directamente a la atmósfera, incluirlas en las Emisiones Totales de la Forma EST1.
Si estas emisiones fluyen a un Equipo de Chimenea o a un Equipo de Control, incluirlas en la Forma de Equipo de Chimenea o Equipo de Control adecuada.

Fin de Forma EQG1

G **SEMARNAP / INE**

FORMA: CTL1 [1]	Equipos de Control de la Contaminación Atmosférica	**Año:** [2]
Pág: 1 de 2		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO *Por Diagrama de Flujo del Proceso y Esquema de Ingeniería*

ID de este equipo:___________ [4] ID del Grupo de Equipos del que este equipo es miembro: ___________ [5]

Descripción de este equipo:____ [6]

La descarga de este equipo va para:

La atmósfera [7] *ó* ID Equipo de Chimenea:________ [8] *ó* ID de Otro Equipo de Control:_______ [9]

CARACTERISTICAS DEL EQUIPO *Obtener de las especificaciones del fabricante*

Fabricante del Equipo:____

Modelo del Equipo:______________________________ No. de Serie del Equipo:______________________

Tipo de Equipo de Control (elegir uno de la siguiente lista)

Adsorbedor	Adsorbente: Carbón activado		Otro:____________
Absorbedor	Tipo: gas empacado		Gas tipo charola
Post-quemador	Tipo: Catalítico	Flama directa	Combustible:________________
Mechero	Combustible:_________________		
Incinerador			
Casa de Bolsas	Presión Positiva Método de limpieza:___________	Presión Negativa Material de la Tela:___________	Relación Aire/Tela:___m/sec
Ciclón	Tipo:______________________		
Condensador	Tipo:_______________________		
Catalizador	Tipo de Catalizador:___________________		
Precipitador Electrostático	No. de campos:______ Método de limpieza:____________	Energía de entrada:_______ /sec Area de recopilación:_______m^2	
Scrubber (Lavador de Gas):	Tipo:________________		
Eliminador de Nieblas			
Recuperación de Vapor	Tipo:________________		
Desulfurizador de Gas	Tipo:________________		

CARACTERISTICAS OPERATIVAS DEL PROCESO *Obtener de los registros de operación*

Tasa Máxima de Flujo o Capacidad:______________ m^3/sec

Temperatura de Entrada:_____^{N}C Temperatura de Salida:_____^{N}C Tiempo de paro: _____ %

Continuar en la Pág. 2 de 2

G **SEMARNAP/INE**

FORMA: CTL1	Equipos de Control de la Contaminación Atmosférica	**Año:** [2]
Pág: 2 de 2		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO ***De la página anterior*** ID de este equipo:__________

ENTRADA TOTAL ***Registrar cada equipo de entrada y ajustar para % de captura.***

Equipo Corriente Arriba ***Enlistar la ID de cada equipo y la Descripción del Proceso por Separado***	**Eficiencia de Captura***	**Corriente de Emisión**	**Emisiones (kg) - Ver ecuaciones posteriores**				
			Gas Orgánico Total (GOT)	**Oxidos de Nitrógeno (NOx)**	**Oxidos de Azufre (SOx)**	**Monóxido de Carbono (CO)**	**Material Particulado (MP)**
	(%)	**Corriente Arriba:**					
		ENTRADA:					
		PERDIDA:					
	(%)	**Corriente Arriba:**					
		ENTRADA:					
		PERDIDA:					
***100% si se captura todo**		**ENTRADA:**					
Totales		**PERDIDA:**					

Todos los Parámetros:
Las emisiones corriente arriba vienen de la Forma para cada equipo corriente arriba
Emisiones de Entrada = Emisiones Corriente Arriba x [Eficiencia de Captura (%)]/100
Emisiones de Pérdida = Emisiones Corriente Arriba - Emisiones de Entrada [Cero si la eficiencia de captura es = 100%]

En la siguiente tabla, registrar las emisiones TOTALES DE ENTRADA

DE SALIDA ***Capturar las emisiones de entrada y calcular la salida***

Artículo de los Datos		**- Ver ecuación siguiente**				
		Gas Total (TOG)	**Nitrógeno**	**Oxidos de (SOx)**	**Monóxido de (CO)**	**Material Particulado (MP)**
Entrada	(De la Tabla Anterior)	(kg)	(kg)	(kg)	(kg)	(kg)
Eficiencia de Control	Datos del Fabricante o Datos de Prueba (0% si no hay control)	(%)	(%)	(%)	(%)	(%)
Emisiones de Salida	Ver Ecuación Siguiente	(kg)	(kg)	(kg)	(kg)	(kg)

*Todos los Emisiores: Emisiones de Salida = Emisiones de Entrada x [100% - Eficiencia de Control (%)] / 100

Si estas emisiones son descargadas directamente a la atmósfera, incluirlas en las Emisiones Totales de la Forma EST1.
Si estas emisiones fluyen a un Equipo de Chimenea o a un Equipo de Control, incluirlas en la Forma de Equipo de Chimenea o Equipo de Control adecuada.

Fin de la Forma CTL1

G **SEMARNAP / INE**

FORMA: CHM1 [1]	Chimeneas de Descarga	**Año:** [2]
Pág: 1 de 1		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO *Por Diagrama de Flujo del Proceso y Esquema de Ingeniería*

ID de este equipo:___________ [4] ID del Grupo de Equipos del que este equipo es miembro: ___________ [5]

Su nombre para este equipo:____ [6]

CARACTERISTICAS DEL EQUIPO *Obtener de las especificaciones del fabricante*

Altura de la chimenea desde el nivel de suelo hasta el punto de descarga: _______m
Diámetro interno de la chimenea (o diámetro efectivo si no es circular) en el punto de descarga:_________m
Si esta chimenea está conectada a un edificio, reistrar la altura de la chimenea sobre el techo:_______m
Coordenadas de la chimenea (grados:minutos:segundos): Longitud:____:____:____ Latitud:____:____:____

CARACTERISTICAS OPERATIVAS *Obtener de los Registros Operativos*

Velocidad de salida:_____m/sec Tasa de Flujo de Escape:_____ m^3/sec
Temperatura de Escape:_____ºC

EMISIONES (Descargadas a través de la chimenea)

Registre cada equipo de entrada y ajuste para el % de captura.

Equipo Corriente Arriba *Enlistar la ID de cada equipo y la descripción del proceso por separado*	**Eficiencia de Captura***	**Corriente de Emisión**	Emisiones (kg) - Ver ecuaciones posteriores				
			Gas Orgánico Total (GOT)	**Oxidos de Nitrógeno (NOx)**	**Oxidos de Azufre (SOx)**	**Monóxido de Carbono (CO)**	**Material Particulado (MP)**
		Corriente					
		DESCARGA:					
		PERDIDA:					
		Corriente					
		DESCARGA:					
		PERDIDA:					
		Corriente					
		DESCARGA:					
		PERDIDA:					
***100% si todas son capturadas**		**DESCARGA:**					
		PERDIDA:					

Todos los Parámetros: Las emisiones corriente arriba vienen de la Forma para cada equipo corriente arriba
Emisiones de Descarga = Emisiones Corriente Arriba x [Eficiencia de Captura (%)]/100
Emisiones de Pérdida = Emisiones Corriente Arriba - Emisiones de Entrada [Cero si la eficiencia de captura es = 100%]

Incluir la DESCARGA TOTAL Y LA PERDIDA TOTAL en la Forma EST1.

Fin de Forma CHM1

G **SEMARNAP / INE**

FORMA: CYC1 [1]	Calderas y Calentadores	**Año:** [2]
Pág: 1 de 2		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO *Por Diagrama de Flujo del Proceso y Esquema de Ingeniería*

ID de este equipo:___________ [4] ID del Grupo de Equipos del que este equipo es miembro: ___________ [5]

Su nombre para este equipo: ____ [6]

El material de salida de este equipo va para:

La atmósfera [7] ó ID Equipo de Chimenea:________ [8] ó ID del Equipo de Control:_______ [9]

CARACTERISTICAS DEL EQUIPO *Obtener de las especificaciones del fabricante*

Fabricante del Equipo:____

Modelo del Equipo:______________________________ No. de Serie del Equipo:______________________

Tipo de Quemador:__________________________________ Número de Quemadores__________________

Tasa Máxima de Calentamiento (energía/tiempo)______________ Método de Encendido:________________

Describir para qué se utiliza este equipo: ____

____

____

CALENDARIO DE OPERACIÓN POR PROCESO *Obtener de los registros operativos*

Combustible de Entrada del Proceso* ***(enlistar)***	Horas/ Día	Días/ Sem.	Sems./ Año	Porcentaje Utilizado Mensualmente											
				Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic

* Nombre común del combustible

Continuar en la Pág. 2 de 2

FORMA: CYC1 [1]	Calderas y Calentadores	**Año:** [2]
Pág: 2 de 2		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO ***De la página anterior*** ID de este equipo:__________

EMISIONES POR PROCESO ***Registrar datos del material de entrada para cada proceso y calcular emisiones de salida.***

Combustible de Entrada ***(Enlistar)****	**Uso Anual de Combustible**	**Contenido de Azufre del Combustible**	**Contenido de Nitrógeno del Combustible**	**Contenido de Cenizas del Combustible**	**Contenido Calorífico del Combustible**	**Densidad del Combustible**
	(kg ó kl)	(%)	(%)	(%)	(J/kg ó J/kl)	(g/l)
	(kg ó kl)	(%)	(%)	(%)	(J/kg ó J/kl)	(g/l)
	(kg ó kl)	(%)	(%)	(%)	(J/kg ó J/kl)	(g/l)

	Emisiones (kg) - Ver ecuaciones posteriores para métodos por omisión				
Combustible de Entrada ***(Enlistar)****	**Gas Orgánico Total (GOT)**	**Oxidos de Nitrógeno (NOx)**	**Oxidos de Azufre (SOx)**	**Monóxido de Carbono (CO)**	**Material Particulado (MP)**
	[____]	[____] [____N%]	[____] [____S%]	[____]	[____] [____Ceniza%]
	[____]	[____] [____N%]	[____] [____S%]	[____]	[____] [____Ceniza%]
	[____]	[____] [____N%]	[____] [____S%]	[____]	[____] [____Ceniza%]
Total					

*Nombre común del combustible

Para todos los parámetros:
Emisiones (kg) = Uso de Combustible (kg ó kl) x [Factor de Emisión] (kg/kg ó kl) ó
Emisiones (kg) = Uso de Combustible (kg ó kl) x Contenido Calorífico del Combustible (J/kg ó J/kl) x [Factor de Emisión] (kg/J)
Emisiones (kg) = Uso de Combustible (kl) x Densidad del Combustible (kg/kl) x [Factor de Emisión]
Para los parámetros específicos:
Emisiones (kg) = Uso de Combustible (kg ó kl) x [%S ó %N ó %Ceniza]/100 x [Factor de Emisión] (kg/kg ó kl)

Si estas emisiones son descargadas directamente a la atmósfera, incluirlas en las Emisiones Totales de la Forma EST1.
Si estas emisiones fluyen a un Equipo de Chimenea o a un Equipo de Control, incluirlas en la Forma de Equipo de Chimenea o Equipo de Control adecuada.

Fin de la Forma CYC1

G **SEMARNAP / INE**

FORMA: EDS1 [1]	Equipo de Desengrasado con Solventes	**Año:** [2]
Pág: 1 de 2		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO *Por Diagrama de Flujo del Proceso y Esquema de Ingeniería*

ID de este equipo:_________ [4] ID del Grupo de Equipos del que este equipo es miembro:______[5]

Su nombre para este equipo: ____ [6]

El material de salida de este equipo va para:

La atmósfera [7] _ó_ ID Equipo de Chimenea:________ [8] _ó_ ID del Equipo de Control:______ [9]

CARACTERISTICAS DEL EQUIPO *Obtener de las especificaciones del fabricante*

Fabricante del Equipo:

Modelo del Equipo:_______________________________ No. de Serie del Equipo:

Longitud: _____________________ Anchura:____________________ Altura del Borde libre:

Describir para qué se utiliza este equipo: ____

____

____

Tipo de Desengrasador: Limpieza Fría por Lote Limpieza con Vapor por Lote En Línea

---

CALENDARIO DE OPERACIÓN POR PROCESO *Obtener de los registros operativos*

Material de Entrada del Proceso* ***(Enlistar)***	Horas/ Día	Días/ Sem.	Sems./ Año	Porcentaje Utilizado Mensualmente											
				Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic

*Nombre común del material

Continuar en la Pág. 2 de 2

FORMA: EDS1 [1]	Equipo de Desengrasado con Solventes	**Año:** [2]
Pág: 2 de 2		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO ***De la página anterior*** ID de este equipo:

EMISIONES POR PROCESO: ***Registrar datos del material de entrada para cada proceso y calcular emisiones de salida.***

Tipo de Solvente *(enlistar)**	**Uso Anual del Material** (kl)	**Cantidad Dispuesta** (kl)	**Densidad del Solvente** (g/l)	**Emisiones (kg) - Ver ecuaciones posteriores para el método por omisión**
				Gas Orgánico Total (GOT)
Total				

*Nombre común del material

Emisiones (kg) = [Uso Anual (kl) - Cantidad Dispuesta (kl)] x Densidad (g/l)

Si estas emisiones son descargadas directamente a la atmósfera, incluirlas en las Emisiones Totales de la Forma EST1.
Si estas emisiones fluyen a un Equipo de Chimenea o a un Equipo de Control, incluirlas en la Forma de Equipo de Chimenea o Equipo de Control adecuada.

Fin de la Forma EDS1

G ***SEMARNAP / INE***

FORMA: MCI1 [1]	Motores de Combustión Interna	**Año:** ***1996*** [2]
Pág: 1 de 2		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO ***Por Diagrama de Flujo del Proceso y Esquema de Ingeniería***

ID de este equipo: ________ [4] ID del Grupo de Equipos del que este equipo es miembro: ___________ [5]

Su nombre para este equipo:____ [6]

El material de salida de este equipo va para:

La atmósfera [7] ***ó*** ID Equipo de Chimenea:________ [8] ***ó*** ID del Equipo de Control:___ [9]

CARACTERISTICAS DEL EQUIPO ***Obtener de las especificaciones del fabricante***

Fabricante del Equipo:____

Modelo del Equipo:______________________________ No. de Serie del Equipo:______________________

Describir para qué se utiliza este equipo: ____

____

Tipo de Motor: Turbina De Pistones

Máxima Capacidad Tasada: _____ kilowatts Carga Promedio:______%

CALENDARIO DE OPERACIÓN POR PROCESO ***Obtener de los registros operativos***

Material de Entrada del Proceso* ***(Enlistar***	Horas/ Día	Días/ Sem.	Sems. / Año	Porcentaje Utilizado Mensualmente											
				Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic
Gas natural															
Gas L.P.															
Gasolina															
Diesel															
Combustóleo															
Otros **(enlistar)**															

*Nombre común del material

Continuar en la Pág. 2 de 2

G **SEMARNAP / INE**

FORMA: MCI1 [1]	Motores de Combustión Interna	**Año:** ***1996*** [2]
Pág: 2 de 2		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO ***De la página anterior*** ID de este equipo:____ ______

EMISIONES POR PROCESO: ***Registrar datos del material de entrada para cada proceso y calcular emisiones de salida.***

Material de Entrada *(Enlistar)**	**Uso Anual del Material**	**Emisiones (kg) - Ver ecuaciones posteriores para el método por omisión**				
		Gas Orgánico Total (GOT)	**Oxidos de Nitrógeno (NOx)**	**Oxidos de Azufre (SOx)**	**Monóxido de Carbono (CO)**	**Material Particulado (MP)**
Gas natural		[____]	[____]	[____] [__S%]	[____]	[____]
Gas L.P.		[____]	[____]	[____] [__S%]	[____]	[____]
Gasolina		[____]	[____]	[____] [__S%]	[____]	[____]
Diesel		[____]	[____]	[____] [__S%]	[____]	[____]
Combustóleo		[____]	[____]	[____] [__S%]	[____]	[____]
Otros		[____]	[____]	[____] [__S%]	[____]	[____]
Total						

Para SOx:

Emisiones (kg) = Uso (Horas) x [Factor] (kg/kw-hr) x Máx. Capacidad Tasada (KW) x Carga Promedio (%) x [S%] / 100

Para todos los Otros Parámetros:

Emisiones (kg) = Uso (Horas) x [Factor] (kg/kw-hr) x Máx. Capacidad Tasada (KW) x Carga Promedio (%) / 100

Si estas emisiones son descargadas directamente a la atmósfera, incluirlas en las Emisiones Totales de la Forma EST1.
Si estas emisiones fluyen a un Equipo de Chimenea o a un Equipo de Control, incluirlas en la Forma de Equipo de Chimenea o Equipo de Control adecuada.

Fin de Forma MCI1

G **SEMARNAP / INE**

FORMA: INC1 [1]	Incineradores	**Año:** ***1996*** [2]
Pág: 1 de 2		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO *Por Diagrama de Flujo del Proceso y Esquema de Ingeniería*

ID de este equipo________ [4] ID del Grupo de Equipos del que este equipo es miembro: ____________ [5]

Su nombre para este equipo:____ [6]

El material de salida de este equipo va para:

La atmósfera [7] ***ó*** ID Equipo de Chimenea:_________ [8] ***ó*** ID del Equipo de Control:_____ [9]

CARACTERISTICAS DEL EQUIPO *Obtener de las especificaciones del fabricante*

Fabricante del Equipo:____

Modelo del Equipo:________________________________ No. de Serie del Equipo:_______________________

Tipo de Residuo: __________________________________ No. de Cámaras:

Describir para qué se utiliza este equipo: ____

____

____

____

CALENDARIO DE OPERACIÓN POR PROCESO *Obtener de los registros operativos*

Material de Entrada del Proceso* ***(Enlistar)***	Horas/ Día	Días/ Sem.	Sems./ Año	Porcentaje Utilizado Mensualmente											
				Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic

*Nombre común del material

Continuar en la Pág. 2 de 2

FORMA: INC1 [1]	Incineradores	**Año:** ***1996*** [2]
Pág: 2 de 2		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO ***De la página anterior*** ID de este equipo:____________

EMISIONES POR PROCESO: ***Registrar datos del material de entrada para cada proceso y calcular emisiones de salida.***

Material de Entrada *(Enlistar)**	Gasto Anual del Material	Unidades	Emisiones (kg) - Ver ecuaciones posteriores para el método por omisión				
			Gas Orgánico Total (GOT)	Oxidos de Nitrógeno (NOx)	Oxidos de Azufre (SOx)	Monóxido de Carbono (CO)	Material Particulado (MP)
			[____]	[____]	[____]	[____]	[____]
			[____]	[____]	[____]	[____]	[____]
			[____]	[____]	[____]	[____]	[____]
			[____]	[____]	[____]	[____]	[____]
			[____]	[____]	[____]	[____]	[____]
			[____]	[____]	[____]	[____]	[____]
			[____]	[____]	[____]	[____]	[____]
Total							

*Nombre común del material

Para todos los parámetros: Emisiones (kg) = Gasto x [Factor de Emisión]

Si estas emisiones son descargadas directamente a la atmósfera, incluirlas en las Emisiones Totales de la Forma EST1.
Si estas emisiones fluyen a un Equipo de Chimenea o a un Equipo de Control, incluirlas en la Forma de Equipo de Chimenea o Equipo de Control adecuada.

Fin de la Forma INC1

G **SEMARNAP / INE**

FORMA: TAP1 [1]	Tanques Abiertos de Proceso	**Año:** [2]
Pág: 1 de 2		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO *Por Diagrama de Flujo del Proceso y Esquema de Ingeniería*

ID de este equipo:___________ [4] ID del Grupo de Equipos del que este equipo es miembro: ___________ [5]

Su nombre para este equipo: ____ [6]

El material de salida de este equipo va para:

La atmósfera [7] ó ID Equipo de Chimenea:________ [8] ó ID del Equipo de Control:_______ [9]

CARACTERISTICAS DEL EQUIPO *Obtener de las especificaciones del fabricante*

Fabricante del Equipo:____

Modelo del Equipo:______________________________ No. de Serie del Equipo:______________________

Describir para qué se utiliza este equipo: ____

____

Dimensiones del Tanque - Longitud:________________ Anchura:______________ Altura:_______________

Tipo de Tanque:_______________________________ Método de Agitación:__________________________

Métodos Anti-Niebra o de Inhibición de Niebla:____

CALENDARIO DE OPERACIÓN POR PROCESO *Obtener de los registros operativos*

Material de Entrada del Proceso* ***(Enlistar)***	Horas/ Día	Días/ Sem.	Sems./ Año	Porcentaje Utilizado Mensualmente											
				Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic

*Nombre común del material

Continuar en la Pág. 2 de 2

G **SEMARNAP / INE**

FORMA: TAP1 [1]	Tanques Abiertos de Proceso	**Año:** [2]
Pág: 2 de 2		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO ***De la página anterior*** ID de este equipo:__________

EMISIONES POR PROCESO: ***Registrar datos del material de entrada para cada proceso y calcular emisiones de salida.***

Material de Entrada *(Enlistar)**	**Tipo de Solución**	**Tipo de Plateado**	**Uso Anual del Material**	**Emisiones (kg) de Gas Orgánico Total (GOT) Emissions (kg) (Ver ecuaciones posteriores para el método por omisión)**
			(kg or kl)	[____]
			(kg or kl)	[____]
			(kg or kl)	[____]
			(kg or kl)	[____]
			(kg or kl)	[____]
			(kg or kl)	[____]
			(kg or kl)	[____]
			Total	

*Nombre común del material

Emisiones (kg) = Uso de Material x [Factor de Emisión]

Si estas emisiones son descargadas directamente a la atmósfera, incluirlas en las Emisiones Totales de la Forma EST1.
Si estas emisiones fluyen a un Equipo de Chimenea o a un Equipo de Control, incluirlas en la Forma de Equipo de Chimenea o Equipo de Control adecuada.

Fin de Forma TPA1

G **SEMARNAP / INE**

FORMA: HOR1 [1]	Hornos	**Año:** [2]
Pág: 1 de 2		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO *Por Diagrama de Flujo del Proceso y Esquema de Ingeniería*

ID de este equipo:___________ [4] ID del Grupo de Equipos del que este equipo es miembro: ___________ [5]

Su nombre para este equipo: ____ [6]

El material de salida de este equipo va para:

La atmósfera [7] *ó* ID Equipo de Chimenea:________ [8] *ó* ID del Equipo de Control:_______ [9]

CARACTERISTICAS DEL EQUIPO *Obtener de las especificaciones del fabricante*

Fabricante del Equipo:____

Modelo del Equipo:______________________________ No. de Serie del Equipo:______________________

Describir para qué se utiliza este equipo: ____

____

____

CALENDARIO DE OPERACIÓN POR PROCESO *Obtener de los registros operativos*

Combustible de Entrada en el Proceso* ***(Enlistar)***	Horas/ Día	Días/ Sem.	Sems./ Año	Porcentaje Utilizado Mensualmente											
				Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic
Gas Natural															
Gas L.P.															
Combustóleo															
Gasolina															
Diesel															
Otro (enlistar)															

Continuar en la Pág. 2 de 2

G **SEMARNAP / INE**

FORMA: HOR1 [1]	Hornos	**Año:** [2]
Pág: 2 de 2		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO ***De la página anterior*** ID de este equipo:__________

EMISIONES POR PROCESO: ***Registrar datos del material de entrada para cada proceso y calcular emisiones de salida.***

Combustible de Entrada *(Enlistar)**	Uso Anual del Combustible	Emisiones (kg) - Ver ecuaciones posteriores para el método por omisión				
		Gas Orgánico Total (GOT)	Oxidos de Nitrógeno (NOx)	Oxidos de Azufre (SOx)	Monóxido de Carbono (CO)	Material Particulado (MP)
Gas Natural	(kg ó kl)	[____]	[____]	[____]	[____]	[____]
LPG	(kg ó kl)	[____]	[____]	[____]	[____]	[____]
Combustóleo	(kg ó kl)	[____]	[____]	[____]	[____]	[____]
Gasolina	(kg ó kl)	[____]	[____]	[____]	[____]	[____]
Diesel	(kg ó kl)	[____]	[____]	[____]	[____]	[____]
Otro (enlistar)	(kg ó kl)	[____]	[____]	[____]	[____]	[____]
Total						

Para todos los parámetros: Emisiones (kg) = Uso de Material x [Factor de Emisión]

Si estas emisiones son descargadas directamente a la atmósfera, incluirlas en las Emisiones Totales de la Forma EST1.
Si estas emisiones fluyen a un Equipo de Chimenea o a un Equipo de Control, incluirlas en la Forma de Equipo de Chimenea o Equipo de Control adecuada.

Fin de Forma HOR1

G **SEMARNAP / INE**

FORMA: IMP1 [1]	Equipo de Impresión	**Año:** [2]
Pág: 1 de 2		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO *Por Diagrama de Flujo del Proceso y Esquema de Ingeniería*

ID de este equipo:___________ [4] ID del Grupo de Equipos del que este equipo es miembro: ___________ [5]

Su nombre para este equipo: ____ [6]

El material de salida de este equipo va para:

La atmósfera [7] ó ID Equipo de Chimenea:_______ [8] ó ID del Equipo de Control:_______ [9]

CARACTERISTICAS DEL EQUIPO *Obtener de las especificaciones del fabricante*

Fabricante del Equipo:____

Modelo del Equipo:___________________________ No. de Serie del Equipo:____________________

Describir para qué se utiliza este equipo: ____

____

Tipo de Impresión: __________________________ Tipo de Sustrato:___________________________

Producto Elaborado:_______________________ Método de Secado: ___________________________

CALENDARIO DE OPERACIÓN POR PROCESO *Obtener de los registros operativos*

Material de Entrada del Proceso* *(Enlistar)*	Horas/ Día	Días/ Sem.	Sems./ Año	Porcentaje Utilizado Mensualmente											
				Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic

*Nombre común del material

Continuar en la Pág. 2 de 2

FORMA: IMP1 [1]	Equipo de Impresión	**Año:** [2]
Pág: 2 de 2		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO ***De la página anterior*** ID de este equipo:__________

EMISIONES POR PROCESO: ***Registrar datos del material de entrada para cada proceso y calcular emisiones de salida.***

Solvente de Entrada ***(enlistar)****	**Uso Anual del Solvente**	**Densidad del Solvente**	**Emisiones (kg) de Gas Orgánico Total (GOT) Emissions (kg) (Ver ecuaciones posteriores para el método por omisión)**
	(kg ó kl)	(g/l)	
	(kg ó kl)	(g/l)	
	(kg ó kl)	(g/l)	
	(kg ó kl)	(g/l)	
	(kg ó kl)	(g/l)	
	(kg ó kl)	(g/l)	
	(kg ó kl)	(g/l)	
		Total	

*Nombre común del material

Emisiones (kg) = Masa de Uso de Solvente (kg)

Emisiones (kg) = Volumen de Uso del Solvente (kl) x Densidad (g/l)

Si estas emisiones son descargadas directamente a la atmósfera, incluirlas en las Emisiones Totales de la Forma EST1.

Si estas emisiones fluyen a un Equipo de Chimenea o a un Equipo de Control, incluirlas en la Forma de Equipo de Chimenea o Equipo de Control adecuada.

Fin de Forma IMP1

G **SEMARNAP / INE**

FORMA: SOL1 [1]	Equipo General de Uso de Solventes	**Año:** [2]
Pág: 1 de 2		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO *Por Diagrama de Flujo del Proceso y Esquema de Ingeniería*

ID de este equipo:__________ [4] ID del Grupo de Equipos del que este equipo es miembro: ___________ [5]

Su nombre para este equipo: ____ [6]

El material de salida de este equipo va para:

La atmósfera [7] ó ID Equipo de Chimenea:________ [8] ó ID del Equipo de Control: _____ [9]

CARACTERISTICAS DEL EQUIPO *Obtener de las especificaciones del fabricante*

Fabricante del Equipo:____

Modelo del Equipo:______________________________ No. de Serie del Equipo:______________________

Describir para qué se utiliza este equipo: ______________________________________

____

____

CALENDARIO DE OPERACIÓN POR PROCESO *Obtener de los registros operativos*

Material de Entrada del Proceso* *(Enlistar)*	Horas/ Día	Días/ Sem.	Sems./ Año	Porcentaje Utilizado Mensualmente											
				Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic

***Nombre del Material que Contiene Solvente**

Continuar en la Pág. 2 de 2

G **SEMARNAP / INE**

FORMA: SOL1 [1]	Equipo General de Uso de Solventes	**Año:** [2]
Pág: 2 de 2		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO ***De la página anterior*** ID de este equipo:___________

EMISIONES POR PROCESO: ***Registrar datos del material de entrada y calcular emisiones de salida.***

Datos del Solvente						**Emisiones (kg) (Ver ecuaciones posteriores*)**
Material Usado (*Enlistar*)	**Uso Anual del Material**	**Cantidad Dispuesta**	**Nombre del Solvente *(Enlistar)***	**Contenido de Solvente en el Material****	**Densidad del Solvente**	**Gas Orgánico Total (GOT)**
	(kl)	(kl)		(g/l ó vol%)	(g/l)	
	(kl)	(kl)		(g/l ó vol%)	(g/l)	
	(kl)	(kl)		(g/l ó vol%)	(g/l)	
	(kl)	(kl)		(g/l ó vol%)	(g/l)	
	(kl)	(kl)		(g/l ó vol%)	(g/l)	
	(kl)	(kl)		(g/l ó vol%)	(g/l)	
***Nombre del Material que Contiene Solvente**				**Total**		

* Emisiones (kg) = [Uso Anual (kl) x Cantidad Dispuesta (kl)] x Contenido de Solvente (g/l), ó
* Emisiones (kg) = [Uso Anual (kl) x Cantidad Dispuesta (kl)] x Contenido de Solvente (vol%) x Densidad (g/l) / 100
** En el empaque, no como se aplica.

Si estas emisiones son descargadas directamente a la atmósfera, incluirlas en las Emisiones Totales de la Forma EST1.
Si estas emisiones fluyen a un Equipo de Chimenea o a un Equipo de Control, incluirlas en la Forma de Equipo de Chimenea o Equipo de Control adecuada.

Fin de Forma SOL1

G **SEMARNAP / INE**

FORMA: ASP1 [1]	Cabinas de Aspersión y Aspersión Abierta	**Año:** [2]
Pág: 1 de 2		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO *Por Diagrama de Flujo del Proceso y Esquema de Ingeniería*

ID de este equipo:___________ [4] ID del Grupo de Equipos del que este equipo es miembro: ___________ [5]

Su nombre para este equipo: ____ [6]

El material de salida de este equipo va para:

La atmósfera [7] ***ó*** ID Equipo de Chimenea:________ [8] ***ó*** ID del Equipo de Control:_______ [9]

CARACTERISTICAS DEL EQUIPO *Obtener de las especificaciones del fabricante*

Fabricante del Equipo:____

Modelo del Equipo:______________________________ No. de Serie del Equipo:______________________

Tipo de Aspersión: Cabina de Aspersión Aspersión Abierta

Descripción de los Artículos Asperjados:____

Método de Aplicación: Lata de Aerosol Equipo de Spray sin Aire Equipo de Spray Convencional

Equipo de Spray de Alto Volumen/Baja Presión (AVBP)

Método de Secado: Secado al Aire Secado en Horno

CALENDARIO DE OPERACIÓN POR PROCESO *Obtener de los registros operativos*

Tipo de Recubrimiento* ***(Enlistar)***	Horas/ Día	Días/ Sem.	Sems./ Año	Porcentaje Utilizado Mensualmente											
				Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic

*Nombre común del material

Continuar en la Pág. 2 de 2

G **SEMARNAP / INE**

FORMA: ASP1 [1]	Cabinas de Aspersión y Aspersión Abierta	**Año:** [2]
Pág: 2 de 2		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO ***De la página anterior*** ID de este equipo:__________

EMISIONES POR PROCESO: ***Registrar datos del material de entrada para cada proceso y calcular emisiones de salida.***

Tipo de Recubrimiento *(Enlistar*)*	**Uso Anual del Solvente**	**Emisiones de Gas Orgánico Total (kg) (Ver ecuaciones posteriores para el método por omisión)**
	(kl)	[____]
	(kl)	[____]
	(kl)	[____]
	(kl)	[____]
	(kl)	[____]
	(kl)	[____]
	(kl)	[____]
	Total	

*Nombre común del material

Para todos los parámetros: Emisiones (kg) = Uso de Material x [Factor de Emisión]

Si estas emisiones son descargadas directamente a la atmósfera, incluirlas en las Emisiones Totales de la Forma EST1.
Si estas emisiones fluyen a un Equipo de Chimenea o a un Equipo de Control, incluirlas en la Forma de Equipo de Chimenea o Equipo de Control adecuada.

Fin de la Forma ASP1

G **SEMARNAP / INE**

FORMA: PDA1 [1]	Pilas de Almacenamiento	**Año:** [2]
Pág: 1 de 2		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO *Por Diagrama de Flujo del Proceso y Esquema de Ingeniería*

ID de este equipo:________ [4] ID del Grupo de Equipos del que este equipo es miembro: ____________ [5]

Su nombre para este equipo:____[6]

El material de salida de este equipo va para:

La atmósfera [7] ***ó*** ID Equipo de Chimenea:_________ [8] ***ó*** ID del Equipo de Control:______ [9]

CARACTERISTICAS DEL EQUIPO *Obtener de las especificaciones del fabricante*

Fabricante del Equipo:____

Modelo del Equipo:________________________________ No. de Serie del Equipo:_______________________

Describir para qué se utiliza este equipo: ____

____

____

CALENDARIO DE OPERACIÓN POR PROCESO *Obtener de los registros operativos*

Material de Entrada del Proceso* ***(Enlistar)***	Horas/ Día	Días/ Sem.	Sems./ Año	Porcentaje Utilizado Mensualmente											
				Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic

*Nombre común del material

Continuar en la Pág. 2 de 2

G **SEMARNAP / INE**

FORMA: PDA1 [1]	Pilas de Almacenamiento	**Año:** [2]
Pág: 2 de 2		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO ***De la página anterior*** ID de este equipo:____________

EMISIONES POR PROCESO: ***Registrar datos del material de entrada para cada proceso y calcular emisiones de salida.***

Material Almacenado *(Enlistar)**	**Gasto Anual**	**Area**	**Duración del Almacenamiento**	**Contenido de Humedad**	**Contenido de Sedimento**	**Emisiones (kg) de Material Particulado (MP) (Ver ecuaciones posteriores para el método por omisión)**
	(kg)	(m2)	(días)	(%)	(%)	[___]
	(kg)	(m2)	(días)	(%)	(%)	[___]
	(kg)	(m2)	(días)	(%)	(%)	[___]
	(kg)	(m2)	(días)	(%)	(%)	[___]
	(kg)	(m2)	(días)	(%)	(%)	[___]
	(kg)	(m2)	(días)	(%)	(%)	[___]
	(kg)	(m2)	(días)	(%)	(%)	[___]
					Total	

*Nombre común del Material

Emisiones (kg) = Uso de Material x [Factor de Emisión]
Cuando sea apropiado, use los factores de emisión que aplican áreas, duración del almacenamiento, contenido de humedad y contenido de sedimentos.

Si estas emisiones son descargadas directamente a la atmósfera, incluirlas en las Emisiones Totales de la Forma EST1.
Si estas emisiones fluyen a un Equipo de Chimenea o a un Equipo de Control, incluirlas en la Forma de Equipo de Chimenea o Equipo de Control adecuada.

Fin de la Forma PDA1

G **SEMARNAP / INE**

FORMA: TNQ1 [1]	Tanques de Almacenamiento de Techo Fijo y Flotante	**Año:** 1996 [2]
Pág: 1 de 2		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO *Por Diagrama de Flujo del Proceso y Esquema de Ingeniería*

ID de este equipo:__________ [4] ID del Grupo de Equipos del que este equipo es miembro: ___________ [5]

Su nombre para este equipo: ____ [6]

El material de salida de este equipo va para:

La atmósfera [7] ***ó*** ID Equipo de Chimenea:________ [8] ***ó*** ID del Equipo de Control:_____ [9]

CARACTERISTICAS DEL EQUIPO *Obtener de los diagramas de ingeniería*

Diseño del Tanque: Techo Flotante (externo) Techo Flotante (Interno) Techo Fijo

Capacidad (volumen):________ m^3 Diámetro:___ m Altura:____ m

[Los siguientes parámetros del equipo pueden ser elimienados, o bien, pueden añadirse parámetros adicionales dependiendo del método para el cálculo de emisiones especificado por la entidad]

Color de la pintura del casco:____________ Color de la pintura del techo:

Condición de la pintura del casco: Buena Regular Mala

Condición de la pintura del techo: Buena Regular Mala

Tipo de techo: *Pan* Pontón Doble Plataforma Cono Domo Otro

Tipo de Sello Primario del Pilote:

Metálico Elástico Montado en Vapor Elástico Montado en Líquido Levas

Tipo de Sello Secundario del Pilote:

Levas Montadas en Pilote Levas Montadas en el Borde Blindaje Climático Otro

Continuar en la Pág. 2 de 2

G ***SEMARNAP / INE***

FORMA: TNQ1 [1]	Tanques de Almacenamiento de Techo Fijo y Flotante	**Año:** *1996* [2]
Pág: 2 de 2		**Licencia SEMARNAP:** [3]

IDENTIFICACION DEL EQUIPO ***De la página anterior*** ID de este equipo:

CALENDARIO DE OPERACIÓN POR PROCESO ***Obtener de los registros operativos***

Material de Entrada del Proceso* ***(Enlistar)***	Porcentaje de Uso Mensual											
	Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic

*Nombre del Material Almacenado

EMISIONES POR PROCESO: ***Registrar datos del material de entrada para cada proceso y calcular emisiones de salida.***

Material de Entrada en el Proceso* (Enlistar)	**Presión de Vapor**	**Temperatura de Almacenamiento Promedio**	**Gasto Anual**	**Emisiones (kg)** Gas Orgánico Total (GOT)**
	(kPa)	(ºC)	(m^3)	
	(kPa)	(ºC)	(m^3)	
	(kPa)	(ºC)	(m^3)	
	(kPa)	(ºC)	(m^3)	
			Total	

***Nombre del Material Almacenado**

**Las emisiones deben ser calculadas de acuerdo con el método de cálculo especificado por la Dependencia.

Si estas emisiones son descargadas directamente a la atmósfera, incluirlas en las Emisiones Totales de la Forma EST1.

Si estas emisiones fluyen a un Equipo de Chimenea o a un Equipo de Control, incluirlas en la Forma de Equipo de Chimenea o Equipo de Control adecuada.

Fin de Forma TNQ1

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Dr. John R. Holmes, State of California Air Resources Board
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MEXICO EMISSIONS INVENTORY PROGRAM
ADVANCED TRAINING WORKBOOK

FINAL

Prepared for:

Western Governors' Association
Denver, Colorado

and

Binational Advisory Committee

Prepared by:

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10389 Old Placerville Road
Sacramento, CA 95827

September 1997

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LIST OF ACRONYMS

AFR	air to fuel ratio
AST	aboveground storage tank
bbl	barrels
Btu	British thermal unit
C	Celsius
C_8H_{18}	octane
CE	control efficiency
CFC	chlorofluorocarbon
cfm	cubic feet per minute
CI	compression ignition
CO	carbon monoxide
CO_2	carbon dioxide
DRE	destruction removal efficiency
EC	elemental carbon
F	Fahrenheit
FAER	fuel/air equivalence ratio

LIST OF ACRONYMS (CONTINUED)

ft	foot
ft^3	cubic foot
g	gram
gal	gallon
GIS	geographic information system
H_2O	water
hr	hour
HVLP	high volume/low pressure
IC	internal combustion
J	joule
kcal	kilocalorie
kg	kilogram
kW	kilowatt
lb	pound
LPG	liquefied petroleum gas
m	meter
m^3	cubic meter
MEK	methyl ethyl ketone
mg	milligram
Mg	megagram (i.e. 10^6 g = 1 metric ton)
ml	milliliter
MMBtu	10^6 British thermal units

LIST OF ACRONYMS (CONTINUED)

mmHg	millimeters of mercury
MMscf	10^6 standard cubic feet
mol	mole
MW	molecular weight
n	number of moles
N_2	nitrogen
ng	nanogram
NMHC	non-methane hydrocarbon
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
O_2	oxygen
OC	organic carbon
P	pressure
PEMEX	Petróleos Mexicanos
PM	particulate matter
$PM_{2.5}$	particulate matter of aerodynamic diameter of 2.5 microns or less
PM_{10}	particulate matter of aerodynamic diameter of 10 microns or less
ppmv	parts per million - volume
psi	pounds per square inch
psia	pounds per square inch - absolute
psig	pounds per square inch - gage

LIST OF ACRONYMS (CONTINUED)

PSM	particle size multiplier
R	ideal gas constant
R	Rankine
ROG	reactive organic gas
RVP	Reid vapor pressure
scf	standard cubic feet
scfm	standard cubic feet per minute
SI	spark ignition
sm^3	standard cubic meter
SO_x	sulfur oxides
T	temperature
TOG	total organic gas
TSP	total suspended particulate
U.S.	United States
U.S. EPA	United States Environmental Protection Agency
V	volume
VKT	vehicle kilometers traveled
wt%	weight percent
yr	year
µg	microgram
µm	micrometer (micron)

Introduction

Purpose and Scope

The purpose of this workbook is to provide example problems that illustrate various emission estimating techniques used during an emissions inventory development effort. In addition, several potential difficulties are also examined. It is intended that the material presented in this workbook will both help facilitate training programs and be used as a resource document during the development of emission estimates by various states and municipalities.

This workbook contains realistic examples. Each example has been carefully written to explain in detail the basis for each illustrated emission estimating technique, as well as any inherent assumptions. Special emphasis has been placed on explaining the thought process and decisions that may be required in applying the illustrated technique. The material presented in this workbook will demonstrate the use of specific engineering principles and will illustrate the application of engineering judgment and problem-solving techniques to the development of emission estimates in Mexico.

Challenges of Estimating Emissions ("Beyond the Cookbook")

With sufficient information, the calculation of the estimated emissions from any source is generally a straightforward mathematical exercise. An analogy can be made that many emission calculation techniques are as straightforward as recipes in a cookbook. When conducting an actual emissions inventory, however, there are often individual sources or entire source categories for which the development of emissions estimates is not so simple. To use the cookbook analogy, there are sources and source categories for which there are no simple recipes in the cookbook.

The most commonly encountered problem in any emissions inventory project is that of incomplete information (data gaps). When there are data gaps, the task of estimating emissions becomes more complex and the application of engineering judgment and various problem-solving skills is required. In this workbook, Example 3 (Residential

Fuel Combustion) was developed specifically to illustrate some of the techniques that are typically used to fill data gaps. Example 3 is a detailed discussion of the methodology used to fill the significant data gaps that were encountered during the development of an air toxics emission inventory for Nogales, Sonora.

Four of the more common methods for filling data gaps are:

- Derive needed information from available data;
- Develop reasonable alternative approaches to estimate emissions;
- Apply assumptions and bounding estimates to the problem; and
- Collect additional data.

Example 3 illustrates the decision process that was used to select the most appropriate of these methods to fill the data gaps encountered in Nogales. Some of the other examples in this workbook also illustrate the techniques that can be used to fill data gaps (see Examples 2a and 7).

In addition to data gaps, other difficulties commonly encountered when conducting an emissions inventory include:

- Selecting the appropriate emission estimation technique for each source, including selecting emission factors;
- Ensuring reasonable accuracy in the data used to prepare the estimate, including selecting information from conflicting data sources; and
- Verifying that the calculated emissions are a realistic estimation of the true emissions from the source. If the calculated emissions are not realistic or if there is no reasonable basis for comparison, then estimating the level of uncertainty in the estimates is necessary.

To achieve the most reasonable and realistic estimate of emissions, one must identify and characterize all of the possible emission types and sources, select the appropriate estimating techniques, develop an understanding of the selected techniques, make any necessary assumptions, and gather or otherwise develop the necessary data for the calculations. Once the necessary information is at hand, the emission estimates must be prepared and thoroughly documented. In addition, critical to the overall quality of any technical project such as the development of emissions estimates is the consistent use of peer review. Reviewers typically are people who are familiar with the specific emission source and are experienced in the field of emission estimation. Each decision, assumption, and calculation should be thoroughly reviewed in order to ensure accuracy and reasonableness in the final estimates.

Like any other major engineering project or scientific research project, there are often many interesting and challenging problems to solve during an emissions inventory development effort. Several of the more common problems have been examined in the examples that are presented in this workbook. As explained in this section and illustrated in the remainder of this workbook, the problems most commonly encountered in developing emission estimates do not always have simple solutions. Those who prepare the emissions estimates will benefit from a more complete understanding of the principles and assumptions inherent in each of the techniques that are illustrated in this workbook. This workbook consists of the following seven examples:

- Example 1 - Stationary internal combustion engines;
- Example 2 - External combustion boilers;
- Example 3 - Residential heating (biomass combustion);
- Example 4 - Gasoline distribution system;
- Example 5 - Solvent evaporation sources;
- Example 6 - Use of point source test data; and
- Example 7 - Particulate matter.

Some of these examples contain multiple parts. In addition, supplemental information is also provided for several examples.

Where possible, examples are calculated using metric units; U.S. units are used elsewhere. A collection of conversion factors and material properties is presented in Appendix A. Also, a listing of other example problems found in the Mexico Emissions Inventory Program Manuals series is provided in Appendix B.

Finally, all examples presented in this workbook represent hypothetical situations. The examples demonstrate various useful calculation methodologies. However, activity data contained within these examples should not be used in real-life situations; instead, actual data should be collected.

Example 1
Stationary Internal Combustion Engines

Stationary internal combustion (IC) engines are significant sources of emissions in urban areas. They are used in a wide range of applications and include engines based on reciprocating and rotary motion. The primary fuels for reciprocating type engines are gasoline, diesel fuel oil, and natural gas. They are used in applications such as generators and pumps. Examples of rotary motion IC engines include gas turbines used for electric power generation and in various process industries, and natural gas-fired pipeline compressor engines and turbines. This problem focuses on reciprocating gasoline- and diesel-powered IC engine emissions.

Problem Statement

Estimate the annual uncontrolled emissions of TOG (total organic gas), CO (carbon monoxide), NO_x (nitrogen oxides), PM_{10} (particulate matter of aerodynamic diameter of 10 microns or less), and SO_x (sulfur oxides) from diesel powered engines.

Available Information

Number of engines:	6
Power rating:	20 kilowatts (kW) per engine
Hours of operation:	12 hours per day, 365 days per year
Average engine load factor:	45%
Fuel type:	Diesel
Fuel usage rate:	5 liters/hour of operation
Heating value of diesel:	4×10^7 joules (J)/liter (19,300 British thermal units [Btu]/lb)
Controlled/uncontrolled emissions:	Uncontrolled

Note: The diesel heating value in joules/liter was converted from the value of 19,300 Btu/lb obtained from the United States Environmental Protection Agency's (U.S. EPA) Compilation of Air Pollution Emission Factors (AP-42) (U.S. EPA, 1995a) Table 3.3-2 as follows:

$$\text{Heating value}\left(\frac{J}{\text{liter}}\right)=\left(19{,}300\,\frac{\text{Btu}}{\text{lb}}\right)\left(7.428\,\frac{\text{lb}}{\text{gal}}\right)\left(\frac{1\,\text{gal}}{3.78\,\text{liters}}\right)\left(\frac{1055\,\text{J}}{\text{Btu}}\right)$$

$$\text{Heating value} = 4.0 \times 10^{7}\,\frac{J}{\text{liter}}$$

Methodology - Power Output Based Emission Factor Method

Emissions are calculated using "brake-specific" emission factors (mass of emissions/power-time) and several types of activity data. The required activity data are engine operation time, power rating, and the engine load factor (power actually used divided by power available). This methodology is represented mathematically with the following equation.

$$\text{Emissions}_p = \sum_{e=1}^{N} P_e \times LF_e \times T_e \times EF_p$$

where:

Emissions_p = Mass of emission of pollutant p (kg);
N = Number of engines;
P_e = Average rated power of engine e (kW);
LF_e = Typical engine load factor of engine e (%);
T_e = Time period of engine operation for engine e (hours); and
EF_p = Emission factor for pollutant p (kg/kW-hr).

Although this example provides all required activity data, the collection of activity data may be an involved process. Typically, equipment information will be collected in equipment inventories. If information is unavailable through equipment inventories, the equipment manufacturers should be contacted. Alternatively, information from similar equipment may be used if no other data are available. U.S. EPA's *Nonroad Engine and Vehicle Emissions Study* (U.S. EPA, 1991a) also provides various typical physical characteristics for IC engines that can be used when specific engine information is unavailable.

The main source of emission factors for stationary internal combustion sources is AP-42, Chapter 3. The emission factors for industrial diesel engines are presented below in Table

1-1.

Table 1-1

Emission Factors for Uncontrolled Diesel Industrial Engines

Pollutant	Emission Factor (g/kW-hr)	Emission Factor (ng/J)
Exhaust TOG	1.50	152
Evaporative TOG	0.00	0.00
Crankcase TOG	0.03	2.71
Refueling TOG	0.00	0.00
Total TOG[a]	1.53	154.71
CO	4.06	410
NO_x	18.8	1,896
PM_{10}	1.34	135
SO_x	1.25	126

Source: AP-42, Table 3.3-1

[a] Total TOG consists of exhaust, evaporative, crankcase, and refueling TOG.

Calculations - Annual Uncontrolled Emissions Using Power Output Based Emission Factors

$$E_{TOG} = (6)(20\ \text{kW})(0.45)\left(\frac{12\ \text{hr}}{\text{day}}\right)\left(\frac{365\ \text{days}}{\text{yr}}\right)\left(\frac{1.53\ \text{g}}{\text{kW-hr}}\right)$$

$$= 362\ \text{kg/yr} = 0.36\ \text{Mg/yr}$$

$$E_{CO} = (6)(20\ \text{kW})(0.45)\left(\frac{12\ \text{hr}}{\text{day}}\right)\left(\frac{365\ \text{days}}{\text{yr}}\right)\left(\frac{4.06\ \text{g}}{\text{kW-hr}}\right)$$

$$= 960\ \text{kg/yr} = 0.96\ \text{Mg/yr}$$

$$E_{NOx} = (6)(20\ \text{kW})(0.45)\left(\frac{12\ \text{hr}}{\text{day}}\right)\left(\frac{365\ \text{days}}{\text{yr}}\right)\left(\frac{18.8\ \text{g}}{\text{kW-hr}}\right)$$

$$= 4{,}447\ \text{kg/yr} = 4.45\ \text{Mg/yr}$$

$$E_{PM_{10}} = (6)(20\ \text{kW})(0.45)\left(\frac{12\ \text{hr}}{\text{day}}\right)\left(\frac{365\ \text{days}}{\text{yr}}\right)\left(\frac{1.34\ \text{g}}{\text{kW-hr}}\right)$$

$$= 317\ \text{kg/yr} = 0.32\ \text{Mg/yr}$$

$$E_{SOx} = (6)(20\ \text{kW})(0.45)\left(\frac{12\ \text{hr}}{\text{day}}\right)\left(\frac{365\ \text{days}}{\text{yr}}\right)\left(\frac{1.25\ \text{g}}{\text{kW-hr}}\right)$$

$$= 296\ \text{kg/yr} = 0.30\ \text{Mg/yr}$$

Alternative Methodology - Fuel Input Based Emission Factor Method

If the physical characteristics of engines are unavailable, an alternative method of estimating emissions can be used that is based upon fuel usage. Fuel input based emission factors can be found in AP-42 and other emission factor sources. Power output emission factors are a "bottom-up" estimation approach that includes considerable equipment-specific information. Fuel input emission factors are a "top-down" estimation approach that tends to miss equipment-specific details. The power output emission factors are the preferred methodology; however, data limitations may indicate that fuel input emission factors should be used.

Emissions are calculated using fuel input based emission factors (mass of emissions/energy content of fuel) and several types of activity data. The required activity data are engine operation time, fuel usage rate, and the heating value of fuel. This methodology is represented mathematically with the following equation.

$$\text{Emissions}_p = \sum_{e=1}^{N} \text{FUR}_e \times T_e \times H \times \text{EF}_p$$

where:
Emissions_p = Mass of emission of pollutant p (kg);
N = Number of engines;
FUR_e = Fuel usage of engine e (liters/hour);
T_e = Time period of engine operation for engine e (hours);
H = Heating value of fuel (J/liter); and
EF_p = Emission factor for pollutant p (ng/J).

Fuel input based emission factors can also be found in AP-42, Chapter 3. These emission factors were presented earlier in this example.

Calculations - Annual Uncontrolled Emissions Using Fuel Input Based Emission Factors

$$E_{TOG} = (6)\left(\frac{5\ \text{liters}}{\text{hour}}\right)\left(\frac{12\ \text{hours}}{\text{day}}\right)\left(\frac{365\ \text{days}}{\text{year}}\right)\left(4.0\ \text{x}\ 10^{7}\right)\left(154.71\ \frac{\text{ng}}{\text{J}}\right)\left(\frac{1\ \text{kg}}{10^{12}\ \text{ng}}\right)$$

$$= 813\ \text{kg/yr}\ = 0.81\ \text{Mg/yr}$$

$$E_{CO} = (6)\left(\frac{5\ \text{liters}}{\text{hour}}\right)\left(\frac{12\ \text{hours}}{\text{day}}\right)\left(\frac{365\ \text{days}}{\text{year}}\right)\left(4.0\ \text{x}\ 10^{7}\ \frac{\text{J}}{\text{liter}}\right)\left(410\ \frac{\text{ng}}{\text{J}}\right)\left(\frac{1\ \text{kg}}{10^{12}\ \text{ng}}\right)$$

$$= 2{,}155\ \text{kg/yr}\ = 2.16\ \text{Mg/yr}$$

$$E_{NOx} = (6)\left(\frac{5\ \text{liters}}{\text{hour}}\right)\left(\frac{12\ \text{hours}}{\text{day}}\right)\left(\frac{365\ \text{days}}{\text{year}}\right)\left(4.0\ \text{x}\ 10^{7}\ \frac{\text{J}}{\text{liter}}\right)\left(1{,}896\ \frac{\text{ng}}{\text{J}}\right)\left(\frac{1\ \text{kg}}{10^{12}\ \text{ng}}\right)$$

$$= 9{,}965\ \text{kg/yr}\ = 9.97\ \text{Mg/yr}$$

$$E_{PM_{10}} = (6)\left(\frac{5\ \text{liters}}{\text{hour}}\right)\left(\frac{12\ \text{hours}}{\text{day}}\right)\left(\frac{365\ \text{days}}{\text{year}}\right)\left(4.0\ \text{x}\ 10^{7}\ \frac{\text{J}}{\text{liter}}\right)\left(135\ \frac{\text{ng}}{\text{J}}\right)\left(\frac{1\ \text{kg}}{10^{12}\ \text{ng}}\right)$$

$$E_{PM_{10}} = 710\ \text{kg/yr}\ = 0.71\ \text{Mg/yr}$$

$$E_{SOx} = (6)\left(\frac{5\ \text{liters}}{\text{hour}}\right)\left(\frac{12\ \text{hours}}{\text{day}}\right)\left(\frac{365\ \text{days}}{\text{year}}\right)\left(4.0\ \text{x}\ 10^{7}\ \frac{\text{J}}{\text{liter}}\right)\left(126\ \frac{\text{ng}}{\text{J}}\right)\left(\frac{1\ \text{kg}}{10^{12}\ \text{ng}}\right)$$

$$= 662\ \text{kg/yr}\ = 0.66\ \text{Mg/yr}$$

Example 1

Stationary Internal Combustion Engines - Supplemental Information

Emission Controls - Air to Fuel Ratio (AFR)

A primary parameter that governs the amount of pollutants produced during combustion is the air to fuel ratio (AFR). The calculation of the AFR is based on the stoichiometric reaction of fuel and air during combustion. Ideal combustion of gasoline (represented as octane) in a spark ignition (SI) engine is chemically represented below.

$$C_8H_{18} + 12.5\,O_2 + 47\,N_2 \rightarrow 8\,CO_2 + 9\,H_2O + 47\,N_2$$

The stoichiometric AFR is simply the ratio of the mass of air over the mass of fuel used in ideal combustion.

Mass of Air: 12.5 g-moles $O_2 \times$ 32 g/g-mole = 400 g
47 g-moles $N_2 \times$ 28 g/g-mole = $\underline{1{,}316\text{ g}}$
1,716 g

Mass of Fuel: 1 g-mole $C_8H_{18} \times$ 114 g/g-mole = 114 g

$$\text{AFR} = \frac{\text{mass of air}}{\text{mass of fuel}} = \frac{1{,}716}{114} = 15.05$$

Of course, the actual stoichiometric AFR calculated above would be slightly different due to the fact that air is not composed solely of nitrogen and oxygen and that gasoline is not equivalent to octane. In fact, gasoline is a mixture of many hydrocarbon compounds and a typical AFR for gasoline is 14.7. The stoichiometric ratios vary based on engine and fuel type. An engine operating at a stoichiometric AFR is said to be operating at a fuel/air equivalence ratio (FAER) of 1.0 where the FAER is defined as the ratio of stoichiometric AFR over the actual AFR. The FAER is less than 1.0 for leaner burning (i.e., more air) operation and greater than 1.0 for richer burning engine operation.

The normal operating range for a conventional spark ignition (SI) engine using gasoline is $12 \leq \text{AFR} \leq 18$, and for compression ignition (CI) engines with diesel $18 \leq \text{AFR} \leq 70$.

Engine performance is often optimized to minimize fuel consumption. This usually minimizes TOG and CO emissions because the combustion efficiency is maximized, but NO_x emissions are also near maximum. However, if the AFR ratio is not correct, engine performance decreases, fuel consumption increases, and emissions of TOG and CO increases.

Figure 1-1 illustrates the effect of AFR on TOG, CO, and NO_x emissions from a SI engine. The shapes of the curves indicate the complexity of emissions control through AFR adjustment. The figure shows that TOG emissions decrease as the AFR increases, or as the fuel-air mixture becomes fuel-lean. This decrease in TOG emissions continues as the mixture becomes leaner, until the mixture becomes so lean that combustion quality becomes poor and misfiring begins to occur. The result is a sharp increase in TOG emissions due to increased emissions of unburned hydrocarbons from the exhaust.

Combustion temperature and oxygen availability strongly affect NO_x emissions. Operation of engines near stoichiometric results in near maximum NO_x emissions due to high combustion temperatures. At this equivalence ratio however, oxygen concentrations are low. As the mixture is fuel-enriched, burned gas temperatures fall, resulting in decreased combustion efficiency. This results in increased TOG and CO emissions and decreased NO_x emissions. TOG and CO emissions increase during fuel-rich conditions because the excess fuel is not completely burned during combustion. The steady increase in the curves is due to the increasing excess of fuel. As the mixture becomes fuel-lean from stoichiometric, increasing oxygen concentration initially offsets the decreasing combustion temperature, resulting in an increase in NO_x emissions. As the mixture becomes leaner, reduced combustion temperature becomes more important than oxygen availability for NO_x emissions, and emissions decrease.

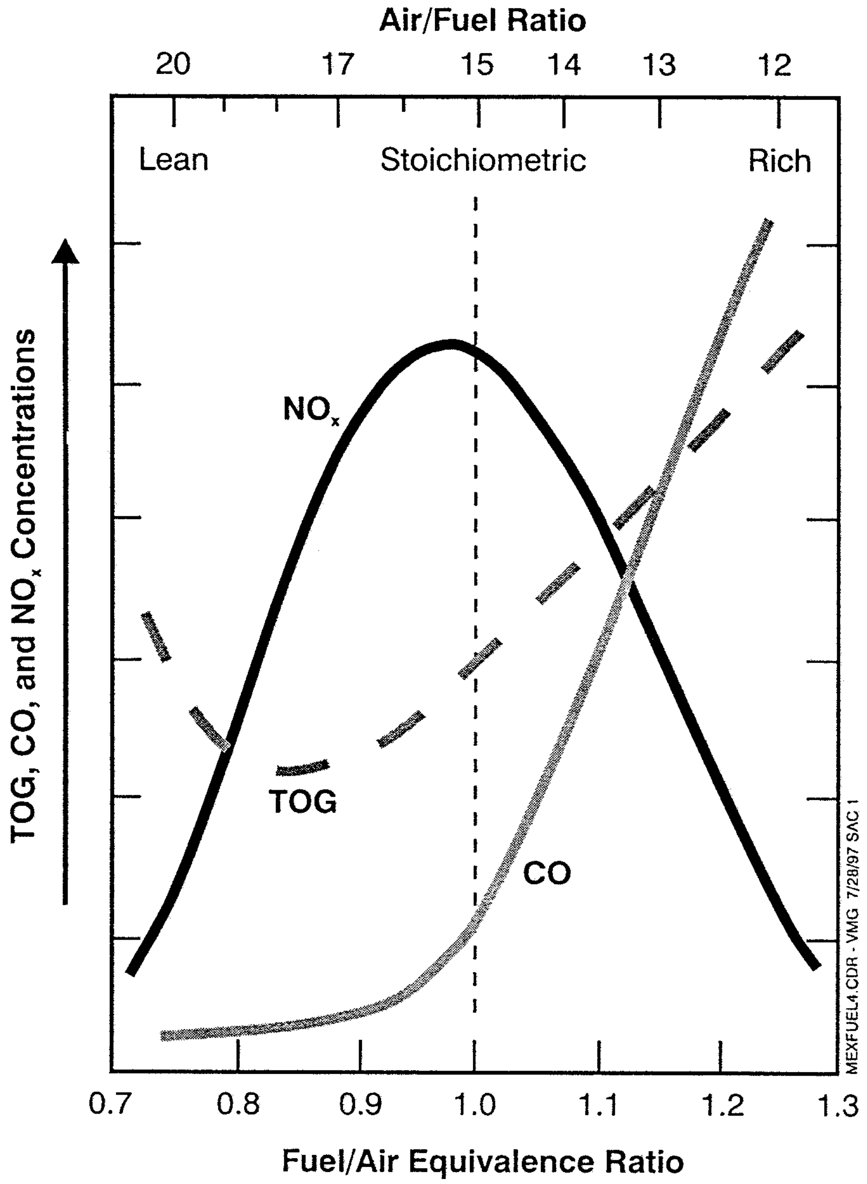

Figure 1-1. Relationship between Air to Fuel Ratio (AFR), Fuel/Air Equivalence Ratio (FAER), and Emitted Pollutants

Example 2a

External Combustion Devices - Fuel Allocation

Introduction

The commonly published emission factors for external combustion devices such as those found in AP-42 (U.S. EPA, 1995a) are based on the size of the device and the quantity of fuel consumed. These emission factors are expressed in units of lb/MMscf (10^6 standard cubic feet) for natural gas or lb/gal for liquid fuel such as diesel fuel. Accurate emission estimates are dependent on accurate fuel use data; however, fuel use data are often not available for individual external combustion devices. There is often only one fuel meter for a building or other facility that contains several combustion devices and the fuel throughput to each individual source must be estimated based on device design and operational parameters.

The example presented below illustrates the fuel allocation technique for a case where a fuel meter measures the total fuel supplied to a group of combustion devices. The fuel throughput for the devices in the example is allocated based on hours of operation and size or capacity of the equipment. The same methodology can be used to apportion fuel consumption among any number of devices, if the capacity and operating hours of each device are known.

Problem Statement

Estimate natural gas consumption for individual external combustion devices based upon device capacity and hours of operation.

Available Information

A tortilla factory contains four tortilla manufacturing machines, each with a burner that operates on natural gas, liquified petroleum gas (LPG), or both. There is one meter on the natural gas line to the building, and in 1996, the total gas consumption was 240 MMscf. Table 2-1 shows the burner capacities and operating hours for 1996 and summarizes the results of the calculations to apportion the total fuel among the four burner. Detailed calculations are shown following Table 2-1.

Table 2-1

Fuel Apportionment to Tortilla Factory External Combustion Devices

GIVEN			CALCULATED			
Burner	**Capacity (MMBtu/hr)**	**Hours Operated in 1996**	**Annual Heat Load at Capacity (MMBtu/yr)**	**% of Total Load**	**Estimated Fuel Consumption**	
					(MMscf/yr)	**(10^6 m^3/yr)**
A	21	4,320	90,720	36	86.4	2.45
B	8	4,512	36,096	14	33.6	0.95
C	21	2,880	60,480	24	57.6	1.63
D	7.5	8,760	65,700	26	62.4	1.77
Total			252,996	100	240.0	6.80

To allocate the fuel consumption among the burners, the calculations are as follows:

1. Calculate the annual heat load for each burner at full capacity:

Annual heat load (MMBtu/yr) = Burner capacity (MMBtu/hr) × Annual hours (hr/yr)
For Boiler A, annual heat load = 21 MMBtu/hr × 4,320 hours/yr
= 90,720 MMBtu/yr

2. Find the total annual heat load for all four burners (see table).

90,720 + 36,096 + 60,480 + 65,700 = 252,996 MMBtu/yr

3. Determine the % of total annual heat load for each burner.

$$\text{For Burner A} = \frac{90{,}720\ \text{MMBtu/yr}}{252{,}996\ \text{MMBtu/yr}}$$

$$= 36\%$$

4. Allocate total fuel throughput to each burner based on % of total annual heat load.

For Burner A = 240 MMscf/yr $\times$ 0.36
= 86.4 MMscf/yr

There are many possible sources of uncertainty in this allocation method and the impact of these uncertainties on the estimated emissions from the sources of interest should be examined. Possible sources of uncertainties include:

- Variable operation of the different devices (there is an unstated assumption in this method that each device operates at the same relative percent of its capacity);
- Incomplete or inaccurate records of hours of operation for one or more devices;
- Incomplete or inaccurate records of fuel consumption; and
- Incomplete or unavailable design data for one or more sources (uncertain capacity).

Example 2b
External Combustion Devices - Emission Factors

Introduction

This problem demonstrates the use of published emission factors to estimate emissions. Although this problem may seem overly simplistic, it is a valuable estimation technique that is used in virtually all emissions inventories.

Problem Statement

Estimate total NO_x emissions from the four tortilla manufacturing machine burners described in Example 2a.

Available Information

External combustion emission factors in AP-42 are classified based upon the heat input of the external combustion device. This classification is shown below:

- Utility/large industrial (>100 MMBtu/hr);
- Small industrial (10-100 MMBtu/hr);
- Commercial (0.3-10 MMBtu/hr); and
- Residential (<0.3 MMBtu/hr).

Based upon this classification, burners A and C from Example 2a are small industrial devices while burners B and D are commercial devices. None of the four burners have any emission control devices attached to them.

Solution

From Table 1.4-2 of AP-42, the NO_x emission factor for small industrial devices is 2240 kg/10^6 m^3, while the emission factor for commercial devices is 1600 kg/10^6 m^3. Emissions from the burners in the tortilla factory are then calculated using the following equation:

$$E_{Total} = \sum_{d=1}^{n} (FC_d \text{ x } EF_d)$$

where:
E_{Total} = Total emissions (kg/yr);
n = Number of devices;
FC_d = Fuel consumption for device d (10^6 m^3/yr); and
EF_d = Emission factor for device d (kg/10^6 m^3).

so

$$\begin{aligned} E_{Total} &= (2.45 \text{ x } 2{,}240) + (0.95 \text{ x } 1{,}600) + (1.63 \text{ x } 2{,}240) + (1.77 \text{ x } 1{,}600) \\ &= 5{,}488 + 1{,}520 + 3{,}651 + 2{,}832 = 13{,}491 \text{ kg/yr} = 13.5 \text{ Mg/yr} \end{aligned}$$

Example 2c
External Combustion Devices - Other Estimating Techniques

Introduction

This problem demonstrates limitations of emission factors, which are widely used in the development of emission inventories.

Emission factors are a widely used emission estimating technique primarily because they are relatively inexpensive and easy to use. However, under certain circumstances, they may not provide an accurate estimate of the emissions from a specific process. It is important to understand that emission factors are based on available source test data. While the published factors may be quite accurate for the specific equipment and conditions that were tested, they may be significantly less accurate for other equipment and conditions.

When conducting an emissions inventory, it is not uncommon to encounter a source for which there are no specific emission factors in the literature. In these cases, it has been a common practice to use published emission factors for source types that appear to be similar. While this practice of extrapolation may appear to be reasonable, it can cause significant errors in the emission estimates.

This problem specifically focuses on the external combustion emission factors that are found in Chapter 1 of AP-42 and presents an example to illustrate a case where these emission factors were not applicable. Example source test data and associated calculations are also presented.

Problem Statement

Estimate TOG emissions from a fume incinerator (an air pollution control device designed to destroy the organic compounds emitted from sources such as large paint booths in the automotive industry).

Available Information

The inputs to the incinerator are the large exhaust air stream from the paint booth (containing small quantities of organics to be destroyed) and natural gas as fuel to the incinerator burners. The engineers who made emissions estimates for several fume incinerators were faced with the problem of not having equipment-specific emission factors or source test data for the incinerators. They examined the incinerator process and determined that the emissions would result primarily from the fuel combustion because the quantity of pollutants in the paint booth exhaust air was small in comparison to the fuel quantity. Knowing that emissions from boilers also result only from the fuel combustion, the engineers logically decided to use the emission factors in AP-42 for boilers with similar heat capacities to estimate the emissions for the fume incinerator.

Unfortunately, this decision resulted in inaccurate emission estimates. In subsequent source testing of the fume incinerators, it was shown that the actual NO_x emissions were approximately eight (8) times higher than the estimated emissions based on the boiler emission factors. Upon detailed examination of the incinerator operation, it was determined that the incinerator process parameters were substantially different than the boiler conditions in two respects:

- The incinerators operated at much higher excess air concentrations than the boilers due to the quantity of exhaust air from the paint booths; and

- The incinerators operated at substantially higher temperatures than the boilers to ensure complete combustion of the organic pollutants.

Both of these conditions are conducive to the formation of thermal NO_x (see Note 1 at end of example), which explains the large difference between the estimated and actual NO_x emissions. These conditions also determine the extent of combustion, which affects the formation of CO and the quantity of unburned organics (TOG) in the incinerator stack gas. Using the published boiler emission factors in this case resulted in substantial errors in the estimated emissions for the incinerators because the incinerators were operated at significantly different conditions than those encountered in the boiler source tests on which the emission factors were based.

The correct methodology for estimating NO_x emissions from the fume incinerator was to conduct source testing. Costly new burner design trials and repeated source testing were required to find a solution that reduced the NO_x emissions from the fume incinerators to acceptable levels without increasing TOG and CO emissions to unacceptable limits. Source test data and calculated emission factors for NO_2 (nitrogen dioxide), NO_x, CO, and non-methane hydrocarbon (NMHC) destruction removal efficiency (DRE) from one of the fume incinerators are presented in Table 2-2. The following paragraphs present the methodology used for calculation of the NO_x and CO emission factors from the source test data. The NMHC DRE data is presented for information only and to illustrate the relationship between NO_x, CO, and TOG emissions from external combustion for varying conditions.

Source test data are often obtained in units that are not useful for estimating emissions. The test data may need to be converted to standard conditions (temperature and pressure) for comparison with other data or may need to be converted from measured units to reportable units. When source testing involves a series of process adjustments to determine the influence of parameters such as temperature or percentage of excess air, then rapid on-site data analysis may be required so the test team can judge the effect of each change. During the fume incinerator source tests conducted in the example above, a spreadsheet was developed to allow the rapid conversion of measured NO_x emissions to the desired emission units. This spreadsheet is presented as Table 2-2 in this workbook and the

Table 2-2

Source Test Data and Calculated Emission Factors for Fume Incinerator

SOURCE TEST ID			NOx EMISSION FACTORS CALCULATED						CO EMISSION FACTORS			
Test Date	Test Temp F		NO2 O2 Bsd lb/MMBtu	NO2 CO2 Bsd lb/MMBtu	NO2 Fuel Bsd lb/MMBtu	NOx @ 3% O2 ppmv	NOx Emission lb/hr	NOx Emission lb per MMcfm	CO O2 Bsd lb/MMBtu	CO CO2 Bsd lb/MMBtu	CO Fuel Bsd lb/MMBtu	NMHC DRE %
3/25/92	1462		0.78	0.81	0.84	633	3.24	15.63	0.000	0.000	0.000	100.0%
3/25/92	1248		0.44	0.48	0.45	360	1.49	7.05	0.184	0.199	0.185	100.0%
3/25/92	1204		0.37	0.40	0.43	298	1.23	5.63	0.195	0.211	0.227	99.7%
3/25/92	1152		0.30	0.34	0.43	245	1.05	4.47	0.567	0.628	0.800	98.6%
3/25/92	1163		0.31	0.31	#N/A	253	1.25	5.31	0.414	0.412	#N/A	99.2%
3/25/92	1206		0.34	0.35	0.38	275	1.47	6.31	0.287	0.294	0.323	99.8%
3/25/92	1258		0.38	0.38	0.41	308	1.75	7.29	0.175	0.173	0.190	100.0%
2/13/92	1050	*	0.21	0.24	#N/A	168	0.52	2.16	0.687	0.773	#N/A	93.6%
2/13/92	1100	*	0.24	0.27	#N/A	198	0.64	2.68	0.744	0.797	#N/A	96.6%
2/13/92	1150	*	0.28	0.32	#N/A	226	0.77	3.21	0.715	0.806	#N/A	98.6%
2/13/92	1200	*	0.33	0.36	#N/A	266	0.95	3.95	0.459	0.498	#N/A	99.5%
2/13/92	1250	*	0.39	0.41	#N/A	317	1.18	4.93	0.219	0.230	#N/A	99.8%
1/31/92	1250		#N/A	0.43	#N/A	#N/A	1.39	6.02	#N/A	#N/A	#N/A	#N/A
1/31/92	1300		#N/A	0.48	#N/A	#N/A	1.67	7.23	#N/A	#N/A	#N/A	#N/A
1/31/92	1350		#N/A	0.56	#N/A	#N/A	2.20	9.53	#N/A	#N/A	#N/A	#N/A
1/31/92	1400		#N/A	0.66	#N/A	#N/A	2.73	11.83	#N/A	#N/A	#N/A	#N/A
1/31/92	1450		#N/A	0.80	#N/A	#N/A	3.49	15.09	#N/A	#N/A	#N/A	#N/A
1/16/92	1450	*	0.74	0.90	#N/A	563	2.90	12.55	0.019	0.019	0.019	99.8%

NOTES

Table 2-2

(Continued)

SOURCE TEST ID		SOURCE TEST DATA												
		Inlet					Exhaust						Fuel	Firing
Test Date	Test Temp F	NOx ppmv	O2 %	CO2 ppmv	CO ppmv	HC ppmv	NOx ppmv	O2 %	CO2 %	CO ppmv	HC ppmv	Exhaust gas scfm	delta P	Rate MMBtu/hr
3/25/92	1462	0.25	20.9	1030	0.5	476.7	129.4	17.25	2.11	0.5	0	3454	7.5	3.87
3/25/92	1248	0.25	20.9	1020	0.5	454	58.5	18	1.62	40.1	0	3532	5.6	3.35
3/25/92	1204	0.25	20.9	1010	0.5	450	46.8	18.1	1.57	41	1.3	3646	4.15	2.88
3/25/92	1152	0.25	20.9	850	0.5	423	37.2	18.2	1.46	114.2	5.8	3897	3	2.45
3/25/92	1163	0.25	20.9	860	0.5	423	44.1	17.8	1.85	95.8	3.5	3942	#N/A	#N/A
3/25/92	1206	0.25	20.9	965	0.5	453	52.4	17.5	1.98	73	0.7	3886	7.45	3.86
3/25/92	1258	0.25	20.9	980	0.5	457	60.5	17.4	2.11	46	0	4003	9	4.24
2/13/92	1050	0.25	20.9	480	0.5	380	18.1	19	1	97.5	24.5	3992	#N/A	#N/A
2/13/92	1100	0.25	20.9	490	0.5	410	22.4	18.9	1.1	111	13.9	3992	#N/A	#N/A
2/13/92	1150	0.25	20.9	505	0.5	415	26.8	18.8	1.1	112	6	3992	#N/A	#N/A
2/13/92	1200	0.25	20.9	530	0.5	510	32.9	18.7	1.2	75.5	2.7	3992	#N/A	#N/A
2/13/92	1250	0.25	20.9	525	0.5	575	41	18.6	1.3	38	1.1	3992	#N/A	#N/A
1/31/92	1250	0.25	20.9	400	0.5	#N/A	50	#N/A	1.5	#N/A	#N/A	3850	#N/A	#N/A
1/31/92	1300	0.25	20.9	400	0.5	#N/A	60	#N/A	1.6	#N/A	#N/A	3850	#N/A	#N/A
1/31/92	1350	0.25	20.9	400	0.5	#N/A	79	#N/A	1.8	#N/A	#N/A	3850	#N/A	#N/A
1/31/92	1400	0.25	20.9	400	0.5	#N/A	98	#N/A	1.9	#N/A	#N/A	3850	#N/A	#N/A
1/31/92	1450	0.25	20.9	400	0.5	#N/A	125	#N/A	2	#N/A	#N/A	3850	#N/A	#N/A
1/16/92	1450	0.25	20.7	550	3	283	104	17.6	1.5	2.5	0.5	3850	#N/A	#N/A
NOTES							2	1, 2	1, 2	1, 2	1, 2			

Notes and Abbreviations for Table 2-2

Notes:

1. %CO_2 and O_2 in the exhaust gas samples = ppmv/10,000
2. Exhaust gas measurements are on a dry basis

Abbreviations:

NMHC	Non-methane hydrocarbons
DRE	Destruction removal efficiency
F	Temperature, degrees Fahrenheit
NO_2	Nitrogen dioxide
O_2	Oxygen
CO	Carbon monoxide
CO_2	Carbon dioxide
O_2 Bsd	Emission factor calculation based on %O_2 in exhaust
CO_2 Bsd	Emission factor calculation based on %CO_2 in exhaust
Fuel Bsd	Emission factor calculation based on fuel flow rate
NO_x	Nitrogen oxides
Temp	Temperature
lb	Pounds
MMBtu	Million British thermal units
ppmv	parts per million (volume)
hr	hour
MMcf	Million cubic feet of inlet gas
HC	Hydrocarbon
scfm	Standard cubic feet per minute
delta P	Differential pressure

explanation of how the spreadsheet was used to calculate NO_x and CO emission factors is presented below.

Given the following operating parameters, the NO_x emission factor (lb/Btu) can be estimated:

- Measured inlet and outlet source test data (all gas concentrations are on a dry basis);
- Test temperature (°F);
- Exhaust gas flow rate (scfm); and
- Natural gas (fuel) firing rate.

The emission factor can be determined based on either the O_2 or CO_2 concentration in the exhaust gas or on the fuel firing rate. All three of these methods are appropriate to use when calculating emission factors from source testing. Both the O_2 and CO_2 based emission factors are calculated using the F Factor method which was promulgated in the October 6, 1975 United States Federal Register as a procedure to replace the original method of determining emission factors. The U.S. EPA has published F factors for common fuels and the F factor values used in these calculations were taken from Stack Sampling Technical Information (U.S. EPA, 1978). The F factor for the O_2 based emission factor for natural gas is 8,740 scf/MMBtu. The F factor for the CO_2 based emission factor for natural gas is 1,040 scf/MMBtu. In this example, the 3/25/92 test data at 1462 °F were used from Table 2-1.

The equation for calculating an O_2 based NO_x emission factor using the F factor method is:

$$E = Cd \text{ x } Fd \text{ x } \frac{20.9}{20.9 - \%O_2}$$

where:

E = Emission rate in lb/MMBtu;
Cd = Pollutant concentration in dry exhaust gas minus pollutant concentration in inlet gas (lb/scf);
Fd = Oxygen based F factor (8,740 scf/MMBtu);
$\%O_2$ = O_2 percent in dry exhaust gas; and
20.9 = Assumed O_2 percent in inlet gas (ambient atmosphere).

The calculation of Cd in lb/scf exhaust gas from the measured concentrations of NO_x (measured as NO_2) in ppmv is shown below.

$$Cd = \frac{[C]_{ppmv} \text{ x } MW}{CF_1}$$

where:

$[C]_{ppmv}$ = Concentration of pollutant in exhaust minus concentration of pollutant in inlet gas in ppmv (scf pollutant/MMscf exhaust gas);
MW = Molecular weight of NO_2 (46 lb/lb-mole); and
CF_1 = Conversion factor based on ideal gas law that 1 lb-mole ideal gas = 380 scf.

Using data from Table 2-1 for the 3/25/92 test data at 1462 °F, the calculation of Cd is:

$$Cd = \frac{\left[(129.4 - 0.25) \frac{\text{scf } NO_x}{10^6 \text{ scf exhaust gas}} \right] \text{ x } \frac{46 \text{ lb}}{\text{lb- mole}}}{380 \text{ scf/ 1 lb- mole}}$$

$$= 1.563 \text{ x } 10^{-5} \frac{\text{lb } NO_x}{\text{scf exhaust gas}}$$

Then the calculation of the NO_x emission factor using the oxygen based F factor is:

$$E = \left(1.563 \text{ x } 10^{-5} \frac{\text{lb } NO_x}{\text{scf}}\right) \text{x } \frac{8{,}740 \text{ scf}}{10^6 \text{ Btu}} \text{ x } \left(\frac{20.9}{20.9 - 17.25}\right)$$

$$E = \frac{0.78 \text{ lb } NO_x}{10^6 \text{ Btu}}$$

The equation for calculating a CO_2 based NO_x emission factor using the F factor method is:

$$E = Cd \text{ x } Fc \text{ x } \left(\frac{100}{\% CO_2}\right)$$

where:
E = Emission rate (lb/MMBtu);
Cd = Pollutant concentration in dry exhaust gas minus pollutant concentration in inlet gas (lb/scf);
Fc = Carbon dioxide based F factor (1,040 scf/MMBtu); and
$\%CO_2$ = CO_2 percent in dry exhaust gas minus CO_2 percent in inlet gas.

The calculation of Cd in lb/scf from the measured concentrations of NO_x in ppmv was done above. The calculation of $\%CO_2$ is as follows:

$$\% CO_2 = \% CO_2 \text{ (in dry exhaust gas as measured) } - \frac{\text{ppmv } CO_2 \text{ in inlet gas}}{10{,}000}$$

$$E = 2.11 - \frac{1{,}030}{10{,}000} = 2.007$$

Then the calculation of the NO_x emission factor using the CO_2 based F factor is:

$$E = \left(\frac{1.563 \text{ x } 10^{-5} \text{ lb NO}_x}{\text{scf}} \right) \text{x } \frac{1{,}040 \text{ scf}}{10^6 \text{ Btu}} \text{ x } \frac{100}{2.007}$$

$$E = \frac{0.81 \text{ lb NO}_x}{10^6 \text{ Btu}}$$

If the fuel firing rate is used to calculate a NO_x emission factor, then the following equation is used:

$$E = \frac{\text{Cd x Q x 60}}{\text{FR}}$$

where:
E = Emission rate (lb/MMBtu);
Cd = Pollutant concentration in dry exhaust gas minus pollutant concentration in inlet gas (lb/scf);
Q = Exhaust flow rate (scf/minute);
60 = Conversion factor from minutes to hours; and
FR = Fuel firing rate (MMBtu/hour).

The calculation of Cd in lb/scf from the measured concentrations of NO_x in ppmv was done above.

So the emission factor based on the fuel firing rate is:

$$E = \frac{\left(\frac{1.563 \text{ x } 10^{-5} \text{ lb NO}_x}{\text{scf}} \right) \text{x} \left(\frac{3{,}454 \text{ scf}}{\text{min}} \right) \text{x} \left(\frac{60 \text{ min}}{\text{hr}} \right),}{3.87 \text{ x } 10^6 \text{ Btu/hr}}$$

$$E = \frac{0.84 \text{ lb NO}_x}{10^6 \text{ Btu}}$$

A comparison of the calculated emission factors with a emission factor from AP-42 is given in Table 2-3.

Table 2-3

Comparison of Calculated Emission Factors

Calculation Method	Emission Factor (lb $NO_x/10^6$ Btu)
O_2 Based F Factor	0.78
CO_2 Based F Factor	0.81
Fuel Firing Rate	0.84
AP-42, Table 1.4-2 Uncontrolled Commercial Boiler*	0.10

* Assumes a natural gas fired higher heating value of 1,000 Btu/scf.

As mentioned earlier, the emission factor taken from AP-42 can be seen to be low by a factor of eight (8).

In order to compare emission factors on an equivalent basis, it is sometimes necessary to adjust the estimated emission factors to a given excess O_2 concentration. This is often done for regulatory purposes. This is done with the following equation.

$$EF_{ex} = EF \text{ x } \frac{(20.9 - O_{2(ex)})}{(20.9 - O_2)}$$

where:
EF_{ex} = NO_x emission factor at desired excess O_2 level (lb/MMBtu);
EF = Calculated NO_x emission factor (lb/MMBtu);
20.9 = Assumed atmospheric O_2 concentration (%);
$O_{2(ex)}$ = Desired excess O_2 concentration (%); and
O_2 = Measured O_2 concentration in dry exhaust gas (%).

Using the O_2-based emission factor calculated above, the NO_x emission factor at 3% excess O_2 for the 3/25/92 test data at 1462 °F is calculated as:

$$NO_x\ (3\%) = 0.78\,\frac{\text{lb NO}_x}{10^6\ \text{Btu}}\ \text{x}\left(\frac{20.9 - 3}{20.9 - 17.25}\right)$$

$$= \frac{3.83\ \text{lb NO}_x}{10^6\ \text{Btu}}$$

The adjusted emission factor differs from the calculated emission factor because the desired excess O_2 concentration (3%) is quite different compared to the actual measured O_2 concentration (17.25%). If the desired excess O_2 concentration is equal to the measured O_2 concentration, then the adjusted emission factor will be identical to the calculated emission factor.

Note 1: NO_x is formed in external combustion in primarily two ways: thermal NO_x and fuel NO_x. Thermal NO_x is formed when nitrogen and oxygen in the combustion air react at high temperatures in the flame. Fuel NO_x is formed by the reaction of any nitrogen in the fuel with combustion air. Thermal NO_x is the primary source of NO_x in natural gas and light oil combustion and the most significant factor affecting its formation is flame temperature. Excess air level and combustion air temperature also are factors in the formation of thermal NO_x. Fuel NO_x formation is dependent on the nitrogen content of the fuel and can account for as much as 50% of the NO_x emissions from the combustion of high-nitrogen fuels - primarily heavy oils.

Each of these methods is described in detail below.

The Heading Load method:

This method uses the average monthly heating load for a typical Nogales house to estimate emissions. The required average monthly heating load for a building can be determined by the following equation (Harris et al., 1985):

$$Q_i = (UA + 0.018V) \times DD_i \times 24$$

where:

Q_i = Average monthly heating load (Btu/month) for month i;
UA = Hourly transmission heat loss per degree of design temperature difference (Btu/hr-°F);
0.018V = Infiltration-ventilation hourly heat loss per degree of design temperature difference (Btu/hr-°F);
DD_i = Monthly degree-days [65°F base temperature] (°F-day/month) for month i; and
24 = Conversion factor from days to hours.

The UA term is actually the product of an overall heat transmission coefficient for a given structural element (U) and the surface area of that structural element (A). The V term represents the hourly volume of infiltration air (the product of hourly air changes and space volume). Guidelines for estimating values for UA and 0.018V for an entire building can be obtained from various engineering handbooks (e.g., ASHRAE, 1997 - chapters 24 and 25). In order to estimate these two variables, some characteristics of a "typical" house must be determined (building material, average floor space, average building height, wall thickness, number of doors, number and size of windows, etc.). A degree-day is the difference between a fixed base temperature (usually 65°F) and the daily mean outdoor temperature, summed up for a specified period of time, such as a month or a year. A higher degree-day total indicates a higher heating load. Degree-days data are typically available from meteorological stations.

The required average annual heating load for a single household is calculated by aggregating each of the average monthly heating loads using different degree days for each month as shown below.

$$Q_{Annual} = \sum_{i=1}^{12} Q_i$$

where: Q_{Annual} = Annual heating load (Btu/year); and
Q_i = Average monthly heating load (Btu/month) for month i.

Once an annual heating load has been estimated, the amount of biomass/waste fuel that provides the required amount of heat can be estimated using an average energy content for that specific fuel. This is shown in the next equation.

$$Fuel_{Annual,f} = \frac{Q_{Annual}}{EC_f}$$

where: $Fuel_{Annual,f}$ = Annual fuel use (lb/year) for fuel f;
Q_{Annual} = Annual heating load (Btu/year); and
EC_f = Energy content (Btu/lb) for fuel f.

This estimated amount of biomass/waste material would need to be adjusted upward to account for cooking activities that use similar fuels.

The LPG Equivalence method:

This method uses average household LPG usage to estimate non-commercial fuel consumption. Since the number of households using LPG in Nogales was known, average per household LPG usage can be estimated if the total amount of LPG consumption is available.

Example 3
Residential Fuel Combustion

Introduction

This example illustrates a common situation where emissions must be estimated with minimal data. In many instances, the inventory specialist will be faced with a shortage of data that requires a creative approach to developing emission estimates. Because of the lack of data, typical emission estimating methods are not always a feasible option. Rather, alternative methods must be identified and examined. Each of the alternative methods will have positive and negative points that must be evaluated before one is selected. In some cases, more than one of the alternative methods may be selected in order to provide a possible range of emission estimates (i.e., bounding calculations). Although one of the estimates will likely be incorporated into the emissions database, the range of estimates provides one measure of the possible uncertainty associated with that specific source category. This is an added benefit of performing bounding calculations.

The following example is based upon the actual data and methodology used in an air toxics inventory for Nogales, Sonora (Radian, 1997). This example is not intended to provide a specific, recommended estimating method, rather, it is designed to present the thought processes that should be employed in order to estimate emissions when faced with incomplete data.

Problem Statement

Determine the annual CO emissions from the combustion of non-commercial fuels. Include only those fuels for heating or cooking purposes. Exclude any waste burning.

Available Information

In Mexico, PEMEX (Petróleos Mexicanos), as well as some government agencies, maintain fairly detailed statistics for the consumption of commercial fuels (e.g., distillate oil, LPG [liquefied petroleum gas], etc.). However, significant quantities of non-commercial fuels are also used in some areas of the country for residential heating and cooking. Examples of non-commercial fuels include wood, other biomass, manure, scrap materials, tires, waste solvents, and other waste-derived fuels. In this problem, these fuels are referred to as biomass/waste fuels. Statistics for these types of fuels are almost nonexistent in most countries, including Mexico.

Although several local officials and residents cited statistics that 98% of the homes in Nogales use LPG as of 1994 (Carrillo, 1996; Gastelum, 1996; Guerrero, 1996), the use of waste derived fuels was considered a potentially significant source of emissions. Unfortunately, very little data regarding the combustion of biomass/waste fuels were available for collection during a local site visit. Overall population and household statistics were available for the inventory domain, but residential biomass/waste fuel combustion rates were not.

Selection of Methodology

Ideally, biomass/waste fuel combustion rates derived from statistically valid surveys would be combined with emission factors to yield emission estimates. However, because survey data were not available, alternate estimation methods were used. Three possible methods were devised that would allow biomass/waste combustion rates to be estimated. These included:

- The Heating Load method;
- The LPG Equivalence method; and

- The Micro-Inventory method.

Each of these methods is described in detail below.

The Heating Load method:

This method uses the average monthly heating load for a typical Nogales house to estimate emissions. The required average monthly heating load for a building can be determined by the following equation (Harris et al., 1985):

$$Q_i = (UA + 0.018V) \times DD_i \times 24$$

where:
Q_i = Average monthly heating load (Btu/month) for month i;
UA = Hourly transmission heat loss per degree of design temperature difference (Btu/hr-°F);
0.018V = Infiltration-ventilation hourly heat loss per degree of design temperature difference (Btu/hr-°F);
DD_i = Monthly degree-days [65°F base temperature] (°F-day/month) for month i; and
24 = Conversion factor from days to hours.

The UA term is actually the product of an overall heat transmission coefficient for a given structural element (U) and the surface area of that structural element (A). The V term represents the hourly volume of infiltration air (the product of hourly air changes and space volume). Guidelines for estimating values for UA and 0.018V for an entire building can be obtained from various engineering handbooks (e.g., ASHRAE, 1997 - chapters 24 and 25). In order to estimate these two variables, some characteristics of a "typical" house must be determined (building material, average floor space, average building height, wall thickness, number of doors, number and size of windows, etc.). A degree-day is the difference between a fixed base temperature (usually 65°F) and the daily mean outdoor temperature, summed up for a specified period of time, such as a month or a year. A higher degree-day total indicates a higher heating load. Degree-days data are typically available from meteorological stations.

The required average annual heating load for a single household is calculated by aggregating each of the average monthly heating loads using different degree days for each month as shown below.

$$Q_{Annual} = \sum_{i=1}^{12} Q_i$$

where:
Q_{Annual} = Annual heating load (Btu/year); and
Q_i = Average monthly heating load (Btu/month) for month i.

Once an annual heating load has been estimated, the amount of biomass/waste fuel that provides the required amount of heat can be estimated using an average energy content for that specific fuel. This is shown in the next equation.

$$Fuel_{Annual,f} = \frac{Q_{Annual}}{EC_f}$$

where:
$Fuel_{Annual,f}$ = Annual fuel use (lb/year) for fuel f;
Q_{Annual} = Annual heating load (Btu/year); and
EC_f = Energy content (Btu/lb) for fuel f.

This estimated amount of biomass/waste material would need to be adjusted upward to account for cooking activities that use similar fuels.

The LPG Equivalence method:

This method uses average household LPG usage to estimate non-commercial fuel consumption. Since the number of households using LPG in Nogales was known, average per household LPG usage can be estimated if the total amount of LPG consumption is available.

$$LPG_{Usage} = \frac{LPG_{Res}}{Households_{LPG}}$$

where:
LPG_{Usage} = Annual per household LPG usage (lb/yr);
LPG_{Res} = Annual total residential LPG usage (lb/yr); and
$Households_{LPG}$ = Total households using LPG.

Using the energy content of LPG and typical biomass/waste fuels, equivalent average per household biomass/waste usage can be estimated.

$$Bio/\ Waste_{Usage} = LPG_{Usage} \text{ x } \frac{EC_{LPG}}{EC_{Bio/Waste}} \text{ x } \frac{Eff_{LPG}}{Eff_{Bio/Waste}}$$

where:
$Bio/Waste_{Usage}$ = Annual per household biomass/waste fuel usage (kg/yr);
LPG_{Usage} = Annual per household LPG usage (liters/yr);
EC_{LPG} = Energy content of LPG (kcal/liter);
$EC_{Bio/Waste}$ = Energy content of biomass/waste fuel (kcal/kg);
Eff_{LPG} = Efficiency of LPG combustion; and
$Eff_{Bio/Waste}$ = Efficiency of biomass/waste fuel combustion.

The Micro-Inventory method

This method involves performing a micro-inventory of 25 or 30 houses that use biomass or waste fuels. A short interview should provide sufficient information. The most important information is the quantity of fuel burned. Most people interviewed will not be able to estimate annual or monthly usage, but they should be able to estimate usage over a shorter period of time. Information should also be collected concerning seasonal usage variations and other burning practices. Annual biomass or waste fuel usage could then be derived using these data.

Analysis and Selection of Emission Estimating Methods

After establishing three alternative methods, it was necessary to select one of these methods. The selection was based upon several selection criteria and general engineering judgment. Selection criteria included such things as ease of use, representativeness, amount of uncertainty, reasonableness, etc. For the Nogales, Sonora air toxics inventory, the LPG Equivalence method was ultimately selected.

The Heating Load and Micro-Inventory methods were not selected for several reasons:

- **Potential for bias.** It would be very difficult to assure that the "typical house" selected for the Heating Load method actually represented the types of houses present in the inventory domain. Likewise, it would be hard to guarantee that the households selected to be interviewed for the Micro-Inventory method would actually be representative of households that burned biomass or waste fuels. The potential for bias would decrease if large scale surveying was conducted to determine house characteristics or fuel usage, but the associated cost would be prohibitive.

- **Availability of data and types of assumptions.** Although available data are limited, the LPG Equivalence method uses these limited data and several reasonable assumptions to estimate emissions. The Heating Load method, on the other hand, would require some additional data collection, as well as a few "less reasonable" assumptions.

- **Reluctant survey participants.** Given that LPG is used in 98% of the homes, the number of households using biomass or waste fuels is in the minority. For the Micro-Inventory method, some of these households might be reluctant to volunteer information regarding their burning practices. Even if responses were given, there might be some question about the validity of the responses.

Solution

Now that the LPG Equivalence method has been selected, it is possible to estimate emissions. The four main steps are outlined below.

1. **Determine number of households that use biomass/waste fuels for heating or cooking.** Based upon census data, geographic information system (GIS) data, and recent growth trends, it was estimated that there are approximately 38,018 households in Nogales (Radian, 1997). As previously mentioned, 98% of the Nogales households have been identified as using LPG. It was assumed that the remaining 2% of the Nogales households use biomass/waste fuels. The total number of households using biomass/waste is given below:

$$\text{Households}_{\text{Bio/Waste}} = \%_{\text{Bio/Waste}} \times \text{Households}_{\text{Total}} = 2\% \times 38{,}018 = 760 \text{ households}$$

where:

$\text{Households}_{\text{Bio/Waste}}$ = Number of households using biomass/waste fuels;

$\%_{\text{Bio/Waste}}$ = Percentage of households using biomass/waste fuels; and

$\text{Households}_{\text{Total}}$ = Total number of households.

2. **Determine per household LPG usage.** Per household LPG usage is determined by dividing the total residential LPG usage by the number of households that use LPG. PEMEX statistics indicated that the 1994 LPG usage for Nogales was 30,203,870 kilograms (Estrada, 1996). It has been determined that 80% of total LPG usage in Mexico is residential usage (Dirección General de Ecología et al., 1995).

The mass usage of LPG is converted to volume usage by estimating the density of LPG. Unfortunately, the exact chemical composition and density of LPG in Nogales is unknown. However, the approximate density of LPG in Nogales can be estimated using the dimensions of a 45 kilogram LPG cylinder and its reported weight. The measurements of a 45 kg LPG cylinder indicated that the height is 1.04 m and the circumference is 1.19 m. As shown below, a cylinder volume and then a density can be calculated from these cylinder dimensions. For a cylinder, the volume is calculated as shown below:

$$V = \boldsymbol{p}\, r^2 h;\; C = 2\boldsymbol{p}\, r$$

$$V = \boldsymbol{p}\left(\frac{C}{2\boldsymbol{p}}\right)^2 h = \frac{C^2 h}{4\boldsymbol{p}}$$

$$V = \frac{(1.19\ \mathrm{m})^2\ \mathrm{x}\ 1.04\ \mathrm{m}}{4\ \mathrm{x}\ 3.14} = 0.1173\ \mathrm{m}^3$$

where: V = cylinder volume (m);
C = cylinder circumference (m);
r = cylinder radius (m); and
h = cylinder height (m).

The approximate density of the LPG is then:

$$\boldsymbol{r} = \frac{m}{V} = \frac{45\ \mathrm{kg}}{0.1173\ \mathrm{m}^3} = 383.6\ \frac{\mathrm{kg}}{\mathrm{m}^3} = 0.384\ \frac{\mathrm{kg}}{\mathrm{liter}}$$

where: ñ = LPG density (kg/liter);
m = LPG mass in a cylinder (kg); and
V = LPG cylinder volume (m^3).

The conversion of LPG from kilograms to liters is then:

$$LPG_v = \frac{LPG_m}{\boldsymbol{r}} = \frac{30{,}203{,}870\ \mathrm{kg}}{0.384\ \mathrm{kg/liter}} = 78{,}655{,}911\ \mathrm{liters}$$

where: LPG_v = Total LPG volume (liter);
LPG_m = Total LPG mass (kg); and
ñ = LPG density (kg/liter).

Total residential LPG use is estimated to be 80% of the total LPG use with the remainder being industrial/commercial usage (Dirección General de Ecología et al., 1995).

$$\mathrm{LPG_{Res}} = \%_{\mathrm{Res}} \ \mathrm{x}\ \mathrm{LPG_{Total}} = 80\% \ \mathrm{x}\ 78{,}655{,}911 \ \mathrm{liters} = 62{,}924{,}729 \ \mathrm{liters}$$

where: $\mathrm{LPG_{Res}}$ = Residential LPG usage (liters/yr);
$\%_{\mathrm{Res}}$ = Percentage of total LPG usage that is residential; and
$\mathrm{LPG_{Total}}$ = Total LPG usage (liters/yr).

The number of households using LPG is given below:

$$\mathrm{Households_{\ LPG}} = \%_{\mathrm{LPG}} \ \mathrm{x}\ \mathrm{Households_{\ Total}} = 98\% \ \mathrm{x}\ 38{,}018 = 37{,}258$$

where: $\mathrm{Households_{LPG}}$ = Number of households using LPG;
$\%_{\mathrm{LPG}}$ = Percentage of total households using LPG; and
$\mathrm{Households_{Total}}$ = Number of total households.

Finally, per household LPG usage is calculated using the following equation:

$$\mathrm{Usage_{\ LPG}} = \frac{\mathrm{LPG_{Res}}}{\mathrm{Households_{\ LPG}}} = \frac{62{,}924{,}729 \ \mathrm{liters}}{37{,}258 \ \mathrm{households}} = 1{,}689 \ \mathrm{liters/hou\ sehold}$$

where: $\mathrm{Usage_{LPG}}$ = Annual per household LPG usage (liters/yr);
$\mathrm{LPG_{Res}}$ = Residential LPG usage (liters/yr); and
$\mathrm{Households_{LPG}}$ = Number households using LPG.

This per household LPG usage should be checked to see if it is reasonable. A very limited number of informal interviews conducted with local residents indicate that a typical household uses one large (45 kg) LPG cylinder per month during the summer and two large cylinders per month during the winter (Monroy, 1996). Assuming that there are eight summer months and four winter months, then a typical household would use approximately 16 large cylinders per year. Using the LPG density calculated above and the weight per cylinder, the number of cylinders used per household can be estimated.

$$\frac{1{,}689 \text{ liters}}{\text{households}} \text{ x } \frac{0.384 \text{ kg}}{\text{liter}} \text{ x } \frac{1 \text{ cylinder}}{45 \text{ kg}} = \frac{14.4 \text{ cylinders}}{\text{household}}$$

Given that these estimates are within 10% of each other, the estimate of 1,689 liters of LPG per household per year seems quite reasonable.

3. **Convert per household LPG usage to per household biomass/waste fuel usage.** The annual per household LPG usage value of 1,689 liter/household calculated above represents the amount of LPG used by an average household for all of its heating and cooking requirements. An equivalent amount of biomass/waste fuel can be estimated based upon fuel energy contents.

Although local residents of Nogales refer to LPG as butane, the exact chemical composition of Nogales LPG is unknown. The local LPG is assumed to be similar to the average national composition of 60% propane and 40% butane (PEMEX, 1996). If the energy content of propane is 6,090 kcal/liter and the energy content of butane is 6,790 kcal/liter (U.S. EPA, 1995a), then the weighted energy content of LPG is calculated as shown below:

$$EC_{LPG} = \%_{prop} \text{ x } EC_{prop} + \%_{but} \text{ x } EC_{but} = (0.6 \text{ x } 6{,}090) + (0.4 \text{ x } 6{,}790) = 6{,}370 \text{ kcal/liter}$$

where:
EC_{LPG} = Energy content of LPG (kcal/liter);
$\%_{prop}$ = Percentage of propane in LPG;
EC_{prop} = Energy content of propane (kcal/liter);
$\%_{but}$ = Percentage of butane in LPG; and
EC_{but} = Energy content of butane (kcal/liter).

Assuming that the energy content of biomass/waste fuels is approximately that of pallet wood (4,445 kcal/kg) (Summit et al, 1996) and that the combustion efficiencies of LPG and biomass/waste fuels are equal, then the annual per household biomass/waste fuel usage can be estimated.

$$\text{Bio/ Waste}_{\text{Usage}} = \text{LPG}_{\text{Usage}} \text{ x } \frac{\text{EC}_{\text{LPG}}}{\text{EC}_{\text{Bio/Waste}}} \text{ x } \frac{\text{Eff}_{\text{LPG}}}{\text{Eff}_{\text{Bio/Waste}}}$$

$$\text{Bio/ Waste}_{\text{Usage}} = \frac{\text{1,689 liters LPG}}{\text{household}} \text{ x } \frac{\text{6,370 kcal/liter LPG}}{\text{4,445 kcal/kg bio/waste}} = \frac{\text{2,420 kg bio/waste}}{\text{household}}$$

where:

$\text{Bio/Waste}_{\text{Usage}}$ = Annual per household biomass/waste fuel usage (kg/yr);
$\text{LPG}_{\text{Usage}}$ = Annual per household LPG usage (liters/yr);
EC_{LPG} = Energy content of LPG (kcal/liter);
$\text{EC}_{\text{Bio/Waste}}$ = Energy content of biomass/waste fuels (kcal/kg);
Eff_{LPG} = Efficiency of LPG combustion; and
$\text{Eff}_{\text{Bio/Waste}}$ = Efficiency of biomass/waste fuel combustion.

4. **Calculate overall CO emissions.** Now that an annual per household biomass/waste fuel usage has been estimated, CO emissions can be calculated using the number of households and a CO emission factor. The CO emission factor for biomass/waste fuels is based upon source test data for combustion of Mexican pallet wood (Summit et al., 1996).

$$\text{Emissions}_{\text{CO}} = \text{Bio/ Waste}_{\text{Usage}} \text{ x Households}_{\text{Bio/Waste}} \text{ x EF}_{\text{CO}}$$

$$\text{Emissions}_{\text{CO}} = \frac{\text{2,420 kg bio/waste}}{\text{household}} \text{ x 760 households x } \frac{\text{31 g CO}}{\text{kg bio/waste}}$$

$$\text{Emissions}_{\text{CO}} = \text{57,015 kg/yr CO} = \text{57.0 Mg/yr CO}$$

where:

$\text{Emissions}_{\text{CO}}$ = Total CO emissions (kg/yr or Mg/yr);
$\text{Bio/Waste}_{\text{Usage}}$ = Annual per household biomass/waste fuel usage (kg/yr);
$\text{Household}_{\text{Bio/Waste}}$ = Number of households using biomass/waste fuels; and
EF_{CO} = CO emission factor (g CO/kg bio/waste).

Discussion of Results

Although the annual CO emissions from residential biomass/waste combustion were estimated to be 57 Mg/yr, the quality of this emission estimate and its underlying assumptions should be examined to determine areas of improvement and possible sources of uncertainty. Several important issues are discussed below.

1. **Number of households using biomass/waste fuels.** Local officials had estimated that 98% of the households used LPG. It was then assumed that the remaining 2% of the households used biomass/waste fuels. This assumption did not account for the possibility that some portion of the remaining 2% of households might use kerosene, distillate fuel, or other types of fuel.

2. **Number of households using LPG.** As mentioned earlier, local officials had estimated that 98% of the households used LPG. However, it is not exactly clear what the basis of this estimate is or how accurate it is. Even if the percentage of houses using LPG was slightly different, it could have a significant impact on the estimate of emissions from biomass/waste fuels. For example, if the actual percentage of households using LPG was 97%, instead of 98%, then emissions from LPG combustion would decline slightly. However, emissions from biomass/waste fuel combustion would be greatly affected; the percentage of houses using biomass/waste would increase from 2% to 3% -- a 50% increase.

3. **Fraction of residential LPG use.** It was assumed in this problem that 80% of the overall LPG used is residential usage. This assumption is based upon national statistics. Local consumption patterns may differ from this.

4. **Combustion efficiencies.** It was assumed in this problem that the combustion efficiencies of LPG and biomass/waste fuels were equal. In reality, the combustion of LPG is likely to be more efficient than the combustion of biomass/waste fuels. This would increase biomass/waste emissions.

5. **Fuel usage patterns.** In converting LPG usage to biomass/waste fuel usage, an implicit assumption is that fuel usage patterns are the same. This is probably not the case. For example, if LPG is used for heating or cooking purposes, then the combustion device can easily be turned off when the desired amount of heat has been obtained.

However, biomass/waste fuel combustion will often continue even after the desired amount of heat has been reached, because it is not desirable or practical to extinguish the fire.

6. **Composition of the biomass/waste fuel.** It was assumed in this problem that the biomass/waste fuel was pallet wood. In reality, biomass/waste fuel is likely to be composed of a wide variety of materials. Each of these materials will have its own energy content and emission factor.

Given the limited data available for this emission estimation problem, it was necessary to make all of the assumptions described above. Ideally, additional information could be gathered that would eliminate the need for some of these assumptions. This would improve the quality of the emission estimates and decrease the associated uncertainty.

Example 4
Gasoline Distribution System

Introduction

The next example is divided into seven parts which are all related to the gasoline distribution system. Although each part addresses an individual source category, these source categories are often conceptually grouped together. This is primarily because the distribution of gasoline is a potentially large source of evaporative total organic gas (TOG) emissions. A typical gasoline distribution system may have hundreds or thousands of individual sources and it is important that all of these sources are accounted for in an emissions inventory. By treating the entire distribution system as a whole, it is often easier to ensure that all possible sources are included.

A hypothetical gasoline distribution system with a manageable number of elements is presented in Figure 4-1. This simplified system contains a bulk terminal and four gasoline stations. Tank trucks transport the gasoline between the bulk terminal and the gasoline stations. This system does not include the petroleum refinery upstream from the bulk terminal or transport from the refinery to the bulk terminal by tank truck, rail car, or marine vessel. In reality, a gasoline distribution system will usually be much more complex than the one presented here. The distribution system in Figure 4-1 will be used throughout Example 4. The concepts presented in these seven problems are not limited to gasoline distribution; they are also applicable to other liquid fuels (e.g., aviation fuel, diesel, or LPG) and gaseous fuels (e.g., natural gas). The specific details and emission factors, however, would be different.

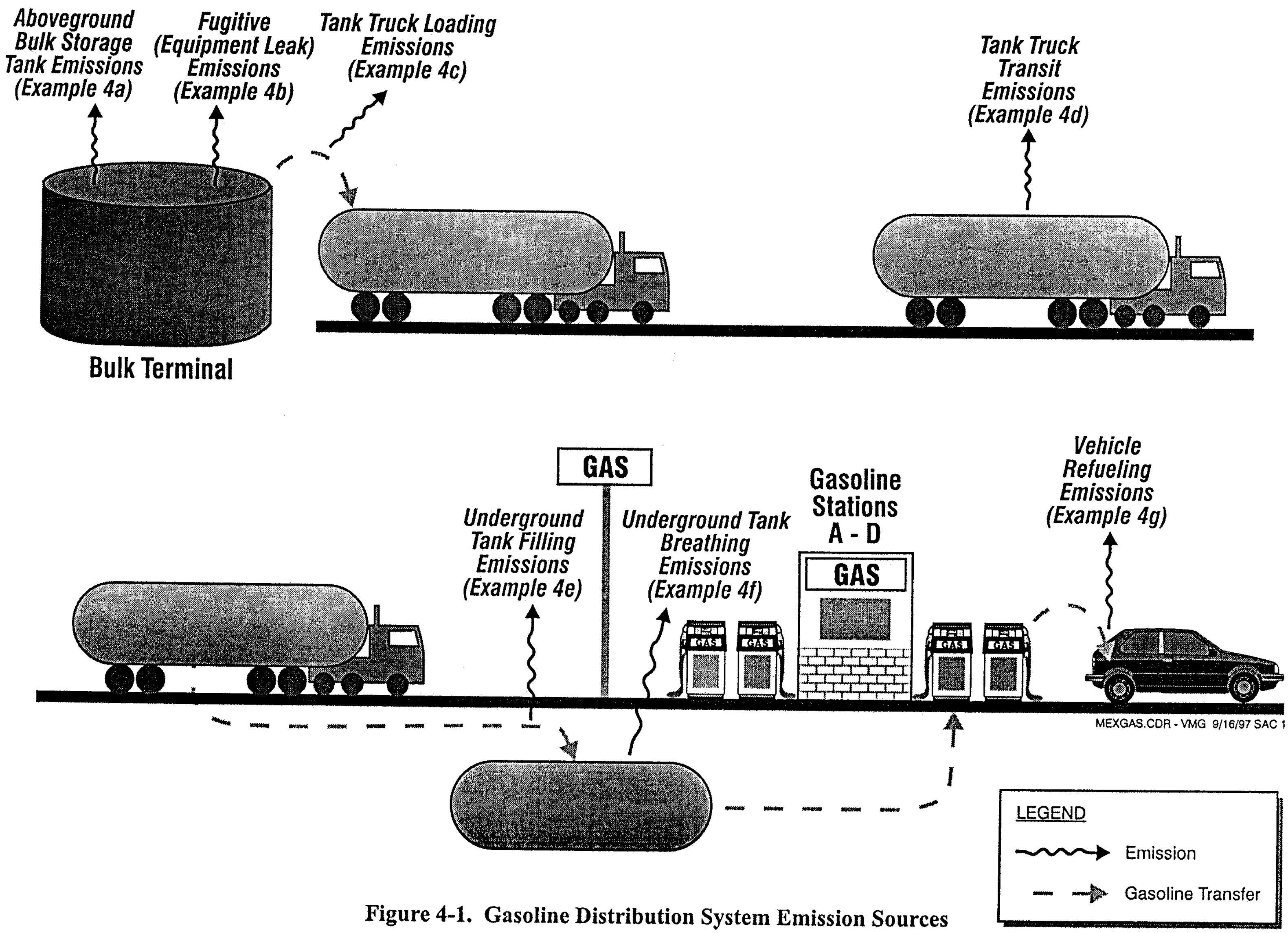

Figure 4-1. Gasoline Distribution System Emission Sources

Example 4a
Aboveground Bulk Storage Tank

Problem Statement

Estimate TOG emissions from standing and working losses at the bulk terminal's aboveground bulk storage tank.

Available Information

The total amount of RVP 9 gasoline pumped through the bulk terminal tank is determined to be 10,000,000 liters per year (2,642,000 gallons per year). The bulk terminal tank is a fixed roof aboveground storage tank (AST) with a capacity of 210,000 gallons. The AST has a cone roof. The liquid height within the tank is unknown at any given time. Meteorological conditions are assumed to be similar to Corpus Christi, Texas.

The following information is also known about the aboveground bulk storage tank:

Stored material = gasoline (RVP 9)
Tank diameter (D) = 37.6 feet
Tank shell height (H_S) = 24 feet
Tank average liquid height (H_L) = 12 feet (the liquid height within the tank is unknown at any given time; assumed to be half of tank shell height)
Tank capacity (V_{LX}) = 210,000 gallons
Tank color = light gray
Tank paint solar absorption (á) = 0.54 (AP-42, Table 7.1-6 for light gray paint in good condition)
Daily maximum ambient temperature (annual average) (T_{AX}) = 81.6°F = 541.27°R (AP-42, Table 7.1-7)
Daily minimum ambient temperature (annual average) (T_{AN}) = 62.5°F = 522.17°R (AP-42, Table 7.1-7)
Insolation (I) = 1521 Btu/ft^2-day (AP-42, Table 7.1-7)
Breather vent pressure setting (P_{BP}) = 0.03 psig (AP-42 default value)
Breather vent vacuum setting (P_{BV}) = -0.03 psig (AP-42 default value)

Molecular Weight Vapor (M_V) = 66.7 lb/lb-mol (Interpolated from AP-42, Table 7.1-2)
Slope of ASTM distillation curve at 10% evaporated (S) = 3.0 (AP-42, Figure 7.1-14a, Note 1)

Solution

Total TOG emissions from fixed roof storage tanks are estimated based on the methodology outlined in AP-42 (U.S. EPA, 1995a), Section 7.1.3.1, Total Losses from Fixed Roof Tanks, February 1996. Estimation methodologies for other types of storage tanks can also be found in AP-42. The AP-42 methodology uses a series of equations rather than emission factors to estimate emissions from storage of organic liquids. Total fixed roof storage tank emissions are the sum of standing and working losses. Standing losses occur from changes in temperature leading to venting of tank vapor to the atmosphere. Working losses result from changes in the liquid level of the tank, primarily from tank filling and emptying operations. These equations are quite involved in order to provide a more accurate estimate of storage tank emissions. Typically, the TANKS software (U.S. EPA, 1996) developed by U.S. EPA will be used to estimate emissions from bulk storage tanks. This example demonstrates the equations that are used within TANKS. Because the TANKS software uses English units, this example was done in English units, rather than metric units. Uncontrolled standing losses will be calculated first followed by uncontrolled working losses.

1. Calculation of Uncontrolled Standing Losses

$$L_S = 365 \text{ x } V_V \text{ x } W_V \text{ x } K_E \text{ x } K_S$$

where:
L_s = Standing losses (lb/yr);
365 = Constant (days/yr);
V_V = Vapor space volume) (ft^3);
W_V = Vapor space density (lb/ft^3);
K_E = Vapor space expansion factor; and
K_S = Vented vapor saturation factor.

Calculation of Vapor Space Volume (V_V)

$$V_V = \frac{\pi}{4} \text{ x } D^2 \text{ x } H_{VO}$$

where: D = Tank diameter (ft); and
H_{VO} = Vapor space outage (ft).

$$H_{VO} = H_S - H_L + H_{RO}$$

where: H_S = Tank shell height (ft);
H_L = Liquid height (ft), (if unknown this value can be assumed to be $0.5H_s$ [i.e., this means that the tank is, on average, one-half full]); and
H_{RO} = Roof outage (ft).

$$H_{RO} = \frac{1}{3} \text{ x } H_R$$

where: H_R = Tank roof height (ft).

$$H_R = R_S \text{ x } S_R$$

where: R_S = Tank shell radius (ft); and
S_R = Cone roof slope (ft/ft) (if unknown, use a standard value of 0.0625 ft/ft [AP-42, page 7.1-12])

For Bulk Terminal Tank:

R_S = $0.5 \times D$
= $0.5 \times$ (37.6 ft) = 18.80 ft

S_R = 0.0625 ft/ft
H_R = (18.80 ft) $\times$ (0.0625 ft/ft) = 1.175 ft

H_{RO} = (1/3) $\times$ (1.175 ft) = 0.3917 ft

H_L = (0.5) $\times$ (24 ft) = 12 ft

H_{VO} = 24 - 12 + 0.3917 = 12.39 ft

V_V = (ð/4) × $(37.6\ \text{ft})^2$ × (12.39 ft) = 13,759 ft^3

Calculation of Vapor Density (W_V)

$$W_V = \frac{(M_V \text{ x } P_{VA})}{(R \text{ x } T_{LA})}$$

where:
M_V = Vapor molecular weight (lb/lb-mol);
P_{VA} = Vapor pressure at average liquid surface temperature (psia);
R = Ideal gas constant (10.731 psia-ft^3/lb-mol°R); and
T_{LA} = Daily average liquid surface temperature (°R).

$$T_{LA} = 0.44T_{AA} + 0.56T_B + 0.0079\alpha I$$

where:
T_{AA} = Daily average ambient temperature (°R);
T_B = Liquid bulk temperature (°R);
á = Tank paint solar absorption; and
I = Daily total solar insolation factor (Btu/ft^2-day) (The solar insolation factor is a function of cloud cover and latitude. Some U.S. values are presented in AP-42, Table 7.1-7.)

$$T_{AA} = \frac{(T_{AX} + T_{AN})}{2}$$

where:
T_{AX} = Daily maximum ambient temperature (°R); and
T_{AN} = Daily minimum ambient temperature (°R).

$$T_B = T_{AA} + 6a - 1$$

T_{AA} = $(T_{AN} + T_{AX})/2 = (522.17 + 541.27)/2 = 531.72{\circ}R$
T_B = $531.72{\circ}R + 6(0.54) - 1 = 533.96{\circ}R$
T_{LA} = $(0.44) \times (531.72{\circ}R) + (0.56) \times (533.96{\circ}R) + (0.0079) \times (0.54) \times (1521\ Btu/ft^2\text{-day}) = 539.47{\circ}R$

$$P_{VA} = \exp\left\{\left[0.7553 - \left(\frac{413}{T_{LA}}\right)\right] S^{0.5} \log_{10}(RVP) - \left[1.854 - \left(\frac{1042}{T_{LA}}\right)\right] S^{0.5}\right\}$$
$$\left\{+\left[\left(\frac{2416}{T_{LA}}\right) - 2.013\right] \log_{10}(RVP) - \left(\frac{8742}{T_{LA}}\right) + 15.64\right\}$$

(Per AP-42 Figure 7.1-13b)

where: T_{LA} = Average liquid surface temperature (◦R); and
RVP = Reid vapor pressure (psia).

Then for RVP 9 Gasoline:

$$P_{VA} = \exp\left\{\left[0.7553 - \left(\frac{413}{539.47_a}\right)\right] 3^{0.5} \log_{10}(9) - \left[1.854 - \left(\frac{1042}{539.47}\right)\right] 3^{0.5}\right\}$$
$$\left\{+\left[\left(\frac{2416}{539.47}\right) - 2.013\right] \log_{10}(9) - \left(\frac{8742}{539.47_a}\right) + 15.64\right\} = 6.72\ \text{psia}$$

Ideally, measured vapor pressure values should be used rather than calculated values from the above equation. The emission calculations are very sensitive to vapor pressure values (P_{VA}). Therefore, it is important to obtain the most accurate value possible.

$$W_V = \frac{\left(\frac{66.7\ \text{lb}}{\text{lb-mol}}\right)(6.72\ \text{psia})}{\left(\frac{10.731\ \text{psia-ft}^3}{\text{lb-mol-}^\circ\text{R}}\right)(539.47^\circ\ \text{R})} = 0.0774\ \text{lb/ft}^3$$

Calculation of the Vapor Expansion Factor (K_E)

$$K_E = \frac{\Delta T_V}{T_{LA}} + \frac{(\Delta P_V - \Delta P_B)}{P_A - P_{VA}}$$

where: $\text{Ä}T_V$ = Daily vapor temperature range (°R);
T_{LA} = Daily average liquid surface temperature (°R);
$\text{Ä}P_V$ = Daily vapor pressure range (psi);
$\text{Ä}P_B$ = Breather vent pressure setting range (psi);
P_A = Atmospheric pressure (normally 14.7 psia, however this may be adjusted for high elevations if necessary); and
P_{VA} = Vapor pressure at the daily average surface temperature (psia).

$\text{Ä}P_B$ = $P_{BP} - P_{BV}$

where: P_{BP} = Breather vent pressure setting
P_{BV} = Breather vent vacuum setting
$\text{Ä}P_B$ = (0.03) - (-0.03) = 0.06 psia

$\text{Ä}T_V$ = $0.72\text{Ä}T_A + 0.028\text{á}I$

where: $\text{Ä}T_A$ = Daily average ambient temperature range (°R)

$\text{Ä}T_A$ = $T_{AX} - T_{AN}$

where: T_{AX} = Daily maximum ambient temperature (°R); and
T_{AN} = Daily minimum ambient temperature (°R).
$\text{Ä}T_A$ = 541.27 - 522.17 = 19.1°R

$\text{Ä}T_V$ = (0.72) × (19.1 °R) + (0.028) × (0.54) × (1521 Btu/ft^2-day) = 36.75 °R
T_{LA} = 539.47°R (previously calculated)
$\text{Ä}P_V$ = $P_{VX} - P_{VN}$

(P_{VX} and P_{VN} estimated using same equation as P_{VA} except using T_{LX} and T_{LV} rather than T_{LA})

where: P_{VX} = vapor pressure at the daily maximum liquid surface temp (psia); and
P_{VN} = vapor pressure at the daily minimum liquid surface temp (psia).

$$P_{VX} = \exp\left\{\left[0.7553 - \left(\frac{413}{T_{LX}}\right)\right] S^{0.5} \log_{10}(RVP) - \left[1.854 - \left(\frac{1042}{T_{LX}}\right)\right] S^{0.5}\right\}$$

$$\left\{+\left[\left(\frac{2416}{T_{LX}}\right) - 2.013\right] \log_{10}(RVP) - \left(\frac{8742}{T_{LX}}\right) + 15.64\right\}$$

$$P_{VN} = \exp\left\{\left[0.7553 - \left(\frac{413}{T_{LN}}\right)\right] S^{0.5} \log_{10}(RVP) - \left[1.854 - \left(\frac{1042}{T_{LN}}\right)\right] S^{0.5}\right\}$$

$$\left\{+\left[\left(\frac{2416}{T_{LN}}\right) - 2.013\right] \log_{10}(RVP) - \left(\frac{8742}{T_{LN}}\right) + 15.64\right\}$$

T_{LX} = Maximum liquid surface temperature
= $T_{LA} + 0.25\ (ÄT_V) = 539.47 + 0.25\ (36.75) = 548.66°R$
T_{LN} = Minimum liquid surface temperature
= $T_{LA} - 0.25\ (ÄT_V) = 539.47 - 0.25\ (36.75) = 530.28°R$

Thus, for RVP 9 Gasoline:

$$P_{VX} = \exp\left\{\left[0.7553 - \left(\frac{413}{548.66_a}\right)\right] 3^{0.5} \log_{10}(9) - \left[1.854 - \left(\frac{1042}{548.66}\right)\right] 3^{0.5}\right\}$$

$$\left\{+\left[\left(\frac{2416}{548.66_a}\right) - 2.013\right] \log_{10}(9) - \left(\frac{8742}{548.66}\right) + 15.64\right\} = 7.93 \text{ psia}$$

$$P_{VN} = \exp\left\{\left[0.7553 - \left(\frac{413}{530.28_a}\right)\right] 3^{0.5} \log_{10}(9) - \left[1.854 - \left(\frac{1042}{530.28}\right)\right] 3^{0.5}\right\}$$

$$\left\{+\left[\left(\frac{2416}{530.28_a}\right) - 2.013\right] \log_{10}(9) - \left(\frac{8742}{530.28}\right) + 15.64\right\} = 5.67 \text{ psia}$$

$ÄP_V$ = $P_{VX} - P_{VN}$
= 7.93 - 5.67
= 2.26 psia

$$K_E = \frac{36.75°\ R}{539.47°\ R} + \frac{(2.26 \text{ psia} - 0.06 \text{ psia})}{(14.7 \text{ psia} - 6.72 \text{ psia})} = 0.3438$$

Calculation of Vapor Saturation Factor (K_S)

$$K_S = \frac{1}{1 + 0.053\, P_{VA}\, H_{VO}}$$

where: P_{VA} = Vapor pressure at daily average liquid surface temp (psia); and

H_{VO} = Vapor space outage (ft).

For RVP 9 Gasoline:

P_{VA} = 6.72 psia; (previously calculated)
H_{VO} = 12.39 ft (previously calculated)

$$K_s = \frac{1}{1 + (0.053)(6.72)(12.39)} = 0.1847$$

Solving for standing losses:

L_S = $365 \times V_V \times W_V \times K_E \times K_S$

V_V = 13,759 ft^3
W_V = 0.0774 lb/ft^3
K_E = 0.3187
K_S = 0.1847
L_S = $(365) \times (13{,}759) \times (0.0774) \times (0.3438) \times (0.1847)$
= 24,683 lb/yr

2. Calculation of Uncontrolled Working Losses

L_W = 0.0010 ´ M_V ´ P_{VA} ´ Q ´ K_N ´ K_P

where: M_V = Vapor molecular weight (lb/mol);
P_{VA} = Vapor pressure at the daily average liquid surface temp (psia);
Q = Annual net throughput (bbl/yr);
K_N = Turnover factor; (For N>36, $K_N = [180 + N]/6N$; For $N \leq 36$, $K_N = 1$) (AP-42, page 7.1-18); and
K_P = working loss product factor (0.75 for crude oils, 1.0 for all other organic liquids; AP-42, page 7.1-18)

$$N = \frac{5.614\,Q}{V_{LX}}$$

where: N = Number of turnovers per year;
5.614 = Conversion factor from bbl to ft^3;
Q = Annual net throughput (bbl/yr); and
V_{LX} = Tank maximum liquid volume (ft^3)

For RVP 9 Gasoline:

M_V = 66.7 lb/lb-mol
P_{VA} = 6.72 psia
Q = 2.642×10^6 gals/yr = 62,905 bbls/yr
V_{LX} = 210,000 gallons = 28,066 ft^3

$$N = \frac{5.614\,(62{,}905\ \text{bbl/yr})}{(28{,}066\ \text{ft}^3)} = 12.58\ /\text{yr}$$

Therefore, K_N = 1.0

K_P = 1.0

L_W = $(0.0010) \times (66.7$ lb/lb-mol$) \times (6.72$ psia$) \times (62{,}905$ bbls/yr$) \times (1.0) \times (1.0)$
= 28,196 lb/yr

3. Calculation of Total Uncontrolled Losses

L_{Total} = $L_S + L_W$ = 24,683 lb/yr + 28,196 lb/yr = 52,879 lb/yr
= 23,981 kg/yr = 24.0 Mg/yr

Example 4a - Supplemental Information
Estimating Individual Species

Introduction

In some air quality applications, estimates of individual species are required. For some source categories, sampling for individual chemical species is performed. However, when this sampling is impractical or too expensive, alternative methods must be used. For tank emissions, Raoult's Law provides a useful method for estimating emissions from individual species.

Problem Statement

Using Raoult's Law, estimate cyclohexane emissions from the bulk terminal tank standing and working losses due to storage and pumping of RVP 9 gasoline.

Available Information

As estimated earlier, the bulk liquid temperature, (T_{LA}), is 80 ^{o}F. The bulk terminal tank is a fixed roof AST. After analysis of the RVP 9 gasoline, it is determined that the liquid gasoline is 0.58 wt% cyclohexane ($x_{liq,c}$ = 0.0058).

Solution

To determine the speciated emissions from tank standing and working losses, the following steps are necessary:

1. Determine the liquid phase speciation of gasoline in the tank.
2. Find the saturated vapor pressure of each species of concern at the bulk liquid temperature.
3. Determine the true vapor pressure of the mixture at the bulk liquid temperature.
4. Using Raoult's Law, determine the vapor phase speciation of the

gasoline in the tank.

5. Calculate the chemical-specific emissions using above steps and results from calculations such as those presented in Problem 4a.

Raoult's Law can be used to determine the vapor phase mole fraction of a particular constituent or species in a mixture based on the liquid phase mole fraction. It is assumed that the vapor is an ideal gas and the liquid is an ideal solution. It also assumed that both are well-mixed and in equilibrium with each other. Simply stated, if the liquid phase composition in a tank is known, then the vapor phase composition in the tank's vapor space can be calculated. The assumptions of ideal behavior and vapor/liquid equilibrium are often not strictly enforced since they are rarely achieved in the real world, and often Raoult's law or another equation of state is the only way to determine vapor phase compositions without actually sampling the tank to measure them.

For a mixture of N species, Raoult's law is expressed as:

$$Y_iP = X_iP_i^{sat}; \qquad i = 1, 2, 3,...,N$$

where:

Y_i = Vapor phase mole fraction of component i;

P = True vapor pressure of the mixture at the bulk liquid temperature;

X_i = Liquid phase mole fraction of component i; and

P_i^{sat} = Saturated vapor pressure of species i at the bulk liquid temperature.

Also, $x_{vap,c}$ = the mass fraction of cyclohexane in the vapor phase

Note that extra steps may be required to convert mass fractions to mole fractions. The above equation is written in terms of mole fractions, however data are commonly available as mass fractions only.

Given:

P_g = True vapor pressure of gasoline = 6.72 psia at 80 °F (previously calculated value for P_{VA}; see Page 4-7)

$P_{cyclohexane}^{sat}$ = Saturated vapor pressure of cyclohexane = 2.069 psia (AP-42, Table 7.1-3)

Rearranging Raoult's Law gives:

$$Y_i = \frac{X_i P_i^{Sat}}{P}$$

Before using this equation, the mass fraction in the liquid phase must be converted to a mole fraction. This is done as follows, using the molecular weights:

MW_g = Molecular weight of liquid gasoline = 100 lb/lb-mol (This is typically obtained from manufacturers or other published values.)

MW_v = Molecular weight of gasoline vapor = 66.7 lb/lb-mol (extrapolated from AP-42, Table 7.1-2)

MW_c = Molecular weight of cyclohexane = 84.16 lb/lb-mol (AP-42, Table 7.1-3)

$$X_c \text{ (mole fraction of cyclohexane in liquid phase)} = \frac{X_{liq,c} MW_g}{MW_c} = \frac{(0.0058)\,(100)}{84.16} = 0.0069$$

We need the, $x_{vap,c}$, the mass fraction of cyclohexane in the vapor phase. Hence, converting as above:

$$X_{vap,c} = \frac{Y_c MW_c}{MW_v} = \frac{(0.00212)(84.16)}{66.7}$$

$$= 0.00267 \text{ lb cyclohexane / lb gasoline vapor}$$

Now, calculate cyclohexane emissions from standing and working losses from the aboveground storage tanks.

L_{Total} = total standing and working losses

= 23,164 kg/yr

$$L_{cyclohexane} = \left(\frac{23{,}164 \text{ kg gasoline vapor}}{\text{yr}}\right)\left(\frac{0.00267 \text{ kg cyclohexane}}{1 \text{ kg gasoline vapor}}\right)$$

$$= 62 \text{ kg cyclohexane/yr}$$

Example 4a - Supplemental Information
Comparison of Raoult's Law with Other Methods

Problem Statement

Compare results obtained using Raoult's Law to measure vapor composition with other techniques.

Solution

Table 4-1 (summer blend gasoline) presents an array of measured and predicted results for the concentrations of several chemicals in vapor and lquid phase gasoline. The results presented here are unrelated to the information presented in the previous Supplemental Information section. As the data clearly show, Raoult's Law predicts both more precise and accurate vapor phase concentrations than either the Peng-Robinson or Redlich-Kwong-Soave equations of state. Equations of state relate the intensive thermodynamic properties (e.g., temperature, pressure, or specific volume) of any substance. Information on the Peng-Robinson or Redlich-Kwong-Soave equations of state can be found in standard chemical engineering thermodynamics textbooks (i.e., Smith and Van Ness, 1987). In addition, Raoult's Law is much easier to use than either of the equations of state. The relative errors shown in the tables are also within reason for the purposes of emissions estimation.

Table 4-1

Summary of Results for Summer Blend Unleaded Gasoline

Toxic Species	Measured		Predicted Vapor Concentration		
	Liquid wt%	Vapor wt%	Raoult[a]	P-R EOS[b]	R-K-S EOS[c]
Cyclohexane	0.58	0.20	0.25	0.27	0.26
Benzene	1.93	0.73	0.83	1.05	0.99
Toluene	10.32	0.81	1.29	1.57	1.45
O-Xylene	3.39	0.05	0.00	0.00	0.00
Isomers of Xylene	9.16	0.21	0.31	0.33	0.30
Ethylbenzene	2.05	0.05	0.00	0.00	0.00
Isopropylbenzene	0.19	—	0.00	0.00	0.00
1,2,4-Trimethylbenzene	3.52	0.04	0.00	0.00	0.00
Molecular Weight of Vapor		67.6	67.0	67.4	67.2
Predicted Vapor Pressure			3.92	4.04	4.00
Relative Concentration Errors:					
Average for all Species			4.0%	10.4%	7.3%
Average for Toxics			22.7%	36.5%	29.6%
Absolute Value for all Species			16.7%	22.2%	19.5%
Absolute Value for Toxics			22.7%	36.5%	29.6%

Notes: [a] Raoult = Raoult's Law
[b] P-R EOS = Peng-Robinson equation of state
[c] R-K-S EOS = Redlich-Kwong-Soave equation of state

Example 4b
Fugitive (Equipment Leak) Emissions

Problem Statement

Estimate fugitive TOG emissions from equipment leaks at the bulk terminal. Example 4a addressed breathing and working losses associated with the aboveground storage tank (AST) at the bulk terminal. This problem accounts for leaks of hydrocarbon vapors from various types of process equipment.

Available Information

The hypothetical gasoline bulk terminal contains the following equipment types: 520 valves, 230 pump seals, 180 flanges, 120 connectors, and 70 other equipment types. Equipment leak emission control techniques have not been implemented at the bulk terminal.

Solution

There are four approaches that are used to estimate fugitive TOG emissions. These approaches, in order of increasing refinement, are:

- Average Emission Factor approach;
- Screening Ranges approach;
- EPA Correlation approach; and
- Unit-Specific Correlation approach.

These approaches are detailed in the U.S. EPA's Protocol Document (U.S. EPA, 1995b). For a facility with a relatively small number of equipment, such as a bulk terminal, usually only the first two approaches would be used. For more complex facilities, such as refineries, the correlation approaches are often utilized. Both the Average Emission

Factor and Screening Ranges approaches require equipment counts. However, the Screening Ranges approach requires some additional information. Only the Average Emission Factor and Screening Ranges approaches will be used in this problem.

Average Emission Factor Approach

Using the Average Emission Factor approach, total emissions for a specific equipment type can be calculated using the following equation:

$$E_e = N_e \times EF_e \times t_e$$

where:
E_e = Uncontrolled fugitive emissions (kg/yr) for equipment type e;
N_e = Number of equipment type e;
EF_e = Uncontrolled emission factor for equipment type e (kg/hr); and
t_e = Annual time of process (hr/yr) (assumed to be 8,760 hours per year).

The average emission factors presented in Table 4-2 for gasoline stored at bulk terminals are taken from Table 2-3 of the Protocol Document. Other average emission factors also exist for refineries, oil and gas production operations, and synthetic organic chemical manufacturing operations. These other operations will have average emission factors for pressure relief valves, open-ended lines, and sampling connections.

Table 4-2

Average Emission Factors

Equipment Type	Emission Factor (kg/hr)
Valves	0.000043
Pump Seals	0.00054
Fittings (Connectors and Flanges)	0.000008
Other Equipment	0.00013

The emissions for each equipment type are calculated below.

$$E_{\text{Valves}} = 520 \text{ valves } \times 0.000043 \text{ kg/hr} \times 8{,}760 \text{ hr/yr} = 195.9 \text{ kg/yr}$$

$$E_{\text{Pump Seals}} = 230 \text{ pump seals } \times 0.00054 \text{ kg/hr} \times 8{,}760 \text{ hr/yr} = 1{,}088 \text{ kg/yr}$$

$$E_{\text{Flanges}} = 180 \text{ flanges } \times 0.000008 \text{ kg/hr} \times 8{,}760 \text{ hr/yr} = 12.6 \text{ kg/yr}$$

$$E_{\text{Connectors}} = 120 \text{ connectors } \times 0.000008 \text{ kg/hr} \times 8{,}760 \text{ hr/yr} = 8.4 \text{ kg/yr}$$

$$E_{\text{Other}} = 70 \text{ other equipment } \times 0.00013 \text{ kg/hr} \times 8{,}760 \text{ hr/yr} = 79.7 \text{ kg/yr}$$

The total fugitive emissions are then summed up as shown below.

$$E_{\text{Total}} = 195.9 + 1{,}088 + 12.6 + 8.4 + 79.7 = 1{,}385 \text{ kg/yr} = 1.4 \text{ Mg/yr of TOG}$$

Screening Ranges Approach

If the Screening Ranges approach is used, then each equipment component is assigned either a "leak" or "no-leak" designation. This assignment is done by screening each component. Screening is done by measuring the TOG concentration in the air right next to the component. If the screening value is ≥10,000 ppmv, then the component is given a "leak" designation. Conversely, if the screening value is <10,000 ppmv, then the component is given a "no-leak" designation. Emissions from "leaking" components are estimated using "leaking" emission factors; emissions from "non-leaking" components are estimated using "non-leaking" emission factors. In spite of their designation, the "non-leaking" components are actually leaking -- they just are leaking at a lesser rate than the "leaking" components.

Using the Screening Ranges approach, total emissions for a specific type of equipment can be calculated using the following equation:

$$E_e = ([N_L \times EF_L] + [N_{NL} \times EF_{NL}]) \times t_e$$

where: E_e = Uncontrolled fugitive emissions (kg/yr) for equipment type e;
N_L = Number of "leaking" equipment components;
EF_L = Uncontrolled emission factor for "leaking" equipment components (kg/hr);

N_{NL} = Number of "non-leaking" equipment components;
EF_{NL} = Uncontrolled emission factor for "non-leaking" equipment components (kg/hr); and
t_e = Annual time of process (hr/yr) (assumed to be 8,760 hours per year).

The screening ranges emission factors presented in Table 4-3 for gasoline stored at bulk terminals are taken from Table 2-7 of the Protocol Document. Like the average emission factors presented earlier, screening ranges emission factors also exist for refineries, oil and gas production operations, and synthetic organic chemical manufacturing operations. There are also screening ranges emission factors for pressure relief valves, open-ended lines, and sampling connections.

Table 4-3

Screening Range Emission Factors

Equipment Type	"Leaking" Emission Factor (³ 10,000 ppmv) (kg/hr)	"Non-Leaking" Emission Factor (<10,000 ppmv) (kg/hr)
Valves	0.023	0.000015
Pump Seals	0.077	0.00024
Fittings (Connectors and Flanges)	0.0065	0.0000072
Other Equipment	0.034	0.000024

After screening, it is determined that the following pieces of equipment are "leaking" (i.e., screening value $\geq$ 10,000 ppmv): 1 valve, 2 flanges, 2 connectors, and 1 piece of other equipment. The TOG emissions for each equipment type are then calculated as follows.

$$E_{\text{Valves}} = ([1 \text{ valve} \times 0.023 \text{ kg/hr}] + [519 \text{ valves} \times 0.000015 \text{ kg/hr}]) \times 8{,}760 \text{ hr/yr} = 270 \text{ kg/yr}$$

$$E_{\text{Pump Seals}} = ([0 \text{ pump seals} \times 0.077 \text{ kg/hr}] + [230 \text{ pump seals} \times 0.00024 \text{ kg/hr}]) \times 8{,}760 \text{ hr/yr} = 484 \text{ kg/yr}$$

$$E_{\text{Flanges}} = ([2 \text{ flanges} \times 0.0065 \text{ kg/hr}] + [178 \text{ flanges} \times 0.0000072 \text{ kg/hr}]) \times 8{,}760 \text{ hr/yr} = 125 \text{ kg/yr}$$

$$E_{\text{Connectors}} = ([2 \text{ connectors} \times 0.0065 \text{ kg/hr}] + [118 \text{ connectors} \times 0.0000072 \text{ kg/hr}]) \times 8{,}760 \text{ hr/yr} = 121 \text{ kg/yr}$$

$$E_{\text{Other Equipment}} = ([1 \text{ other equipment} \times 0.034 \text{ kg/hr}] + [69 \text{ other equipment} \times 0.000024 \text{ kg/hr}] \times 8{,}760 \text{ hr/yr} = 312 \text{ kg/yr}$$

The total fugitive emissions are then summed up as shown below.

$$E_{\text{Total}} = 270 + 484 + 125 + 121 + 312 = 1{,}312 \text{ kg/yr} = 1.3 \text{ Mg/yr}$$

Although this sample problem is hypothetical, it shows that a more refined approach might produce significantly different results than a more simplified approach. In general, the Screening Ranges approach will give lower results than the Average Emission Factor approach. However, the increased data collection requirements associated with the more refined approaches must be weighed against the need for more accurate results.

Example 4c
Tank Truck Loading Emissions

Problem Statement

Estimate TOG emissions from gasoline tank truck loading at the bulk terminal. Tank trucks are used to transport gasoline from the bulk terminal to the individual gasoline stations. This problem addresses the actual loading of the tank trucks.

Available Information

The total amount of gasoline loaded at the bulk terminal into gasoline tank trucks is 10,000,000 liters per year. All of the gasoline tank trucks transporting product to the four gasoline stations are loaded using dedicated normal service splash loading. For splash loading, the fill pipe that dispenses gasoline is lowered only part way into the cargo tank. Emissions are caused by the resulting "splashing" and turbulence. The product temperature of all delivered gasoline and ambient temperature is 80 °F. There is not any vapor balance control used.

Solution

The quantity of uncontrolled emissions from tank truck loading is dependent upon whether the tank truck is equipped for submerged, splash, or vapor balance filling. Uncontrolled emissions are also dependent upon the vapor pressure of the unloaded gasoline, the molecular weight of the vapors expelled from the cargo tank, and the temperature at which the gasoline is loaded. In addition, vapor balance filling, which returns vapors displaced from the truck cargo tank back to a vapor recovery unit at the bulk terminal, will have a control efficiency ranging from 90 to over 99 percent. The following equation can be used to estimate uncontrolled loading losses (AP-42, Section 5.2.2.1.1).

$$EF_{UL} = 12.46 \text{ x } \frac{SPM}{T}$$

where:
EF_{UL} = Uncontrolled loading loss emission factor (lb/1000 gal);
S = Saturation factor;
P = True vapor pressure of gasoline (pounds per square inch absolute [psia]);
M = Molecular weight of vapors (lb/lb-mole); and
T = Temperature of loaded gasoline (°R).

Saturation factors (S) for various modes of operation, which represent how close the expelled vapor comes to saturation, are presented in Table 4-4

Table 4-4

Saturation Factors (S) for Calculating Petroleum Liquid Loading Losses

Type of Service	Splash Loading	Submerged Loading
Clean Cargo Tank	1.45	0.50
Dedicated Normal Service	1.45	0.60
Dedicated Vapor Balance Service	1.00	1.00

True vapor pressures and molecular weights of gasoline vapors can be derived from Figure 7.1-5, Figure 7.1-6, and Table 7.1-2 of AP-42. Excerpted information from Table 7.1-2 is presented in Table 4-5.

Table 4-5

Physical Properties of Gasoline

Gasoline RVP	Vapor Molecular Weight at 60°F (lb/lb-mole)	True Vapor Pressure (psi)						
		40 °F	50 °F	60 °F	70 °F	80 °F	90 °F	100 °F
13 psia	62	4.7	5.7	6.9	8.3	9.9	11.7	13.8
10 psia	66	3.4	4.2	5.2	6.2	7.4	8.8	10.5
7 psia	68	2.3	2.9	3.5	4.3	5.2	6.2	7.4

The vapor molecular weight and true vapor pressure for RVP 9 gasoline values must be interpolated from values presented in the table above. This interpolation is shown below.

$$VMW_i = VMW_x + \left(\frac{RVP_x - RVP_i}{RVP_x - RVP_n} \right) \left(VMW_n - VMW_x \right)$$

$$TVP_i = TVP_x - \left(\frac{RVP_x - RVP_i}{RVP_x - RVP_n} \right) \left(TVP_x - TVP_n \right)$$

where: VMW_i = Vapor molecular weight interpolated to RVP 9;
VMW_x = Vapor molecular weight at maximum RVP (10) in interpolation range;
VMW_n = Vapor molecular weight at minimum RVP (7) in interpolation range;
RVP_i = Interpolated RVP (9);
RVP_x = Maximum RVP (10);
RVP_n = Minimum RVP (7);
TVP_i = True vapor pressure interpolated to RVP 9;
TVP_x = True vapor pressure at maximum RVP (10); and
TVP_u = True vapor pressure at minimum RVP (7).

$$VMW_9 = 66 + \left(\frac{10 - 9}{10 - 7} \right) \left(68 - 66 \right) = 66.7 \text{ lb/lb- mole}$$

$$TVP_9 = 7.4 - \left(\frac{10 - 9}{10 - 7} \right) \left(7.4 - 5.2 \right) = 6.7 \text{ psi}$$

The saturation factor for dedicated normal service splash loading is 1.45. Finally, converting the gasoline temperature from Fahrenheit degrees to Rankine degrees gives a temperature of 540 °R.

Thus, the uncontrolled loading emission factors are calculated below.

$$EF_{UL(RVP9)} = \frac{12.46 \text{ x } 1.45 \text{ x } 6.7 \text{ x } 66.7}{540} = 14.95 \text{ lb/ } 1000 \text{ gal}$$

Controlled loading emission factors are then calculated using the following equation.

$$EF_{CL} = (1 - CE) \text{ x } EF_{UL}$$

where:
EF_{CL} = Controlled loading loss emission factor (lb/1000 gal);
CE = Vapor control efficiency; and
EF_{UL} = Uncontrolled loading loss emission factor (lb/1000 gal).

However, for this problem, vapor control is not utilized during tank truck loading, so controlled loading loss emission factors need not be calculated.

Total tank truck loading losses can be estimated by the following equation.

$$\text{Emissions} = \sum_{i=1}^{n} EF_{UL,CL} \text{ X } \text{Fuel}_i$$

where:
Emissions = Total tank truck loading emissions (kg/yr);
n = Number of different types of operation modes and fuel types;
$EF_{UL,CL}$ = Uncontrolled or controlled tank truck loading emission factor for operation mode or fuel type i (mg/liter); and
Fuel_i = Annual amount of fuel delivered for each operation mode or fuel type i (liters/yr).

Converting the loading emission factors from units of lb/1000 gal to units of mg/liter:

$$EF_{UL(RVP\,9)} = \left(\frac{14.95\text{ lb}}{1000\text{ gal}}\right)\left(\frac{453.6\text{ g}}{1\text{ lb}}\right)\left(\frac{1000\text{ mg}}{1\text{ g}}\right)\left(\frac{1\text{ gal}}{3.785\text{ liter}}\right) = 1{,}792\text{ mg liter}$$

$$\text{Emissions} = \frac{1{,}792\text{ mg}}{\text{liter}} \text{ x } (1 \text{ x } 10^{7}\text{ liters}) = 17{,}920\text{ kg/yr} = 17.9\text{ Mg/yr}$$

Example 4d
Tank Truck Transit Emissions

Problem Statement

After gasoline is loaded into tank trucks, it is transported to gasoline stations. Although tank trucks do have enclosed cargo tanks, emissions do occur while in transit. This problem focuses on the emissions that occur while the tank truck is in transit.

Estimate TOG emissions from gasoline tank trucks in transit from the bulk terminal to PEMEX gasoline stations A, B, C, and D.

Available Information

The following amounts of gasoline are transported to the four gasoline stations for sale:

Gasoline Station	Gasoline Dispensed (liters/yr)
A	4,000,000
B	2,500,000
C	2,000,000
D	1,500,000

Solution

The quantity of emissions from gasoline tank trucks is dependent upon the extent of venting that occurs during transit, which in turn depends upon the vapor tightness of the tank, the pressure relief valve settings, the pressure in the tank at the start of the trip, the vapor pressure of the fuel being transported, and the degree of fuel vapor saturation of the space in the tank. The emissions are not directly proportional to the time spent in transit.

AP-42, Table 5.2-5 presents transit loss emission factors for gasoline tank trucks both loaded with product and returning with vapors for RVP 10 gasoline. These emission factors are presented in Table 4-6 for both "typical" and "extreme" transit conditions. Extreme conditions refer to the unlikely event that all of the determining factors listed above combine to cause maximum emissions.

Table 4-6
Total Uncontrolled Emission Factors for Gasoline Tank Trucks

Transit Conditions	Loaded with product (mg/liter of gasoline)	Returning with vapor (mg/liter of gasoline)
Typical	0 - 1.0	0 - 13.0
Extreme	0 - 9.0	0 - 44.0

Total transit loss emissions will include both the trip from the bulk terminal to the gas stations (loaded with product) and the return trip from the gas stations back to the bulk terminal (empty tanks). Total transit loss emissions can be estimated by the following equation.

$$\text{Emissions} = \sum_{i=1}^{n} ([EF_{l,c} + EF_{r,c}] \text{ x } Fuel_i)$$

where: Emissions = Total refueling emissions (kg/yr);
n = Number of gasoline stations;
$EF_{l,c}$ = "Loaded with product" transit loss emission factor for gasoline transported to station i under transit conditions c (mg/liter);
$EF_{r,c}$ = "Returning with vapor" transit loss emission factor for gasoline transported to station i under transit conditions c (mg/liter); and
$Fuel_i$ = Annual amount of fuel dispensed from gasoline station i (liters/yr).

Assuming that gasoline transported to stations A, B, and C is transported under "typical" conditions and gasoline transported to stations D is transported under "extreme" conditions, estimate overall transit emissions. For each emission factor, assume that the midpoint of the range listed in the table above provides a reasonable estimate.

$$\text{Emissions} = ([0.5 + 6.5]\ \text{mg/liter}) \times ([4 \times 10^6] + [2.5 \times 10^6] + [2 \times 10^6]\ \text{liters})$$

$$+ ([4.5 + 22]\ \text{mg/liter}) \times (1.5 \times 10^6\ \text{liters})$$

$$= 59.5\ \text{kg/yr} + 39.75\ \text{kg/yr}$$

$$= 99\ \text{kg/yr}$$

Note that the amount of gasoline sold in this problem is equal to the amount of gasoline transported. This, however, is not always the case. If transit emissions are estimated for the transport of gasoline from a refinery to a bulk terminal and then from the bulk terminal to gasoline stations, then the transit emissions would be twice as much because the gasoline is "transported" twice. Gasoline may also be transported through an inventory domain even though its origin and/or destination may lie outside of the inventory domain.

Example 4e
Underground Tank Filling Emissions

Problem Statement

Estimate TOG emissions from gasoline tank truck unloading at gasoline stations A, B, C, and D. After tank trucks arrive at the gasoline stations, they unload their cargo into the underground storage tanks at the gasoline station. This unloading is similar to the loading of the tank trucks at the bulk terminal.

Available Information

The following amounts of gasoline are transported to the four gasoline stations for sale:

Gasoline Station	Gasoline Delivered (liters/yr)
A	4,000,000
B	2,500,000
C	2,000,000
D	1,500,000

The following modes of operation are in place at the four gasoline stations:

Gasoline Station	Mode of Operation
A	Submerged loading - normal service
B	Submerged loading - vapor balance service
C	Splash loading - normal service
D	Splash loading - normal service

For splash loading, the fill pipe that dispenses gasoline is lowered only part way into the storage tank. Emissions are caused by the resulting "splashing" and turbulence. For submerged loading, the fill pipe extends nearly to the bottom of the storage tank. Because of this, liquid turbulence and the resulting emissions are reduced relative to splash loading. Vapor balance service retrieves the vapors displaced during gasoline unloading and transports the vapors back to the tank truck.

Solution

The quantity of emissions from underground tank filling is dependent upon whether the gasoline station tank is equipped for submerged, splash, or submerged vapor balance filling. Vapor balance filling, which returns vapors displaced from the gasoline station tank back to the tank truck, will have a control efficiency ranging from 93 to 100 percent relative to uncontrolled emissions. Table 4-7 shows the emission factors for underground tank filling (AP-42, Table 5.2-7).

Table 4-7

Emission Factors for Underground Tank Filling at Gasoline Stations

Type of Operation	Emission Factor (mg/liter throughput)
Submerged	880
Splash	1,380
Balanced Submerged	40

Total underground tank filling emissions can be estimated by the following equation.

$$\text{Emissions} = \sum_{i=1}^{n} EF_i \text{ X } Fuel_i$$

where: Emissions = Total underground tank filling emissions (kg/yr);
EF_i = Underground tank filling emission factor for operation type i (mg/liter); and
$Fuel_i$ = Annual amount of fuel delivered for operation type i (liters/yr).

$$Emissions = (880\,[4 \times 10^6] + 40\,[2.5 \times 10^6] + 1{,}380\,[2 \times 10^6] + 1{,}380\,[1.5 \times 10^6])$$

$$\begin{aligned} Emissions = 3{,}520 + 100 + 2{,}760 + 2{,}070 &= 8{,}450 \text{ kg/yr} \\ &= 8.45 \text{ Mg/yr} \end{aligned}$$

Example 4f
Underground Tank Breathing Emissions

Problem Statement

Estimate TOG emissions from underground tank breathing at gasoline stations A, B, C, and D.

Available Information

The following amounts of gasoline were sold at the four gasoline stations in the region:

Gasoline Station	Gasoline Dispensed (liters/yr)
A	4,000,000
B	2,500,000
C	2,000,000
D	1,500,000
Total	10,000,000

Solution

The quantity of emissions from underground breathing losses is mainly dependent upon evaporation and barometric pressure changes. Also, the frequency of gasoline withdrawal from the tank also has an effect on the emissions quantity because fresh air brought into the tank will enhance the evaporation rate. An average breathing emission rate for U.S. gasoline stations has been estimated to be 120 mg/liter of gasoline throughput (AP-42, Table 5.2-7). The tank equations presented in AP-42, Section 7 could be used to estimate emissions from underground gasoline storage tanks at gasoline stations. However, the large number of gasoline station tanks usually precludes the use of these equations. Total underground breathing losses can be estimated using the following equation with the average breathing emission rate.

$$\text{Emissions} = \sum_{i=1}^{n} EF_{UB} \text{ X } Fuel_i$$

where:
Emissions = Total underground tank breathing emissions (kg/yr);
n = Number of gasoline stations;
EF_{UB} = Underground breathing loss emission factor for gasoline station i (mg/liter) [U.S. average value - 120 mg/liter];
$Fuel_i$ = Annual amount of fuel delivered to gasoline station i (liters/yr).

$$\text{Emissions} = (120[4 \text{ x } 10^6] + 120[2.5 \text{ x } 10^6] + 120[2 \text{ x } 10^6] + 120[1.5 \text{ x } 10^6])$$

$$\text{Emissions} = 480 + 300 + 240 + 180 = 1{,}200 \text{ kg/yr} = 1.2 \text{ Mg/yr}$$

Example 4g
Vehicle Refueling Emissions

Problem Statement

Estimate TOG emissions from vehicle refueling at gasoline stations A, B, C, and D. Refueling emissions consist of both vapors displaced from the vehicle tank by dispensed gasoline, as well as gasoline spillage.

Available Information

The four gasoline stations in the distribution system dispense the following quantities of RVP 9 of gasoline:

Gasoline Station	Gasoline Dispensed (liters/yr)
A	4,000,000
B	2,500,000
C	2,000,000
D	1,500,000

The temperature of the dispensed fuel is 24 °C (75 °F) and the temperature of the fuel in the vehicle tank is about 30 °C (86 °F). Stations A and C are uncontrolled; stations B and D are controlled using vapor control which transfers displaced vapors from the vehicle fuel tank back to the underground storage tank vapor space.

Solution

The quantity of emissions from displaced vapors depends upon the gasoline temperature, vehicle tank temperature, gasoline Reid vapor pressure (RVP), and dispensing rate. The following equation can be used to estimate uncontrolled displacement losses based upon the factors mentioned above (AP-42, Section 5.2.2.3).

$$EF_u = 264.2[(-5.909) - 0.0949(\Delta T) + 0.0884(T_D) + 0.485(RVP)]$$

where:
EF_u = Uncontrolled TOG emission factor for vehicle refueling (mg/liter);
ÄT = Difference between temperature of fuel in vehicle tank and temperature of dispensed fuel (°F);
T_D = Temperature of dispensed fuel (°F); and
RVP = Reid vapor pressure (psia).

The uncontrolled displacement loss emission factors for each gas station are calculated below.

$$EF_u = 264.2[(-5.909) - 0.0949(11°) + 0.0884(75°) + 0.485(9)] = 1{,}068 \text{ mg/liter}$$

Controlled displacement losses must be estimated for stations B and D. AP-42 indicates that typical U.S. vapor control efficiencies range from 88-92% (AP-42, Section 5.2.2.3). The equation for calculating a controlled displacement loss factor is shown below.

$$EF_c = (1 - CE) \text{ x } EF_u$$

where:
EF_c = Controlled TOG emission factor for vehicle refueling (mg/liter);
CE = Vapor control efficiency; and
EF_u = Uncontrolled TOG emission factor for vehicle refueling (mg/liter).

Assuming that the Stage II vapor control efficiency is 88%, then the controlled displacement loss emission factors for stations B and D are calculated as follows.

$$EF_{cB,\,cD} = (1 - 0.88) \text{ x } 1{,}068 \text{ mg/liter} = 128 \text{ mg/liter}$$

In addition to displacement losses, spillage losses occur during vehicle refueling. The U.S. spillage emission factor (EF_s) has been estimated to be 80 mg/liter of fuel dispensed. The actual amount of spillage is dependent upon several factors such as gasoline station business characteristics, tank configuration, and operator techniques.

Total refueling losses can be estimated by the following equation.

$$\text{Emissions} = \sum_{i=1}^{n} ([EF_{u,c} + EF_{s}] \text{ x } Fuel_{i})$$

where:

Emissions = Total refueling emissions (kg/yr);
n = Number of gasoline stations;
$EF_{u,c}$ = Uncontrolled or controlled displacement loss emission factor for gasoline station i (mg/liter);
EF_{s} = Spillage emission factor for gasoline station i (mg/liter); and
$Fuel_{i}$ = Annual amount of fuel dispensed from gasoline station i (liters/yr).

Assuming that the U.S. spillage emission factor of 80 mg/liter is appropriate for Mexico, estimate overall refueling emissions.

$$\text{Emissions} = ([1{,}068 + 80][4 \text{ x } 10^{6}] + [128 + 80][2.5 \text{ x } 10^{6}] + [1{,}068 + 80][2 \text{ x } 10^{6}] + [128 + 80][1.5 \text{ x } 10^{6}])$$

Emissions = 4,592 + 520 + 2,296 + 312 = 7,720 kg/yr
= 7.72 Mg/yr

Example 4 - Summary

Emission estimates from the seven sources within a typical gasoline distribution system have been shown in Examples 4a through 4g. These hypothetical emission estimates are presented in Table 4-8.

Table 4-8

Summary of Emissions from Gasoline Distribution System

Emission Source	Emission Estimate (kg/yr)	Percentage of Total Emissions
Aboveground Bulk Storage Tank (4a)	23,981	39.5%
Fugitive (Equipment Leak) [Screening Range] (4b)	1,312	2.2%
Tank Truck Loading (4c)	17,920	29.5%
Tank Truck Transit (4d)	99	0.2%
Underground Tank Filling (4e)	8,450	13.9%
Underground Tank Breathing (4f)	1,200	2.0%
Vehicle Refueling (4g)	7,720	12.7%
Total	**60,682**	**100.0%**

From the table above, it can be seen that fugitive, tank truck transit, and underground tank breathing emissions are relatively small compared to the other emission sources. The emission estimates and distribution presented above are hypothetical; actual emission estimates will be different. Efforts to improve future inventory accuracy should focus on the larger sources in the gasoline distribution system.

Example 5a

Solvent Evaporation - Degreasing

Introduction

Solvent degreasing or surface cleaning operations occur at a wide variety of manufacturing, scientific, and repair facilities. Surface cleaning operations involve the use of solvent liquids or vapors to remove water-insoluble contaminants such as grease, oils, waxes, carbon deposits, fluxes, and tars from metal, plastic, glass, and other surfaces. Solvent degreasing operations may involve the use of a number of different solvents, such as acetone, methyl ethyl ketone (MEK), alcohols, 1,1,1-trichloroethane, or CFC-113.

Typical solvent cleaning equipment can be categorized as:

- **Batch cold cleaning machines**. These machines are batch loaded and liquid solvent is sprayed, dipped, or brushed onto the surfaces that are to be cleaned.
- **Batch vapor cleaning machines**. These machines are batch loaded, and the materials to be cleaned are exposed to vaporized solvent. The condensing solvent flushes the contaminants from the surfaces to be cleaned.
- **In-line cleaning machines**. These machines are loaded using a conveyor on a continual basis and are often custom-made for large-scale operations. An in-line solvent cleaning machine may use liquid or vapor solvent.

Problem Statement

Estimate annual TOG emissions from a batch cold cleaning machine and a batch vapor cleaning machine.

Available Information

Batch cold cleaning machine

- Solvent used is aliphatic hydrocarbon (e.g., Stoddard solvent, petroleum naphtha);
- Cold cleaner capacity is 200 liters;
- Solvent density is 0.8 g/ml (0.8 kg/liter);
- Solvent log data are shown in Table 5-1.

Table 5-1

Solvent Log Data

Date	Solvent Added (liters)	Waste Liquid Removed (liters)	Waste Sludge Removed (kg)
2 Feb	200	195	--
30 May	200	203	--
15 Aug	200	198	1.3
28 Nov	200	205	--

- Added fresh solvent is 100% TOG;
- Waste liquid is 95 wt% TOG (includes contaminants such as water, grease, oil, flux, etc.);
- Waste liquid is assumed to have the same density as fresh solvent;
- Solid waste (sludge) is 10 wt% TOG.

Batch vapor cleaning machine

- Solvent used is perchloroethylene;
- Capacity is 200 liters;
- Solvent density is 1.6 g/ml (1.6 kg/liter);
- Solvent consumption data are shown in Table 5-2.

Table 5-2

Solvent Consumption Data

Date	Solvent Added (liters)	Waste Liquid Removed (liters)	Waste Sludge Removed (kg)
14 Jan	20	--	--
8 Feb	35	--	--
26 Mar	200	178	--
10 Apr	20	--	--
2 May	25	--	--
18 May	20	--	--
20 Jun	200	160	--
4 Jul	15	--	--
6 Aug	30	--	--
18 Sep	200	167	2
3 Nov	50	--	--
15 Dec	200	185	--

- Fresh solvent is 100% TOG;
- Waste liquid is 95 wt% TOG (includes contaminants such as water, grease, oil, flux, etc.);
- Waste liquid is assumed to have the same density as fresh solvent; and
- Solid waste (sludge) is 10 wt% TOG.

Solution

Emissions from cold cleaning occur through waste solvent and sludge evaporation, solvent carryout or “dragout”, solvent bath evaporation, spray evaporation and agitation. Emissions from vapor degreasing are due to diffusion and convection, solvent carryout or “dragout”, exhaust systems, and waste solvent and sludge evaporation.

Since it would be very time- and cost-intensive to collect data on all of these loss mechanisms, emission rates are usually estimated from solvent consumption data for the particular degreasing operation under consideration. If solvent consumption data are not available, emission factors based on number of employees or population data are available in literature (e.g., U.S. EPA, 1991b). For point source emission calculations, it is highly recommended that the following mass balance equation be used to estimate emissions:

$$E = (Q_{in} \text{ x } \boldsymbol{r}_{in} \text{ x } TOG_{in}) - (Q_{out(liq)} \text{x } \boldsymbol{r}_{out(liq)} \text{ x } TOG_{out(liq)}) - (Q_{out(solid)} \text{x } TOG_{out(solid)})$$

where: E = Total TOG emissions (kg);
Q_{in} = Amount of solvent added to the degreaser (liters);
$\tilde{n}_{in}$ = Density of solvent added to the degreaser (kg/liter);
TOG_{in} = TOG content of the solvent added to the degreaser (wt%);
$Q_{out(liq)}$ = Amount of liquid waste removed from the degreaser (liters);
$\tilde{n}_{out(liq)}$ = Density of liquid waste removed from the degreaser (kg/liter);
$TOG_{out(liq)}$ = TOG content of liquid waste removed from the degreaser (wt%);
$Q_{out(solid)}$ = Amount of solid waste (sludge) removed from the degreaser (kg); and
$TOG_{out(solid)}$ = TOG content of solid waste (sludge) removed from the degreaser (wt%).

Batch cold cleaning machine

Emissions from the batch cold cleaning machine are calculated using the mass balance equation given above. Data from the solvent log are used to calculate the amount of solvent added (Q_{in}), the amount of liquid waste removed ($Q_{out(liq)}$), and the amount of sludge removed ($Q_{out(solid)}$).

Q_{in} = (200 + 200 + 200 + 200) = 800 liters
$Q_{out(liq)}$ = (195 + 203 + 198 + 205) = 801 liters
$Q_{out(solid)}$ = 1.3 kg

Total emissions are then calculated as follows:

$$E = (800 \text{ x } 0.8 \text{ x } 100\%) - (801 \text{ x } 0.8 \text{ x } 95\%) - (1.3 \text{ x } 10\%) = 31 \text{ kg TOG/yr}$$

Batch vapor cleaning machine

Emissions from the batch vapor cleaning machine are calculated using the same mass balance equation given above. Once again, data from the solvent log are used to calculate Q_{in}, $Q_{out(liq)}$, and $Q_{out(solids)}$.

where: Q_{in} = (20 + 35 + 200 + 20 + 25 + 20 + 200 + 15 + 30 + 200 + 50 + 200) = 1015 liters
$Q_{out(liq)}$ = (178 + 160 + 167 + 185) = 690 liters
$Q_{out(solid)}$ = 2 kg

Total emissions are then calculated as follows:

$$E = (1015 \text{ x } 1.6 \text{ x } 100\%) - (690 \text{ x } 1.6 \text{ x } 95\%) - (2 \text{ x } 10\%) = 575 \text{ kg TOG/yr}$$

The following issues should be considered when estimating emissions from solvent degreasing:

- Cold cleaner solvent consumption logs usually only include records of changeouts (i.e., all the liquid waste is removed and fresh solvent is added for the full cleaner capacity).

- Vapor degreaser consumption logs usually include records of changeouts and replenishments (i.e., fresh solvent is added to replace evaporated solvent without any liquid waste being removed at the same time).

- The TOG content of the liquid and solid wastes should preferably be determined using periodic sampling. However, frequent sampling is usually cost-prohibitive, so engineering judgement is often used to estimate the TOG content of liquid and solid wastes.

- The amount of TOG recovered in the solid waste (sludge) is usually very small compared to the amount of TOG recovered in the liquid waste. Therefore, it is often conservatively assumed that the TOG in the solid waste is emitted to the air.

- Emissions from some degreasing solvents (e.g., perchloroethylene, freons, etc.) should not be included in ROG (reactive organic gas) inventories.

- Engineering judgement may be needed to reconcile the time period defined by the consumption log with the time period needed for the emission calculations. For example, the batch cold cleaner consumption log contains no data after 28 Nov, but the cold cleaner is still emitting until the end of the annual emission period (i.e., 31 Dec). For actual emission inventories, it is generally assumed that these additional emissions will be reflected at the time of the next consumption entry (i.e., in the next calendar year).

Example 5b
Solvent Evaporation - Surface Coating

Introduction

Surface coating includes all processes in which a liquid material is applied to the surface of a solid substrate. Air emissions result from both the evaporation of the solvents or other organic carriers in the coatings, and from the "overspray" of particulate materials that do not adhere to each part. Particulate emissions can be reduced through the use of paint booths and other control devices. In addition to the actual surface coating materials, emissions also result from materials used for surface preparation prior to the application of surface coatings and for cleanup afterwards.

Problem Statement

Estimate TOG, PM, and zinc compound emissions from the surface coating operation described below. Include all surface coating, thinning, surface preparation, and cleanup materials. There are no records that indicate the amount of paint used.

Available Information

Two types of paint (polyurethane and primer) are used. The polyurethane paint consists of a base and a hardener that must be mixed together. In addition, the polyurethane paint must be thinned with a thinner. The mixing ratio of the polyurethane is 7:2:1 (base:hardener:thinner). The primer does not have component parts and does not require thinning. The material characteristics of the base, hardener, thinner, primer, and other surface preparation and cleanup solvents are given in Table 5-3.

Table 5-3

Surface Coating Material Characteristics

Material	Density (grams/liter)	VOC Content (grams/liter)	Solids Content (%)
Polyurethane-base	700	520	31
Polyurethane-hardener	750	330	35
Polyurethane-thinner	820	820	-
Primer	680	460	40
Surface Preparation Solvent	820	820	-
Cleanup Solvent	820	820	-

Also, 2% of the solids of Paint 1 (as mixed) and 1.5% of the solids of Paint 2 are zinc compounds.

Half of the polyurethane is applied using high volume/low pressure (HVLP) spray equipment, while the other half is applied using conventional spray equipment. The primer is applied using aerosol spray cans. The polyurethane is used in a paint booth equipped with dry particulate filters (approximate control efficiency [CE] of 90%), but the primer is used in an open area.

The surface coating operation paints kitchen appliance parts. Annual throughput of the operation is 25,000 parts. Painters working at the surface coating operation estimate that each part requires 0.8 liters of polyurethane and 0.2 liters of primer. The painters also estimate that the solvents used for surface preparation are 40% of the volume of paint applied on each part, while cleanup solvents are 15% of the volume of paint applied. It is assumed that all surface preparation and cleanup solvents are applied in a wipe application and that 100% of the applied solvent evaporates. Only about 95% of polyurethane or primer in a given container can actually be applied to the parts to be painted; the remaining 5% cannot be used. Nonetheless, it should be assumed that all solvents in the waste paint evaporate to the atmosphere.

Solution - TOG

Determine the amount of polyurethane, primer, surface preparation solvent, and cleanup solvent required.

The amount of applied paint is calculated by multiplying the number of parts by the amount of polyurethane and primer required for each part.

$$\text{Applied Polyurethane} = 25{,}000 \text{ parts x } \frac{0.8 \text{ liters}}{\text{part}} = 20{,}000 \text{ liters}$$

$$\text{Applied Primer} = 25{,}000 \text{ parts x } \frac{0.2 \text{ liters}}{\text{part}} = 5{,}000 \text{ liters}$$

$$\text{Total Applied Paint} = 20{,}000 + 5{,}000 = 25{,}000 \text{ liters}$$

The amount of paint applied is actually only 95% of the amount of paint used. The amount of paint actually mixed is calculated below.

$$\text{Mixed Polyurethane} = \frac{20{,}000 \text{ liters}}{0.95} = 21{,}053 \text{ liters}$$

$$\text{Mixed Primer} = \frac{5{,}000 \text{ liters}}{0.95} = 5{,}263 \text{ liters}$$

The amount of preparation and cleanup solvents are calculated from the amount of paint actually applied.

$$\text{Preparation Solvent} = \frac{0.40 \text{ liters solvent}}{\text{liter paint}} \text{ x } 25{,}000 \text{ liters} = 10{,}000 \text{ liters}$$

$$\text{Cleanup Solvent} = \frac{0.15 \text{ liters solvent}}{\text{liter paint}} \text{ x } 25{,}000 \text{ liters} = 3{,}750 \text{ liters}$$

The TOG content of the polyurethane is calculated as the weighted average of the TOG content of each of the components (base, hardener, and thinner).

$$\text{TOG}_{\text{poly}} = (\%_{\text{base}} \text{ x } \text{TOG}_{\text{base}}) + (\%_{\text{hard}} \text{ x } \text{TOG}_{\text{hard}}) + (\%_{\text{thin}} \text{ x } \text{TOG}_{\text{thin}})$$

$$\text{TOG}_{\text{poly}} = (0.7 \text{ x } 520) + (0.2 \text{ x } 330) + (0.1 \text{ x } 820) = 512 \text{ grams/liter}$$

Emissions are then calculated by multiplying the quantity of each paint or solvent used by its respective TOG content.

$$\text{Emissions}_{\text{ Poly}} = 21{,}053 \text{ liters x } \frac{512 \text{ grams}}{\text{liter}} = 10{,}779 \text{ kg}$$

$$\text{Emissions}_{\text{ Primer}} = 5{,}263 \text{ liters x } \frac{460 \text{ grams}}{\text{liter}} = 2{,}421 \text{ kg}$$

$$\text{Emissions}_{\text{ Prep}} = 10{,}000 \text{ liters x } \frac{820 \text{ grams}}{\text{liter}} = 8{,}200 \text{ kg}$$

$$\text{Emissions}_{\text{ Cleanup}} = 3{,}750 \text{ liters x } \frac{820 \text{ grams}}{\text{liter}} = 3{,}075 \text{ kg}$$

$$\text{Emissions}_{\text{ TOG-Total}} = 10{,}779 + 2{,}421 + 8{,}200 + 3{,}075 = 24{,}475 \text{ kg} = 24.5 \text{ Mg}$$

Solution - PM

Uncontrolled PM emissions can be calculated using the following equation.

$$\text{Emissions}_{\text{ i}} = \text{P}_{\text{i}} \text{ x } r_{\text{i}} \text{ x } \text{SC}_{\text{i}} \text{ x } (1 - h)$$

where:
Emissions_i = Total uncontrolled emissions for surface coating, i (kg);
P_i = Amount of paint applied (liter);
ñ_i = Density of surface coating, i (g/liter);
SC_i = Solids content of surface coating, i (fraction); and
ç = Transfer efficiency of application method (fraction).

First, the density and solids content of the polyurethane paint needs to be determined. Density and solids content information are taken from the material characteristics table.

$$SC_{Tot} = \frac{(700)(0.31)(0.70) + (750)(0.35)(0.20) + (820)(0.00)(0.10)}{722} = 28.3\%$$

$$r_{poly} = (\%_{base} \text{ x } r_{base}) + (\%_{hard} \text{ x } r_{hard}) + (\%_{thin} \text{ x } r_{thin})$$

$$r_{poly} = 0.7 \text{ x } 700 + 0.2 \text{ x } 750 + 0.1 \text{ x } 820 = 722 \text{ grams/liter}$$

$$SC_{poly} = \frac{r_{base} SC_{base} \%_{base} + r_{hard} SC_{hard} \%_{hard} + r_{thin} SC_{thin} \%_{thin}}{r_{poly}}$$

Transfer efficiencies for various application methods are presented in Table 5-4.

Table 5-4

Surface Coating Transfer Efficiencies

Application Method	Transfer Efficiency
Aerosol Spray Can	0.24
Airless Spray Equipment	0.35
Brush or Roller	0.95
Conventional Air Spray Equipment	0.30
High Volume/Low Pressure (HVLP) Spray Equipment	0.60

Source: SCAQMD, 1996

Uncontrolled PM emissions are calculated below.

$$\text{Emissions}_{\text{Poly,HVLP}} = \frac{722 \text{ grams}}{\text{liter}} \times 0.283 \times (1 - 0.60) \times 10{,}000 \text{ liters} = 817 \text{ kg}$$

$$\text{Emissions}_{\text{Poly,other}} = \frac{722 \text{ grams}}{\text{liter}} \times 0.283 \times (1 - 0.30) \times 10{,}000 \text{ liters} = 1{,}430 \text{ kg}$$

$$\text{Emissions}_{\text{Primer}} = \frac{680 \text{ grams}}{\text{liter}} \times 0.4 \times (1 - 0.24) \times 5{,}000 \text{ liters} = 1{,}034 \text{ kg}$$

The controlled PM emissions for the polyurethane are calculated below.

$$\text{Emissions}_{\text{Poly,cont}} = (1 - \text{CE}) (\text{Emissions}_{\text{Poly,HVLP}} + \text{Emissions}_{\text{Poly,other}})$$

where: CE = control efficiency

$$\text{Emissions}_{\text{Poly,cont}} = (1 - 0.90) (817 + 1{,}430) = 225 \text{ kg}$$

Finally, total combined PM emissions for the polyurethane and the primer are calculated.

$$\text{Emissions}_{\text{Total}} = 225 + 1{,}034 = 1{,}259 \text{ kg} = 1.3 \text{ Mg}$$

Solution - Zinc Compounds

Emissions of a specific species are simply calculated by multiplying overall PM emissions by the percentage of that specific species. Using this method, zinc compound emissions are calculated below.

$$\text{Emissions}_{\text{Zn,poly}} = 2\% \times 225 \text{ kg PM}_{10} = 4.5 \text{ kg}$$

$$\text{Emissions}_{\text{Zn,primer}} = 1.5\% \times 1{,}034 \text{ kg PM}_{10} = 15.5 \text{ kg}$$

$$\text{Emissions}_{\text{Zn,total}} = 4.5 + 15.5 = 20 \text{ kg}$$

Example 6

Point Source Stack Emissions

Introduction

Among the various emission estimating techniques, source sampling provides the most reliable emission estimates (although the costs also tend to be the highest). The reason for the high accuracy is that the effects of equipment- and process-specific parameters are actually being measured by the sampling equipment. Although source sampling can provide accurate emission estimates, sometimes much effort is required to convert sampling data into emission estimates. This example demonstrates the process of converting concentration measurements into mass emission rates.

Problem Statement

Determine the average hourly and annual emissions of NO_x from a process stack given typical stack measurements.

Available Information

The following average measurements have been collected from the stack through approved source testing methods:

Actual stack gas flow rate:	7486 cfm
Stack gas temperature:	80.0°C
Stack diameter:	0.75 m
Water vapor content:	2.1%vol
CO_2 content:	9.5%vol
NO_x concentration:	48 ppmv

The remainder of the stack gas should be assumed to be air. The process operates 24 hours per day, 330 days per year.

Solution

The steps necessary to determine the daily and annual NO_x emissions from this process stack with the information provided are:

1. Collect the data needed for stack gas calculations and define terms:

   Standard molar volume (V_s) (at 20°C): 0.024 m^3/g-mole
   Molecular weight (MW) of NO_x: 46 (NO_x is expressed as NO_2 by convention)
   Standard conditions: 20°C and 760 mmHg

   Standard conditions (temperature and pressure) are often used so that all emissions are reported on the same basis. Different standard conditions may apply in different jurisdictions and for different applications.

2. Determine the metric flow rate of the stack gas (volume/unit time) at stack conditions (m^3/min):

   a. Given:

      Actual stack gas flow rate: 7486 cfm
      Stack temperature: 80.0°C

   b. Metric flow rate of stack gas at stack conditions:

$$= \left(\frac{7486\,\text{ft}^3}{\text{min}}\right)\left(\frac{0.3048\,\text{m}}{\text{ft}}\right)^3 = 2.12 \text{ x } 10^2\,\frac{\text{m}^3}{\text{min}}\left(\text{at } 80°\text{C, stack pressure}\right)$$

3. Determine the volumetric flow rate of NO_x in the stack gas (volume/unit time):

a. The stack gas in this example is wet (2.1% water by volume). The information given does not specify if the NO_x concentration was measured on a wet basis or a dry basis. However, from knowledge of analytical techniques, it is known that NO_x measurements are made and reported on a dry basis, therefore the dry stack gas flow rate must first be calculated.

b. Calculate the dry stack gas volumetric flow rate:

   1. Given:

      Stack gas water content: 2.1% by volume
      Wet stack gas flow rate: 2.12×10^2 m^3/min
      (at 80°C, stack pressure)

   2. Dry stack gas flow rate:

$$Q_{dry} = Q_{wet}\left(\frac{V_{dry}}{V_{wet}}\right)$$

$$= \frac{2.08 \text{ x } 10^2 \text{ m}^3 \text{ stack gas (dry)}}{\text{min}}$$

where: Q_{dry} = dry stack gas flow rate;

$$= \left(\frac{2.12 \text{ x } 10^2 \text{ m}^3 \text{ stack gas (wet)}}{\text{min}}\right)\left(\frac{(1 - 0.021) \text{ m}^3 \text{ stack gas (dry)}}{1 \text{ m}^3 \text{ stack gas (wet)}}\right)$$

Q_{wet} = wet stack gas flow rate; and
V_{dry}/V_{wet} = fraction of air in wet stack gas.

c. Calculate NO_x flow rate:

   1. Given:

      NO_x concentration: 48 ppmv

   2. NO_x flow rate:

$$Q_{NOx} = Q_{dry}C_{NOx}$$

where: Q_{NOx} = NO_x flow rate;
Q_{dry} = dry stack gas flow rate; and
C_{NOx} = NO_x concentration

$$\left(2.08 \text{ x } 10^2 \frac{\text{m}^3 \text{ stack gas}}{\text{min}}\right)\left(\frac{48 \text{ m}^3 \text{ NO}_x}{10^6 \text{ m}^3 \text{ stack gas}}\right) = \frac{9.98 \text{ x } 10^{-3} \text{ m}^3 \text{ NO}_x}{\text{min}} (\text{at } 80° \text{C, stack pressure, dry basis}$$

4. Correct the volumetric flow rate of NO_x to standard conditions (20°C and 760 mmHg) using the ideal gas law.

   a. For this example, it is assumed that correction is required only for temperature because the stack gas is assumed to be at 1 atmosphere (760 mmHg) due to the stack being open to the atmosphere at sea level.

   b. From the ideal gas law (PV = nRT), the relationship between gas volume and gas temperature is:

      V = nRT/P
      V/T = nR/P

   c. In this example, regardless of the temperature of the stack, the number of moles (n) of the NO_x in the stack gas, gas constant (R), and pressure (P) of the stack gas are constant. Therefore, the relationship between gas volume and gas temperature can be developed as follows for any two absolute temperatures (T_1 and T_2):

      $V_1/T_1 = n_1R_1/P_1$ and $V_2/T_2 = n_2R_2/P_2$

      Since nR/P is constant, then $n_1R_1/P_1 = n_2R_2/P_2$, therefore:

      $V_1/T_1 = V_2/T_2$

   d. Solving for the unknown gas volume (V_2) at the new temperature (T_2),

      $V_2 = V_1T_2/T_1$

e. The equation for the unknown volume flow rate (Q_2) at the new temperature (T_2) is similar,

$$Q_2 = Q_1T_2/T_1$$

f. Calculate the volume flow rate of NO_x (Q_2) at the new temperature (20°C) (absolute temperatures must be used in this calculation):

$$Q_2 = \left(9.96 \text{ x } 10^{-3} \frac{\text{m}^3\ \text{NO}_\text{x}}{\text{min}}\right)\left(\frac{[20°\text{C} + 273]}{[80°\text{C} + 273]}\right) = 8.27 \text{ x } 10^{-3} \frac{\text{Sm}^3 \text{ (standard cubic meter)}}{\text{min}} \left(\text{at } 20°\text{C, } 760 \text{ m}\right.$$

5. Determine mass flow rate and daily and annual NO_x emissions (mass/day and mass/year):

a. Given:

$$\text{Volumetric flow rate of } \text{NO}_\text{x} = 8.27 \text{ x } 10^{-3} \frac{\text{Sm}^3}{\text{min}}$$

$$\text{V}_\text{s}\,(\text{standard molar volume}) = 0.024 \frac{\text{Sm}^3}{\text{g- mole}}\,(20°\text{C, } 760 \text{ mmHg})$$

$$\text{MW of } \text{NO}_\text{x}\,(\text{as } \text{NO}_2) = 46 \frac{\text{g}}{\text{g- mole}}$$

$$\text{Annual stack operation} = 24 \text{ hours per day, } 330 \text{ days per year}$$

b. Mass flow rate of NO_x:

$$\text{M}_{\text{NO}_\text{x}} = \frac{\text{Q}_{\text{NO}_\text{x}}\,\text{MW}_{\text{NO}_\text{x}}}{\text{V}_\text{S}}$$

where: M_{NOx} = NO_x mass flow rate;
Q_{NOx} = NO_x volumetric flow rate;
MW_{NOx} = NO_x molecular weight; and
V_s = standard molar volume

$$\left(8.27 \text{ x } 10^{-3} \frac{\text{Sm}^3 \text{ NO}_x}{\text{min}}\right)\left(\frac{1 \text{ g-mole NO}_x}{0.024 \text{ Sm}^3 \text{ NO}_x}\right)\left(\frac{46 \text{ g NO}_x}{\text{g-mole NO}_x}\right) = 15.8 \frac{\text{g NO}_x}{\text{min}}$$

c. Hourly emissions:

$$\left(\frac{15.8 \text{ g NO}_x}{\text{min}}\right)\left(\frac{60 \text{ min}}{1 \text{ hr}}\right)\left(\frac{1 \text{ kg}}{10^3 \text{ g}}\right) = 0.948 \frac{\text{kg NO}_x}{\text{hr}}$$

d. Annual emissions:

$$\left(\frac{0.948 \text{ kg NO}_x}{\text{hr}}\right)\left(\frac{24 \text{ hr}}{\text{day}}\right)\left(\frac{330 \text{ days}}{\text{yr}}\right) = 7.51 \text{ x } 10^3 \text{ kg/yr}$$

$$= 7.5 \text{ Mg/yr}$$

Example 7

Particulate Matter - Estimation of PM_{10}, $PM_{2.5}$, OC, and EC

Introduction

Particulate emissions consist of particles with a wide range of sizes. They range in size from near molecular dimensions to 100 microns in diameter. Particles with diameters greater than 100 microns do not stay suspended for any significant period of time and settle out near their point of origin. Consequently, these particles are usually not considered in air quality applications. Currently, most inventory efforts focus on PM_{10} (particulate matter with an aerodynamic diameter of less than or equal to 10 microns). However, as the focus of air quality has grown to include visibility issues, more attention has been given to $PM_{2.5}$ (particulate matter with an aerodynamic diameter of less than or equal to 2.5 microns) emissions. Visibility-related research also requires an analysis of particulate composition. The amount of light extinction caused by particulate matter is a function of its chemical composition. Particulate matter containing organic carbon (OC) or elemental carbon (EC) absorbs light; whereas, particulate matter containing other chemical compounds tends to scatter light.

Problem Statement

Estimate PM_{10}, $PM_{2.5}$, OC, and EC emissions given total suspended particulate (TSP) emissions from paved and unpaved roads.

Available Information

Using standard estimating methodologies, it has been estimated that TSP emissions are 600 Mg for paved roads and 3,000 Mg for unpaved roads within a particular inventory domain.

Solution - PM_{10} and $PM_{2.5}$

Ideally, site-specific PM_{10} and $PM_{2.5}$ fractions would be developed for re-entrained paved and unpaved road dust emissions in every location. However, this is often not practical. As a result, average PM_{10} and $PM_{2.5}$ fractions are often used to estimate PM_{10} and $PM_{2.5}$ emissions. There are several sources for these average PM_{10} and $PM_{2.5}$ fractions.

The first source of PM_{10} and $PM_{2.5}$ fractions is AP-42 (U.S. EPA, 1995a). The equations used to estimate re-entrained road dust emissions from paved and unpaved roads utilize particle size multipliers (PSM) (AP-42, Sections 13.2.1 and 13.2.2). These particle size multipliers are listed in Table 7-1.

Table 7-1

AP-42 Paved and Unpaved Road Dust Particle Size Multipliers

Aerodynamic Diameter of Particle	Paved Roads (g/VKT)	Unpaved Roads (dimensionless)
PM_{30}*	24	1
PM_{10}	4.6	0.36
$PM_{2.5}$	2.1	0.095

*PM_{30} is sometimes termed "suspendable particulate" (SP) and is often used as a surrogate for TSP.

The PM_{10} and $PM_{2.5}$ fractions (F_{10} and $F_{2.5}$) are obtained by dividing the PM_{10} and $PM_{2.5}$ particle size multipliers (PSM_{10} and $PSM_{2.5}$) by the TSP particle size multiplier (PSM_{TSP}).

$$F_{10\text{-paved}} = \frac{PSM_{10\text{-paved}}}{PSM_{TSP\text{-paved}}} = \frac{4.6}{24} = 0.192$$

$$F_{2.5\text{-paved}} = \frac{PSM_{2.5\text{-paved}}}{PSM_{TSP\text{-paved}}} = \frac{2.1}{24} = 0.088$$

$$F_{10\text{-unpaved}} = \frac{PSM_{10\text{-unpaved}}}{PSM_{TSP\text{-unpaved}}} = \frac{0.36}{1} = 0.360$$

$$F_{2.5\text{-unpaved}} = \frac{PSM_{2.5\text{-unpaved}}}{PSM_{TSP\text{-unpaved}}} = \frac{0.095}{1} = 0.095$$

Another source of PM_{10} and $PM_{2.5}$ fractions is EPA's SPECIATE database (U.S. EPA, 1992). The SPECIATE database contains speciation profiles for a wide range of emission categories. Many of these profiles are composite profiles. In addition, mass fractions for different size intervals are given for each emission category. Based on composite profiles, the PM_{10} and $PM_{2.5}$ fractions (F_{10} and $F_{2.5}$) for paved and unpaved roads are given in Table 7-2.

Table 7-2
SPECIATE Paved and Unpaved Road Dust Mass Fractions

Particle Size Interval (ì m)	Paved Road Fraction (SPECIATE profile 41130)	Unpaved Road Fraction (SPECIATE profile 41220)
0-2.5	0.25	0.3
0-10	0.44	0.73

Similarly, the California Air Resources Board provides its own mass fractions for different size intervals (ARB, 1996). These are given in Table 7-3.

Table 7-3
ARB Paved and Unpaved Road Dust Mass Fractions

Particle Size Interval (ì m)	Paved Road Fraction	Unpaved Road Fraction
<1	0.03	0.05
1-2.5	0.05	0.08
2.5-10	0.38	0.49
>10	0.54	0.38

Because the mass fractions do not correspond to PM_{10} and $PM_{2.5}$ fractions, certain mass fractions must be summed together as demonstrated below.

For paved roads:

$$F_{2.5} = F_{<1} + F_{1-2.5} = 0.03 + 0.05 = 0.08$$
$$F_{10} = F_{<1} + F_{1-2.5} + F_{2.5\text{-}10} = 0.03 + 0.05 + 0.38 = 0.46$$

For unpaved roads:

$$F_{2.5} = F_{<1} + F_{1-2.5} = 0.05 + 0.08 = 0.13$$
$$F_{10} = F_{<1} + F_{1-2.5} + F_{2.5\text{-}10} = 0.05 + 0.08 + 0.49 = 0.62$$

After obtaining PM_{10} and $PM_{2.5}$ fractions, PM_{10} and $PM_{2.5}$ emissions are then calculated using the following equation.

$$\text{Emissions}_{i} = \text{Emissions}_{TSP} \text{ x } F_{i}$$

where: Emissions_i = Emissions of aerodynamic diameter less than i microns;
Emissions_{TSP} = Emissions of total suspended particulate matter; and
F_i = Fraction of total suspended particulate matter of aerodynamic diameter less than i microns.

Because generic PM_{10} and $PM_{2.5}$ fractions are being used rather than site-specific fractions, PM_{10} and $PM_{2.5}$ emissions will be estimated using PM_{10} and $PM_{2.5}$ fractions from each of the three sources presented above. In addition, the average of the three PM_{10} and $PM_{2.5}$ fractions is used to estimate PM_{10} and $PM_{2.5}$ emissions. All four of the estimates are presented in Table 7-4. It should be noted that none of these estimates have been identified as being better or more accurate than the others. There is still considerable uncertainty associated with paved and unpaved road emission estimates. Research is underway to improve the existing methodologies for these source categories. This example simply demonstrates how to derive PM_{10} and $PM_{2.5}$ estimates from TSP emissions.

Table 7-4

PM_{10} and $PM_{2.5}$ Emissions Calculated Using Different Size Fractions

Road Type	Pollutant	Source of Fraction	Size Fraction	TSP (Mg/yr)	Emissions (Mg/yr)
Paved	PM_{10}	AP-42	0.192	600	115.2
		SPECIATE	0.44		264
		ARB	0.46		276
		Average	0.364		218.4
	$PM_{2.5}$	AP-42	0.088	600	52.8
		SPECIATE	0.25		150
		ARB	0.08		48
		Average	0.139		83.4
Unpaved	PM_{10}	AP-42	0.36	3,000	1,080
		SPECIATE	0.73		2,190
		ARB	0.62		1,860
		Average	0.57		1,710
	$PM_{2.5}$	AP-42	0.095	3,000	285
		SPECIATE	0.30		900
		ARB	0.13		390
		Average	0.175		525

Solution - OC and EC

Like PM_{10} and $PM_{2.5}$ fractions, site-specific OC and EC fractions should be developed whenever possible in order to obtain the most accurate emission estimates. In some instances, however, detailed laboratory analysis is not possible. Generic speciation profiles must then be used. A source for generic speciation profiles is EPA's SPECIATE database. These SPECIATE speciation profiles indicate the percentage of individual compounds relative to overall particulate matter emissions. For paved and unpaved road dust, these speciation profiles include various metal species, in addition to OC and EC.

Hypothetical sampling data gives the following OC and EC fractions for paved and unpaved roads. Three samples were taken for both paved and unpaved roads. Two size fractions were sampled - fine (0-2.5 ì m) and coarse (2.5-10 ì m). These data are presented in Table 7-5.

Table 7-5

Hypothetical OC and EC Sampling Data

Road Type	Sample	Size Fraction	OC fraction (wt%)	EC fraction (wt%)
Paved	#1	Fine	17.27	0.72
		Coarse	12.35	0.44
	#2	Fine	19.41	0.45
		Coarse	10.89	0.60
	#3	Fine	18.54	0.63
		Coarse	11.37	0.53
	Average	Fine	18.41	0.60
		Coarse	11.54	0.52
Unpaved	#1	Fine	2.46	0.00
		Coarse	1.50	0.00
	#2	Fine	2.71	0.00
		Coarse	1.65	0.00
	#3	Fine	2.77	0.00
		Coarse	1.29	0.00
	Average	Fine	2.65	0.00
		Coarse	1.48	0.00

The OC and EC fractions (F_{OC} and F_{EC}) for $PM_{2.5}$ can be taken directly from the table above because fine particulate is defined as $PM_{2.5}$. The OC and EC fractions for PM_{10} must be calculated using a weighted average of fine and coarse OC and EC fractions. Additional sampling data (not included in the table on the previous page) indicates that paved road dust PM_{10} consists of 54 wt% coarse particulate and 46 wt% fine particulate, whereas unpaved road dust PM_{10} consists of 35 wt% coarse particulate and 65 wt% fine particulate. The weighted OC and EC fractions for PM_{10} are calculated using the following equation.

$$F_i = (F_{i,c} \text{ x } \%_c) + (F_{i,f} \text{ x } \%_f)$$

where F_i = Overall fraction of species i;
$F_{i,c}$ = Fraction of species i in coarse portion of particulate;
$\%_c$ = Weight percent of coarse particulate;
$F_{i,f}$ = Fraction of species i in fine portion of particulate; and
$\%_f$ = Weight percent of fine particulate.

The weighted PM_{10} OC and EC fractions are calculated below for both paved and unpaved roads.

$$F_{OC,paved} = (11.54 \text{ x } 0.54) + (18.41 \text{ x } 0.46) = 14.70$$
$$F_{EC,paved} = (0.52 \text{ x } 0.54) + (0.60 \text{ x } 0.46) = 0.56$$

OC and EC emissions are calculated in Table 7-6. PM_{10} and $PM_{2.5}$ emissions are assumed to be equal to the average values calculated earlier.

Table 7-6

Calculated OC and EC Emissions

Road Type	Pollutant	Emissions (Mg/yr)	OC Fraction	OC Emissions (Mg/yr)	EC Fraction	EC Emissions (Mg/yr)
Paved	PM_{10}	218.4	0.1470	32.1	0.0056	1.2
	$PM_{2.5}$	83.4	0.1841	15.4	0.0060	0.5
Unpaved	PM_{10}	1710	0.0224	38.3	0.0000	0.0
	$PM_{2.5}$	525	0.0265	13.9	0.0000	0.0

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APPENDIX A

MISCELLANEOUS DATA AND CONVERSION FACTORS

(Information in this appendix is taken from AP-42, Appendix A. Fuel parameters are for U.S. fuels; Mexico fuels are likely to differ and should be examined carefully.)

SOME USEFUL WEIGHTS AND MEASURES

Unit Of Measure	Equivalent	
grain	0.002	ounces
gram	0.04	ounces
ounce	28.35	grams
kilogram	2.21	pounds
pound	0.45	kilograms
pound (troy)	12	ounces
ton (short)	2000	pounds
ton (long)	2240	pounds
ton (metric)	2200	pounds
ton (shipping)	40	feet^3
centimeter	0.39	inches
inch	2.54	centimeters
foot	30.48	centimeters
meter	1.09	yards
yard	0.91	meters
mile	1.61	kilometers
centimeter^2	0.16	inches^2
inch^2	6.45	centimeters^2
foot^2	0.09	meters^2
meter^2	1.2	yards^2
yard^2	0.84	meters^2
mile^2	2.59	kilometers^2
centimeter^3	0.061	inches^3
inch^3	16.39	centimeters^3
foot^3	283.17	centimeters^3
foot^3	1728	inches^3

SOME USEFUL WEIGHTS AND MEASURES (cont.)

meter^3	1.31	yeads^3
yard^3	0.77	meters^3
cord	128	feet^3
cord	4	meters^3
peck	8	quarts
bushel (dry)	4	pecks
bushel	2150.4	inches^3
gallon (U. S.)	231	inches^3
barrel	31.5	gallons
hogshead	2	barrels
township	36	miles^2
hectare	2.5	acres

MISCELLANEOUS DATA

One cubic foot of anthracite coal weighs about 53 pounds.

One cubic foot of bituminous coal weighs from 47 to 50 pounds.

One ton of coal is equivalent to two cords of wood for steam purposes.

A gallon of water (U. S. Standard) weighs 8.33 pounds and contains 231 cubic inches.

There are 9 square feet of heating surface to each square foot of grate surface.

A cubic foot of water contains 7.5 gallons and 1728 cubic inches, and weighs 62.5 lbs.

Each nominal horsepower of a boiler requires 30 to 35 pounds of water per hour.

A horsepower is equivalent to raising 33,000 pounds one foot per minute, or 550 pounds one foot per second.

To find the pressure in pounds per square inch of a column of water, multiply the height of the column in feet by 0.434.

TYPICAL PARAMETERS OF VARIOUS FUELS[a]

Type Of Fuel	Heating Value		Sulfur % (by weight)	Ash % (by weight)
	kcal	Btu		
Solid Fuels				
Bituminous Coal	7,200/kg	13,000/lb	0.6-5.4	4-20
Anthracite Coal	6,810/kg	12,300/lb	0.5-1.0	7.0-16.0
Lignite (@ 35% moisture)	3,990/kg	7,200/lb	0.7	6.2
Wood (@ 40% moisture)	2,880/kg	5,200/lb	N	1-3
Bagasse (@ 50% moisture)	2,220/kg	4,000/lb	N	1-2
Bark (@ 50% moisture)	2,492/kg	4,500/lb	N	1-3[b]
Coke, Byproduct	7,380/kg	13,300/lb	0.5-1.0	0.5-5.0
Liquid Fuels				
Residual Oil	$9.98 \times 10^6/m^3$	150,000/gal	0.5-4.0	0.05-0.1
Distillate Oil	$9.30 \times 10^6/m^3$	140,000/gal	0.2-1.0	N
Diesel	$9.12 \times 10^6/m^3$	137,000/gal	0.4	N
Gasoline	$8.62 \times 10^6/m^3$	130,000/gal	0.03-0.04	N
Kerosene	$8.32 \times 10^6/m^3$	135,000/gal	0.02-0.05	N
Liquid Petroleum Gas	$6.25 \times 10^6/m^3$	94,000/gal	N	N
Gaseous Fuels				
Natural Gas	$9{,}341/m^3$	1,050/SCF	N	N
Coke Oven Gas	$5{,}249/m^3$	590/SCF	0.5-2.0	N
Blast Furnace Gas	$890/m^3$	100/SCF	N	N

N = negligible.

[b] Ash content may be considerably higher when sand, dirt, etc., are present.

THERMAL EQUIVALENTS FOR VARIOUS FUELS

Type Of Fuel	kcal	Btu (gross)
Solid fuels		
Bituminous coal	(5.8 to 7.8) x 10^6/Mg	(21.0 to 28.0) x 10^6/ton
Anthracite coal	7.03 x 10^6/Mg	25.3 x 10^6/ton
Lignite	4.45 x 10^6/Mg	16.0 x 10^6/ton
Wood	1.47 x 10^6/m^3	21.0 x 10^6/cord
Liquid fuels		
Residual fuel oil	10 x 10^3/liter	6.3 x 10^6/bbl
Distillate fuel oil	9.35 x 10^3/liter	5.9 x 10^6/bbl
Gaseous fuels		
Natural gas	9,350/m^3	1,050/ft^3
Liquefied petroleum gas		
Butane	6,480/liter	97,400/gal
Propane	6,030/liter	90,500/gal

WEIGHTS OF SELECTED SUBSTANCES

Type Of Substance	g/liter	lb/gal
Asphalt	1030	8.57
Butane, liquid at 60°F	579	4.84
Crude oil	850	7.08
Distillate oil	845	7.05
Gasoline	739	6.17
Propane, liquid at 60°F	507	4.24
Residual oil	944	7.88
Water	1000	8.4

DENSITIES OF SELECTED SUBSTANCES

Substance	Density	
Fuels		
Crude Oil	874 kg/m^3	7.3 lb/gal
Residual Oil	944 kg/m^3	7.88 lb/gal
Distillate Oil	845 kg/m^3	7.05 lb/gal
Gasoline	739 kg/m^3	6.17 lb/gal
Natural Gas	673 kg/m^3	1 lb/23.8 ft^3
Butane	579 kg/m^3	4.84 lb/gal (liquid)
Propane	507 kg/m^3	4.24 lb/gal (liquid)
Wood (Air dried)		
Elm	561 kg/m^3	35 lb/ft^3
Fir, Douglas	513 kg/m^3	32 lb/ft^3
Fir, Balsam	400 kg/m^3	25 lb/ft^3
Hemlock	465 kg/m^3	29 lb/ft^3
Hickory	769 kg/m^3	48 lb/ft^3
Maple, Sugar	689 kg/m^3	43 lb/ft^3
Maple, White	529 kg/m^3	33 lb/ft^3
Oak, Red	673 kg/m^3	42 lb/ft^3
Oak, White	769 kg/m^3	48 lb/ft^3
Pine, Southern	641 kg/m^3	40 lb/ft^3
Agricultural Products		
Corn	25.4 kg/bu	56 lb/bu
Milo	25.4 kg/bu	56 lb/bu
Oats	14.5 kg/bu	32 lb/bu
Barley	21.8 kg/bu	48 lb/bu
Wheat	27.2 kg/bu	60 lb/bu
Cotton	**¡Error! No se encuentra el origen de la referencia.**226 kg/bale	500 lb/bale
Mineral Products		
Brick	2.95 kg/brick	6.5 lb/brick

Substance	Density	
Cement	170 kg/bbl	375 lb/bbl
Cement	1483 kg/m^3	2500 lb/yd^3
Concrete	2373 kg/m^3	4000 lb/yd^3
Glass, Common	2595 kg/m^3	162 lb/ft^3
Gravel, Dry Packed	1600 - 1920 kg/m^3	100 - 120 lb/ft^3
Gravel, Wet	2020 kg/m^3	126 lb/ft^3
Gypsum, Calcined	880 - 960 kg/m^3	55 - 60 lb/ft^3
Lime, Pebble	850 - 1025 kg/m^3	53 - 64 lb/ft^3
Sand, Gravel (Dry, loose)	1440 - 1680 kg/m^3	90 - 105 lb/ft^3

CONVERSION FACTORS

The table of conversion factors on the following pages contains factors for converting English to metric units and metric to English units as well as factors to manipulate units within the same system. The factors are arranged alphabetically by unit within the following property groups.

- Area
- Density
- Energy
- Force
- Length
- Mass
- Pressure
- Velocity
- Volume
- Volumetric Rate

To convert a number from one unit to another:

1. Locate the unit in which the number is currently expressed in the left-hand column of the table;

2. Find the desired unit in the center column; and

3. Multiply the number by the corresponding conversion factor in the right-hand column.

CONVERSION FACTORS[a]

To Convert From	To	Multiply By
Area		
Acres	Sq feet	4.356×10^{4}
Acres	Sq kilometers	4.0469×10^{-3}
Acres	Sq meters	4.0469×10^{3}
Acres	Sq miles (statute)	1.5625×10^{-3}
Acres	Sq yards	4.84×10^{3}
Sq feet	Acres	2.2957×10^{-5}
Sq feet	Sq cm	929.03
Sq feet	Sq inches	144.0
Sq feet	Sq meters	0.092903
Sq feet	Sq miles	3.587×10^{-8}
Sq feet	Sq yards	0.111111
Sq inches	Sq feet	6.9444×10^{-3}
Sq inches	Sq meters	6.4516×10^{-4}
Sq inches	Sq mm	645.16
Sq kilometers	Acres	247.1
Sq kilometers	Sq feet	1.0764×10^{7}
Sq kilometers	Sq meters	1.0×10^{6}
Sq kilometers	Sq miles	0.386102
Sq kilometers	Sq yards	1.196×10^{6}
Sq meters	Sq cm	1.0×10^{4}
Sq meters	Sq feet	10.764
Sq meters	Sq inches	1.55×10^{3}
Sq meters	Sq kilometers	1.0×10^{-6}
Sq meters	Sq miles	3.861×10^{-7}
Sq meters	Sq mm	1.0×10^{6}
Sq meters	Sq yards	1.196
Sq miles	Acres	640.0
Sq miles	Sq feet	2.7878×10^{7}
Sq miles	Sq kilometers	2.590

CONVERSION FACTORS (cont.).

Sq miles	Sq meters	2.59×10^6
Sq miles	Sq yards	3.0976×10^6
Sq yards	Acres	2.0661×10^{-4}
Sq yards	Sq cm	8.3613×10^3
Sq yards	Sq ft	9.0
Sq yards	Sq inches	1.296×10^3
Sq yards	Sq meters	0.83613
Sq yards	Sq miles	3.2283×10^{-7}
Density		
Dynes/cu cm	Grams/cu cm	1.0197×10^{-3}
Grains/cu foot	Grams/cu meter	2.28835
Grams/cu cm	Dynes/cu cm	980.665
Grams/cu cm	Grains/milliliter	15.433
Grams/cu cm	Grams/milliliter	1.0
Grams/cu cm	Pounds/cu inch	1.162
Grams/cu cm	Pounds/cu foot	62.428
Grams/cu cm	Pounds/cu inch	0.036127
Grams/cu cm	Pounds/gal (Brit.)	10.022
Grams/cu cm	Pounds/gal (U. S., dry)	9.7111
Grams/cu cm	Pounds/gal (U. S., liq.)	8.3454
Grams/cu meter	Grains/cu foot	0.4370
Grams/liter	Pounds/gal (U. S.)	8.345×10^{-3}
Kilograms/cu meter	Grams/cu cm	0.001
Kilograms/cu meter	Pounds/cu ft	0.0624
Kilograms/cu meter	Pounds/cu in	3.613×10^{-5}
Pounds/cu foot	Grams/cu cm	0.016018
Pounds/cu foot	kg/cu meter	16.018
Pounds/cu inch	Grams/cu cm	27.68
Pounds/cu inch	Grams/liter	27.681
Pounds/cu inch	kg/cu meter	2.768×10^4

CONVERSION FACTORS (cont.).

Pounds/gal (U. S., liq.)	Grams/cu cm	0.1198
Pounds/gal (U. S., liq.)	Pounds/cu ft	7.4805
Energy		
Btu	Cal. gm (IST.)	251.83
Btu	Ergs	1.05435×10^{10}
Btu	Foot-pounds	777.65
Btu	Hp-hours	3.9275×10^{-4}
Btu	Joules (Int.)	1054.2
Btu	kg-meters	107.51
Btu	kW-hours (Int.)	2.9283×10^{-4}
Btu/hr	Cal. kg/hr	0.252
Btu/hr	Ergs/sec	2.929×10^{6}
Btu/hr	Foot-pounds/hr	777.65
Btu/hr	Horsepower (mechanical)	3.9275×10^{-4}
Btu/hr	Horsepower (boiler)	2.9856×10^{-5}
Btu/hr	Horsepower (electric)	3.926×10^{-4}
Btu/hr	Horsepower (metric)	3.982×10^{-4}
Btu/hr	Kilowatts	2.929×10^{-4}
Btu/lb	Foot-pounds/lb	777.65
Btu/lb	Hp-hr/lb	3.9275×10^{-4}
Btu/lb	Joules/gram	2.3244
Calories, kg (mean)	Btu (IST.)	3.9714
Calories, kg (mean)	Ergs	4.190×10^{10}
Calories, kg (mean)	Foot-pounds	3.0904×10^{3}
Calories, kg (mean)	Hp-hours	1.561×10^{-3}
Calories, kg (mean)	Joules	4.190×10^{3}
Calories, kg (mean)	kg-meters	427.26
Calories, kg (mean)	kW-hours (Int.)	1.1637×10^{-3}
Ergs	Btu	9.4845×10^{-11}
Ergs	Foot-poundals	2.373×10^{-6}

CONVERSION FACTORS (cont.).

Ergs	Foot-pounds	7.3756×10^{-8}
Ergs	Joules (Int.)	9.99835×10^{-8}
Ergs	kW-hours	2.7778×10^{-14}
Ergs	kg-meters	1.0197×10^{-8}
Foot-pounds	Btu (IST.)	1.2851×10^{-3}
Foot-pounds	Cal. kg (IST.)	3.2384×10^{-4}
Foot-pounds	Ergs	1.3558×10^{7}
Foot-pounds	Foot-poundals	32.174
Foot-pounds	Hp-hours	5.0505×10^{-7}
Foot-pounds	Joules	1.3558
Foot-pounds	kg-meters	0.138255
Foot-pounds	kW-hours (Int.)	3.76554×10^{-7}
Foot-pounds	Newton-meters	1.3558
Foot-pounds/hr	Btu/min	2.1432×10^{-5}
Foot-pounds/hr	Ergs/min	2.2597×10^{5}
Foot-pounds/hr	Horsepower (mechanical)	5.0505×10^{-7}
Foot-pounds/hr	Horsepower (metric)	5.121×10^{-7}
Foot-pounds/hr	Kilowatts	3.766×10^{-7}
Horsepower (mechanical)	Btu (mean)/hr	2.5425×10^{3}
Horsepower (mechanical)	Ergs/sec	7.457×10^{9}
Horsepower (mechanical)	Foot-pounds/hr	1.980×10^{6}
Horsepower (mechanical)	Horsepower (boiler)	0.07602
Horsepower (mechanical)	Horsepower (electric)	0.9996
Horsepower (mechanical)	Horsepower (metric)	1.0139
Horsepower (mechanical)	Joules/sec	745.70
Horsepower (mechanical)	Kilowatts (Int.)	0.74558
Horsepower (boiler)	Btu (mean)/hr	3.3446×10^{4}
Horsepower (boiler)	Ergs/sec	9.8095×10^{10}
Horsepower (boiler)	Foot-pounds/min	4.341×10^{5}
Horsepower (boiler)	Horsepower (mechanical)	13.155

CONVERSION FACTORS (cont.).

Horsepower (boiler)	Horsepower (electric)	13.15
Horsepower (boiler)	Horsepower (metric)	13.337
Horsepower (boiler)	Joules/sec	9.8095×10^{3}
Horsepower (boiler)	Kilowatts	9.8095
Horsepower (electric)	Btu (mean)/hr	2.5435×10^{3}
Horsepower (electric)	Cal. kg/hr	641.87
Horsepower (electric)	Ergs/sec	7.46×10^{9}
Horsepower (electric)	Foot-pounds/min	3.3013×10^{4}
Horsepower (electric)	Horsepower (boiler)	0.07605
Horsepower (electric)	Horsepower (metric)	1.0143
Horsepower (electric)	Joules/sec	746.0
Horsepower (electric)	Kilowatts	0.746
Horsepower (metric)	Btu (mean)/hr	2.5077×10^{3}
Horsepower (metric)	Ergs/sec	7.355×10^{9}
Horsepower (metric)	Foot-pounds/min	3.255×10^{4}
Horsepower (metric)	Horsepower (mechanical)	0.98632
Horsepower (metric)	Horsepower (boiler)	0.07498
Horsepower (metric)	Horsepower (electric)	0.9859
Horsepower (metric)	kg-meters/sec	75.0
Horsepower (metric)	Kilowatts	0.7355
Horsepower-hours	Btu (mean)	2.5425×10^{3}
Horsepower-hours	Foot-pounds	1.98×10^{6}
Horsepower-hours	Joules	2.6845×10^{6}
Horsepower-hours	kg-meters	2.73745×10^{5}
Horsepower-hours	kW-hours	0.7457
Joules (Int.)	Btu (IST.)	9.4799×10^{-4}
Joules (Int.)	Ergs	1.0002×10^{7}
Joules (Int.)	Foot-poundals	12.734
Joules (Int.)	Foot-pounds	0.73768
Joules (Int.)	kW-hours	2.778×10^{-7}

CONVERSION FACTORS (cont.).

Joules (Int.)/sec	Btu (mean)/min	0.05683
Joules (Int.)/sec	Cal. kg/min	0.01434
Joules (Int.)/sec	Horsepower	1.341×10^{-3}
Kilogram-meters	Btu (mean)	9.2878×10^{-3}
Kilogram-meters	Cal. kg (mean)	2.3405×10^{-3}
Kilogram-meters	Ergs	9.80665×10^{7}
Kilogram-meters	Foot-poundals	232.715
Kilogram-meters	Foot-pounds	7.233
Kilogram-meters	Hp-hours	3.653×10^{-6}
Kilogram-meters	Joules (Int.)	9.805
Kilogram-meters	kW-hours	2.724×10^{-6}
Kilogram-meters/sec	Watts	9.80665
Kilowatts (Int.)	Btu (IST.)/hr	3.413×10^{3}
Kilowatts (Int.)	Cal. kg (IST.)/hr	860.0
Kilowatts (Int.)	Ergs/sec	1.0002×10^{10}
Kilowatts (Int.)	Foot-poundals/min	1.424×10^{6}
Kilowatts (Int.)	Foot-pounds/min	4.4261×10^{4}
Kilowatts (Int.)	Horsepower (mechanical)	1.341
Kilowatts (Int.)	Horsepower (boiler)	0.10196
Kilowatts (Int.)	Horsepower (electric)	1.3407
Kilowatts (Int.)	Horsepower (metric)	1.3599
Kilowatts (Int.)	Joules (Int.)/hr	3.6×10^{6}
Kilowatts (Int.)	kg-meters/hr	3.6716×10^{5}
Kilowatt-hours (Int.)	Btu (mean)	3.41×10^{3}
Kilowatt-hours (Int.)	Foot-pounds	2.6557×10^{6}
Kilowatt-hours (Int.)	Hp-hours	1.341
Kilowatt-hours (Int.)	Joules (Int.)	3.6×10^{6}
Kilowatt-hours (Int.)	kg-meters	3.6716×10^{5}
Newton-meters	Gram-cm	1.01972×10^{4}
Newton-meters	kg-meters	0.101972

CONVERSION FACTORS (cont.).

Newton-meters	Pound-feet	0.73756
Force		
Dynes	Newtons	1.0×10^{-5}
Dynes	Poundals	7.233×10^{-5}
Dynes	Pounds	2.248×10^{-6}
Newtons	Dynes	1.0×10^{-5}
Newtons	Pounds (avdp.)	0.22481
Poundals	Dynes	1.383×10^{4}
Poundals	Newtons	0.1383
Poundals	Pounds (avdp.)	0.03108
Pounds (avdp.)	Dynes	4.448×10^{5}
Pounds (avdp.)	Newtons	4.448
Pounds (avdp.)	Poundals	32.174
Length		
Feet	Centimeters	30.48
Feet	Inches	12
Feet	Kilometers	3.048×10^{-4}
Feet	Meters	0.3048
Feet	Miles (statute)	1.894×10^{-4}
Inches	Centimeters	2.540
Inches	Feet	0.08333
Inches	Kilometers	2.54×10^{-5}
Inches	Meters	0.0254
Kilometers	Feet	3.2808×10^{3}
Kilometers	Meters	1000
Kilometers	Miles (statute)	0.62137
Kilometers	Yards	1.0936×10^{3}
Meters	Feet	3.2808
Meters	Inches	39.370
Micrometers	Angstrom units	1.0×10^{4}

CONVERSION FACTORS (cont.).

Micrometers	Centimeters	1.0×10^{-3}
Micrometers	Feet	3.2808×10^{-6}
Micrometers	Inches	3.9370×10^{-5}
Micrometers	Meters	1.0×10^{-6}
Micrometers	Millimeters	0.001
Micrometers	Nanometers	1000
Miles (statute)	Feet	5280
Miles (statute)	Kilometers	1.6093
Miles (statute)	Meters	1.6093×10^{3}
Miles (statute)	Yards	1760
Millimeters	Angstrom units	1.0×10^{7}
Millimeters	Centimeters	0.1
Millimeters	Inches	0.03937
Millimeters	Meters	0.001
Millimeters	Micrometers	1000
Millimeters	Mils	39.37
Nanometers	Angstrom units	10
Nanometers	Centimeters	1.0×10^{-7}
Nanometers	Inches	3.937×10^{-8}
Nanometers	Micrometers	0.001
Nanometers	Millimeters	1.0×10^{-6}
Yards	Centimeters	91.44
Yards	Meters	0.9144
Mass		
Grains	Grams	0.064799
Grains	Milligrams	64.799
Grains	Pounds (apoth. or troy)	1.7361×10^{-4}
Grains	Pounds (avdp.)	1.4286×10^{-4}
Grains	Tons (metric)	6.4799×10^{-8}
Grams	Dynes	980.67

CONVERSION FACTORS (cont.).

Grams	Grains	15.432
Grams	Kilograms	0.001
Grams	Micrograms	**¡Error! No se encuentra el origen de la referencia.**1 x 10^{6}
Grams	Pounds (avdp.)	2.205 x 10^{-3}
Grams	Tons, metric (megagrams)	**¡Error! No se encuentra el origen de la referencia.**1 x 10^{-6}
Kilograms	Grains	1.5432 x 10^{4}
Kilograms	Poundals	70.932
Kilograms	Pounds (apoth. or troy)	2.679
Kilograms	Pounds (avdp.)	2.2046
Kilograms	Tons (long)	9.842 x 10^{-4}
Kilograms	Tons (metric)	0.001
Kilograms	Tons (short)	1.1023 x 10^{-3}
Megagrams	Tons (metric)	1.0
Milligrams	Grains	0.01543
Milligrams	Grams	1.0 x 10^{-3}
Milligrams	Ounces (apoth. or troy)	3.215 x 10^{-5}
Milligrams	Ounces (avdp.)	3.527 x 10^{-5}
Milligrams	Pounds (apoth. or troy)	2.679 x 10^{-6}
Milligrams	Pounds (avdp.)	2.2046 x 10^{-6}
Ounces (apoth. or troy)	Grains	480
Ounces (apoth. or troy)	Grams	31.103
Ounces (apoth. or troy)	Ounces (avdp.)	1.097
Ounces (avdp.)	Grains	437.5
Ounces (avdp.)	Grams	28.350
Ounces (avdp.)	Ounces (apoth. or troy)	0.9115
Ounces (avdp.)	Pounds (apoth. or troy)	0.075955
Ounces (avdp.)	Pounds (avdp.)	0.0625
Pounds (avdp.)	Poundals	32.174
Pounds (avdp.)	Pounds (apoth. or troy)	1.2153
Pounds (avdp.)	Tons (long)	4.4643 x 10^{-4}

CONVERSION FACTORS (cont.).

Pounds (avdp.)	Tons (metric)	4.5359×10^{-4}
Pounds (avdp.)	Tons (short)	5.0×10^{-4}
Pounds (avdp.)	Grains	7000
Pounds (avdp.)	Grams	453.59
Pounds (avdp.)	Ounces (apoth. or troy)	14.583
Pounds (avdp.)	Ounces (avdp.)	16
Tons (long)	Kilograms	1.016×10^{3}
Tons (long)	Pounds (apoth. or troy)	2.722×10^{3}
Tons (long)	Pounds (avdp.)	2.240×10^{3}
Tons (long)	Tons (metric)	1.016
Tons (long)	Tons (short)	1.12
Tons (metric)	Grams	1.0×10^{6}
Tons (metric)	Megagrams	1.0
Tons (metric)	Pounds (apoth. or troy)	2.6792×10^{3}
Tons (metric)	Pounds (avdp.)	2.2046×10^{3}
Tons (metric)	Tons (long)	0.9842
Tons (metric)	Tons (short)	1.1023
Tons (short)	Kilograms	907.18
Tons (short)	Pounds (apoth. or troy)	2.4301×10^{3}
Tons (short)	Pounds (avdp.)	2000
Tons (short)	Tons (long)	0.8929
Tons (short)	Tons (metric)	0.9072
Pressure		
Atmospheres	cm of H_2O (4°C)	1.033×10^{3}
Atmospheres	Ft of H_2O (39.2°F)	33.8995
Atmospheres	In. of Hg (32°F)	29.9213
Atmospheres	kg/sq cm	1.033
Atmospheres	mm of Hg (0°C)	760
Atmospheres	Pounds/sq inch	14.696
Inches of Hg (60°F)	Atmospheres	0.03333

CONVERSION FACTORS (cont.).

Inches of Hg (60°F)	Grams/sq cm	34.434
Inches of Hg (60°F)	mm of Hg (60°F)	25.4
Inches of Hg (60°F)	Pounds/sq ft	70.527
Inches of H_2O (4°C)	Atmospheres	2.458 x 10^{-3}
Inches of H_2O (4°C)	In. of Hg (32°F)	0.07355
Inches of H_2O (4°C)	kg/sq meter	25.399
Inches of H_2O (4°C)	Pounds/sq ft	5.2022
Inches of H_2O (4°C)	Pounds/sq inch	0.036126
Kilograms/sq cm	Atmospheres	0.96784
Kilograms/sq cm	cm of Hg (0°C)	73.556
Kilograms/sq cm	Ft of H_2O (39.2°F)	32.809
Kilograms/sq cm	In. of Hg (32°F)	28.959
Kilograms/sq cm	Pounds/sq inch	14.223
Millimeters of Hg (0°C)	Atmospheres	1.3158 x 10^{-3}
Millimeters of Hg (0°C)	Grams/sq cm	1.3595
Millimeters of Hg (0°C)	Pounds/sq inch	0.019337
Pounds/sq inch	Atmospheres	0.06805
Pounds/sq inch	cm of Hg (0°C)	5.1715
Pounds/sq inch	cm of H_2O (4°C)	70.309
Pounds/sq inch	In. of Hg (32°F)	2.036
Pounds/sq inch	In. of H_2O (39.2°F)	27.681
Pounds/sq inch	kg/sq cm	0.07031
Pounds/sq inch	mm of Hg (0°C)	51.715
Velocity		
Centimeters/sec	Feet/min	1.9685
Centimeters/sec	Feet/sec	0.0328
Centimeters/sec	Kilometers/hr	0.036
Centimeters/sec	Meters/min	0.6
Centimeters/sec	Miles/hr	0.02237

CONVERSION FACTORS (cont.).

Feet/minute	cm/sec	0.508
Feet/minute	Kilometers/hr	0.01829
Feet/minute	Meters/min	0.3048
Feet/minute	Meters/sec	5.08×10^{-3}
Feet/minute	Miles/hr	0.01136
Feet/sec	cm/sec	30.48
Feet/sec	Kilometers/hr	1.0973
Feet/sec	Meters/min	18.288
Feet/sec	Miles/hr	0.6818
Kilometers/hr	cm/sec	27.778
Kilometers/hr	Feet/hr	3.2808×10^{3}
Kilometers/hr	Feet/min	54.681
Kilometers/hr	Meters/sec	0.27778
Kilometers/hr	Miles (statute)/hr	0.62137
Meters/min	cm/sec	1.6667
Meters/min	Feet/min	3.2808
Meters/min	Feet/sec	0.05468
Meters/min	Kilometers/hr	0.06
Miles/hr	cm/sec	44.704
Miles/hr	Feet/hr	5280
Miles/hr	Feet/min	88
Miles/hr	Feet/sec	1.4667
Miles/hr	Kilometers/hr	1.6093
Miles/hr	Meters/min	26.822
Volume		
Barrels (petroleum, U. S.)	Cu feet	5.6146
Barrels (petroleum, U. S.)	Gallons (U. S.)	42
Barrels (petroleum, U. S.)	Liters	158.98
Barrels (U. S., liq.)	Cu feet	4.2109
Barrels (U. S., liq.)	Cu inches	7.2765×10^{3}

CONVERSION FACTORS (cont.).

Barrels (U. S., liq.)	Cu meters	0.1192
Barrels (U. S., liq.)	Gallons (U. S., liq.)	31.5
Barrels (U. S., liq.)	Liters	119.24
Cubic centimeters	Cu feet	3.5315×10^{-5}
Cubic centimeters	Cu inches	0.06102
Cubic centimeters	Cu meters	1.0×10^{-6}
Cubic centimeters	Cu yards	1.308×10^{-6}
Cubic centimeters	Gallons (U. S., liq.)	2.642×10^{-4}
Cubic centimeters	Quarts (U. S., liq.)	1.0567×10^{-3}
Cubic feet	Cu centimeters	2.8317×10^{4}
Cubic feet	Cu meters	0.028317
Cubic feet	Gallons (U. S., liq.)	7.4805
Cubic feet	Liters	28.317
Cubic inches	Cu cm	16.387
Cubic inches	Cu feet	5.787×10^{-4}
Cubic inches	Cu meters	1.6387×10^{-5}
Cubic inches	Cu yards	2.1433×10^{-5}
Cubic inches	Gallons (U. S., liq.)	4.329×10^{-3}
Cubic inches	Liters	0.01639
Cubic inches	Quarts (U. S., liq.)	0.01732
Cubic meters	Barrels (U. S., liq.)	8.3864
Cubic meters	Cu cm	1.0×10^{6}
Cubic meters	Cu feet	35.315
Cubic meters	Cu inches	6.1024×10^{4}
Cubic meters	Cu yards	1.308
Cubic meters	Gallons (U. S., liq.)	264.17
Cubic meters	Liters	1000
Cubic yards	Bushels (Brit.)	21.022
Cubic yards	Bushels (U. S.)	21.696
Cubic yards	Cu cm	7.6455×10^{5}

CONVERSION FACTORS (cont.).

Cubic yards	Cu feet	27
Cubic yards	Cu inches	4.6656×10^4
Cubic yards	Cu meters	0.76455
Cubic yards	Gallons	168.18
Cubic yards	Gallons	173.57
Cubic yards	Gallons	201.97
Cubic yards	Liters	764.55
Cubic yards	Quarts	672.71
Cubic yards	Quarts	694.28
Cubic yards	Quarts	807.90
Gallons (U. S., liq.)	Barrels (U. S., liq.)	0.03175
Gallons (U. S., liq.)	Barrels (petroleum, U. S.)	0.02381
Gallons (U. S., liq.)	Bushels (U. S.)	0.10742
Gallons (U. S., liq.)	Cu centimeters	3.7854×10^3
Gallons (U. S., liq.)	Cu feet	0.13368
Gallons (U. S., liq.)	Cu inches	231
Gallons (U. S., liq.)	Cu meters	3.7854×10^{-3}
Gallons (U. S., liq.)	Cu yards	4.951×10^{-3}
Gallons (U. S., liq.)	Gallons (wine)	1.0
Gallons (U. S., liq.)	Liters	3.7854
Gallons (U. S., liq.)	Ounces (U. S., fluid)	128.0
Gallons (U. S., liq.)	Pints (U. S., liq.)	8.0
Gallons (U. S., liq.)	Quarts (U. S., liq.)	4.0
Liters	Cu centimeters	1000
Liters	Cu feet	0.035315
Liters	Cu inches	61.024
Liters	Cu meters	0.001
Liters	Gallons (U. S., liq.)	0.2642
Liters	Ounces (U. S., fluid)	33.814

CONVERSION FACTORS (cont.).

Volumetric Rate		
Cu ft/min	Cu cm/sec	471.95
Cu ft/min	Cu ft /hr	60. 0
Cu ft/min	Gal (U. S.)/min	7.4805
Cu ft/min	Liters/sec	0.47193
Cu meters/min	Gal (U. S.)/min	264.17
Cu meters/min	Liters/min	999.97
Gallons (U. S.)/hr	Cu ft/hr	0.13368
Gallons (U. S.)/hr	Cu meters/min	6.309×10^{-5}
Gallons (U. S.)/hr	Cu yd/min	8.2519×10^{-5}
Gallons (U. S.)/hr	Liters/hr	3.7854
Liters/min	Cu ft/min	0.0353
Liters/min	Gal (U. S., liq.)/min	0.2642

Where appropriate, the conversion factors appearing in this table have been rounded to four to six significant figures for ease in use. The accuracy of these numbers is considered suitable for use with emissions data; if a more accurate number is required, tables containing exact factors should be consulted.

CONVERSION FACTORS FOR COMMON AIR POLLUTION MEASUREMENTS

AIRBORNE PARTICULATE MATTER

To Convert From	To	Multiply By
Milligrams/cu m	Grams/cu ft	283.2×10^{-6}
	Grams/cu m	0.001
	Micrograms/cu m	1000.0
	Micrograms/cu ft	28.32
	Pounds/1000 cu ft	62.43×10^{-6}
Grams/cu ft	Milligrams/cu m	35.3145×10^{3}
	Grams/cu m	35.314
	Micrograms/cu m	35.314×10^{6}
	Micrograms/cu ft	1.0×10^{6}
	Pounds/1000 cu ft	2.2046
Grams/cu m	Milligrams/cu m	1000.0
	Grams/cu ft	0.02832
	Micrograms/cu m	1.0×10^{6}
	Micrograms/cu ft	28.317×10^{3}
	Pounds/1000 cu ft	0.06243
Micrograms/cu m	Milligrams/cu m	0.001
	Grams/cu ft	28.317×10^{-9}
	Grams/cu m	1.0×10^{-6}
	Micrograms/cu ft	0.02832
	Pounds/1000 cu ft	62.43×10^{-9}
Micrograms/cu ft	Milligrams/cu m	35.314×10^{-3}
	Grams/cu ft	1.0×10^{-6}
	Grams/cu m	35.314×10^{-6}
	Micrograms/cu m	35.314
	Pounds/1000 cu ft	2.2046×10^{-6}
Pounds/1000 cu ft	Milligrams/cu m	16.018×10^{3}
	Grams/cu ft	0.35314
	Micrograms/cu m	16.018×10^{6}

To Convert From	To	Multiply By
	Grams/cu m	16.018
	Micrograms/cu ft	353.14×10^{3}

CONVERSION FACTORS FOR COMMON AIR POLLUTION MEASUREMENTS (cont.).

SAMPLING PRESSURE

To Convert From	To	Multiply By
Millimeters of mercury (0◦C)	Inches of water (60◦F)	0.5358
Inches of mercury (0◦C)	Inches of water (60◦F)	13.609
	Millimeters of mercury (0◦C)	1.8663
Inches of water (60◦F)	Inches of mercury (0◦C)	73.48×10^{-3}

CONVERSION FACTORS FOR COMMON AIR POLLUTION MEASUREMENTS (cont.).

ATMOSPHERIC GASES

To Convert From	To	Multiply By
Milligrams/cu m	Micrograms/cu m	1000.0
	Micrograms/liter	1.0
	ppm by volume (20°C)	24.04/M
	ppm by weight	0.8347
	Pounds/cu ft	62.43 x 10^{-9}
Micrograms/cu m	Milligrams/cu m	0.001
	Micrograms/liter	0.001
	ppm by volume (20°C)	0.02404/M
	ppm by weight	834.7 x 10^{-6}
	Pounds/cu ft	62.43 x 10^{-12}
Micrograms/liter	Milligrams/cu m	1.0
	Micrograms/cu m	1000.0
	ppm by volume (20°C)	24.04/M
	ppm by weight	0.8347
	Pounds/cu ft	62.43 x 10^{-9}
ppm by volume (20°C)	Milligrams/cu m	M/24.04
	Micrograms/cu m	M/0.02404
	Micrograms/liter	M/24.04
	ppm by weight	M/28.8
	Pounds/cu ft	M/385.1 x 10^{6}
ppm by weight	Milligrams/cu m	1.198
	Micrograms/cu m	1.198 x 10^{-3}
	Micrograms/liter	1.198
	ppm by volume (20°C)	28.8/M
	Pounds/cu ft	7.48 x 10^{-6}
Pounds/cu ft	Milligrams/cu m	16.018 x 10^{6}
	Micrograms/cu m	16.018x 10^{9}
	Micrograms/liter	16.018x 10^{6}

To Convert From	To	Multiply By
	ppm by volume (20◦C)	385.1 x 10^6/M
	ppm by weight	133.7 x 10^3

M = Molecular weight of gas.

CONVERSION FACTORS FOR COMMON AIR POLLUTION MEASUREMENTS (cont.).

VELOCITY

To Convert From	To	Multiply By
Meters/sec	Kilometers/hr	3.6
	Feet/sec	3.281
	Miles/hr	2.237
Kilometers/hr	Meters/sec	0.2778
	Feet/sec	0.9113
	Miles/hr	0.6214
Feet/sec	Meters/sec	0.3048
	Kilometers/hr	1.09728
	Miles/hr	0.6818
Miles/hr	Meters/sec	0.4470
	Kilometers/hr	1.6093
	Feet/sec	1.4667

ATMOSPHERIC PRESSURE

To Convert From	To	Multiply By
Atmospheres	Millimeters of mercury	760.0
	Inches of mercury	29.92
	Millibars	1013.2
Millimeters of mercury	Atmospheres	1.316×10^{-3}
	Inches of mercury	39.37×10^{-3}
	Millibars	1.333
Inches of mercury	Atmospheres	0.03333
	Millimeters of mercury	25.4005
	Millibars	33.35
Millibars	Atmospheres	0.00987
	Millimeters of mercury	0.75
	Inches of mercury	0.30

VOLUME EMISSIONS

To Convert From	To	Multiply By
Cubic m/min	Cubic ft/min	35.314
Cubic ft/min	Cubic m/min	0.0283

BOILER CONVERSION FACTORS

1 Megawatt = 10.5 x 10^{6} Btu/hr
(8 to 14 x 10^{6} Btu/hr)

1 Megawatt = 8 x 10^{3} lb steam/hr
(6 to 11 x 10^{3} lb steam/hr)

1 BHP = 34.5 lb steam/hr

1 BHP = 45 x 10^{3} Btu/hr
(40 to 50 x 10^{3} Btu/hr)

1 lb steam/hr = 1.4 x 10^{3} Btu/hr
(1.2 to 1.7 x 10^{3} Btu/hr)

NOTES: In the relationships,

Megawatt is the net electric production of a steam electric power plant.

BHP is boiler horsepower.

lb steam/hr is the steam production rate of the boiler.

Btu/hr is the heat input rate to the boiler (based on the gross or high heating value of the fuel burned).

For less efficient (generally older and/or smaller) boiler operations, use the higher values expressed. For more efficient operations (generally newer and/or larger), use the lower values.

Volume	cu in	ml	liters	ounces (U. S. fl.)	gallons (U. S.)	barrels (U. S.)	cu ft
Cubic inches		16.3868	0.0163868	0.5541	4.3290x10^{-3}	1.37429x10^{-4}	5.78704x10^{-4}
Milliliters	0.061024		0.001	0.03381	2.6418x10^{-4}	8.387x10^{-6}	3.5316x10^{-5}
Liters	61.024	1000		33.8147	0.26418	8.387x10^{-3}	0.035316
Ounces (U. S. fl.)	1.80469	29.5729	0.029573		7.8125x10^{-3}	2.48x10^{-4}	1.0443x10^{-3}
Gallons (U. S.)[a]	231	3785.3	3.7853	128		0.031746	0.13368
Barrels (U. S.)	7276.5	1.1924x10^{5}	119.2369	4032.0	31.5		4.2109
Cubic feet	1728	2.8316x10^{4}	28.316	957.568	7.481	0.23743	

[a] U.S. gallon of water at 16.7ºC (62ºF) weighs 3.780kg or 8.337 pounds (avoir.)

Mass	grams	kilograms	ounces (avoir.)	pounds (avoir.)	grains	tons (U. S.)	milligrams
Grams		0.001	3.527x10^{-2}	2.205x10^{-3}	15.432	1.102x10^{-6}	1000

Kilograms	1000		35.274	2.2046	15432	1.102×10^{-3}	1×10^{6}
Ounces (avoir.)	28.350	0.028350		0.0625	437.5	3.125×10^{-5}	2.8350×10^{4}
Pounds (avoir.)[a]	453.59	0.45359	16.0		7000	5.0×10^{-4}	4.5359×10^{5}
Grains	0.06480	6.480×10^{-5}	2.286×10^{-3}	1.429×10^{-4}		7.142×10^{-8}	64.799
Tons (U. S.)	9.072×10^{5}	907.19	3.200×10^{4}	2000	1.4×10^{7}		9.0718×10^{8}
Milligrams	0.001	1×10^{-6}	3.527×10^{-5}	2.205×10^{-6}	0.015432	1.102×10^{-9}	

[a] Mass of 27.692 cubic inches water weighed in air at 4.0ºC, 760 mm mercury pressure.

Work and Energy	g cal.	kg cal.	ergs	joules	Btu	ft lb	kg meters	L-Atm	HP hours	ft poun
Gram calories (mean)		0.001	$4.186x10^{7}$	4.186	$3.9680x10^{-3}$	3.0874	0.42685	0.041311	$1.5593x10^{-6}$	99.33
Kilogram calories	1000		$4.186x10^{10}$	4186	3.9680	3087.4	426.85	41.311	$1.5593x10^{-3}$	9933
Ergs	$2.3889x10^{-8}$	$2.3889x10^{-11}$		$1x10^{-7}$	$9.4805x10^{-11}$	$7.3756x10^{-8}$	$1.0197x10^{-8}$	$9.8689x10^{-10}$	$3.7251x10^{-14}$	2.3730x
Joules	0.23889	$2.3889x10^{-4}$	$1x10^{7}$		$9.4805x10^{-4}$	0.73756	0.10197	$9.8689x10^{-3}$	$3.7251x10^{-7}$	23.73
Btu (mean)	251.98	0.25198	$1.0548x10^{10}$	1054.8		777.98	107.56	10.409	$3.9292x10^{-4}$	2.5030x
Foot pounds	0.32389	$3.2389x10^{-4}$	$1.35582x10^{7}$	1.3558	$1.2854x10^{-3}$		0.13825	0.013381	$5.0505x10^{-7}$	32.17
Kilogram meters	2.3427	$2.3427x10^{-3}$	$9.8066x10^{7}$	9.8066	$9.2967x10^{-3}$	7.2330		0.096781	$3.6529x10^{-6}$	232.7
Liter atmospheres (normal)	24.206	$2.4206x10^{-2}$	$1.0133x10^{9}$	101.328	0.09606	74.735	10.333		$3.7745x10^{-5}$	2404.
Horsepower hours	$6.4130x10^{5}$	641.30	$2.6845x10^{13}$	$2.6845x10^{6}$	2454.0	$1.9800x10^{6}$	$2.7374x10^{5}$	26494		6.3705x
Foot poundals	0.010067	$10.067x10^{-6}$	$4.21402x10^{5}$	0.04214	$3.9952x10^{-5}$	0.031081	$4.2972x10^{-3}$	$4.1558x10^{-4}$	$1.5697x10^{-8}$	
Kilowatt hours	$8.6001x10^{5}$	860.01	$3.6000x10^{13}$	$3.6000x10^{6}$	3413.0	$2.6552x10^{6}$	$3.6709x10^{-5}$	$3.5529x10^{6}$	1.3440	8.5430x
Watt hours	860.01	0.86001	$3.6000x10^{10}$	3600	3.4130	2655.3	367.09	$3.5529x10^{3}$	$1.3410x10^{-3}$	8.5430x

Power	watts	kW	ft lb/sec	erg/sec	Btu/min	g cm/sec	kg cal/min	HP	lumens
Watts		0.001	0.73756	1x10^{7}	0.056884	1.0197x10^{4}	0.01433	1.341x10^{-3}	668
Kilowatts	1000		737.56	1x10^{10}	56.884	1.0197x10^{7}	14.3334	1.3410	6.68x10^{5}
Foot pounds per second	1.35582	1.3558x10^{-3}		1.3558x10^{7}	0.077124	1.3826x10^{4}	0.019433	1.8182x10^{-3}	906.28
Ergs per second	1x10^{-7}	1x10^{-10}	7.3756x10^{-8}		5.688x10^{-9}	1.0197x10^{-3}	1.4333x10^{-9}	1.3410x10^{-10}	6.6845x10^{-5}
Btu[a] per minute	17.580	0.017580	12.9600	1.7580x10^{8}		1.7926x10^{5}	0.2520	0.023575	11751
Gram centimeters per second	9.8067x10^{-5}	9.8067x10^{-8}	7.2330x10^{-5}	980.665	5.5783x10^{-6}		1.4056x10^{-6}	1.3151x10^{-7}	0.065552
Kilogram calories per minute	69.767	0.069767	51.457	6.9770x10^{8}	3.9685	7.1146x10^{5}		0.093557	46636
Horsepower (U. S.)	745.7	0.7457	550	7.457x10^{9}	42.4176	7.6042x10^{6}	10.688		498129
Lumens	1.496x10^{-3}	1.496x10^{-6}	1.0034x10^{-3}	1.496x10^{4}	8.5096x10^{-5}	15.254	2.1437x10^{-5}	2.0061x10^{-6}	
Joules per second	1	0.001	0.73756	1x10^{7}	0.056884	1.0197x10^{4}	0.01433	1.341x10^{-3}	668
Btu[a] per hour	0.29299	2.9299x10^{-4}	0.21610	2.9299x10^{6}	0.01667	2.9878x10^{3}	4.1997x10^{-3}	3.9291x10^{-4}	195.80

[a] Brotish thermal Units (Mean)

CONVERSION FACTORS FOR VARIOUS SUBSTANCES[a]

Type Of Substance	Conversion Factors
Fuel	
Oil	1 bbl = 159 liters (42 gal)
Natural gas	1 therm = 100,000 Btu (approx.25000 kcal)
Gaseous Pollutants	
O_3	1 ppm, volume = 1960µg/m^3
NO_2	1 ppm, volume = 1880µg/m^3
SO_2	1 ppm, volume = 2610µg/m^3
H_2S	1 ppm, volume = 1390 µg/m^3
CO	1 ppm, volume = 1.14 mg/m^3
HC (as methane)	1 ppm, volume = 0.654 mg/m^3
Agricultural products	
Corn	1 bu = 25.4 kg = 56 lb
Milo	1 bu = 25.4 kg = 56 lb
Oats	1 bu = 14.5 kg = 32 lb
Barley	1 bu = 21.8 kg = 48 lb
Wheat	1 bu = 27.2 kg = 60 lb
Cotton	1 bale = 226 kg = 500 lb
Mineral products	
Brick	1 brick = 2.95 kg = 6.5 lb
Cement	1 bbl = 170 kg = 375 lb
Cement	1 yd^3 = 1130 kg = 2500 lb
Concrete	1 yd^3 = 1820 kg = 4000 lb
Mobile sources, fuel efficiency	
Motor vehicles	1.0 mi/gal = 0.426 km/liter
Waterborne vessels	1.0 gal/naut mi = 2.05 liters/km
Miscellaneous liquids	
Beer	1 bbl = 31.5 gal
Paint	1 gal = 4.5 to 6.82 kg = 10 to 15 lb
Varnish	1 gal = 3.18 kg = 7 lb
Whiskey	1 bbl = 190 liters = 50.2 gal
Water	1 gal = 3.81 kg = 8.3 lb

Many of the conversion factors in this table represent average values and approximations and some of the values vary with temperature and pressure. These conversion factors should, however, be sufficiently accurate for general field use.

APPENDIX B

INDEX OF EXAMPLE PROBLEMS IN MEXICO EMISSIONS INVENTORY MANUALS

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Volume VI - Motor Vehicle Inventory Development

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Section 3.4.2	Effects of Vehicle Speed

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FINAL

Elaborado para:

La Asociación de Gobernadores del Oeste
Denver, Colorado

y

El Comité Asesor Binacional

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LISTA DE ACRONIMOS

bbl	barriles
Btu	Unidad térmica británica
C	Celsius
C_8H_{18}	octano
CE	carbón elemental
CFC	clorofluorocarbono
cfm	pie cúbico por minuto
CI	combustión interna
co	carbón orgánico
CO	monóxido de carbono
CO_2	dióxido de carbono
EC	eficiencia de control
ec	encendido por chispa
ERD	eficiencia de remoción de la destrucción
EU	Estados Unidos
F	Fahrenheit
ft	pie
ft^3	pie cúbico
g	gramo
gal	galón
GOR	gas orgánico reactivo

GOT	gas orgánico total
H_2O	agua
hr	hora
HVLP	alto volumen/baja presión
IC	ignición por compresión
J	joule
kcal	kilocaloría
kg	kilogramo
kW	kilowatt
lb	libra
LPG	gas licuado de petróleo (gas LP)
m	metro
m^3	metro cúbico
MEK	metil-etil-cetona
Mg	megagramo (i.e. 10^6 g = 1 tonelada métrica)
mg	miligramo
ml	mililitro
MMBtu	10^6 unidades térmicas británicas
mmHg	milímetros de mercurio
MMscf	10^6 pies cúbicos estándar
mol	mol
MW	peso molecular

n	número de moles
N_2	Nitrógeno
ng	nanogramo
NMHC	hidrocarburos no metánicos
NO_2	dióxido de nitrógeno
NO_x	óxidos de nitrógeno
O_2	Oxígeno
P	Presión
PEMEX	Petróleos Mexicanos
PM	Material particulado (partículas)
PM_{10}	Partículas de diámetro aerodinámico menor o igual a 10 micrómetros
$PM_{2.5}$	Partículas de diámetro aerodinámico menor o igual a 2.5 micrómetros
ppmv	partes por millón - volumen
psi	libras por pulgada cuadrada
psia	libras por pulgada cuadrada absolutas
psig	libras por pulgada cuadrada (manométrica)
PSM	multiplicador del tamaño de partícula
PST	partículas suspendidas totales
PVR	presión de vapor de Reid
R	constante de los gases ideales
R	Rankine
RAC	relación aire a combustible

REAC	relación de equivalencia aire/combustible
scf	pie cúbico estándar
scfm	pie cúbico estándar por minuto
SIG	Sistema de Información Geográfica
sm^3	metro cúbico estándar
SO_x	óxidos de azufre
T	temperatura
TAA	tanque de almacenamiento aéreo
U.S. EPA	Agencia de Protección Ambiental de Estados Unidos
V	volumen
VKT	kilómetros recorridos por vehículo
wt%	porcentaje en peso
µg	microgramo
µm	micrómetro (micrón)

Introducción

Objetivo y Alcance

El objetivo de este cuaderno de trabajo consiste en proporcionar ejemplos de problemas que ilustren las diversas técnicas para la estimación de emisiones que son utilizadas durante el desarrollo de un inventario de emisiones. El material que se presenta en este cuaderno pretende por un lado, facilitar los programas de capacitación, y por otro, ser utilizado como un recurso documental durante el desarrollo de estimaciones de emisiones por parte de diversas autoridades estatales y municipales.

Este cuaderno de trabajo contiene ejemplos apegados a la realidad, cada uno de los cuales ha sido cuidadosamente redactado para explicar en detalle las bases de cada técnica de estimación, así como cualesquier supuestos inherentes a ésta. Se ha puesto un énfasis especial para explicar el proceso de razonamiento y las decisiones que pueden tomarse al aplicar la técnica ilustrada. El material de este cuaderno de trabajo mostrará el uso de principios ingenieriles específicos e ilustrará la aplicación del juicio ingenieril y las técnicas de solución de problemas para el desarrollo de los estimados de emisiones en México.

Retos de las Técnicas de Emisión ("Más Allá del Libro de Cocina")

Con la información suficiente, el cálculo de los estimados de emisión de cualquier fuente es, en general, un ejercicio matemático directo. Es posible hacer una analogía en el sentido de que las técnicas de estimados de emisión son tan directas como recetas en un libro de cocina. Sin embargo, cuando se conduce un inventario de emisiones real, a menudo existen fuentes individuales o categorías de fuentes completas para las que el desarrollo de estimados de emisión no es tan simple. Para aplicar la analogía del libro de cocina, existen fuentes y categorías de fuente para las que no existen recetas sencillas.

El problema que se encuentra con mayor frecuencia en cualquier proyecto de inventario de emisiones es la falta de información. En estos casos, la tarea de estimar las emisiones se hace más compleja, y se requiere la aplicación del juicio ingenieril y diversas habilidades para la resolución de problemas. En este cuaderno de trabajo, el Ejemplo 3 (Combustión Residencial) fue desarrollado específicamente para ilustrar algunas de las técnicas que son utilizadas de manera típica para subsanar la falta de datos. Este Ejemplo es una discusión detallada de la metodología utilizada durante el desarrollo de un inventario de emisiones atmosféricas de tóxicos para Nogales, Sonora.

Cuatro de los métodos más comunes para remediar la falta de datos consisten en:

- Derivar la información necesaria a partir de los datos disponibles
- Desarrollar enfoques alternativos razonables para estimar las emisiones
- Aplicar supuestos y estimados limitados al problema
- Recopilar datos adicionales.

El Ejemplo 3 ilustra el proceso de decisión utilizado para seleccionar el más apropiado de estos métodos. Algunos otros ejemplos en este cuaderno de trabajo también ilustran las técnicas que pueden utilizarse para remediar la falta de datos (ver Ejemplos 2a y 7).

Otras dificultades que se encuentran comúnmente al conducir un inventario de emisiones incluyen:

- La selección de la técnica de estimación de emisiones adecuada para cada fuente, incluyendo la selección de los factores de emisión
- El asegurar una precisión razonable en los datos utilizados para elaborar el estimado, incluyendo la selección de la información de fuentes de datos conflictivas

- La verificación de que las emisiones calculadas constituyan una estimación realista de las emisiones verdaderas de la fuente. Si las emisiones calculadas no son realistas, o si no existe una base de comparación razonable, entonces es necesario calcular el nivel de incertidumbre del estimado.

Para lograr el estimado de emisiones más razonable y realista, es necesario identificar y caracterizar todos los tipos y fuentes de emisión posibles, seleccionar las técnicas de estimación adecuadas, desarrollar una comprensión de las técnicas seleccionadas, hacer cualesquier supuestos necesarios y reunir, o desarrollar de alguna otra forma, los datos necesarios para los cálculos. Una vez que la información necesaria esté disponible, los estimados de emisión deben prepararse y documentarse a fondo. Adicionalmente, y como aspecto crítico de la calidad general de cualquier proyecto técnico similar al desarrollo de estimados de emisión, se encuentra la revisión consistente por parte de expertos. Los revisores en general, son personas familiarizadas con la fuente de emisión específica, con experiencia en el campo de la estimación de emisiones. Cada decisión, suposición y cálculo debe ser revisado detalladamente para asegurar la precisión y racionalidad de los estimados finales.

Al igual que en cualquier otro proyecto ingenieril o de investigación científica de gran magnitud, con frecuencia existen muchos problemas interesantes y demandantes que deben ser resueltos durante un esfuerzo de desarrollo de inventario de emisiones. Varios de los problemas más comunes han sido analizados en los ejemplos que se presentan en este cuaderno de trabajo. Como se explica en esta sección y se ilustra en el resto del documento, los problemas más frecuentes no siempre tienen soluciones simples. Los responsables de la elaboración de estimados de emisión se beneficiarán de un entendimiento más profundo de los principios y supuestos inherentes a cada una de las técnicas que se ilustran en este cuaderno de trabajo que, el cual, a su vez, está integrado por siete ejemplos:

- Ejemplo 1 – Motores Estacionarios de Combustión Interna
- Ejemplo 2 – Equipos de Combustión Externa
- Ejemplo 3 – Calefacción Residencial (combustión de biomasa)

- Ejemplo 4 – Sistemas de Distribución de Gasolina
- Ejemplo 5 – Fuentes de Evaporación de Solventes
- Ejemplo 6 – Uso de Datos de Prueba en Fuente Puntual
- Ejemplo 7 – Partículas.

Algunos de estos ejemplos tienen varias partes. Adicionalmente, también se presenta información complementaria para diversos ejemplos.

En los casos donde fue posible, los ejemplos se calcularon utilizando unidades métricas. Las unidades inglesas se utilizan en los demás casos. El Apéndice A contiene una recopilación de factores de conversión y propiedades de los materiales; y el Apéndice B, presenta una lista de ejemplos de problemas que se encuentran en la Serie de Manuales para el Programa del Inventario de Emisiones de México.

Finalmente, todos los ejemplos recopilados en este cuaderno de trabajo presentan situaciones hipotéticas. Los ejemplos muestran las diversas metodologías de cálculo que son útiles. Sin embargo, los datos de actividad contenidos en tales ejemplos **NO** deben ser utilizados en situaciones reales; en su lugar, es necesario recopilar los datos reales.

Ejemplo 1

Motores Estacionarios de Combustión Interna

Los motores estacionarios de combustión interna (CI), son fuentes significativas de emisiones en áreas urbanas que se utilizan en una amplia gama de actividades e incluyen máquinas con movimiento reciprocante (de pistones) y rotatorio. Los principales tipos de combustible para los motores de pistones son la gasolina, el diesel, el combustóleo y el gas natural. Estos son utilizados en equipos tales como generadores y bombas. Los ejemplos de motores CI de movimiento rotatorio incluyen las turbinas de gas utilizadas para la generación de energía eléctrica y en diversas industrias de proceso, y los compresores y turbinas alimentados con gas natural de los gasoductos. Este problema se enfoca en las emisiones de motores CI de pistones alimentados con gasolina y diesel.

Planteamiento del Problema

Estimar las emisiones anuales no controladas de gases orgánicos totales (GOT), monóxido de carbono (CO) óxidos de nitrógeno (NO_x), partículas de diámetro aerodinámico inferior o igual a 10 micrómetros (PM_{10}) y óxidos de azufre (SO_x) provenientes de motores alimentados con diesel.

Información Disponible

Número de Motores:	6
Potencia Nominal:	20 kilowatts (kW) por motor
Horas de Operación:	12 horas diarias, 356 días al año
Factor de Carga Promedio del Motor:	45%
Tipo de Combustible:	Diesel
Tasa de Uso de Combustible:	5 litros/hora de operación
Valor Calorífico del Diesel:	4×10^7 joules (J)/litro (19,300 Btu/lb)
Emisiones Controladas o No Controladas:	No Controladas

Nota: el valor calorífico del diesel en joules/litro fue convertido a partir del valor de 19,300 Btu/lb obtenido en la *Compilation of Air Pollution Emission Factors* (Compilación de Factores de Emisión de Contaminación Atmosférica) (AP-42) (U.S. EPA, 1995a) Tabla 3.3-2, de la EPA como se muestra a continuación:

$$\text{Valor Calorífico}\left(\frac{\text{J}}{\text{litro}}\right)=\left(19{,}300\,\frac{\text{Btu}}{\text{lb}}\right)\left(7.428\,\frac{\text{lb}}{\text{gal}}\right)\left(\frac{1\,\text{gal}}{3.78\,\text{litros}}\right)\left(\frac{1055\,\text{J}}{\text{Btu}}\right)$$

$$\text{Valor Calorífico} = 4.0 \text{ x } 10^{7}\,\frac{\text{J}}{\text{litro}}$$

Metodología – Método del Factor de Emisión Basado en la Potencia Generada

Las emisiones se calculan utilizando factores de emisión específicos (masa de emisión/potencia-tiempo) y diversos tipos de datos de actividad: tiempo de operación del motor, potencia nominal, y el factor de carga del motor (potencia realmente utilizada sobre la potencia disponible). Matemáticamente, esta metodología se representa con la siguiente ecuación:

$$\text{Emisiones}_{p} = \sum_{e=1}^{N} P_e \text{ x } LF_e \text{ x } T_e \text{ x } EF_p$$

donde:

Emisiones_p = Masa de emisión del contaminante p (kg)

N = Número de motores

P_e = Potencia nominal promedio del motor e (kW)

LF_e = Factor de carga típico del motor e (%)

T_e = Periodo de operación del motor e (horas)

EF_p = Factor de emisión para el contaminante p (kg/kW-hr).

Si bien este ejemplo proporciona todos los datos de actividad requeridos, la recopilación de dichos datos puede implicar un proceso adicional. Típicamente, la información del equipo será recopilada en los inventarios de equipo (datos de placa). Si la información no está disponible a través de los inventarios de equipo, debe contactarse al fabricante. De manera alternativa, la información de equipo similar podría ser utilizada si no hubiera otros datos disponibles. El *Nonroad Engine and Vehicle Emissions Study* (Estudio de Emisiones de Motores y Vehículos que no Circulan por Carretera) (U.S. EPA, 1991a) contiene diversas características físicas típicas de motores CI que pueden ser utilizadas cuando la información específica del motor no está disponible.

La referencia principal para los factores de emisión de fuentes estacionarias de combustión interna es el Capítulo 3 del AP-42. La Tabla 1-1 presenta los factores de emisión para motores diesel industriales.

Tabla 1-1

Factores de Emisión para Motores Industriales a Diesel No Controlados

Contaminante	Factor de Emisión (g/kW-hr)	Factor de Emisión (ng/J)
GOT de Escape	1.50	152
GOT Evaporativos	0.00	0.00
GOT del Cárter	0.03	2.71
GOT de Reabastecimiento de Combustible	0.00	0.00
TOG[a] Totales	1.53	154.71
CO	4.06	410
NO_x	18.8	1,896
PM_{10}	1.34	135
SO_x	1.25	126

Fuente: AP-42, Tabla 3.3-1

[a] Los GOT totales están integrados por los GOTs de escape, evaporativos, del cárter y de reabastecimiento de combustible.

Cálculos – Emisiones No Controladas Anuales Utilizando Factores de Emisión Basados en la Potencia Generada

$$E_{TOG} = (6)(20\ kW)(0.45)\left(\frac{12\ hr}{día}\right)\left(\frac{365\ días}{año}\right)\left(\frac{1.53\ g}{kW\text{- }hr}\right)$$

$$= 362\ kg/\ año = 0.36\ Mg/\ año$$

$$E_{CO} = (6)(20\ kW)(0.45)\left(\frac{12\ hr}{día}\right)\left(\frac{365\ días}{año}\right)\left(\frac{4.06\ g}{kW\text{- }hr}\right)$$

$$= 960\ kg/\ año = 0.96\ Mg/\ año$$

$$E_{NOx} = (6)(20\ kW)(0.45)\left(\frac{12\ hr}{día}\right)\left(\frac{365\ días}{año}\right)\left(\frac{18.8\ g}{kW\text{- }hr}\right)$$

$$= 4{,}447\ kg/\ año = 4.45\ Mg\ año$$

$$E_{PM_{10}} = (6)(20\ kW)(0.45)\left(\frac{12\ hr}{día}\right)\left(\frac{365\ días}{año}\right)\left(\frac{1.34\ g}{kW\text{- }hr}\right)$$

$$= 317\ kg/\ año = 0.32\ Mg/\ año$$

$$E_{SOx} = (6)(20\ kW)(0.45)\left(\frac{12\ hr}{día}\right)\left(\frac{365\ días}{año}\right)\left(\frac{1.25\ g}{kW\text{- }hr}\right)$$

$$= 296\ kg/\ año = 0.30\ Mg/\ año$$

Metodología Alternativa – Método del Factor de Emisión Basado en el Consumo de Combustible

Si las características físicas de los motores no están disponibles, es posible utilizar un método alternativo para la estimación de emisiones basado en el uso de combustible. Los factores de emisión basados en el consumo de combustible están disponibles en el AP-42 y otras fuentes. Los factores de potencia generada son un enfoque de estimación de "arriba hacia abajo" que incluyen una considerable cantidad de información específica del equipo. Los factores de emisión de consumo de combustible son enfoques de estimación "de abajo hacia arriba" que tienden a omitir los detalles específicos del equipo. Los factores de emisión basados en la potencia generada son la metodología preferida, sin embargo, las limitaciones de los datos podrían apuntar hacia la utilización de los factores de emisión de consumo de energía.

Las emisiones se calculan utilizando los factores de emisión basados en la entrada de combustible (masa de emisiones/contenido energético del combustible), y diversos tipos de datos de actividad. Los datos de actividad requeridos son: tiempo de operación del motor, tasa de uso de combustible y valor calorífico del combustible. Matemáticamente, esta metodología se representa con la siguiente ecuación:

$$\text{Emisiones}_p = \sum_{e=1}^{N} \text{FUR}_e \text{ x } T_e \text{ x } H \text{ x } \text{EF}_p$$

donde:

Emisiones_p = Masa de emisión del contaminante p (kg)
N = Número de motores
FUR_e = Uso de combustible del motor e (litros/hora)
T_e = Periodo de operación del motor e (horas)
H = Valor calorífico del combustible (J/litro)
EF_p = Factor de emisión para el contaminante p (ng/J).

Los factores de emisión basados en el consumo de combustible también pueden encontrarse en el Capítulo 3 del AP-42, mismos que se presentaron anteriormente en este ejemplo.

Cálculos – Emisiones Anuales No Controladas Utilizando Factores de Emisión Basados en el Consumo de Combustible

$$E_{TOG} = (6)\left(\frac{5\ \text{litros}}{\text{hora}}\right)\left(\frac{12\ \text{horas}}{\text{día}}\right)\left(\frac{365\ \text{días}}{\text{año}}\right)\left(4.0\ \text{x}\ 10^{7}\,\frac{\text{J}}{\text{litro}}\right)\left(154.71\,\frac{\text{ng}}{\text{J}}\right)\left(\frac{1\,\text{kg}}{10^{12}\ \text{ng}}\right)$$

$$= 813\,\text{kg/año}\ = 0.81\,\text{Mg/año}$$

$$E_{CO} = (6)\left(\frac{5\ \text{litros}}{\text{hora}}\right)\left(\frac{12\ \text{horas}}{\text{día}}\right)\left(\frac{365\ \text{días}}{\text{año}}\right)\left(4.0\ \text{x}\ 10^{7}\,\frac{\text{J}}{\text{litro}}\right)\left(410\,\frac{\text{ng}}{\text{J}}\right)\left(\frac{1\,\text{kg}}{10^{12}\ \text{ng}}\right)$$

$$= 2{,}155\ \text{kg/año}\ = 2.16\,\text{Mg/año}$$

$$E_{NOx} = (6)\left(\frac{5\ \text{litros}}{\text{hora}}\right)\left(\frac{12\ \text{horas}}{\text{día}}\right)\left(\frac{365\ \text{días}}{\text{año}}\right)\left(4.0\ \text{x}\ 10^{7}\,\frac{\text{J}}{\text{litro}}\right)\left(1{,}896\,\frac{\text{ng}}{\text{J}}\right)\left(\frac{1\,\text{kg}}{10^{12}\ \text{ng}}\right)$$

$$= 9{,}965\ \text{kg/año}\ = 9.97\,\text{Mg/año}$$

$$E_{PM_{10}} = (6)\left(\frac{5\ \text{litros}}{\text{hora}}\right)\left(\frac{12\ \text{horas}}{\text{día}}\right)\left(\frac{365\ \text{días}}{\text{año}}\right)\left(4.0\ \text{x}\ 10^{7}\,\frac{\text{J}}{\text{litro}}\right)\left(135\,\frac{\text{ng}}{\text{J}}\right)\left(\frac{1\,\text{kg}}{10^{12}\ \text{ng}}\right)$$

$$E_{PM_{10}} = 710\ \text{kg/año}\ = 0.71\,\text{Mg/año}$$

$$E_{SOx} = (6)\left(\frac{5\ \text{litros}}{\text{hora}}\right)\left(\frac{12\ \text{horas}}{\text{día}}\right)\left(\frac{365\ \text{días}}{\text{año}}\right)\left(4.0\ \text{x}\ 10^{7}\,\frac{\text{J}}{\text{litro}}\right)\left(126\,\frac{\text{ng}}{\text{J}}\right)\left(\frac{1\,\text{kg}}{10^{12}\ \text{ng}}\right)$$

$$= 662\ \text{kg/año}\ = 0.66\,\text{Mg/año}$$

Ejemplo 1

Motores Estacionarios de Combustión Interna – Información Complementaria

Controles de Emisión – Relación Aire a Combustible (RAC)

Uno de los parámetros principales que determinan la cantidad de contaminantes producidos durante la combustión es la relación aire a combustible (RAC). El cálculo de la RAC se basa en la reacción estequiométrica del combustible y el aire durante la combustión. La combustión ideal de la gasolina (representada por el octano), en un motor de encendido por chispa (ec) tiene la siguiente representación:

$$C_8H_{18} + 12.5\,O_2 + 47\,N_2 \rightarrow 8\,CO_2 + 9\,H_2O + 47\,N_2$$

La RAC estequiométrica es simplemente la relación de la masa de aire sobre la masa de combustible utilizado en una combustión ideal.

Masa de aire: 12.5 g-moles $O_2 \times 32$ g/g-mol = 400 g

47 g-moles $N_2 \times 28$ g/g-mol = 1,316 g

1,716 g

Masa de Combustible: 1 g-mol $C_8H_{18} \times 114$ g/g-mol = 114 g

$$\text{AFR} = \frac{\text{masa de aire}}{\text{masa de combustibl e}} = \frac{1{,}716}{114} = 15.05$$

Por supuesto, la RAC estequiométrica real aquí calculada puede variar ligeramente debido al hecho de que el aire no está compuesto sólo por nitrógeno y oxígeno, y que la gasolina no es equivalente al octano. De hecho, la gasolina es una mezcla de muchos compuestos de hidrocarburos, y una RAC típica para la gasolina es de 14.7. Las relaciones estequiométricas varían con base en el tipo de motor y de combustible. Se dice que un motor que opera a una RAC estequiométrica está operando en una relación de equivalencia aire/combustible (REAC) de 1.0, donde la REAC se define como la relación de la RAC estequiométrica sobre la RAC real. La REAC es menor que 1.0 para la operación del quemador de mezcla pobre (i. e., más aire), y mayor que 1.0 para la operación de motores con quemador de mezcla rica. El intervalo operativo para un motor de ec convencional de gasolina es $12 \leq \text{RAC} \leq 18$, y para los motores de ignición por compresión (IC) a diesel es de $18 \leq \text{RAC} \leq 70$.

Con frecuencia, el desempeño de un motor es optimizado para minimizar el consumo de combustible. Esto, en general, minimiza también las emisiones de GOT y CO debido a la maximización en la eficiencia de la combustión, pero las emisiones de NO_x también están cerca del máximo. Sin embargo, si la relación RAC no es correcta, el desempeño del motor disminuye, y el consumo de combustible aumenta incrementando también las emisiones de GOT y CO.

La Figura 1-1 ilustra el efecto de la RAC en las emisiones de GOT, CO y NO_x de un motor SI. Las formas de las curvas indican la complejidad del control de emisiones mediante el ajuste de RAC. La figura muestra que las emisiones de GOTs disminuyen a medida que la RAC incrementa, o que la mezcla combustible-aire se hace pobre en combustible. Este decremento en las emisiones de GOTs continúa a medida en que la mezcla se hace pobre en combustible, hasta que la mezcla se hace tan pobre que la calidad de la combustión se hace deficiente y comienza a haber problemas de encendido. El resultado es un incremento significativo en las emisiones de GOTs debido al incremento en las emisiones de hidrocarburos no quemados en el escape.

La temperatura de combustión y la disponibilidad de oxígeno afectan en gran medida las emisiones de NO_x. La operación de motores cerca del punto estequiométrico resulta en emisiones de NO_x cercanas al máximo, debido a las elevadas temperaturas de combustión. En esta relación de equivalencia, sin embargo, las concentraciones de oxígeno son bajas. A medida en que la mezcla se enriquece con combustible, las temperaturas del gas quemado bajan, ocasionando un decremento en la eficiencia de la combustión. Esto, a su vez, resulta en un incremento de las emisiones de GOTs y CO, y una disminución en las NO_x. Las primeras aumentan debido a las condiciones de riqueza de combustible, dado que el exceso de combustible no es quemado completamente durante la combustión. El incremento sostenido en las curvas se debe al aumento constante del exceso de combustible. A medida que la mezcla se hace pobre en combustible a partir del punto estequiométrico, el incremento en la concentración de oxígeno inicialmente compensa la decreciente temperatura de combustión, resultando en un incremento en las emisiones de NO_x. A medida en que la mezcla se hace pobre, la temperatura de combustión reducida se hace más importante que la disponibilidad de oxígeno para las emisiones de NO_x, y, en consecuencia, las emisiones disminuyen.

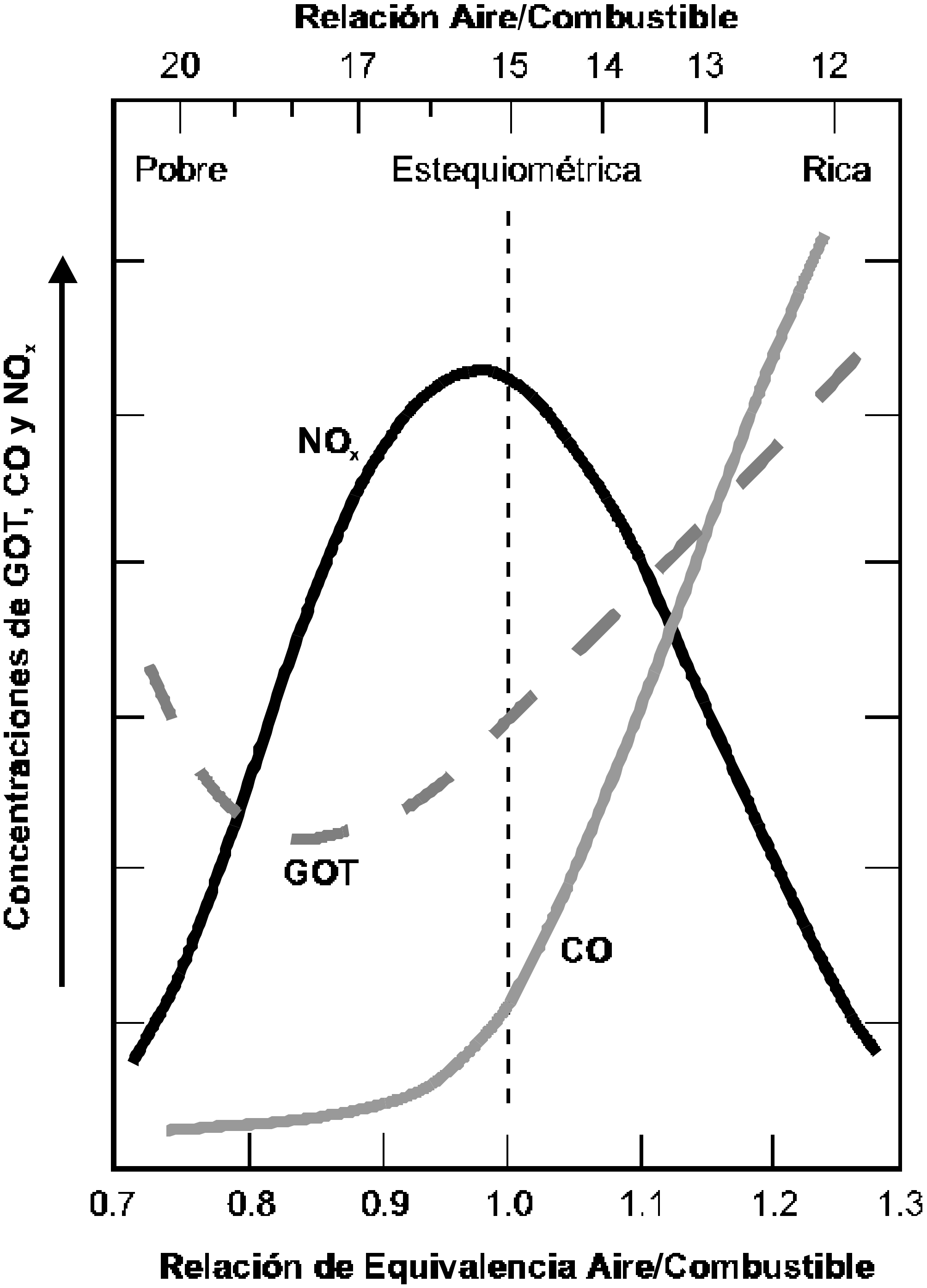

Figura 1-1. **Correspondencia entre la Relación Aire a Combustible (RAC), Relación de Equivalencia Aire/Combustible (REAC) y Contaminantes Emitidos**

Ejemplo 2a

Equipos de Combustión Externa – Prorrateo de Combustible

Introducción

Los factores de emisión que son comúnmente publicados para los equipos de combustión externa tales como los que se encuentran en el AP-42 (U.S. EPA, 1995a), se basan en el tamaño del equipo y en la cantidad de combustible consumido. Estos factores de emisión están expresados en unidades de lb/MMscf (libras/10^6 pies cúbicos estándar) para gas natural, ó lb/gal para combustibles líquidos como el diesel. La precisión de los estimados de emisión depende de la precisión de los datos de uso de combustible; sin embargo, estos datos a menudo no están disponibles para los equipos individuales de combustión externa. Con frecuencia existe un solo parámetro de medición de combustible para un edificio u otro establecimiento que contiene diversos equipos de combustión, y el consumo de combustible para cada fuente individual debe ser estimado con base en el diseño del equipo y los parámetros operativos.

El ejemplo que se presenta a continuación ilustra la técnica de prorrateo de combustible para un caso en el que un medidor registra el combustible total abastecido a un conjunto de equipos. El consumo de combustible para los equipos en el ejemplo se define con base en las horas de operación y el tamaño o capacidad del equipo. La misma metodología puede ser utilizada para prorratear el consumo de combustible entre cualquier número de equipos, si se conoce la capacidad y horas de operación de cada uno de ellos.

Planteamiento del Problema

Estimar el consumo de gas natural para cada equipo de combustión externa individual con base en la capacidad y las horas de operación del equipo.

Información Disponible

Una tortillería tiene cuatro maquinas tortilladoras, cada una de ellas con un quemador que funciona con gas natural, gas LP o ambos. Existe sólo un medidor en la línea de gas natural para el establecimiento, y se sabe que en 1996, el consumo total de gas fue de 240 MMscf. La Tabla 2-1 muestra las capacidades del quemador y las horas de operación para 1996, y resume los resultados de los cálculos de prorrateo del combustible total entre las cuatro tortilladoras (quemadores). Los cálculos detallados se presentan posteriormente.

Tabla 2-1

Distribución de Combustible para los Equipos de Combustión Externa en Tortillerías

DADO			CALCULADO			
Quemador	Capacidad (MMBtu/hr)	Horas Operadas en 1996	Carga Anual de Calor para la Capacidad (MMBtu/año)	% de la Carga Total	Consumo de Combustible Estimado	
					(MMscf/año)	(10^6 m^3/año)
A	21	4,320	90,720	36	86.4	2.45
B	8	4,512	36,096	14	33.6	0.95
C	21	2,880	60,480	24	57.6	1.63
D	7.5	8,760	65,700	26	62.4	1.77
Total			252,996	100	240.0	6.80

Para prorratear el consumo de combustible entre los quemadores, los cálculos son como se muestra a continuación:

1. Calcular la carga anual de calor para cada quemador a su máxima capacidad:

Carga Anual de Calor (MMBtu/año) = Capacidad del quemador (MMBtu/hr) × Horas Anuales (hr/año)

Para el quemador A, carga anual de calor = 21 MMBtu/hr × 4,320 horas/año

= 90,720 MMBtu/año

2. Encontrar la carga anual de calor total para los cuatro quemadores (ver Tabla).

$$90{,}720 + 36{,}096 + 60{,}480 + 65{,}700 \quad = \quad 252{,}996 \text{ MMBtu/año}$$

3. Determinar el % de la carga anual de calor total para cada quemador.

$$\text{Para el Quemador A} = \frac{90{,}720 \text{ MMBtu/año}}{252{,}996 \text{ MMBtu/año}}$$

$$= 36\%$$

4. Asignar el rendimiento de combustible total para cada quemador con base en el porcentaje de la carga anual de calor total.

$$\begin{aligned} \text{Para el quemador A} \quad &= \quad 240 \text{ MMscf/año} \times 0.36 \\ &= \quad 86.4 \text{ MMscf/año} \end{aligned}$$

Existen muchas fuentes de incertidumbre potenciales en este método de prorrateo, y su impacto en las emisiones estimadas para las fuentes de interés deben ser analizadas. Estas incluyen:

- La operación variable de los diferentes equipos (en este método existe el supuesto implícito de que cada equipo opera al mismo porcentaje relativo de su capacidad).
- Los registros incompletos o imprecisos de las horas de operación para uno o más equipos.
- Los registros incompletos o imprecisos del consumo de combustible
- Los datos de diseño incompletos o no disponibles para una o más fuentes (capacidad incierta).

Ejemplo 2b

Equipos de Combustión Externa – Factores de Emisión

Introducción

Este problema muestra el uso de los factores de emisión publicados para estimar las emisiones. Si bien este problema podría parecer simplista, es una técnica de estimación valiosa que se utiliza en prácticamente todos los inventarios de emisiones.

Planteamiento del Problema

Estimar las emisiones totales de NO_x de los quemadores de las cuatro máquinas tortilladoras descritas en el Ejemplo 2a.

Información Disponible

Los factores de emisión de combustión externa en el AP-42 están clasificados con base en la generación de calor del equipo de combustión externa, como se muestra a continuación:

- Planta de generación industrial de gran tamaño (>100 MMBtu/hr)
- Industrial pequeña (10-100 MMBtu/hr)
- Comercial (0.3-10 MMBtu/hr)
- Residencial (<0.3 MMBtu/hr).

Con base en esta clasificación, los quemadores A y C del Ejemplo 2a son equipos industriales pequeños, mientras que los quemadores B y D son equipos comerciales. Ninguno de los cuatro quemadores tiene instalado ningún tipo de equipos de control de emisiones.

Solución

A partir de la Tabla 1.4-2 del AP-42, el factor de emisión de NO_x para equipos industriales pequeños es de 2,240 kg/10^6 m^3 y el de equipos comerciales es de 1,600 kg/10^6 m^3 Las emisiones de los quemadores de la tortillería se calculan aplicando la siguiente ecuación:

$$E_{Total} = \sum_{d=1}^{n} (FC_d \text{ x } EF_d)$$

donde:

E_{Total} = Emisiones Totales (kg/año)

n = Número de equipos

FC_d = Consumo de combustible por equipo d (10^6 m^3/año)

EF_d = Factor de emisión para el equipo d (kg/10^6 m^3).

entonces:

$$\begin{aligned} E_{Total} &= (2.45 \text{ x } 2{,}240) + (0.95 \text{ x } 1{,}600) + (1.63 \text{ x } 2{,}240) + (1.77 \text{ x } 1{,}600) \\ &= 5{,}488 + 1{,}520 + 3{,}651 + 2{,}832 = 13{,}491 \text{ kg/yr } = 13.5 \text{ Mg/yr} \end{aligned}$$

Ejemplo 2c

Equipos de Combustión Externa – Otras Técnicas de Estimación

Introducción

Este problema muestra las limitaciones de los factores de emisión, que son ampliamente utilizados en el desarrollo de inventarios de emisiones.

Los factores de emisión son una técnica de estimación de emisiones ampliamente utilizada, en particular porque son relativamente baratos y fáciles de usar. Sin embargo, bajo ciertas circunstancias pueden no proporcionar una estimación precisa de las emisiones de un proceso específico. Es importante comprender que los factores de emisión se basan en los resultados de pruebas en fuente específicas. Si bien los factores publicados pueden ser adecuados para el equipo y condiciones particulares para los que fueron probados, su precisión puede disminuir de manera significativa para otros equipos y condiciones.

Cuando se realiza un inventario de emisiones, no es raro encontrar una fuente para la que no existen factores de emisión específicos en la literatura. En estos casos, se ha hecho práctica común el utilizar los factores de emisión publicados para los tipos de fuente que podrían ser similares. Si bien esta práctica de extrapolación parecería razonable, puede ocasionar errores significativos en los estimados de emisión.

Este problema se enfoca específicamente en los factores de emisión de combustión externa que se encuentran en el Capítulo 1 del AP-42, y presenta un ejemplo para ilustrar el caso en que estos factores de emisión no son aplicables. Asimismo, se presentan los ejemplos de los datos de prueba en fuente y los cálculos asociados.

Planteamiento del Problema

Estimar las emisiones de GOT de un incinerador de vapores (equipo de control para abatir la contaminación del aire, diseñado para destruir los compuestos orgánicos emitidos de fuentes tales como las grandes cabinas de pintado en la industria automotriz).

Información Disponible

Las entradas al incinerador son la corriente de aire de venteo de la cabina de pintado (que contiene pequeñas cantidades de los vapores orgánicos a ser destruidos), y el gas natural combustible para los quemadores del incinerador. Los ingenieros que realizaron los estimados de emisión para diversos incineradores de vapores se enfrentaron al problema de no tener factores de emisión específicos para el equipo, o datos de prueba en fuente para los incineradores. Ellos analizaron el proceso del incinerador y determinaron que las emisiones provenían principalmente del consumo de combustible, dado que la cantidad de contaminantes en el aire de venteo de la cabina de pintado era pequeña comparada con la cantidad de combustible. Sabiendo que las emisiones de los quemadores también resultarían sólo de la combustión de combustible, los ingenieros lógicamente decidieron utilizar los factores de emisión en el AP-42 para calderas con capacidades caloríficas similares para estimar las emisiones del incinerador de vapores.

Desafortunadamente, esta decisión arrojó estimados de emisiones imprecisos. En las subsecuentes pruebas en fuente de los incineradores de vapores se demostró que las emisiones de NO_x reales eran aproximadamente ocho (8) veces más elevadas que las emisiones estimadas con base en los factores de emisión de calderas. Después de un detallado análisis de la operación del incinerador, se determinó que sus parámetros operativos eran sustancialmente diferentes a las condiciones de las calderas en dos aspectos:

- Los incineradores operaban a concentraciones de aire excesivo mucho más altas que las calderas debido a la gran cantidad del aire de venteo de las cabinas de pintado
- Los incineradores operaban a temperaturas sustancialmente más elevadas que las calderas para asegurar la combustión completa de los contaminantes orgánicos.

Estas dos condiciones llevan a la formación de NO_x térmico (ver Nota 1 al final del Ejemplo), lo que explica la gran diferencia entre las emisiones de NO_x reales y las estimadas. Estas condiciones determinan el alcance de la combustión que también afecta la formación de CO y la cantidad de los gases orgánicos no incinerados (GOTs) en el gas de la chimenea del incinerador. En este caso, el haber utilizado los factores de emisión de calderas publicados resultó en un error sustancial en las emisiones estimadas para los incineradores debido a que éstos estaban siendo operados en condiciones significativamente diferentes a las de las pruebas en caldera en la que los factores de emisión fueron basados.

La metodología correcta para estimar las emisiones de NO_x del incinerador de vapores consistió en realizar pruebas en fuente. Se requirieron costosos ensayos para el diseño del quemador y repetidas pruebas en fuente para encontrar una solución que redujera las emisiones de NO_x de los incineradores de vapores a niveles aceptables sin incrementar las emisiones de GOT y CO a límites inaceptables. La Tabla 2-2 presenta los datos de prueba en fuente y los factores de emisión calculados para dióxido de nitrógeno (NO_2), NO_x, CO, y la eficiencia de remoción de la destrucción (ERD) de hidrocarburos no metánicos (HCNM), para uno de los incineradores de vapores. Los siguientes párrafos presentan la metodología utilizada para el cálculo de los factores de emisión de NO_x y CO de los datos de prueba en fuente. Los datos ERD HCNM se presentan sólo como información y para ilustrar la relación entre las emisiones de NO_x, CO y GOTs de la combustión externa para condiciones variables.

Los datos de prueba en fuente con frecuencia se obtienen en unidades que no son útiles para estimar las emisiones. Es posible que los datos de prueba deban ser convertidos a condiciones estándar (temperatura y presión) para ser comparados con otros datos, o ser convertidos a partir de las unidades medidas a otras unidades deseadas. Cuando las pruebas en fuente involucran una serie de ajustes del proceso para determinar la influencia de parámetros tales como la temperatura o el porcentaje del aire excesivo, puede requerirse un rápido análisis de los datos en sitio, de manera tal que el equipo de estudio pueda ponderar el efecto de cada cambio. Durante las pruebas en fuente del incinerador de vapores conducidas en el ejemplo anterior, se desarrolló una hoja de cálculo para permitir la rápida conversión de las emisiones de NO_x a las unidades de emisión deseadas. Esta hoja de cálculo se presenta como la Tabla 2-2 de este cuaderno de trabajo, y la explicación de la forma en que fue utilizada para calcular los factores de emisión de NO_x y CO se presenta posteriormente.

Tabla 2-2.
Datos de Prueba en Fuente y Cálculo de Factores de Emisión para Incinerador de Vapores

ID PRUEBA EN FUENTE			**FACTORES DE EMISIÓN DE NOx CA**						**FACTORES DE EMISIÓN DE CO**			
Fecha de la Prueba	Temperatura de la Prueba °F		NO2 O2Bsd lb/MMBtu	NO2 CO2 Bsd lb/MMBtu	NO2 Bsd del Combustible lb/MMBtu	NOx @ 3% O2 ppmv	Emisión de NOx lb/hr	Emisión de NOx lb por MMcfm	CO O2 Bsd lb/MMBtu	CO CO2 Bsd lb/MMBtu	CO Bsd del Combustible lb/MMBtu	HCNM ERD %
3/25/92	1462		0.78	0.81	0.84	633	3.24	15.63	0.000	0.000	0.000	100.0%
3/25/92	1248		0.44	0.48	0.45	360	1.49	7.05	0.184	0.199	0.185	100.0%
3/25/92	1204		0.37	0.40	0.43	298	1.23	5.63	0.195	0.211	0.227	99.7%
3/25/92	1152		0.30	0.34	0.43	245	1.05	4.47	0.567	0.628	0.800	98.6%
3/25/92	1163		0.31	0.31	#N/A	253	1.25	5.31	0.414	0.412	#N/A	99.2%
3/25/92	1206		0.34	0.35	0.38	275	1.47	6.31	0.287	0.294	0.323	99.8%
3/25/92	1258		0.38	0.38	0.41	308	1.75	7.29	0.175	0.173	0.190	100.0%
2/13/92	1050	*	0.21	0.24	#N/A	168	0.52	2.16	0.687	0.773	#N/A	93.6%
2/13/92	1100	*	0.24	0.27	#N/A	198	0.64	2.68	0.744	0.797	#N/A	96.6%
2/13/92	1150	*	0.28	0.32	#N/A	226	0.77	3.21	0.715	0.806	#N/A	98.6%
2/13/92	1200	*	0.33	0.36	#N/A	266	0.95	3.95	0.459	0.498	#N/A	99.5%
2/13/92	1250	*	0.39	0.41	#N/A	317	1.18	4.93	0.219	0.230	#N/A	99.8%
1/31/92	1250		#N/A	0.43	#N/A	#N/A	1.39	6.02	#N/A	#N/A	#N/A	#N/A
1/31/92	1300		#N/A	0.48	#N/A	#N/A	1.67	7.23	#N/A	#N/A	#N/A	#N/A
1/31/92	1350		#N/A	0.56	#N/A	#N/A	2.20	9.53	#N/A	#N/A	#N/A	#N/A
1/31/92	1400		#N/A	0.66	#N/A	#N/A	2.73	11.83	#N/A	#N/A	#N/A	#N/A
1/31/92	1450		#N/A	0.80	#N/A	#N/A	3.49	15.09	#N/A	#N/A	#N/A	#N/A
1/16/92	1450	*	0.74	0.90	#N/A	563	2.90	12.55	0.019	0.019	0.019	99.8%

Notas:

Tabla 2-2 (Continuación)
Datos de Prueba en Fuente y Cálculo de Factores de Emisión para Incinerador de Vapores

ID PRUEBA EN FUENTE			**Entrada**						**Escape**				**Alimentación de Combustible**		
Fecha de la Prueba	Tempe-ratura de la Prueba °F		NOx ppmv	O2 %	CO2 ppmv	CO ppmv	HC ppmv	NOx ppmv	O2 %	CO2 %	CO ppmv	HC ppmv	Gas de Escape scfm	delta P	Tasa de Con-sumo Ener-gético MMBtu/hr
3/25/92	1462		0.25	20.9	1030	0.5	476.7	129.4	17.25	2.11	0.5	0	3454	7.5	3.87
3/25/92	1248		0.25	20.9	1020	0.5	454	58.5	18	1.62	40.1	0	3532	5.6	3.35
3/25/92	1204		0.25	20.9	1010	0.5	450	46.8	18.1	1.57	41	1.3	3646	4.15	2.88
3/25/92	1152		0.25	20.9	850	0.5	423	37.2	18.2	1.46	114.2	5.8	3897	3	2.45
3/25/92	1163		0.25	20.9	860	0.5	423	44.1	17.8	1.85	95.8	3.5	3942	#N/A	#N/A
3/25/92	1206		0.25	20.9	965	0.5	453	52.4	17.5	1.98	73	0.7	3886	7.45	3.86
3/25/92	1258		0.25	20.9	980	0.5	457	60.5	17.4	2.11	46	0	4003	9	4.24
2/13/92	1050	*	0.25	20.9	480	0.5	380	18.1	19	1	97.5	24.5	3992	#N/A	#N/A
2/13/92	1100	*	0.25	20.9	490	0.5	410	22.4	18.9	1.1	111	13.9	3992	#N/A	#N/A
2/13/92	1150	*	0.25	20.9	505	0.5	415	26.8	18.8	1.1	112	6	3992	#N/A	#N/A
2/13/92	1200	*	0.25	20.9	530	0.5	510	32.9	18.7	1.2	75.5	2.7	3992	#N/A	#N/A
2/13/92	1250	*	0.25	20.9	525	0.5	575	41	18.6	1.3	38	1.1	3992	#N/A	#N/A
1/31/92	1250		0.25	20.9	400	0.5	#N/A	50	#N/A	1.5	#N/A	#N/A	3850	#N/A	#N/A
1/31/92	1300		0.25	20.9	400	0.5	#N/A	60	#N/A	1.6	#N/A	#N/A	3850	#N/A	#N/A
1/31/92	1350		0.25	20.9	400	0.5	#N/A	79	#N/A	1.8	#N/A	#N/A	3850	#N/A	#N/A
1/31/92	1400		0.25	20.9	400	0.5	#N/A	98	#N/A	1.9	#N/A	#N/A	3850	#N/A	#N/A
1/31/92	1450		0.25	20.9	400	0.5	#N/A	125	#N/A	2	#N/A	#N/A	3850	#N/A	#N/A
1/16/92	1450	*	0.25	20.7	550	3	283	104	17.6	1.5	2.5	0.5	3850	#N/A	#N/A
Notas:								2	1, 2	1, 2	1, 2	1, 2			

Notas y Abreviaturas para la Tabla 2-2

Notas:

1. $\%CO_2$ y O_2 en las muestras del gas de escape = ppmv/10,000
2. Las mediciones del gas de escape están en una base seca.

Abreviaturas:

CO	Monóxido de carbono
CO_2	Dióxido de carbono
CO_2Bsd	Cálculo del factor de emisión basado en el $\%CO_2$ en el escape
delta P	Presión diferencial
ERD	Eficiencia de remoción de la destrucción
F	Grados Fahrenheit (temperatura)
Bsd del Combustible	Cálculo del factor de emisión basado en la tasa de flujo del combustible
HC	Hidrocarburo
hr	hora
lb	Libras
MMBtu	Millones de unidades térmicas británicas
MMcf	Millones de pies cúbicos de gas de entrada
HCNM	Hidrocarburos no metánicos
NO_2	Dióxido de nitrógeno
NO_x	Oxidos de nitrógeno
O_2	Oxígeno
O_2Bsd	Cálculo del factor de emisión basado en el $\%O_2$ en el escape
ppmv	Partes por millón (volumen)
scfm	Pie cúbico estándar por minuto
Temp	Temperatura

Dados los siguientes parámetros operativos, el factor de emisión de NO_x (lb/Btu) puede estimarse:

- Con los datos de entrada y salida medidos en la prueba en fuente (todas las concentraciones de gas están en una base seca)
- Con la temperatura de prueba (°F)
- Con la tasa de flujo de los gases de escape (scfm)
- Con la tasa de alimentación de gas natural (combustible).

El factor de emisión puede ser determinado con base en la concentración de O_2 ó de CO_2 en el gas de escape o en la tasa de alimentación del combustible. Cualquiera de estos tres métodos es adecuado para utilizarse en el cálculo de factores de emisión de pruebas en fuente. Ambos factores de emisión basados en O_2 y CO_2 fueron calculados utilizando el método del Factor F, que el 6 de octubre de 1975 fue promulgado por el Registro Federal *(Federal Register)* de EU, como el procedimiento que sustituye al método original para determinar los factores de emisión. La EPA ha publicado factores F para los combustibles más comunes, y los valores del factor F utiizados en estos cálculos se tomaron del *Stack Sampling Technical Information* (U.S. EPA, 1978). El factor F para el factor de emisión basado en O_2 para gas natural es de 8,740 scf/MMBtu. El factor F para el factor de emisión basado en CO_2 para gas natural es de 1,040 scf/MMBtu. En este ejemplo se utilizaron los datos de prueba 25/03/1992 a 1,462 °F de la Tabla 2-1.

La ecuación para el cálculo de un factor de emisión de NO_x basado en O_2 utilizando en método del factor F es:

$$E = Cd \text{ x } Fd \text{ x } \frac{20.9}{20.9 - \%O_2}$$

donde:

E = Tasa de emisión en lb/MMBtu

Cd = Concentración del contaminante en base seca menos la concentración del contaminante en el gas de entrada (lb/scf)

Fd = Factor F basado en oxígeno (8,740 scf/MMBtu)

$\%O_2$ = Porcentaje de O_2 en el gas de escape seco

20.9 = Porcentaje de O_2 supuesto en el gas de entrada (en condiciones de atmósfera ambiente)

A continuación se presenta el cálculo del Cd en lb/scf del gas de escape a partir de las concentraciones de NO_x (medidas como NO_2) en ppmv:

$$Cd = \frac{[C]_{ppmv} \text{ x } MW}{CF_1}$$

donde:

$[C]_{ppmv}$ = Concentración del contaminante en el escape menos la concentración de contaminante en el gas de entrada en ppmv (scf contaminante/MMscf gas de escape)

MW = Peso molecular del NO_2 (46 lb/lb-mole)

CF_1 = Factor de conversión basado en la ley de los gases ideales de que 1 lb-mole de gas ideal = 380 scf.

Utilizando los datos de la Tabla 2-1 para los datos de prueba 25/03/92 a 1,462 °F, el cálculo de Cd es:

$$C\,d = \frac{\left[(129.4 - 0.25)\,\frac{\text{scf } NO_x}{10^6 \text{ scf gas de escape}}\right]_, \text{ x } \frac{46 \text{ lb}}{\text{lb - mol}}}{380 \text{ scf/1 lb - mol}}$$

$$= 1.563 \text{ x } 10^{-5}\,\frac{\text{lb } NO_x}{\text{scf gas de escape}}$$

Entonces, el cálculo del factor de emisión de NO_x utilizando el factor F basado en oxígeno es:

$$E = \left(1.563 \text{ x } 10^{-5} \frac{\text{lb } NO_x}{\text{scf}}\right) \text{x } \frac{8{,}740 \text{ scf}}{10^6 \text{ Btu}} \text{ x } \left(\frac{20.9}{20.9 - 17.25}\right)$$

$$E = \frac{0.78 \text{ lb } NO_x}{10^6 \text{ Btu}}$$

La ecuación para calcular un factor de emisión de NO_x basado en CO_2 utilizando el método del factor F es:

$$E = \text{Cd x Fc x} \left(\frac{100}{\% CO_2}\right)$$

donde:

E = Tasa de emisión (lb/MMBtu)

Cd = Concentración del contaminante en el gas de escape seco menos la concentración del contaminante en el gas de entrada (lb/scf)

Fc = CO_2 basado en el factor F (1,040 scf/MMBtu)

$\%CO_2$ = Porcentaje de CO_2 en el gas de escape seco menos el porcentaje de CO_2 en el gas de entrada.

El cálculo de Cd en lb/scf a partir de las concentraciones medidas de NO_x en ppmv se realizó anteriormente. El cálculo del $\%CO_2$ es como se muestra a continuación:

$$\% CO_2 = \% CO_2 \text{ (como se midió en el gas de escape seco)} - \frac{\text{ppmv } CO_2 \text{ en el gas de entrada}}{10{,}000}$$

$$E = 2.11 - \frac{1{,}030}{10{,}000} = 2.007$$

Entonces, el cálculo del factor de emisión de NO_x utilizando el factor F basado en CO_2 es:

$$E = \left(\frac{1.563 \times 10^{-5}\ \text{lb } NO_x}{\text{scf}}\right) x\ \frac{1{,}040\ \text{scf}}{10^6\ \text{Btu}}\ x\ \frac{100}{2.007}$$

$$E = \frac{0.81\ \text{lb } NO_x}{10^6\ \text{Btu}}$$

Si se utiliza la tasa de alimentación de combustible para calcular un factor de emisión de NO_x, entonces se aplica la siguiente ecuación:

$$E = \frac{Cd\ x\ Q\ x\ 60}{FR}$$

donde:

E	=	Tasa de emisión (lb/MMBtu)
Cd	=	Concentración del contaminante en el gas de escape seco menos la concentración del contaminante en el gas de entrada (lb/scf)
Q	=	Tasa de flujo de escape (scf/minuto)
60	=	Factor de conversión de minutos a horas
FR	=	Tasa de alimentación energética de combustible (MMBtu/hora)

El cálculo de la Cd en lb/scf a partir de las concentraciones de NO_x medidas en ppmv se hizo anteriormente.

Por lo tanto, el factor de emisión basado en la tasa de alimentación de combustible es:

$$E = \frac{\left(\frac{1.563 \times 10^{-5}\ \text{lb } NO_x}{\text{scf}}\right) x \left(\frac{3{,}454\ \text{scf}}{\text{min}}\right) x \left(\frac{60\ \text{min}}{\text{hr}}\right)}{3.87 \times 10^6\ \text{Btu/hr}}$$

$$E = \frac{0.84\ \text{lb } NO_x}{10^6\ \text{Btu}}$$

La Tabla 2-3 muestra una comparación de los factores de emisión calculados con un factor de emisión dado en el AP-42.

Tabla 2-3

Comparación de los Factores de Emisión Calculados

Método de Cálculo	**Factor de Emisión (lb $NO_x/10^6$ Btu)**
Factor F basado en O_2	0.78
Factor F basado en CO_2	0.81
Tasa de Alimentación de Combustible	0.84
AP-42, Tabla 1.4-2 Caldera Comercial No Controlada *	0.10

* Supone un mayor valor calorífico alimentado con gas natural de 1,000 Btu/scf.

Como se mencionó anteriormente, el factor de emisión tomado del AP-42 puede ser menor hasta en un factor de ocho (8).

Para comparar los factores de emisión en una base equivalente, en ocasiones es necesario ajustar los factores de emisión estimados a una concentración de O_2 en exceso dada. Esto se realiza a menudo con propósitos regulatorios, mediante la siguiente ecuación:

$$EF_{ex} = EF \text{ x } \frac{(20.9 - O_{2(ex)})}{(20.9 - O_2)}$$

donde:

EF_{ex} = Factor de emisión de NO_x al nivel de O_2 en exceso deseado (lb/MMBtu)

EF = Factor de emisión de NO_x calculado (lb/MMBtu)

20.9 = Concentración de O_2 atmosférico supuesta (%)

$O_{2(ex)}$ = Concentración de O_2 en exceso deseada (%)

O_2 = Concentración de O_2 medida en el gas de escape seco (%).

Usando el factor de emisión basado en O_2 anterior, el factor de emisión de NO_x a un exceso de O_2 del 3% para los datos de prueba del 25/03/92 a 1462 °F se calcula como:

$$NO_x\ (3\%) = 0.78\,\frac{\text{lb } NO_x}{10^6 \text{ Btu}} \text{ x } \left(\frac{20.9 - 3}{20.9 - 17.25}\right)$$

$$= \frac{3.83 \text{ lb } NO_x}{10^6 \text{ Btu}}$$

El factor de emisión ajustado difiere del factor de emisión calculado debido a que la concentración de O_2 en exceso deseada (3%) es muy diferente comparada con la concentración de O_2 medida real (17.25%). Si la concentración del O_2 en exceso deseada es igual a la concentración de O_2 medida, entonces el factor de emisión ajustado será idéntico al factor de emisión calculado.

Nota 1:
El NO_x se forma en la combustión externa de dos formas principales: NO_x térmico y NO_x del combustible *(fuel NO_x)*. El NO_x térmico se forma cuando el nitrógeno y el oxígeno en el aire de combustión reaccionan a altas temperaturas en la flama. El NO_x del combustible se forma por la reacción de cualquier compuesto de nitrógeno en el combustible con el aire de la combustión. El NO_x térmico es la principal fuente de NO_x en la combustión de gas natural y aceite ligero, y el factor más significativo que afecta su formación es la temperatura de la flama. El nivel del exceso de aire y la temperatura del aire de la combustión también son factores que intervienen en la formación de NO_x térmico. La formación de NO_x del combustible depende del contenido de nitrógeno en el combustible y puede constituir hasta el 50% de las emisiones de NO_x de la combustión de combustibles con alto contenido de nitrógeno, principalmente aceites pesados.

Ejemplo 3
Combustión Residencial

Introducción

Este ejemplo ilustra una situación común en la que las emisiones deben ser estimadas con un mínimo de datos. En muchas casos, el especialista del inventario se enfrentará con una escasez de datos que requiere un enfoque creativo para el desarrollo de estimados de emisión. Debido a la falta de datos, los métodos típicos para la estimación de emisiones no siempre son una opción factible. En su lugar, deben identificarse y analizarse otros métodos opcionales. Cada uno de los métodos alternativos tendrán aspectos positivos y negativos que deben ser evaluados antes de seleccionar alguno de ellos. En ciertos casos, podrían seleccionarse más de uno de los métodos alternativos para obtener un posible intervalo de estimados de emisión (i. e., cálculos de intervalo). Si bien es factible que uno de los estimados fuera incorporado en la base de datos de emisiones, el intervalo de estimados proporciona una medición de la incertidumbre potencial asociada con esa categoría de fuente específica. Esto es un beneficio adicional de los cálculos de intervalo.

El siguiente ejemplo se basa en los datos y metodología reales que fueron utilizados en un inventario de tóxicos del aire para Nogales, Sonora (Radian, 1997), y no tiene el objetivo de dar un método de estimación específico y recomendado, sino que está diseñado para presentar los procesos de razonamiento que deben aplicarse para estimar las emisiones cuando haya datos incompletos.

Planteamiento del Problema

Determinar las emisiones anuales de CO de la combustión de combustibles no comerciales. Incluir sólo aquellos combustibles destinados a propósitos de cocinado y calefacción. Excluir el quemado de cualquier residuo.

Información Disponible

En México, Petróleos Mexicanos (Pemex), así como algunas entidades gubernamentales mantienen estadísticas con cierto grado de detalle para el consumo de combustibles comerciales (e. g., petróleo destilado, gas LP, etc.). Sin embargo, en algunas áreas del país se utilizan cantidades significativas de combustibles no comerciales, para calefacción y para la cocina. Los ejemplos de combustibles no comerciales incluyen la madera, otro tipo de biomasa, bosta, materiales de desecho, llantas, solventes residuales y otros combustibles derivados de residuos. En este problema, tales energéticos son denominados combustibles de biomasa o residuos. En la mayoría de los países, incluyendo a México, las estadísticas para estos tipos de combustibles son prácticamente inexistentes.

Si bien según diversas estadísticas oficiales y la información proporcionada por los residentes indican que, para 1994 el 98% de los hogares en Nogales usan gas LP (Carrillo, 1996; Gastelum, 1996; Guerrero, 1996), el uso de combustibles derivados de residuos fue considerado una fuente potencialmente significativa de emisiones. Sin embargo, durante la visita al sitio se encontró muy poca información relacionada con la combustión de combustibles de biomasa o residuos. Las estadísticas de población y vivienda generales estuvieron disponibles para el dominio del inventario, pero no así las tasas de combustión de dichos tipos de combustibles.

Selección de la Metodología

De manera ideal, las tasas de combustión de los combustibles de biomasa o residuos a partir de estudios estadísticamente válidos deberían ser combinados con los factores de emisión para arrojar estimados de emisión. Sin embargo, debido a que los datos de los estudios no estuvieron disponibles, se utilizaron métodos de estimación alternativos. Se consideraron tres métodos que podrían permitir la estimación de las tasas de combustión de combustibles de biomasa o residuos, que incluyen:

- El Método de la Carga Calorífica
- El Método de Equivalencia de Gas LP
- El Método del Micro-inventario.

Cada uno de estos métodos se describe detalladamente a continuación.

El Método de la Carga Calorífica

Para estimar las emisiones, este método usa la carga calorífica mensual promedio para una casa típica en Nogales. La carga calorífica mensual promedio requerida para un edificio puede ser determinada con la siguiente ecuación (Harris et al., 1985):

$$Q_i = (UA + 0.018V) \times DD_i \times 24$$

donde:

Q_i = Carga calorífica mensual promedio (Btu/mes) para el mes i

UA = Pérdida de calor por transmisión por hora por grado de diferencia de temperatura de diseño (Btu/hr-°F);

0.018V = Pérdida de calor por infiltración-ventilación por hora por grado de diferencia de temperatura de diseño (Btu/hr-°F);

DD_i = Grados-días mensuales [temperatura base de 65°F] (°F-día/mes) para el mes i

24 = Factor de conversión de días a horas.

El término UA en realidad es el producto de un coeficiente general de transmisión de calor para un elemento estructural dado (U) y el área de la superficie de dicho elemento estructural (A). El término V representa el volumen de infiltración de aire por hora (el producto de los cambios del aire y el volumen del espacio por hora). Los lineamientos para estimar los valores para UA y 0.018V para un edificio completo pueden ser obtenidos de diversos manuales de ingeniería (e. g., ASHRAE, 1997 – capítulos 24 y 25). Para estimar estas dos variables, deben determinarse algunas características de una casa "típica" (material de construcción, espacio promedio del piso, altura promedio de la construcción, grosor de las paredes, número de puertas, número y tamaño de las ventanas, etc.). Un grado-día es la diferencia entre una temperatura base fija (usualmente 65°F) y la temperatura promedio a la intemperie, en un periodo de tiempo específico, por ejemplo, mes o año. Un grado-día más elevado indica una carga calorífica más alta. Los datos grado-día típicamente están disponibles en las estaciones meteorológicas.

La carga calorífica anual promedio requerida para una vivienda individual se calcula agregando cada una de las cargas caloríficas mensuales promedio utilizando diferentes grados-días para cada mes, como se muestra a continuación.

$$Q_{Anual} = \sum_{i=1}^{12} Q_i$$

donde:

Q_{Anual} = Carga calorífica anual (Btu/año)

Q_i = Carga calorífica mensual promedio (Btu/mes) para el mes i.

Una vez que la carga calorífica anual ha sido estimada, es posible calcular la cantidad de combustibles de biomasa o residuos que proporciona la cantidad de calor requerida, utilizando un contenido energético promedio para ese combustible específico. Esto se muestra en la siguiente ecuación:

$$Fuel_{Anual,f} = \frac{Q_{Anual}}{EC_f}$$

donde:

$Fuel_{Anual,f}$ = Uso anual de combustible (lb/año) para el combustible f

Q_{Anual} = Carga calorífica anual (Btu/año)

EC_f = Contenido de energía (Btu/lb) para el combustible f.

Esta cantidad estimada de material biomasa o residuos requeriría ser ajustada a la alza para incluir las actividades de la cocina que utilizan combustibles similares.

El método de Equivalencia de Gas LP

Este método aplica un uso promedio doméstico de gas LP para estimar el consumo de combustible no comercial. Dado que el número de hogares en Nogales que utilizan gas LP era conocido, era posible estimar el uso promedio de gas LP por vivienda si la cantidad total del consumo de este combustible estaba disponible.

$$GLP_{Uso} = \frac{GLP_{Res}}{Viviendas_{GLP}}$$

donde:

GLP_{Uso} = Uso anual de GLP por vivienda (lb/año);

GLP_{Res} = Uso residencial anual total de GLP (lb/año)

$Viviendas_{GLP}$ = Vivientas totales que usan GLP.

Utilizando el contenido energético del GLP y combustibles de biomasa o residuos típicos, es posible estimar el uso promedio equivalente de biomasa o residuos por vivienda.

$$Bio/\ Res_{Uso} = GLP_{Uso} \times \frac{EC_{GLP}}{EC_{Bio/Res}} \times \frac{Eff_{GLP}}{Eff_{Bio/Res}}$$

donde:

Bio/Res_{Uso} = Uso de combustibles de biomasa o residuos anual por vivienda (kg/año)

GLP_{Uso} = Uso anual de GLP por vivienda (litros/año)

EC_{GLP} = Contenido energético del GLP (kcal/litro)

$EC_{Bio/Res}$ = Contenido energético de combustibles de biomasa o residuos (kcal/kg)

Eff_{GLP} = Eficiencia de la combustión del GLP

$Eff_{Bio/Res}$ = Eficiencia de la combustión del combustible de biomasa o residuos.

El Método del Micro-inventario

Este método implica la realización de un micro-inventario de 25 o 30 viviendas que utilicen combustibles de biomasa o residuos. Una corta entrevista puede proporcionar información suficiente. La información más importante es la cantidad de combustible quemado. La mayoría de las personas entrevistadas no podrán estimar el uso anual o mensual, pero sí pueden estimar el uso en un periodo de tiempo más corto. La información también debe ser recopilada con respecto a las variaciones estacionales en el uso y otras prácticas de quemado. El uso anual de los combustibles de biomasa o residuos puede entonces ser derivado a partir de estos datos.

Análisis y Selección de los Métodos de Estimación de Emisiones

Después de establecer tres métodos alternativos, fue necesario seleccionar uno de ellos. Esta selección estuvo basada en diversos criterios y en el juicio ingenieril general. Los criterios de selección incluyeron aspectos tales como la facilidad de uso, el grado de representatividad, la magnitud de la incertidumbre, la racionalidad, etc. Finalmente, para el inventario de tóxicos del aire de Nogales, Sonora, se eligió el método de Equivalencia del GLP.

Los métodos de Carga Calorífica y Micro-Inventario no se seleccionaron por diversas razones, entre las que destacan:

- **Sesgo Potencial.** Sería muy difícil asegurar que la "vivienda típica" seleccionada para el método de Carga Calorífica realmente representa los tipos de vivienda que existen en el dominio del inventario. De manera similar, sería difícil garantizar que las viviendas seleccionadas para la entrevista del método del Micro-Inventario en realidad fueran representativas de las viviendas que queman combustibles de biomasa o residuos. El sesgo potencial habría disminuido si se hubiese realizado un estudio de gran escala para determinar las características de las viviendas o el uso de combustibles, pero el costo asociado lo habría hecho prohibitivo.

- **Disponibilidad de los datos y tipos de suposiciones.** Si bien los datos disponibles son limitados, el método de Equivalencia del GLP utiliza estos datos limitados, así como diversas suposiciones razonables para estimar las emisiones. El método de la Carga Calorífica, por otro lado, habría requerido la recopilación de algunos datos adicionales, así como ciertas suposiciones "menos razonables".

- **Participantes Renuentes a Participar en la Encuesta.** Dado que el GLP se utiliza en 98% de los hogares, el número de viviendas que utilizan combustibles de biomasa o residuos son la minoría. Para el método del Micro-Inventario, algunas de estas viviendas se rehusarían a dar información voluntaria con respecto a sus prácticas que quemado de combustible. Incluso si las respuestas fueran dadas, podría haber algunas dudas con respecto a su validez.

Solución

Ahora que el método de Equivalencia del GLP ha sido seleccionado, es posible estimar las emisiones. A continuación se describen los cuatro pasos principales.

1. **Determinar el número de viviendas que usan combustibles de biomasa o residuos para calefacción o la cocina.** Con base en los datos del censo, el sistema de información geográfica (SIG) y las tendencias recientes del crecimiento, se estimó que en Nogales había aproximadamente 38,018 viviendas (Radian, 1997). Como se mencionó anteriormente, se había identificado que el 98% de las viviendas en Nogales utilizaban GLP. Se hizo el supuesto de que el 2% de las viviendas restantes en esta localidad utilizaban combustibles de biomasa o residuos. A continuación se da el número total de viviendas que utilizan combustibles de biomasa o residuos:

$$\text{Viviendas}_{\text{Bio/Res}} = \%_{\text{Bio/Res}} \text{ x } \text{Viviendas}_{\text{Total}} = 2\% \text{ x } 38{,}018 = 760 \text{ viviendas}$$

donde:

$\text{Viviendas}_{\text{Bio/Res}}$ = Número de viviendas que usan combustibles de biomasa o residuos

$\%_{\text{Bio/Res}}$ = Porcentaje de viviendas que usan combustibles de biomasa o residuos

$\text{Viviendas}_{\text{Total}}$ = Número total de viviendas.

2. **Determinar el uso de GLP por vivienda.** El uso de GLP por vivienda se determina dividiendo el uso de GLP residencial total por el número total de viviendas que usan GLP. Las estadísticas de Pemex indicaron que el uso de GLP en 1994 para Nogales fue de 30,203,870 de kilogramos (Estrada, 1996). Se ha determinado que el 80% del uso total de GLP en México es residencial (Dirección General de Ecología et al., 1995).

El uso en masa de GLP es convertido a uso en volumen mediante la estimación de la densidad del GLP. Desafortunadamente, la composición química exacta y la densidad del GLP en Nogales son desconocidas. Sin embargo, la densidad aproximada puede estimarse utilizando las dimensiones de un cilindro de GLP de 45 kg y su peso reportado. Las mediciones de un cilindro de GLP de 45 kg indicaron que su altura es de 1.04 m y la circunferencia de 1.19 m. Como se muestra a continuación, el volumen del cilindro y, posteriormente, su densidad pueden ser calculados a partir de estas dimensiones. Para un cilindro, el volumen se calcula como se muestra a continuación:

$$V = \pi r^2 h; \qquad C = 2\pi r$$

$$V = \pi \left(\frac{C}{2\pi} \right)^2 h = \frac{C^2 h}{4\pi}$$

$$V = \frac{(1.19\ \mathrm{m})^2 \times 1.04\ \mathrm{m}}{4 \times 3.14} = 0.1173\ \mathrm{m}^3$$

donde:

V = volumen del cilindro (m)

C = circunferencia del cilindro (m)

r = radio del cilindro (m)

h = altura del cilindro (m).

Entonces, la densidad aproximada del GLP es:

$$r = \frac{\mathrm{m}}{\mathrm{V}} = \frac{45\ \mathrm{kg}}{0.1173\,\mathrm{m}^3} = 383.6\,\frac{\mathrm{kg}}{\mathrm{m}^3} = 0.384\,\frac{\mathrm{kg}}{\mathrm{liter}}$$

donde:

ρ = Densidad del GLP (kg/litro)

m = Masa del GLP en un cilindro (kg)

V = Volumen del cilindro de GLP (m^3).

La conversión de kilogramos a litros de GLP entonces, es:

$$\mathrm{GLP}_{\mathrm{v}} = \frac{\mathrm{GLP}_{\mathrm{m}}}{r} = \frac{30{,}203{,}870\ \mathrm{kg}}{0.384\ \mathrm{kg/litro}} = 78{,}655{,}911\ \mathrm{litros}$$

donde:

GLP_v = Volumen total de GLP (litro)

GLP_m = Masa total de GLP (kg)

ρ = Densidad del GLP (kg/litro).

Se estima que el uso residencial representa el 80% del uso total del GLP, y el resto es para uso industrial y comercial (Dirección General de Ecología et al., 1995).

$$\mathrm{GLP}_{\mathrm{Res}} = \%_{\mathrm{Res}} \times \mathrm{GLP}_{\mathrm{Total}} = 80\% \times 78{,}655.911\ \mathrm{Litros} = 62{,}924{,}729\ \mathrm{litros}$$

donde:

GLP_{Res} = Uso residencial del GLP (litros/año)

$\%_{Res}$ = Porcentaje del uso total del GLP que es residencial

GLP_{Total} = Uso total de GLP (litros/año).

A continuación se da el número de viviendas que utilizan GLP:

$\text{Viviendas}_{\text{GLP}} = \%_{\text{GLP}} \text{ x } \text{Viviendas}_{\text{Total}} = 98\% \text{ x } 38{,}018 = 37{,}\ 258$

donde:

$\text{Viviendas}_{\text{GLP}}$ = Número de viviendas que utilizan GLP

$\%_{\text{GLP}}$ = Porcentaje total de viviendas que usan GLP

$\text{Viviendas}_{\text{Total}}$ = Número total de viviendas.

Finalmente, el uso de GLP por vivienda se calcula utilizando la siguiente ecuación:

$$\text{Uso}_{\text{GLP}} = \frac{\text{GLP}_{\text{Res}}}{\text{Viviendas}_{\text{GLP}}} = \frac{62{,}924{,}729 \text{ litros}}{37{,}258 \text{ viviendas}} = 1{,}689 \text{ litros/vivienda}$$

donde:

Uso_{GLP} = Uso anual de GLP por vivienda (litros/año)

GLP_{Res} = Uso residencial de GLP (litros/año)

$\text{Viviendas}_{\text{GLP}}$ = Número de viviendas que usan GLP.

Es necesario revisar la racionalidad de este uso de GLP por vivienda. Un número muy limitado de entrevistas informales conducidas con residentes locales indican que una vivienda típica utiliza un cilindro de GLP grande (45 kg) al mes durante el verano, y dos cilindros grandes mensuales durante el invierno (Monroy, 1996). Suponiendo que hay ocho meses de verano y cuatro de invierno, una vivienda típica usará aproximadamente 16 cilindros grandes al año. Aplicando la densidad del GLP calculada anteriormente y el peso por cilindro, es posible estimar el número de cilindros utilizados por vivienda.

$$\frac{1{,}689 \text{ litros}}{\text{viviendas}} \text{ x } \frac{0.384 \text{ kg}}{\text{litro}} \text{ x } \frac{1 \text{ cilindro}}{45 \text{ kg}} = \frac{14.4 \text{ cilindros}}{\text{vivienda}}$$

Dado que estos estimados están dentro de un 10% entre sí, el estimado de 1,689 litros de GLP por vivienda por año parece bastante razonable.

3. Convertir el uso de GLP por vivienda a uso de combustibles de biomasa o

residuos por vivienda. El valor de uso anual de GLP de 1,689 litros/vivienda calculado anteriormente, representa la cantidad de GLP utilizado por una vivienda promedio para todos sus requerimientos de calefacción y cocina. Una cantidad equivalente de combustibles de biomasa o residuos puede ser estimada con base en el contenido energético del combustible.

Si bien los residentes locales de Nogales se refieren al GLP como gas butano, la composición química exacta para el GLP de Nogales es desconocida. Se supone que el GLP local es similar a la composición nacional promedio de 60% de propano y 40% de butano (Pemex, 1996). Si el contenido energético del propano es de 6,090 kcal/litro y el contenido energético del butano es de 6,790 kcal/litro (U.S. EPA, 1995a), entonces, el contenido energético ponderado del GLP se calcula como se muestra a continuación:

$$EC_{GLP} = \%_{prop} \text{ x } EC_{prop} + \%_{but} \text{ x } EC_{but} = (0.6 \text{ x } 6{,}090) + (0.4 \text{ x } 6{,}790) = 6{,}370 \text{ kcal/litro}$$

donde:

EC_{GLP} = Contenido energético del GLP (kcal/litro)
$\%_{prop}$ = Porcentaje de propano en el GLP
EC_{prop} = Contenido energético del propano (kcal/litro)
$\%_{but}$ = Porcentaje de butano en el GLP
EC_{but} = Contenido energético del butano (kcal/litro).

Suponiendo que el contenido energético de los combustibles de biomasa o residuos es aproximadamente el de una tabla de madera (4,445 kcal/kg) (Summit et al, 1996) y que las eficiencias de combustión del GLP y los combustibles de biomasa o residuos son iguales, entonces es posible estimar el uso de combustibles de biomasa o residuos por vivienda:

$$\text{Bio/ Res}_{\text{Uso}} = \text{GLP}_{\text{Uso}} \text{ x } \frac{\text{EC}_{\text{GLP}}}{\text{EC}_{\text{Bio/Res}}} \text{ x } \frac{\text{Eff}_{\text{LPG}}}{\text{Eff}_{\text{Bio/Res}}}$$

$$\text{Bio/ Res}_{\text{Uso}} = \frac{\text{1,689 litros GLP}}{\text{vivienda}} \text{ x } \frac{\text{6,370 kcal/litro GLP}}{\text{4,445 kcal/kg bio/res}} = \frac{\text{2,420 kg bio/res}}{\text{vivienda}}$$

donde:

$\text{Bio/Res}_{\text{Uso}}$ = Uso anual de combustibles de biomasa o residuos por vivienda (kg/año);

GLP_{Uso} = Uso anual de GLP por vivienda (litros/año)

EC_{GLP} = Contenido energético del GLP (kcal/litro)

$\text{EC}_{\text{Bio/Res}}$ = Contenido energético de los combustibles de biomasa o residuos (kcal/kg)

Eff_{GLP} = Eficiencia de la combustión del GLP

$\text{Eff}_{\text{Bio/Res}}$ = Eficiencia de la combustión de combustibles de biomasa o residuos.

4. **Calcular las emisiones totales de CO.** Ahora que el uso anual de combustibles de biomasa o residuos anual por vivienda ha sido estimado, las emisiones de CO pueden calcularse utilizando el número de viviendas y un factor de emisión de CO. El factor de emisión de CO para los combustibles de biomasa o residuos se basa en los datos de prueba en fuente de la tabla de madera mexicana (Summit et al., 1996).

$$\text{Emisiones}_{\text{CO}} = \text{Bio/ Res}_{\text{Uso}} \text{ x Viviendas}_{\text{Bio/Res}} \text{ x EF}_{\text{CO}}$$

$$\text{Emisiones}_{\text{CO}} = \frac{\text{2,420 kg bio/res}}{\text{vivienda}} \text{ x 760 viviendas x } \frac{\text{31 g CO}}{\text{kg bio/res}}$$

$$\text{Emisiones}_{\text{CO}} = \text{57,015 kg/año CO} = \text{57.0 Mg/año de CO}$$

donde:

Emisiones_{CO} = Emisiones totales de CO (kg/año ó Mg/año)

Bio/Res_{Uso} = Uso anual de combustibles de biomasa o residuos por vivienda (kg/año)

$\text{Vivienda}_{Bio/Res}$ = Número de viviendas que usan combustibles de biomasa o residuos

EF_{CO} = Factor de emisión de CO (g CO/kg bio/res).

Discusión de los Resultados

Si bien las emisiones anuales de CO de la combustión residencial de combustibles de biomasa o residuos se estimaron en 57 Mg/año, la calidad de este estimado de emisión y sus supuestos subyacentes deben ser analizados para identificar las áreas de mejora y las fuentes de incertidumbre potenciales. A continuación se discuten algunos aspectos:

1. **Número de viviendas que utilizan combustibles de biomasa o residuos.** Las autoridades locales habían estimado que el 98% de la viviendas utilizaban GLP. Se supuso que el 2% restante de las viviendas utilizaban combustibles de biomasa o residuos. Este supuesto no tomó en cuenta la posibilidad de que alguna fracción del 2% restante de las viviendas utilizara queroseno, combustible destilado u otros tipos de energéticos.

2. **Número de viviendas que utilizan GLP.** Como se mencionó anteriormente, las autoridades locales habían estimado que el 98% de las viviendas utilizaba GLP. Sin embargo, no queda clara cuál es la base de este estimado, ni su precisión. Incluso si el porcentaje de hogares que utiliza GLP fuera ligeramente diferente, podría tener un impacto significativo en el estimado de emisiones para los combustibles. Por ejemplo, si el porcentaje real de viviendas que utilizan GLP fuera del 97% en lugar del 98%, entonces, las emisiones por la combustión de GLP disminuirían ligeramente. Sin embargo, las emisiones de la combustión de combustibles de

biomasa o residuos sería afectada en gran medida; el porcentaje de las vivienda que utilizan combustibles de biomasa o residuos incrementaría del 2% al 3%, lo que representa un incremento del 50%.

3. **Fracción de uso residencial del GLP.** En este problema se supuso que el 80% del GLP general tiene un uso residencial. Este supuesto se basa en las estadísticas nacionales. Sin embargo, los patrones locales de consumo pueden ser diferentes.

4. **Eficiencias de la Combustión.** En este problema se supuso que las eficiencias de combustión de GLP y los combustibles de biomasa o residuos es igual. En realidad, es probable que la combustión del GLP sea más eficiente que la de los combustibles de biomasa o residuos. Esto incrementaría las emisiones de biomasa o residuos.

5. **Patrones del Uso de Combustibles.** Un supuesto implícito al convertir el uso de GLP a uso de combustibles de biomasa o residuos, es que los patrones de uso del combustible son iguales. En la realidad, es probable que esto no suceda. Por ejemplo, si el GLP se utiliza para propósitos de calefacción o cocina, entonces el equipo de combustión puede ser apagado cuando se ha obtenido la cantidad de calor deseada. Sin embargo, la combustión de los combustibles de biomasa o residuos a menudo continuará después de que se ha alcanzado la cantidad deseada de calor, debido a que no es conveniente o práctico el apagar el fuego.

6. **Composición de los combustibles de biomasa o residuos.** En este problema se asumió que el combustible de biomasa o residuo era madera de tarima. En realidad, es probable que los combustibles de biomasa o residuos estén integrados por una amplia variedad de materiales, cada uno de los cuales tendrá su propio contenido energético y su propio factor de emisión.

Dados los limitados datos disponibles para este problema de emisión, fue necesario hacer todos los supuestos descritos anteriormente. De manera ideal, podría recopilarse información adicional que eliminaría la necesidad de algunos de estos supuestos, lo que mejoraría la calidad de los estimados de emisión y reduciría la incertidumbre asociada.

Ejemplo 4
Sistema de Distribución de Gasolina

Introducción

El siguiente ejemplo está dividido en siete partes, que están relacionadas con el sistema de distribución de gasolina. Si bien cada parte se refiere a una categoría de fuente individual, estas categorías de fuente a menudo son agrupadas de manera conceptual. Esto se debe principalmente a que la distribución de gasolina es una fuente potencialmente grande de emisión de gases orgánicos evaporativos totales (GOT). Un sistema de distribución de gasolina típico puede tener cientos o miles de fuentes individuales, y es importante que todas estas fuentes sean contabilizadas en un sistema de inventario. Al tratar el sistema de distribución como un todo, en general es más fácil garantizar que todas las fuentes posibles están incluidas.

La Figura 4-1 presenta un sistema de distribución de gasolina hipotético con un número manejable de elementos. Este sistema simplificado contiene una terminal a granel y cuatro estaciones de gasolina. Las pipas transportan la gasolina entre la terminal y las estaciones de servicio. Este sistema **NO** incluye la refinería de petróleo que distribuye a la terminal a granel, o el transporte desde la refinería hasta dicha terminal por pipa, carro-tanque o buque-tanque. En realidad, un sistema de distribución de gasolina va a ser mucho más complejo que el esquema que aquí se presenta. El sistema de distribución en la Figura 4-1 va a ser utilizado en todo el Ejemplo 4. Los conceptos que se presentan en estos siete problemas no están limitados a la distribución de gasolina; también son aplicables a otros combustibles líquidos (e. g., gas avión, diesel o GLP), y gaseosos (gas natural). Sin embargo, los detalles específicos y los factores de emisión van a ser diferentes.

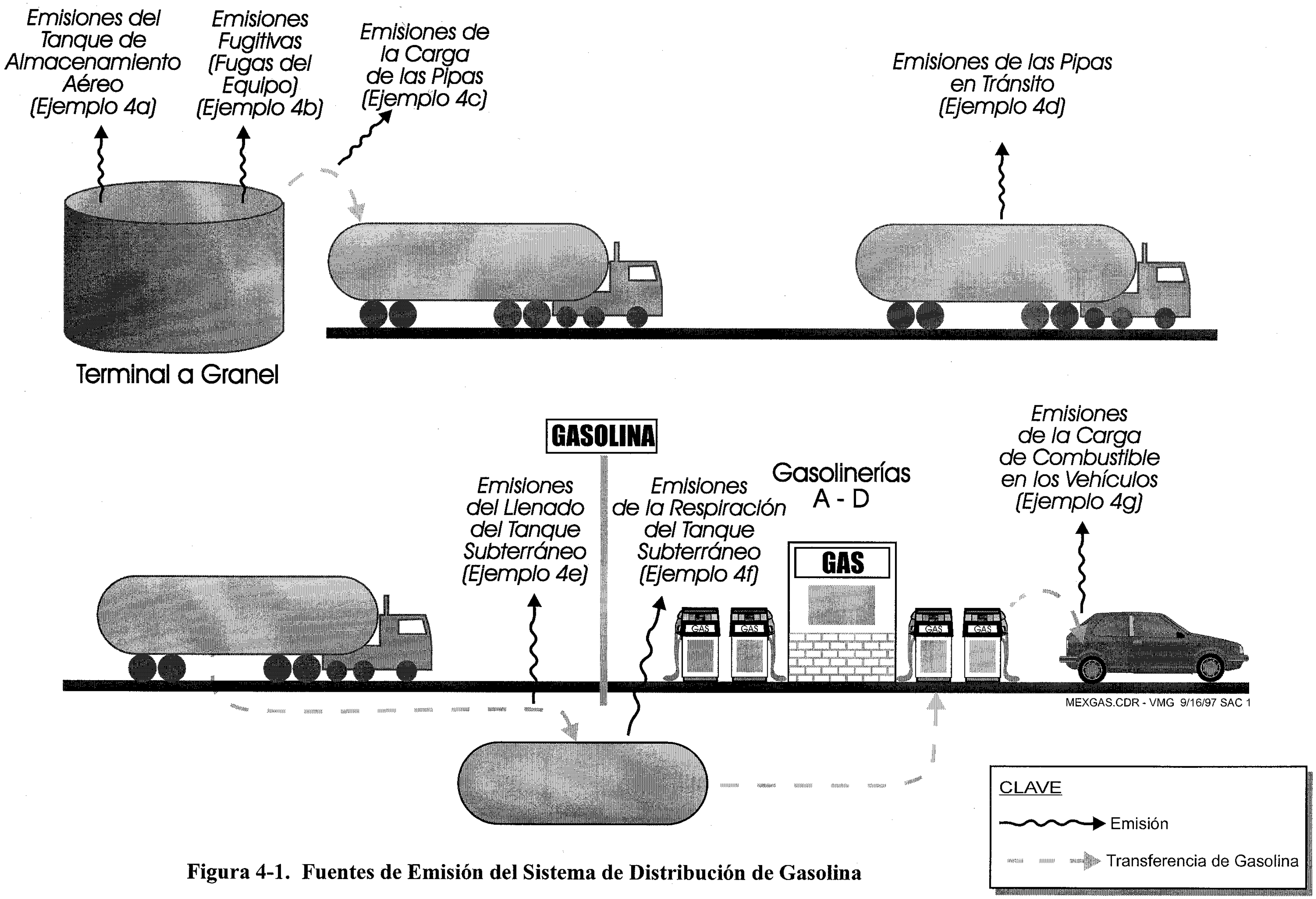

Figura 4-1. Fuentes de Emisión del Sistema de Distribución de Gasolina

Ejemplo 4a

Tanque de Almacenamiento Aéreo para Despacho a Granel

Planteamiento del Problema

Estimar las emisiones de GOTs de las pérdidas en reposo y de trabajo en el tanque de almacenamiento aéreo para despacho a granel.

Información Disponible

Se ha determinado que la cantidad total de gasolina con una presión de vapor Reid de 9 (PVR 9) que es bombeada a través del tanque a granel de la terminal es de 10,000,000 litros al año (2,642,000 galones al año). Este tanque es un tanque de almacenamiento aéreo de techo fijo (TAA) con capacidad de 210,000 galones. El TAA tiene techo cónico. La altura del líquido dentro del tanque es desconocida en un momento dado. Se supone que las condiciones meteorológicas son similares a las de Corpus Christi, Texas.

Se cuenta con la siguiente información sobre el tanque de almacenamiento aéreo para despacho a granel:

- Material almacenado = gasolina (PVR 9)
- Diámetro del tanque (D) = 37.6 pies
- Altura del casco del tanque (H_S) = 24 pies
- Altura promedio del líquido en el tanque = 12 pies (la altura del líquido dentro del tanque se desconoce en un momento determinado; se supone que es la mitad de la altura del casco del tanque)
- Capacidad del tanque (V_{LX}) = 210,000 galones
- Color del tanque = gris claro
- Absorción solar de la pintura del tanque (α) = 0.54 (AP-42, Tabla 7.1-6 para pintura gris claro en buenas condiciones)
- Temperatura ambiente máxima diaria (promedio anual) (T_{AX}) = 81.6°F = 541.27°R (AP-42, Tabla 7.1-7)
- Temperatura ambiente mínima diaria (promedio anual) (T_{AN}) = 62.5°F = 522.17°R (AP-42, Tabla 7.1-7)
- Insolación (I) = 1521 Btu/ft^2-día (AP-42, Tabla 7.1-7)

- Punto de ajuste de la presión del venteo del respirador (P_{BP}) = 0.03 psig (AP-42 valor por omisión)
- Punto de ajuste del vacío del venteo del respirador (P_{BV}) = -0.03 psig (AP-42 valor por omisión)
- Peso molecular del vapor (M_V) = 66.7 lb/lb-mol (interpolado del AP-42, Tabla 7.1-2)
- Pendiente de la curva de destilación ASTM a una evaporación del 10% (S) = 3.0 (AP-42, Figura 7.1-14a, Nota 1)

Solución

Las emisiones totales de GOTs de los tanques de almacenamiento de techo fijo son estimadas con base en la metodología descrita en el AP-42 (U.S. EPA, 1995a), Sección 7.1.3.1, *Total Losses from Fixed Roof Tanks* (Pérdidas Totales de los Tanques con Techo Fijo), Febrero 1996. Las metodologías de estimación para otros tipos de tanques de almacenamiento puede encontrarse también en el AP-42, donde se presenta una serie de ecuaciones más que factores de emisión para estimar las emisiones del almacenamiento de líquidos orgánicos. Las emisiones de los tanques de almacenamiento de techo fijo son la suma de las pérdidas en reposo y de trabajo. Las primeras ocurren como consecuencia de los cambios de temperatura que conducen al venteo del vapor del tanque a la atmósfera. Las pérdidas de trabajo resultan de los cambios en el nivel del líquido del tanque, principalmente por las operaciones de llenado y vaciado. Estas ecuaciones tienen el objetivo de dar una estimación más precisa de las emisiones del tanque de almacenamiento. Típicamente, el software TANKS (U.S. EPA, 1996) desarrollado por la EPA será utilizado para estimar las emisiones de los tanques de almacenamiento a granel. este ejemplo muestra las ecuaciones que se utilizan en el TANKS. Debido a que este software utiliza unidades inglesas, el ejemplo se desarrolló en unidades inglesas, y no en unidades métricas. En primer lugar se calcularán las pérdidas en reposo no controladas y, posteriormente, las pérdidas de trabajo no controladas.

1. Cálculo de las Pérdidas en Reposo No Controladas

$$L_S = 365 * V_V * W_V * K_E * K_S$$

donde:

L_s = Pérdidas en reposo (lb/año)

365 = Constante (días/año)

V_V = Volumen del espacio de vapor (ft^3)

W_V = Densidad del espacio de vapor (lb/ft^3)

K_E = Factor de expansión del espacio de vapor

K_S = Factor de saturación del vapor venteado

Cálculo del Volumen del Espacio de Vapor (V_V)

$$V_V = \frac{p}{4} \text{ x } D^2 \text{ x } H_{VO}$$

donde:

D = Diámetro del tanque (ft)

H_{VO} = Pérdida por almacenamiento del espacio de vapor (ft).

$$H_{VO} = H_S - H_L + H_{RO}$$

donde:

H_S = Altura del casco del tanque (ft)

H_L = Altura del líquido (ft) (si este valor se desconoce, puede suponerse que es de $0.5H_s$ [esto significa que el tanque está en promedio, lleno hasta la mitad])

H_{RO} = Pérdida por almacenamiento del techo (ft).

$$H_{RO} = \frac{1}{3} \text{ x } H_R$$

donde:

H_R = Altura del techo del tanque (ft).

$$H_R = R_S \text{ x } S_R$$

donde:

R_S = Radio del casco del tanque (ft)

S_R = Pendiente del cono del techo (ft/ft) (si se desconoce, usar el valor estándar de 0.0625 ft/ft [AP-42, pág. 7.1-12])

Para el Tanque a Granel de la Terminal:

R_S	=	$0.5 \times D$		
	=	$0.5 \times (37.6 \text{ ft}) = 18.80$ ft		
S_R	=	0.0625 ft/ft		
H_R	=	$(18.80 \text{ ft}) \times (0.0625 \text{ ft/ft})$	=	1.175 ft
H_{RO}	=	$(1/3) \times (1.175 \text{ ft})$	=	0.3917 ft
H_L	=	$(0.5) \times (24 \text{ ft})$	=	12 ft
H_{VO}	=	24 - 12 + 0.3917 = 12.39 ft		
V_V	=	$(\pi/4) \times (37.6 \text{ ft})^2 \times (12.39 \text{ ft})$	=	13,759 ft^3

Cálculo de la Densidad de Vapor (W_V)

$$W_V = \frac{(M_V \text{ x } P_{VA})}{(R \text{ x } T_{LA})}$$

donde:

M_V = Peso molecular del vapor (lb/lb-mol)

P_{VA} = Presión de vapor a la temperatura superficial promedio del líquido (psia)

R = Constante de los gases ideales (10.731 psia-ft^3/lb-mol°R)

T_{LA} = Temperatura superficial promedio diaria del líquido (°R).

$$T_{LA} = 0.44T_{AA} + 0.56T_{B} + 0.0079\alpha I$$

donde:

T_{AA} = Temperatura ambiente promedio diaria (°R)

T_{B} = Temperatura del líquido a granel (°R)

α = Absorción solar de la pintura del tanque

I = Factor de insolación total diario (Btu/ft^2-día) (el factor de insolación solar está en función de la cobertura de nubes y la latitud. El AP.42, Tabla 7.1-7 muestra algunos valores para EU).

$$T_{AA} = \frac{(T_{AX} + T_{AN})}{2}$$

donde:

T_{AX} = Temperatura ambiente máxima diaria (°R)

T_{AN} = Temperatura ambiente mínima diaria (°R).

$$T_{B} = T_{AA} + 6\alpha - 1$$

T_{AA} = $(T_{AN} + T_{AX})/2 = (522.17 + 541.27)/2 = 531.72°R$

T_{B} = $531.72°R + 6(0.54) - 1 = 533.96°R$

T_{LA} = $(0.44) \times (531.72°R) + (0.56) \times (533.96°R) + (0.0079) \times (0.54) \times (1521\ \text{Btu/ft}^2\text{-día}) = 539.47°R$

$$P_{AV} = \left\{\left[0.7553 - \left(\frac{413}{T_{LA}}\right)\right] S^{0.5} \log_{10}(PVR) - \left[1.854 - \left(\frac{1042}{T_{LA}}\right)\right] S^{0.5} + \left[\left(\frac{2416}{T_{LA}}\right) - 2.013\right] \log_{10}(PVR) - \left(\frac{8742}{T_{LA}}\right) + 15.64\right\}$$

(Según el AP-42 Figura 7.1-13b)

donde:

T_{LA} = Temperatura promedio de la superficie del líquido (°R)

PVR = Presión de Vapor de Reid (psia).

Entonces, para la gasolina PVR 9:

$$P_{VA} = \exp\left\{\left[0.7553 - \left(\frac{413}{539.47_a}\right)\right]3^{0.5}\log_{10}(9) - \left[1.854 - \left(\frac{1042}{539.47}\right)\right]3^{0.5} + \left[\left(\frac{2416}{539.47}\right) - 2.013\right]\log_{10}(9) - \left(\frac{8742}{539.47_a}\right) + 15.64\right\} = 6.72\ \text{psia}$$

Idealmente, los valores de presión de vapor medidos deben ser utilizados en lugar de los valores calculados con la ecuación anterior. Los cálculos de emisiones son muy sensibles a los valores de presión de vapor (P_{VA}). Por lo tanto, es importante obtener el valor más preciso posible.

$$W_V = \frac{\left(\frac{66.7\ \text{lb}}{\text{lb-mol}}\right)(6.72\ \text{psia})}{\left(\frac{10.731\ \text{psia-ft}^3}{\text{lb-mol-}^\circ\text{R}}\right)(539.47^\circ\ \text{R})} = 0.0774\ \text{lb/ft}^3$$

Cálculo del Factor de Expansión de Vapor (K_E)

$$K_E = \frac{\Delta T_V}{T_{LA}} + \frac{(\Delta P_V - \Delta P_B)}{P_A - P_{VA}}$$

donde:

ΔT_V = Intervalo diario de la temperatura del vapor (°R)

T_{LA} = Temperatura promedio diaria de la superficie del líquido (°R)

ΔP_V = Intervalo diario de la presión de vapor (psi)

ΔP_B = Intervalo de ajuste de la presión de venteo del respirador (psi)

P_A = Presión atmosférica (normalmente 14.7 psia, sin embargo, ésta puede ser ajustada para elevaciones altas, si es necesario)

P_{VA} = Presión de vapor a la temperatura diaria superficial promedio (psia).

$$\Delta P_B = P_{BP} - P_{BV}$$

donde:

P_{BP} = Punto de ajuste de la presión de venteo del respiradero

P_{BV} = Punto de ajuste del vacío del venteo del respiradero

ΔP_B = (0.03) - (-0.03) = 0.06 psia

$$\Delta T_V = 0.72 \Delta T_A + 0.028 \alpha I$$

donde:

ΔT_A = Intervalo diario de la temperatura ambiente promedio (°R)

$$\Delta T_A = T_{AX} - T_{AN}$$

donde:

T_{AX} = Temperatura ambiente máxima diaria (°R)

T_{AN} = Temperatura ambiente mínima diaria (°R).

ΔT_A = 541.27 - 522.17 = 19.1°R

ΔT_V = $(0.72) \times (19.1\ °R) + (0.028) \times (0.54) \times (1521\ Btu/ft^2\text{-día}) = 36.75\ °R$

T_{LA} = 539.47°R (calculada anteriormente)

ΔP_V = $P_{VX} - P_{VN}$

(P_{VX} y P_{VN} son estimadas utilizando la misma ecuación que P_{VA} excepto que T_{LX} y T_{LV} se utilizan en lugar de T_{LA}).

donde:

P_{VX} = Presión de vapor a la temperatura diaria máxima de la superficie del líquido (psia)

P_{VN} = Presión de vapor a la temperatura diaria mínima de la superficie (psia).

$$P_{VX} = \exp\left\{\left[0.7553 - \left(\frac{413}{T_{LX}}\right)\right] S^{0.5}\log_{10}(PVR) - \left[1.854 - \left(\frac{1042}{T_{LX}}\right)\right] S^{0.5} + \left[\left(\frac{2416}{T_{LX}}\right) - 2.013\right]\log_{10}(PVR) - \left(\frac{8742}{T_{LX}}\right) + 15.64\right\}$$

$$P_{VN} = \exp\left\{\left[0.7553 - \left(\frac{413}{T_{LN}}\right)\right] S^{0.5}\log_{10}(PVR) - \left[1.854 - \left(\frac{1042}{T_{LN}}\right)\right] S^{0.5} + \left[\left(\frac{2416}{T_{LN}}\right) - 2.013\right]\log_{10}(PVR) - \left(\frac{8742}{T_{LN}}\right) + 15.64\right\}$$

T_{LX} = Máxima temperatura diaria en la superficie del líquido

= $T_{LA} + 0.25\ (\Delta T_V) = 539.47 + 0.25\ (36.75) = 548.66°R$

T_{LN} = Mínima temperatura diaria en la superficie del líquido

= $T_{LA} - 0.25\ (\Delta T_V) = 539.47 - 0.25\ (36.75) = 530.28°R$

Entonces, para la gasolina PVR 9:

$$P_{VX} = \exp\left\{\left[0.7553 - \left(\frac{413}{548.66_a}\right)\right] 3^{0.5}\log_{10}(9) - \left[1.854 - \left(\frac{1042}{548.66}\right)\right] 3^{0.5} + \left[\left(\frac{2416}{548.66_a}\right) - 2.013\right]\log_{10}(9) - \left(\frac{8742}{548.66}\right) + 15.64\right\} = 7.93 \text{ psia}$$

$$P_{VN} = \exp\left\{\left[0.7553 - \left(\frac{413}{530.28_a}\right)\right] 3^{0.5}\log_{10}(9) - \left[1.854 - \left(\frac{1042}{530.28}\right)\right] 3^{0.5} + \left[\left(\frac{2416}{530.28_a}\right) - 2.013\right]\log_{10}(9) - \left(\frac{8742}{530.28}\right) + 15.64\right\} = 5.67 \text{ psia}$$

$$\begin{aligned} \Delta P_V &= P_{VX} - P_{VN} \\ &= 7.93 - 5.67 \\ &= 2.26 \text{ psia} \end{aligned}$$

$$K_E = \frac{36.75° R}{539.47° R} + \frac{(2.26 \text{ psia} - 0.06 \text{ psia})}{(14.7 \text{ psia} - 6.72 \text{ psia})} = 0.3438$$

Cálculo del Factor de Saturación de Vapor (K_S)

$$K_S = \frac{1}{1 + 0.053 P_{VA} H_{VO}}$$

donde:

P_{VA} = Presión de vapor a la temperatura promedio diaria de la superficie del líquido (psia)

H_{VO} = Pérdida por almacenamiento del espacio de vapor (ft).

Para gasolina PVR 9:

P_{VA}=6.72 psia (calculado anteriormente)

H_{VO}=12.39 ft (calculado anteriormente)

$$K_s = \frac{1}{1 + (0.053)(6.72)(12.39)} = 0.1847$$

Solución para las Pérdidas en Reposo:

$$L_S = 365 \times V_V \times W_V \times K_E \times K_S$$

donde:

V_V = 13,759 ft^3

W_V = 0.0774 lb/ft^3

K_E = 0.3187

K_S = 0.1847

L_S = (365) × (13,759) × (0.0774) × (0.3438) × (0.1847)

= 24,683 lb/año

2. Cálculo de las Pérdidas de Trabajo No Controladas

$$\mathbf{L_W = 0.0010 \times M_V \times P_{VA} \times Q \times K_N \times K_P}$$

donde:

M_V = Peso molecular del vapor (lb/mol)

P_{VA} = Presión de vapor a la temperatura promedio diaria de la superficie del líquido (psia)

Q = Almacenamiento anual neto (bbl/año)

K_N = Factor de almacenamiento (para $N>36$, $K_N = [180 + N]/6N$; para $N \leq 36$, $K_N = 1$) (AP-42, pág. 7.1-18)

K_P = Factor de pérdida de producto por trabajo (0.75 para petróleos crudos; 1.0 para todos los demás líquidos orgánicos; AP-42, pág. 7.1-18)

$$N = \frac{5.614\,Q}{V_{LX}}$$

donde:

N = Número de veces que se llena el tanque al año

5.614 = Factor de conversión de bbl a ft^3

Q = Almacenamiento anual neto (bbl/año)

V_{LX} = Máximo volumen de líquido del tanque (ft^3)

Para gasolina PVR 9:

M_V = 66.7 lb/lb-mol

P_{VA} = 6.72 psia

Q = 2.642×10^6 gal/año = 62,905 bbls/año

V_{LX} = 210,000 galones = 28,066 ft^3

$$N = \frac{5.614\,(62{,}905\ \text{bbl/yr})}{(28{,}066\ ft^3)} = 12.58\,/\text{yr}$$

Por lo tanto,

K_N = 1.0

K_P = 1.0

L_W = (0.0010) × (66.7 lb/lb-mol) × (6.72 psia) × (62,905 bbls/año) × (1.0) × (1.0)

= 28,196 lb/año

3. Cálculo de Pérdidas Totales No Controladas

L_{Total} = L_S + L_W = 24,683 lb/año + 28,196 lb/año = 52,879 lb/año

= 23,981 kg/año = 24.0 Mg/año.

Ejemplo 4a – Información Complementaria
Estimación de Especies Individuales

Introducción

En algunas aplicaciones de calidad del aire, se requiere la estimación de especies químicas individuales. Para algunas categorías, se realiza el muestreo de especies individuales. Sin embargo, cuando este muestreo es impráctico o demasiado costoso, deben utilizarse métodos alternativos. Para las emisiones de tanques, la Ley de Raoult constituye un método útil para estimar las emisiones de especies individuales.

Planteamiento del Problema

Utilizando la Ley de Raoult, estimar las emisiones de ciclohexano de las pérdidas en reposo y de trabajo en el tanque a granel de la terminal debidas al almacenamiento y bombeo de gasolina PVR 9:

Información Disponible

Como se estimó anteriormente, la temperatura del líquido a granel, (T_{LA}), es de 80°F. El tanque de granel de la terminal es un tanque TAA con techo fijo. Después del análisis de la gasolina PVR 9 se determinó que la gasolina líquida es ciclohexano en una proporción de 0.58% en peso ($x_{liq,c} = 0.0058$).

Solución

Para determinar las emisiones especiadas de las pérdidas en reposo y de trabajo del tanque, son necesarios los siguientes pasos:

1. Determinar la especiación de la fase líquida de la gasolina contenida en el tanque.

2. Encontrar la presión de vapor saturado de cada especie de interés a la temperatura del líquido a granel.

3. Determinar la verdadera presión de vapor de la mezcla a la temperatura del líquido a granel.

4. Aplicando la Ley de Raoult, determinar la especiación de la fase de vapor de la gasolina en el tanque.

5. Calcular las emisiones específicas por sustancia química utilizando los pasos anteriores, y los resultados de los cálculos como se presentan en el Problema 4a.

La Ley de Raoult puede ser utilizada para determinar la fracción molar de la fase de vapor para un componente o especie particular en una mezcla basada en la fracción molar de la fase líquida. Se supone que el vapor es un gas ideal y que el líquido es una solución ideal. También se supone que ambos están bien mezclados y en equilibrio entre sí. Planteado simplemente, si la composición de la fase líquida del tanque es conocida, entonces la composición de la fase de vapor en el espacio de vapor del tanque puede ser calculada. Los supuestos sobre la conducta ideal y el equilibrio vapor/líquido con frecuencia no se aplican de manera estricta, dado que raramente se presentan en el mundo real y, a menudo, la Ley de Raoult u otra ecuación de estado es la única forma de determinar las composiciones de la fase de vapor sin tener que muestrear físicamente el tanque para medirlas.

Para una mezcla de N especies, la Ley de Raoult se expresa como:

$$Y_iP = X_iP_i^{sat}; \qquad i = 1, 2, 3,...,N$$

donde:

Y_i = Fracción molar de la fase de vapor del componente i

P = Vapor de presión real de la mezcla a la temperatura del líquido a granel

X_i = Fracción molar de la fase líquida del componente i

$P_i^{saturación}$ = Presión de vapor saturado de la especie i a la temperatura del líquido a granel.

También,
$x_{vap,c}$ = La fracción de masa del ciclohexano en la fase de vapor.

Cabe señalar que es posible que se requieran pasos extra para convertir las fracciones de masa a fracciones molares. La ecuación anterior está escrita en términos de fracciones molares; sin embargo, los datos están comúnmente disponibles sólo como fracciones de masa.

Dadas:
P_g = Presión de vapor real para la gasolina = 6.72 psia a 80°F (valor previamente calculado para P_{VA}; ver pág. 4-7)
$P_{cyclohexane}^{sat}$ = Presión de vapor saturado de ciclohexano = 2.069 psia (AP-42, Tabla 7.1-3)

Reacomodando la Ley de Raoult se tiene:

$$Y_i = \frac{X_i P_i^{Sat}}{P}$$

Antes de usar esta ecuación, la fracción de masa en la fase líquida debe ser convertida a una fracción molar. Esto se hace como se muestra a continuación, utilizando los pesos moleculares.

MW_g = Peso molecular de la gasolina líquida = 100 lb/lb-mol (esto se obtiene típicamente de los fabricantes o de otros valores publicados)
MW_v = Peso molecular del vapor de gasolina = 66.7 lb/lb-mol (extrapolado del AP-42, Tabla 7.1-2)
MW_c = Peso molecular del ciclohexano = 84.16 lb/lb-mol (AP-42, Tabla 7.1-3)

$$X_c \text{ (fracción molar del ciclohexano en fase líquida)} = \frac{X_{liq,c}\, MW_g}{MW_c} = \frac{(0.0058)\,(100)}{84.16} = 0.0069$$

$$Y_c \text{ (fracción molar del ciclohexano en fase de vapor)} = \frac{X_c\, P_c^{sat}}{P_g} = \frac{(0.0069)\,(2.069)}{6.72} = 0.00212$$

Se necesita el valor de $x_{vap,c}$, la fracción de masa del ciclohexano en la fase de vapor. Por lo tanto, convirtiendo como anteriormente:

$$X_{vap,c} = \frac{Y_c\, MW_c}{MW_v} = \frac{(0.00212)\,(84.16)}{66.7}$$

$$= 0.00267 \text{ lb ciclohexano / lb vapor de gasoline}$$

Ahora, calcular las emisiones de ciclohexano de las pérdidas en reposo y de trabajo de los tanques superficiales de almacenamiento.

L_{Total} = Pérdidas totales en reposo y de trabajo
= 23,164 kg/año

$$L_{ciclohexano} = \left(\frac{23{,}164 \text{ kg vapor de gasolina}}{\text{año}}\right)\left(\frac{0.00267 \text{ kg ciclohexan o}}{1 \text{ kg vapor de gasolina}}\right)$$

$$= 62 \text{ kg ciclohexan o/año}$$

Ejemplo 4a – Información Complementaria
Comparación de la Ley de Raoult con Otros Métodos

Planteamiento del Problema

Comparar los resultados obtenidos utilizando la Ley de Raoult para medir la composición del vapor con otras técnicas.

Solución

La Tabla 4-1 (mezcla de gasolina en verano) presenta una selección de los resultados medidos y proyectados para las concentraciones de diversas sustancias químicas en las fases líquida y de vapor de la gasolina. Estos resultados no están relacionados con la información presentada en la sección de Información Complementaria anterior. Como los datos lo presentan claramente, la Ley de Raoult predice con mayor precisión las concentraciones en la fase de vapor que las ecuaciones de estado de Peng-Robinson o Redlich-Kwong-Soave. Las ecuaciones de estado relacionan las intensas propiedades termodinámicas (e. g., temperatura, presión o volumen específico) de cualquier sustancia. La información sobre las ecuaciones de estado de Peng-Robinson o Redlich-Kwong-Soave pueden encontrarse en los libros de texto de termodinámica para ingeniería química (i.e., Smith and Van Ness, 1987). Adicionalmente, la Ley de Raoult es mucho más fácil de usar que las otras ecuaciones de estado. Los errores relativos mostrados en las tablas también están dentro de la razón para los propósitos de la estimación de emisiones.

Tabla 4-1

Resumen de los Resultados para la Mezcla de Gasolina sin Plomo en Verano

Especies Tóxicas	**Medidas**		**Concentración de Vapor Proyectada**		
	Líquido wt%	**Vapor wt%**	**Raoult[a]**	**P-R EOS[b]**	**R-K-S EOS[c]**
Ciclohexano	0.58	0.20	0.25	0.27	0.26
Benceno	1.93	0.73	0.83	1.05	0.99
Tolueno	10.32	0.81	1.29	1.57	1.45
O-xileno	3.39	0.05	0.00	0.00	0.00
Isómeros de xileno	9.16	0.21	0.31	0.33	0.30
Etilbenceno	2.05	0.05	0.00	0.00	0.00
Isopropilbenceno	0.19	—	0.00	0.00	0.00
1,2,4-trimetilbenceno	3.52	0.04	0.00	0.00	0.00
Peso molecular del vapor		67.6	67.0	67.4	67.2
Presión de vapor proyectada			3.92	4.04	4.00
Errores de la concentración relativa:					
Promedio para todas las especies			4.0%	10.4%	7.3%
Promedio para tóxicos			22.7%	36.5%	29.6%
Valor absoluto para todas las especies			16.7%	22.2%	19.5%
Valor absoluto para los tóxicos			22.7%	36.5%	29.6%

Notes: [a] Raoult = Ley de Raoult

[b] P-R EOS = Ecuación de estado de Peng-Robinson

[c] R-K-S EOS = Ecuación de estado de Redlich-Kwong-Soave

Ejemplo 4b

Emisiones Fugitivas (Fugas del Equipo)

Planteamiento del Problema

Estimar las emisiones fugitivas de GOT de fugas en equipos de la terminal a granel. El Ejemplo 4a se refirió a las pérdidas por venteo y las de trabajo asociadas con el tanque de almacenamiento aéreo (TAA) en la terminal a granel. Este problema se refiere a las pérdidas de vapores de hidrocarburos en diversos tipos de equipo de proceso.

Información Disponible

La terminal hipotética de gasolina a granel contiene los siguientes tipos de equipo: 520 válvulas, 230 sellos de bomba, 180 bridas, 120 conectores, y otros 70 tipos de equipo. En la terminal a granel, no se han instrumentado técnicas de control de emisión de fugas de los equipos.

Solución

Existen cuatro enfoques utilizados para estimar las emisiones fugitivas de GOT, que en orden ascendente de refinamiento son:

- Factor de Emisión Promedio
- Separación de Intervalos
- Correlación de la EPA
- Correlación Unidad-Específico.

Estos enfoques se detallan en el Documento de Protocolo de la EPA (U.S. EPA, 1995b). Para un establecimiento industrial con una cantidad relativamente baja de equipo, tal como una terminal a granel, normalmente se utilizarán sólo los dos primeros enfoques. Para otros establecimientos más complejos, como las refinerías, con frecuencia se utilizan los enfoques de correlación. Tanto el enfoque del Factor de Emisión Promedio como el de Separación de Intervalos requieren el conteo del equipo. Sin embargo, el enfoque de Separación de Intervalos requiere de información adicional. En este problema sólo se utilizarán los enfoques de Factor de Emisión Promedio y el de Separación de Intervalos.

Enfoque del Factor de Emisión Promedio

Utilizando el enfoque del Factor de Emisión Promedio, las emisiones totales para un tipo específico de equipo pueden ser calculadas utilizando la siguiente ecuación:

$$E_e = N_e \times EF_e \times t_e$$

donde:

E_e = Emisiones fugitivas no controladas (kg/año) para el equipo tipo e

N_e = Cantidad de equipo tipo e

EF_e = Factor de emisión no controlada para el equipo tipo e (kg/hr)

t_e = Tiempo anual de proceso (hr/año) (se supone que es de 8,760 horas/año).

Los factores de emisión promedio presentados en la Tabla 4-2 para la gasolina almacenada en las terminales a granel fueron tomados de la Tabla 2-3 del Documento de Protocolo. Otros factores de emisión promedio existen también para las refinerías, para las operaciones de producción de petróleo y gas, y para las operaciones de manufactura de sustancias orgánicas sintéticas. Estas otras operaciones tendrán factores de emisión promedio para las válvulas de alivio de presión, líneas abiertas y conexiones de muestreo.

Tabla 4-2

Factores de Emisión Promedio

Tipo de Equipo	**Factor de Emisión (kg/hr)**
Válvulas	0.000043
Sellos de bomba	0.00054
Aditamentos (conectores y bridas)	0.000008
Otro equipo	0.00013

A continuación se calculan las emisiones para cada tipo de equipo:

$E_{Válvulas}$ = 520 válvulas * 0.000043 kg/hr * 8,760 hr/año = 195.9 kg/año

$E_{Sellosbomba}$ = 230 sellos de bomba * 0.00054 kg/hr * 8,760 hr/año = 1,088 kg/año

E_{Bridas} = 180 bridas * 0.000008 kg/hr * 8,760 hr/año = 12.6 kg/año

$E_{Conectores}$ = 120 conectores * 0. 000008 kg/hr * 8,760 hr/año = 8.4 kg/año

E_{Otros} = 70 equipos varios * 0. 00013 kg/hr * 8,760 hr/año = 79.7 kg/año

Entonces, las emisiones fugitivas totales son calculadas como se muestra a continuación:

$$E_{Total} = 195.9 + 1{,}088 + 12.6 + 8.4 + 79.7 = 1{,}385 \text{ kg/año } = 1.4 \text{ Mg/año de GOT}$$

Enfoque de Separación de Intervalos

Si se utiliza el enfoque de Separación de Intervalos, entonces cada componente del equipo es clasificado como “con fuga” o “sin fuga”. Esta clasificación se realiza separando cada componente. La separación se hace midiendo la concentración de GOTs en el aire justo a un lado del componente. Si el valor es ≥10,000 ppmv, entonces, el componente recibe la designación de “con fuga”. En el caso contrario, si el valor de separación es <10,000 ppmv, el componente recibe la designación “sin fuga”. Las emisiones de los componentes “con fugas” se estiman utilizando factores de emisión de “con fuga”; las emisiones de los componentes “sin fugas” se estiman utilizando los factores de emisión “sin fugas”, A pesar de su designación como “sin fugas”, los componentes en realidad tienen fugas – sólo que éstas tienen una tasa de emisión menor que los componentes “con fugas”.

Aplicando el factor de Separación de Intervalos, las emisiones totales para un tipo específico de equipo pueden calcularse con la siguiente ecuación:

$$E_e = ([N_L \times EF_L] + [N_{NL} \times EF_{NL}]) \times t_e$$

donde:
E_e = Emisiones fugitivas no controladas (kg/año) para el equipo tipo e
N_L = Número de componentes del equipo “con fugas”
EF_L = Factor de emisiones no controladas de los componentes del equipo “con fugas” (kg/hr)
N_{NL} = Número de componentes del equipo “sin fugas”
EF_{NL} = Factor de emisiones no controladas para los componentes del equipo “sin fugas” (kg/hr)
t_e = Tiempo anual del proceso (hr/año) (se asume que son 8,760 horas por año).

Los factores de emisión separados en intervalos de emisión que se presentan en la Tabla 4-3 para la gasolina almacenada en terminales a granel son tomados de la Tabla 2-7 del Documento de Protocolo. Al igual que los factores de emisión promedio presentados anteriormente, los factores de emisión separados en intervalos de emisión también existen para refinerías, operaciones de producción de petróleo y gas, y operaciones de manufactura de sustancias químicas orgánicas sintéticas. También hay factores de emisión separados en intervalos para las válvulas de alivio de presión, las líneas abiertas y las conexiones de muestreo.

Tabla 4-3

Factores de Emisión de Separación de Intervalos

Tipo de Equipo	**Factor de Emisión “Con Fugas” (≥ 10,000 ppmv) (kg/hr)**	**Factor de Emisión “Sin Fugas” (<10,000 ppmv) (kg/hr)**
Válvulas	0.023	0.000015
Sellos de bomba	0.077	0.00024
Aditamentos (conectores y bridas)	0.0065	0.0000072
Otro equipo	0.034	0.000024

Después de la separación, se determina si las siguientes partes del equipo pertenecen a la categoría “con fugas” (i. e., valor de separación ≥ 10,000 ppmv): 1 válvula, 2 bridas, 2 conectores y una pieza de otro equipo. Las emisiones de GOT para cada tipo de equipo se calculan como se muestra a continuación:

$E_{\text{Válvulas}}$ = ([1 válvula * 0.023 kg/hr] + [159 válvulas * 0.000015 kg/hr]) * 8,760 hr/año = 270 kg/año
$E_{\text{Sellosbomba}}$ = ([0 sellos de bomba * 0.077 kg/hr] + [230 sellos de bomba 0.00024 kg/hr]) * 8,760 hr/año = 484 kg/año
E_{Bridas} = ([2 bridas * 0.0065 kg/hr] + [178 bridas * 0.0000072 kg/hr]) * 8,760 hr/año = 125 kg/año
$E_{\text{Conectores}}$ = ([2 conectores * 0.0065 kg/hr] + [118 conectores * 0.0000072 kg/hr]) * 8,760 hr/año = 121 kg/año
E_{Otros} = ([1 equipos otros * 0.034 kg/hr] + [69 equipos otros * 0.000024 kg/hr] * 8,760 hr/año = 312 kg/año

Entonces, las emisiones fugitivas totales son sumadas:

$$E_{\text{Total}} = 270 + 484 + 125 + 121 + 312 = 1{,}312 \text{ kg/año} = 1.3 \text{ Mg/año}$$

Si bien el problema de este ejemplo es hipotético, muestra que un enfoque más refinado puede producir resultados significativamente diferentes que un enfoque simplificado. En general, el enfoque de Separación de Intervalos va a arrojar resultados más bajos que el enfoque del Factor de Emisión Promedio. Sin embargo, los mayores requerimientos asociados con la recopilación de datos con los enfoques más elaborados deben ponderarse contra la necesidad de resultados más precisos.

Ejemplo 4c

Emisiones de la Carga de Pipas

Planteamiento del Problema

Estimar las emisiones de GOT de la carga de pipas de gasolina en la terminal de despacho a granel. Las pipas se utilizan para transportar la gasolina de la terminal a granel a las gasolinerías individuales. Este problema se refiere a la carga real de las pipas

Información Disponible

La cantidad total de gasolina cargada en la terminal a granel en pipas es de 10,000,000 litros anuales. Todas las pipas de gasolina que transportan el producto a las cuatro gasolinerías son abastecidas utilizando una “carga con salpicadura de servicio normal” *(normal service splash loading)*. Para la carga con salpicadura, la tubería de llenado que despacha la gasolina es bajada sólo parcialmente dentro del tanque de carga. Las emisiones son ocasionadas por las “salpicaduras” y turbulencia ocasionada. La temperatura de toda la gasolina entregada y la temperatura ambiente es de 80 °F.   No existe ningún sistema de control de balance de vapor.

Solución

La cantidad de las emisiones no controladas de la carga de pipas depende de que si la pipa está equipada para un llenado sumergido, por salpicadura o con balance de vapor. Las emisiones no controladas también dependen de la presión de vapor de la gasolina descargada, el peso molecular de los vapores expelidos del tanque de carga, y la temperatura a la que la gasolina es cargada. Adicionalmente, en el llenado con balance de vapor, donde se regresan los vapores desplazados de la pipa a una unidad de recuperación de vapor en la terminal a granel, se tendrá una eficiencia de control que fluctúa entre el 90 y 99 por ciento. La siguiente ecuación puede ser utilizada para estimar las pérdidas de carga no controladas (AP-42, Sección 5.2.2.1.1).

$$EF_{UL} = 12.46 \times \frac{SPM}{T}$$

donde:

EF_{UL} = Factor de emisión de pérdida de carga no controlada (lb/1000 gal)

S = Factor de saturación

P = Presión de vapor real de la gasolina (libras por pulgada cuadrada absoluta [psia])

M = Peso molecular de los vapores (lb/lb-mol)

T = Temperatura de la gasolina cargada (°R).

Los factores de saturación (S) para varios modos de operación, que representan qué tan cerca de la saturación llega el vapor expelido, se presenta en la Tabla 4.4.

Tabla 4-4

Factores de Saturación (S) para Calcular las Pérdidas de Carga de Petróleo Líquido

Tipo de Servicio	Carga por Salpicadura	Carga Sumergida
Tanque de carga limpio	1.45	0.50
Servicio normal	1.45	0.60
Servicio con balance de vapor	1.00	1.00

Las presiones de vapor reales y los pesos moleculares de los vapores de gasolina pueden derivarse de las Figuras 7.1-5 y 7.1-6,y de la Tabla 7.1-2 del AP-42. La Tabla 4-5 presenta información extraída de la Tabla 7.1-2.

Tabla 4-5

Propiedades Físicas de la Gasolina

Presión de Vapor Reid de la Gasolina	Peso Molecular del Vapor a 60°F (lb/lb-mole)	Presión de Vapor real (psi)						
		40 °F	50 °F	60 °F	70 °F	80 °F	90 °F	100 °F
13 psia	62	4.7	5.7	6.9	8.3	9.9	11.7	13.8
10 psia	66	3.4	4.2	5.2	6.2	7.4	8.8	10.5
7 psia	68	2.3	2.9	3.5	4.3	5.2	6.2	7.4

Los valores del peso molecular del vapor y la presión de vapor real para la gasolina PVR 9 deben ser interpolados a partir de los valores presentados en la Tabla anterior, como se muestra a continuación:

$$VMW_i = VMW_x + \left(\frac{PVR_x - PVR_i}{PVR_x - PVR_n} \right) (VMW_n - VMW_x)$$

$$TVP_i = TVP_x - \left(\frac{PVR_x - PVR_i}{PVR_x - PVR_n} \right) (TVP_x - TVP_n)$$

donde:

VMW_i = Peso molecular del vapor interpolado para PVR 9

VMW_x = Peso molecular del vapor a la PVR máxima PVR (10) en el intervalo de interpolación

VMW_n = Peso molecular del vapor a la PVR mínima (7) en el intervalo de interpolación

RVP_i = PVR interpolada (9)

RVP_x = PVR máxima (10)

RVP_n = PVR mínima (7)

TVP_i = Presión de vapor real interpolada para PVR 9

TVP_x = Presión de vapor real a la PVR máxima (10)

TVP_u = Presión de vapor real a la PVR mínima (7).

$$VMW_9 = 66 + \left(\frac{10 - 9}{10 - 7} \right) (68 - 66) = 66.7 \text{ lb/lb- mol}$$

$$TVP_9 = 7.4 - \left(\frac{10 - 9}{10 - 7} \right) (7.4 - 5.2) = 6.7 \text{ psi}$$

El factor de saturación para el servicio de carga por salpicadura es de 1.45. Finalmente, al convertir la temperatura de la gasolina de grados Fahrenheit a grados Rankine se obtiene una temperatura de 540°R.

Entonces, los factores de emisión de carga no controlada se calculan como se muestra a continuación:

$$EF_{UL(RVP\,9)} = \frac{12.46 \text{ x } 1.45 \text{ x } 6.7 \text{ x } 66.7}{540} = 14.95 \text{ lb}/1000 \text{ gal}$$

Los factores de emisión de carga controlada se calculan utilizando la siguiente ecuación:

$$EF_{CL} = (1 - CE) \text{ x } EF_{UL}$$

donde:

EF_{CL} = Factor de emisión de pérdidas controladas de carga (lb/1000 gal)

CE = Eficiencia de control de vapor

EF_{UL} = Factor de emisión de pérdidas no controladas de carga (lb/1000 gal).

Sin embargo, para este problema, durante la carga de las pipas no se utiliza un control de vapor, por lo tanto, no es necesario calcular los factores de emisión de carga controlada.

Las pérdidas totales de la carga de pipas pueden ser estimadas de la siguiente ecuación:

$$\text{Emisiones} = \sum_{i=1}^{n} EF_{UL,CL} \text{ X } \text{Combustible}_i$$

donde:

Emisiones = Emisiones totales de la carga de pipas (kg/año)

n = Cantidad de modos de operación y tipos de combustible diferentes

$EF_{UL,CL}$ = Factor de emisión controlada o no controlada de la carga de pipas para el modo de operación o el tipo de combustible i (mg/litro)

$Fuel_i$ = Cantidad anual de combustible entregado por cada modo de operación o tipo de combustible i (litros/año).

Convertir los factores de emisión de carga de unidades de lb/1000 gal a unidades de mg/litro:

$$EF_{UL(RVP\,9)} = \left(\frac{14.95 \text{ lb}}{1000 \text{ gal}}\right)\left(\frac{453.6 \text{ g}}{1 \text{ lb}}\right)\left(\frac{1000 \text{ mg}}{1 \text{ g}}\right)\left(\frac{1 \text{ gal}}{3.785 \text{ liter}}\right) = 1{,}792 \text{ mg litro}$$

$$\text{Emisiones} = \frac{1{,}792\ \text{mg}}{\text{litro}}\ \text{x}\ (1\ \text{x}\ 10^{7}\ \text{litros}) = 17{,}920\ \text{kg/año} = 17.9\ \text{Mg/año}$$

Ejemplo 4d
Emisiones de las Pipas en Tránsito

Planteamiento del Problema

Después de que la gasolina es cargada en las pipas, se transporta a las gasolinerías. Si bien las pipas tienen tanques cerrados, las emisiones se presentan durante el tránsito. Este problema se enfoca a las emisiones que se presentan mientras la pipa está en tránsito.

Estimar las emisiones de GOT de las pipas de gasolina en tránsito desde la terminal a granel hasta las gasolinerías de Pemex A, B, C y D.

Información Disponible

Las siguientes cantidades de gasolina son transportadas a las cuatro gasolinerías para su venta:

Gasolinería	Gasolina Despachada (litros/año)
A	4,000,000
B	2,500,000
C	2,000,000
D	1,500,000

Solución

La cantidad de emisiones de las pipas de gasolina depende del grado de venteo que se presente en tránsito que, a su vez, depende de la hermeticidad en el tanque, el ajuste de la presión en la válvula de alivio, la presión en el tanque al principio del recorrido, la presión de vapor del combustible transportado y el grado de saturación de vapor del combustible en el espacio del tanque. Las emisiones **no** son directamente proporcionales a la duración del translado.

La Tabla 5-2-5 del AP-42 presenta los factores de emisión de pérdida en tránsito para las pipas de gasolina tanto cargadas con producto como para su regreso con vapores para la gasolina

PVR 10. Estos factores de emisión se presentan en la Tabla 4-6 para condiciones de tránsito "típicas" y "extremas". La referencia a las condiciones extremas se hace para el caso poco probable en que todos los factores determinantes que se mencionan anteriormente se combinen para ocasionar emisiones máximas.

Tabla 4-6

Factores de Emisiones No Controladas para Pipas de Gasolina

Condiciones de Tránsito	Cargada con Producto (mg/litro de gasolina)	Regresando con Vapor (mg/litro de gasolina)
Típicas	0 - 1.0	0 - 13.0
Extremas	0 - 9.0	0 - 44.0

Las emisiones totales por pérdidas en tránsito incluyen tanto el recorrido de la terminal a granel a la gasolinería (cargada con producto), y el viaje de regreso desde las gasolinerías a la terminal a granel (tanques vacíos). Estas emisiones pueden ser estimadas con la siguiente ecuación:

$$\text{Emisiones} = \sum_{i=1}^{n} ([EF_{l,c} + EF_{r,c}] \text{ x Combustible}_i)$$

donde:

Emisiones = Emisiones totales de recarga (kg/año)

n = Número de gasolinerías

$EF_{l,c}$ = Factor de emisión de pérdida en tránsito "cargada con producto" para la gasolina transportada a la estación i en condiciones de tránsito c (mg/litro)

$EF_{r,c}$ = Factor de emisión de pérdida en tránsito "regreso con vapor" para la gasolina transportada de la estación i en condiciones de tránsito c (mg/litro)

Combustible_i = Cantidad anual de combustible despachado de la gasolinería i (litros/año).

Estimar las emisiones generales en tránsito suponiendo que la gasolina es transportada a las estaciones A, B y C en condiciones "típicas", y que a la gasolinería D es transportada en condiciones "extremas". Para cada factor de emisión, suponer que el punto medio del intervalo enlistado en la Tabla anterior constituye una estimación razonable.

$$\text{Emisiones} = ([0.5 + 6.5]\ \text{mg/litro})\ \ x\ ([4\ x\ 10^6] + [2.5\ x\ 10^6] + [2\ x\ 10^6]\ \text{litros})$$

$$+ ([4.5 + 22]\ \text{mg/litro})\ \ x\ (1.5\ x\ 10^6\ \text{litros})$$

$$= 59.5\ \text{kg/año} + 39.75\ \text{kg/año}$$

$$= 99\ \text{kg/año}$$

Cabe señalar que la cantidad de gasolina vendida a las gasolinerías en este problema es igual a la cantidad de gasolina transportada. Esto, sin embargo, no siempre sucede. Si las emisiones en tránsito son estimadas para el transporte de gasolina de una refinería a una terminal de despacho a granel y, posteriormente de ésta a las gasolinerías, entonces las emisiones en tránsito serían del doble, debido a que la gasolina es “transportada” dos veces. La gasolina también podría ser transportada a través del dominio de un inventario de emisiones, si bien su origen y/o destino podría encontrarse fuera de éste.

Ejemplo 4e

Emisiones del Llenado de Tanques Subterráneos

Planteamiento del Problema

Estimar las emisiones de GOTs de la descarga de gasolina de las pipas en las gasolinerías A, B, C y D. Después que las pipas llegan a la gasolinerías, descargan en los tanques de almacenamiento subterráneos. Esta descarga es similar a la carga de las pipas en la terminal de despacho a granel.

Información Disponible

Las siguientes cantidades de gasolina son transportadas a las cuatro gasolinerías para su venta:

Gasolinería	Gasolina (litros/año)
A	4,000,000
B	2,500,000
C	2,000,000
D	1,500,000

Las cuatro gasolina tienen los siguientes modos de operación:

Gasolinería	Modo de Operación
A	Carga sumergida – servicio normal
B	Carga sumergida – servicio con balance de vapor
C	Carga con salpicadura – servicio normal
D	Carga con salpicadura – servicio normal

Para la carga con salpicadura, la manguera de llenado que despacha la gasolina es bajada sólo parcialmente dentro del tanque de almacenamiento. Las emisiones son ocasionadas por las "salpicaduras" y turbulencia resultantes. Para la carga sumergida, la manguera de llenado se extiende prácticamente hasta el fondo del tanque de almacenamiento. Debido a esto, la turbulencia del líquido y las emisiones resultantes son reducidas, en comparación con la carga por salpicadura. El servicio con balance de vapor recupera los vapores desplazados durante la descarga de gasolina y los lleva de regreso al tanque de la pipa.

Solución

La cantidad de emisiones del llenado de tanques subterráneos depende de que si el tanque de la gasolinería está equipado para un llenado sumergido, por salpicadura o de balance de vapor sumergido. El llenado de balance de vapor, que regresa los vapores desplazados del tanque de la gasolinería al tanque de la pipa, va a tener una eficiencia de control que fluctúa de 93 a 100 por ciento con respecto a las emisiones no controladas. La Tabla 4-7 muestra los factores de emisión para el llenado de tanques subterráneos (AP-42, Tabla 5.2-7).

Tabla 4-7

Factores de Emisión para el Llenado de Tanques Subterráneos en Gasolinerías

Tipo de Operación	Factor de Emisión (rendimiento en mg/litro)
Sumergida	880
Por Salpicadura	1,380
Sumergida con Balance	40

Las emisiones totales del llenado de tanques subterráneos pueden estimarse con la siguiente ecuación:

$$\text{Emisiones} = \sum_{i=1}^{n} EF_i \times \text{Combustible}_i$$

donde:

Emisiones = Emisiones totales del llenado de tanques subterráneos (kg/año)

EF_i = Factor de emisión para el llenado de tanques subterráneos para la operación tipo i (mg/litro)

$Combustible_i$ = Cantidad anual de combustible entregado para la operación tipo i (litros/año).

$$\text{Emisiones} = (880\,[4 \times 10^6] + 40\,[2.5 \times 10^6] + 1{,}380\,[2 \times 10^6] + 1{,}380\,[1.5 \times 10^6])$$

$$\text{Emisiones} = 3{,}520 + 100 + 2{,}760 + 2{,}070 = 8{,}450 \text{ kg/año}$$

$$= 8.45 \text{ Mg/año}$$

Ejemplo 4f

Emisiones de la Respiración de Tanques Subterráneos

Planteamiento del Problema

Estimar las emisiones de GOT de la respiración del tanque subterráneo en las gasolinerías A, B, C y D.

Información Disponible

Las siguientes cantidades de gasolina fueron vendidas en las cuatro gasolinerías de la región:

Gasolinería	Gasolina Despachada (litros/año)
A	4,000,000
B	2,500,000
C	2,000,000
D	1,500,000
Total	10,000,000

Solución

La cantidad de emisiones por pérdidas debidas a la respiración de tanques de almacenamiento subterráneos depende principalmente de la evaporación y los cambios en la presión barométrica. Por otro lado, la frecuencia de extracción del tanque también puede afectar las emisiones debido a que el aire fresco que entra va a incrementar la tasa de evaporación. Se ha estimado una tasa de emisión por respiración promedio para gasolinerías estadounidenses de 120 mg/litro de gasolina (AP-42, Tabla 5.2-7). Las ecuaciones de tanque presentadas en la Sección 7 del AP-42, pueden utilizarse para estimar las emisiones de los tanque de almacenamiento subterráneos en gasolinerías. Sin embargo, el gran número de tanques de gasolinería generalmente impide el uso de estas ecuaciones. Las pérdidas totales por respiración de los tanques de almacenamiento subterráneos pueden estimarse con la siguiente ecuación, con la tasa de emisión promedio por respiración:

$$\text{Emisiones} = \sum_{i=1}^{n} EF_{UB} \text{ x } \text{Comustible}_{i}$$

donde:

Emisiones = Emisiones totales por respiración del tanque subterráneo (kg/año)

n = Número de gasolinerías

EF_{UB} = Factor de emisión de pérdida por respiración subterránea para la gasolinería i (mg/litro) [valor estadounidense promedio - 120 mg/litro]

$Combustible_i$ = Cantidad anual de combustible entregada a la gasolinería i (litros/año).

$$\text{Emisiones} = (120[4 \text{ x } 10^6] + 120[2.5 \text{ x } 10^6] + 120[2 \text{ x } 10^6] + 120[1.5 \text{ x } 10^6])$$

$$\text{Emisiones} = 480 + 300 + 240 + 180 = 1{,}200 \text{ kg/año} = 1.2 \text{ Mg/año}$$

Ejemplo 4g

Emisiones de la Carga de Combustible en Vehículos

Planteamiento del Problema

Estimar las emisiones de GOT de la carga de combustible en vehículos en las gasolinerías A, B, C y D. Estas emisiones están integradas tanto por los vapores desplazados del tanque del vehículo, como por los derrames de gasolina.

Información Disponible

Las cuatro gasolinerías en el sistema de distribución despachan las siguientes cantidades de gasolina PVR 9:

Gasolinería	Gasolina Despachada (litros/año)
A	4,000,000
B	2,500,000
C	2,000,000
D	1,500,000

La temperatura del combustible despachado es de 24°C (75 °F), y la temperatura del combustible en el tanque del vehículo es de aproximadamente 30°C (86 °F). Las gasolinerías A y C no cuentan con equipo de control de vapores, mientras que las B y D cuentan con control de vapor que transfiere los vapores desplazados del tanque de combustible del vehículo al espacio de vapor del tanque de almacenamiento subterráneo.

Solución

La cantidad de emisiones de los vapores desplazados dependen de la temperatura de la gasolina, la temperatura del tanque del vehículo, la presión de vapor de Reid de la gasolina (PVR) y de la tasa de despacho. La siguiente ecuación puede ser utilizada para estimar las pérdidas por desplazamiento no controlado basadas en los factores mencionados anteriormente (AP-42, Sección 5.2.2.3).

$$EF_u = 264.2[(-5.909) - 0.0949(\Delta T) + 0.0884(T_D) + 0.485(RVP)]$$

donde:

EF_u = Factor de emisión no controlada de GOTs para recarga de combustible (mg/litro)

ΔT = Diferencia entre la temperatura del combustible en el tanque del vehículo y la temperatura del combustible despachado (°F)

T_D = Temperatura del combustible despachado (°F)

PVR = Presión de Vapor de Reid (psia).

A continuación se calculan los factores de emisión de pérdidas por desplazamiento no controlado para cada gasolinería:

$$EF_u = 264.2[(-5.909) - 0.0949(11°) + 0.0884(75°) + 0.485(9)] = 1{,}068 \text{ mg/ litro}$$

Las pérdidas por desplazamiento controladas deben ser estimadas para las gasolinerías B y D. El AP-42 indica que las eficiencias típicas estadounidenses de control de vapor fluctúan entre 88 a 92% (AP-42, Sección 5.2.2.3). A continuación se muestra la ecuación para calcular un factor de pérdida por desplazamiento controlado:

$$EF_c = (1 - CE) \text{ x } EF_u$$

donde:

EF_c = Factor de emisión controlada de GOT para la recarga vehicular (mg/litro);

CE = Eficiencia del control de vapores

EF_u = Factor de emisión no controlada de GOT para la recarga vehicular (mg/litro).

Suponiendo que la eficiencia del control de vapor de la Etapa II es del 88%, entonces, los factores de emisión de pérdida por desplazamiento controlado para las gasolinerías B y D se calculan como se muestra a continuación:

$$EF_{cB,cD} = (1 - 0.88) \text{ x } 1{,}068 \text{ mg/litro } = 128 \text{ mg/litro}$$

Además de las pérdidas por desplazamiento, las pérdidas por derrames también se presentan durante la recarga de combustible. El factor de emisión estadounidense para derrames (EF_s) se ha estimado en 80 mg/litro de combustible despachado. La cantidad real del derrame depende de diversos factores, tales como las características comerciales de la gasolinería, la configuración del tanque, y las técnicas del operador.

Las pérdidas totales de la recarga pueden estimarse con la siguiente ecuación:

$$\text{Emisiones } = \sum_{i=1}^{n} ([EF_{u,c} + EF_s] \text{ x Comustible }_i)$$

donde:

Emisiones = Emisiones totales por recarga (kg/año)

n = Número de gasolinerías

$EF_{u,c}$ = Factor de emisión de pérdida por desplazamiento controlada o no controlada para la gasolinería i (mg/litro)

EF_s = Factor de emisión por derrame para la gasolinería i (mg/litro)

Combustible_i = Cantidad anual de combustible despachado por la gasolinería i (litros/año).

Asumiendo que el factor de emisión de derrame estadounidense de 80 mg/litro sea adecuado para México, estimar las emisiones generales de la recarga de combustible.

$$\text{Emisiones} = ([1{,}068 + 80][4 \times 10^{6}] + [128 + 80][2.5 \times 10^{6}] + [1{,}068 + 80][2 \times 10^{6}] + [128 + 80][1.5 \times 10^{6}])$$

$$\text{Emisiones} = 4{,}592 + 520 + 2{,}296 + 312 = 7{,}720 \text{ kg/año} = 7.72 \text{ Mg/año}$$

Ejemplo 4 - Resumen

Los estimados de emisión de las siete fuentes dentro de un sistema de distribución de gasolina típico han sido presentados a través de los ejemplos 4a a 4g, y se presentan en la Tabla 4-8.

Tabla 4-8

Resumen de las Emisiones del Sistema de Distribución de Gasolina

Fuente de Emisión (Ejemplo)	Estimado de Emisión (kg/año)	Porcentaje de las Emisiones Totales
Tanque Aéreo de Almacenamiento a Granel (4a)	23,981	39.5%
Fugitivas (Fugas de Equipo) [Separación de Intervalos] (4b)	1,312	2.2%
Carga de Pipas (4c)	17,920	29.5%
Pipas en Tránsito (4d)	99	0.2%
Llenado del Tanque Subterráneo (4e)	8,450	13.9%
Respiración del Tanque Subterráneo (4f)	1,200	2.0%
Recarga Vehicular (4g)	7,720	12.7%
Total	**60,682**	**100.0%**

En la Tabla anterior se puede observar que las emisiones fugitivas, las de las pipas en tránsito y las de respiración del tanque subterráneo son relativamente pequeñas, comparadas con las otras fuentes de emisión. Los estimados de emisión y la distribución presentados anteriormente son hipotéticos; los estimados de emisión reales serán diferentes. Los esfuerzos para mejorar la precisión del inventario en el futuro deberán enfocarse hacia las mayores fuentes de emisión en el sistema de distribución de gasolina.

Ejemplo 5a

Evaporación de Solventes - Desengrasado

Introducción

El desengrasado con solventes y las operaciones de limpieza de superficies con solventes se llevan a cabo en una amplia variedad de establecimientos industriales, científicos y de reparación. Las operaciones de limpieza de superficies implican en uso de solventes líquidos o vapores para eliminar los contaminantes insolubles en agua tales como grasa, aceites, ceras, depósitos de carbón, resinas y alquitranes de las superficies de metal, plástico, vidrio y otros materiales. Las operaciones de desengrasado con solventes pueden implicar el uso de un gran número de sustancias diferentes, tales como la acetona, metil-etil-cetona (MEK), alcoholes, 1,1,1-tricloroetano o CFC-113.

El equipo típico para la limpieza de solventes puede clasificarse como:

- **Máquinas de limpieza por lotes en frío**. Estas máquinas se cargan con un lote, que se asperja, sumerge o cepilla con el solvente líquido para ser limpiado.

- **Máquinas de limpieza por lotes con vapor.** Estas máquinas se cargan con un lote, y los materiales a ser limpiados se exponen al solvente vaporizado. El solvente condensado arrastra los contaminantes de las superficies a ser limpiadas.

- **Máquinas de limpieza en línea**. Estas máquinas se cargan continuamente utilizando un transportador, y a menudo están fabricadas especialmente para operaciones a gran escala. La máquina de limpieza de solvente el línea puede utilizar solventes líquidos o en vapor.

Planteamiento del Problema

Estimar las emisiones de GOT anuales de una máquina de limpieza por lotes en frío y de una máquina de limpieza por lotes con vapor.

Información Disponible

Máquina de limpieza por lotes en frío

- El solvente utilizado es hidrocarburo alifático (e. g., Stoddard®, nafta)
- La capacidad del limpiador en frío es de 200 litros.
- La densidad del solvente es de 0.8 g/ml (0.8 kg/litro)
- La bitácora de los datos de uso del solvente se muestran en la Tabla 5-1.

Tabla 5-1

Datos de la Bitácora de Uso de Solventes

Fecha	Solvente Adicionado (litros)	Residuos Líquidos Eliminados (litros)	Lodos Residuales Eliminados (kg)
2 Feb	200	195	--
30 May	200	203	--
15 Ago	200	198	1.3
28 Nov	200	205	--

- El solvente nuevo añadido contiene 100% de GOT
- El residuo líquido es 95 wt% GOT (incluye los contaminantes tales como agua, grasa, aceite, resina, etc.)
- Se supone que el residuo líquido tiene la misma densidad que el solvente nuevo.
- El residuo sólido (lodos) es 10 wt% GOT.

Máquina de limpieza por lotes con vapor

- El solvente utilizado es percloroetileno
- La capacidad es de 200 litros
- La densidad del solvente es de 1.6 g/ml (1.6 kg/litro)
- Los datos de consumo del solvente se muestran en la Tabla 5-2.

Tabla 5-2

Datos de Consumo de Solvente

Fecha	Solvente Adicionado (litros)	Residuos Líquidos Eliminados (litros)	Lodos Residuales Eliminados (kg)
14 Ene	20	--	--
8 Feb	35	--	--
26 Mar	200	178	--
10 Abr	20	--	--
2 May	25	--	--
18 May	20	--	--
20 Jun	200	160	--
4 Jul	15	--	--
6 Ago	30	--	--
18 Sep	200	167	2
3 Nov	50	--	--
15 Dic	200	185	--

- El solvente nuevo es 100% GOT
- El residuo líquido es 95 wt% GOT (incluye contaminantes tales como agua, grasa, aceite, resina, etc.)
- Se asume que la densidad del residuo líquido es igual la densidad del solvente nuevo
- Los residuos sólidos (lodos) son 10 wt% GOT.

Solución

Las emisiones de la limpieza en frío se presentan a través de la evaporación del solvente residual y de los lodos, el arrastre del solvente, la evaporación del baño de solvente, la evaporación del aspersor y la agitación. Las emisiones del desengrasado con vapor se deben a la difusión y convección, arrastre de solvente, los sistemas de venteo y la evaporación de los solventes y lodos residuales.

Dado que la recopilación de datos para todos estos mecanismos de emisión sería sumamente costosa y requeriría mucho tiempo, generalmente se estiman tasas de emisiones para los datos de consumo de solvente para la operación de desengrasado particular que se está analizando. Si no existen datos de consumo de solventes, los factor de emisión basados en el número de empleados o los datos de población pueden obtenerse de la literatura (e. g., U.S. EPA, 1991b). Para la estimación de emisiones en fuentes puntuales, es sumamente recomendable que se utilice la siguiente ecuación de balance de masas:

$$E = (Q_{in} \text{ x } r_{in} \text{ x } TOG_{in}) - (Q_{out(liq)} \text{ x } r_{out(liq)} \text{ x } TOG_{out(liq)}) - (Q_{out(solid)} \text{ x } TOG_{out(solid)})$$

donde:

E = Emisiones de GOT totales (kg)

Q_{in} = Cantidad del solvente añadido al desengrasador (litros)

ρ_{in} = Densidad del solvente añadido al desengrasador (kg/litro)

GOT_{in} = Contenido de GOTs del solvente añadido al desengrasador (wt%)

$Q_{out(liq)}$ = Cantidad de residuos líquidos eliminados del desengrasador (litros)

$\rho_{out(liq)}$ = Densidad de los residuos líquidos retirados del desengrasador (kg/litro)

$GOT_{out(liq)}$ = Contenido de GOTs de los residuos líquidos retirados del desengrasador (wt%)

$Q_{out(solid)}$ = Cantidad de residuos sólidos (lodos) eliminados del desengrasador (kg)

$GOT_{out(solid)}$ = Contenido de GOTs de los residuos sólidos (lodos) eliminados del desengrasador (wt%).

Máquina de limpieza por lotes en frío

Las emisiones de la máquina de limpieza por lotes en frío se calculan utilizando la ecuación de balance de masa anterior. Los datos de la bitácora de solventes se utilizan para calcular la cantidad de solvente añadido (Q_{in}), la cantidad de residuos líquidos retirados($Q_{out(liq)}$), y la cantidad de lodos eliminados($Q_{out(solid)}$).

Q_{in}=(200 + 200 + 200 + 200) = 800 litros

$Q_{out(liq)}$=(195 + 203 + 198 + 205) = 801 litros

$Q_{out(solid)}$=1.3 kg

Entonces, las emisiones totales se calculan como se muestra a continuación:

$$E = (800 \times 0.8 \times 100\%) - (801 \times 0.8 \times 95\%) - (1.3 \times 10\%) = 31 \text{ kg GOT/año}$$

Máquina de limpieza por lotes con vapor

Las emisiones de la máquina de limpieza por lotes con vapor se calculan aplicando la misma ecuación de balance de masa anterior. Una vez más, los datos de la bitácora de solventes se utiliza para calcular Q_{in}, $Q_{out(liq)}$, y $Q_{out(solids)}$.

Donde:

Q_{in} = (20 + 35 + 200 + 20 + 25 + 20 + 200 + 15 + 30 + 200 + 50 + 200) = 1015 litros

$Q_{out(liq)}$ = (178 + 160 + 167 + 185) = 690 litros

$Q_{out(solid)}$ = 2 kg

Entonces, las emisiones totales se calculan como se muestra a continuación:

$$E = (1015 \times 1.6 \times 100\%) - (690 \times 1.6 \times 95\%) - (2 \times 10\%) = 575 \text{ kg GOT/año}$$

Cuando se estiman las emisiones del desengrasado con solventes, es necesario considerar los siguientes aspectos:

- En general, las bitácoras de consumo de solventes de los limpiadores en frío sólo incluyen los registros de los cambios (i. e., todos los residuos líquidos son eliminados y se añade solvente nuevo para toda la capacidad del limpiador).
- En general, las bitácoras de consumo de los desengrasadores de vapor incluyen los registros de los cambios y rellenados (i. e., se adiciona solvente nuevo para reemplazar el solvente evaporado sin que ningún tipo de residuos líquidos haya sido eliminado al mismo tiempo).

- El contenido de GOT de los residuos líquidos y sólidos debe, preferentemente, ser determinado con el muestreo periódico. Sin embargo, el costo de un muestreo frecuente lo hace prohibitivo, por lo tanto, a menudo el juicio ingenieril es utilizado para estimar el contenido de GOT en los residuos sólidos y líquidos.

- La cantidad de GOTs recuperada en los residuos sólidos (lodos) generalmente es muy pequeña, comparada con la que se recupera en los residuos líquidos. Por lo tanto, con frecuencia se supone, de manera conservadora que los GOTs en los residuos sólidos son emitidos al aire.

- Las emisiones de algunos solventes desengrasantes (e. g., percloroetileno, freones, etc.), no deben ser incluidas en los inventarios de GOR (gases orgánicos reactivos).

- Es posible que el juicio ingenieril sea necesario para reconciliar el periodo de tiempo definido por la bitácora de consumo con el periodo de tiempo necesario para el cálculo de las emisiones. Por ejemplo, la bitácora de consumo del limpiador por lotes en frío no contiene datos después del 28 de noviembre, pero el equipo seguiría teniendo emisiones hasta el final del periodo de emisión anual (i. e., 31 de diciembre). Para los inventarios de emisiones reales, generalmente se supone que estas emisiones adicionales se reflejarán en la entrada del siguiente consumo (i. e., en el siguiente año calendario).

Ejemplo 5b

Evaporación de Solventes – Recubrimiento de Superficies

Introducción

El recubrimiento de superficies incluye todos los procesos en que se aplica materiales líquidos a la superficie de un sustrato sólido. Las emisiones al aire se producen tanto de la evaporación de solventes u otros propelentes orgánicos en los recubrimientos, y del “sobreaspersado” de los materiales particulados que no se adhieren a las partes. Las emisiones particuladas pueden reducirse con la utilización de cabinas de pintado y otros equipos de control. Además de los materiales existentes para el recubrimiento de superficies, las emisiones también provienen de los materiales utilizados para la preparación de superficies previa a la aplicación del recubrimiento y para la limpieza posterior.

Planteamiento del Problema

Estimar las emisiones de GOTs, PM y compuestos de zinc de la operación de recubrimiento de superficies que se describe posteriormente. Incluir todos los materiales para el recubrimiento de superficies, adelgazamiento, preparación de superficies y limpieza. No existen registros que indiquen la cantidad de pintura utilizada.

Información Disponible

Se utilizan dos tipos de pintura (poliuretano y primer). La pintura de poliuretano consiste de una base y un endurecedor que deben mezclarse, Además, debe ser rebajada con un adelgazador. La proporción de mezcla del poliuretano es 7:2:1 (base:endurecedor:adelgazante). El primer no tiene componentes y no requiere ser adelgazado. Las características del material de la base, endurecedor, adelgazante, primer y otros solventes para la preparación y limpieza de superficies se presentan en la Tabla 5-3.

Tabla 5-3

Características de los Materiales para el Recubrimiento de Superficies

Material	Densidad (gramos/litro)	Contenido de COVs (gramos/litro)	Contenido de Sólidos (%)
Base – poliuretano	700	520	31
Endurecedor – Poliuretano	750	330	35
Adelgazador – Poliuretano	820	820	-
Primer	680	460	40
Solvente para la preparación de superficies	820	820	-
Solvente de limpieza	820	820	-

Por otro lado, 2% de los sólidos de la Pintura 1 (mezclada), y 1.5% de los sólidos en la Pintura 2 son compuestos de zinc.

La mitad del poliuretano se aplica utilizando equipo de aspersión de alto volumen/baja presión (HVLP), mientras que la otra mitad se aplica con equipo de aspersión convencional. El primer se aplica directamente de latas de spray en aerosol. El poliuretano se utiliza en una cabina de pintado equipada con filtros secos de partículas [eficiencia de control (EC) aproximada, 90%], pero el primer se utiliza en un área abierta.

La operación de recubrimiento de superficies consiste en pintar partes de aparatos de cocina. El producto anual de la operación es de 25,000 partes. Los pintores que trabajan en esta operación estiman que cada parte requiere 0.8 litros de poliuretano y 0.2 litros de primer; y que los solventes utilizados para la preparación de superficie constituyen el 40% de la pintura aplicada a cada parte, mientras que los solventes de limpieza son el 15%. Se supone que todos los solventes de preparación y limpieza de la superficie se aplican por frotamiento y que el 100% de los solventes aplicados se evaporan. Sólo el 95% del poliuretano o primer de un contenedor dado puede ser aplicado realmente a las partes que serán pintadas; el 5% restante no puede ser utilizado. Sin embargo, debe asumirse que todos los solventes en la pintura residual se evaporan a la atmósfera.

Solución - GOT

Determinar las cantidades de poliuretano, primer, solvente para preparación de superior y limpieza que se requieren:

La cantidad de la pintura aplicada se calcula multiplicando el número de partes por la cantidad de poliuretano y primer requerida por cada parte.

$$\text{Poliuretano Aplicado} = 25{,}000 \text{ partes x } \frac{0.8 \text{ litros}}{\text{parte}} = 20{,}000 \text{ litros}$$

$$\text{Primer Aplicado} = 25{,}000 \text{ partes x } \frac{0.2 \text{ litros}}{\text{parte}} = 5{,}000 \text{ litros}$$

$$\text{Pintura Aplicada Total} = 20{,}000 + 5{,}000 = 25{,}000 \text{ litros}$$

La cantidad de pintura aplicada en realidad es sólo el 95% de la cantidad de pintura usada. La cantidad de pintura realmente mezclada se calcula a continuación:

$$\text{Poliuretano Mezclado} = \frac{20{,}000 \text{ litros}}{0.95} = 21{,}053 \text{ litros}$$

$$\text{Primer Mezclado} = \frac{5{,}000 \text{ litros}}{0.95} = 5{,}263 \text{ litros}$$

La cantidad de los solventes de preparación y limpieza se calculan a partir de la cantidad de pintura realmente aplicada:

$$\text{Solvente de Preparación} = \frac{0.40 \text{ litros de solvente}}{\text{litro de pintura}} \text{ x } 25{,}000 \text{ litros} = 10{,}000 \text{ litros}$$

$$\text{Solvente de Limpieza} = \frac{0.15 \text{ litros de solvente}}{\text{litro de pintura}} \text{ x } 25{,}000 \text{ litros} = 3{,}750 \text{ litros}$$

El contenido de GOTs del poliuretano se calcula como el promedio ponderado del contenido de GOTs de cada uno de los componentes (base, endurecedor y adelgazador).

$$TOG_{poly} = (\%_{base} \text{ x } TOG_{base}) + (\%_{hard} \text{ x } TOG_{hard}) + (\%_{thin} \text{ x } TOG_{thin})$$

$$TOG_{poly} = (0.7 \text{ x } 520) + (0.2 \text{ x } 330) + (0.1 \text{ x } 820) = 512 \text{ gramos/litro}$$

Entonces, las emisiones se calculan multiplicando la cantidad de cada pintura o solvente utilizada por su respectivo contenido de GOTs.

$$\text{Emisiones}_{\text{Poly}} = 21{,}053 \text{ litros x } \frac{512 \text{ gramos}}{\text{litro}} = 10{,}779 \text{ kg}$$

$$\text{Emisiones}_{\text{Primer}} = 5{,}263 \text{ litros x } \frac{460 \text{ gramos}}{\text{litro}} = 2{,}421 \text{ kg}$$

$$\text{Emisiones}_{\text{Prep}} = 10{,}000 \text{ litros x } \frac{820 \text{ gramos}}{\text{litro}} = 8{,}200 \text{ kg}$$

$$\text{Emisiones}_{\text{Cleanup}} = 3{,}750 \text{ litros x } \frac{820 \text{ gramos}}{\text{litro}} = 3{,}075 \text{ kg}$$

$$\text{Emisiones}_{\text{TOG-Total}} = 10{,}779 + 2{,}421 + 8{,}200 + 3{,}075 = 24{,}475 \text{ kg} = 24.5 \text{ Mg}$$

Solución - PM

Las emisiones no controladas de PM pueden calcularse con la siguiente ecuación:

$$\text{Emisiones}_i = P_i \text{ x } \rho_i \text{ x } SC_i \text{ x } (1 - \eta)$$

donde:

Emisiones_i = Emisiones totales no controladas del recubrimiento de superficies, i (kg)

P_i = Cantidad de pintura aplicada (litro)

ρ_i = Densidad del recubrimiento de superficies, i (g/litro)

SC_i = Contenido de sólidos del recubrimiento de superficies, i (fracción)

η = Eficiencia de transferencia del método de aplicación (fracción).

Primero necesita determinarse la densidad y el contenido de sólidos de la pintura de poliuretano. Esta información se obtiene de la Tabla de características del material.

$$\boldsymbol{r}_{poly} = (\%_{base} \text{ x } \boldsymbol{r}_{base}) + (\%_{hard} \text{ x } \boldsymbol{r}_{hard}) + (\%_{thin} \text{ x } \boldsymbol{r}_{thin})$$

$$_{poly} = 0.7 \text{ x } 700 + 0.2 \text{ x } 750 + 0.1 \text{ x } 820 = 722 \text{ gramos/litro}$$

$$SC_{poly} = \frac{\boldsymbol{r}_{base} SC_{base} \%_{base} + \boldsymbol{r}_{hard} SC_{hard} \%_{hard} + \boldsymbol{r}_{thin} SC_{thin} \%_{thin}}{\boldsymbol{r}_{poly}}$$

$$SC_{Tot} = \frac{(700)(0.31)(0.70) + (750)(0.35)(0.20) + (820)(0.00)(0.10)}{722} = 28.3\%$$

La Tabla 5-4 presenta las eficiencias de transferencia para los diversos métodos de aplicación.

Tabla 5-4

Eficiencias de Transferencia en el Recubrimiento de Superficies

Método de Aplicación	Eficiencia de Transferencia
Aerosol eb kata	0.24
Equipo de aspersión sin aire	0.35
Cepillo o rodillo	0.95
Equipo de aspersión de aire convencional	0.30
Equipo de aspersión de alto volumen/baja presión (HVLP)	0.60

Fuente: SCAQMD, 1996

Las emisiones no controladas de PM se calculan como:

$$\text{Emisiones}_{Poly,HVLP} = \frac{722 \text{ gramos}}{\text{litro}} \text{ x } 0.283 \text{ x } (1 - 0.60) \text{ x } 10{,}000 \text{ litros} = 817 \text{ kg}$$

$$\text{Emisiones}_{Poly,otros} = \frac{722 \text{ gramos}}{\text{litro}} \text{ x } 0.283 \text{ x } (1 - 0.30) \text{ x } 10{,}000 \text{ litros} = 1{,}430 \text{ kg}$$

$$\text{Emisiones}_{Primer} = \frac{680 \text{ gramos}}{\text{litro}} \text{ x } 0.4 \text{ x } (1 - 0.24) \text{ x } 5{,}000 \text{ litros} = 1{,}034 \text{ kg}$$

Las emisiones controladas de PM se calculan como:

$$\text{Emisiones}_{Poly,cont} = (1 - CE) \, (\text{Emisiones}_{Poly,HVLP} + \text{Emisiones}_{Poly,other})$$

donde:

CE = eficiencia de control

$$\text{Emisiones}_{\text{Poly,cont}} = (1 - 0.90)\ (817\ + 1{,}430)\ = 225\ \text{kg}$$

Finalmente se calculan las emisiones combinadas de PM totales para el poliuretano y el primer.

$$\text{Emisiones}_{\text{Total}} = 225 + 1{,}034 = 1{,}259\ \text{kg} = 1.3\ \text{Mg}$$

Solución – Compuestos de Zinc

Las emisiones de una especie química particular se calcula multiplicando las emisiones generales de PM por el porcentaje de dicha especie. Utilizando este método, a continuación se calculan las emisiones de compuestos de zinc.

$$\text{Emisiones}_{\text{Zn,poly}} = 2\%\ \text{x}\ 225\ \text{kg PM}_{10} = 4.5\ \text{kg}$$

$$\text{Emisiones}_{\text{Zn,primer}} = 1.5\%\ \text{x}\ 1{,}034\ \text{kg PM}_{10} = 15.5\ \text{kg}$$

$$\text{Emisiones}_{\text{Zn,total}} = 4.5 + 15.5 = 20\ \text{kg}$$

Ejemplo 6

Emisiones de Chimenea en Fuente Puntual

Introducción

Entre las diversas técnicas de estimación de emisiones, el muestreo en fuente permite obtener las estimaciones más confiables (aunque el costo también tiende a ser el más elevado). La razón para obtener la alta precisión radica en que los efectos de los parámetros específicos del equipo y del proceso son medidos directamente por el equipo de muestreo. Si bien el muestreo en fuente puede proporcionar estimados de emisión precisos, en algunas ocasiones se requiere demasiado esfuerzo para convertir los datos del muestreo en estimados de emisiones. Este ejemplo muestra el proceso para convertir las mediciones de concentración en tasas de emisión de masa.

Planteamiento del Problema

Determinar las emisiones promedio de NO_x por hora y anuales de una chimenea de proceso dadas las mediciones típicas de la chimenea.

Información Disponible

Las siguientes mediciones promedio han sido recopiladas de la chimenea a partir de métodos de prueba en fuente autorizados:

Tasa de flujo de gas real de la chimenea:	7486 cfm
Temperatura del gas de chimenea:	80.0°C
Diámetro de la chimenea:	0.75 m
Contenido de vapor de agua:	2.1%vol
Contenido de CO_2:	9.5%vol
Concentración de NO_x:	48 ppmv

Se supone que el resto del gas de la chimenea es aire. El proceso opera 24 horas al día, 330 días al año.

Solución

Los pasos necesarios para determinar las emisiones de NO_x diarias y anuales de esta chimenea de proceso con la información disponible son:

1. Recopilar los datos necesarios para realizar los cálculos de emisión de la chimenea y definir los términos:

Volumen molar estándar (V_s) (a 20°C):	0.024 m^3/g-mol
Peso molecular (MW) de NO_x:	46 (los NO_x se expresan como NO_2 por convención)
Condiciones estándar:	20°C y 760 mmHg

   Las condiciones estándar (temperatura y presión) se utilizan con frecuencia, de manera tal que todas las emisiones se reporten en la misma base. Diferentes condiciones estándar pueden ser válidas en diferentes jurisdicciones y para aplicaciones distintas.

2. Determinar la tasa métrica de flujo del gas de la chimenea (volumen/unidad de tiempo) en las condiciones de la chimenea (m^3/min):
   - a. Dadas:

Tasa de flujo real de gas de la chimenea:	7486 cfm
Temperatura de la chimenea:	80.0°C

   - b. Tasa métrica de flujo del gas de la chimenea en las condiciones de la chimenea:

$$= \left(\frac{7486\,\text{ft}^3}{\text{min}} \right) \left(\frac{0.3048\,\text{m}}{\text{ft}} \right)^3 = 2.12 \text{ x } 10^2 \frac{\text{m}^3}{\text{min}} \left(\text{a } 80°\,\text{C, presión de la chimenea} \right)$$

3. Determinar la tasa de flujo volumétrico de NO_x en el gas de la chimenea

(volumen/unidad de tiempo):

a. El gas de la chimenea en este ejemplo está húmedo (2.1% de agua por volumen). La información proporcionada no especifica si la concentración de NO_x fue medida en base seca o húmeda. Sin embargo, a partir del conocimiento de las técnicas analíticas, se sabe que las mediciones de NO_x se hacen y se reportan en base seca; por lo tanto, primero debe calcularse la tasa de flujo de gas seco.

b. Calcular la tasa de flujo volumétrico de gas seco de la chimenea:

   1. Dados:

      Contenido de agua del gas de la chimenea: 2.1% por volumen

      Tasa de flujo del gas húmedo de la chimenea: 2.12×10^2 m^3/min (a 80°C, presión de la chimenea)

   2. Tasa de flujo del gas seco de la chimenea:

$$Q_{dry} = Q_{wet}\left(\frac{V_{dry}}{V_{wet}}\right)$$

donde:

Q_{dry} = tasa de flujo de gas seco de la chimenea

Q_{wet} = tasa de flujo de gas húmedo de la chimenea

V_{dry}/V_{wet} = fracción de aire en el gas húmedo de la chimenea.

$$= \left(\frac{2.12 \text{ x } 10^2 \text{ m}^3 \text{gas de chimenea (húmedo)}}{\text{min}}\right)\left(\frac{(1 - 0.021) \text{ m}^3 \text{ gas de chimenea (seco)}}{1 \text{ m}^3 \text{ gas de chimenea (húmedo)}}\right)$$

$$= \frac{2.08 \text{ x } 10^2 \text{ m}^3 \text{ gas de chimenea (seco)}}{\text{min}}$$

c. Calcular la tasa de flujo de NO_x:

1. Dados:

Concentración de NO_x: 48 ppmv

2. Tasa de flujo de NO_x:

Q_{NOx} = $Q_{dry}C_{NOx}$

donde:

Q_{NOx} = tasa de flujo de NO_x

Q_{dry} = tasa de flujo del gas seco de la chimenea

C_{NOx} = concentración de NO_x

$$\left(2.08 \text{ x } 10^2 \frac{\text{m}^3 \text{ gas de chimenea}}{\text{min}}\right)\left(\frac{48 \text{ m}^3 \text{ NO}_\text{x}}{10^6 \text{ m}^3 \text{ gas de chimenea}}\right)$$

$$= \frac{9.98 \text{ x } 10^{-3} \text{ m}^3 \text{ NO}_\text{x}}{\text{min}} \left(\text{a } 80°\text{C, presión de chimea, base seca}\right)$$

4. Corregir la tasa de flujo volumétrica de NO_x a condiciones estándar (20°C y 760 mmHg) aplicando la ley del gas ideal.

   a. Para este ejemplo, se supone que la corrección se requiere sólo para la temperatura, debido a que se supone que el gas de la chimenea está a 1 atmósfera (760 mmHg) puesto que la chimenea está abierta a la atmósfera al nivel del mar.
   b. A partir de la ley del gas ideal (PV = nRT), la relación entre el volumen y la temperatura del gas es:

$$V=nRT/P$$

$$V/T=nR/P$$

c. En este ejemplo, independientemente de la temperatura de la chimenea, se consideran constantes el número de moles (n) del NO_x en el gas de la chimenea, la constante del gas (R) y la presión (P) del gas de la chimenea. Por lo tanto, las relaciones entre el volumen y la temperatura del gas pueden ser desarrolladas como se muestra a continuación para cualquier pareja de temperatura absolutas. (T_1 y T_2):

$$V_1/T_1=n_1R_1/P_1 \quad \text{y} \quad V_2/T_2 = n_2R_2/P_2$$

Dado que nR/P es constante, entonces $n_1R_1/P_1 = n_2R_2/P_2$, por lo tanto:

$$V_1/T_1=V_2/T_2$$

d. Al despejar para el volumen desconocido de gas (V_2) a la nueva temperatura (T_2),

$$V_2=V_1T_2/T_1$$

e. La ecuación para la tasa de flujo volumétrico desconocida (Q_2) a la nueva temperatura (T_2) es similar,

$$Q_2=Q_1T_2/T_1$$

f. Calcular la tasa de flujo volumétrico de NO_x (Q_2) a la nueva temperatura (20°C) (en este cálculo deben utilizarse temperaturas absolutas):

$$Q_2 = \left(9.96 \text{ x } 10^{-3} \frac{\text{m}^3 \text{ NO}_\text{x}}{\text{min}}\right)\left(\frac{[20\,^\circ\text{C} + 273]}{[80\,^\circ\text{C} + 273]}\right) = 8.27 \text{ x } 10^{-3} \frac{\text{Sm}^3 \text{ (m}^3\text{estándar)}}{\text{min}} \left(\text{a } 20^\circ\text{C, } 760 \text{ mmHg}\right)$$

5. Determinar la tasa de flujo másico y las emisiones de NO_x diarias y anuales (masa/día y masa/año):

a. Dados:

$$\text{Tasa de flujo volumétrico de } NO_x = 8.27 \text{ x } 10^{-3} \frac{Sm^3}{min}$$

$$V_s\left(\text{volumen molar estándar}\right) = 0.024 \frac{Sm^3}{g\text{ - mole}}\left(20°C,\ 760\ mmHg\right)$$

$$MW \text{ de } NO_x \left(\text{como } NO_2\right) = 46 \frac{g}{g\text{ - mole}}$$

Operación anual de la chimenea = 24 horas diarias, 330 días al año

b. Tasa de flujo másico de NO_x:

$$M_{NO_x} = \frac{Q_{NO_x} MW_{NO_x}}{V_S}$$

donde:

M_{NOx} = Tasa de flujo de masa de NO_x

Q_{NOx} = Tasa de flujo volumétrica de NO_x

MW_{NOx} = Peso molecular del NO_x

V_s = Volumen molar estándar

$$\left(8.27 \text{ x } 10^{-3} \frac{Sm^3\ NO_x}{min}\right)\left(\frac{1\ g\text{-}mole\ NO_x}{0.024\ Sm^3\ NO_x}\right)\left(\frac{46\ g\ NO_x}{g\text{-}mole\ NO_x}\right) = 15.8 \frac{g\ NO_x}{min}$$

c. Emisiones por hora:

$$\left(\frac{15.8\ g\ NO_x}{min}\right)\left(\frac{60\ min}{1\ hr}\right)\left(\frac{1\ kg}{10^3\ g}\right) = 0.948 \frac{kg\ NO_x}{hr}$$

d. Emisiones anuales:

$$\left(\frac{0.948\ \text{kg}\ NO_x}{\text{hr}}\right)\left(\frac{24\ \text{hr}}{\text{day}}\right)\left(\frac{330\ \text{days}}{\text{yr}}\right) = 7.51 \text{ x } 10^3\ \text{kg/año}$$

$$= 7.5\ \text{Mg/año}$$

Ejemplo 7

Partículas – Estimación de PM_{10}, $PM_{2.5}$, Carbón Orgánico y Carbón Elemental

Introducción

Las emisiones de partículas están formadas por partículas dentro de una amplia gama de tamaños, que fluctúan desde las dimensiones casi moleculares hasta las 100 micras de diámetro. Las partículas con diámetros superiores a las 100 micras no permanecen suspendidas por un periodo de tiempo significativo y se depositan cerca de su punto de origen. En consecuencia, estas partículas no son consideradas generalmente en las aplicaciones de calidad del aire. Actualmente, la mayoría de los esfuerzos de inventario se enfocan en las PM_{10} (partículas con diámetro aerodinámico menor o igual a 10 micras). Sin embargo, a medida en que el enfoque de la calidad del aire ha crecido para incluir los aspectos de visibilidad, se ha puesto más atención a las emisiones de $PM_{2.5}$ (partículas con un diámetro aerodinámico menor o igual a 2.5 micras). La investigación relacionada con la visibilidad también requiere un análisis de la composición de las partículas. La magnitud de la extinción de luz ocasionada por las partículas está en función de su composición química. Las partículas que contienen carbón orgánico (co) o carbón elemental (CE) absorben la luz, mientras que las partículas que contienen otros tipos de compuestos químicos tienden a dispersarla.

Planteamiento del Problema

Estimar las emisiones de PM_{10}, $PM_{2.5}$, oc y CE dadas las emisiones de partículas suspendidas totales (PST) de caminos pavimentados y no pavimentados.

Información Disponible

Utilizando las metodologías de estimación estándar, se ha considerado que las emisiones de PST son de 600 Mg para los caminos pavimentados y de 3,000 Mg para los no pavimentados dentro del dominio de un inventario particular.

Solución - PM_{10} y $PM_{2.5}$

De manera ideal, las fracciones de PM_{10} y $PM_{2.5}$ deberían ser desarrolladas para las emisiones de polvo re-suspendidos en caminos pavimentados y no pavimentados en cada localidad. Sin embargo, esto no es práctico y, como resultado, las fracciones promedio de PM_{10} y $PM_{2.5}$ son utilizadas con frecuencia para estimar las emisiones de PM_{10} y $PM_{2.5}$, respectivamente. Existen diversas fuentes para estas fracciones promedio para PM_{10} y $PM_{2.5}$.

La primera fuente de las fracciones de PM_{10} y $PM_{2.5}$ es el AP-42 (U. S. EPA, 1995a). Las ecuaciones utilizadas para estimar las emisiones de polvo re-suspendidas de caminos pavimentados y no pavimentados utilizan los multiplicadores del tamaño de partícula (PSM) (AP-42, Secciones 13.2.1 y 13.2.2), que se presentan en la Tabla 7-1.

Tabla 7-1

Multiplicadores para el Tamaño de Partícula de Polvo para Caminos Pavimentados y No Pavimentados del AP-42

Diámetro Aerodinámico de la Partícula	Caminos Pavimentados (g/VKT)	Caminos No Pavimentados (adimensional)
PM_{30}*	24	1
PM_{10}	4.6	0.36
$PM_{2.5}$	2.1	0.095

*Las PM_{30} en algunas ocasiones son denominadas "partículas suspendibles" (SP) y con frecuencia son utilizadas como sustituto de las PST.

Las fracciones de PM_{10} y $PM_{2.5}$ (F_{10} y $F_{2.5}$) se obtienen dividiendo los multiplicadores del tamaño de partícula PM_{10} y $PM_{2.5}$ (PSM_{10} y $PSM_{2.5}$) entre el multiplicador del tamaño de partícula PST (PSM_{PST}).

$$F_{2.5\text{-no pavimentado}} = \frac{PSM_{2.5\text{-no pavimentado}}}{PSM_{PST\text{-no pavimentado}}} = \frac{0.095}{1} = 0.095$$

$$F_{2.5\text{-pavimentado}} = \frac{PSM_{2.5\text{-pavimentado}}}{PSM_{PST\text{-pavimentado}}} = \frac{2.1}{24} = 0.088$$

$$F_{10\text{-pavimentado}} = \frac{PSM_{10\text{-pavimentado}}}{PSM_{TSP\text{-pavimentado}}} = \frac{4.6}{24} = 0.192$$

$$F_{10\text{-no pavimentado}} = \frac{PSM_{10\text{-no pavimentado}}}{PSM_{TSP\text{-no pavimentado}}} = \frac{0.36}{1} = 0.360$$

Otra fuente de fracciones de PM_{10} y $PM_{2.5}$ es la base de datos SPECIATE de la EPA (U. S. EPA, 1992). Esta base de datos contiene los perfiles de especiación para una amplia gama de categorías de emisión; muchos de estos perfiles son compuestos. Adicionalmente, se dan las fracciones de masa para diferentes intervalos de tamaño de cada categoría de emisión. Con base en los perfiles compuestos, las fracciones de PM_{10} y $PM_{2.5}$ (F_{10} y $F_{2.5}$) para caminos pavimentados y no pavimentados se presentan en la Tabla 7-2.

Tabla 7-2

Fracciones de Masa de Polvo para Caminos Pavimentados y No Pavimentados de la Base de Datos SPECIATE

Intervalo del Tamaño de Partícula (μm)	**Fracción para Caminos Pavimentados** **(Perfil 41130 de SPECIATE)**	**Fracción para Caminos No Pavimentados** **(Perfil 41220 de SPECIATE)**
0-2.5	0.25	0.3
0-10	0.44	0.73

De manea similar, el Consejo de Recursos del Aire de California proporciona sus propias fracciones de masa para diferentes intervalos de tamaño (ARB, 1996), que se presentan en la Tabla 7-3.

Tabla 7-3

Fracciones de Masa de Polvo para Caminos Pavimentados y No Pavimentados de la ARB

Intervalo del Tamaño de Partícula (mm)	Fracción para Caminos Pavimentados	Fracción para Caminos No Pavimentados
<1	0.03	0.05
1-2.5	0.05	0.08
2.5-10	0.38	0.49
>10	0.54	0.38

Debido a que las fracciones de masa no son correspondientes con las fracciones PM_{10} y $PM_{2.5}$, ciertas fracciones de masa deben sumarse como se muestra a continuación:

Para caminos pavimentados:

$$F_{2.5} = F_{<1} + F_{1\text{-}2.5} = 0.03 + 0.05 = 0.08$$

$$F_{10} = F_{<1} + F_{1\text{-}2.5} + F_{2.5\text{-}10} = 0.03 + 0.05 + 0.38 = 0.46$$

Para caminos no pavimentados:

$$F_{2.5} = F_{<1} + F_{1\text{-}2.5} = 0.05 + 0.08 = 0.13$$

$$F_{10} = F_{<1} + F_{1\text{-}2.5} + F_{2.5\text{-}10} = 0.05 + 0.08 + 0.49 = 0.62$$

Después de obtener las fracciones PM_{10} y $PM_{2.5}$, las emisiones de PM_{10} y $PM_{2.5}$ son calculadas aplicando la siguiente ecuación:

$$\text{Emisiones}_{i} = \text{Emisiones}_{PST} \times F_{i}$$

donde:

Emisiones_i = Emisiones de diámetro menor que i micras

Emisiones_{PST} = Emisiones de PST

F_i = Fracción de PST de diámetro menor que i micras.

Debido a que se utilizan fracciones PM_{10} y $PM_{2.5}$ genéricas, y no específicas del sitio, las emisiones serán estimadas utilizando las fracciones PM_{10} y $PM_{2.5}$ de cada una de las tres fuentes presentadas anteriormente. Adicionalmente, el promedio de las tres fracciones de PM_{10} y $PM_{2.5}$ será utilizado para estimar las emisiones. Los cuatro estimados se presentan en la Tabla 7-4. Cabe señalar que ninguno de estos estimados ha sido identificado como mejor o más preciso que los otros. Aún existe una incertidumbre considerable asociada con los estimados para caminos pavimentados y no pavimentados. La investigación para mejorar las metodologías existentes para estas categorías de fuentes está en desarrollo. Este ejemplo simplemente muestra la forma de derivar los estimados de PM_{10} y $PM_{2.5}$ a partir de las emisiones de PST.

Tabla 7-4

Emisiones de PM_{10} y $PM_{2.5}$ Calculadas a Partir de Diferentes Fracciones de Tamaño

Tipo de Camino	Contaminante	Fuente de Fracción	Tamaño de Fracción	PST (Mg/año)	Emisiones (Mg/año)
Pavimentado	PM_{10}	AP-42	0.192	600	115.2
		SPECIATE	0.44		264
		ARB	0.46		276
		Promedio	0.364		218.4
	$PM_{2.5}$	AP-42	0.088	600	52.8
		SPECIATE	0.25		150
		ARB	0.08		48
		Promedio	0.139		83.4
No pavimentado	PM_{10}	AP-42	0.36	3,000	1,080
		SPECIATE	0.73		2,190
		ARB	0.62		1,860
		Promedio	0.57		1,710
	$PM_{2.5}$	AP-42	0.095	3,000	285
		SPECIATE	0.30		900
		ARB	0.13		390
		Promedio	0.175		525

Carbón Orgánico y Carbón Elemental – Solución

Al igual que con las fracciones PM_{10} y $PM_{2.5}$, las fracciones de carbón orgánico (co) y carbón elemental (CE) específicas para el sitio deben ser desarrolladas siempre que sea posible, con el objetivo de obtener los estimados de emisión más precisos. En algunos casos, sin embargo, un análisis de laboratorio detallado no es posible, entonces, deben utilizarse perfiles de especiación genérica. Una fuente de éstos es la base de datos SPECIATE de la EPA. Estos perfiles de especiación SPECIATE indican el porcentaje de compuestos individuales relativos a las emisiones totales de partículas. Para el polvo de caminos pavimentados y no pavimentados, estos perfiles incluyen varias especies de metales, además de los existentes para co y CE.

Los datos de muestreos hipotéticos dan las siguientes fracciones de co y CE para caminos pavimentados y sin pavimentar. Se tomaron tres muestras para ambos tipos de caminos. Se muestrearon dos fracciones de tamaño – fina (0-2.5 μm) y gruesa (2.5-10 μm). Estos datos se presentan en la Tabla 7-5.

Tabla 7-5

Datos Hipotéticos del Muestreo de co y CE

Tipo de Camino	Muestra	Tamaño de Fracción	Fracción co (wt%)	Fracción CE (wt%)
Pavimentado	#1	Fina	17.27	0.72
		Gruesa	12.35	0.44
	#2	Fina	19.41	0.45
		Gruesa	10.89	0.60
	#3	Fina	18.54	0.63
		Gruesa	11.37	0.53
	Promedio	Fina	18.41	0.60
		Gruesa	11.54	0.52
No pavimentado	#1	Fina	2.46	0.00
		Gruesa	1.50	0.00
	#2	Fina	2.71	0.00
		Gruesa	1.65	0.00
	#3	Fina	2.77	0.00
		Gruesa	1.29	0.00
	Promedio	Fina	2.65	0.00
		Gruesa	1.48	0.00

Las fracciones co y CE (F_{co} y F_{CE}) para $PM_{2.5}$ pueden tomarse directamente de la Tabla anterior debido a que las partículas finas se definen como $PM_{2.5}$. Las fracciones co y CE para PM_{10} deben calcularse aplicando un promedio ponderado de las fracciones fina y gruesa de las co y CE. Los datos adicionales del muestro (no incluidos en la Tabla anterior), indican que las PM_{10} del polvo de los caminos pavimentados están integradas por 54 wt% de partículas gruesas y 46 wt% partículas finas; mientras que las PM_{10} del polvo de caminos no pavimentados consiste de 35 wt% de partículas gruesas y 65 wt% de partículas finas. Las fracciones ponderadas de co y CE para PM_{10} se calculan aplicando la siguiente ecuación:

$$F_i = (F_{i,c} \text{ x } \%_c) + (F_{i,f} \text{ x } \%_f)$$

donde:

F_i = Fracción total de la especie i

$F_{i,c}$ = Fracción de la especie i en la porción gruesa de las partículas

$\%_c$ = Porcentaje en peso de las partículas gruesas

$F_{i,f}$ = Fracción de la especie i en la porción fina de las partículas

$\%_f$ = Porcentaje en peso de las partículas finas.

Las fracciones ponderadas de co y CE de las PM_{10} para caminos pavimentados y no pavimentados se calculan a continuación:

$$F_{co,\text{ pavimentado}} = (11.54 \text{ x } 0.54) + (18.41 \text{ x } 0.46) = 14.70$$

$$F_{CE,\text{pavimentado}} = (0.52 \text{ x } 0.54) + (0.60 \text{ x } 0.46) = 0.56$$

$$F_{co,\text{ no pavimentado}} = (1.48 \text{ x } 0.35) + (2.65 \text{ x } 0.65) = 2.24$$

$$F_{CE,\text{no pavimentado}} = (0.00 \text{ x } 0.35) + (0.00 \text{ x } 0.65) = 0.00$$

Las emisiones de co y CE son calculadas en la Tabla 7-6. Se supone que las emisiones de PM_{10} y $PM_{2.5}$ son iguales a los valores promedio calculados anteriormente.

Tabla 7-6

Calculo de Emisiones de co y CE

Tipo de Camino	Contami-nante	Emisiones (Mg/año)	Fracción co	Emisiones co (Mg/año)	Fracción CE	Emisiones CE (Mg/año)
Pavimen-tado	PM_{10}	218.4	0.1470	32.1	0.0056	1.2
	$PM_{2.5}$	83.4	0.1841	15.4	0.0060	0.5
No pavimen-tado	PM_{10}	1710	0.0224	38.3	0.0000	0.0
	$PM_{2.5}$	525	0.0265	13.9	0.0000	0.0

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APENDICE A

DATOS MISCELANEOS Y FACTORES DE CONVERSION

(La información en este apéndice ha sido tomada del Apéndice A del AP-42. Los parámetros son para combustibles estadounidenses; los combustibles mexicanos pueden ser diferentes y deben analizarse cuidadosamente).

PESOS Y MEDIDAS DE USO FRECUENTE

Unidad de Medida	Equivalente	
gramo	0.04	onzas
grano	0.002	onzas
kilogramo	2.21	libras
libra	0.45	kilogramos
libra (troy)	12	onzas
onza	28.35	gramos
tonelada (corta)	2000	libras
tonelada (de embarque)	40	pies^3
tonelada (larga)	2240	libras
tonelada (métrica)	2200	libras
centímetro	0.39	pulgadas
metro	1.09	yardas
milla	1.61	kilómetros
pie	30.48	centímetros
pulgada	2.54	centímetros
yarda	0.91	metros
centímetro^2	0.16	pulgadas^2
metro^2	1.2	yardas^2
milla^2	2.59	kilómetros^2
pie^2	0.09	metros^2
pulgada^2	6.45	centímetros^2
yarda^2	0.84	metros^2
centímetro^3	0.061	pulgadas^3
pie^3	283.17	centímetros^3
pie^3	1728	pulgadas^3
pulgada^3	16.39	centímetros^3
metro^3	1.31	yardas^3
yarda^3	0.77	metros^3

PESOS Y MEDIDAS DE USO FRECUENTE (Continuación)

Unidad de Medida	Equivalente	
barril	31.5	galones
bushel	2150.4	pulgadas^3
bushel (seco)	4	pecks
cuerda	128	pies^3
cuerda	4	metros^3
galón (EU)	231	pulgadas^3
hectárea	2.5	acres
hogshead	2	barriles
peck	8	cuartos
township	36	millas^2

DATOS MISCELANEOS

- Un pie cúbico de carbón de antracita pesa alrededor de 53 libras.
- Un pie cúbico de carbón bituminoso pesa de 47 a 50 libras.
- Para propósitos de generación de vapor, una tonelada de carbón es equivalente a dos cuerdas de madera.
- Un galón de agua (estándar EU) pesa 8.33 libras y continene 231 pulgadas cúbics.
- Cada pie cuadrado de superficie de parrilla tiene 9 pies cuadrados de superficie de calentamiento.
- Un pie cúbico de agua contiene 7.5 galones, 1728 pulgadas cúbicas, y pesa 62.5 lbs.
- Cada caballo de fuerza nominal de una caldera requiere de 30 a 35 libras de agua por hora.
- Un caballo de fuerza equivale a levantar 33,000 libras-pie por minuto, ó 550 libras-pie por segundo.
- Para encontrar la presión en libras por pulgada cuadrada de una columna de agua, multiplicar la altura de la columna en pies por 0.434.

PARAMETROS TIPICOS DE DIVERSOS COMBUSTIBLES[a]

Tipo de Combustible	Valor Calorífico		Azufre % (por peso)	Ceniza % (por peso)
	kcal	Btu		
Combustibles Sólidos				
Carbón bituminoso	7,200/kg	13,000/lb	0.6-5.4	4-20
Carbón de antracita	6,810/kg	12,300/lb	0.5-1.0	7.0-16.0
Lignita (@ 35% humedad)	3,990/kg	7,200/lb	0.7	6.2
Madera (@ 40% humedad)	2,880/kg	5,200/lb	N	1-3
Bagazo (@ 50% humedad)	2,220/kg	4,000/lb	N	1-2
Corteza (@ 50% humedad)	2,492/kg	4,500/lb	N	1-3[b]
Coque, derivado	7,380/kg	13,300/lb	0.5-1.0	0.5-5.0
Combustibles Líquidos				
Aceite residual	9.98 x 10^6/m^3	150,000/gal	0.5-4.0	0.05-0.1
Aceite destilado	9.30 x 10^6/m^3	140,000/gal	0.2-1.0	N
Diesel	9.12 x 10^6/m^3	137,000/gal	0.4	N
Gasolina	8.62 x 10^6/m^3	130,000/gal	0.03-0.04	N
Queroseno	8.32 x 10^6/m^3	135,000/gal	0.02-0.05	N
Gas licuado de petróleo	6.25 x 10^6/m^3	94,000/gal	N	N
Combustibles gaseosos				
Gas natural	9,341/m^3	1,050/SCF	N	N
Gas de coque para horno	5,249/m^3	590/SCF	0.5-2.0	N
Gas para fundidora	890/m^3	100/SCF	N	N

[a] N = despreciable

[b] El contenido de cenizas puede ser considerablemente mayor cuando hay presencia de arena, suciedad, etc.

EQUIVALENTES TERMICOS PARA DIVERSOS COMBUSTIBLES

Tipo de Combustible	kcal	Btu (neto)
Combustibles sólidos		
Carbón bituminoso	(5.8 to 7.8) x 10^6/Mg	(21.0 to 28.0) x 10^6/tonelada
Carbón de antracita	7.03 x 10^6/Mg	25.3 x 10^6/tonelada
Lignita	4.45 x 10^6/Mg	16.0 x 10^6/tonelada
Madera	1.47 x 10^6/m^3	21.0 x 10^6/cuerda
Combustibles líquidos		
Combustóleo residual	10 x 10^3/litro	6.3 x 10^6/bbl
Combustóleo destilado	9.35 x 10^3/litro	5.9 x 10^6/bbl
Combustibles gaseosos		
Gas natural	9,350/m^3	1,050/ft^3
Gas licuado de petróleo		
Butano	6,480/litro	97,400/gal
Propano	6,030/litro	90,500/gal

PESO DE SUSTANCIAS SELECCIONADAS

Tipo de Sustancia	g/litro	lb/gal
Asfalto	1030	8.57
Butano, líquido a 60°F	579	4.84
Petróleo crudo	850	7.08
Petróleo destilado	845	7.05
Gasolina	739	6.17
Propano, líquido a 60°F	507	4.24
Aceite residual	944	7.88
Agua	1000	8.4

DENSIDADES DE SUSTANCIAS SELECCIONADAS

Sustancia	Densidad	
Combustibles		
Petróleo crudo	874 kg/m^3	7.3 lb/gal
Aceite residual	944 kg/m^3	7.88 lb/gal
Petróleo destilado	845 kg/m^3	7.05 lb/gal
Gasolina	739 kg/m^3	6.17 lb/gal
Gas natural	673 kg/m^3	1 lb/23.8 ft^3
Butano	579 kg/m^3	4.84 lb/gal (líquido)
Propano	507 kg/m^3	4.24 lb/gal (líquido)
Madera (secada al aire)		
Olmo	561 kg/m^3	35 lb/ft^3
Abeto, Douglas	513 kg/m^3	32 lb/ft^3
Abeto, Balsámico	400 kg/m^3	25 lb/ft^3
Pinabeto	465 kg/m^3	29 lb/ft^3
Nogal americano	769 kg/m^3	48 lb/ft^3
Maple, Azucarero	689 kg/m^3	43 lb/ft^3
Maple, Blanco	529 kg/m^3	33 lb/ft^3
Encino, Rojo	673 kg/m^3	42 lb/ft^3
Encino, Blanco	769 kg/m^3	48 lb/ft^3
Pino, Sureño	641 kg/m^3	40 lb/ft^3
Productos agrícolas		
Maíz	25.4 kg/bu	56 lb/bu
Mijo	25.4 kg/bu	56 lb/bu
Avena	14.5 kg/bu	32 lb/bu
Cebada	21.8 kg/bu	48 lb/bu
Trigo	27.2 kg/bu	60 lb/bu
Algodón	226 kg/paca	500 lb/paca

DENSIDADES DE SUSTANCIAS SELECCIONADAS (Continuación)

Sustancia	Densidad	
Productos Minerales		
Ladrillo	2.95 kg/ladrillo	6.5 lb/ladrillo
Cemento	170 kg/bbl	375 lb/bbl
Cemento	1483 kg/m^3	2500 lb/yd^3
Concreto	2373 kg/m^3	4000 lb/yd^3
Vidrio, Común	2595 kg/m^3	162 lb/ft^3
Grava, empacada en seco	1600 - 1920 kg/m^3	100 - 120 lb/ft^3
Grava, húmeda	2020 kg/m^3	126 lb/ft^3
Yeso, calcinado	880 - 960 kg/m^3	55 - 60 lb/ft^3
Cal, trozos	850 - 1025 kg/m^3	53 - 64 lb/ft^3
Arena, grava (seca, suelta)	1440 - 1680 kg/m^3	90 - 105 lb/ft^3

FACTORES DE CONVERSION

La tabla de factores de conversión de las siguientes páginas contienen los factores para convertir unidades inglesas a métricas, y métricas a inglesas, así como los factores para manejar las unidades dentro del mismo sistema. Los factores están organizados alfabéticamente dentro de las siguientes categorías:

- Area
- Densidad
- Energía
- Fuerza
- Longitud
- Masa
- Presión
- Velocidad
- Volumen
- Flujo

Para convertir un número de una unidad a otra:

1. Localice la unidad en la que el número está expresado en la columna izquierda de la tabla.
2. Encuentre la unidad deseada en la columna del centro
3. Muntiplique el número por el factor de conversión correspondiente en la columna de la derecha.

FACTORES DE CONVERSION[a]

Para Convertir de	A	Multiplicar por
Area		
Acres	Kilómetros cuadrados	4.0469×10^{-3}
Acres	Metros cuadrados	4.0469×10^{3}
Acres	Millas cuadradas (estatuto)	1.5625×10^{-3}
Acres	Pies cuadrados	4.356×10^{4}
Acres	Yardas cuadradas	4.84×10^{3}
Kilómetros cuadrados	Acres	247.1
Kilómetros cuadrados	Metros cuadrados	1.0×10^{6}
Kilómetros cuadrados	Millas cuadradas	0.386102
Kilómetros cuadrados	Pies cuadrados	1.0764×10^{7}
Kilómetros cuadrados	Yardas cuadradas	1.196×10^{6}
Metros cuadrados	Centímetros cuadrados	1.0×10^{4}
Metros cuadrados	Kilómetros cuadrados	1.0×10^{-6}
Metros cuadrados	Millas cuadradas	3.861×10^{-7}
Metros cuadrados	Milímetros cuadrados	1.0×10^{6}
Metros cuadrados	Pies cuadrados	10.764
Metros cuadrados	Pulgadas cuadradas	1.55×10^{3}
Metros cuadrados	Yardas cuadradas	1.196
Millas cuadradas	Acres	640.0
Millas cuadradas	Kilómetros cuadrados	2.590
Millas cuadradas	Pies cuadrados	2.7878×10^{7}
Millas cuadradas	Metros cuadrados	2.59×10^{6}
Millas cuadradas	Yardas cuadradas	3.0976×10^{6}
Pies cuadrados	Acres	2.2957×10^{-5}
Pies cuadrados	Centímetros cuadrados	929.03
Pies cuadrados	Pulgadas cuadradas	144.0
Pies cuadrados	Metros cuadrados	0.092903
Pies cuadrados	Millas cuadradas	3.587×10^{-8}
Pies cuadrados	Yardas cuadradas	0.111111
Pulgadas cuadradas	Metros cuadrados	6.4516×10^{-4}
Pulgadas cuadradas	Milímetros cuadrados	645.16
Pulgadas cuadradas	Pies cuadrados	6.9444×10^{-3}

FACTORES DE CONVERSION (Continuación)

Para Convertir de	A	Multiplicar por
Yardas cuadradas	Acres	2.0661×10^{-4}
Yardas cuadradas	Centímetros cuadrados	8.3613×10^{3}
Yardas cuadradas	Metros cuadrados	0.83613
Yardas cuadradas	Millas cuadradas	3.2283×10^{-7}
Yardas cuadradas	Pies cuadrados	9.0
Yardas cuadradas	Pulgadas cuadradas	1.296×10^{3}
Densidad		
Dinas/centímetro cúbico	Gramos/centímetro cúbico	1.0197×10^{-3}
Gramos/centímetro cúbico	Dinas/centímetro cúbico	980.665
Gramos/centímetro cúbico	Granos/mililitro	15.433
Gramos/centímetro cúbico	Gramos/mililitro	1.0
Gramos/centímetro cúbico	Libras/pie cúbico	62.428
Gramos/centímetro cúbico	Libras/pulgada cúbica	0.036127
Gramos/centímetro cúbico	Libras/gal (Brit.)	10.022
Gramos/centímetro cúbico	Libras/gal (EU, secos)	9.7111
Gramos/centímetro cúbico	Libras/gal (EU, líquidos)	8.3454
Gramos/litro	Libras/gal (EU)	8.345×10^{-3}
Gramos/metro cúbico	Granos/pie cúbico	0.4370
Granos/pie cúbico	Gramos/metro cúbico	2.28835
Kilogramos/metro cúbico	Gramos/centímetro cúbico	0.001
Kilogramos/metro cúbico	Libras/pie cúbico	0.0624
Kilogramos/metro cúbico	Libras/pulgada cúbica	3.613×10^{-5}
Libras/pie cúbico	Gramos/centímetro cúbico	0.016018
Libras/pie cúbico	kg/metro cúbico	16.018
Libras/pulgada cúbica	Gramos/centímetro cúbico	27.68
Libras/pulgada cúbica	Gramos/litro	27.681
Libras/pulgada cúbica	kg/metro cúbico	2.768×10^{4}
Libras/gal (EU, líq.)	Gramos/centímetro cúbico	0.1198
Libras/gal (EU, líq.)	Libras/Pie cúbico	7.4805
Energía		
Btu	Caloría-gramo (IST.)	251.83
Btu	Ergs	1.05435×10^{10}
Btu	Hp-horas	3.9275×10^{-4}

FACTORES DE CONVERSION (Continuación)

Para Convertir de	A	Multiplicar por
Btu	Joules (Int.)	1054.2
Btu	kg-metros	107.51
Btu	kW-horas (Int.)	2.9283×10^{-4}
Btu	Libras-pie	777.65
Btu/hr	Caballo de fuerza (caldera)	2.9856×10^{-5}
Btu/hr	Caballo de fuerza (eléctrico)	3.926×10^{-4}
Btu/hr	Caballo de fuerza (mecánico)	3.9275×10^{-4}
Btu/hr	Caballo de fuerza (métrico)	3.982×10^{-4}
Btu/hr	Cal. kg/hr	0.252
Btu/hr	Ergs/seg	2.929×10^{6}
Btu/hr	Kilowatts	2.929×10^{-4}
Btu/hr	Libras-pie/hr	777.65
Btu/lb	Hp-hr/lb	3.9275×10^{-4}
Btu/lb	Joules/gramo	2.3244
Btu/lb	Libras-pie/lb	777.65
Caballo de fuerza (caldera)	Btu (promedio)/hr	3.3446×10^{4}
Caballo de fuerza (eléctrico)	Btu (promedio)/hr	2.5435×10^{3}
Caballo de fuerza (mecánico)	Btu (promedio)/hr	2.5425×10^{3}
Caballo de fuerza (eléctrico)	Caballo de fuerza (caldera)	0.07605
Caballo de fuerza (mecánico)	Caballo de fuerza (caldera)	0.07602
Caballo de fuerza (caldera)	Caballo de fuerza (eléctrico)	13.15
Caballo de fuerza (mecánico)	Caballo de fuerza (eléctrico)	0.9996
Caballo de fuerza (caldera)	Caballo de fuerza (mecánico)	13.155
Caballo de fuerza (caldera)	Caballo de fuerza (métrico)	13.337
Caballo de fuerza (eléctrico)	Caballo de fuerza (métrico)	1.0143
Caballo de fuerza (mecánico)	Caballo de fuerza (métrico)	1.0139
Caballo de fuerza (eléctrico)	Cal. kg/hr	641.87
Caballo de fuerza (caldera)	Ergs/seg	9.8095×10^{10}
Caballo de fuerza (eléctrico)	Ergs/seg	7.46×10^{9}
Caballo de fuerza (mecánico)	Ergs/seg	7.457×10^{9}
Caballo de fuerza (caldera)	Joules/seg	9.8095×10^{3}
Caballo de fuerza (eléctrico)	Joules/seg	746.0
Caballo de fuerza (mecánico)	Joules/seg	745.70

FACTORES DE CONVERSION (Continuación)

Para Convertir de	A	Multiplicar por
Caballo de fuerza (caldera)	Kilowatts	9.8095
Caballo de fuerza (eléctrico)	Kilowatts	0.746
Caballo de fuerza (mecánico)	Kilowatts (Int.)	0.74558
Caballo de fuerza (mecánico)	Libras-pie/hr	1.980×10^{6}
Caballo de fuerza (caldera)	Libras-pie/min	4.341×10^{5}
Caballo de fuerza (eléctrico)	Libras-pie/min	3.3013×10^{4}
Caballo de fuerza (métrico)	Btu (promedio)/hr	2.5077×10^{3}
Caballo de fuerza (métrico)	Caballo de fuerza (caldera)	0.07498
Caballo de fuerza (métrico)	Caballo de fuerza (eléctrico)	0.9859
Caballo de fuerza (métrico)	Caballo de fuerza (mecánico)	0.98632
Caballo de fuerza (métrico)	Ergs/seg	7.355×10^{9}
Caballo de fuerza (métrico)	kg-metros/seg	75.0
Caballo de fuerza (métrico)	Kilowatts	0.7355
Caballo de fuerza (métrico)	Libras-pie/min	3.255×10^{4}
Caballo de fuerza-horas	Btu (promedio)	2.5425×10^{3}
Caballo de fuerza-horas	Joules	2.6845×10^{6}
Caballo de fuerza-horas	kg-metros	2.73745×10^{5}
Caballo de fuerza-horas	kW-horas	0.7457
Caballo de fuerza-horas	Libras-pie	1.98×10^{6}
Caloría, kg (promedio)	Btu (IST.)	3.9714
Caloría, kg (promedio)	Ergs	4.190×10^{10}
Caloría, kg (promedio)	Hp-horas	1.561×10^{-3}
Caloría, kg (promedio)	Joules	4.190×10^{3}
Caloría, kg (promedio)	kg-metros	427.26
Caloría, kg (promedio)	kW-horas (Int.)	1.1637×10^{-3}
Caloría, kg (promedio)	Libras-pie	3.0904×10^{3}
Ergs	Btu	9.4845×10^{-11}
Ergs	Joules (Int.)	9.99835×10^{-8}
Ergs	kg-metros	1.0197×10^{-8}
Ergs	kW-horas	2.7778×10^{-14}
Ergs	Libras-pie	7.3756×10^{-8}
Ergs	Poundal-pie	2.373×10^{-6}
Joules (Int.)	Btu (IST.)	9.4799×10^{-4}

FACTORES DE CONVERSION (Continuación)

Para Convertir de	A	Multiplicar por
Joules (Int.)	Ergs	1.0002×10^{7}
Joules (Int.)	kW-horas	2.778×10^{-7}
Joules (Int.)	Libras-pie	0.73768
Joules (Int.)	Poundales-pie	12.734
Joules (Int.)/seg	Btu (promedio)/min	0.05683
Joules (Int.)/seg	Caballo de fuerza	1.341×10^{-3}
Joules (Int.)/seg	Cal. kg/min	0.01434
Kilogramo-metros	Btu (promedio)	9.2878×10^{-3}
Kilogramo-metros	Cal. kg (promedio)	2.3405×10^{-3}
Kilogramo-metros	Ergs	9.80665×10^{7}
Kilogramo-metros	Hp-horas	3.653×10^{-6}
Kilogramo-metros	Joules (Int.)	9.805
Kilogramo-metros	kW-horas	2.724×10^{-6}
Kilogramo-metros	Libras-pie	7.233
Kilogramo-metros	Poundales-pie	232.715
Kilogramo-metros/seg	Watts	9.80665
Kilowatt-horas (Int.)	Btu (promedio)	3.41×10^{3}
Kilowatt-horas (Int.)	Hp-horas	1.341
Kilowatt-horas (Int.)	Joules (Int.)	3.6×10^{6}
Kilowatt-horas (Int.)	kg-metros	3.6716×10^{5}
Kilowatt-horas (Int.)	Libras-pie	2.6557×10^{6}
Kilowatts (Int.)	Btu (IST.)/hr	3.413×10^{3}
Kilowatts (Int.)	Caballo de fuerza (caldera)	0.10196
Kilowatts (Int.)	Caballo de fuerza (eléctrico)	1.3407
Kilowatts (Int.)	Caballo de fuerza (mecánico)	1.341
Kilowatts (Int.)	Caballo de fuerza (métrico)	1.3599
Kilowatts (Int.)	Cal. kg (IST.)/hr	860.0
Kilowatts (Int.)	Ergs/seg	1.0002×10^{10}
Kilowatts (Int.)	Joules (Int.)/hr	3.6×10^{6}
Kilowatts (Int.)	kg-metros/hr	3.6716×10^{5}
Kilowatts (Int.)	Libras-pie/min	4.4261×10^{4}
Kilowatts (Int.)	Poundales-pie/min	1.424×10^{6}
Newton-metros	Gramo-cm	1.01972×10^{4}

FACTORES DE CONVERSION (Continuación)

Para Convertir de	A	Multiplicar por
Newton-metros	kg-metros	0.101972
Newton-metros	Libra-pies	0.73756
Libras-pie	Btu (IST.)	1.2851 x 10^{-3}
Libras-pie	Cal. kg (IST.)	3.2384 x 10^{-4}
Libras-pie	Ergs	1.3558 x 10^{7}
Libras-pie	Hp-horas	5.0505 x 10^{-7}
Libras-pie	Joules	1.3558
Libras-pie	kg-metros	0.138255
Libras-pie	kW-horas (Int.)	3.76554 x 10^{-7}
Libras-pie	Newton-metros	1.3558
Libras-pie	Poundales-pie	32.174
Libras-pie/hr	Btu/min	2.1432 x 10^{-5}
Libras-pie/hr	Caballo de fuerza (mecánico)	5.0505 x 10^{-7}
Libras-pie/hr	Caballo de fuerza (métrico)	5.121 x 10^{-7}
Libras-pie/hr	Ergs/min	2.2597 x 10^{5}
Libras-pie/hr	Kilowatts	3.766 x 10^{-7}
Fuerza		
Dinas	Libras	2.248 x 10^{-6}
Dinas	Newtons	1.0 x 10^{-5}
Dinas	Poundales	7.233 x 10^{-5}
Libras (avdp.)	Dinas	4.448 x 10^{5}
Libras (avdp.)	Newtons	4.448
Libras (avdp.)	Poundales	32.174
Newtons	Dinas	1.0 x 10^{-5}
Newtons	Libras (avdp.)	0.22481
Poundales	Dinas	1.383 x 10^{4}
Poundales	Libras (avdp.)	0.03108
Poundales	Newtons	0.1383
Longitud		
Kilómetros	Metros	1000
Kilómetros	Millas (estatuto)	0.62137
Kilómetros	Pies	3.2808 x 10^{3}
Kilómetros	Yardas	1.0936 x 10^{3}

FACTORES DE CONVERSION (Continuación)

Para Convertir de	A	Multiplicar por
Metros	Pies	3.2808
Metros	Pulgadas	39.370
Micrómetros	Centímetros	1.0×10^{-3}
Micrómetros	Metros	1.0×10^{-6}
Micrómetros	Milímetros	0.001
Micrómetros	Nanómetros	1000
Micrómetros	Pies	3.2808×10^{-6}
Micrómetros	Pulgadas	3.9370×10^{-5}
Micrómetros	Unidades Angstrom	1.0×10^{4}
Milímetros	Centímetros	0.1
Milímetros	Metros	0.001
Milímetros	Micrómetros	1000
Milímetros	Mils	39.37
Milímetros	Pulgadas	0.03937
Milímetros	Unidades Angstrom	1.0×10^{7}
Millas (estatuto)	Kilómetros	1.6093
Millas (estatuto)	Metros	1.6093×10^{3}
Millas (estatuto)	Pies	5280
Millas (estatuto)	Yardas	1760
Nanómetros	Centímetros	1.0×10^{-7}
Nanómetros	Micrómetros	0.001
Nanómetros	Milímetros	1.0×10^{-6}
Nanómetros	Pulgadas	3.937×10^{-8}
Nanómetros	Unidades Angstrom	10
Pies	Centímetros	30.48
Pies	Kilómetros	3.048×10^{-4}
Pies	Metros	0.3048
Pies	Millas (estatuto)	1.894×10^{-4}
Pies	Pulgadas	12
Pulgadas	Centímetros	2.540
Pulgadas	Kilómetros	2.54×10^{-5}
Pulgadas	Metros	0.0254
Pulgadas	Pies	0.08333
Yardas	Centímetros	91.44
Yardas	Metros	0.9144

FACTORES DE CONVERSION (Continuación)

Para Convertir de	A	Multiplicar por
Masa		
Gramos	Dinas	980.67
Gramos	Granos	15.432
Gramos	Kilogramos	0.001
Gramos	Libras (avdp.)	2.205×10^{-3}
Gramos	Microgramos	1×10^{6}
Gramos	Toneladas, métricas (megagramos)	1×10^{-6}
Granos	Gramos	0.064799
Granos	Libras (apoth. o troy)	1.7361×10^{-4}
Granos	Libras (avdp.)	1.4286×10^{-4}
Granos	Miligramos	64.799
Granos	Toneladas (métricas)	6.4799×10^{-8}
Kilogramos	Granos	1.5432×10^{4}
Kilogramos	Libras (apoth. o troy)	2.679
Kilogramos	Libras (avdp.)	2.2046
Kilogramos	Poundals	70.932
Kilogramos	Toneladas (corta)	1.1023×10^{-3}
Kilogramos	Toneladas (larga)	9.842×10^{-4}
Kilogramos	Toneladas (métrica)	0.001
Libras (avdp.)	Gramos	453.59
Libras (avdp.)	Granos	7000
Libras (avdp.)	Libras (apoth. o troy)	1.2153
Libras (avdp.)	Onzas (apoth. o troy)	14.583
Libras (avdp.)	Onzas (avdp.)	16
Libras (avdp.)	Poundales	32.174
Libras (avdp.)	Toneladas (corta)	5.0×10^{-4}
Libras (avdp.)	Toneladas (corta)	5.0×10^{-4}
Libras (avdp.)	Toneladas (larga)	4.4643×10^{-4}
Libras (avdp.)	Toneladas (métrica)	4.5359×10^{-4}
Megagramos	Toneladas (métrica)	1.0
Miligramos	Gramos	1.0×10^{-3}

FACTORES DE CONVERSION (Continuación)

Para Convertir de	A	Multiplicar por
Miligramos	Granos	0.01543
Miligramos	Libras (apoth. o troy)	2.679×10^{-6}
Miligramos	Libras (avdp.)	2.2046×10^{-6}
Miligramos	Onzas (apoth. o troy)	3.215×10^{-5}
Miligramos	Onzas (avdp.)	3.527×10^{-5}
Onzas (apoth. o troy)	Gramos	31.103
Onzas (apoth. o troy)	Granos	480
Onzas (avdp.)	Gramos	28.350
Onzas (avdp.)	Granos	437.5
Onzas (avdp.)	Libras (apoth. o troy)	0.075955
Onzas (avdp.)	Libras (avdp.)	0.0625
Onzas (avdp.)	Onzas (apoth. o troy)	0.9115
Onzas (apoth. o troy)	Onzas (avdp.)	1.097
Toneladas (corta)	Kilogramos	907.18
Toneladas (corta)	Libras (apoth. o troy)	2.4301×10^{3}
Toneladas (corta)	Libras (avdp.)	2000
Toneladas (corta)	Toneladas (larga)	0.8929
Toneladas (corta)	Toneladas (métrica)	0.9072
Toneladas (larga)	Kilogramos	1.016×10^{3}
Toneladas (larga)	Libras (avdp.)	2.240×10^{3}
Toneladas (larga)	Toneladas (corta)	1.12
Toneladas (larga)	Toneladas (métrica)	1.016
Toneladas (métrica)	Gramos	1.0×10^{6}
Toneladas (métrica)	Libras (apoth. o troy)	2.6792×10^{3}
Toneladas (métrica)	Libras (avdp.)	2.2046×10^{3}
Toneladas (métrica)	Megagramos	1.0
Toneladas (métrica)	Toneladas (corta)	1.1023
Toneladas (métrica)	Toneladas (larga)	0.9842

FACTORES DE CONVERSION (Continuación)

Para Convertir de	A	Multiplicar por
Presión		
Atmósferas	cm de H_2O (4°C)	1.033×10^{3}
Atmósferas	Pie de H_2O (39.2°F)	33.8995
Atmósferas	Pulgada de Hg (32°F)	29.9213
Atmósferas	kg/Centímetros cuadrados	1.033
Atmósferas	Libras/ pulgada cuadrada	14.696
Atmósferas	mm de Hg (0°C)	760
Kilogramos/Centímetros cuadrados	Atmósferas	0.96784
Kilogramos/Centímetros cuadrados	cm de Hg (0°C)	73.556
Kilogramos/Centímetros cuadrados	Pie de H_2O (39.2°F)	32.809
Kilogramos/Centímetros cuadrados	Pulgada de Hg (32°F)	28.959
Kilogramos/Centímetros cuadrados	Libras/pulgada cuadrada	14.223
Libras/pulgada cuadrada	Atmósferas	0.06805
Libras/pulgada cuadrada	cm de H_2O (4°C)	70.309
Libras/pulgada cuadrada	cm de Hg (0°C)	5.1715
Libras/pulgada cuadrada	Pulgadas de H_2O (39.2°F)	27.681
Libras/pulgada cuadrada	Pulgadas de Hg (32°F)	2.036
Libras/pulgada cuadrada	kg/Centímetros cuadrados	0.07031
Libras/pulgada cuadrada	milímetros de Hg (0°C)	51.715
Milímetros de Hg (0°C)	Atmósferas	1.3158×10^{-3}
Milímetros de Hg (0°C)	Gramos/Centímetros cuadrados	1.3595
Milímetros de Hg (0°C)	Libras/pulgada cuadrada	0.019337
Pulgadas de H_2O (4°C)	Atmósferas	2.458×10^{-3}
Pulgadas de Hg (60°F)	Atmósferas	0.03333
Pulgadas de Hg (60°F)	Gramos/Centímetros cuadrados	34.434
Pulgadas de H_2O (4°C)	In. de Hg (32°F)	0.07355
Pulgadas de H_2O (4°C)	kg/metro cuadrado	25.399
Pulgadas de H_2O (4°C)	Libras/Pies cuadrados	5.2022
Pulgadas de Hg (60°F)	Libras/Pies cuadrados	70.527
Pulgadas de H_2O (4°C)	Libras/pulgada cuadrada	0.036126
Pulgadas de Hg (60°F)	mm de Hg (60°F)	25.4

FACTORES DE CONVERSION (Continuación)

Para Convertir de	A	Multiplicar por
Velocidad		
Centímetros/seg	Kilómetros/hr	0.036
Centímetros/seg	Metros/min	0.6
Centímetros/seg	Millas/hr	0.02237
Centímetros/seg	Pies/min	1.9685
Centímetros/seg	Pies/seg	0.0328
Kilómetros/hr	cm/seg	27.778
Kilómetros/hr	Metros/seg	0.27778
Kilómetros/hr	Millas (estatuto)/hr	0.62137
Kilómetros/hr	Pies/hr	3.2808×10^{3}
Kilómetros/hr	Pies/min	54.681
Metros/min	cm/seg	1.6667
Metros/min	Kilómetros/hr	0.06
Metros/min	Pies/min	3.2808
Metros/min	Pies/seg	0.05468
Millas/hr	cm/seg	44.704
Millas/hr	Kilómetros/hr	1.6093
Millas/hr	Metros/min	26.822
Millas/hr	Pies/hr	5280
Millas/hr	Pies/min	88
Millas/hr	Pies/seg	1.4667
Pies/minuto	cm/seg	0.508
Pies/minuto	Kilómetros/hr	0.01829
Pies/minuto	Metros/min	0.3048
Pies/minuto	Metros/seg	5.08×10^{-3}
Pies/minuto	Millas/hr	0.01136
Pies/seg	cm/seg	30.48
Pies/seg	Kilómetros/hr	1.0973
Pies/seg	Metros/min	18.288
Pies/seg	Millas/hr	0.6818

FACTORES DE CONVERSION (Continuación)

Para Convertir de	A	Multiplicar por
Volumen		
Barriles (EU, líq.)	Galones (EU, líq.)	31.5
Barriles (EU, líq.)	Litros	119.24
Barriles (EU, líq.)	Métro cúbico	0.1192
Barriles (EU, líq.)	Pie cúbico	4.2109
Barriles (EU, líq.)	Pulgada cúbica	7.2765×10^{3}
Barriles (petróleo, EU)	Galones (EU)	42
Barriles (petróleo, EU)	Litros	158.98
Barriles (petróleo, EU)	Pie cúbico	5.6146
Centímetros cúbicos	Yardas cúbicas	1.308×10^{-6}
Centímetros cúbicos	Galones (EU, líq.)	2.642×10^{-4}
Centímetros cúbicos	Métro cúbico	1.0×10^{-6}
Centímetros cúbicos	Pie cúbico	3.5315×10^{-5}
Centímetros cúbicos	Pulgada cúbica	0.06102
Centímetros cúbicos	Cuartos (EU, líq.)	1.0567×10^{-3}
Galones (EU, líq.)	Barriles (EU, líq.)	0.03175
Galones (EU, líq.)	Barriles (petróleo, EU)	0.02381
Galones (EU, líq.)	Bushels (EU)	0.10742
Galones (EU, líq.)	Centímetros cúbicos	3.7854×10^{3}
Galones (EU, líq.)	Yardas cúbicas	4.951×10^{-3}
Galones (EU, líq.)	Cuartos (EU, líq.)	4.0
Galones (EU, líq.)	Galones (vino)	1.0
Galones (EU, líq.)	Litros	3.7854
Galones (EU, líq.)	Métro cúbico	3.7854×10^{-3}
Galones (EU, líq.)	Onzas (EU, fluídas)	128.0
Galones (EU, líq.)	Pie cúbico	0.13368
Galones (EU, líq.)	Pintas (EU, líq.)	8.0
Galones (EU, líq.)	Pulgada cúbica	231
Litros	Centímetros cúbicos	1000
Litros	Galones (EU, líq.)	0.2642
Litros	Métro cúbico	0.001

FACTORES DE CONVERSION (Continuación)

Para Convertir de	A	Multiplicar por
Litros	Onzas (EU, fluid)	33.814
Litros	Pie cúbico	0.035315
Litros	Pulgada cúbica	61.024
Metros cúbicos	Barriles (EU, líq.)	8.3864
Metros cúbicos	Centímetro cúbico	1.0×10^{6}
Metros cúbicos	Yardas cúbicas	1.308
Metros cúbicos	Galones (EU, líq.)	264.17
Metros cúbicos	Litros	1000
Metros cúbicos	Pie cúbico	35.315
Metros cúbicos	Pulgada cúbica	6.1024×10^{4}
Pies cúbicos	Centímetros cúbicos	2.8317×10^{4}
Pies cúbicos	Galones (EU, líq.)	7.4805
Pies cúbicos	Litros	28.317
Pies cúbicos	Métro cúbico	0.028317
Pulgadas cúbicas	Centímetro cúbico	16.387
Pulgadas cúbicas	Yardas cúbicas	2.1433×10^{-5}
Pulgadas cúbicas	Cuartos (EU, líq.)	0.01732
Pulgadas cúbicas	Galones (EU, líq.)	4.329×10^{-3}
Pulgadas cúbicas	Litros	0.01639
Pulgadas cúbicas	Métro cúbico	1.6387×10^{-5}
Pulgadas cúbicas	Pie cúbico	5.787×10^{-4}
Yardas cúbicas	Bushels (Brit.)	21.022
Yardas cúbicas	Bushels (EU)	21.696
Yardas cúbicas	Centímetro cúbico	7.6455×10^{5}
Yardas cúbicas	Cuartos	672.71
Yardas cúbicas	Cuartos	694.28
Yardas cúbicas	Cuartos	807.90
Yardas cúbicas	Galones	168.18
Yardas cúbicas	Galones	173.57
Yardas cúbicas	Galones	201.97
Yardas cúbicas	Litros	764.55
Yardas cúbicas	Métro cúbico	0.76455
Yardas cúbicas	Pie cúbico	27
Yardas cúbicas	Pulgada cúbica	4.6656×10^{4}

FACTORES DE CONVERSION (Continuación)

Para Convertir de	A	Multiplicar por
Flujo		
Galones (U. S.)/hr	Litros/hr	3.7854
Galones (U. S.)/hr	Metros cúbicos/min	6.309×10^{-5}
Galones (U. S.)/hr	Pie cúbico/hr	0.13368
Galones (U. S.)/hr	Yardas cúbicas/min	8.2519×10^{-5}
Litros/min	Galón (U. S., liq.)/min	0.2642
Litros/min	Pie cúbico/min	0.0353
Metros cúbicos/min	Galón (U. S.)/min	264.17
Metros cúbicos/min	Litros/min	999.97
Pie cúbico/min	Centímetro cúbico/seg	471.95
Pie cúbico/min	Galón (U. S.)/min	7.4805
Pie cúbico/min	Litros/sec	0.47193
Pie cúbico/min	Pie cúbico /hr	60. 0

[a] En donde ha sido conveniente, los factores de conversión de esta tabla han sido redondeados de seis a cuatro cifras significativas para facilitar su uso. La precisión de estos números se considera adecuada para su aplicación en datos de emisiones. Si se requiere una cifra más precisa, será necesario consultar los factores exactos.

FACTORES DE CONVERSION MAS COMUNES PARA LAS MEDICIONES DE LA CONTAMINACION DEL AIRE

PARTICULAS SUSPENDIDAS

Para Convertir de	A	Multiplicar por
Gramos/metro cúbico	Gramos/pie cúbico	0.02832
	Libras/1000 pie cúbico	0.06243
	Microgramos/metro cúbico	1.0 x 10^{6}
	Microgramos/pie cúbico	28.317 x 10^{3}
	Miligramos/metro cúbico	1000.0
Gramos/pie cúbico	Gramos/metro cúbico	35.314
	Libras/1000 pie cúbico	2.2046
	Microgramos/metro cúbico	35.314 x 10^{6}
	Microgramos/pie cúbico	1.0 x 10^{6}
	Miligramos/metro cúbico	35.3145 x 10^{3}
Libras/1000 pie cúbico	Gramos/metro cúbico	16.018
	Gramos/pie cúbico	0.35314
	Microgramos/metro cúbico	16.018 x 10^{6}
	Microgramos/pie cúbico	353.14 x 10^{3}
	Miligramos/metro cúbico	16.018 x 10^{3}
Microgramos/metro cúbico	Gramos/metro cúbico	1.0 x 10^{-6}
	Gramos/pie cúbico	28.317 x 10^{-9}
	Libras/1000 pie cúbico	62.43 x 10^{-9}
	Microgramos/pie cúbico	0.02832
	Miligramos/metro cúbico	0.001
Microgramos/pie cúbico	Gramos/metro cúbico	35.314 x 10^{-6}
	Gramos/pie cúbico	1.0 x 10^{-6}
	Libras/1000 pie cúbico	2.2046 x 10^{-6}
	Microgramos/metro cúbico	35.314
	Miligramos/metro cúbico	35.314 x 10^{-3}
Miligramos/metro cúbico	Gramos/metro cúbico	0.001
	Gramos/pie cúbico	283.2 x 10^{-6}
	Libras/1000 pie cúbico	62.43 x 10^{-6}
	Microgramos/metro cúbico	1000.0
	Microgramos/pie cúbico	28.32

FACTORES DE CONVERSION MAS COMUNES PARA LAS MEDICIONES DE LA CONTAMINACION DEL AIRE (Continuación(

PRESION DE MUESTREO

Para Convertir de	A	Multiplicar por
Milímetros de mercurio (0°C)	Pulgadas de agua (60°F)	0.5358
Pulgadas de agua (60°F)	Pulgadas de mercurio (0°C)	73.48×10^{-3}
Pulgadas de mercurio (0°C)	Pulgadas de agua (60°F)	13.609
	Milímetros de mercurio (0°C)	1.8663

GASES ATMOSFERICOS

Para Convertir de	A	Multiplicar por
Libras/pie cúbico	Miligramos/metro cúbico	16.018×10^{6}
	Microgramos/metro cúbico	16.018×10^{9}
	Microgramos/litro	16.018×10^{6}
	ppm por volumen (20°C)	$385.1 \times 10^{6}/M$
	ppm por peso	133.7×10^{3}
Microgramos/litro	Miligramos/metro cúbico	1.0
	Microgramos/metro cúbico	1000.0
	ppm por volumen (20°C)	24.04/M
	ppm por peso	0.8347
	Libras/pie cúbico	62.43×10^{-9}
Microgramos/metro cúbico	Miligramos/metro cúbico	0.001
	Microgramos/litro	0.001
	ppm por volumen (20°C)	0.02404/M
	ppm por peso	834.7×10^{-6}
	Libras/pie cúbico	62.43×10^{-12}
Miligramos/metro cúbico	Microgramos/metro cúbico	1000.0
	Microgramos/litro	1.0
	ppm por volumen (20°C)	24.04/M
	ppm por peso	0.8347
	Libras/pie cúbico	62.43×10^{-9}
ppm por peso	Miligramos/metro cúbico	1.198
	Microgramos/metro cúbico	1.198×10^{-3}
	Microgramos/litro	1.198
	ppm por volumen (20°C)	28.8/M
	Libras/pie cúbico	7.48×10^{-6}

GASES ATMOSFERICOS (Continuación)

Para Convertir de	A	Multiplicar por
ppm por volumen (20°C)	Miligramos/metro cúbico	M/24.04
	Microgramos/metro cúbico	M/0.02404
	Microgramos/litro	M/24.04
	ppm por peso	M/28.8
	Libras/pie cúbico	M/385.1 x 10^6

M = Peso molecular del gas.

VELOCIDAD

Para Convertir de	A	Multiplicar por
Kilómetros/hr	Metros/seg	0.2778
	Millas/hr	0.6214
	Pies/seg	0.9113
Metros/seg	Kilómetros/hr	3.6
	Millas/hr	2.237
	Pies/seg	3.281
Millas/hr	Kilómetros/hr	1.6093
	Metros/seg	0.4470
	Pies/seg	1.4667
Pies/seg	Kilómetros/hr	1.09728
	Metros/seg	0.3048
	Millas/hr	0.6818

PRESION ATMOSFERICA

Para Convertir de	A	Multiplicar por
Atmósferas	Milibares	1013.2
	Milímetros de mercurio	760.0
	Pulgadas de mercurio	29.92
Milibares	Atmósferas	0.00987
	Milímetros de mercurio	0.75
	Pulgadas de mercurio	0.30
Milímetros de mercurio	Atmósferas	1.316×10^{-3}
	Milibares	1.333
	Pulgadas de mercurio	39.37×10^{-3}
Pulgadas de mercurio	Atmósferas	0.03333
	Milibares	33.35
	Milímetros de mercurio	25.4005

EMISIONES DE VOLUMEN

Para Convertir de	A	Multiplicar por
Metro cúbico/min	Pie cúbico/min	35.314
Pie cúbico/min	Metro cúbico/min	0.0283

FACTORES DE CONVERSIÓN DE CALDERA

1 Megawatt = 10.5×10^6 Btu/hr (8 to 14×10^6 Btu/hr)

1 Megawatt = 8×10^3 lb vapor/hr (6 to 11×10^3 lb vapor/hr)

1 BHP = 34.5 lb vapor/hr

1 BHP = 45×10^3 Btu/hr (40 to 50×10^3 Btu/hr)

1 lb vapor /hr = 1.4×10^3 Btu/hr (1.2 to 1.7×10^3 Btu/hr)

NOTAS: En las relaciones,

Megawatt es la producción eléctrica neta de una planta termoeléctrica de vapor.

BHP es un caballo de fuerza de caldera.

lb vapor/hr es la tasa de producción de vapor de la caldera.

Btu/hr es la tasa de entrada de calor a la caldera (basada en el valor calorífico neto o alto del combustible quemado).

Para operaciones de caldera (generalmente más antiguas y/o pequeñas) menos eficientes, usar los mayores valores expresados. Para operaciones más eficientes (generalmente más nuevas y/o grandes), usar el menor valor.

Volumen	**In^3**	**ml**	**litros**	**onzas (EU fl.)**	**galones (EU)**	**barriles (EU)**	**pie cúbico**
Pulgadas cuadradas		16.3868	0.0163868	0.5541	4.3290×10^{-3}	1.37429×10^{-4}	5.78704×10^{-4}
Mililitros	0.061024		0.001	0.03381	2.6418×10^{-4}	8.387×10^{-6}	3.5316×10^{-5}
Litros	61.024	1000		33.8147	0.26418	8.387×10^{-3}	0.035316
Onzas (EU fl.)	1.80469	29.5729	0.029573		7.8125×10^{-3}	2.48×10^{-4}	1.0443×10^{-3}
Galones (EU)[a]	231	3785.3	3.7853	128		0.031746	0.13368
Barriles (EU)	7276.5	1.1924×10^{5}	119.2369	4032.0	31.5		4.2109
Pies cúbicos	1728	2.8316×10^{4}	28.316	957.568	7.481	0.23743	

[a] Galón EU de agua a 16.7°C (62°F) pesa 3.780 kg ó 8.337 libras (avoir.)

Masa	**gramos**	**kilogramos**	**onzas (avoir.)**	**libras (avoir.)**	**granos**	**toneladas (EU)**	**miligramos**
Gramos		0.001	$3.527x10^{-2}$	$2.205x10^{-3}$	15.432	$1.102x10^{-6}$	1000
Kilogramos	1000		35.274	2.2046	15432	$1.102x10^{-3}$	$1x10^{6}$
Onzas (avoir.)	28.350	0.028350		0.0625	437.5	$3.125x10^{-5}$	$2.8350x10^{4}$
Libras (avoir.)[a]	453.59	0.45359	16.0		7000	$5.0x10^{-4}$	$4.5359x10^{5}$
Granos	0.06480	$6.480x10^{-5}$	$2.286x10^{-3}$	$1.429x10^{-4}$		$7.142x10^{-8}$	64.799
Toneladas (EU)	$9.072x10^{5}$	907.19	$3.200x10^{4}$	2000	$1.4x10^{7}$		$9.0718x10^{8}$
Miligramos	0.001	$1x10^{-6}$	$3.527x10^{-5}$	$2.205x10^{-6}$	0.015432	$1.102x10^{-9}$	

[a] Masa de 27.692 pulgadas cúbicas de agua pesadas en aire a 4.0°C, y presión de 760 mm de mercurio.

Trabajo y Energía	**g cal.**	**kg cal.**	**ergs**	**joules**	**Btu**	**ft lb**	**kg metros**	**L-Atm**	**HP horas**	**ft poundales**	**kWh**	**Wh**
Gramo caloría (promedio)		0.001	$4.186x10^{7}$	4.186	$3.9680x10^{-3}$	3.0874	0.42685	0.041311	$1.5593x10^{-6}$	99.334	$1.1628x10^{-6}$	$1.1628x10^{-3}$
Kilogramo caloría	1000		$4.186x10^{10}$	4186	3.9680	3087.4	426.85	41.311	$1.5593x10^{-3}$	99334	$1.1628x10^{-3}$	1.1628
Ergs	$2.3889x10^{-8}$	$2.3889x10^{-11}$		$1x10^{-7}$	$9.4805x10^{-11}$	$7.3756x10^{-8}$	$1.0197x10^{-8}$	$9.8689x10^{-10}$	$3.7251x10^{-14}$	$2.3730x10^{-6}$	$2.7778x10^{-14}$	$2.7778x10^{-11}$
Joules	0.23889	$2.3889x10^{-4}$	$1x10^{7}$		$9.4805x10^{-4}$	0.73756	0.10197	$9.8689x10^{-3}$	$3.7251x10^{-7}$	23.730	$2.7778x10^{-7}$	$2.7778x10^{-4}$
Btu (promedio)	251.98	0.25198	$1.0548x10^{10}$	1054.8		777.98	107.56	10.409	$3.9292x10^{-4}$	$2.5030x10^{4}$	$2.930x10^{-4}$	0.2930
Libras-pie	0.32389	$3.2389x10^{-4}$	$1.35582x10^{7}$	1.3558	$1.2854x10^{-3}$		0.13825	0.013381	$5.0505x10^{-7}$	32.174	$3.7662x10^{-7}$	$3.7662x10^{-4}$
Kilogramo metros	2.3427	$2.3427x10^{-3}$	$9.8066x10^{7}$	9.8066	$9.2967x10^{-3}$	7.2330		0.096781	$3.6529x10^{-6}$	232.71	$2.7241x10^{-6}$	$2.7241x10^{-3}$
Litro Atmósferas (normal)	24.206	$2.4206x10^{-2}$	$1.0133x10^{9}$	101.328	0.09606	74.735	10.333		$3.7745x10^{-5}$	2404.5	$2.8164x10^{-5}$	$2.8164x10^{-2}$
Caballo de fuerza horas	$6.4130x10^{5}$	641.30	$2.6845x10^{13}$	$2.6845x10^{6}$	2454.0	$1.9800x10^{6}$	$2.7374x10^{5}$	26494		$6.3705x10^{7}$	0.7457	745.7
Poundales-pie	0.010067	$10.067x10^{-6}$	$4.21402x10^{5}$	0.04214	$3.9952x10^{-5}$	0.031081	$4.2972x10^{-3}$	$4.1558x10^{-4}$	$1.5697x10^{-8}$		$1.17055x10^{-8}$	$1.17055x10^{-5}$
Kilowatt horas	$8.6001x10^{5}$	860.01	$3.6000x10^{13}$	$3.6000x10^{6}$	3413.0	$2.6552x10^{6}$	$3.6709x10^{-5}$	$3.5529x10^{6}$	1.3440	$8.5430x10^{7}$		1000
Watt horas	860.01	0.86001	$3.6000x10^{10}$	3600	3.4130	2655.3	367.09	$3.5529x10^{3}$	$1.3410x10^{-3}$	$8.5430x10^{1}$	0.001	

Potencia	**watts**	**kW**	**ft lb/seg**	**erg/seg**	**Btu/min**	**g cm/seg**	**kg cal/min**	**HP**	**lumens**	**joules/seg**	**Btu/hr**
Watts		0.001	0.73756	1x10^{7}	0.056884	1.0197x10^{4}	0.01433	1.341x10^{-3}	668	1	3.41304
Kilowatts	1000		737.56	1x10^{10}	56.884	1.0197x10^{7}	14.3334	1.3410	6.68x10^{5}	1000	3413.04
Libras-pie por segundo	1.35582	1.3558x10^{-3}		1.3558x10^{7}	0.077124	1.3826x10^{4}	0.019433	1.8182x10^{-3}	906.28	1.3558	4.6274
Ergs por segundo	1x10^{-7}	1x10^{-10}	7.3756x10^{-8}		5.688x10^{-9}	1.0197x10^{-3}	1.4333x10^{-9}	1.3410x10^{-10}	6.6845x10^{-5}	1x10^{-7}	3.4130x10^{-7}
Btu[a] por minuto	17.580	0.017580	12.9600	1.7580x10^{8}		1.7926x10^{5}	0.2520	0.023575	11751	17.580	60
Gramo centímetros por segundo	9.8067x10^{-5}	9.8067x10^{-8}	7.2330x10^{-5}	980.665	5.5783x10^{-6}		1.4056x10^{-6}	1.3151x10^{-7}	0.065552	9.8067x10^{-5}	3.3470x10^{-4}
Kilogramo caloría por minuto	69.767	0.069767	51.457	6.9770x10^{8}	3.9685	7.1146x10^{5}		0.093557	46636	69.769	238.11
Caballo de fuerza (EU)	745.7	0.7457	550	7.457x10^{9}	42.4176	7.6042x10^{6}	10.688		498129	745.7	2545.1
Lumens	1.496x10^{-3}	1.496x10^{-6}	1.0034x10^{-3}	1.496x10^{4}	8.5096x10^{-5}	15.254	2.1437x10^{-5}	2.0061x10^{-6}		1.496x10^{-3}	5.1069x10^{-3}
Joules por segundo	1	0.001	0.73756	1x10^{7}	0.056884	1.0197x10^{4}	0.01433	1.341x10^{-3}	668		3.41304
Btu[a] por hora	0.29299	2.9299x10^{-4}	0.21610	2.9299x10^{6}	0.01667	2.9878x10^{3}	4.1997x10^{-3}	3.9291x10^{-4}	195.80	0.29299	

[a] Unidades térmicas británicas (promedio)

FACTORES DE CONVERSION PARA DIVERSAS SUSTANCIAS[a]

Tipo de Sustancia	Factores de Conversión
Combustible	
Petróleo	1 bbl = 159 litros (42 gal)
Gas natural	1 therm = 100,000 Btu (aprox.25000 kcal)
Contaminantes Gaseosos	
O_3	1 ppm, volumen = 1960µg/m^3
NO_2	1 ppm, volumen = 1880µg/m^3
SO_2	1 ppm, volumen = 2610µg/m^3
H_2S	1 ppm, volumen = 1390 µg/m^3
CO	1 ppm, volumen = 1.14 mg/m^3
HC (como metano)	1 ppm, volumen = 0.654 mg/m^3
Productos Agrícolas	
Maíz	1 bushel = 25.4 kg = 56 lb
Mijo	1 bushel = 25.4 kg = 56 lb
Avenas	1 bushel = 14.5 kg = 32 lb
Cebada	1 bushel = 21.8 kg = 48 lb
Trigo	1 bushel = 27.2 kg = 60 lb
Algodón	1 paca = 226 kg = 500 lb
Productos Minerales	
Ladrillo	1 ladrillo = 2.95 kg = 6.5 lb
Cemento	1 bbl = 170 kg = 375 lb
Cemento	1 yd^3 = 1130 kg = 2500 lb
Concreto	1 yd^3 = 1820 kg = 4000 lb
Fuentes móviles, eficiencia del combustible	
Vehículos automotores	1.0 milla/gal = 0.426 km/litro
Embarcaciones	1.0 gal/milla náutica= 2.05 litros/km
Líquidos Misceláneos	
Cerveza	1 bbl = 31.5 gal
Pintura	1 gal = 4.5 a 6.82 kg = 10 a 15 lb
Barniz	1 gal = 3.18 kg = 7 lb
Whiskey	1 bbl = 190 litros = 50.2 gal
Agua	1 gal = 3.81 kg = 8.3 lb

[a] Muchos de los factores de conversión de esta tabla representan valores promedio y aproximaciones, y algunos valores pueden cambiar con la temperatura y presión. Sin embargo, estos valores de conversión deben tener la precisión necesaria para el uso general en campo.

APENDICE B

INDICE DE LOS EJEMPLOS EN LOS MANUALES DEL INVENTARIO DE EMISIONES DE MEXICO

Ejemplo de los Problemas en los Manuales del Programa del Inventario de Emisiones de México

Volumen III – Técnicas Básicas de Estimación de Emisiones

Sección 3.2	Datos de Muestreo en Fuente
Sección 3.3	Datos del Monitoreo Continuo de Emisiones
Sección 4.2.2	Modelo Multivariado
Sección 5.10	Resultado de Encuestas
Sección 6.1	Factores de Emisión Basados en el Proceso
Sección 6.2	Factores de Emisión Basados en el Censo
Sección 7.0	Balance de Materiales
Sección 8.0	Extrapolación
Apéndice III-A	Modelos de Emisiones (polvos fugitivos, rellenos sanitarios, tanques de almacenamiento, carga de derivados del petróleo, residuos y aguas residuales)

Volumen IV – Desarrollo del Inventario de Fuentes Puntuales

Sección 3.1	Factores de Emisión
Sección 3.2	Datos de Prueba en Fuente
Sección 3.3	Balance de Materiales
Sección 4.1	Análisis de Combustibles
Sección 5.1	Efectividad de Control
Sección 7.3	Estimación del Error

Volumen V – Desarrollo del Inventario de Fuentes de Area

Sección 4.0	Combustión de Fuente Estacionaria
Sección 5.0	Fuentes Móviles que no Circulan por Carretera
Sección 6.0	Uso de Solventes
Sección 7.0	Almacenamiento y transporte de Derivados del Petróleo
Sección 8.0	Fuentes Industriales Ligeras y Comerciales
Sección 9.0	Agricultura
Sección 10.0	Manejo de Residuos
Sección 11.0	Fuentes de Area Misceláneas

Volumen VI – Desarrollo del Inventario de Vehículos Automotores

Sección 3.4.1	Efectos de la Temperatura, Altitud, PVR del Combustible, Combustibles Oxigenados, Programas de Inspección y Mantenimiento y Programas Anti-Alteraciones (PAA)
Sección 3.4.2	Efectos de la Velocidad del Vehículo

670017 5202
Septiembre 25, 1997

John T. Leary
Gerente de Proyecto
Asociación de Gobernadores del Oeste
600 17th Street
Suite 1705, Torre Sur
Denver, CO 80202

Asunto: Entrega del "Cuaderno de Trabajo para la Capacitación Avanzada en la Metodología del Proyecto del Inventario de Emisiones de México".

Estimado John:

Anexa se encuentra una copia de la versión final del "Cuaderno de Trabajo para la Capacitación Avanzada en la Metodología del Proyecto del Inventario de Emisiones de México". Este cuaderno contiene diversos ejemplos relacionados con el inventario de emisiones que complementarán y fortalecerán el curso de extensión a nivel universitario que hemos desarrollado, así como otras actividades de capacitación en México. Nosotros anticipamos que este cuaderno de trabajo también será un valioso recurso durante la próxima prueba de la metodología en Mexicali.

En caso de tener cualesquier preguntas con respecto al material anexo, por favor comuníquese conmigo al (916) 857-7451 o con Marty Wolf al (916) 857-7468.

Atentamente

William R. Oliver
Gerente de Proyecto

Anexos

c: Victor Hugo Páramo, INE (cinco copias)
Comité Asesor Binacional
José Ortega, Corporación Radian
Jim Yarbrough, U.S. EPA Región VI
Archivo del Proyecto

INVENTARIO DE EMISIONES DE MEXICALI

INFORME FINAL

(Versión Final)

Preparado para :
Grupo Técnico del Inventario Mexicali

Preparado por :
Ingeniería en Control Ambiental y Riesgo Industrial, S. de R. L. M. I.

Septiembre de 1999

Contenido

Indice de Tablas y Figuras

Abreviaturas y Acrónimos

A.S.A.	Aeropuertos y Servicios Auxiliares
AP-42	Compilation of Air Pollutant Emission Factors. Vol. 1, Stationary Point and Area Sources
Av.	Avenida
Blv.	Bulevar
Calz.	Calzada
CEEMSA	Compañía Editora de Enciclopedias de México
CO	Monóxido de Carbono
CONAGUA	Comisión Nacional del Agua
CONASUPO	Compañía Nacional de Subsistencias Populares
COPLADEMM	Comité de Planeación para el Desarrollo del Municipio de Mexicali
COV's	Compuestos Orgánicos Volátiles
DGE	Dirección General de Ecología del Gobierno del Estado de B. C.
FAAED	Federal Aviation Administration Emision Database
Gas L. P.	Gas Licuado de Petróleo
GOT	Gases Orgánicos Totales
g/gal	gramos por galón
g/km	gramos por kilómetro
g/m^3	gramos por metro cúbico
Ha	Hectárea
HC	Hidrocarburos
HCNM	Hidrocarburos no metánicos
HDDV	Camiones pesados a diesel (camiones de carga y autobuses)
HDGV	Camiones pesados a gasolina (camiones de carga y autobuses)
ICBC	Instituto de Cultura de Baja California
INE	Instituto Nacional de Ecología
INEGI	Instituto Nacional de Estadística Geografía e Informática
kcal	kilocalorías
kg/ton	kilogramos por tonelada
$kg/\ m^3$	kilogramos por metro cúbico
km	kilómetro
km/hr	kilómetros por hora
KRV	kilómetros recorridos por vehículo
l	Litro
lb/in^2	Libras por pulgada cuadrada
LDGV	Vehículos ligeros a gasolina (Automóviles y Taxis)
LDGT1	Camiones ligeros a gasolina (Pick-ups)
LDGT2	Camiones ligeros a gasolina
MC	Motocicletas

ml/gal	Mililitros por galón
ml/l	Mililitros por litro
ml/ m^3	Mililitros por metro cúbico
min	Minuto
m^3	Metro cúbico
NH_3	Amoniaco Anhidro
NO_2	Bióxido de Nitrógeno
NOx	Oxidos de Nitrógeno
Part	Partículas
Pb	Plomo
PCBEIS	Biogenic Emissions Inventory System for Personal Computer
PEMEX	Petróleos Mexicanos
PM	Material Particulado
PM10	Material particulado con diámetro dinámico menor o igual a 10 micrones
PROFEPA	Procuraduría Federal de Protección al Ambiente
PVR	Presión de Vapor Reid
S	Azufre
SAGAR	Secretaría de Agricultura, Ganadería y Desarrollo Rural
SCT	Secretaría de Comunicaciones y Transportes
SEDESOL	Secretaría de Desarrollo Social
SEMARNAP	Secretaría de Medio Ambiente, Recursos Naturales y Pesca
SO_2	Bióxido de Azufre
SOx	Oxidos de azufre
TEP	Tetraetilo de Plomo
TOG	Gases Orgánicos Totales
Ton. (ton)	Tonelada
ton/año	Toneladas por año
U.S. EPA (EPA)	United States Environment Protection Agency (Agencia de Protección Ambiental de los Estados Unidos de América)
U. S. INS	United States Inmigration and Naturalization Service (Servicio de Inmigración y Naturalización de los Estados Unidos de América)
UABC	Universidad Autónoma de Baja California
USA (EU)	Estados Unidos de América
UTM	Universal Transverse Mercator (Sistema universal de coordenadas geográficas)
VOC’s	Compuestos Orgánicos Volátiles
ZMVM	Zona Metropolitana del Valle de México
°C	Grados Celsius
°F	Grados Farenheit

1 Introducción

El inventario de emisiones de contaminantes atmosféricos es indispensable tanto para la definición de políticas de prevención y control de la calidad del aire por parte de la autoridad, como para la instrumentación de medidas correctivas por parte del empresario para reducir las emisiones generadas por su industria. Su importancia es de tal magnitud que constituye la base para el desarrollo integral de planes y programas para mejorar la calidad del aire. Un inventario permite conocer la ubicación de los diferentes tipos de fuentes emisoras, así como los tipos de contaminantes que emite cada una de ellas.

La elaboración de un inventario de emisiones desagregado, preciso y actualizado es una tarea compleja que demanda la integración sistemática de la información en un marco de cooperación institucional entre el gobierno local y federal. Algunas experiencias internacionales señalan que son necesarios años de estudio y una considerable cantidad de recursos para definir correctamente un inventario.[1]

La elaboración de un Inventario de Emisiones para Mexicali parte de la necesidad de analizar el comportamiento de los contaminantes atmosféricos que permita identificarlos, cuantificarlos y desarrollar estrategias para su abatimiento, a partir de un esfuerzo tripartita entre instituciones federales, estatales y municipales, con la colaboración de instituciones de Estados Unidos de América que apoyan los trabajos binacionales en esta materia.

Este proyecto fue auspiciado por la Western Governors' Association, institución que hace la aportación de los recursos económicos recibidos de la U. S. Environmental Protection Agency para el desarrollo del inventario, así como para el desarrollo de la metodología a utilizar.

Se contó con la participación de la Agencia de Protección del Ambiente (U. S. EPA Region IX) y del California Air Resources Board de los Estados Unidos de Norteamérica, quienes apoyaron con asesoría e información.

La Secretaría de Medio Ambiente Recursos Naturales y Pesca y el Instituto Nacional de Ecología dieron la cobertura institucional tanto a nivel local como central para desarrollar este proyecto, debido a la necesidad de cumplir con convenios internacionales en materia ecológica, apoyar a los municipios en la elaboración de sus planes de calidad del aire para el cumplimiento de la norma vigente y como parte del Programa Integral de Planeación y Control de la Contaminación que se está impulsando con los gobiernos estatales y municipales.

Por parte del Gobierno del Estado y del Ayuntamiento de Mexicali a través de la Dirección General de Ecología y la Dirección de Catastro, Control Urbano y Ecología, respectivamente, participaron proporcionando información y aportando sus opiniones en la revisión de los avances, lo que permitió conocer con mayor precisión las fuentes y áreas de impacto de las emisiones. Esto permitirá, a su vez, definir con bases sólidas la política ambiental y normatividad local en la esfera de sus competencias.

Se buscó con este proyecto probar y ajustar la metodología desarrollada para México por Radian International LLC. Puesto que cada región de México donde se levante un inventario de emisiones puede tener algunas circunstancias muy particulares; se sabe que es posible hacer la metodología más estandarizada para todo México, a partir del conocimiento obtenido con el desarrollo del inventario de emisiones para Mexicali.

En forma paralela al desarrollo de este proyecto, se capacitó personal técnico que posteriormente sea capaz de mantener actualizado el inventario y pueda impulsar y desarrollar otros estudios complementarios, así como del diseño de políticas y normatividad con bases técnicas y fundamentadas. Se impartieron: un curso introductorio a Inventario de Emisiones, un Taller de Emisiones de Fuentes Vehiculares, un curso de Entrenamiento a Entrenadores dirigido al Grupo Técnico que incluyó la revisión y adecuación del Cuestionario de Fuentes Puntuales y un Taller para el llenado del Cuestionario de Fuentes Puntuales en el que participaron representantes de la industria, tanto de jurisdicción federal como estatal.

Para este proyecto se definieron tres grupos de participantes formados de la siguiente manera:

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[1] Gobierno del Estado de Jalisco, et. al. 1997. Programa para el Mejoramiento de la Calidad del Aire en la Zona Metropolitana de Guadalajara 1997-2001

Tabla 1.1 Grupos del Inventario de Emisiones de Mexicali 1996

Grupo Administrativo	INE SEMARNAP B. C. RADIAN (Consultor)
Grupo Técnico	INE SEMARNAP (Delegación B. C.) Gobierno del Estado (Dirección General de Ecología) Ayuntamiento de Mexicali (Dirección de Catastro, Control Urbano y Ecología) U.S. EPA Región IX Western Governors’ Association California Air Resources Board (CARB) Imperial County Air Pollution Control District (ICAPCD) Radian International LLC/Corporación Radian, S. A. de C. V. Ingeniería en Control Ambiental y Riesgo Industrial, S. de R. L. M. I. (Contratista)
Grupo Inventario Mexicali	Gobierno del Estado (DGE) Ayuntamiento de Ensenada Ayuntamiento de Mexicali Ayuntamiento de Rosarito Ayuntamiento de Tecate Ayuntamiento de Tijuana Centro de Investigación Científica y Educación Superior de Ensenada (CICESE) Instituto Tecnológico de Mexicali (ITM) Instituto Tecnológico de Tijuana (ITT) Ingeniería en Control Ambiental y Riesgo Industrial (ICAR).

Las funciones sustantivas de cada grupo fueron:

Grupo Administrativo: Coordinación de la aplicación de los fondos del proyecto.

Grupo Técnico: Definición de los alcances, usos y desarrollo del inventario en forma colegiada, tomando en cuenta las propuestas de los otros participantes.

Grupo Inventario Mexicali: Cada dependencia propuso los representantes para participar en las capacitaciones impartidas por INE y Radian, aportaron también aquella información derivada de sus actividades y atribuciones requerida dentro del inventario, además de su participación en algunas reuniones de evaluación de avances y experiencias del proyecto.

2 Antecedentes y Características de Mexicali

El surgimiento de Mexicali está estrechamente relacionado con la colonización y desarrollo agrícola de la región en ambos lados de la frontera. A fines del siglo pasado y primeros años del presente se llevaron a cabo por la compañía americana California Development los trabajos de irrigación y desarrollo urbano de las ciudades de El Centro, Imperial y Heber. El desarrollo del desierto del Colorado al que más tarde se llamó Valle Imperial estuvo financiado y dirigido por el empresario Canadiense George Chaffey. Fue este quien en 1901 decidió fundar la ciudad de Caléxico. En 1902 Antonio H. Heber sustituye a Chaffey en la dirección de las compañías Imperial Land y California Development. Con el apoyo de inversionistas Americanos, Heber compra el 17 de octubre de 1902 a la Sociedad de Irrigación y Terrenos de la Baja California un predio de 187.6 hectáreas en territorio mexicano colindante con la nueva población de Caléxico y comisiona al ingeniero Charles Rockwood para elaborar el trazo del pueblo de Mexicali.

Entre los años de 1904 y 1905 la empresa Colorado River Land adquirió la mayor parte de los terrenos irrigables en el valle de Mexicali. De manera simultánea a la operación de venta de lotes agrícolas el empresario inició la operación de venta de lotes urbanos. El compromiso de los empresarios Americanos con los nuevos colonos del Valle Imperial y de Mexicali incluía la entrega de agua para irrigación que se tomaría del Río Colorado.

En los años veinte fue peculiar el crecimiento de la industria cervecera pero a pesar de sus volúmenes de producción no transformaron la ciudad en una ciudad industrial. El surgimiento de la industrialización en el valle de Mexicali se dió hasta fines de los años cuarenta cuando la agroindustria en esta zona logró transformar en forma significativa el padrón espacial de crecimiento de la entidad con 117 establecimientos industriales. Las principales industrias fueron las plantas despepitadoras de algodón, la elaboración de aceites y grasas vegetales, el enlatado de pescados y mariscos; la elaboración de vinos y licores, el embotellado de aguas gaseosas, el empaque de carnes y la pasteurización de la leche. Al inicio de los años cincuenta ya se contaba con 525 establecimientos industriales. A finales de la década de los cincuenta inicia la instalación de las primeras industrias maquiladoras en la ciudad de Mexicali y con el Programa de Industrialización en la Frontera Norte a mediados de la década de los sesenta, surgen los primeros parques industriales para el establecimiento de las maquiladoras. Esto hace que la economía de la ciudad cambie y a partir de entonces, su carácter primordialmente agrícola se transforma a uno de mayor diversidad y estabilidad. La demanda de mano de obra por la industria maquiladora trae como consecuencia el incremento en la tasa de inmigración proveniente principalmente de los estados con mayor desempleo y pobreza de la República Mexicana.[2]

A partir de entonces, y sobre todo después de las devaluaciones del peso en 1982, esta rama se ha desarrollado muy rápidamente, la mayoría son propiedad de compañías norteamericanas o tienen alguna vinculación con ellas, aunque recientemente se estan instalando firmas asiáticas y europeas.

Se concentran principalmente en la fabricación y ensamble de productos eléctricos y electrónicos, accesorios para automóviles, confección de prendas de vestir y producción de empaques.[3]

Como parte del proceso de crecimiento de la maquiladora, está el desarrollo de parques industriales, los cuales proveen infraestructura y servicios a los establecimientos industriales. Aunado a lo anterior, las autoridades y grupos empresariales han promovido en forma constante este desarrollo.

La industria nacional también ha crecido en estas últimas décadas en lo que ha influido de manera importante el desarrollo del campo geotérmico de Cerro Prieto que surte de energía eléctrica a la región. También hay diversificación de giros entre los que se encuentran la industria del vidrio, fundición, automotriz y papel, entre otras.

El crecimiento industrial ha traido consigo la consolidación y el incremento de pequeños establecimientos industriales de servicio a las empresas más grandes, sobre todo en las áreas de soldadura, maquinado y de reparación, así como también de los comercios que surten equipos, papelería, materiales de limpieza, materiales diversos, equipo de cómputo y servicios de mantenimiento, limpieza y vigilancia .

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[2] UABC. 1991. Mexicali Una Historia. Tomo I. Instituto de Investigaciones Históricas, UABC.

[3] CEEMSA, ICBC. 1989. Diccionario Enciclopédico de B. C.

2.1 Aspectos geográficos

Mexicali presenta condiciones diferentes al resto de México por su clima, vegetación y ubicación geográfica. Las temperaturas durante el año son extremas (5 °C en invierno a 50 °C en verano), con clima muy seco, su precipitación pluvial promedio es mínima (<100 mm/año), existe poca vegetación natural predominando la de tipo matorral (cactus, chamizo, gobernadora, mezquite, pinillo) y el terreno es plano con una elevación promedio de 10 metros sobre el nivel medio del mar en el área de estudio seleccionada, con suelos tipo regosol cálcico y solonchak órtico.

Limita al norte con el Valle Imperial de California, al Oeste y Sur con los municipios de Tecate y Ensenada, al Este con Yuma en Arizona (compartiendo la frontera natural del Río Colorado), el Estado de Sonora y el Golfo de California.

2.2 Población

El total de población estimada a 1996 es de 716,551 habitantes (49.8% mujeres, 50.2% hombres; 32.5% menor de 15 años, 30% de 15 a 29 años, 21.1% de 30 a 44 años, y, 16.4% de 45 años y más) de los cuales 519,513 (72.5%) corresponden a la zona urbana de la Ciudad de Mexicali. [4]

El crecimiento demográfico promedio a partir de la década de 1950 es de 3.88% a nivel municipal y de 4.63% para la Ciudad de Mexicali, como se puede observar en el cuadro siguiente.

Tabla 2.2.1 Crecimiento Poblacional 1950-1996

Año	Municipal	Cd. de Mexicali
1950	124,362	64,668
1960	281,333	197,214
1970	396,324	263,498
1980	510,664	341,559
1990	601,938	438,377
1996 e	716,551	519,513
TMCA	3.88%	4.63%

e.- estimada, TMCA.- Tasa Media de Crecimiento Anual

Es necesario aclarar que a esta cantidad se adicionó la población de las localidades conurbadas consideradas dentro del fundo legal de la ciudad, entre las que destacan por su tamaño poblacional el Ejido Puebla, la Col. Progreso y la Col. Zaragoza, para un total de 545,754 personas, cantidad base para los cálculos a lo largo del inventario.

2.3 Crecimiento urbano

El rápido crecimiento poblacional de la ciudad, ha llevado aparejado el crecimiento de los servicios urbanos para cubrir las necesidades básicas de la población como son agua potable, energía eléctrica, drenaje, escuelas, abastecimiento de mercancías, calles y carreteras, aumentando así los problemas característicos de zonas urbanas; esto es crecimiento desordenado, falta de servicios, aumento del tráfico, incremento de los desechos sólidos, y por lo tanto aumento de la contaminación ambiental.

Muestra de lo anterior se puede apreciar en el cuadro siguiente, donde se anotan, para todo el municipio, el número de viviendas y los porcentajes de cobertura de los servicios básicos para diferentes años censales. [5,6]

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[4] COPLADEMM. 1997. Anuario Estadístico Municipal de Mexicali 1996.

[5] INEGI. Cuaderno Estadístico Municipal. Edición 1994.

[6] COPLADE.1984. Estadísticas Generales de B. C. 1983.

Tabla 2.3.1 Viviendas y Cobertura de Servicios 1960-1990

Año	No. de Viviendas	Energía Eléctrica (%)	Agua Potable (%)	Drenaje (%)
1960	51,589	63.5	42.9	24.0
1970	68,175	79.1	71.8	39.3
1980	100,892	91.6	87.3	60.5
1990	131,605	96.6	91.0	69.8

2.4 Aspectos económicos

Las actividades económicas principales del municipio son la agricultura de riego abastecida con agua del Río Colorado y pozos en cerca de 180,000 hectáreas con cultivos principales como el algodón (43,000 ha.), el trigo (53,400 ha.), la cebada, el cártamo, el maíz, hortalizas diversas y forrajes; la ganadería donde resaltan la producción de leche y carne de bovino; la industria nacional y de exportación principalmente metalmecánica, electrónica, eléctrica, alimenticia, vidrio y agroquímicos; además el comercio y los servicios financieros, de gobierno, talleres de reparación y restaurantes.

Para 1996 se estima que de la población ocupada se dedicó al sector de actividades primarias (agricultura, ganadería y pesca) el 18%, 26% al sector industrial, el 53% al sector terciario (comercio y servicios) y el 4% no está suficientemente especificada la actividad. En forma global este indicador - que se muestra en el cuadro siguiente - presenta una tasa de crecimiento mayor al de población total, lo que refleja un aumento acelerado de las actividades económicas.[4, 5]

Tabla 2.4.1 Población Ocupada 1950-1996

Año	Población Ocupada
1950	41,040
1960	84,455
1970	94,087
1980	169,532
1990	200,104
1996 /e	349,315

e.- estimada

El crecimiento económico y de la población en las décadas recientes en Mexicali han contribuido a altos niveles de contaminación del aire en esta área. Es por esto la importancia de desarrollar un inventario de emisiones para identificar las principales fuentes de contaminación del aire en Mexicali, lo que permitirá iniciar y establecer estrategias de control apropiadas.

2.5 Descripción y ubicación industrial

En la ciudad de Mexicali se encuentran ubicadas alrededor de 1,087 establecimientos industriales, de los cuales menos del 1% corresponde a la minería y extracción del petróleo y el grueso de los establecimientos lo constituye la industria manufacturera con el 99%; de estos, la mayoría corresponde a la micro y pequeña industria, sólo el 11% corresponde a la industria mediana y grande, razón por la cual el número de establecimientos registrados con emisiones es bajo respecto al total.[7]

Las principales concentraciones de establecimientos industriales se dan en: la zona aledaña al Bulevar López Mateos, el corredor González Ortega a lo largo de la Carretera a San Luis Río Colorado y sobre la Carretera a San Felipe, así como en los parques y centros industriales Mexicali I, Mexicali II, Mexicali III, Mexicali IV, Las Californias, Progreso, Marán, EXX-XI, El Vigía, Cucapah, Cachanilla, Margar y Nelson.

2.6 Fuentes de área características de Mexicali

En Mexicali existe una diversidad de fuentes generadoras de contaminantes clasificadas como fuentes de área, dentro de las cuales destacan por su cantidad emitida las siguientes:

- Los vehículos, adicionalmente a la contaminación provocada por la quema de combustible al circular, constituyen la fuente generadora más importante debido, en primer término, a que el parque vehicular se considera obsoleto y con deficiencias en el mantenimiento; en segundo lugar, a su paso por las calles no pavimentadas y pavimentadas levantan gran catidad de partículas; y, por último, la acumulación y paso lento en la zona centro de la ciudad para cruzar la frontera y los autobuses urbanos que finalizan e inician ahí sus rutas.

- Mexicali es una zona con muy baja precipitación pluvial, con alrededor del 40% de calles no pavimentadas, lotes baldíos diseminados por toda la mancha urbana, por lo cual se tienen altas emisiones de partículas de polvo por efecto de los vientos.

- La distribución de combustibles también constituye una fuente considerable, debido a la evaporación por los efectos de las altas temperaturas durante el transporte y almacenamiento de estos, así como por las operaciones de abastecimiento a los vehículos y el llenado de tanques de gas L. P. para su reparto en los hogares.

- Por ser una zona altamente agrícola, en el Valle de Mexicali se realizan quemas de residuos de cultivos de trigo, espárrago y zacate, cuya contaminación es transportada por los vientos.

Otras fuentes características de Mexicali son las comidas preparadas al carbón en un gran número de establecimientos fijos y ambulantes, las labores de labranza agrícola, aplicación de agroquímicos y corrales de manejo y engorda de ganado, las emisiones de la quema accidental y clandestina de llantas y basura, cuyas emisiones son importantes pero menos cuantiosas.

2.7 Características de la vialidad en Mexicali

La zona urbana de la ciudad de Mexicali esta conformada por una red de calles irregular, situada sobre terreno predominantemente plano, con una traza de ejes longitudinales y transversales que permiten la comunicación entre los diversos sectores de la ciudad con una longitud de alrededor de 1,800 kilómetros, aunque no totalmente fluida debido a la existencia de barreras que interrumpen la continuidad de las vialidades como el cauce del Río Nuevo, la vía del ferrocarril y el crecimiento urbano no planificado.[8]

El límite norte es la línea internacional con los Estados Unidos de América colindando con la ciudad de Calexico y el Valle Imperial, California y hacia los otros puntos limita con terrenos dedicados a la agricultura y grandes baldíos.

Los accesos a la ciudad son varios, por la parte norte las dos garitas internacionales, el mayor tráfico se registra en la que se encuentra situada en la zona centro y otra al oriente de la ciudad que fue puesta en operación a finales de 1996 y también alberga la aduana de carga; por la parte oriente la vía principal de acceso es la carretera Federal #2 a San Luis Río Colorado que conecta la Península de Baja California con el resto del país; al sur se comunica con la carretera Federal #5 al Puerto de San Felipe y la parte sur del Valle de Mexicali; y, al occidente la vía de acceso es la carretera Federal #2 a Tecate y Tijuana.

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[7] INEGI. Cuaderno Estadístico Municipal, Mexicali, B. C. Edición 1997.

[8] XIV Ayuntamiento de Mexicali. Programa de Desarrollo Urbano Centro de Población Mexicali, B. C. 1993-2007.

Las vialidades que registran mayor tráfico son: el Bulevar Lázaro Cárdenas que conecta las carreteras de San Luis Río Colorado y Tijuana, además de permitir internamente en la ciudad el tránsito de las zonas sureste y suroeste de la ciudad; el Bulevar López Mateos comunica desde la garita del centro hasta la salida a las carreteras que van a San Luis Río Colorado y San Felipe; la Calzada Justo Sierra permite el tráfico de la línea internacional hacia el sur conectándose con el Bulevar Benito Juárez y el Bulevar Francisco L. Montejano; la Calzada Independencia atraviesa de oriente a poniente la ciudad en su parte media. Otras arterias de significancia son el Bulevar Anáhuac, el Bulevar Carranza, la Calzada Cuauhtémoc, la Avenida Madero, la Avenida Colón, la Avenida Sinaloa, la Avenida Zaragoza, la Calle Heróico Colegio Militar, la Calle Río Culiacán, y recientemente construidas o ampliadas la Carretera Unión (Calz. Héctor Terán) y la Calzada Manuel Gómez Morín (Periférico), entre otras, tal como se muestra en la Tabla 2.7.1.

Tabla 2.7.1 Principales Vialidades de Mexicali

Nombre	Sentido	Longitud Aproximada (km)
Blv. Lázaro Cárdenas	Este-Oeste	21.7
Blv. Adolfo López Mateos	Norte-Sur	8.3
Blv. Rodolfo Sánchez Taboada (Carretera a San Luis)	Este-Oeste	10.7
Calz. Justo Sierra	Norte-Sur	2.3
Blv. Francisco L. Montejano	Norte-Sur	2.5
Blv. Castellón	Este-Oeste	3.6
Carretera a San Felipe (hasta acceso a Fracc. Campestre)	Norte-Sur	4.2
Calz. Independencia	Este-Oeste	9.0
Blv. Anáhuac	Norte-Sur	3.5
Av. Zaragoza	Este-Oeste	2.2
Calz. De las Américas	Este-Oeste	4.1
Calz. Cuauhtémoc	Este-Oeste	3.0
Calz. Manuel Gómez Morín (Periférico Oriente)	Norte-Sur	5.2
Blv. Carranza	Norte-Sur	5.6
Calz. CETYS	Este-Oeste	1.9
Carretera Unión	Este-Oeste	8.1
Calz. Heróico Colegio Militar	Norte-Sur	4.4
Av. Cristóbal Colón	Este-Oeste	7.7
Av. Francisco I. Madero	Este-Oeste	4.0
Av. Argentina	Este-Oeste	4.1
Av. Sinaloa	Este-Oeste	2.3
Av. Pioneros	Este-Oeste	0.9
Calle del Hospital	Norte-Sur	0.6
Diagonal Alfareros	Norte-Sur	1.2
Av. Calafia	Norte-Sur	0.9
Calle Uxmal	Norte-Sur	2.6
Calle Tuxtla Gutiérrez	Norte-Sur	2.8
Calle Ulises Irigoyen	Norte-Sur	2.3
Calle “G”	Norte-Sur	2.7
Calle “J”	Norte-Sur	3.5
Calle “K”	Norte-Sur	3.2
Calle Río Culiacán	Norte-Sur	4.8
Calle Río Mocorito	Norte-Sur	4.8
Calle Río Presidio	Norte-Sur	3.6
Calle Cuarta	Norte-Sur	2.8
Calle Novena	Norte-Sur	2.5

Fuente: UABC (1994). Estudio Integral de Vialidad y Transporte Urbano de Mexicali, Baja California. XIV Ayuntamiento de Mexicali. Programa de Desarrollo Urbano de Centro de Población de Mexicali, B. C. 1993-2007. INEGI (1997). Carta Urbana Base, Escala 1:25,000.

Por las características y ubicación de la ciudad, el terreno plano ha permitido la construcción de vialidades amplias pavimentadas, con por lo menos 4 carriles; en 1996 aproximadamente 11.63 millones de metros cuadrados de vialidad se encontraban pavimentados, lo que representa 62% de la traza urbana, sin embargo es importante mencionar que el pavimento presenta diferentes grados de deterioro apreciable en el 60% de la superficie pavimentada con daños como baches, grietas, desprendimiento de agregados y ondulaciones entre otros.[9]

Las vialidades no pavimentadas en 1996 cubrían un área de 7.79 millones de metros cuadrados que representaron el 38%, estas se ubican principalmente al sur, al sureste y al poniente de la ciudad donde se localizan las colonias populares de reciente creación y algunas que a pesar de tener tiempo de construidas no han contado con pavimentación.

2.8 Características del parque vehicular en Mexicali

El parque vehicular oficialmente registrado en Mexicali en 1996 fue de 240,810 vehículos[10] los cuales en su gran mayoría provienen de los Estados Unidos de América, de donde se importan usados a precios relativamente más bajos que los vehículos nacionales. Estos vehículos en ocasiones ya presentan fallas mecánicas del motor y los sistemas de control de emisiones se encuentran deteriorados.

Esa facilidad de adquisición ha tenido como consecuencias el incremento acelerado del parque vehicular, así como la proliferación de modelos antiguos mutilados de los sistemas de inyección de combustible y los sistemas anticontaminantes, condiciones que los hace más contaminantes que los vehículos nuevos.

En la Tabla 2.8.1 se puede apreciar el crecimiento del parque vehicular según las estadísticas oficiales, sin embargo es necesario considerar que para tener datos precisos de la composición del mismo, a estas cantidades se les debe agregar una cantidad porcentual de vehículos flotantes porque los registros no contemplan el número de vehículos utilizados por los residentes de Mexicali que trabajan en el lado americano y los ciudadanos extranjeros que laboran en el lado mexicano.

Tabla 2.8.1 Comportamiento del parque vehicular

Año	Número de Vehículos	Incremento Anual Promedio (%)
1980	86,319	
1985	104,500	3.9
1989	126,565	4.9
1992	151,485	6.1
1994	173,674	7.1
1996	240,810	17.8

Fuentes: Compilada con información de Secretaría de Planeación y Finanzas. Sistema de Control Vehicular. 1996. Centro SCT02. Departamento de Autotransporte Federal. 1996. UABC (1994). Estudio Integral de Transporte y Vialidad. Para 1994 y anteriores.

En la distribución por tipo de vehículo utilizada para los cálculos de este inventario, se tiene que el mayor porcentaje corresponde a automóviles particulares, predominando los importados, en una proporción de 9 a 1 con respecto a los de fabricación nacional.[11]

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[9] Ayuntamiento de Mexicali. 1993. Programa de Desarrollo Urbano 1993-2007.

[10] Secretaría de Planeación y Finanzas. 1996. Reporte de Estadísticas por Municipio. Centro SCT02. S/f. Vehículos del Autotransporte Federal Registrados.

[11] Valor obtenido del “Reporte de Estadísticas por Municipio. 1996” de la Secretaría de Planeación y Finanzas.

3 Obtención de Información

A partir del mes de noviembre de 1997 se inició la recopilación de información establecida en el Plan de Trabajo, en el que se detallaron los datos a recopilar necesarios para realizar los cálculos de factores y de emisiones y las fuentes probables de información.

3.1 Registros oficiales

Inicialmente se realizó la revisión de los archivos de la Delegación de SEMARNAP y la Delegación de la Dirección General de Ecología del Estado en Mexicali, de donde se efectuó el levantamiento de la información disponible de las empresas para 1996, obteniendo los datos de la solicitud de Licencia de Funcionamiento y la Cédulas de Operación Anual para los establecimientos de jurisdicción federal; para el caso de las de jurisdicción estatal las fuentes de información fueron la solicitud de registro en el Registro Estatal de Fuentes Emisoras a la Atmósfera y los informes para la revalidación de dicho registro.

Esta etapa constituyó el origen principal para la elaboración de la base de datos de las fuentes puntuales, de las cuales se obtuvo información general del establecimiento, uso de materias primas, equipos de proceso y de control, equipos de combustión y su consumo de combustibles, así como las emisiones reportadas a la autoridad como producto de sus actividades, regularmente obtenidas de mediciones.

3.2 Cuestionario a fuentes puntuales

Dentro de los objetivos del inventario se incluyó el probar las ventajas y desventajas de la aplicación de un Cuestionario de Fuentes Puntuales[12] diseñado para recopilar datos sobre las emisiones contaminantes al aire y la operación de los establecimientos industriales en México, para definir su aplicabilidad en aquellos que se lleven a cabo posteriomente en el resto del país.

Primeramente se efectuó una revisión del cuestionario original por el Grupo Técnico para adecuarlo a las características de la industria en Mexicali, tanto para las de jurisdicción federal como estatal, además de la definición de la estrategia de aplicación y recolección.

Seguidamente se invitó a las industrias a participar en un “Taller de Emisiones a la Atmósfera” al que asistieron 42 industrias, en el cual se les explicaron los alcances del inventario de emisiones y especialmente la forma de llenado del cuestionario que debería ser contestado y remitido posteriormente con la información derivada de mediciones o estimaciones conforme a las características del proceso particular de cada una. Las empresas que no asistieron les fue enviado el cuestionario por servicio de mensajería.

Durante el período concedido a las industrias para la devolución y llenado del cuestionario, les fue proporcionanda asistencia técnica y datos de factores para la estimación de las emisiones; de esta manera se logró obtener información adicional de las industrias, así como también la capacitación del personal encargado de tareas de gestión ambiental en las mismas, lo que permitirá mejorar la calidad de la información que periodicamente debe ser entregada a la autoridad.

Complementariamente al cuestionario, ya que era un dato solicitado en el mismo, se llevó a cabo una recopilación de la localización georeferenciada de las fuentes puntuales, mediante la utilización de un geoposicionador con el cual se recorrieron todas las industrias incluidas en el inventario para obtener su localización UTM.

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[12] Radian/SEMARNAP. Junio 1998. Cuestionario de Fuentes Puntuales en México,

3.3 Solicitud de información

A partir del mes de abril de 1998 se inició la recopilación de información a oficinas públicas , organismos y empresas definidas en el Plan de Trabajo como posibles fuentes de información. Al efecto, se solicitó oficialmente a través de la Delegación de SEMARNAP, información por escrito y se tuvieron reuniones con dependencias y organismos para la obtención y verificación de los datos recabados. También, durante las reuniones de trabajo del Grupo Técnico se revisó la información recolectada a fin de validarla y en su caso decidir el uso más adecuado. En la Tabla 3.3.1 siguiente se anota una relación de las fuentes y la información proporcionada por cada una de estas:

Tabla 3.3.1 Información obtenida para el inventario

Organismo	Información proporcionada
Aeropuertos y Servicios Auxiliares, Administración del Aeropuerto de Mexicali	Vuelos y ventas de combustibles aéreos en el Aeropuerto de Mexicali en 1996.
Ayuntamiento de Mexicali, Dirección de Catastro, Control Urbano y Ecología	Estudio Integral de Vialidad y Transporte Urbano de Mexicali. Aplicación de asfalto. Licencias de construcción. Superfices pavimentads, sin pavimento, lotes baldíos y áreas verdes.
Ayuntamiento de Mexicali, Dirección de Obras Públicas	Volumen de Basura generado en Mexicali en 1996.
California Air Resources Board	Factores climatológicos y de emisión de partículas en el Valle Imperial.
Centro SCT 02, Departamento de Autotransporte Federal	Camiones del Servicio Público Federal registrados en Mexicali.
COBACH, Departamento de Obras	Maquinaria de jardín.
CESPM, Gerencia de Planeación	Volumen de aguas negras tratadas. Superficie de Lagunas de Oxidación. Longitud de drenes de aguas negras. Maquinaria de construcción.
CONAGUA, Gerencia Regional en Baja California, Oficina de Meteorología	Información Climatológica de Mexicali para 1996.
CONASUPO, Delegación en Baja California	Relación de Tortillerías y sus consumos de maíz y harina de maíz subsidiados.
Gas Silza, S. A. de C. V.	Ventas de gas L. P. en 1996.
Instituto Nacional de Ecología	Factores de emisión de partículas en vehículos. Modelos para computadora personal: Mobile 5 Juárez, FAAED, PCBeis y Tanks3.
PEMEX, Subdirección de Producción, Superintendencia de Ventas en Mexicali	Relación de ventas por tipo de combustible para Mexicali. Características de los combustibles.
Radian International, LLC	Factores AP-42, Quinta Edición.
SAGAR, Delegación Baja California	Consumo de fertilizantes y pesticidas. Superficie sin cultivar. Superficie de quemas agrícolas. Cantidad de tractores y trilladoras.
Secretaría de Desarrollo Económico, Dirección de Estadística e Indicadores Económicos	Número de Hospitales y camas en Mexicali. Cruces Fronterizos. Corridas de autobuses en la Central de Autobuses de Mexicali.

Secretaría de Fomento Agropecuario, Direcciones de Agricultura, Ganadería y Comercialización	Superficie cultivada por tipo de cultivo Censo ganadero Guías técnicas de cultivos
Secretaría de Planeación y Finanzas, Departamento de Control Vehicular	Vehículos registrados por municipio
UABC, Dirección de Obras	Maquinaria de Jardín.
UABC, Instituto de Ingeniería, Coordinación de Meteorología	Temperaturas horarias.

La información detallada en la tabla se utilizó para fuentes de área y naturales, fundamentalmente, y algunos datos sirvieron para complementar cálculos en fuentes vehiculares y fuentes puntuales.

3.4 Recopilación bibliográfica

Esta se inició con la recepción por el Grupo Técnico de la metodología desarrollada para el inventario y posteriormente diversas publicaciones de inventarios ya desarrollados en México. Se obtuvieron de las instituciones trabajos publicados con estadísticas locales, información geográfica y estadísticas diversas indicadas en las referencias bibliográficas.

4 Inventario de Emisiones

En la integración de este primer inventario se incluyeron las emisiones generadas por las fuentes puntuales registradas (industrias) de jurisdicción federal y jurisdicción estatal, de las cuales se recopiló también información referente a las materias primas y combustibles utilizados, así como la producción obtenida, esto para que mediante la combinación de métodos como la aplicación de factores de emisión, mediciones y balance de material se estimaran las emisiones de contaminantes criterio totales del sector industrial de Mexicali.

El inventario de emisiones de fuentes de área incluye las emisiones de fuentes que por su tamaño se consideran pequeñas, son numerosas y se encuentran dispersas por lo cual es difícil incluirlas adecuadamente en el inventario de fuentes puntuales, sean estas de tipo industrial, comercial o de servicios. Además, las fuentes de área emiten contaminantes al aire en forma significativa que deben ser incluidos en un inventario de emisiones para garantizar que esté completo.

Las fuentes de área agrupan las emisiones de fuentes similares dentro de categorías y consta de las siguientes:

- Combustión en fuentes estacionarias (e. g., combustión doméstica y comercial ligera).
- Fuentes móviles que no circulan por carreteras (e. g., trenes y equipo móvil).
- Uso de solventes (e. g.,limpiadurías o tintorerías, aplicación de asfaltos).
- Almacenamiento, transporte y distribución de productos del petróleo (e. g., gasolina).
- Fuentes industriales ligeras y comerciales (e. g., panaderías, asados al carbón).
- Agricultura (e. g., corrales de engorda, quemas agrícolas).
- Manejo de residuos (e. g., rellenos sanitarios, tratamiento de aguas).
- Fuentes de área misceláneas (e. g., incendios, caminos no pavimentados).

En cuanto a fuentes naturales, en el inventario se consideran las emisiones generadas por la vegetación urbana, la vegetación nativa de la región y los cultivos, cuyos contaminantes se emiten por efecto de factores climáticos y por el tipo mismo de la vegetación. También se incluyen en esta clasificación las emisiones provocadas por la acción de los vientos sobre los terrenos de cultivo, terrenos baldíos y calles sin pavimentar.

En la tabla siguiente se anota un resumen de las emisiones por cada tipo de fuente y para cada uno de los contaminantes, tanto los cinco considerados “contaminantes criterio” así como el plomo y el amoniaco.

Tabla 4.1 Resumen de Emisiones de Mexicali 1996 (Toneladas)

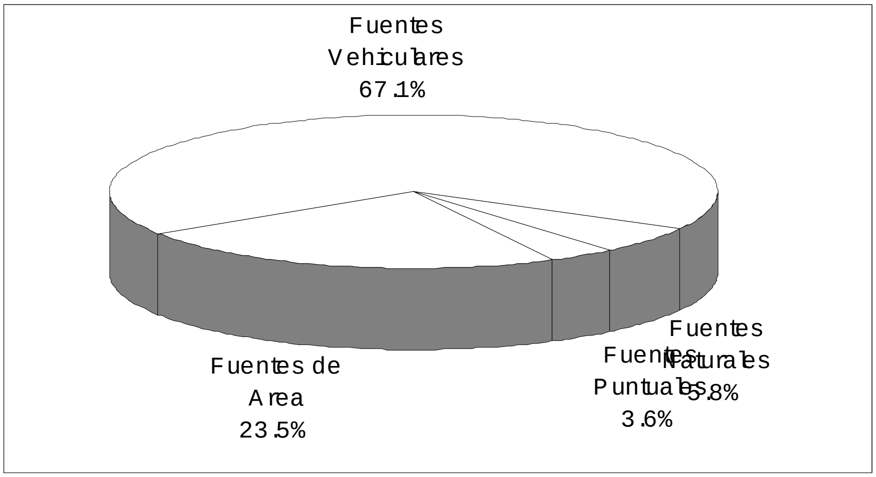
Sector	PM 10	SO_2	CO	NOx	HC	Pb	NH_3	Total
Fuentes Puntuales	1,994	2,849	4,721	1,537	1,407	0.2	3,060	15,568
Fuentes de Area	61,932	11	18,944	735	15,379	NE	4,749	101,750
Fuentes Vehiculares	515	937	243,073	14,927	31,184	2	NA	290,638
Fuentes Naturales	20,548	NE	NE	1,348	3,441	NA	NE	25,337
Total	**84,989**	**3,797**	**266,738**	**18,547**	**51,411**	**2**	**7,809**	**433,293**

NA: No Aplica NE: No Estimado

Figura 4.1 Emisiones por Contaminante y Tipo de Fuente 1996 (Toneladas)

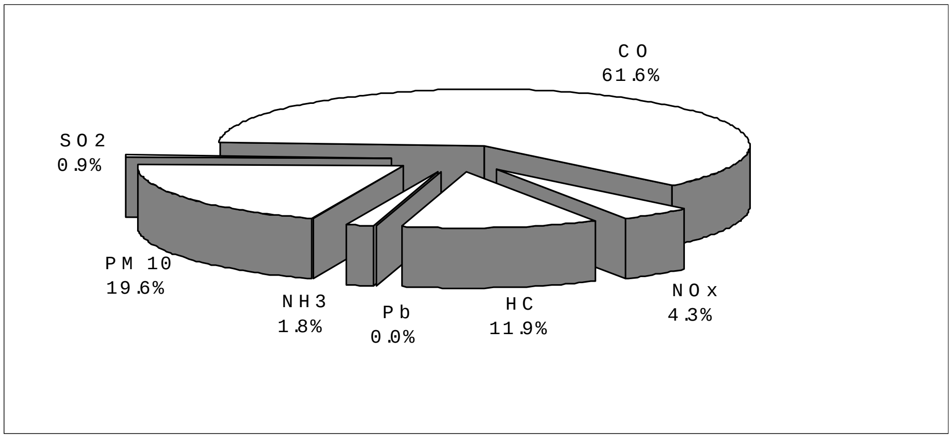
En la Tabla 4.1 y Figuras 4.1, 4.2 y 4.3, se puede apreciar que en tres tipos de fuentes y 3 contaminantes se concentra el grueso de las emisiones generadas en Mexicali, con predominancia del monóxido de carbono emitido por los vehículos automotrices que representa mas de la mitad del total de todas las emisiones. Le sigue en importancia la emisión de partículas de fuentes de área cuyo origen principal son las partículas emitidas por los vehículos en calles pavimentadas y no pavimentadas. En tercer lugar se encuentran los hidrocarburos provenientes del transporte.

Figura 4.2 Emisión por tipo de fuente (Porcentaje)



Por tipo de fuente los vehículos automotrices emiten el 67.1% de la emisión total, el segundo lugar lo acupan las fuentes de área con el 23.5%, el tercero las fuentes naturales con el 5.8% y en último lugar con el 3.6% las fuentes puntuales. Como lo muestra la figura 4.2.

Figura 4.3 Emisión por contaminante (Porcentaje)

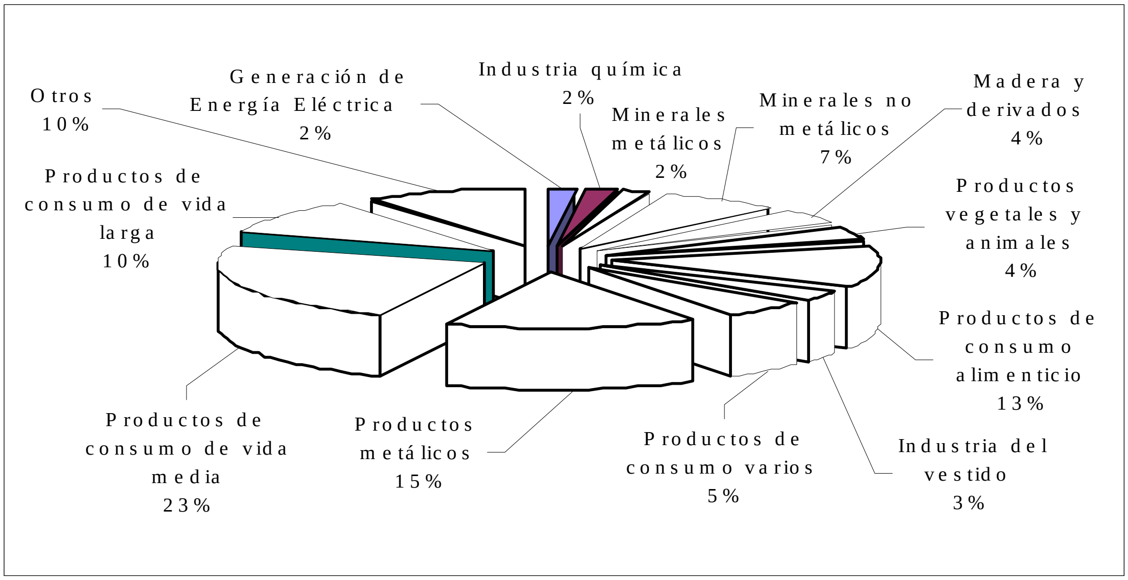


En los siguientes incisos se describe el comportamiento por cada uno de los tipos de fuentes, desglosando las emisiones por categorías y cada uno de los contaminantes criterio, así como de plomo y amoniaco definidos desde el Plan de Trabajo para ser considerados en las estimaciones de Mexicali.

4.1 Fuentes puntuales

Referente a la contribución de emisiones a la atmósfera la industria mediana y grande es la que más aportan en este sector; de estas industrias se obtuvo información referente a su operación en 1996 de 112 establecimientos de la Cédula de Operación Anual y los informes anuales a la DGE, clasificándose en 13 giros, de los cuales el de Productos de consumo de vida media agrupa al 23% de los establecimientos, seguido por el de Productos metálicos con el 15%, el de Productos de consumo alimenticio con el 13%, el de Productos de consumo de vida larga con el 10%, Otros con el 10%, el de Minerales no metálicos con el 7% y el 22% lo constituyen los restantes giros, tal y como se muestra en la Figura 4.1.1.

Tabla 4.1.1 Distribución de Fuentes Puntuales de Mexicali en 1996



De las 112 industrias incluidas en la base de datos del inventario, 36 corresponden a la jurisdicción de la federación con mayor presencia en los giros de generación de energía eléctrica, alimentos, minerales metálicos, minerales no metálicos, productos de consumo de vida larga – del ramo automotriz, principalmente -, plantas distribuidoras de líquidos orgánicos, fertilizantes e insecticidas. De estos 36 establecimientos, 10 son maquiladoras.

Los otros 76 establecimientos reportan sus emisiones a la atmósfera a las autoridades ambientales estatales; el giro más numeroso es Productos de Consumo de Vida Media, específicamente la industria maquiladora electrónica (20 empresas) que producen tableros de circuitos impresos y televisores y sus partes, principalmente; enseguida se encuentra el giro de Productos Metálicos en el cual también predominan por su número las maquiladoras dedicadas al pulido, ensamble y recubrimiento de artículos metálicos diversos.

Las empresas no maquiladoras de jurisdicción estatal -26 industrias- se encuentran principalmente en los giros relacionados con alimentos, materiales para construcción y empaques.

4.1.1 Comportamiento por contaminante

Con base en los cálculos realizados, se tiene que el total de emisiones de fuentes puntuales en Mexicali es de 15,568 ton/año, de esas las emisiones de monóxido de carbono son mayoritarias, también se puede observar una contribución importante de bióxidos de azufre y amoniaco, tal y como se muestra en la siguiente tabla.

Tabla 4.1.1.1 Emisión total por contaminante de fuentes puntuales en 1996

Contaminante	Emisiones Totales (ton/año)	Emisiones Totales (porcentaje)
PM 10	1,994	13%
SO_2	2,849	18%
CO	4,721	30%
NOx	1,537	10%
HC	1,407	9%
Pb	0.2	NS
NH_3	3,060	20%
Total	**15,568**	**100%**

Es adecuado señalar que en el informe de fuentes puntuales no se incluyó el amoniaco, pues no es contaminante criterio y usualmente no se incorpora en los inventarios de INE. Las cantidades registradas de este se refieren, principalmente, a las emisiones de vapor endógeno para generar energía eléctrica en Cerro Prieto y emisiones fugitivas de los sistemas de congelación de las empresas de alimentos y bebidas.

4.1.2 Comportamiento por giro

Como se puede apreciar enseguida, los giros minerales metálicos y minerales no metálicos son los que más liberan contaminantes al aire en la ciudad de Mexicali, estos dos giros emiten 9,605 toneladas anuales, lo que representa el 62% del total de emisiones del sector industrial.

Tabla 4.1.2.1 Emisiones por giro industrial en 1996 (toneladas)

Giro	# Est.	PM 10	SO_2	CO	NOx	HC	Pb	NH_3	Total
Generación de energía eléctrica	2	18	83	134	595	17	NA	3,037	3,884
Industria química	2	NS	NS	NS	1	NS	NE	NE	1
Minerales metálicos	2	105	857	4,486	153	1	NS	NE	5,602
Minerales no metálicos	8	1,669	952	59	590	733	NS	NE	4,003
Madera y derivados	5	1	12	2	8	NS	NE	NE	23
Productos vegetales y animales	4	83	652	11	89	71	NS	12	918
Productos de consumo alimenticio	14	45	18	7	34	1	NS	11	116
Industria del vestido	3	NS	NS	NS	NS	2	NA	NE	2
Productos de consumo varios	6	15	270	2	34	167	NS	NE	488
Productos metálicos	17	34	NS	2	8	124	NS	NE	168
Productos de consumo de vida media	27	2	NS	3	4	95	0.2	NE	104
Productos de consumo de vida larga	11	22	5	15	20	138	NE	NE	200
Otros	11	NS	NS	NS	1	58	NS	NE	59
Total	112	1,994	2,849	4,721	1,537	1,407	0.2	3,060	15,568

Fuente: Base de datos de fuentes puntuales

En lo que respecta a plomo, las emisiones registradas son producto de las operaciones de soldadura en las empresas del ramo electrónico, con muy baja participación dentro de las emisiones totales, tanto por tipo de fuente como por cantaminante. Una fuente adicional de plomo en el sector industrial lo constituyen las emisiones de combustión de combustóleo, sin embargo estas son poco significativas.

Tabla 4.1.3 Emisiones por giro industrial en 1996 (porcentaje)

Giro	# Est.	PM 10	SO_2	CO	NOx	HC	Pb	NH_3	Total
Generación de energía eléctrica	2	0.90%	2.91%	2.84%	38.71%	1.21%	NA	99.25%	24.95%
Industria química	2	NS	NS	NS	0.07%	NS	NE	NE	0.01%
Minerales metálicos	2	5.27%	30.08%	95.02%	9.95%	0.07%	NS	NE	35.98%
Minerales no metálicos	8	83.70%	33.42%	1.25%	38.39%	52.10%	NS	NE	25.71%
Madera y derivados	5	0.05%	0.42%	0.04%	0.52%	NS	NS	NE	0.15%
Productos vegetales y animales	4	4.16%	22.89%	0.23%	5.79%	5.05%	NS	0.39%	5.90%
Productos de consumo alimenticio	14	2.26%	0.63%	0.15%	2.21%	0.07%	NS	0.36%	0.75%
Industria del vestido	3	NS	NS	NS	NS	0.14%	NA	NE	0.01%
Productos de consumo varios	6	0.75%	9.48%	0.04%	2.21%	11.87%	NS	NE	3.13%
Productos metálicos	17	1.71%	NS	0.04%	0.52%	8.81%	NS	NE	1.08%
Productos de consumo de vida media	27	0.10%	NS	0.06%	0.26%	6.75%	100.00%	NE	0.67%
Productos de consumo de vida larga	11	1.10%	0.18%	0.32%	1.30%	9.81%	NE	NE	1.28%
Otros	11	NS	NS	NS	0.07%	4.12%	NS	NE	0.38%
Total	112	100.00%	100.00%	100.00%	100.00%	100.00%	100%	100.00%	100.00%

Fuente: Base de datos de fuentes puntuales

En la anterior distribución se observa que del aporte total de emisiones generadas por el sector industrial, los giros de mayor contribución en contaminantes son minerales metálicos, minerales no metálicos, generación de energía eléctrica, productos vegetales y animales, y productos de consumo varios los cuales contribuyen con el 36%, 26%, 25%, 6%, 4% y 3% a las emisiones, respectivamente.

4.2 Fuentes de área

Las fuentes de área evaluadas en Mexicali, emitieron en total de 101,750 toneladas durante 1996, que corresponden a 61,932 toneladas de Partículas PM-10, 11 toneladas de SO$_2$, 18,944 toneladas de CO, 735 toneladas de NOx, 15,379 toneladas de hidrocarburos y 4,749 toneladas de amoniaco, cuyo desglose por categoría se anota en la tabla siguiente.

Tabla 4.2.1 Resumen de emisiones por categoría y contaminante (Toneladas)

Tipo de Fuente/Categoría	**PM 10**	**SO$_2$**	**CO**	**NOx**	**HC**	**NH$_3$**	**Total**
Fuentes de Combustión							
Combustión comercial, industrial ligera y de servicios	1	NS	3	24	1	NA	29
Combustión residencial	4	6	79	121	8	NA	218
Fuentes Móviles no Carreteras							
Locomotoras	6	NE	34	237	14	NA	291
Aeronaves	NE	NS	111	6	12	NA	129
Otros equipos	45	NE	398	246	61	NA	750
Cruces fronterizos	NS	NE	2,606	19	294	NA	2,919
Terminales de autobuses	2	NE	904	48	133	NA	1,087
Fuentes Evaporativas							
Recubrimiento industrial	NA	NA	NA	NA	254	NA	254
Pintado de carrocerías	NE	NA	NA	NA	458	NA	458
Recubrimiento de superficies arquitectónicas	NE	NA	NA	NA	1,141	NA	1,141
Pintura de tránsito	NE	NA	NA	NA	22	NA	22
Limpieza de superficies en industria (desengrasado)	NA	NA	NA	NA	1,718	NA	1,718
Lavado en seco (tintorerías)	NA	NA	NA	NA	327	NA	327
Artes gráficas	NA	NA	NA	NA	322	NA	322
Aplicación de asfalto	NA	NA	NA	NA	1,568	NA	1,568
Uso comercial y doméstico de solventes	NA	NA	NA	NA	2,292	NA	2,292
Comercialización y distribución de combustibles	NA	NA	NA	NA	1,596	NA	1,596
Carga de combustible en aeronaves	NA	NA	NA	NA	NS	NA	-
Distribución de gas L. P.	NA	NA	NA	NA	2,260	NA	2,260
Fuentes Industriales Ligeras o Comerciales							
Panaderías	NA	NA	NA	NA	76	NA	76
Asados al carbón	228	NA	NE	NE	28	NA	256
Ladrilleras	NE	NE	NE	NE	NE	NE	-
Agricultura							
Aplicación de plaguicidas	NA	NA	NA	NA	587	NA	587
Corrales de engorda de ganado	1,180	NA	NA	NA	NA	NA	1,180
Quemas agrícolas	2,143	NA	14,325	NE	1,949	NA	18,417
Aplicación de fertilizantes	NA	NA	NA	NA	NA	2,745	2,745
Desechos de animales	NA	NA	NA	NA	NA	1,554	1,554
Labranza agrícola	1,283	NA	NA	NA	NA	NA	1,283
Manejo de residuos							
Manejo de residuos (quema a cielo abierto)	88	5	460	33	164	NA	750
Tratamiento de aguas residuales	NA	NA	NA	NA	92	NA	92
Fuentes de Area Misceláneas							
Incendios en construcciones	2	NE	24	1	2	NA	29
Partículas de caminos pavimentados	3,261	NA	NA	NA	NA	NA	3,261
Partículas de caminos no pavimentados	53,689	NA	NA	NA	NA	NA	53,689
Emisiones domésticas de amoniaco	NA	NA	NA	NA	NA	450	450
Suma	**61,932**	**11**	**18,944**	**735**	**15,379**	**4,749**	**101,750**

4.2.1 Fuentes de combustión

Esta categoría incluye las emisiones de aquellos equipos pequeños como son calderas, de calefacción, estufas, calentadores de agua, etc. Los combustibles considerados para esta categoría incluyen combustibles fósiles líquidos o gaseosos, así como biomasa o combustibles derivados de residuos de madera.

El combustible más utilizado es el gas L. P. calculándose el consumo residencial en 36,829.3 toneladas y 7,325 toneladas en las otras actividades – tortillerías, panaderías, hoteles, restaurantes, etc. - cuyo valor se estimó disminuyendo al consumo total municipal el consumo reportado en fuentes puntuales y el consumo residencial en otras áreas del municipio no consideradas para el inventario.

4.2.1.1 Combustión comercial, industrial y de servicios

Se considera dentro de esta subcategoría a todos aquellos establecimientos relacionados con actividades comerciales como pueden ser; hoteles, restaurantes, escuelas, hospitales, edificios gubernamentales, tortillerías, panaderías,etc.

Conforme a la tabla siguiente, se muestran las emisiones calculadas mediante la aplicación de factores de AP-42 por contaminante para la combustión comercial, industrial ligera y de servicios.

Tabla 4.2.1.2 Emisiones de combustión comercial, industrial y de servicios

PM10	SO_2	CO	NO_x	HC
1	NS	3	24	1

Toneladas anuales

4.2.1.2 Combustión residencial

Se considera dentro de esta subcategoría la quema de combustibles en los hogares, tanto de gas L. P. como fuente principal, como de madera y keroseno.

Para obtener las emisiones se distribuyó la cantidad de población conforme a los porcentajes de consumo por tipo de combustible y se le aplicaron los factores de emisión para cada uno de ellos. De las estadísticas de ventas de gas L. P. se estimó un consumo promedio de 67.5 kg/persona/año, que se tomó como base para calcular también la cantidad de leña y otros combustibles (calculado como keroseno), asumiendo que se requiere la misma cantidad de energía – 728,325 kcal/persona/año - de cualquier combustible a nivel doméstico.

Conforme a la tabla siguiente, se muestran las emisiones calculadas mediante la aplicación de factores de AP-42 por contaminante para la combustión residencial.

Tabla 4.2.1.2 Emisiones de combustión residencial en 1996

Combustible utilizado y % de población	Población consumidora	Uso Anual (kg/persona)	Consumo Total Anual (Toneladas)	Contaminantes	Factor de Emisión (g/kg)	Emisión Anual (toneladas)
Leña o carbón (0.89%)	4,857	272	1,321.1	CO	47.3	62.5
				HC	2.9	3.8
				NOx	1.6	2.1
Gas L. P. (97.81%)	533,802	67.5	56,281.6	CO	0.44	15.9
				HC	0.12	4.3
				NOx	3.23	116.4
				SOx	8.00E-05	0.0
				PM	0.1	3.6
Otro combustible (1.30%)	7,095	111	787.5	CO	0.71	0.6
				HC	0.36	0.3
				NOx	2.56	2.0
				SOx	8.07	6.4
				PM	0.46	0.4
Suma	545,754			**CO**		**79**
				HC		**8**
				NOx		**121**
				SOx		**6**
				PM		**4**

Elaborado con factores de las Tablas 1.3-1, 1.3-2 y 1.5-1 de AP-42 y datos del Conteo de Población y Vivienda 1995.

4.2.2 Fuentes móviles no carreteras

Esta categoría se incluye en el inventario de emisiones de fuentes de área, debido a que en la estimación de emisiones se emplean metodologías específicas para cada caso. Las subcategorías que se incluyen son: Locomotoras, aeronaves, Otro equipo móvil que no circula por carretera (incluyendo equipo recreativo, de construcción, industrial, de jardinería, agrícola, comercial ligero y de servicio de aeropuertos), cruces fronterizos, Terminales de autobuses y camiones. Estas dos últimas subcategorías se refieren a vehículos automotrices, pero las emisiones que generan durante las estancias en un punto sin moverse y con el motor encendido, se consideran fuentes de área.

Los tipos de fuentes móviles no carreteras que existen en Mexicali son las siguientes: aeronaves y equipo aeroportuario de apoyo, locomotoras de patio y foráneas, equipo de construcción, equipo agrícola y equipo de jardinería, los vehículos de tipo recreativo se consideran no significativos. Cabe aclarar que el **SO_2** no se anota debido a que se consideró en forma global en fuentes móviles al calcularse esa emisión por balance de materia, a partir de las ventas globales de combustibles.

Los cruces fronterizos son una fuente importante de emisiones por el alto número de vehículos que se acumulan para cruzar la frontera de Mexicali a Calexico; la Central de Autobuses de Mexicali es otro punto de tomarse en cuenta pues las corridas de los autobuses foráneos llegan allí por su localización intermedia entre Tijuana y el resto del país, además de las corridas normales que dan servicio regional y nacional desde y hacia Mexicali; como parte también de esta categoría, los autobuses urbanos tienen la característica de terminar las rutas en el centro de la ciudad creando aglomeraciones continuas en los paraderos situados en una pequeña área de esa zona.

4.2.2.1 Locomotoras

Los ferrocarriles tienen dos tipos de operación: de arrastre (foránea) y de patio (o cambio) que hacen su recorrido dentro de un área delimitada.

Las locomotoras de arrastre generalmente viajan entre localidades distantes, desde una ciudad a otra (incluyendo el servicio de carga intermodal, el servicio de carga mixto y el transporte de pasajeros), Mexicali se conecta con el resto del país a través de la línea que va a Benjamín Hill, Sonora; y, hacia Estados Uidos de Norteamérica cruzando por el centro de la ciudad la línea internacional. Actualmente el movimiento del ferrocarril es por carga, pues durante 1996 se dejó de prestar el servicio de pasajeros. El tipo de locomotoras diesel-eléctricas utilizan un motor de diesel, y un alternador o generador para producir la electricidad requerida para alimentar los motores de tracción, de ahí que los contaminantes se produzcan por combustión del diesel. Este equipo es el que transita por las vías de Mexicali.

Se determinó que para Mexicali se tiene una longitud de vías férreas equivalente a 86 km, y, de acuerdo a la estimación que se hizo respecto al total nacional, el consumo de diesel es de 2’743,991 litros al año.

En el área de Mexicali se tienen únicamente 4 locomotoras de patio que dan el servicio de entrega y recepción de carga a las empresas que se encuentran establecidas en las cercanías de la vía principal y cuentan con espuelas de acceso a sus instalaciones. Los principales productos manejados son: chatarra, aceites comestibles, cemento, gas, fertilizantes y semillas.

El movimiento de las máquinas generan 291 ton/año de emisiones, como se muestra en la tabla siguiente:

Tabla 4.2.2.1 Emisiones de Locomotoras

PM 10	SO_2	CO	NOx	HC
6	NE	34	237	14

Toneladas Anuales

4.2.2.2 Aeronaves

En esta categoría se incluyen naves con alas fijas, desde el motor individual más pequeño hasta las aeronaves comerciales de mayor tamaño.

El número de operaciones de aterrizajes y de despegues durante 1996 en el Aeropuerto Internacional de Mexicali es de 6,243 vuelos de acuerdo a información proporcionada por la Administración de dicho aeropuerto.

El mayor número de operaciones, además de los vuelos comerciales diarios, corresponde a la aviación general en la que predominan aviones pequeños de 2 a 4 plazas, con poca afluencia de jets de negocios y aviones más grandes.

Para estimar las emisiones generadas por el aterrizaje y despegue de las aeronaves, se utilizó el modelo para computadora personal FAAED, el cual calcula los contaminantes emitidos a partir de la cantidad de ciclos de llegada y salida por cada tipo de avión. Los resultados que se obtuvieron son los siguientes:

Tabla 4.2.2.2 Emisiones de aeronaves

CO	NOx	HC
111	6	12

Toneladas anuales

4.2.2.3 Otros equipos

En Mexicali los equipos mayormente utilizados son los de jardín, de construcción e industriales y en la zona del valle los de tipo agrícola. La estimación de liberación de contaminantes de tales equipos se anota en la tabla siguiente:

Tabla 4.2.2.3 Emisiones de equipos móviles no carreteros

PM 10	SO_2	CO	NO_x	HC
45	NE	398	246	61

Toneladas Anuales

4.2.2.4 Cruces fronterizos

En Mexicali se tienen dos Garitas Internacionales: La Garita Internacional ubicada en el centro de Mexicali y la nueva Garita por la cual pasa la totalidad de transporte de carga desde finales de 1996, está ubicada en la parte Noreste de la ciudad. Los vehículos (tanto mexicanos como estadounidenses) a menudo se forman por largos periodos de tiempo (hasta de 1 hora), mientras esperan ingresar a EU y pasar las inspecciones aduanales. Los vehículos en la fila normalmente no apagan sus motores, sino que los mantienen encendidos mientras avanzan lentamente, estimándose en aproximadamente 7 millones al año. Esta categoría de emisiones también es aplicable a los vehículos que entran a México (si bien el tiempo de espera al parecer es menor, comparado con los vehículos que esperan entrar en EU).

La emisiones fueron calculadas utilizando el modelo Mobile5 Juárez, haciendo una corrida para cada mes, a una velocidad de 4 km/hr y un tiempo de espera promedio de 15 minutos, estimándose sus emisiones en 2,919 toneladas al año distribuidas conforme a la siguiente tabla.

Tabla 4.2.2.4 Emisiones vehiculares en cruces fronterizos

Categoría	Emisión Total			
	PM 10	CO	NOx	HC
Autos Particulares	NS	2,085	15	234
Pick Ups	NS	516	4	59
Motocicletas	NS	4	ns	1
Total	NS	2,606	19	294

Toneladas Anuales NS: No Significativo

4.2.2.5 Terminales de autobuses

Se consideraron las emisiones generadas por terminales de autobuses y camiones. En Mexicali se tienen 2 fuentes emisoras: La Central de Autobuses de Mexicali y las terminales de los autobuses urbanos en el centro de la ciudad. Respecto a la Central de Autobuses de Mexicali durante 1996, se desplazaron 835,262 personas, con un número de corridas o viajes de 90,445 en autobuses foráneos.

En el centro de la ciudad confluyen todas la rutas de autobuses urbanos, permaneciendo en los paraderos o haciendo fila en la calle, en espera de subir y bajar pasaje, regularmente con el motor encendido; lo mismo sucede en las terminales de inicio de ruta.

Las emisiones de ambas subcategorías se obtuvieron mediante corridas del Mobile 5 Juárez con el tiempo de espera correspondiente y una velocidad de 4 km/hr, cuyos resultados se presentan en la siguiente tabla:

Tabla 4.2.2.6 Emisiones en terminales de autobuses

Subcategoría	**Emisión Total (toneladas)**			
	PM10	**CO**	**NOx**	**HC**
Central de Autobuses	NS	3	2	1
Autobus urbano a diesel	2	45	37	8
Autobus urbano a gasolina	NS	856	9	124
Total	2	904	48	133

Toneladas Anuales NS: No Significativo.

4.2.3 Fuentes evaporativas

Se refiere a todas aquellas actividades que generan emisiones fugitivas de hidrocarburos debidas a la utilización de materiales que tienen en su composición solventes orgánicos.

4.2.3.1 Recubrimiento industrial de superficies

En esta subcategoría se consideran la operaciones de aplicación de recubrimientos como pintura, laca, barniz u otro recubimiento, conteniendo solvente, a superficies diversas con fines decorativos o de protección. Estos procesos incluyen diferentes etapas en su uso y aplicación para una amplia gama de productos como muebles, automóviles, maquinaria, madera, artículos y accesorios diversos, así como también el mantenimiento de maquinaria y equipo industrial.

De la emisión total se disminuyeron 444 toneladas de HC calculadas en fuentes puntuales.

4.2.3.2 Pintado de carrocerías

En esta actividad se consideran las emisiones que se generan por pequeñas arreglos de autos, las cuales pueden incluir pintado, reparación y restauración de carrocerías de automóviles, camiones ligeros y otros vehículos. Es importante señalar que el recubrimiento de vehículos nuevos no está incluida en esta categoría de fuente; debido a que se le debe considerar en el inventario de fuentes puntuales.

4.2.3.3 Recubrimiento de superficies arquitectónicas

Se refiere a la aplicación de recubrimientos tales como pintura, barniz o laca y el uso de solventes como adelgazantes y limpiadores a las superficies arquitectónicas de casas y edificios en general.

4.2.3.4 Pintura de tránsito

Se refiere al mantenimiento y reparación que se les da a los carriles, banquetas, marcas de dirección, señales de tránsito, superficies pavimentadas y no pavimentadas para facilitar el tráfico de vehículos, tanto en obras nuevas como las ya establecidas.

4.2.3.5 Limpieza de superficies (desengrasado)

Las operaciones de limpieza de superficies involucran el uso de solventes líquidos o vapores de solventes, para eliminar contaminantes insolubles en agua tales como grasa, aceite, ceras, depósitos de carbón, óxidos y alquitranes de superficies tales como metales, plásticos, vidrios y otros. Este proceso se lleva a cabo en una gran variedad de operaciones de manufactura, científicas y de reparación. Las operaciones de limpieza con solventes implican el uso de sustancias diversas, así como de distintos procedimientos de limpieza.

A la emisión total estimada con el factor de 3.27 kg/persona/año de AP-42, se le restaron 67 toneladas reportadas por las industrias para el inventario de fuentes puntuales.

4.2.3.6 Lavado en seco (limpiadurías o tintorerías)

El lavado en seco es un servicio para la limpieza de ropa, cortinas, artículos de cuero y otros productos de tela. En sus operaciones se utilizan solventes orgánicos halogenados o destilados de petróleo. El tamaño de los establecimientos de lavado en seco en Mexicali es desde plantas industriales medianas a pequeñas, por lo que todas se incluyen como fuente de área, cuya actividad se incrementa o disminuye conforme la época fría o caliente del año.

4.2.3.7 Artes gráficas

Las artes gráficas incluyen las operaciones que están relacionadas con la impresión de periódicos, revistas, libros y otros materiales impresos. Las emisiones que se generan dependen de la composición de las tintas de impresión la cual es muy variable, pero todas constan de tres componentes principales: pigmentos, aglutinantes y solventes. Los solventes se evaporan de las tintas hacia la atmósfera durante el proceso de secado. Predominan en esta ciudad los establecimientos pequeños, aunque se incluyen las editoras de periódicos.

4.2.3.8 Uso comercial y doméstico de solventes

Debido a los ingredientes de los productos comerciales y de consumo que sirven como agentes para el secado (a través de la evaporación), además durante el uso del producto se emiten co-solventes y agentes limpiadores.

Las emisiones de las categorías anteriores se calcularon utilizando factores per cápita, estimándose así que en Mexicali se emiten 5,440 toneladas al año de COV´s, por el uso de solventes en sus diversas modalidades, tal como se describe en la Tabla siguiente:

Tabla 4.2.3.1 Emisiones de fuentes evaporativas

Categoría	**toneladas anuales**
Recubrimiento Industrial de Superficies	254
Pintado de Carrocerías	458
Recubrimiento de Superficies Arquitectónicas	1,141
Pintura de Tránsito	22
Limpieza de Superficies	1,718
Limpieza en Seco	327
Artes Graficas	322
Aplicación de asfalto	1,568
Uso Comercial y doméstico de Solventes	2,292
TOTAL	**5,446**

4.2.3.9 Aplicación de asfalto

Las superficies y pavimentos de asfalto están compuestos por un agregado compactado y un adhesivo de asfalto. El agregado transmite la carga desde la superficie hacia la base, absorbe el desgaste abrasivo del tráfico y proporciona una superficie antiderrapante. El adhesivo mantiene al agregado unido y evita los movimientos o pérdida de éste. Esta categoría de fuente maneja las emisiones de hidrocarburos de la evaporación de estos adhesivos.

En cuanto a la aplicación de asfaltos se tiene un consumo anual de 8,000 m^3 caracterizado como de curado medio con una pérdida promedio del 20% del peso aplicado, resultando una emisión de 2,240 toneladas de VOC’s.

4.2.3.10 Comercialización y Distribución de productos del petróleo

Por lo general, los diversos puntos de emisión asociados con el almacenamiento y transporte de productos de petróleo se consideran demasiado numerosos para ser incluidos en el inventario de fuentes puntuales en una región de inventario determinada. Por lo tanto estas pequeñas fuentes de evaporación necesitan ser incluidas en un inventario de fuentes de área. Dentro de esta categoría se identifican tres actividades:

Distribución de gasolina (incluye a las pipas de gasolina en tránsito, la descarga de pipas, la respiración de los tanques subterráneos, la carga de los vehículos y derrames durante la carga); carga de combustible en aeronaves y distribución de gas licuado de petróleo.

Es importante señalar que las emisiones generadas por almacenamiento de diesel y gasolina de la planta distribuidora de PEMEX se consideraron en el inventario de fuentes puntuales.

Distribución de gasolina

Para la distribución de gasolina en Mexicali, se transporta en pipas y poliducto desde la terminal de Rosarito hasta la terminal ubicada al poniente de la ciudad y de esta a las estaciones de servicio en pipas; por lo que se producen emisiones evaporativas que se presentan en todos los puntos del proceso de distribución de gasolina. Las operaciones consideradas como fuentes de área son las estaciones expendedoras de gasolina (estaciones de servicio o gasolinerías) y las pipas distribuidoras de gasolina en tránsito.

De acuerdo a la información de la tabla siguiente, en 1996 se distribuyeron 602,561 m^3 de gasolinas, la cual se distribuye al detalles a los vehículos mediante 130 estaciones de servicio, se estima que se emiten 1,596 ton/año de HC.

Tabla 4.2.3.2 Emisiones por almacenamiento y transporte de productos de petróleo

Combustible	Consumo 1996 (m^3)	Emisiones (Ton/año)
Nova	12,488.80	1,596
Magna	584,137.01	
Premium	3,940.00	
Total gasolina	602,561.81	

4.2.3.11 Carga de combustible en aeronaves

Los dos combustibles utilizados para las aeronaves son la turbosina y el gas avión. Las emisiones ocurren si el aire cargado de vapor en un tanque parcialmente vacío es desplazado a la atmósfera cuando se recarga el tanque. En 1996 se distribuyeron 13,999 m^3 de turbosina y 1,779 m^3 de gas avión los cuales generaron 0.117 toneladas/año de HC.

Tabla 4.2.3.3 Emisiones por carga de combustible a aeronaves

Combustible	Consumo (m^3)	Emisión (ton/año)
Turbosina	13,999	0.104
Gas avión	1,779	0.013

En 1996 las principales aerolíneas que consumieron turbosina fueron Mexicana con el 85%, A.S.A. (Aviación General) con el 8%, Aerolitoral el 3% y otras aerolíneas el 4%. Mientras que para el gas avión la aviación general consumió el 67% y la fumigación agrícola el 33% restante.

4.2.3.12 Distribución de Gas L. P.

Las fugas o la evaporación de los sistemas de almacenamiento y distribución de gas L.P. representan una importante fuente de contaminación cuyas emisiones debe ser consideradas cuando se desarrolla un inventario de emisiones de área. El Instituto Mexicano del Petróleo y algunos investigadores de la Universidad de California han identificado a las fugas de gas L.P. como una fuente potencialmente significativa de emisiones de hidrocarburos. Si bien una parte del gas L.P. es usado por los sectores industriales, comerciales y de servicios, en México el gas L.P. se usa sobre todo a nivel doméstico, tanto para cocinar como para calentar agua. En esta categoría de fuente se estiman las emisiones generadas en toda la distribución de gas L.P.

Al igual que en el resto del país en Mexicali, la distribución y almacenamiento del gas L.P. para uso doméstico se hace principalmente por medio de tanques portátiles de 45 kg que se venden en camiones distribuidores y además existe una pequeña zona de distrubución por tubería subterránea. Los tanques vacíos se recolectan y se llenan en centros especializados de las dos empresas distribuidoras. Otra forma de almacenamiento del gas L.P. doméstico es en tanques estacionarios, cuya capacidades, por lo general de 300 kg., se usan principalmente en los restaurantes y pequeños establecimientos industriales y comerciales. Estos tanques se llenan a domicilio por camiones especiales equipados con mangueras. En Mexicali se cuenta con 2 empresas que en 1996, distribuyeron 62,774.5 toneladas de gas L.P., lo cual generó 2,260 toneladas de HC.

4.2.4 Fuentes industriales ligeras o comerciales

Se clasifican dentro de esta categoría las siguientes: Panaderías; Ladrilleras; Actividades de Construcción; Señales de Tránsito; Asados al carbón y Vendedores Ambulantes.

4.2.4.1 Panaderías

Se considera en las panaderías que la fermentación de la levadura produce emisiones de hidrocarburos, consistentes principalmente de etanol generado durante la fermentación y levantado de la levadura, así como en el horneado. Las emisiones provienen de un proceso biológico y, como es típico en estos procesos, dependen de un gran número de variables como la duración del tiempo de levantado para la levadura, la cantidad de azúcares fermentables en la masa y la temperatura de fermentación. Aplicando un factor per cápita, se estima que la emisión de hidrocarburos por elaboración de pan asciende a 76.4 toneladas durante 1996.

4.2.4.2 Producción de Ladrillos

En esta categoría no fue posible calcular sus emisiones, ya que no existe información sobre la cantidad de producción ni los tipos y cantidades de combustible utilizados, aunque extraoficialmente se estima existen 10 establecimientos asentados en el área sur de la ciudad en la zona conocida como Rivera Campestre y un número no determinado a más de 30 km. al oriente de la ciudad en el Valle de Mexicali.

4.2.4.3 Asados al carbón

La actividad de las carnes asadas se refiere al cocinado de carne, ya sea de res o de pollo, sobre una flama abierta durante la cual la grasa escurre adentro de la flama abierta y al quemarse produce partículas y gases orgánicos.

En Mexicali esta categoría es una de las principales, ya que los establecimentos se distribuyen en toda la ciudad. La comida preparada en estas unidades incluye fundamentalmente carne asada y al pastor para tacos, burritos, pollo asado y otras menos importantes como hamburguesas y “hot dogs”. Los combustibles utilizados son carbón de leña y gas L.P.

El tipo de establecimientos es muy variado, desde vendedores ambulantes con una pequeña parrilla, hasta taquerías fijas con amplias instalaciones y horario de operación las 24 horas, aunque el horario más usual es de las 17:00 a las 23:00 horas.

En la tabla siguiente se muestran las emisiones generadas en este tipo de giros la cual representa 256 toneladas al año.

Tabla 4.2.4.1 Emisiones de asados al carbón

Tipo de carne	Cantidad consumida (ton/año)	Emisiones de PM10 (ton/año)	Emisiones de TOG (ton/año)
Res	6,346	208	24
Pollo	1,991	20	4
Total	8,337	228	28

4.2.5 Agricultura

Esta categoría abarca diferentes subcategorías que han sido características desde el origen de Mexicali, entre las que se pueden mencionar: Aplicación de plaguicidas, Corrales de Engorda de Ganado; Quemas Agrícolas; Aplicación de Fertilizantes; Desechos de Animales y Labranza Agrícola, mismas que se presentan en las zona aledaña a la ciudad, con influencia también, en su parte norte, de emisiones de este tipo generadas del otro lado de la frontera, en el Valle Imperial California.

4.2.5.1 Aplicación de plaguicidas

En los cultivos del Valle de Mexicali se aplican diferentes tipos de plaguicidas y herbicidas para el control de plagas, principalmente insectos, nemátodos y malezas. Según datos proporcionados por la Delegación Estatal de la SAGAR se aplicaron en 1996 un total de 739,492 unidades (kilogramos o litros) de esos productos, tanto en mezclas líquidas o polvos en forma terrestre y aérea.

Las emisiones se estimaron mediante la metodología recomendada en el Manual de Fuentes de Area y los factores de AP-42, en los cuales se considera la presión de vapor del ingrediente activo, el tipo de concentración del producto, el contenido de COV's y la forma de aplicación. El cálculo se hizo a partir de las cantidades recomendadas por producto en cada cultivo de la zona y de las hectáreas cultivadas.

Se obtuvo una emisión total de 587 toneladas, correspondiendo el 23% a los gases del ingrediente activo y el 77% restante a los compuestos orgánicos volátiles presentes como ingrediente inerte.

4.2.5.2 Corrales de engorda de ganado

Los corrales de engorda de ganado son áreas utilizadas para engordar o retener el ganado antes de comercializarlo o transferirlo a otro lugar. Por lo general el proceso de engorda consiste en alimentar al ganado con una ración de alimentos balanceados de alta energía por un periodo de cuatro a cinco meses. Los corrales pueden ser una fuente importante de partículas fugitivas. El principal mecanismo de generación es el movimiento del ganado sobre el polvo del suelo y el estiércol seco. El tránsito vehicular y la acción del viento en la vecindad del corral también pueden contribuir a las emisiones de partículas. De acuerdo a Información proporcionada por la Secretaría de Fomento Agropecuario para el año 1996, se manejaron 98,300 cabezas de ganado lo cual generó 1,180 toneladas de PM_{10}.

4.2.5.3 Quemas Agrícolas

Se considera en esta categoría a las quemas de restos de cultivos en la zona agrícola, con el fin de preparar los campos para dobles cultivos o para el siguiente ciclo agrícola. De acuerdo a información proporcionada por la Delegación Estatal de SAGAR se tiene la siguiente tabla la superficie sujeta a la práctica de quemado.

Tabla 4.2.5.1 Superficie de quemas agrícolas

Cultivo	**Superficie Cultivada (Ha)**
Trigo	53,557
Espárrago	1,757
Zacate Bermuda	1,881
Total	57,195

Con los factores de AP-42, de cantidad de material combustible por hectárea y contaminantes emitidos aplicados al tipo de cultivo, se obtuvieron las emisiones de 18,279 toneladas al año como se consignan en la tabla siguiente:

Tabla 4.2.5.2 Emisiones por quemas agrícolas

PM 10	**CO**	**HC**
2,143	14,325	1,949

Toneladas Anuales

La época de mayor incidencia de emisiones es durante los meses de junio y julio y se debe a la gran superficie que representa el trigo, mientras que el zacate bermuda y el espárrago se queman en invierno.

4.2.5.4 Aplicación de fertilizantes

La aplicación de fertilizantes nitrogenados es muy variada, dependiendo del tipo de cultivo y características del suelo, principalmente. Sus formas de aplicación más usuales son granuladas esparcidas al boleo y líquidas o gaseosas diluidas en el agua de riego o inyectadas al suelo, lo cual produce emisiones de amoníaco (NH_3) a la atmósfera.

Los de mayor consumo son urea granulada con el 31%, 11-52-00 granulado con el 29%, UN32 con el 15% y amoníaco anhidro con el 11%, constituyendo el resto los fertilizantes del tipo N-P-K granulados y líquidos.

Sus emisiones están determinadas por el contenido de nitrógeno, influenciadas por factores como condiciones meteorológicas, características del suelo, técnicas de aplicación; para ello se han desarrollado factores de emisión que van de 12 a 187 kg de NH_3 por tonelada aplicada, basados en los factores mencionados, aunque se siguen investigando por U. S. EPA.

Se aplicaron 115,500 unidades (kilogramos o litros según la presentación) durante 1996, informó la Delegación Estatal de SAGAR - los cuales distribuyeron por fertilizante conforme a las recomendaciones de aplicación por hectárea de cultivo, resultando una emisión total de amoníaco de 2,745 toneladas.

4.2.5.5 Desechos de Animales

El ganado y otros animales domésticos de granja son otra fuente importante de emisiones de amoníaco. Estas emisiones resultan de la conversión del nitrógeno excretado en amoniaco y su subsecuente volatilización. Se piensa que el nitrógeno contenido en la orina del ganado se convierte fácilmente en amoníaco y se emite como tal. En cambio, las emisiones de amoníaco del estiércol por lo general requieren considerable descomposición.

En Mexicali existe una gran cantidad de instalaciones para la crianza y explotación de animales, localizadas alrededor de la ciudad en las zonas suburbanas agrícolas. Las especies que se manejan son principalmente gallina de postura, ganado vacuno, ganado caprino y ganado porcino; el ganado ovino y equino no son significativos.

De acuerdo al Censo Ganadero de 1996 proporcionado por la Secretaría de Fomento Agropecuario del Estado, se aplicaron los factores de emisión en kilogramos de NH_3 por cabeza por año a cada clasificación de animales, obteniéndose una emisión total de 1,554 toneladas, de las cuales el 70% corresponde a ganado vacuno, 12% a caprino, 10% a aves 8% a porcino.

4.2.5.6 Labranza Agrícola

El polvo fugitivo de las operaciones agrícolas puede contribuir de manera significativa a las emisiones de PM_{10} en algunas áreas rurales. Por lo general las operaciones agrícolas se dividen en tres clasificaciones: preparación del suelo, mantenimiento del suelo y cosecha. La categoría de labranza agrícola se enfoca principalmente en la preparación del suelo. Ésta incluye operaciones tales como: arado, rastreo, nivelado, surcado y bordeo, además de la cosecha por medio de la trilla mecanizada.

Con la aplicación de la metodología propuesta en el Manual V y los factores de AP-42 a los cultivos y su respectiva superficie, se obtuvo una emisión de PM_{10} de 1,283 toneladas.

4.2.6 Manejo de residuos

En esta categoría se incluyen las actividades que se refieren al tratamiento, controlado y no controlado de los residuos sólidos y líquidos de las áreas urbanas.

4.2.6.1 Incineración en Sitio

La incineración en sitio es la quema **confinada** de basura y otros desechos lo cual no se da en forma sistemática en la ciudad, por lo que no se realizó ningún cálculo al respecto.

Manejo de Residuos - Quema a Cielo Abierto

En algunas áreas la quema a cielo abierto es el método preferido para eliminar los residuos sólidos.

En Mexicali se recolectaron un promedio de 600 toneladas diarias, según información recabada en el Anuario Estadístico Municipal, la cual es enviada totalmente al relleno sanitario, no se tiene contemplada la incineración, solamente se da la quema clandestina y por incendio de basureros.

Estimaciones de la Oficina Municipal de Ecología indican que la basura quemada en forma clandestina llega al orden del 5%, lo que representa un total anual de 10,950 toneladas anuales, que generaron 750 toneladas de contaminantes al año, como se describe en la siguiente tabla:

Tabla 4.2.6.1 Emisiones por incineración de basura

Descripción	PM 10	SOx	CO	NOx	HC
Factor (kg/ton)	8.0	0.5	42.0	3.0	15.0
Emisión (ton/año)	**88**	**5**	**460**	**33**	**164**

4.2.6.2 Tratamiento de Aguas Residuales

Existen procesos industriales que generan aguas residuales que contienen compuestos orgánicos. Esta agua residuales se recolectan, se someten a un tratamiento de sus contaminantes.

Además de las aguas residuales industriales, las plantas también pueden tratar aguas domésticas, institucionales o comerciales, así como aguas que ingresan al sistema de alcantarillado desde el suelo y desde los escurrimientos pluviales.

Al aplicar la metodología se estimaron las emisiones de las plantas de tratamiento operadas por la CESPM, resultando una emisión de 92 toneladas anuales de hidrocarburos.

4.2.7 Fuentes de área misceláneas

En este apartado se incorporan todos aquellas categorías de fuentes emisoras que no tienen una clasificación específica pero sus emisiones son apreciables y medibles.

4.2.7.1 Incendios de Construcciones

Igual que otras fuentes de combustión, los incendios de construcciones generan emisiones de GOT, CO, NO_x y partículas. Sin embargo, a diferencia de otras fuentes de combustión, estos incendios no son intencionales y en consecuencia la cantidad de combustible quemado puede ser difícil de determinar.

De acuerdo a información disponible de la Dirección de Bomberos y Protección Civil, en 1996 ocurrieron 244 incendios en casas habitación, con emisiones estimadas de 29 toneladas distribuidas por contaminante confrome a la tabla siguiente:

Tabla 4.2.7.1 Emisiones por incendios en construcciones

PM 10	CO	NOx	HC
2	24	1	2

Toneladas anuales

4.2.7.2 Partículas de Caminos Pavimentados

Al circular los vehículos sobre las superficies de caminos pavimentados, el polvo que se ha depositado sobre la superficie pavimentada o que ha sido llevado a ésta, es arrastrado por la estela turbulenta del vehículo y se emite como partículas. En la actualidad, las emisiones se calculan como una función de la carga de sedimentos de la superficie pavimentada y del peso promedio de los vehículos que circulan sobre ella. A su vez, la carga de sedimentos es función del tipo de camino. Por lo general, los caminos con altos volúmenes de tránsito tienen menores cargas de sedimentos que aquellos con bajos volúmenes. El sedimento se define como el material que atraviesa una criba de malla 200 usando el método ASTM-C-136. Para el caso de Mexicali se consideró una carga de 0.32 g/m^2 (desarrollado por CARB para el Valle Imperial aplicable a calles locales) dado que la mayor parte de las zonas pavimentadas están en zonas residenciales. El cálculo efectuado como lo recomienda el Manual V, arroja una cantidad de 3,261 toneladas de PM-10 por efecto del paso de vehículos en este tipo de calles.

4.2.7.3 Partículas de Caminos No Pavimentados

Al igual que en calles pavimentadas, cuando los vehículos circulan sobre las superficies de los caminos sin pavimentar el polvo que contienen es arrastrado por la estela turbulenta del vehículo y es emitido como partículas. En el momento en que los vehículos pasan sobre la superficie la fuerza de las ruedas muele el material del camino en partículas más pequeñas reponiendo así parcialmente el contenido de sedimentos del camino.

Para el caso particular de Mexicali donde más del 40% de las calles no cuentan con carpeta asfáltica, y donde las calles solamente se les dá el paso con la maquinaria, la compactación del camino ha sido mediante el paso por años de los vehículos, y considerando el tipo de suelo existente en la ciudad, el cual es de vertisoles háplicos cuyo contenido de limo en un terreno suelto es del 22 al 26%, en los caminos no pavimentados por ser el limo la partícula más fina y por la presencia de lluvias erráticas y torrenciales estas pequeñas partículas van hacia las capas inferiores del suelo, quedando en la capa superior cantidades que van del 1 al 18% dependiendo del grado de compactación. Para la ciudad se consideró un 11% de limo (valor por omisión del Volumen V), para el caso de la humedad del suelo se consideró un 1.3%, esto de acuerdo a información proporcionada por técnicos de laboratorio de suelos, otra consideración que se hizo para el cálculo de las emisiones fue el peso promedio de los vehículos considerándose 1.9 toneladas, por último se estima que el recorrido de kilómetros acumulados por los vehículos que circulan en estas calles es de más de 175 millones.

Es importante mencionar que para el cálculo de las emisiones se utilizó la fórmula publicada en septiembre de 1998 por la EPA, debido a que esta modifica a la anteriormente publicada en Manual V de inventarios de emisiones de fuentes de área. Esta categoría genera 53,689 toneladas al año de PM-10.

4.2.7.4 Emisiones Domésticas de Amoníaco

Esta categoría consiste de diversas fuentes domésticas de amoníaco (NH_3) incluyendo los desechos de mascotas, la transpiración y la respiración humanas, el uso doméstico de amoníaco, el humo de cigarrillos y los desechos humanos sin tratar. A nivel individual, las emisiones de estas fuentes son relativamente pequeñas. Sin embargo, a nivel colectivo, suelen ser significativas.

Con los factores establecidas en el Manual V de la metodología, se estima una emisión anual de 450 toneladas de amoníaco.

4.3 Fuentes Vehiculares

En Mexicali las emisiones generadas por los vehículos automotores contribuyen significativamente en el deterioro de la calidad del aire, lo cual es producto del consumo de combustibles fósiles por el parque vehicular, cuya cantidad se ha venido incrementando en forma significativa en los últimos años; a su vez es importante mencionar que la conformación del parque vehicular en su gran mayoría esta integrado por vehículos importados de los Estados Unidos de Norteamérica predominando los vehículos antiguos con tecnología carente de dispositivos para el control de la contaminación.

Como parte importante del proyecto del Inventario de Emisiones de Mexicali fue probar la metodología propuesta para México en una ciudad mexicana fronteriza, en la integración del Inventario de Emisiones de Mexicali se realizó el inventario de emisiones generadas por el sector transporte utilizando los métodos recomendados en el Volumen VI -Desarrollo del Inventario de Vehículos Automotores- elaborado por Radian International para el Instituto Nacional de Ecología.

Como parte de las actividades del programa antes de iniciar la integración del inventario de emisiones en esta ciudad, se impartió un curso taller a los integrantes del grupo técnico con el propósito de que todos los integrantes estuvieran familiarizados con la serie de datos que son necesarios para la integración de un inventario de emisiones total y en caso de que su dependencia u organismo posea información, esta sea proporcionada para los fines del proyecto.

El inventario requirió recabar datos locales sobre la composición y características del parque vehicular, las condiciones climatológicas, consumo y características de combustibles, datos de actividad por tipo de vehículo, principalmente.

Para el desarrollo de los factores de emisión se utilizó el modelo MOBILE5-Juárez, el cual calcula los factores de emisión en gramos por kilómetro recorrido para hidrocarburos, monóxido de carbono y óxidos de nitrógeno por cada tipo de vehículo que utilicen como combustible gasolina o diesel, a este modelo se le alimentaron los datos correspondientes a la ciudad de Mexicali para cada uno de los 12 mese del año 1996. Esto se hizo por considerar que la variación de las temperaturas máximas y mínimas tiene gran influencia en la determinación de los factores de emisión y por lo tanto repercute en las emisiones generadas por el sector transporte.

Para el cálculo de las emisiones de óxidos de azufre y plomo generadas en la ciudad de Mexicali se estimaron utilizando el balance de materiales, considerando el consumo y parámetros de calidad de gasolinas y diesel para el año 1996. Para estimar las emisiones de partículas PM_{10} se utilizaron factores recomendados por el Instituto Nacional de Ecología.

En la tabla siguiente se presenta el resumen de las emisiones estimadas para cada tipo de vehículo y para cada contaminante.

Tabla 4.3.1 Emisiones totales de fuentes vehiculares 1996 (toneladas)

Categoría de Vehículo	PM10	SO_2	CO	NOx	HC	Pb	Total
Autos particulares	80	507	143,957	6,283	18,427	1	169,255
Taxis	1	7	2,102	92	269	NS	2,471
Pick-up	34	216	58,828	2,570	7,742	1	69,391
Camiones de pasajeros a gasolina	2	10	4,623	206	454	NS	5,295
Camiones de pasajeros a diesel	22	7	159	248	41	NA	477
Camiones de carga ligera a diesel	5	32	8,694	441	1,289	NA	10,461
Camiones de carga pesada a gasolina	7	47	21,621	962	2,122	NS	24,759
Camiones de carga pesada a diesel	363	107	2,638	4,113	673	NA	7,894
Motocicletas	1	4	451	12	167	NS	635
Total	515	937	243,073	14,927	31,184	2	290,638

Como puede notarse, la mayor fuente de contaminación del aire la constituyen los vehículos, sobresaliendo por su magnitud el monóxido de carbono en primer lugar, los hidrocarburos no quemados y evaporados en segundo término, seguidos por los óxidos de nitrógeno, bióxido de azufre, partículas y plomo, en ese orden. También se concluye del cuadro anterior que los automóviles particulares y pick ups producen más del 80% de esos contaminantes.

4.4 Fuentes Naturales

Dentro de este sector las mayores emisiones son de partículas PM 10 siendo la principal fuente emisora la erosión del suelo por efecto del viento, debido a que esta ciudad se ubica en la zona desértica donde una extensa superficie no cuenta con vegetación y el tipo de suelo que es predominantemente arcilloso favorece el aporte de partículas. Dentro de las zonas identificadas como generadoras se tienen a las áreas agrícolas, los espacios sin cobertura vegetal dentro de la ciudad, caminos sin pavimentar y lotes baldíos.

Por lo que se refiere a las emisiones de compuestos orgánicos volátiles estas provienen principalmente de los cultivos de la región entre los que tenemos el trigo, las hortalizas, el algodonero, el rye gras y la alfalfa, entre otras. El ciclo de cada uno de ellos es variable y es de unos meses medio año, a excepción de la alfalfa y frutales que son un cultivos perennes. También se incluyen las áreas verdes urbanas y la escasa vegetación nativa presente en la región.

Para este inventario se consideraron también las emisiones de óxidos de nitrógeno generadas por dicha vegetación, que sumadas a las anteriores significan el total de contaminantes emitidos por las fuentes biogénicas.

Tabla 4.4.1 Emisiones de fuentes naturales en 1996 (Toneladas)

Tipo de Fuente/Categoría	**PM 10**	**NOx**	**HC**	**Total**
Erosión Eólica				
Calles no pavimentadas y lotes baldíos	12,112	NA	NA	12,112
Cultivos	8,436	NA	NA	8,346
Vegetación				
Areas verdes y cultivos	NA	1,348	3,441	4,789
Suma	**20,548**	**1,348**	**3,441**	**25,337**

En la tabla anterior se resumen las emisiones de fuentes naturales en cada de las categorías estudiadas y para cada tipo de contaminante presente.

4.4.1 Erosión Eólica

Durante los periodos de vientos de alta velocidad, las partículas pequeñas de polvo pueden ser arrastradas por el viento y emitidas a la atmósfera como partículas. Por lo general, estas emisiones se asocian con suelos perturbados, como los campos agrícolas en cultivo o grandes sitios de construcción. Además, las emisiones pueden originarse en terrenos baldíos, en cunetas que contienen tierra suelta y en caminos sin pavimentar. Los suelos naturales que no han sido perturbados se consideran fuentes no significativas de polvo movido por el viento.

4.4.1.1 Erosión en calles sin pavimentar y lotes baldíos

Se considera en este apartado un área de 797 hectáreas de calles sin pavimentar y 1,980 hectáreas de lotes baldíos, según información de la Dirección de Catastro, Control Urbano y Ecología, sujeta a los efectos del viento.

Para calcular las emisiones se utilizó la fórmula 11.50-1 del Volumen V de la metodología, con un factor climático “C” de 3.5 aplicado por CARB en el Valle Imperial, resultando una emisión de 12,112 toneladas de PM 10 anuales.

4.4.1.2 Erosión en cultivos

Para el cálculo de emisiones generadas por el viento en los cultivos se tomaron en cuenta los cuatro cultivos preponderantes – algodón, alfalfa, rye grass y trigo - en un radio equivalente a la distancia de la ciudad al aeropuerto y sus superficies respectivas, que totalizaron 47,500 hectáreas.

El método para estimar las emisiones es el recomendado en la metodología, incorporando los datos locales del clima y suelos, calculándose de esta forma una emisión de 8,436 toneladas de PM10 anuales.

4.4.2 Vegetación

Para el cálculo de las emisiones para este sector se consideraron los diferentes cultivos de la zona, la vegetación urbana y natural, estimándose emisiones de compuestos orgánicos volátiles y óxidos de nitrógeno utilizando el modelo PCBeis ajustado para las condiciones de vegetación y clima de Mexicali. Las emisiones fueron de 1,348 toneladas de NOx y 3,441 toneladas de hidrocarburos, haciendo un total de 4,789 toneladas al año.

5 Proyecciones

Con la finalidad de darle una perspectiva en el tiempo al inventario, se desarrollaron proyecciones al año 2005 por tipo de fuente y categorías, como fue previsto desde el Plan de Trabajo, para los mismos contaminantes evaluados, excepto el plomo cuya fuente principal es la gasolina Nova ya descontinuada para usarse en Mexicali y las emisiones de este contaminante por otras fuentes son muy poco significativas.

Las premisas básicas para la proyección son el crecimiento poblacional y el crecimiento industrial de donde se derivaron el incremento del parque vehicular y de otras categorías. Con las tasas de crecimiento se actualizaron las tasas de actividad para cada fuente o categoría a las que se les aplicaron los factores de emisión y de esa manera obtener la emisión proyectada de emisiones.

5.1 Generalidades

Conforme a los datos del Consejo Estatal de Población[13], Mexicali tiene una tasa actual de crecimiento anual del 2.6%, con el cual se obtiene una población proyectada de 1996 a 2005 de 687,580 habitantes, equivalentes al 26% respecto a 1996, para la zona urbana y localidades cercanas consideradas dentro del área de estudio.

Con datos publicados por la Secretaría de Desarrollo Económico[14] se estimó para 2005 un incremento global del empleo del 87.5%, con tendencia a la baja en la participación porcentual de la industria en este indicador, de donde se asume un incremento industrial promedio del 80% de 1996 a 2005, con predominancia de la industria maquiladora.

El porcentaje proyectado de incremento mencionado, se asume en virtud de no encontrarse proyecciones directas sobre indicadores industriales y de servicios al año 2005, de ahí que se tomaran las tendencias globales de crecimiento en la elaboración de los cálculos para la proyección de emisiones a la atmósfera de las diferentes fuentes consideradas.

De acuerdo a las emisiones proyectadas, presentadas por fuente y categoría en los incisos siguientes, se tendrá una disminución del – 6.3% global de 1996 a 2005, influido a la baja por fuentes vehiculares con –14.4% debido al cambio paulatino a modelos de automóvil más nuevos, por el –3.3% de fuentes naturales y por el –1.9% de fuentes puntuales; mientras que a la alza influyó el aumento de 15.3% en fuentes de área por el incremento poblacional que afecta prácticamente todas las categorías de esta clasificación. Esto se puede constatar en la Tabla 5.1.1 siguiente.

Tabla 5.1.1 Comparativo de Emisiones 1996-2005 por Tipo de Fuente

Sector	Emisión Estimada 1996 (Toneladas)	Emisión Proyectada 2005 (Toneladas)	Diferencia (%)
Fuentes Puntuales	15,568	15,278	- 1.9
Fuentes de Area	101,750	117,347	15.3
Fuentes Vehiculares	290,638	248,678	- 14.4
Fuentes Naturales	25,337	24,507	- 3.3
Total	**433,293**	**405,810**	**- 6.3**

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[13] CONEPO. 1999. Proyecciones de Población para el Estado de B. C.

[14] Secretaría de Desarrollo Económico. 1999. Perspectivas Económicas de B. C.

Respecto a la emisión por contaminantes, las partículas PM10, el amoniaco y los óxidos de nitrógeno presentan incrementos del 16.6%, 1.6% y 1.1%, mientras que disminuyen el SO_2, el CO y los HC con –25.4%, -14.4% y –4.8%, respectivamente, como se anota en la Tabla 5.1.2.

Tabla 5.1.2 Comparativo de Emisiones 1996-2005 por Tipo de Contaminante (Toneladas)

Contaminante	**Emisión Estimada 1996 (Toneladas)**	**Emisión Proyectada 2005 (Toneladas)**	**Diferencia (%)**
Partículas PM_{10}	84,989	99,138	16.6
Bióxido de Azufre	3,797	2,832	- 25.4
Monóxido de Carbono	266,738	228,196	- 14.4
Oxidos de Nitrógeno	18,547	18,753	1.1
Hidrocarburos	51,411	48,959	- 4.8
Amoniaco	7,809	7,932	1.6
Plomo	2	N. E.	N. E.
Total	**433,293**	**405,810**	**- 6.3**

No Evaluado

5.2 Fuentes Puntuales

La proyección de estas emisiones se efectuó en 2 partes: la primera se refiere a combustión y la segunda a procesos de producción. Inicialmente se separaron las emisiones por tipo de combustible utilizado, se estimó la cantidad de cada combustible a sustituir por gas natural según las líneas de distribución (combustóleo 13,690 m^3, diesel 11,030 m^3 y gas L. P. 31,990 m^3), de donde se obtuvo el consumo base de combustibles y se proyectó el uso de cada uno al año 2005, utilizando el factor de 80% del crecimiento industrial. Para convertir esas cantidades a gas natural se usó la cantidad de energía equivalente de cada combustible respecto al gas natural obteniendo así un total de 46.8 millones de metros cúbicos que proyectados al 2005 con el mismo factor de 80% resultan 84.2 millones de metros cúbicos. Finalmente se aplicaron los factores de emisión de AP-42 a cada combustible, con lo que se obtuvo el valor proyectado de emisiones.

Las emisiones de proceso se proyectaron por empresa y por tipo de contaminante a partir de la cantidad emitida en 1996, aplicando el factor de crecimiento de 26% para las empresas nacionales cuya actividad está más ligada al crecimiento poblacional y el de 80% a las maquiladoras que son las industrias de mayor crecimiento en la región.

La Tabla 5.2.1 se presentan los resultados de las proyecciones por tipo de proceso y contaminante, el desarrollo del cálculo para llegar a esas cantidades se puede consultar en el anexo de cálculo.

Tabla 5.2.1 Emisiones de Fuentes Puntuales Proyectadas al año 2005

Categoría	**PM 10**	**SO_2**	**CO**	**NOx**	**HC**	**NH_3**	**Total**
Emisiones de Combustión	55	527	204	774	26	N. A.	1,586
Emisiones de Proceso	2,357	1,098	4,520	717	1,934	3,066	13,692
Total	2,412	1,625	4,724	1,491	1,960	3,066	15,278

Toneladas

En base a la tabla anterior y la Tabla 4.1.2.1 se observa un decremento de 1.9% respecto a 1996, debido principalmente a la disminución de emisiones de combustión por el uso de gas natural en sustitución de diesel y combustóleo.

5.3 Fuentes de Area

La forma de calcular la emisión proyectada en esta gama de fuentes, fue aplicando en la mayoría de los casos el factor de 26% de crecimiento poblacional proyectado a la tasa de actividad de cada una y enseguida el factor de emisión y/o modelo corresppondiente (Mobile 5 Juárez o FAAED). Para el caso de combustión residencial y de servicios se estimó con información de la empresa distribuidora local que aproximadamente 120,000 personas utilizarán gas natural a nivel doméstico para el año de la proyección. En el caso de la combustión en fuentes comerciales e industriales se dividió el consumo de gas L. P. de 1996 en consumo de gas natural y gas L. P. en proporción similar a las fuentes puntuales (11% para L. P. y 89% para gas natural) proyectando el consumo de ambos con un incremento de 26%, ya que este se liga al crecimiento poblacional por estar relacionado con los servicios.

En el caso de las fuentes emisoras de las actividades agrícolas, se asumió que no habrá diferencias significativas en las emisiones, pues no se preven cambios en los patrones de cultivo y la superficie manejada permanecerá prácticamente igual.

Respecto a las emisiones de partículas en caminos pavimentados y no pavimentados, se usó el total proyectado de kilómetros recorridos por los vehículos obtenido en fuentes vehiculares y se desagregaron de la misma forma que en el inventario para 1996.

Finalmente, la generación de aguas residuales se calculó con la cantidad de 2,335 litros por segundo, mencionada en el programa de desarrollo citado, como la capacidad que se tendrá en operación para el año 2005 en las diferentes plantas de tratamiento.

Tabla 5.3.1 Emisiones de Fuentes de Area Proyectadas al año 2005.

Categoría	**PM 10**	**SO_2**	**CO**	**NOx**	**HC**	**NH_3**	**Total**
Combustión comercial, industrial ligera y de servicios	1	NS	4	20	1	NA	26
Combustión residencial	1	NS	35	189	6	NA	231
Locomotoras	6	4	34	237	14	NA	295
Aeronaves	NE	NS	174	32	23	NA	229
Otros equipos	46	20	461	252	67	NA	846
Cruces fronterizos	NS	NE	2,121	26	277	NA	2,424
Terminales de autobuses	3	NE	473	37	94	NA	607
Recubrimiento industrial	NA	NA	NA	NA	212	NA	212
Pintado de carrocerías	NE	NA	NA	NA	578	NA	578
Recubrimientos de superficies arquitectónicas	NE	NA	NA	NA	1,437	NA	1,437
Pintura de tránsito	NE	NA	NA	NA	28	NA	28
Limpieza de superficies en industria (desengrasado)	NA	NA	NA	NA	2,133	NA	2,133
Lavado en seco (tintorerías)	NA	NA	NA	NA	413	NA	413
Artes gráficas	NA	NA	NA	NA	406	NA	406
Aplicación de asfalto	NA	NA	NA	NA	1,980	NA	1,980
Uso comercial y doméstico de solventes	NA	NA	NA	NA	2,888	NA	2,888
Comercialización y distribución de combustibles	NA	NA	NA	NA	1,921	NA	1,921
Distribución de gas L. P.	NA	NA	NA	NA	1,510	NA	1,510
Panaderías	NA	NA	NA	NA	92	NA	92
Asados al carbón	288	NA	NE	NE	36	NA	324
Aplicación de plaguicidas	NA	NA	NA	NA	587	NA	587
Corrales de engorda de ganado	1,180	NA	NA	NA	NA	NA	1,180
Quemas agrícolas	2,143	NA	14,325	NE	1,949	NA	18,417
Aplicación de fertilizantes	NA	NA	NA	NA	NA	2,745	2,745
Desechos de animales	NA	NA	NA	NA	NA	1,554	1,554
Labranza agrícola	1,283	NA	NA	NA	NA	NA	1,283
Manejo de residuos (quema a cielo abierto)	110	7	580	41	210	NA	948
Tratamiento de aguas residuales	NA	NA	NA	NA	147	NA	147
Incendios en construcciones	2	NE	30	1	3	NA	36
Partículas de caminos pavimentados	4,109	NA	NA	NA	NA	NA	4,109
Partículas de caminos no pavimentados	67,187	NA	NA	NA	NA	NA	67,187
Emisiones domésticas de amoniaco	NA	NA	NA	NA	NA	567	567
Total	76,359	31	18,237	835	17,019	4,866	117,347

Toneladas NA: No Aplica NE: No Estimado NS: No Significativo

En la Tabla 5.3.1 se anotan las emisiones por contaminante y categoría de área proyectadas al año 2005, de la cual se deriva un aumento del 15.3% en el total de emisiones respecto a 1996. Influye significativamente en dicho incremento la emisión de partículas levantadas por el transporte en calles pavimentadas y no pavimentadas.

5.4 Fuentes Vehiculares

La forma en que se calcularon las emisiones proyectadas de los vehículos automotores es similar a la usada para 1996, se corrió el modelo Mobile 5 Juárez para obtener los factores de emisión por categoría de vehículo en cada mes del año y se aplicaron a la cantidad de kilómetros recorridos y los días de cada mes, de donde se obtuvo la emisión anual de hidrocarburos, monóxido de carbono y óxidos de nitrógeno.

El número de vehículos se obtuvo de la proporción de vehículos por habitante en 1996 aplicada a la cantidad de población en el año 2005, para cada tipo de vehículo. Se mantuvo la cantidad de kilómetros recorridos por día por vehículo, ya que no se tiene información de cambios en este indicador, ni en el de velocidad promedio.

El consumo de combustibles se estimó a partir del promedio de consumo por kilómetro en 1996, por vehículos de gasolina y vehículos diesel, multiplicado por la cantidad de kilómetros recorridos proyectada a 2005, resultando 756,632 y 216,120 metros cúbicos de gasolina y Diesel Sin, respectivamente.

Respecto a la cantidad de bióxido de azufre, se calculó con el consumo global proyectado de gasolina y diesel, aplicando el porcentaje de contenido de azufre en peso consignado en la NOM-086-ECOL publicada por SEMARNAP/INE para regular la calidad de los combustibles. Las cantidades obtenidas, 1,032.3 toneladas en la gasolina y 143.5 toneladas en diesel, se distribuyeron por tipo de vehículo conforme a la proporción respecto al total de kilómetros anuales recorridos. El factor de emisión de partículas es el mismo de 1996 para gasolina y diesel. La emisión de plomo no se calculó, ya que en 1996 dejó de utilizarse la gasolina Nova en Mexicali, que significaba el origen principal de este contaminante.

Tabla 5.4.1 Emisiones de Fuentes Vehiculares Proyectadas al año 2005

Categoría de Vehículo	**Vehículos**	**KrV Día**	**PM 10**	**SO2**	**CO**	**NOx**	**HC**	**Total**
Autos particulares	211,860	45	101	636	131,203	6,993	16,151	155,084
Taxis	1,392	100	1	9	1,916	102	236	2,264
Pick-up	57,960	70	43	271	47,792	3,104	6,586	57,796
Camiones de pasajeros a gasolina	1,010	185	2	13	2,282	224	315	2,836
Camiones de pasajeros a diesel	326	185	28	8	166	178	31	411
Camiones de carga ligera a gasolina	8,454	70	7	40	7,882	479	1,058	9,466
Camiones de carga pesada a gasolina	8,742	100	9	58	10,678	1,049	1,475	13,269
Camiones de carga pesada a diesel	12,448	80	457	135	2,750	2,934	503	6,779
Motocicletas	1,198	70	1	6	566	16	184	773
Total	**303,390**	**-**	**649**	**1,176**	**205,235**	**15,079**	**26,539**	**248,678**

Con los datos de la tabla anterior se tiene un total de emisiones que representa una disminución de 14.4% respecto a 1996. La disminución obedece principalmente al cambio de la edad del parque vehicular - se hace más nuevo en promedio - supuesto dentro del modelo Mobile 5 Juárez.

Por contaminante, comparando con la Tabla 4.3.1, se nota aumento en partículas PM10 y SO_2 obtenidas por balance de materia, así como en NOx calculados con los factores de Mobile; los decrementos se dan en CO y HC con 15.5% y 14.9%, respectivamente, representando la tendencia a la baja por ser los de mayor emisión.

5.5 Fuentes Naturales

En lo que se refiere a este tipo de fuentes, la categoría de emisiones de vegetación no se realizaron proyecciones debido a que no existen tendencias de cambio significativas en las áreas verdes y los cultivos.

En erosión de suelos se tomaron los datos del Programa de Desarrollo Urbano de Centro de Población Mexicali, B. C. donde se anota una cantidad esperada de 1,840 hectáreas de lotes baldíos y una factibilidad técnico-económica de pavimentar 500,000 metros cuadrados de calles, los que se disminuyeron de los considerados para 1996 y con esos datos se calculó la emisión proyectada.

Tabla 5.5.1 Emisiones de Fuentes Naturales Proyectadas al año 2005

Categoría	PM 10	SO2	CO	NOx	HC	Total
Calles no pavimentadas y lotes baldíos	11,282	NA	NA	NA	NA	11,282
Partículas de tierras de cultivos	8,436	NA	NA	NA	NA	8,436
Vegetación	NA	NA	NA	1,348	3,441	4,789
Suma	**19,718**	**-**	**-**	**1,348**	**3,441**	**24,507**

Toneladas NA: No Aplica

Se observa una disminución de 3.3% respecto a las emisiones de 1996 por la disminución del área que se espera esté sujeta a erosión, tanto en lotes baldíos como en calles sin pavimentar.

6 Aseguramiento y Control de Calidad

Con el objetivo de obtener resultados del inventario adecuados, se llevaron a cabo diversas actividades de control y aseguramiento de calidad, mismas que iniciaron desde el diseño del Plan de Trabajo, también con las opiniones y observaciones del Grupo Técnico respecto a los alcances, manejo y disponibilidad de información, aplicación de factores de emisión y metodología durante el desarrollo de los trabajos.

El Instituto Nacional de Ecología se encargó de definir los conceptos de aplicación de aseguramiento y control de calidad, así como de su seguimiento a través de cada etapa del proyecto, conforme al esquema que se describe en los siguientes incisos.

6.1 Aplicación de metodologías

Inicialmente se revisaron los manuales de Fundamentos del Inventario de Emisiones (Volumen II), Técnicas Básicas de Estimación de Emisiones (Volumen III), y Desarrollo del Inventario de Fuentes de Area (Volumen VI) de la serie de manuales para inventarios en México como referencias básicas para el desarrollo del inventario.

Se consultaron las secciones de AP-42 referentes a las categorías y subcategorías en estudio existentes en Mexicali.

Los procedimientos de cálculo y modelos para la estimación de emisiones fueron estudiados para determinar su aplicabilidad y adaptaciones necesarias de acuerdo al tipo de fuentes existentes en Mexicali, la información recabada de las fuentes de información y bibliografía, así como los requerimientos de datos en cada caso.

6.2 Cálculos

Los cálculos se realizaron siguiendo las recomendaciones de los manuales, y en general se verificó su desarrollo y exactitud para garantizar al máximo posible el resultado final.

Los supuestos, datos de entrada, información adicional y otras actividades referentes a los cálculos fueron documentados para posibilitar su revisión y verificación; la documentación de soporte cubre:

- Información proporcionada por las fuentes.
- Información bibliográfica.
- Archivos de entrada y salida de los modelos mecanísticos para computadora utilizados.
- Hojas de cálculo utilizando factores de emisión y balance de materiales.
- Memorias de cálculos manuales
- Reportes de resultados.

Los cálculos se elaboraron en forma manual, utilizando hojas de cálculo electrónicas y aplicando modelos mecanísticos como el PCBeis y Mobile 5 Juárez. En este último caso se cuidó la alimentación adecuada y correcta de los requerimientos de información del modelo, los supuestos que se tomaron en cuenta y la lógica de los resultados para Mexicali.

6.3 Manejo de información

En el proceso de transcripción de datos, desarrollo de cálculos, llenado de hojas de cálculo, aplicación de factores y aplicación de modelos se verificó la exactitud y veracidad de la transcripción de datos de las fuentes de información de origen, así como los traspasos de datos de las fuentes impresas a las hojas de cálculo y/o cálculos manuales, corrigiendo y actualizando cuando fue necesario.

Para efectos de dimensionar los resultados, se realizaron algunas comparaciones con respecto a emisiones del mismo tipo de otros inventarios.

7 Conclusiones

Como se puede observar, en esta ciudad son los vehículos automotores la principal fuente de emisión de contaminantes a la atmósfera, tanto las generadas por el proceso de combustión del combustible que los impulsa, como por su tránsito en las calles pavimentadas y no pavimentadas levantando partículas con sus ruedas.

Respecto a los vehículos es importante la tendencia a la disminución de emisiones conforme cambia a modelos más recientes el parque vehicular, por el cambio tecnológico que esto implica.

En lo que se refiere a la industria, esta tiene baja presencia en el total de emisiones, aunque deben regularse las emisiones de partículas en procesos, básicamente en manejo de granos en las industrias de alimento y manejo de agregados en minerales no metálicos, así como las emisiones fugitivas de hidrocarburos en los procesos de desengrase, limpieza y recubrimiento de superficies.

La disminución más importante en este sector se debe a la sustitución de combustibles pesados como el combustóleo y el diesel con gas natural, con lo que se reduce sensiblemente la emisión de bióxido de azufre.

Las emisiones generadas por las fuentes de área se distribuyeron en 34 subcategorías y 3 de fuentes naturales existentes en Mexicali.

Las máximas emisiones se registran en las partículas PM10, siendo las categorías más emisoras los caminos no pavimentados, la erosión en suelos agrícolas, las partículas generadas en caminos pavimentados por efecto del paso de los vehículos y el viento y las provenientes de quemas agrícolas.

De acuerdo a la aplicación del cuestionario a fuentes puntuales, este representó un buen avance técnico para el registro de las emisiones a nivel planta, sin embargo coincidieron diversos factores para su poca respuesta, como la necesidad de mayor tiempo para su llenado y devolución, la extensión del plazo para la entrega de la Cédula de Operación Anual y su carácter voluntario para la industria.

8 Recomendaciones

Establecer los mecanismos y acuerdos necesarios entre las dependencias federales, estatales y municipales para interrelacionar sus programas y actividades para asegurar el seguimiento de las políticas, líneas de acción y proyectos derivados del presente y próximos inventarios de emisiones.

Mantener e incrementar los controles administrativos, bases de datos y demás fuentes de información de datos de las dependencias oficiales, para la actualización contínua del inventario de emisiones. Esto permitirá a la vez desarrollar escenarios de impacto de políticas y programas mediante el uso de modelos mecanísticos y de dispersión de contaminantes.

Establecer programas de aprovechamiento de espacios abandonados y/o regularización de lotes baldíos, cercándolos y forestándolos para evitar la acumulación de basura, pastos y fauna nociva que en un momento dado provocan emisiones contaminantes por quema o descomposición de materia orgánica.

Promover con la comunidad programas prioritarios de forestación con especies de árboles de baja emisión de orgánicos volátiles, estableciendo los mecanismos que incentiven la participación de los diversos sectores de la sociedad.

Establecer un programa de medidas de seguridad para la prevención de riesgos de incendio incendio en el basurero municipal y lotes baldíos, a fin de evitar las altas emisiones anuales de contaminantes.

Incentivar a la industria que, en cumplimiento a las disposiciones ambientales, regule y disminuya sus emisiones al ambiente, principalmente en lo que se refiere a calibración de los equipos de combustión para disminuir las emisiones de CO e hidrocarburos, así como la instalación de equipos de control de emisiones de polvos y gases orgánicos volátiles.

Establecer un programa de control vehicular en el que se contemplen: verificación de emisiones y condiciones mecánicas, concientización de los automovilistas a que en forma voluntaria y conciente mantenagan en niveles adecuados las emisiones de sus automóviles incentivando a aquellos que si cumplan, control por parte de las autoridades federales de los modelos de vehículos susceptibles de importar incluyendo límites de emisión que eviten el envejecimiento del parque vehicular.

Establecer un programa de revestimiento de calles sin pavimentar mediante el uso de agregados y aditivos que reduzcan las emisiones de PM10 y PM2.5 provocadas por la circulación de vehículos.

Incentivar a las autoridades y sector educativo por los esfuerzos que desarrollen en el establecimiento de acciones tendientes a prevenir la contaminación ambiental.

Generar una cultura en la sociedad mediante una campaña en los medios masivos de comunicación promoviendo los beneficios, objetivos, metas y líneas de acción establecidas para mejorar la calidad ambiental de la ciudad y el municipio. Esto puede incluir selección y disposición adecuada de la basura doméstica, utilización de productos del hogar biodegradables o con bajo contenido de solventes, mantenimiento vehicular adecuado, forestación, entre muchos otros.

Establecer con las intituciones educativas de enseñanza media y superior (UABC, CETYS, ITM, CBTIS, CETIS, etc.) programas de investigación y desarrollo para mejorar la recolección de información y establecimiento de bases de datos que apoyen la elaboración de inventarios, así como el desarrollo de modelos para prevenir situaciones de riesgo por contaminación ambiental y desarrollo de tecnologías domésticas regionales de reducción, reutilización y reciclo de desechos en los hogares.

Promover la aplicación efectiva de la legislación ambiental que aun no está en práctica como la verificación vehicular y el control de quemas agrícolas.

Impulsar los mecanismos que permitan generar en forma clara los reglamentos, normas y demás ordenamientos legales para el control más estricto de quemas de basura urbana, disposición de llantas, utilización de rellenos sanitarios, etc. dentro del ámbito legal de las autoridades locales y estatales.

Establecer los mecanismos de participación interinstitucional entre diferentes órdenes de gobierno y organismos sociales tendientes a vigilar el cumplimiento de la reglamentación en materia de contaminación ambiental.

Con el propósito de seguir generando inventarios, es necesario iniciar con una serie de estudios cuyo objetivo sea el proporcionar mejores datos de entrada al modelo Mobile-Juárez, entre ellos se pueden sugerir estudios de aforos vehiculares, tasa de actividad por tipo de vehículo, clasificación vehicular más detallada, grado de mutilación de los equipos de control de la contaminación en los vehículos, entre otros.

También se deberá considerar la realización de estudios para desarrollar factores de emisión propios para la región, donde se parta de un modelo de factores de emisión básicos obtenidos de pruebas vehiculares en Mexicali, además de patrones de manejo que permitan obtener un ciclo de manejo específico para la zona.

Considerando los grandes volúmenes de monóxido de carbono emitidos, es necesario iniciar a la brevedad con un programa de verificación vehicular en esta ciudad.

Mexicali se encuentra en rápido crecimiento, donde debido al parque vehicular viejo, la situación debe considerarse como un problema potencial, que puede incrementarse con el tiempo, por lo que es necesario emprender acciones tendientes a disminuir las emisiones de contaminantes para detener el deterioro de la calidad del aire.

Por último, será necesario continuar con el registro permanente del consumo y calidad de los combustibles que se suministran a la zona, principalmente respecto al contenido de plomo, contenido de azufre y PVR.

Es recomendable estudiar la utilización de métodos de estabilización de suelos y/o pavimentación de calles para reducir las emisiones de partículas generadas en calles no pavimentadas.

Proponer a las autoridades correspondientes instrumentar un programa de recuperación de vapores en terminales de servicio y distribución de combustibles.

9 Glosario de Términos

Aforo. Medición del número y tipo de vehículos que transitan en un punto dado de una vialidad durante un tiempo determinado.

Ambiente. Conjunto de elementos físicos, químicos y biológicos (naturales o artificiales inducidos por el hombre), que propician la existencia, transformación y desarrollo de organismos.

Atmósfera. Capa de aire que circunda la tierra y que se extiende alrededor de 100 kilómetros por encima de la superficie terrestre. Su composición consiste en una mezcla de 78% de Nitrógeno, 21% de Oxígeno y 1% de diversos gases (Argón, Neón, Bióxido de Carbono y vapor de agua principalmente).

Atmósfera. Capa de aire que circunda la tierra y que se extiende alrededor de 100 kilómetros por encima de la superficie terrestre. Su composición consiste en una mezcla de 78% de Nitrógeno, 21% de Oxígeno y 1% de diversos gases (Argón, Neón, Bióxido de Carbono y vapor de agua principalmente).

Bióxido de azufre (SO_2). Contaminante producido durante los procesos de combustión de combustibles con contenido de azufre.

Bióxido de Nitrógeno (NO_2). Contaminante generado cuando el nitrógeno contenido en los combustibles y en el aire es oxidado en un proceso de combustión.

Combustibles fósiles. Compuestos orgánicos de los restos de plantas y animales que vivieron en la Tierra en épocas anteriores a la aparcición del hombre (carbón mineral, petróleo y gas).

Combustibles. Sustancias capaces de sufrir una oxidación violenta acompañada de desprendimiento de calor y algunas veces de flama.

Combustión. Proceso de oxidación rápida de combustibles acompañados de liberación de energía en forma de calor y luz.

Contaminación. Presencia de materia o energía cuya naturaleza, ubicación o cantidad produce efectos ambientales indeseables, afectando la integridad física, biológica, química o radiológica de los ecosistemas.

Contaminación. Presencia de materia o energía cuya naturaleza, ubicación o cantidad produce efectos ambientales indeseables, afectando la integridad física, biológica, química o radiológica de los ecosistemas.

Contaminante. Sustancia que al incorporarse a la atmósfera, agua, suelo, flora, fauna o cualquier otra parte del ambiente, altera o modifica su composición, afecta la salud o impide su utilización como recurso.

Despepitadora de algodón. Industria dedicada a la separación de la semilla y fibra del algodón. La fibra se obtiene en forma de pacas comprimidas.

Ecosistema. Unidad estructural funcional y de organización básica de interacción de los organismos entre sí y con el ambiente, en un espacio determinado.

Emisión. Descarga de contaminantes a la atmósfera provenientes de vehículos, fuentes industriales, comerciales y residenciales, así como de fuentes naturales.

Energía. Capacidad de un sistema para desarrollar trabajo.

Erosión. Destrucción y eliminación de ciertas características físicas, químicas o biológicas de los suelos, por efecto climáticos o por la actividad del hombre.

Factor de Emisión. Relación entre la cantidad de contaminación producida y la cantidad de materias primas consumidas, energía utilizada o distancia recorrida.

Fuente Móvil. Máquina, aparato o dispositivo emisor de contaminantes que no tiene un lugar fijo (automóviles, barcos, aviones, etc).

Fuente. Sitio, sistema o vehículo desde el cual se emiten contaminantes.

Hidrocarburos. Compuestos orgánicos constituídos principalmente por Carbono e Hidrógeno en cantidades variables. Forman parte de los combustibles y lubricantes más usuales.

Inventario de emisiones. Un listado, por fuente, de la cantidad de contaminantes descargados al aire en una comunidad; se utiliza para establecer normas o niveles de emisión.

Mineral. Material del que se extraen metales y otras sustancias que poseen aplicaciones diversas en la rama industrial, comercial o residencial.

Monóxido de Carbono. Gas tóxico, incoloro e inodoro, producido por la oxidación incompleta de combustibles de origen fósil.

Oxidos. Compuestos formados por Oxígeno y otro elemento exclusivamente. (ej. Monóxido de Carbono, Bióxido de Azufre etc.).

Parque Vehicular. Cantidad de vehículos automotores que circulan en un asentamiento humano.

Partículas. Contaminante suspendido en el aire generado por los procesos de combustión, calentamiento, transporte, producción y manipulación de materiales pulverizados o líquidos, formado de cenizas, hollín, humos, polvos, nieblas y aerosoles.

Productos de consumo de Vida Media. Bienes dedicados al comsumo familiar con vida útil de pocos años representados principalmente por los aparatos domésticos, refacciones y accesorios.

Productos de consumo de Vida Larga. Bienes cuya duración es de varios años y se refiere a vehículos, maquinaria y equipo.

Vialidad. Conjunto de vías o espacios geográficos destinados a la circulación y desplazamiento de vehículos y peatones.

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Final

Mexico Emissions Inventory Program Inventory Methodology Development for the Country of Mexico:

Lessons Learned from the Application of the Mexico Emissions Inventory Methodology in the City of Mexicali, Baja California

Prepared for:

Western Governors' Association
Denver, Colorado
and
Binational Advisory Committee

February 11, 2000

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MEXICO EMISSIONS INVENTORY PROGRAM

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ACRONYMS

ADT	average daily traffic
ARB	California Air Resources Board
BAC	Binational Advisory Committee
B.C.	Baja California
CO	carbon monoxide
COA	Cédula de Operación Anual (annual certificate of operation)
DDF	Departamento del Distrito Federal (Federal District of Mexico City)
EPA	U.S. Environmental Protection Agency
HAP	hazardous air pollutant
HC	hydrocarbons
ICAPCD	Imperial County Air Pollution Control District
ICAR	Ingeniería en Control Ambiental y Riesgo, S. de R.L.M.I.
INE	Instituto Nacional de Ecología (National Institute of Ecology)
LPG	liquefied petroleum gas
NH_3	ammonia
NO_x	nitrogen oxides
Pb	lead
PEMEX	Petróleos Mexicanos
$PM_{2.5}$	particulate matter less than 2.5 µm in diameter
PM_{10}	particulate matter less than 10 µm in diameter
PSQ	point source questionnaire

QA	quality assurance
QC	quality control
RVP	Reid Vapor Pressure
SEMARNAP	Secretaría de Medio Ambientes, Recuros Naturals, y Pesca (Secretariat of the Environment, Natural Resources, and Fisheries)
SO_2	sulfur dioxide
SO_x	sulfur oxides
U.S.	United States
TOC	total organic compounds
TOG	total organic gases
TSP	total suspended particulate
VKT	vehicle kilometers traveled
VOC	volatile organic compound
WGA	Western Governors’ Association
Yr	year
µm	micrometer

PROLOGUE

This report is a final version of a draft document originally prepared in May 1999 to document the “lessons learned” during the development of the Mexicali emissions inventory. The draft document contained 19 specific “lessons” associated with the Mexicali emissions inventory. Some of these identified lessons were things that should be repeated in future inventories, while other lessons were things that should be changed or avoided.

However, the draft “lessons learned” document was developed before the final Mexicali Emissions Inventory Report had been completed. In fact, the interim reports documenting emission estimates for point sources, area sources, and natural sources had not even been finalized prior to the release of the draft document. Ideally, the final inventory report would have been completed before this document was started. However, due to scheduling requirements associated with the Tijuana emissions inventory, it was decided that this document should be developed prior to finalization of the Mexicali emissions inventory in order to assist the Tijuana inventory effort.

Although the timing of the inventory report and the “lessons learned” report development was less than ideal, one positive aspect of this timing was that many of the lessons from the draft “lessons learned” were incorporated into the final inventory report which improved the quality of the final inventory. Conversely, due to the incorporation of the “lessons learned” into the final inventory report, the draft “lessons learned” report no longer accurately represented the conditions of the final inventory report.

One option for the final “lessons learned” report would have been to revise the text to match the final inventory report rather than the draft version. This revision might have required significant effort. Instead, it was decided that considerable benefit had already been obtained by incorporating the “lessons learned” into the final inventory report and that not much more would be gained by revising this document to match the final inventory report. As a result, the main text of the draft “lessons learned” report is contained in this document virtually unchanged, while a prologue and epilogue have been added to explain the relationship of the final “lessons learned” report to the draft version. The only changes to the main text are those needed for consistency. In general, these changes are relatively minor.

1.0 INTRODUCTION

The Mexicali emissions inventory was developed under the Mexico Emissions Inventory Development Program and represents the first time that the overall Mexico methodology was implemented. The Mexico methodology is documented in a series of manuals developed by Radian International (Radian) for the Western Governors' Association (WGA) and Mexico's Instituto Nacional de Ecología (National Institute of Ecology [INE]).

The primary purpose of this report is to document the "lessons learned" from applying the Mexico methodology in Mexicali, and identify what should be repeated and what changes should be made during subsequent inventory efforts in Mexico. This report will be useful when conducting the Tijuana, Baja California, inventory during 1999-2000. The focus of this report is more on the "procedural" issues encountered during the inventory process, and less on the "technical" issues. (A technical validation of the Mexicali inventory will be conducted under a separate task, and should be completed in mid-2000.)

This report is based on the experiences of INE, Radian, and the Mexicali inventory subcontractor (Ingeniería en Control Ambiental y Riesgo, S. de R.L.M.I. [ICAR]), during inventory development in Mexicali. The technical work conducted by ICAR is documented in three reports:

- Final Motor Vehicles Interim Report (ICAR, 1998a).
- Draft Point Sources Interim Report (ICAR, 1999a); and
- Draft Area and Natural Sources Interim Report (ICAR, 1999b).

In addition, ICAR will develop an overall Mexicali Emissions Inventory Report; however, that report is not yet available. (The Spanish version of the final Mexicali Emissions Inventory Report was completed in September 1999; an English translation will be available in February 2000).

In order to answer the question "What should be changed?" several recommendations are made. These recommendations will help INE focus their efforts as they strive to improve Mexico's emissions inventories in the future.

2.0 BACKGROUND OF THE MEXICALI EMISSIONS INVENTORY

The Mexicali emissions inventory was conducted from October 1997 to May 1999 for the metropolitan area of Mexicali, the capital of the state of Baja California. The inventory base year was 1996 and emissions from point sources, area and natural sources, and motor vehicles were included. The following pollutants were inventoried: hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2), and particulate matter with an aerodynamic diameter less than 10 micrometers (µm) (PM_{10}). Some emission estimates for ammonia (NH_3) and lead (Pb) were also included.

2.1 Mexico Methodology Development Project

The Mexico Methodology Development Project was initiated by WGA in 1994 with U.S. EPA funding for the purpose of increasing emissions inventory capabilities within the country of Mexico. One of the early project tasks was to evaluate numerous emissions estimating methodologies and determine which ones were most applicable to Mexico. The recommended methodologies were presented to the Binational Advisory Committee (BAC), with the methodologies described in greater detail in emission inventory manuals.

Mexicali was selected by INE and the BAC as an appropriate test site for the validity of the recommended methodologies. Potential revisions to the recommended methodologies may be developed from the results of the Mexicali inventory.

2.2 Inventory Objectives

Several objectives were identified at the start of the Mexicali inventory development process. Some of these objectives relate directly to the Mexico Methodology Development Project; other objectives contribute to overall air quality programs within the country of Mexico. The four main inventory objectives are described as follows:

- **Capacity Building.** The Mexicali emissions inventory effort provided government, industry, and consultants in Mexicali the opportunity to build capacity by drawing upon U.S. inventory expertise. This capacity can then be effectively used in the future to develop emissions inventories for other regions in Mexico.
- **Methodology Testing.** Mexicali was selected as the site for testing the Mexico Methodology Development Project. Through the implementation of the recommended methodologies in an actual inventory, the validity of the methodologies in Mexico can be assessed. Data availability and estimated emissions accuracy may be used as criteria for this assessment.
- **Mexicali Emissions Inventory Development.** Because Mexicali is a growing metropolitan area, its air quality will require increasing attention. Emissions inventories are one of the first elements that need to be developed for air quality management. With the exception of some large industrial facilities that are under federal or state jurisdiction, air emissions from sources in the Mexicali metropolitan area have never been inventoried. The Mexicali inventory serves as the initial emissions inventory for the Mexicali area.
- **Support of the 1999-2003 Mexicali Air Quality Improvement Program.** INE is currently developing an air quality improvement program for Mexicali. The Mexicali inventory serves a central role in this program. Without an accurate inventory, any air quality improvement strategies that may be developed are technically unfounded.

2.3 Inventory Participants

Many interested parties filled active roles in the development process of the Mexicali emissions inventory. The functions and activities of the key participants are detailed as follows:

- **INE.** As the main environmental agency in Mexico, INE provided extensive guidance for the inventory development process and identified appropriate Mexico-specific data and information. INE also ensured that the Mexicali inventory supported the Mexicali air quality improvement program and other national air quality objectives. INE was responsible for implementing the quality assurance and quality control (QA/QC) program for the inventory.

- **SEMARNAP B.C.** SEMARNAP, Baja California (B.C.) is the state-level environmental government agency in Mexicali. This agency provided data collection assistance for ICAR and coordinated local agency particpation for the inventory. Their personnel's knowledge of local environmental conditions in Baja California facilitated the inventory development process.

- **ICAR.** Ingeniería en Control Ambiental y Riesgo Industrial, S. de R.L.M.I (ICAR) was the Mexicali contractor selected to perform the majority of technical work on the Mexicali inventory. ICAR's responsibilities included data collection, emission estimation, inventory database management, and report writing.

- **Radian.** Radian International provided technical oversight and review for the Mexicali inventory. As the developer of the recommended methods being tested in Mexicali, Radian also provided technical guidance to INE and ICAR, including training on motor vehicle emissions estimating and the point source questionnaire. Radian reviewed all inventory documents produced by ICAR.

- **Mexicali Technical Group.** The Mexicali Technical Group provided overall guidance for the inventory development process. Bimonthly meetings were held to report on inventory development progress and resolve any problems that had occurred. In addition to the participants described above, representatives from the following agencies were members of the Mexicali Technical Group:
  - Baja California General Office of Ecology;
  - Mexicali City Council;
  - U.S. EPA Region IX;
  - WGA;
  - California Air Resources Board (ARB); and
  - Imperial County Air Pollution Control District (ICAPCD).

3.0 GENERAL OBSERVATIONS

Some observations and lessons learned during implementation of the Mexico emissions inventory methodology in Mexicali were general in nature and related to the success of the overall inventory, not to any specific source category. These general observations range from the successful development of an emissions inventory work plan to the absence of important inventory quality assurance/quality control (QA/QC) guidance document. Details related to these observations are discussed below.

Lesson #1: **A work plan should be developed for every emission inventory effort and should be based on the objectives and end uses defined for the emissions inventory.**

An emissions inventory work plan was developed for the Mexicali inventory by ICAR in the early stages of the project (ICAR, 1998b). Based on the objectives and end uses defined for the Mexicali inventory, this work plan provided a guideline for identifying sources and emissions data, and establishing specific inventory attributes such as base year, emission or pollutant types, etc. Even though it was necessary to deviate from the work plan during inventory development in order to take advantage of new and evolving data sources and methods, the work plan provided a framework for successful completion of the emissions inventory. Development of a work plan should be repeated in the initial stages of other emissions inventories developed for Mexico, even if an inventory has been previously developed for a specific area, since inventory attributes will change over time.

Lesson #2: **Methodology training sessions should be conducted at the beginning of the emissions inventory development process to familiarize inventory staff with difficult or new methodologies.**

Training was an important part of the inventory development process in Mexicali. The following training courses were offered:

- General emissions estimating methodology training was offered by INE, to SEMARNAP B.C., other agency staff, and ICAR at the beginning of the inventory to discuss the work plan and share understanding of the inventory objectives.

- Motor vehicle emissions methodology training was offered to INE, SEMARNAP B.C., other agency staff, and ICAR to teach them about the use of U.S. EPA's emission factor models and other relevant motor vehicle methodology issues.

- Point source questionnaire (PSQ) training was offered to agency staff in a "train-the-trainers" format. Subsequently, agency staff offered two one-day training sessions to representatives from many Mexicali industries on the new PSQ content and use, and data-collection procedures.

These training courses contributed to the successful completion of the emissions inventory in Mexicali. Similar training should be considered for other areas in Mexico, especially where inventories are developed for the first time.

Lesson #3: A technical group should be established for the inventory project and a communication protocol should be defined.

A Mexicali Technical Group was established early in the inventory process (see Section 2.3 of this report for details). An important feature of the group was the cross section of interests represented (e.g., Mexico and United States federal, state, and local governments, and contractors). The group represented diverse interests, and participated at different levels to ensure that the inventory objectives were met and capacity building was accomplished. The group met bimonthly and served as the main forum for communicating progress, problems, methodology changes, and other technical issues that arose during inventory development.

The importance of following a "communication protocol" became apparent during the report-approval process. For example, it was necessary to establish and follow a set procedure for review of the interim reports that involved translation into English, distribution for review, collection of comments, and submittal of consolidated comments to ICAR. If not planned for in advance during future inventory efforts, a communication delay or breakdown can adversely impact the project's budget and schedule.

Lesson #4: A quality assurance/quality control (QA/QC) plan should be available to all inventory staff at the beginning of the emissions inventory development.

One significant challenge presented to the inventory developers was the absence of an official QA/QC plan. A QA/QC plan is important for all parts of an emissions inventory, but particularly for those components that contain large quantities of data, such as point sources. If a QA/QC plan is implemented, then questionable data or "outliers" can be identified for future research. Without a QA/QC plan in place, all data within an inventory are incorrectly assumed to be equally valid.

Also, a QA/QC plan is important to ensure the quality of the area and natural sources portion of an emissions inventory, where the many area source categories require many different emissions calculations. Although the calculations themselves may be relatively simple, errors may be made due to the large number of calculations and variety of data sources. f a QA/QC plan is implemented, then higher quality area and natural source emission estimates will be generated. Without a QA/QC plan, some crucial errors in the inventory are likely to be made, thereby invalidating portions of the findings.

A QA/QC plan should be in place prior to commencement of any data collection activities. Training should also be provided, if needed. This was particularly true for development of motor vehicle emissions in Mexicali since inventory staff were relatively unfamiliar with the estimation methodology (e.g., motor vehicle emission factor models). In this case, great effort was required simply to understand and implement the estimation methodology, and less time than necessary may have been spent performing important QA/QC activities, which may have been exacerbated by the lack of official guidance. The QA/QC plan should address both emission factor model input data and output results.

Similar to the work plan, the QA/QC plan needs to be flexible and evolve as the emissions inventory is developed in order to address the QA/QC needs of specific source categories with the data available for the inventory region. QA/QC resources should be allocated based on the relative significance of each source category to the overall emissions inventory.

Lesson #5: **The existing Mexico Emissions Inventory Program Manuals should be updated to incorporate new methodology information identified during the Mexicali inventory effort. Development of additional manuals would help support the overall emissions inventory process.**

The primary reference materials used in development of the Mexicali emissions inventory were the Mexico Emissions Inventory Program Manuals. Specifically, Volumes II through VI provided recommended methods and guidance on a range of topics including emissions inventory fundamentals, emissions estimating techniques, and methods for estimating emissions from point sources, area sources, and motor vehicles. After each inventory effort, these manuals should be updated to incorporate any new methodology information identified for the benefit of future inventory efforts.

Having additional manuals would be helpful. Development of Volume IX (Emissions Inventory Program Evaluation) is underway; however, funding for development of the inventory manual providing specific guidance on estimating emissions from natural sources (i.e., biogenic VOC and soil NO_x) has not been secured. The absence of a methodology document addressing natural sources (planned as Volume VII of the Mexico Emissions Inventory Program Manuals) was an obstacle noted by the inventory developers during development of the Mexicali emissions inventory.

4.0 POINT SOURCES

A large number of industrial facilities in Mexicali exert considerable influence on the local economy. The emissions from these sources cannot be overlooked in the context of air quality in the Mexicali metropolitan area. This section briefly summarizes the methods used to estimate emissions from industrial (i.e., point) sources in Mexicali, and identifies several lessons learned during the emissions inventory development.

4.1 Summary of Methodology

Approximately 1,076 industrial facilities (including large, medium, small, and micro industries) are located in the Mexicali metropolitan area. The point source portion of the inventory included only the 112 facilities (primarily large and medium-sized industries) that applied for an annual certificate of operation (i.e., Cédula de Operación Anual [COA]) in 1996. Of these 112 facilities, 36 facilities were under federal environmental jurisdiction due to their economic sector (e.g., electricity generation, metal production, mineral production, etc.), and the remaining 76 facilities were under state environmental jurisdiction. Over half of the facilities (60) were maquiladora facilities (i.e., foreign-owned “twin plants”) and the remainder (52) were Mexican-owned facilities. Point source emissions were primarily derived from existing federal and state records. For federal sources, data were collected from the COA itself or COA applications. For state sources, data were mainly collected from the Air Emissions Sources State Register.

In addition, a point source questionnaire (PSQ), specially designed to improve the quantity and quality of point source inventory data collected in Mexico, was implemented for the Mexicali inventory. Mexico’s current COA application process facilitates data collection on a facility level and focuses primarily on combustion sources. In order to improve emissions inventory quality, the PSQ facilitates data collection on a process-specific basis (e.g., boilers, degreasers, paint spray booths, etc.). The PSQ was used along with Volume IV of the Mexico Emissions Inventory Program Manuals (Point Source Inventory Development) (Radian, 1996) to estimate emissions from some point source categories.

Because the PSQ was significantly different from the COA, INE and ICAR offered two one-day PSQ training sessions for Mexicali industry staff. Also, ICAR provided assistance to industry staff by answering questions that arose during PSQ preparations. It was emphasized that industries would benefit from additional environmental training for their staffs and improved data quality for their official data submittals. Although PSQ results were not used as the primary data source for the point source inventory, they provided valuable insight regarding potential implementation of the PSQ on a larger scale within Mexico.

4.2 Lessons Learned

Lessons learned during development of the point source emissions inventory in Mexicali include the need to adequately define point sources (vs. area sources) and reasons for limited success of the PSQ. Also, a QA/QC plan is essential for a thorough assessment of inventory accuracy, as well as more complete documentation of inventory procedures.

Lesson #6: The size and type of sources to be included in the point source inventory should be defined at the beginning of the inventory development process. This would clearly distinguish point sources from area sources and ensure that no emissions sources are omitted or double-counted.

As noted above, point sources were defined as those 112 facilities that applied for COAs in 1996. However, the distinction between point sources and area sources as presented in the Draft Point Source Interim Report was not clear. The distinction between point and area (i.e., small, dispersed point sources) was based upon a definition (i.e., facilities that did or did not apply for an annual operating license) rather than a numerical cutoff (e.g., emissions greater than a predetermined threshold amount). It is possible that a facility that did not apply for an annual COA might have emissions greater than a facility that did apply for a COA. This may result in a large point source either being overlooked or inventoried as an area source without important point source characteristics or location information. This could lead, in turn, to erroneous modeling or implementation of “wrong” control measures.

Because of this potentially confusing situation, it is not clear if emissions from 964 industrial facilities (1,076 facilities present in Mexicali, minus the 112 facilities with COAs or applications for COAs) have been properly accounted for in the area source portion of the inventory. The only evidence of point source and area source reconciliation (see Section 5.0, Lesson #12 for more details) documented in the Draft Point Source Interim Report is that point source liquified petroleum gas (LPG) consumption was subtracted from the overall LPG consumption in order to determine commercial, residential, and service sector LPG consumption.

Lesson #7: Certain aspects associated with training and implementation of the PSQ should be repeated during future inventory efforts, while others should be changed to achieve a higher rate of return and more complete forms.

The final return rate for the PSQ was approximately 20%. Although this return rate is low compared to the required federal COA (80%), it is similar to other voluntary surveys both in Mexico and the United States. The rate of return of the PSQ in Mexicali was influenced by several factors described as follows:

- Completion of the PSQ was voluntary and was requested only a few weeks after submittal of the (required) COA. Industry resources were adversely impacted by the “closeness” of the COA and PSQ submittals.

- Environmental consultants were hired by several companies to assist with completing the PSQ and conducting other environmental compliance activities. However, return rates and data quality did not significantly increase for those companies that retained a consultant.

- Efforts by the local agency (i.e., SEMARNAP B.C. and INE) to contact each facility via letters, and by ICAR to make followup phone calls, contributed to the high attendance rates at the training sessions (i.e., 43 industries). However, the number of one-day training sessions or the scope of the material covered may have been insufficient for some facilities; most of the submitted PSQs were from facilities that did not attend the training sessions. It should be noted that one-day sessions are easier for facility staff to attend because this format has less of an impact on work schedules than multiple-day sessions.

- There was only about one month between the industry training course and the deadline for the PSQ to be completed.

- Detailed operational records required to complete the PSQ often were not available for Mexicali industries.

- Industry was usually familiar only with monitoring or material balance emission estimating techniques; therefore, data collection favors these methods.

- Industry often was unable to provide any information beyond that required by the official COAs; many returned PSQs had data only for combustion sources.

In order to increase the PSQ return rate, several actions could be taken. One significant step would be to make the PSQ submittal mandatory. However, in the short term, this appears unlikely because legislative approval would be required. Also, a longer survey period would reduce the pressure of time constraints on facility staff, encouraging participation and more complete responses.

The two one-day training sessions were reasonably well-attended (43 facilities were represented), but additional classes likely would increase participation. ICAR received 48 calls from facility staff requesting advice regarding the PSQ;

participation rates could be improved further by proactive followup calls to industry. Overall, it appears that the PSQ may have been too complex relative to the technical abilities of the Mexicali industry workforce, as evidenced by the actual returned PSQ data collection forms and comments collected by ICAR. Additional training classes and workshops are possible tools that could be offered to facility staff to raise their level of familiarity with the PSQ and sense of value in the inventory process, thus increasing the rate of return of completed PSQs and quality of emissions data reported.

Lesson #8: The quality of the point source inventory was limited by a lack of an official QA/QC plan and guidance document.

For the Mexicali inventory, the lack of a QA/QC plan was evident by some of the technical issues discovered during the review of the draft Point Sources Interim Report (ICAR, 1999a), including:

- Incorrect totals of subsector facilities.
- Potential under-reporting of maquiladora facilities relative to other metropolitan areas and statistics stated in the Mexicali Emissions Inventory Work Plan (ICAR, 1998b).
- Potential over-reporting of CO (i.e., 95% of the point source CO was from two metallic mineral facilities).
- Potential over-reporting of SO_x (i.e., large quantities of SO_x [652 tons/yr] from four vegetable and animal product facilities).
- Virtually no HC emissions were reported from the two chemical facilities.

Lesson #9: Insufficient documentation prevented thorough review of the point source inventory. There should be enough inventory documentation in a final report to allow readers to understand the inventory methodology and the significance of the results.

Inventory documentation is an important part of every emissions inventory. Documentation should clearly describe the entire inventory methodology. Without sufficient documentation, the final inventory results may be known but the quality and meaning of those results cannot be assessed.

Although the draft Point Sources Interim Report contained several pages devoted to emission totals, there were only a few tables containing emission factor information and very little discussion regarding activity data. Because much of the point source data used in the Mexicali inventory came from existing federal and state records (many that contain confidential information), it is likely that ICAR was unable to provide this information in the draft Point Sources Interim Report. Regardless, additional explanation would be helpful regarding the following:

- How were data from official records and the completed PSQs integrated together within the inventory?
- How were existing control measures incorporated into the inventory?
- Is the inventory limited to primarily combustion emissions? Have process and fugitive emissions been included?
- What emissions were estimated with emission factors? With actual monitoring data? With material balances? With other methods?
- Do the inventory developers have other recommendations for improving the point source inventory in the future?

5.0 AREA AND NATURAL SOURCES

Area sources are a broad category that includes all emission sources that are too small and/or dispersed to be counted as point sources; it does not include on-road motor vehicles. Area source emissions are typically a significant portion of the overall inventory of emissions. In Mexicali, area sources are important contributors of HC and CO emissions, and are the predominant source of particulate emissions. Because area sources include a large number of diverse source categories, activity data must be collected from a wide variety of sources.

Unlike point source, area source, and motor vehicle emissions that all result from human activities, natural source emissions represent emissions occurring regardless of human presence. Natural emissions should be estimated in order to provide an accurate assessment of background conditions for a particular area, to understand the relative significance of each source category contributing to the total emissions, and to develop appropriate air quality control strategies.

This section briefly summarizes the methods used to estimate emissions from area and natural sources in Mexicali, and identifies several lessons learned during emissions inventory development.

5.1 Summary of Methodology

Area and natural sources comprise seven major source category "groups" within the Mexicali inventory:

- Combustion sources (e.g., natural gas combustion, non-road mobile sources, etc.);
- Evaporative sources (e.g., architectural surface coating, degreasing, etc.);
- Commercial/light industrial sources (e.g., bakeries, charbroiling, etc.);

- Agricultural sources (e.g., pesticide application, agricultural burning, etc.);

- Waste management sources (e.g., open burning, wastewater treatment, etc.);

- Other sources (e.g., structural fires, paved and unpaved road dust, etc.); and

- Natural sources (i.e., wind erosion and biogenic emissions).

Area and natural source activity data were provided by a variety of sources. In general, emission factors were applied to activity data in order to estimate emissions. For most source categories, these emission factors were provided in Volume V of the Mexico Emissions Inventory Program Manuals (Area Source Inventory Development) (Radian, 1997b). In some cases, however, INE provided new emission factors that were thought to be more appropriate for use in Mexicali than the emission factors in the Area Source Manual.

5.2 Lessons Learned

Lessons learned during development of the area and natural source emissions inventory in Mexicali include the need to explicitly define inventory pollutants and distinquish between point sources and area sources. Flexibility and innovation must be used to address unique or previously uninventoried source categories. Caution should be exercised when per-capita or per-employee emission factors are used, and priority should always be given to the use of locally measured data over average and/or default values. Finally, QA/QC guidelines are essential in producing quality area and natural source emission estimates.

Lesson #10:	**It is important to define the specific pollutants to be estimated early in the inventory development process. For a pollutant such as “hydrocarbons,” where the term is ambiguous (e.g., VOC, TOC, TOG, etc.), the definition and emissions estimation methods should be documented to ensure accurate and consistent use of the definition.**

Every emissions inventory has several basic characteristics, or attributes, that must be identified early in the inventory development process in order to provide a framework for consistent and meaningful results. One of these basic attributes is the pollutants to be inventoried. For some pollutants, their definitions are explicit (e.g., CO or SO_2). Other pollutants, however, must be more clearly defined. For example, type or size of particulate matter should be designated (i.e., total suspended particulate [TSP], PM_{10}, particulate matter with an aerodynamic diameter less than 2.5 µm [$PM_{2.5}$]). Likewise, if hydrocarbons (HC) are to be inventoried, the exact HC definition should be specified (e.g., total organic gases [TOG] or volatile organic compounds [VOC]). These pollutant definitions should then be used consistently throughout the inventory.

The Mexicali Emissions Inventory Work Plan (ICAR, 1998b) indicates that total organic compounds (TOC) or TOG will be inventoried. However, reference to HC, VOC, and TOG were all made in the draft Area and Natural Sources Interim Report (ICAR, 1999b). It is possible that these three definitions were used interchangeably to represent the same group of hydrocarbons, but this is not clear. It is possible, too, that some emission factors were incorrectly applied. Also, if these three pollutants were estimated for different source categories, then the total sum of "hydrocarbons" as shown in the interim report would not necessarily be accurate.

Lesson #11: **Because this was an initial inventory, there were several new source categories that were not addressed in the Mexico Area Source Inventory Development Manual, and other categories for which data could not be identified or deviations from the Mexico methodology were warranted. Flexibility and innovation were used to address these situations.**

Every emissions inventory is unique. Some new, location-specific source categories may be discovered for which existing emissions estimating methods do not exist, or deviations from existing methods may be necessary to accommodate alternative data types. For the Mexicali inventory, three new area source categories were identified; however, emissions from these categories were not included due to the absence of available methodologies and data.

These categories include:

- Vehicle fires;
- Hazardous waste disposal in landfills; and
- Public latrines.

Possible sources of applicable emissions estimating methodologies for these source categories would be other emissions inventories; references containing methodologies for similar categories that could be adapted for use; and use of engineering judgment, extrapolation, or ratioing techniques based on emission totals from other similar types of sources.

Even if emissions cannot be estimated, it is still important to document the existence of the source category, type of emissions (e.g., TOG, PM_{10}, etc.), possible emissions magnitude, and relevant activity data. For example, ICAR identified brick manufacturing as a source category in the Mexicali inventory, with an estimated 10 brick manufacturing facilities located in the south part of Mexicali. Unfortunately, they were unable to identify any brick production statistics or fuel usage information. As a result, emissions were not estimated for this category. However, because ICAR documented this information in the Area Source Interim Report, it will support inventory revisions in the future.

Lesson #12: The distinction between point sources and area sources should be adequately defined at the beginning of the inventory development process to ensure accurate point/area source reconciliation.

As mentioned in Section 4.2, Lesson #6, the distinction between point sources and area sources must be clear at the beginning of the inventory development process. For example, the draft Point Sources Interim Report (ICAR, 1999a) indicates that 112 facilities (those that applied for their annual operating license in 1996) out of the 1,076 industrial facilities located in Mexicali are included in the point source inventory; therefore, it is reasonable to assume that the remaining 964 industrial facilities are included in the area source inventory. However, area source LPG consumption (i.e., commercial, residential, and service sectors) was the only source category adjusted to exclude potential point source emissions. Area source solvent and surface coating emissions were not adjusted for potential point source emissions. Furthermore, the accuracy of this adjustment for LPG combustion is questionable, because it is not clear whether or not the remaining 964 industrial facilities are actually included in the commercial, residential, and service sectors (e.g., hotels, restaurants, schools, hospitals, government buildings, tortilla factories, housing, bakeries, etc.).

In order to ensure that emissions are properly allocated to point sources and area sources, the following point source/area source reconciliation steps should be implemented:

- Examine point source records to identify all facilities that could generate emissions that might overlap with emissions from area source categories (e.g., fuel combustion, solvent use, surface coating, etc.).
- For those facilities that should have emissions but have not reported any, estimate emissions using ratios (i.e., on a per-employee, per-unit-of-fuel-combustion, or per-unit-of-production basis) or similar engineering bases.
- For each source category, subtract point source emission estimates from total emissions to obtain area source emission estimates. (See Section 2.3.1 of Volume V of the Mexico Emissions Inventory Program Manuals for more information.)

Lesson #13: The appropriateness of certain area source emission factors based on per-capita or default data should be assessed, and the emission factors should be modified to include location-specific data, or avoided as necessary.

Emissions from many area source categories with very disperse emissions (e.g., surface coating or degreasing sources) often are estimated using per-capita or per-employee emission factors. Use of these emission factors assumes that generalized large-scale usage patterns are applicable. These emission factors may be appropriate for national or regional inventories, but they may not be appropriate for smaller-scale inventories. Local usage patterns may significantly affect the accuracy of emissions estimated with per-capita or per-employee emission factors. It is important that the appropriateness of these emission factors be established prior to estimating emissions.

For Mexicali, the recommended methodology for several area source categories included using per-capita emission factors derived from data developed for the Federal District of Mexico City (Departamento del Distrito Federal [DDF]). INE, however, recommended that per-capita emission factors from AP-42, which are based on U.S. data, be used to estimate emissions. Mexicali's close proximity to the U.S. might warrant use of the AP-42 emission factors; however, DDF emission factors might more appropriately represent conditions within Mexico. Currently, it is not clear which emission factors would be better to use in Mexicali. Further research into these per-capita emission factors is needed.

Every emissions inventory should ideally use measured data that accurately represent local conditions within the inventory domain. In actuality, the unavailability of local data sometimes forces the use of nonlocal data or default values. Use of nonlocal data may be appropriate in an inventory if the location from where it derived is similar to the inventory domain. The use of default values, however, will invariably introduce uncertainty into the inventory.

The use of default values occurred throughout the Mexicali inventory. Given the amount of available data in Mexicali, this was to be expected. However, care should be given when using default values. This is illustrated particularly well with the paved and unpaved road dust categories that constitute over 60% of the estimated PM_{10} emissions for Mexicali. For paved road dust emissions, Mexicali-specific silt loading data were unavailable. Instead, the 50th percentile value for low-ADT (average daily traffic) roads from AP-42 was used. The best alternative would be to collect local silt loading data. The measurement of silt loading is relatively simple and inexpensive. A less-suitable alternative, but better than using AP-42 default values, would be to use silt loading data from nearby, similar areas (i.e., Imperial County or other areas in Southern California). The default values from AP-42 should be used only as a last resort.

For unpaved road dust emissions, no silt content or soil moisture data were available, so rough estimates were made using engineering judgment. Silt content estimates were on the low end of the valid data range and lower than the average default value, and the soil moisture estimates were on the high end of the valid data range and higher than the average default value. As a result, the estimated emissions are likely to be underestimated. This is shown by the estimated unpaved road dust emission factor for Mexicali being a factor of 10 lower than that used by the ARB for their state inventory. Actual measured data are preferable to undocumented engineering judgment.

Another example of an area source methodology that was used in the Mexicali inventory and that may not accurately represent local conditions is the wind erosion methodology. Taken from AP-42, this method uses several adjustment factors. One of these adjustment factors is a climatic factor (“C”) which represents a range of different wind speeds and soil surface moistures. INE and ICAR believe that the “C” factor may not be entirely applicable for an extremely arid region such as Mexicali, because the emissions estimates resulting from use of this method seem excessively high. Investigation into the “C” factor, its origin, and the range of values under which it produces the best results is needed.

Lesson #14: The lack of a QA/QC document and procedure prevented consistent and thorough quality review of the area and natural source inventory. Having an official QA/QC guideline would have improved the quality of the area and natural source inventory.

For the Mexicali inventory, some of the possible QA/QC issues discovered during review of the draft Area and Natural Sources Interim Report (ICAR, 1999b) include the following:

- Fuel combustion emissions only estimated for LPG.
- Incorrect use of the recommended methodology for the asphalt application category (i.e., evaporation loss percentage applied to the entire weight of asphalt, rather than the diluent weight; unreasonable evaporation loss percentage for medium-cure asphalt).
- Potential underestimating of PM_{10} emissions from paved and unpaved road dust due to the use of default values and engineering judgment estimates.
- Potential low population of non-road mobile equipment relative to the large-scale agricultural and industrial operations of Mexicali.
- No identified area source industrial surface coating.
- Incorrect application of gasoline distribution emission factors to diesel distribution (i.e., gasoline distribution emission factors are based on typical gasoline volatility, which is much higher than diesel volatility).
- Use of some incorrect domestic ammonia emission factors (i.e., due to typographical errors).

6.0 MOTOR VEHICLE SOURCES

Like most metropolitan areas, motor vehicles are significant contributors of air pollution in Mexicali. Consequently, considerable attention was given to the motor vehicle portion of the Mexicali inventory. This section briefly summarizes the methods used to estimate emissions from motor vehicles in Mexicali, and identifies several lessons learned during the emissions inventory development.

6.1 Summary of Methodology

Vehicle travel statistics (measured in vehicle kilometers traveled [VKT]) were combined with emission factors to calculate HC, CO, NO_x, and PM_{10} emissions. Fuel consumption data and fuel characteristics were used to estimate SO_2 and lead emissions.

Motor vehicle data were collected from four primary sources:

- Comprehensive Study of Urban Transit and Transportation for Mexicali, Baja California (UABC, 1994) (VKT statistics, vehicle speeds);
- Departamento de Control de Vehículos, Secretaria de Planeación y Finanzas, Gobierno del Estado de Baja California;
- Departamento de Transporte Federal (truck statistics); and
- Petróleos Mexicanos (PEMEX) (fuel sales and fuel characteristics).

Monthly emission factors for HC, CO, and NO_x emissions were estimated using MOBILE-Juárez (a motor vehicle emission factor model modified using U.S.-Mexico border region motor vehicle data). Particulate matter emissions factors used in other Mexico inventories were provided by INE for use in Mexicali.

Because the inventory methodology for motor vehicles used emission factor models and activity data that were unfamiliar to some inventory staff, a two-day motor vehicle inventory training session was conducted at the beginning of inventory activities. This training session included motor vehicle inventory fundamentals, data collection, and hands-on use of the pertinent emission factor computer models. The primary reference used for the training and development of motor vehicle emissions in Mexicali was Volume VI of the Mexico Emissions Inventory Program Manuals (Motor Vehicle Inventory Development) (Radian, 1997a).

6.2 Lessons Learned

Lessons learned during development of the motor vehicle emissions inventory in Mexicali include recognition of the importance of timeliness and a method of identifying emissions data, training, and a quality assurance/quality control (QA/QC) policy and plan.

Lesson #15: Sources of emissions data should be identified as early as possible in the inventory development process. Otherwise, data sources that change, or are identified late, may negatively impact the inventory development schedule and/or available resources.

To the greatest extent possible, data sources to be used in the inventory should be identified early. Also region-specific or Mexico-specific data should be used, rather than default or U.S.-specific data. Likewise, the most accurate activity data available should be used. Other circumstances also may require that new data sources be incorporated into the inventory midway through the inventory development process.

One significant data source that was quickly identified was the Comprehensive Study of Urban Transit and Transportation for Mexicali, Baja California (UABC, 1994). This study was valuable in determining the overall fleet VKT and vehicle speed. It should be noted, however, that this study may be atypical, and similar studies may not exist in other metropolitan areas within Mexico.

In contrast, there were two data sources that were identified after considerable time and resources had been expended in collecting alternative data. First, fuel characteristic data collected by the ARB were going to be used in the inventory. Several months after this decision was made, however, it was suggested that Mexicali PEMEX data would provide more accurate Reid vapor pressure (RVP) values. Another example of emissions data discovered late in the process was the Mexico-specific PM_{10} emission factors for gasoline- and diesel-fueled vehicles. While it was recognized that these factors were more appropriate for Mexicali than the recommended methodology of U.S. EPA's PART5 emission factor model, this was not disclosed until after the submittal of the first interim report for motor vehicles. In both cases, emissions had to be recalculated due to the newly identified data. Additional time and resources were spent for these recalculations. In particular, the new PEMEX RVP data made it necessary for the MOBILE-Juárez emission factor model to be rerun.

Time and effort can be saved during future Mexico inventory efforts, such as in Tijuana, since the Tijuana PEMEX data and Mexico-specific diesel PM_{10} emission factors can be used from the beginning of the inventory development process.

Lesson #16: Motor vehicle data from Ciudad Juárez and/or countrywide data were used when local data were not available in order to avoid using default U.S. data.

In general, considerable amounts of Mexicali-specific data were used to estimate emissions from motor vehicles. Also, during the Mexicali inventory, new important Mexico-specific data were made available (see Lesson #15, page 6-2). For some of the data, however, Mexicali-specific data were not sufficiently disaggregated. In these cases, Baja California (i.e., state-level) statistics or engineering judgment were used to disaggregate the data. Also, several input parameters to the MOBILE-Juárez model were set to Ciudad Juárez default values (e.g., mileage accumulation rates and model year distributions) or U.S. default values (e.g., tampering rates). Although these approaches were not ideal, they were the appropriate choice given the lack of Mexicali-specific information, which can be attributed to the early state of motor vehicle emissions data development in Mexico.

Lesson #17: The motor vehicle training conducted at the beginning of the inventory process was successful and improved the quality of the Mexicali motor vehicle emissions inventory.

Compared to point and area sources, the methodology for motor vehicles is considerably more complex. As a result, a hands-on motor vehicle training session, including topics such as motor vehicle inventory fundamentals and operation of motor vehicle emission factor models, was conducted for ICAR and other local emissions inventory participants. Based upon ICAR's work on the motor vehicle portion of the Mexicali inventory, it is clear they learned the basic concepts of estimating motor vehicle emissions and became proficient in using motor vehicle-related inventory data and tools. This training had a direct effect on the successful completion of the motor vehicle emissions inventory, and should be repeated in areas where inventory developers are unfamiliar with the motor vehicle emissions methods. One topic that should be added to the motor vehicle training is QA/QC.

Lesson #18: The lack of a QA/QC document and procedure prevented consistent and thorough quality review. Having an official QA/QC guideline would have helped facilitate the implementation of the emissions inventory methodology (e.g., assist with planning, data collection, data management, and reporting writing) and improve the overall quality of the inventory.

Some QA/QC activities were performed at the end of the emissions inventory (e.g., fuel economies were calculated from VKT, and fuel consumption statistics for "reasonableness" and overall emission comparisons were made with other metropolitan areas such as Guadalajara, Monterrey, and Ciudad Juárez); however, QA/QC was not widely applied to the inventory data used to calculate emissions. For instance, "reality" checks of daily VKT by different vehicle types and average vehicle speeds were not performed prior to submittal of the draft interim report.

Lesson #19: Assistance by local authorities helps to expedite collection of emissions data.

Emissions inventory development is often a time-critical exercise; therefore, it is crucial that the effort required for collection of data for all sources be identified as soon as possible. Official requests to obtain nonpublic data should be made promptly by the inventory's sponsoring agency. Staff from the sponsoring agency can also facilitate data collection in situations where there is resistance or delays from other agencies that normally do not participate in air quality-related activities.

The effort needed to collect inventory data varies depending upon the data source. Some inventory data are normally available for public use and, therefore, are relatively easy to collect during the inventory development process. Vehicle speeds and VKT data (UABC, 1994) and vehicle fleet statistics from the Federal Transportation Department and the Secretariat of Planning and Finance are included in this category. Other necessary inventory data, however, are sometimes confidential, proprietary, and/or not normally available to the public. Proper permission and authorization is typically required to access these types of restricted data (e.g., PEMEX fuel sales data and fuel characteristics).

As part of the Mexicali inventory, the PEMEX data were identified as being essential for the development of motor vehicle emissions. Initial efforts by ICAR to collect this data from the local PEMEX offices in Mexicali were unsuccessful. After ICAR reported on the difficulties of collecting PEMEX data at a meeting of the Mexicali Technical Group, INE and SEMARNAP, B.C. made an official request to PEMEX for this restricted data. This official request enabled ICAR to receive the PEMEX data with adequate time to complete their emissions calculations.

7.0 RECOMMENDATIONS

This section summarizes recommendations for future inventory efforts in Mexico. These recommendations are based on the lessons learned (procedures that went well and procedures that could be improved) from the Mexicali emissions inventory effort.

General Recommendations

- A work plan should be developed in the initial stages of every emissions inventory, regardless of whether it is a first-time inventory or a revision. The work plan provides direction for the overall inventory effort and should be based on the objectives and end uses defined for the emissions inventory.

- Methodology training sessions should be conducted at the beginning of the inventory development process in order to familiarize inventory staff with difficult or new methodologies (e.g., new point source questionnaire or motor vehicle emission factor models). Potential problems and solutions can be discussed during these sessions.

- A technical group should be established for the inventory project. This group should meet periodically to review project progress and resolve any problems encountered.

- A communication protocol should be established at the beginning of the inventory development process to facilitate the collection and dissemination of information.

- A QA/QC plan should be available to all inventory staff in order to improve overall inventory quality.

- The existing manuals should be updated to incorporate new methodology information identified during the Mexicali inventory effort (e.g., point source questionnaire, new unpaved road emission factors from AP-42, new Mexico-specific particulate emission factors for motor vehicles, etc.). Development of additional manuals would help support the overall emissions inventory process.

Point Source Recommendations

- Point sources should be clearly defined at the beginning of the inventory development process in order to eliminate double-counting and missed emissions between point sources and area sources.

- Proactive promotion of the PSQ from the beginning of the inventory effort by the sponsoring agencies (i.e., INE and SEMARNAP, B.C.) would be beneficial. It seems that some industries were unprepared to participate in this voluntary survey. Additional promotion would allow INE and SEMARNAP the opportunity to more fully explain the PSQ to industry and convince them of its benefits.

- The PSQ should be distributed so that it does not conflict with other required submittals. It was indicated that some industries were unable to fill out the PSQ because it immediately followed the federally administered Cédula.

- Because of the unfamiliarity and complexity of the new PSQ, it is recommended that a longer survey period, as well as additional training classes or "help sessions," be provided.

- In order to improve the technical capabilities of industry, additional inventory- or air quality-related training classes and workshops should be developed for industry. For example, class topics might include learning how to use AP-42, U.S. EPA's TANKS model, or monitoring data to estimate emission rates.

- Point source documentation should be developed to the extent that people uninvolved with the actual inventory development process can understand the methodology used and the associated results.

Area and Natural Source Recommendations

- Specific inventory pollutants should be defined at the beginning of the inventory development process with emission estimates made consistently following these pollutant definitions. Ambiguous use of pollutant definitions may introduce potential errors.

- Technical flexibility and innovation should be used during inventory development, when necessary. Methodologies may not exist or be appropriate for some source categories. Expected inventory data may be unavailable. Local conditions may require modifications to the existing methodology.

- Location-specific inventory data should always be preferred over default or per capita data. If location-specific data are unavailable, then default or per-capita data can be used, but only after their appropriateness for the inventory domain has been evaluated.

Motor Vehicle Recommendations

- The recommended priority of motor vehicle data, in descending preferential order, is local data, other border region data, other Mexico data, and finally, U.S. default data. Local data or other border region data are preferable over U.S. default data and should be used wherever possible.

- Motor vehicle training should be conducted at the beginning of the inventory development process. As part of this training, motor vehicle QA/QC techniques should be explained and ways to recognize potential motor vehicle data problems should be emphasized.

- Local authorities should be used to collect emissions inventory data in the most effective manner possible. This will allow inventory resources to be utilized effectively.

8.0 REFERENCES

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EPILOGUE

In conclusion, the Mexicali emissions inventory was successful in satisfying the four main inventory objectives described in Section 2.2: capacity building, methodology testing, Mexicali emissions inventory development, and support of the 1999-2003 Mexicali Air Quality Improvement Program. It is the first comprehensive inventory developed for the Mexicali metropolitan region; subsequent inventories are sure to follow as efforts to improve the air quality in Mexicali continue.

In reviewing the process used to develop the Mexicali emissions inventory, a total of 19 specific “lessons” were identified. Some of these lessons have applicability to this inventory only, while other lessons have more general applicability to many types of inventories. Although all of the lessons identified within the main text of this report are important, several of these lessons deserve some extra emphasis. These include the importance of a work plan (Lesson #1), necessity of a QA/QC plan at the beginning of inventory development (Lessons #4, #8, #14, and #18), and adequate definition of point and area sources (Lesson #6 and #12). The most important aspect of all of these lessons is that they are “lessons learned” that can be used to improve future inventories conducted in Mexico. If these lessons are reviewed both before and during subsequent emission inventory development efforts, then some of the successes of the Mexicali inventory can be repeated and some of the difficulties encountered can be avoided in the future.

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CONTENIDO

PRESENTACIÓN

Un inventario de emisiones es el elemento base para desarrollar un programa de calidad del aire consistente y con posibilidades de llegar a una reducción equitativa y eficáz de las emisiones que producen las industrias, los comercios y servicios, los vehículos automotores, los suelos y la vegetación.

En México desde hace varias décadas se elaboran inventarios de emisiones, más sin embargo las metodologías y técnicas de cálculos empleadas no están estandarizadas, lo cual impide con frecuencia efectuar comparaciones y evaluar las tendencias de las emisiones. Este último punto es fundamental para evaluar el impacto de los programas y medidas de prevención y control de la contaminación atmosférica.

Por otra parte, un inventario completo, detallado y validado, permite identificar con mayor precisión las fuentes que contribuyen con la mayor proporción de las emisiones contaminantes, permitiendo así el identificar e instrumentar acciones con metas cuantificables en términos de la reducción de emisiones alcanzada.

Es por lo anterior que el *Instituto Nacional de Ecología* se ha marcado en esta materia una serie de actividades progresivas que irán permitiendo la homogeneización y uniformización en la elaboración de los inventarios y para ello ha considerado y está en proceso de elaborar un conjunto de manuales con el propósito de que sirvan de referencia a todos aquellos interesados que requieran elaborar inventarios de emisiones.

Un elemento complementario y de igual importancia es la capacitación técnica para construir inventarios de emisiones a la atmósfera. Para ello el INE, con apoyo de la Asociación de Gobernadores del Oeste y la Agencia de Protección Ambiental de los E.U.A., y con la participación de la Universidad Autónoma Metropolitana-Azcapotzalco, desarrolló un *Curso de Inventarios de Emisiones para México* como un parte de un proyecto global que pretende consolidar la capacidad técnica a nivel nacional de los profesionales que trabajan en este campo.

Las notas que se presentan en este documento corresponden a una versión corta del curso original. Este curso corto ha sido concebido para ser impartido a una audiencia de ingenieros, profesionistas y técnicos de los sectores industria, comercios y servicios, principalmente, en una sesión intensiva de una sola jornada. Por lo tanto es un curso ejecutivo que permite al participante recibir los conceptos básicos más importantes, necesarios para el desarrollo de inventarios de emisiones de contaminantes a la atmósfera.

Adrián Fernández Bremauntz

I. Principios Básicos de Inventarios de Emisiones

Notas

Principios Básicos de Inventarios de Emisiones

- Desarrollo de inventarios de emisiones
- Usos de los inventarios de emisiones
- Área geográfica
- Fuentes de contaminantes
- Metodologías básicas

Desarrollo de Inventarios de Emisiones

- Los Inventarios de Emisión son conjuntos de datos que caracterizan las liberaciones de contaminantes de las fuentes emisoras
  - > Permiten identificar qué contaminantes son emitidos
  - > Permiten cuantificar la tasa de emisión
- Son los cimientos para la construcción de un plan de calidad del aire
- Son instrumentos importantes en el manejo de relaciones públicas entre las autoridades y la sociedad

Usos de los Inventarios de Emisiones

- Determina el cumplimiento de las diferentes reglamentaciones
- Desarrolla las condiciones para licencias de funcionamiento
- Estima impactos a la calidad del aire, en conjunto con modelos

Usos de los Inventarios de Emisiones (continuación)

- Permiten determinar las especificaciones para el equipo de control
- Permiten determinar créditos de emisiones
- Permiten calcular cuotas de emisión y multas por emisiones en exceso

Usos de los Inventarios de Emisiones (continuación)

- Permiten establecer la aplicabilidad de los diferentes requerimientos regulatorios
- Satisfacen los requerimientos establecidos en las regulaciones en cuanto a reportes
- Permiten identificar áreas de incertidumbre en el inventario
- Permiten analizar escenarios potenciales del tipo "¿ qué pasaría si...?

Área Geográfica

- Por lo general, las áreas de los inventarios se definen por la división política
- Con frecuencia las áreas del inventario son conjuntos de jurisdicciones que experimentan problemas comunes de calidad del aire
- El tipo de inventario determina el área geográfica exacta que debe cubrirse

Fuentes de Contaminantes

- Hay diferentes categorías de fuentes de contaminantes:
    - Fuentes naturales, fuentes antropogénicas;
    - Fuentes puntuales, fuentes de área;
    - Fuentes estacionarias, fuentes móviles;
    - Fuentes originadas por fenómenos naturales
    - Fuentes biogénicas

Fuentes Puntuales

- Son fuentes estacionarias, grandes, que se caracterizan por emitir cantidades de contaminantes por arriba de un cierto umbral (por ejemplo 10 ton por año de NO_x)

Fuentes de Área

- Son fuentes demasiado pequeñas o numerosas para ser consideradas fuentes puntuales
- Por lo general sus emisiones se calculan a partir de factores de emisión y de niveles de actividad
- Incluyen a las fuentes móviles que no circulan por calles o por carreteras:
    - Aeronaves
    - Trenes
    - Botes
    - Maquinaria para construcción
    - Otros tipos de equipo

Fuentes Móviles

- Las fuentes móviles que circulan por calles o por carreteras incluyen:
    - Automóviles
    - Camiones
    - Motocicletas

Fuentes Naturales

- Emisiones resultantes de procesos naturales
- Emisiones biogénicas

Metodologías Básicas

- Muestreo en la fuente
- Modelos de emisiones
- Factores de emisión
- Encuestas
- Balances de materiales
- Extrapolaciones

Muestreo en la Fuente

- Cumplimiento con las regulaciones de calidad del aire
- Desarrollo de normas reglamentarias
- Evaluación del desempeño y diseño de los dispositivos para control de la contaminación atmosférica
- Mediciones de cribado

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Modelos de Emisiones

- Mecanísticos
- De variable múltiple
- Adaptativos

Factores de Emisión

- Un factor de emisión es un razón que relaciona la cantidad de contaminante liberado a la atmósfera con una unidad de actividad
  - Basados en proceso
  - Basado en censos
- “AP-42 Recopilación de factores de emisión de contaminantes del aire”

Factores de Emisión

- Los factores de emisión (FE) se usan con frecuencia para estimar las emisiones de diferentes tipos de fuentes
  - Basados en “masa de contaminante por unidad de actividad”
    - Ejemplo de un factor de emisión: gramos de CO/kilómetro recorrido por vehículo (KRV)
  - Confiabilidad de los factores de emisión
    - Los factores de emisión de la EPA de los EEUU están clasificados en A,B,C,D,E
    - “A” se considera el más confiable para un tipo dado de fuente - probablemente se basa en mediciones en la fuente
    - Las clasificaciones más bajas indican que ésa es la confianza que se puede tener en ese factor de emisión

Factores de Emisión (continuación)

- Cálculo de Emisiones
  - Emisiones = Factor de Emisión (FE) x Dato de Actividad (DA)
  - Ajustar las emisiones por eficiencia del equipo de control (EC) si lo hay, es decir:
  - Emisiones = FE x DA (1-EC)

Factores de Emisión (continuación)

- Datos de actividad
  - Para procesos industriales los datos de actividad son generalmente reportados como tasas respecto al peso de proceso (por ejemplo kg, ton, o l por hora)
  - Para el equipo en el que se quema combustible los datos de actividad son reportados como tasas de consumo de combustible (por ejemplo, ton, l, o kJ por hora)

Ejemplo de Factores de Emisión

Encuestas

- Se diseñan cuestionarios para recolectar datos de emisiones
- Las mas eficientes son formas para recolección de datos y cuestionarios
- Las formas pueden servir como documentación de antecedentes
- Pueden ser genéricas o específicas para un tipo de industria o de dispositivo

Ejemplo de Encuesta de Fuentes Puntuales

Balance de Materiales

- Se usan las mediciones de otros componentes de un proceso para determinar las emisiones de los contaminantes a la atmósfera

Ejemplos de Balance de Materiales

Extrapolación

- Escalar las emisiones de una fuente de emisiones dada a otra fuente basándose en un parámetro de escalamiento conocido para ambas fuentes
  - > Cantidad de producción
  - > Area
  - > Número de empleados

Jerarquías para la Estimación de Emisiones

METODOS PROPUESTOS PARA FUENTES PUNTUALES

CATEGORIA PRINCIPAL	***SUBCATEGORIA***	***RECOMENDACIONES A CORTO PLAZO***	***RECOMENDACIONES A LARGO PLAZO***	***CONTAMINANTES A ESTIMAR***
GENERACION DE ELECTRICIDAD	COMBUSTION POR TIPO DE COMBUSTIBLE	Muestreo en Fuente/Directo	Muestreo en Fuente/Directo	CO, NOx, SOx, COV, NH_3 y Partíc.
COMBUSTION EN INDUSTRIA, COMERCIOS Y SERVICIOS	POR TIPO DE COMBUSTIBLE	Cuestionario/ Factores de Emisión	Muestreo en Fuente/directo	CO, NOx, SOx, COV, NH_3 y Partíc.
INDUSTRIA QUIMICA	EMISIONES DE PROCESO	Cuestionario/ Factores de Emisión	Muestreo en Fuente/Directo	NH_3,HCl, H_2SO_4, H_2S, H_3PO_4, SO_2, CO, COV, etc.
	EMISIONES POR COMBUSTION	Cuestionario/ Factores de Emisión	Muestreo en Fuente/Directo	CO, NOx, SOx, COV, NH_3 y Partíc.
	EMISIONES FUGITIVAS EN EQUIPOS	Cuestionario/ Modelo Multivariado	Muestreo en Fuente/Indirecto	COV
	TANQUES DE ALMACENAMIENTO	Cuestionario/ Modelo Mecanístico	Cuestionario/ Modelo Mecanístico	COV
	USO DE SOLVENTES VARIOS	Cuestionario/ Balance de Materiales	Cuestionario/ Balance de Materiales	COV, NH_3 y SOx
REFINACION DE PETROLEO	EMISIONES DE PROCESO	Muestreo en Fuente/Directo	Muestreo en Fuente/Directo	COV, NH_3 y SOx
	EMISIONES POR COMBUSTION	Cuestionario/ Factores de Emisión	Muestreo en Fuente/Directo	CO, NOx, SOx, COV, NH_3 y Partíc.
	EMISIONES FUGITIVAS EN EQUIPOS	Cuestionario/ Modelo Multivariado	Muestreo en Fuente/Indirecto	COV
	TANQUES DE ALMACENAMIENTO	Cuestionario/ Modelo Mecanístico	Cuestionario/ Modelo Mecanístico	COV
	USO DE SOLVENTES VARIOS	Cuestionario/ Balance de Materiales	Cuestionario/ Balance de Materiales	COV
INGENIOS AZUCAREROS	EMISIONES DE PROCESO	Cuestionario/Factores de Emisión	Muestreo en Fuente/Directo	Partíc.
	EMISIONES POR COMBUSTION	Cuestionario/Factores de Emisión	Muestreo en Fuente/Directo	CO, NOx, SOx, COV, NH_3 y Partíc.
	EMISIONES FUGITIVAS	Cuestionario/Factores de Emisión	Muestreo en Fuente/Indirecto	Partíc.
CURTIDO Y ACABADO DE PIELES	EMISIONES DE PROCESO	Cuestionario/Factores de Emisión	Muestreo en Fuente/Directo	COV
	EMISIONES POR COMBUSTION	Cuestionario/Factores de Emisión	Muestreo en Fuente/Directo	CO, NOx, SOx, COV, NH_3 y Partíc.
	EMISIONES FUGITIVAS	Cuestionario/Factores de Emisión	Muestreo en Fuente/Indirecto	COV

PRODUCTOS DE HULE Y PLASTICO	EMISIONES DE PROCESO	Cuestionario/Factores de Emisión	Cuestionario/Factores de Emisión	COV
	EMISIONES POR COMBUSTION	Cuestionario/Factores de Emisión	Muestreo en Fuente/Directo	CO, NOx, SOx, COV, NH_3 y Partíc.
FABRICACION DE PRODUCTOS METALICOS	EMISIONES DE PROCESO	Cuestionario/Factores de Emisión	Cuestionario/Factores de Emisión	Partíc. y COV en acabado de productos
	EMISIONES POR COMBUSTION	Cuestionario/Factores de Emisión	Cuestionario/Factores de Emisión	CO, NOx, SOx, COV, NH_3 y Partíc.
FABRICACION DE PRODUCTOS TEXTILES	EMISIONES DE PROCESO	Cuestionario/Factores de Emisión	Cuestionario/Factores de Emisión	COV
	EMISIONES POR COMBUSTION	Cuestionario/Factores de Emisión	Muestreo en Fuente/Directo	CO, NOx, SOx, COV, NH_3 y Partíc.
DISPOSICION DE RESIDUOS SOLIDOS	EMISIONES DE RELLENOS SANITARIOS	Cuestionario/Modelo Mecanístico	Cuestionario/Modelo Mecanístico	COV
	QUEMA A CIELO ABIERTO	Muestreo en Fuente/Indirecto	Muestreo en Fuente/Indirecto	CO, NOx, SOx, COV y Partíc.
	INCINERACION DE RESIDUOS SOLIDOS MUNICIPALES	Muestreo en Fuente/Directo	Muestreo en Fuente/Directo	CO, NOx, SOx, COV y Partíc.
PRODUCCION PRIMARIA DE METALES	EMISIONES DE PROCESO	Muestreo en Fuente/Directo	Muestreo en Fuente/Directo	SOx y Partíc.
	EMISIONES POR COMBUSTION	Cuestionario/Factores de Emisión	Muestreo en Fuente/Directo	CO, NOx, SOx, COV, NH_3 y Partíc.
	EMISIONES FUGITIVAS	Cuestionario/Balance de materiales	Cuestionario/Balance de materiales	Partíc.
PRODUCCION SECUNDARIA DE METALES	EMISIONES DE PROCESO	Cuestionario/Factores de Emisión	Muestreo en Fuente/Directo	Partíc. y COV
	EMISIONES POR COMBUSTION	Cuestionario/Factores de Emisión	Muestreo en Fuente/Directo	CO, NOx, SOx, COV, NH_3 y Partíc.
PRODUCCION DE CEMENTO, VIDRIO Y PRODUCTOS MINERALES NO METALICOS	EMISIONES DE PROCESO	Cuestionario/Factores de Emisión	Muestreo en Fuente/Directo	Partíc. y COV en acabado de productos
	EMISIONES POR COMBUSTION	Cuestionario/Factores de Emisión	Muestreo en Fuente/Directo	CO, NOx, SOx, COV, NH_3 y Partíc.
	EMISIONES FUGITIVAS	Cuestionario/Factores de Emisión	Muestreo en Fuente/Indirecto	Partíc. y COV en acabado de productos
INDUSTRIA AUTOMOTRIZ	EMISIONES DE PROCESO	Cuestionario/Factores de Emisión	Muestreo en Fuente/Directo	COV
	EMISIONES POR COMBUSTION	Cuestionario/Factores de Emisión	Muestreo en Fuente/Directo	CO, NOx, SOx, COV, NH_3 y Partíc.
	EMISIONES FUGITIVAS	Cuestionario/Factores de Emisión	Muestreo en Fuente/Indirecto	COV

INDUSTRIA DEL PAPEL Y CELULOSA	EMISIONES DE PROCESO	Cuestionario/Factores de Emisión	Muestreo en Fuente/Directo	SOx, COV y Partíc.
	EMISIONES POR COMBUSTION	Cuestionario/Factores de Emisión	Muestreo en Fuente/Directo	CO, NOx, SOx, COV, NH_3 y Partíc.
PRODUCCION DE PETROLEO Y GAS	EMISIONES DE PROCESO	Cuestionario/Factores de Emisión	Muestreo en Fuente/Directo	COV
	EMISIONES POR COMBUSTION	Cuestionario/Factores de Emisión	Muestreo en Fuente/Directo	CO, NOx, SOx, COV, NH_3 y Partíc.
	EMISIONES FUGITIVAS	Cuestionario/Factores de Emisión	Muestreo en fuente/Indirecto	COV
	TANQUES DE ALMACENAMIENTO	Cuestionario/Modelo Mecanístico	Cuestionario/Modelo Mecanístico	COV
INDUSTRIA DE LA IMPRESION	EMISIONES DE PROCESO	Cuestionario/Factores de Emisión	Cuestionario/Factores de Emisión	COV
	EMISIONES FUGITIVAS	Cuestionario/Balance de materiales	Cuestionario/Balance de materiales	COV
RECUBRIMIENTO DE SUPERFICIES Y PINTURA	EMISIONES DE PROCESO	Cuestionario/Balance de materiales	Cuestionario/Balance de materiales	COV
	EMISIONES POR DESENGRASE	Cuestionario/Balance de materiales	Cuestionario/Balance de materiales	COV
	EMISIONES FUGITIVAS	Cuestionario/Balance de materiales	Cuestionario/Balance de materiales	COV
TERMINALES DE ALMACENAMIENTO DE COMBUSTIBLES	OPERACIONES DE CARGA	Cuestionario/Factores de Emisión	Cuestionario/Factores de Emisión	COV
	TANQUES DE ALMACENAMIENTO	Cuestionario/Modelo Mecanístico	Cuestionario/Modelo Mecanístico	COV
MINERIA Y CANTERAS	EMISIONES DE PROCESO	Cuestionario/Factores de Emisión	Muestreo en Fuente/Indirecto	Partíc.
	EMISIONES FUGITIVAS	Cuestionario/Factores de Emisión	Muestreo en Fuente/Indirecto	Partíc.
FABRICACION DE PRODUCTOS DE MADERA	EMISIONES DE PROCESO	Cuestionario/Factores de Emisión	Cuestionario/Factores de Emisión	Partíc. y COV
	EMISIONES POR COMBUSTION	Cuestionario/Factores de Emisión	Muestreo en Fuente/Directo	CO, NOx, SOx, COV, NH_3 y Partíc.
PROCESOS Y ACTIVIDADES INDUSTRIALES VARIAS	EMISIONES DE PROCESO	Cuestionario/Factores de Emisión	Cuestionario/Factores de Emisión	CO, NOx, SOx, COV, NH_3 y Partíc.
	EMISIONES POR COMBUSTION	Cuestionario/Factores de Emisión	Cuestionario/Factores de Emisión	CO, NOx, SOx, COV, NH_3 y Partíc.
	EMISIONES FUGITIVAS	Cuestionario/Balance de materiales	Cuestionario/Balance de materiales	COV

INSTALACIONES PUBLICAS	EMISIONES POR COMBUSTION	Cuestionario/Factores de Emisión	Cuestionario/Factores de Emisión	CO, NOx, SOx, COV, NH_3 y Partíc.
	EMISIONES FUGITIVAS	Cuestionario/Balance de materiales	Cuestionario/Balance de materiales	COV
INDUSTRIA ALIMENTICIA Y DE AGRICULTURA	EMISIONES DE PROCESO	Cuestionario/Factores de Emisión	Cuestionario/Factores de Emisión	Partíc. y COV
	EMISIONES POR COMBUSTION	Cuestionario/Factores de Emisión	Muestreo en Fuente/Directo	CO, NOx, SOx, COV y Partíc.
PLANTAS DE ASFALTO	EMISIONES DE PROCESO	Cuestionario/Factores de Emisión	Cuestionario/Factores de Emisión	Partíc. y COV
	EMISIONES POR COMBUSTION	Cuestionario/Factores de Emisión	Muestreo en Fuente/Directo	CO, NOx, SOx, COV, NH_3 y Partíc.

METODOS PROPUESTOS PARA FUENTES DE AREA

CATEGORIA PRINCIPAL	***SUBCATEGORIA***	***RECOMENDACIONES A CORTO PLAZO***	***RECOMENDACIONES A LARGO PLAZO***	***CONTAMINANTES A ESTIMAR***
COMBUSTION EN FUENTES ESTACIONARIAS/ INDUSTRIALES Y COMERCIALES	POR TIPO DE COMBUSTIBLE	Balance de materiales/Factores de Emisión AP-42	Balance de materiales/Factores de Emisión	CO, NOx, SOx, COV, NH_3 y Partíc.
COMBUSTION EN FUENTES ESTACIONARIAS/ COMBUSTIBLES COMERCIALES Y RESIDENCIALES	POR TIPO DE COMBUSTIBLE COMERCIAL	Balance de materiales/Factores de Emisión AP-42	Balance de materiales/Factores de Emisión	CO, NOx, SOx, COV, NH_3 y Partíc.
COMBUSTION EN FUENTES ESTACIONARIAS/ COMBUSTIBLES DERIVADOS DE BIOMASA O RESIDUOS	POR TIPO DE COMBUSTIBLE DERIVADO DE RESIDUOS	Cuestionario/Factores de Emisión AP-42	Cuestionario/Modelo multivariado	CO, NOx, SOx, COV, NH_3 y Partíc.
POLVOS DE CAMINOS PAVIMENTADOS	NO APLICA	MOBILE, KRV/Metodología AP-42	MOBILE, KRV /Cuestionario/ Metodología AP-42	Partíc.
POLVOS DE CAMINOS NO PAVIMENTADOS	NO APLICA	Cuestionario/ Metodología AP-42	Cuestionario/ Metodología AP-42	Partíc.
RECUBRIMIENTO Y LIMPIEZA DE SUPERFICIES CON SOLVENTES INDUSTRIALES	POR SECTOR INDUSTRIAL	Extrapolación/Inventario mexicano de fuentes puntuales	Cuestionario/Modelo multivariado	COV
LIMPIEZA DE SUPERFICIES INDUSTRIALES (DESENGRASE)	POR SECTOR INDUSTRIAL	Extrapolación/Inventario mexicano de fuentes puntuales	Cuestionario/Modelo multivariado	COV
LIMPIEZA EN SECO (TINTORERIAS)	POR TIPO DE SOLVENTE	Factores de emisión basados en censos	Cuestionario/Modelo multivariado	COV
CONSUMO DE SOLVENTES	POR TIPO DE PRODUCTO	Factores de emisión basados en censos	Cuestionario/Modelo multivariado	COV
ALMACENAJE Y TRANSPORTE DE COMBUSTIBLES (tanques de almacenam.; operac.carga/descarga; fugas de ductos; terminales almacenam.; estaciones servic.; camiones y barcos de transporte)	POR TIPO DE PRODUCTO	Balance de materiales/Modelos mecanísticos/ Factores de emisión	Balance de materiales/Modelos mecanísticos/ Factores de emisión	COV
PRODUCCION AGRICOLA	GANADERIA	Factores de emisión basados en censos	Cuestionario/Modelo multivariado	NH_3 y Partíc.

MANEJO DE RESIDUOS/ INCINERACION EN SITIO	NO APLICA	Balance de materiales	Cuestionario/Modelo multivariado	CO, NOx, COx, COV y Partíc.
DISPOSICION DE RESIDUOS/ QUEMA DE RESIDUOS	NO APLICA	Cuestionario	Cuestionario/Modelo multivariado	CO, NOx, COx, COV y Partíc.
INCENDIOS	INCENDIOS	Cuestionario/Factores de emisión AP-42	Modelo multivariado	CO, NOx, COx, COV y Partíc.
	QUEMAS PROGRAMADAS	Cuestionario/Factores de emisión AP-42	Modelo multivariado	CO, NOx, COx, COV y Partíc.
BAÑOS PUBLICOS	NO APLICA	Factores de emisión basados en censos o AP-42	Factores de emisión basados en censos	CO, NOx, COx, COV y Partíc.
PROCESOS INDUSTRIALES	POR SECTOR INDUSTRIAL	Factores de emisión basados en censos /Tecnologías de inventarios de gases de invernadero	Cuestionario/Modelo multivariado	CO, NOx, COx, COV y Partíc.
RECUBRIMIENTOS ARQUITECTONICOS Y LIMPIEZA DE SUPERFICIES CON SOLVENTES	NO APLICA	Factores de emisión basados en censos	Balance de materiales	COV
EMISIONES DOMESTICAS DE AMONIACO	NO APLICA	Factores de emisión basados en censos		NH_3
TORTILLERIAS	NO APLICA	Factores de emisión basados en censos	Factores de emisión basados en censos	CO, NOx, COx, COV y Partíc.
LADRILLERAS	NO APLICA	Cuestionario	Cuestionario/Modelo multivariado	CO, NOx, COx, COV y Partíc.
CONSTRUCCION DE INMUEBLES	NO APLICA	Factores de emisión AP-42/Cuestionario	Cuestionario/Modelo multivariado	Partíc.
RECUBRIMIENTOS Y LIMPIEZA DE SUPERFICIES CON SOLVENTES/ SEÑALAMIENTO DE TRAFICO	NO APLICA	Factores de emisión basados en censos	Balance de materiales	COV
FABRICACION DE HULE Y PLASTICO	NO APLICA	Extrapolación/Inventario mexicano de fuentes puntuales	Cuestionario	COV
RELLENOS SANITARIOS Y MANEJO DE DESECHOS	NO APLICA	Balance de Materiales /Modelo mecanístico	Cuestionario/Modelo Mecanístico	COV
PANADERIAS	NO APLICA	Factores de Emisión basados en censos	Factores de Emisión basados en censos	COV

RECUBRIMIENTO Y LIMPIEZA DE SUPERFICIES CON SOLVENTES/ ACABADOS AUTOMOTRICES	NO APLICA	Factores de emisión basados en censos	Cuestionario/Modelo multivariado	COV
ARTES GRAFICAS	NO APLICA	Factores de emisión basados en censos	Cuestionario/Modelo multivariado	COV
ASFALTADO	NO APLICA	Balance de materiales/ Factores de emisión AP-42	Balance de materiales/ Factores de emisión	COV
PRODUCCION AGRICOLA	APLICACION DE PESTICIDAS	Balance de materiales	Cuestionario/Modelo multivariado	COV
	APLICACION DE FERTILIZANTES	Balance de materiales	Cuestionario/Modelo multivariado	NH_3
	QUEMA AGRICOLA	Cuestionario	Cuestionario/Modelo multivariado	Partíc.
	CULTIVO	Cuestionario/Modelo multivariado	Cuestionario/Modelo multivariado	Partíc.
INCENDIOS	EDIFICIOS Y ESTRUCTURAS	Cuestionario/Factores de emisión AP-42	Cuestionario/Factores de emisión	CO, NOx, SOx, COV y Partíc.
MANEJO DE DESECHOS Y PLANTAS DE TRATAMIENTO DE AGUAS RESIDUALES	NO APLICA	Factores de emisión AP-42/Cuestionario	Cuestionario/Modelo multivariado	COV y NH_3
CANALES DE AGUAS NEGRAS	NO APLICA			COV y NH_3
PUESTOS AMBULANTES (ALIMENTOS)	NO APLICA			CO, NOx, SOx, COV y Partíc.

METODOS PROPUESTOS PARA FUENTES MOVILES

CATEGORIA PRINCIPAL	***RECOMENDACIONES A CORTO PLAZO***	***RECOMENDACIONES A LARGO PLAZO***	***CONTAMINANTES A ESTIMAR***
VEHICULOS EN CIRCULACION	Utilización del MOBILE MCMA/MMA/JUAREZ y MOBILE5C	Utilización del MOBILE MCMA /MMA/JUAREZ y MOBILE5C	CO, NOx, SOx, COV , NH_3 y Partíc.
AERONAVES	Cuestionario/Factores De Emisión AP-42	Cuestionario/Factores De Emisión	CO, NOx, SOx, COV, NH_3 y Partíc.
FERROCARRILES	Cuestionario/Factores De Emisión AP-42	Cuestionario/Factores De Emisión	CO, NOx, SOx, COV, NH_3 y Partíc.
BARCOS COMERCIALES	Cuestionario/Factores De Emisión AP-42	Cuestionario/Factores De Emisión	CO, NOx, SOx, COV, NH_3 y Partíc.
MAQUINARIA AGRICOLA	Cuestionario/Modelo multivariado	Cuestionario/Modelo multivariado	CO, NOx, SOx, COV, NH_3 y Partíc.
MAQUINARIA DE CONSTRUCCION	Cuestionario/Modelo multivariado	Cuestionario/Modelo multivariado	CO, NOx, SOx, COV, NH_3 y Partíc.
MAQUINARIA INDUSTRIAL	Cuestionario/Modelo multivariado	Cuestionario/Modelo multivariado	CO, NOx, SOx, COV , NH_3 y Partíc.
EQUIPO COMERCIAL LIGERO	Cuestionario/Modelo multivariado	Cuestionario/Modelo multivariado	CO, NOx, SOx, COV , NH_3 y Partíc.
EQUIPO DE JARDINERIA	Cuestionario/Modelo multivariado	Cuestionario/Modelo multivariado	CO, NOx, SOx, COV , NH_3 y Partíc.
EQUIPO DE RECREACION	Cuestionario/Modelo multivariado	Cuestionario/Modelo Multivariado	CO, NOx, SOx, COV, NH_3 y Partíc.
BARCOS DE RECREACION	Cuestionario/Modelo multivariado	Cuestionario/Modelo multivariado	CO, NOx, SOx, COV, NH_3 y Partíc.

METODOS PROPUESTOS PARA FUENTES NATURALES

CATEGORIA PRINCIPAL	*RECOMENDACIONES A CORTO PLAZO*	*RECOMENDACIONES A LARGO PLAZO*	*CONTAMINANTES A ESTIMAR*
COV DE VEGETACION	Modelo multivariado	Modelo multivariado	COV
PARTICULAS DE EROSION/VIENTO	Modelo multivariado	Modelo multivariado	Partíc.
NOx DE SUELO	Modelo multivariado	Modelo multivariado	NOx
NH_3 DE SUELO	Modelo multivariado	Modelo multivariado	NH_3
TORMENTAS	NO APLICA	Modelo mecanístico	NOx
ORIGEN GEOGENICO	NO APLICA	Investigación de campo	SOx, COV y Partíc.

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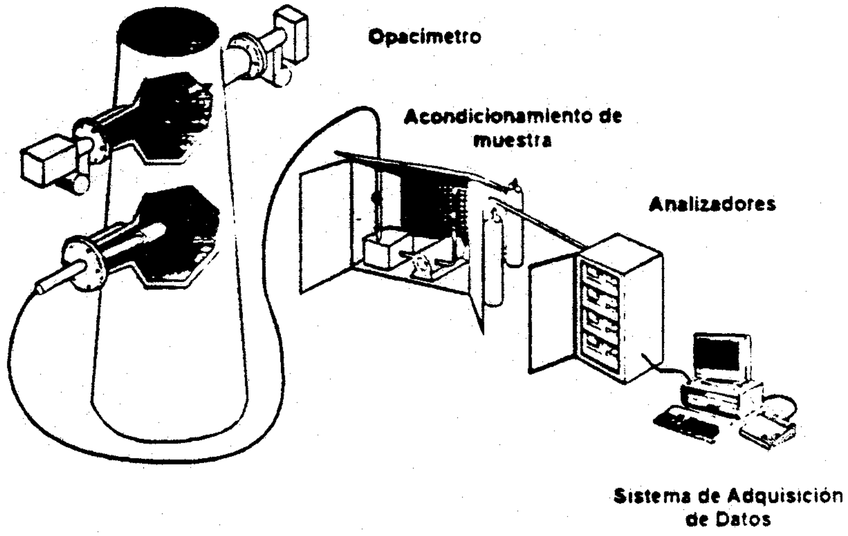
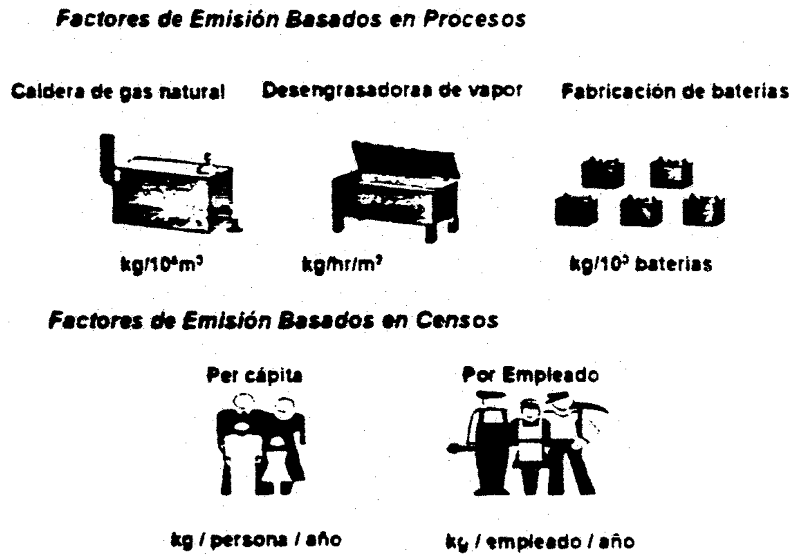
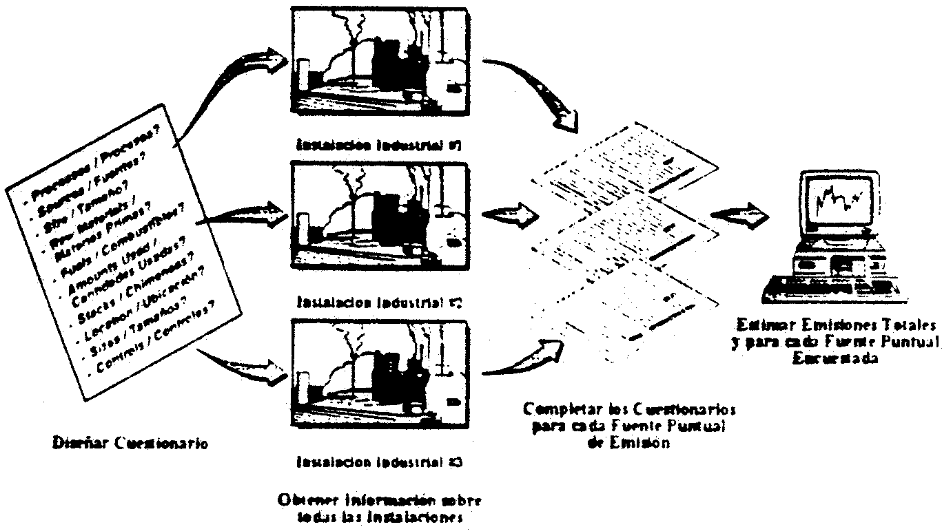


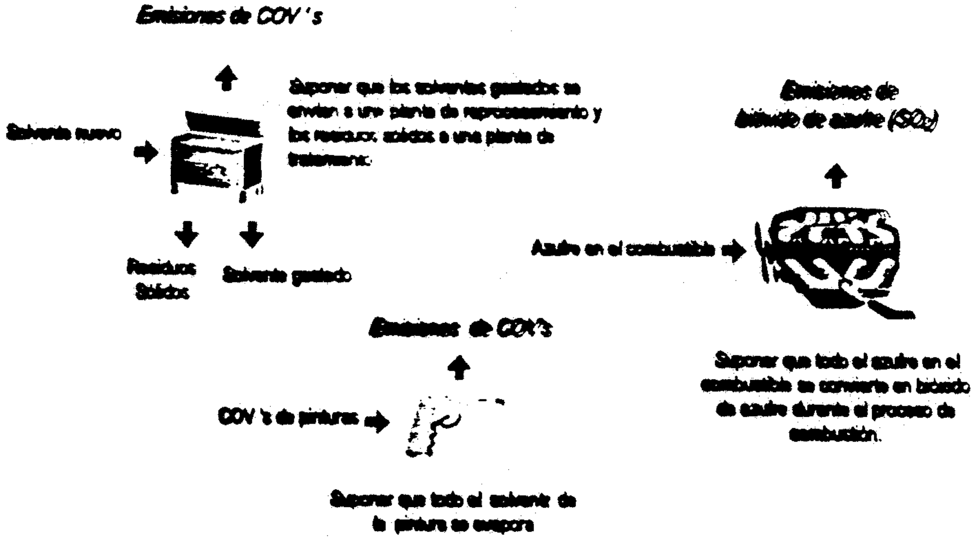
Ejemplos de Factores de Emisión



Ejemplo de Encuesta de Fuentes Puntuales



Ejemplos de Balance de Materiales

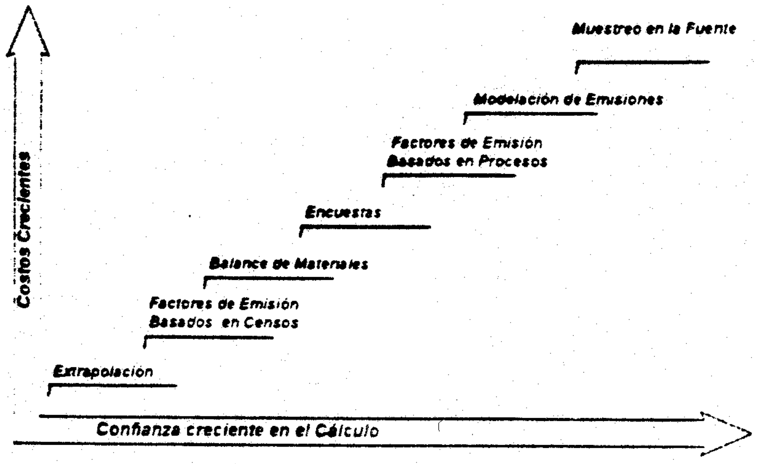


Suponer que los solventes gastados se envían a una planta de reprocesamiento y los residuos sólidos a una planta de tratamiento.

Suponer que todo el solvente de la pintura se evapora

Suponer que todo el azufre en el combustible se convierte en bióxido de azufre durante el proceso de combustión.

Jerarquías para la Estimación de Emisiones



II. Fuentes Puntuales	*Notas*
Definición de Fuentes Puntuales · **Fuentes puntuales son instalaciones, plantas o actividades para las cuales se mantienen registros individuales** · **Lo ideal sería tener registros individuales para todas las instalaciones industriales** · **En realidad, numerosas instalaciones pequeñas dentro de una región se tratan frecuentemente como fuentes de área** **Definición de Fuentes Puntuales (Continuación)** · **En México las fuentes no están clasificadas de manera estricta.** · **A partir de las enmiendas al Acta del Aire Limpio de 1990 (Clean Air Act; EPA de los EE.UU.)** > **Emisiones de COV's > 10 toneladas por año** > **Emisiones de NO_X y CO > 100 toneladas por año** > **Distingue niveles de corte para SO_X, Pb, PS/PM_{10} y contaminantes atmosféricos tóxicos** **Tipos de Fuentes Puntuales** · **Categorías Mayores** > **Plantas Termoeléctricas** > **Industria Química** > **Refinerías de Petróleo** > **Producción de Metales (Primaria/Secundaria)** > **Producción de Cemento** > **Productos Minerales Diversos** **Tipos de Fuentes Puntuales** · **Categorías Mayores (continuación)** > **Industria de los Vehículos Automotores** > **Operaciones de Preparación de Pulpa de Madera** > **Producción de Gas y Petróleo** > **Impresión y Publicaciones** > **Recubrimiento de Superficies** > **Terminales de Combustible**	

Tipos de Fuentes Puntuales

- **Categorías Mayores (continuación)**
    - **Minería y Explotación de Canteras**
    - **Manufactura de Productos de Madera**
    - **Producción de Azúcar**
    - **Curtiduría y Acabado de Pieles**
    - **Producción de Vidrio**
    - **Partes de Hule y de Plástico**

Tipos de Fuentes Puntuales

- **Categorías Mayores (continuación)**
    - **Fabricación de Partes Metálicas**
    - **Productos Textiles**
    - **Disposición de Residuos Sólidos**
    - **Agricultura y Alimentos**
    - **Plantas de Asfalto**

Tipos de Fuentes Puntuales

- **Subcategorías**
    - **Emisiones de Combustión**
    - **Emisiones de Procesos**
    - **Emisiones Fugitivas**
    - **Emisiones de Tanques de Almacenamiento**
    - **Uso de Solventes Variados**

Planeación de un Inventario de Fuentes Puntuales

- **Definir fuentes y categorías por inventariar**
- **Considerar usos finales/futuros del inventario**
- **Determinar recursos humanos y presupuesto disponible**

Desarrollar un plan de aseguramiento de la calidad (AC)

Planeación de un Inventario de Fuentes Puntuales (Continuación)

- **Identificar procedimientos AC/CC para el desarrollo de inventarios**
- **Determinar análisis de datos y verificación de métodos**
- **Determinar manejo de datos y procedimientos para rendir informes**
- **Seleccionar métodos de recolección de datos**

Planeación de un Inventario de Fuentes Puntuales (Continuación)

- **Revisar requerimientos del sistema de cómputo para asegurar la capacidad de recolección de datos**
- **Determinar el papel del inventario de datos existente**
- **Identificar fuentes y datos omitidos previamente**
- **Determinar cuales fuentes serán inventariadas como puntuales y cuales como fuentes de área**

Proceso para el Desarrollo de Inventarios de Fuentes Puntuales

Alcance del Inventario

- **Las fuentes puntuales pueden ser inventariadas a tres niveles de detalle**
  - **Nivel Planta**
  - **Nivel Proceso o "de segmento"**
  - **Nivel Puntual o “de chimenea”**

Elementos de Información

- **Nivel Planta**
  - **Nombre de la planta**
  - **Identificación de la planta**
  - **Descriptores geográficos**
  - **Contacto en la planta (nombre y número de teléfono)**
  - **Nivel de corte de emisiones de fuente puntual por contaminante**

Elementos de Información

- Nivel proceso/segmento
  - Número de identificación del proceso (Código de Clasificación de Fuentes [Source Classification Code SCC])
  - Datos a nivel de proceso
  - Datos de Operación (real, máxima y de diseño)
  - Parámetros del combustible
  - Equipo de control y eficiencias
  - Emisiones por segmento
  - Unidades de emisión

Elementos de Información

- Nivel puntual/chimenea
  - Producción anual porcentual (estacional)
  - Horario de operación normal
  - Emisiones medidas/estimadas
  - Eficiencia de control por contaminante
  - Datos de chimenea

Identificación de Fuentes Puntuales

- Inventarios Existentes
  - Delegaciones SEMARNAP
  - INE/SEMARNAP
- Datos licencia / cumplimiento
- Listas de fuentes SEMARNAP - Normas Oficiales Mexicanas (NOM's)
- Información local
  - Listas de las Cámaras de Comercio y de las Cámaras de Industriales
- Publicaciones
- Asociaciones Profesionales

Factores que Influyen en las Emisiones

- **Factores de Diseño y de Proceso**
  - **Características de la combustión**

los productos de combustión dependen del tipo de combustible, tipo de horno, configuración de la carga y las condiciones de operación

- La NOM-085-ECOL-1994 establece límites para las emisiones de combustión
- La NOM-086-ECOL-1994 define las especificaciones para los combustibles fósiles líquidos y gaseosos
- Las especificaciones para gas natural y productos de petróleo varían por región geográfica

Factores que Influyen en las Emisiones

- **Antigüedad del equipo**
- **Prácticas de operación**
- **Materias primas**
- **Datos meteorológicos/climatológicos**
- **Uso de combustibles en el proceso**
  - **Ejemplos:**
    - secadores de los pellets en las plantas de negro de humo.
    - secadores calentados con gas natural en operaciones de recubrimiento
- **Componentes con emisiones fugitivas**
  - **Bombas, válvulas, válvulas de alivio, bridas, compresoras**

Procesos que por lo general se omiten (Continuación)

- **Dispositivos de control**
  - **Dispositivos usados como parte de los procesos de manufactura y no para control de la contaminación del aire**
  - **Dispositivos que actúan como dispositivos de control y como fuentes de emisión (mecheros, quemadores de CO)**
- **Uso de solventes variados**
- **Emisiones de vehículos presentes en el sitio**

Procesos que por lo general se omiten (Continuación)

- **Aditivos del proceso**
  - **Sustancias químicas añadidas a los procesos de producción o de control**
- **Pilas de almacenamiento**
  - **Son fuente de partículas si no están cubiertas**
- **Manejo de materiales**
  - **Materiales sin cubrir transportados en camiones o en vagones**
  - **Bandas transportadoras, sistemas de transporte neumático**

Eficiencia Control/Captura

La eficiencia de control indica el porcentaje del contaminante que es removido de la corriente de emisión antes de que ésta sea liberada a la atmósfera

- **La eficiencia de captura indica el porcentaje de la corriente de emisión que es llevada al equipo de control**
- **Eficiencia total = eficiencia de control x eficiencia de captura**

Eficiencia Control/Captura

- **La eficiencia control/captura puede ser calculada basándose en:**

Pruebas del equipo llevadas a cabo en las instalaciones o a partir de pruebas hechas en equipos similares en otras instalaciones

  - **Estimaciones a partir de las especificaciones del fabricante o de valores hallados en la bibliografía**
  - **Juicio con criterio de ingeniería**

Eficiencia Control/Captura

- **La Eficiencia Control/Captura puede ser calculada basándose en:**
  - **Muestreo en la fuente**
  - **Diseño del fabricante o especificaciones de funcionamiento garantizadas**
  - **Valores en la bibliografía**

Equipo de Control (para partículas)

- **Ciclón**
- **Filtros de tela**
- **Precipitador electrostático**
- **Lavador**

Equipo de Control (para gases)

- **Absorción**
- **Adsorción**
- **Condensación**
- **Incineración**
- **Reducción selectiva**

Datos de Chimenea

- **Parámetros de la chimenea que usualmente se requieren para modelado**
  - **localización de la chimenea**
    - sistema de geoposicionamiento (geopositioning system [GPS])
    - datos de reconocimientos/mapas CAD
    - mapas topográficos

Datos de Chimenea (Continuación)

- **Altura de la chimenea**
  - **clinómetro**
  - **diámetro**
  - **dibujos de ingeniería**
- **Diámetro de la chimenea**

Datos de Chimenea (Continuación)

- **Temperatura de los gases de salida**
- **Velocidad de salida de los gases**
- **Tasa de flujo de los gases de salida**

Eficacia de la Regla

La Eficacia de la Regla (ER) es una medida de la habilidad de un programa regulatorio para lograr reducciones de las emisiones gracias al cumplimiento cabal de las regulaciones aplicables a todas las fuentes durante todo el tiempo

- **La ER refleja la suposición de que por lo general las regulaciones no son 100 porciento efectivas**
- **Las fuentes que están completamente sin control deben tener una ER de cero**

Eficacia de la Regla

- **Los cambios en los procesos irreversibles que eliminen el uso de COV's deben tener una ER de 100 porciento**
- **Métodos para calcular la ER de un inventario**
  - **Usar un valor asumido**
    - La EPA de los EE.UU. sugiere un valor asumido de 80%
  - **Usar un estudio específico para una categoría y un área geográfica**

Eficacia de la Regla

- **Ejemplo de aplicación de la ER**
  - **Emisiones sin control = 50 kg/día**
  - **Eficiencia estimada del dispositivo de control = 90%**
  - **Eficacia de la norma = 80%**
  - **Emisiones después del control = 50 kg/día x [1-(0.90)x(0.80)] = 14 kg/día**

Otros Parámetros

- **Exclusión de COV’s no reactivos**
  - **Algunos COV’s son considerados no reactivos en condiciones atmosféricas**

Otros Parámetros

Métodos de Estimación de Emisiones

- **Corto plazo:**
  - **Muestreos en la fuente (Directos e Indirectos)**
    - plantas termoeléctricas
    - refinerías de petróleo (emisiones del proceso)
    - producción primaria de metales (emisiones del proceso)
    - incineradores de residuos municipales
  - **Encuestas/Factores de Emisión**
    - la mayor parte de las fuentes

Métodos de Estimación de Emisiones

Corto plazo (continuación):

- **Balance de materiales**
  - **emisiones de COV's del uso de solventes para recubrimientos superficiales a nivel de la planta**
- **Modelos mecanísticos**
  - **tanques de almacenamiento de líquidos orgánicos**
  - **rellenos sanitarios**
- **Modelos de Variables Múltiples**

- emisiones fugitivas petroquímicas (válvulas, bridas, compresoras)

Métodos de Estimación de Emisiones

- **Largo plazo:**
  - **Muestreo en la fuente (Directos e Indirectos)**
  - **Encuestas/Factores de Emisión**
  - **Balance de Materiales**
  - **Modelos Mecanísticos**

Ejemplo de Cálculo: Factores de Emisión

- **Estimar las emisiones contaminantes provenientes de una planta de energía eléctrica que usa combustóleo como combustible:**
  - **Suponer las siguientes características de la planta:**
    - 750 m^3 de combustóleo/año
    - % de azufre del combustóleo 3.8

Ejemplo de Cálculo: Factores de Emisión

- **(01) Partículas**
- **(05) SO_2**
- **(10) CO**
- **(15) NOx**
- **(20) HC**

Ejemplo de Cálculo: Factores de Emisión

> **Partículas**

- **FE PST = 4.88 Kg PST/m^3 combustóleo**

Kg PST=4.88 Kg PST/m^3 x 750 m^3=3,660

> **SO_2**

- **FE SO_2 = 19(3.8) = 72.2 Kg SO_2/m^3 combustóleo**

Kg SO_2= 72.2 Kg SO_2/m^3 x 750 m^3= 54,150

Ejemplo de Cálculo: Factores de Emisión

> **CO**

- **FE CO = 0.6 Kg CO/m^3 combustóleo**

Kg CO= 0.6 Kg CO/m^3 x 750 m^3= 450

> **NOx**

- **FE NOx = 15 Kg NOx/m^3 combustóleo**

Kg NOx=15 Kg NOx/m^3 x 750 m^3= 11,250

Ejemplo de Cálculo: Factores de Emisión

> **HC**

- **FE HC = 0.12 Kg HC/m^3 combustóleo**

Kg HC= 0.12 Kg HC/m^3x 750 m^3= 450

Ejemplo de Cálculo: Muestreo en la Fuente

- **Estimar emisiones de COV a partir de Medición en una empresa de recubrimiento de papel:**
  - **Equipo de recubrimiento que usa solventes orgánicos**
  - **Solvente componente único**
  - **1 líneas de recubrimiento**
  - **La línea con chimenea y dispositivo de control dedicados**
  - **La planta opera 16 hrs/día, 312 días/año**

Ejemplo de Cálculo: Muestreo en la Fuente

- **Datos de prueba en la fuente para la línea**
  - **controlada con un adsorbedor de carbón**
  - **Tasa de flujo (Q_a) = 283.2 m3/s**
  - **Concentración a la salida controlada (C) = 96 ppm (tolueno)**
  - **Peso molecular (MW) tolueno = 92 Kg/*Kg*-mol**

Ejemplo de Cálculo: Muestreo en la Fuente

- **Datos de prueba en la fuente para la línea**
- **Eficiencia de captura de las emisiones fugitivas (CAP_{eff}) = 90%**
- **Tasa de emisión en la chimenea (E_a) después del dispositivo de control**
  - **μg/m^3 = (ppm) x (PM) x (1000) / 24.5**

    μg/m^3 = (96) x (92) x (1000)/24.5

    μg/m^3 =360,489.8
  - **μg/hr= 360,489.8 μg/m^3 x (283.2 m^3/s)x (3600s/hr)**

    μg/hr = 3.67 10^{11}

Ejemplo de Cálculo: Muestreo en la Fuente

  - **Kg/hr = 3.67 10^{11}μg/hr x (1 gr/10^6μg) x (1Kg/1000 gr)**
- **= 367**
  - **E_a (anual) = (367 Kg/hr) x (16 hr/día) x (312 día/año)**

    = 1,832,064 Kg/año

Cálculo de Emisiones

- **Modelos Mecanísticos**
  - **Utilizan principios químicos y físicos y el conocimiento del proceso tecnológico**
  - **Se usan por lo general para el almacenamiento y transferencia de líquidos orgánicos**

Cálculo de Emisiones (Continuación)

- **Modelos de Variable Múltiple**

Metodología híbrida que combina varios enfoques tradicionales de inventario e información específica del sitio dentro de un marco de extrapolación

- Las estimaciones de las emisiones se expresan en términos de un conjunto de variables que ayudan a caracterizar al sistema

Recolección de Datos

- **Encuestas**
- **Inspecciones de la planta**
- **Otros inventarios**

Encuestas

- **Las mas eficientes son formas para recolección de datos y cuestionarios**
- **Las formas pueden servir como documentación de antecedentes**
- **Pueden ser genéricas o específicas para un tipo de industria o de dispositivo**

Encuestas Generales

- **Cuando usarse:**
  - **cuando se trata de hacer el reconocimiento de un gran número de instalaciones**
  - **cuando la agencia no está familiarizada con muchas de las fuentes**
  - **cuando los recursos de la agencia son limitados**

Encuestas Generales

- **Desarrollo de encuestas:**
  - **Establecer un formato adecuado y simple**
  - **Definir preguntas apropiadas**
  - **Elaborar una documento con instrucciones**
  - **Diseñar el cuestionario para el nivel técnico correcto**

Encuestas Generales

- Desarrollo de cuestionarios (continuación):
  - Hacer el cuestionario lo mas corto posible
  - Asegurarse de que las preguntas no requieren de explicaciones adicionales
  - Solicitar información de los procesos
  - Obtener datos de actividad para cada tipo de fuente
  - Obtener información de los dispositivos de control

Encuestas Específicas por Industria

- Ventajas
  - Generalmente son más cortas
  - Pueden usar terminología específica de la industria lo que mejora la comunicación
- Desventajas
  - Su diseño puede requerir recursos considerables
  - Las formas contestadas deben ser procesadas individualmente
  - Las encuestas pueden ser enviadas a una industria incorrecta

Formas de Recolección de Datos a Nivel de Instalación

- Encuestas INE de fuentes puntuales
- Datos integrados en la base de datos SNIFF

Formas de Recolección de Datos a Nivel de Dispositivo

- Pueden ser distribuidos en blanco o pueden ser completados parcialmente por la agencia basándose en información colectada previamente
- Apropiadas para actualizaciones periódicas (mensual, anual, etc.)

Codificación de Datos

- Durante la etapa de recolección de datos se deben desarrollar procedimientos para su codificación, almacenamiento y recuperación

- **El uso de códigos únicos asegura que los datos sean mantenidos y recuperados apropiadamente**
- **Los datos deben estar en un formato reconocible y consistente**
- **Un sistema útil de codificación de datos debe permitir:**
    - **La identificación del tipo de datos incluídos**
    - **El almacenamiento y recuperación de datos específicos**

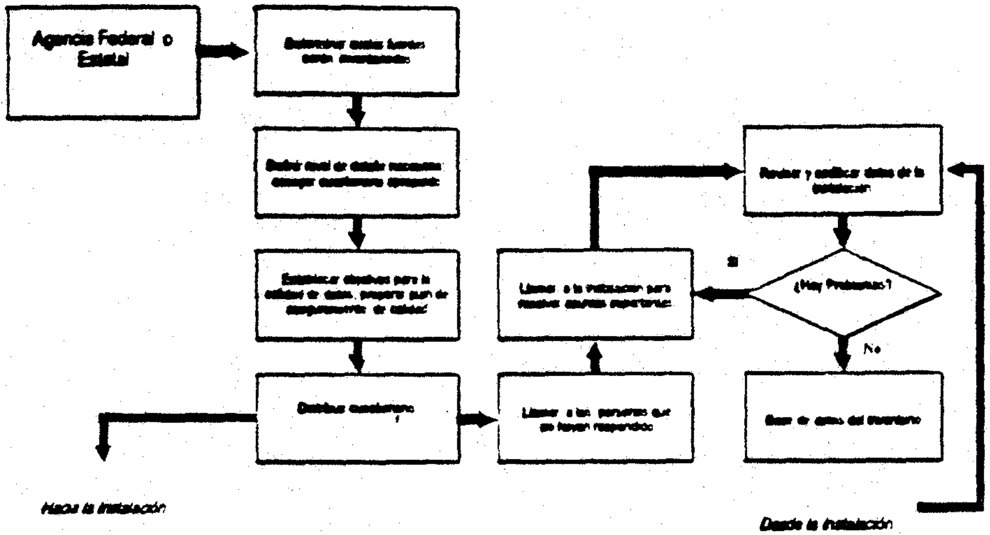
Bases de Datos de los Inventarios

- **Base de Datos del Sistema Nacional de Información de Fuentes Fijas (SNIFF)**
    - **Base de datos actual de la información obtenida con los cuestionarios industriales INE**
    - **permite la entrada de datos para cinco contaminantes criterio**
    - **Los códigos de datos fueron desarrollados por el INE y están listados en catálogos**

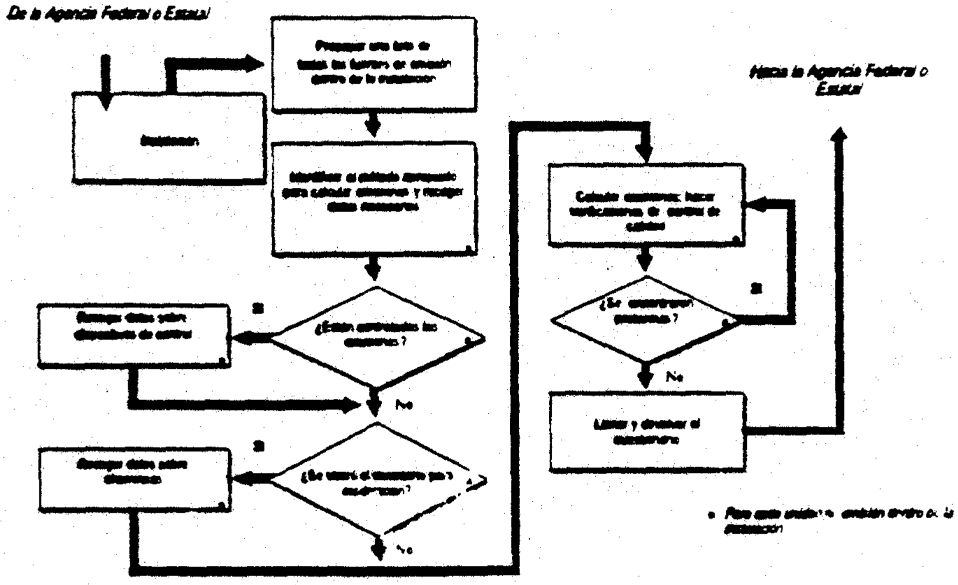
Codificación de Datos

- **Se podría considerar un método mas preciso y descriptivo para la identificación de la actividad industrial**
- **Ejemplo - Código para Clasificación de Fuentes (Source Classification Code System [SCC])**

Proceso para el Desarrollo de Inventarios de Fuentes Puntuales



Proceso para el Desarrollo de Inventarios de Fuentes Puntuales



III. Fuentes de Área

Notas

Definición de Fuente de Área

- Las fuentes de área son aquellas demasiado pequeñas y numerosas para ser manejadas individualmente como fuentes puntuales
- Las fuentes de área pueden clasificarse en tres grandes grupos :
  - De combustión (de combustibles fósiles)
  - Evaporativas
  - De partículas fugitivas

Tipos de Fuentes de Área

- Ejemplos de fuentes de combustión:
  - combustión en fuentes estacionarias
    - Industrial y comercial
    - Combustibles comerciales para uso residencial
    - Combustibles para uso residencial derivados de residuos ó de biomasa
  - Tratamiento de residuos (incineración)
    - Manejo de residuos (incineración in situ)
    - Disposición de residuos (quema de basura)
  - Quemas agrícolas / forestales / de estructuras

Tipos de Fuentes de Área

- Ejemplos de fuentes evaporativas:
  - Uso doméstico de gas LP
  - Uso de solventes orgánicos
    - Solventes de tipo comercial
    - Recubrimiento de superficies y solventes para Limpieza (industrial)
    - Limpieza industrial de superficies (desengrasado)
    - Tintorerías

Tipos de Fuentes de Área

- Ejemplos de fuentes evaporativas (continuación)
  - Almacenamiento y distribución de materiales orgánicos
    - Tanques de almacenamiento
    - Carga / descarga
    - Fugas de tuberías, estaciones de servicio y camiones
  - Tratamiento y disposición de residuos
  - Fermentación

Tipos de Fuentes de Área

- Ejemplos de fuentes de partículas fugitivas
  - Caminos, pavimentados y no pavimentados
  - Pilas de almacenamiento
  - Producción agrícola
  - Construcción de edificios

Planeación de Inventarios de Fuentes de Área

- Definir las categorías de fuentes por inventariar
  - Determinar los contaminantes emitidos
  - Jerarquizar las categorías basándose en el potencial de las emisiones

Planeación de Inventarios de Fuentes de Área

- Identificar las categorías con componentes de fuentes puntuales
- Identificar las regulaciones que afectan a las emisiones
- Identificar el método que se usará para hacer los cálculos de emisión
- Definir los procedimientos de aseguramiento y control de calidad (AC/CC) para hacer los inventarios de fuentes de área

Planeación de Inventarios de Fuentes de Área

- Definir los datos por recolectar:
  - Factores de emisión
  - Datos de actividad
  - Eficiencias de control
  - Efectividad / Penetración de la regla
  - Rendimiento por período
  - Horarios de operación (p.ej., días por semana y semanas por año)

Guías para Realizar Inventarios de Fuentes de Área

- Desarrollo de Inventarios de Emisiones; Manual de Fuentes de Área (Volumen V)
- Documentos de procedimientos para el desarrollo de Inventarios de emisiones de la Agencia de Protección ambiental de los EE.UU.
- Boletín CHIEF de la Agencia de Protección Ambiental de los EE.UU.
- Métodos del plan de mejoramiento de los inventarios de Emisiones (EIIP) de los EE.UU.
- Técnicas rápidas para realizar Inventarios de fuentes (Economopoulos, 1993)

Influencias Geográficas y Otras, en México

- Las fuentes de área no son homogéneas desde el punto de vista geográfico
  - Es probable que los inventarios de emisiones desarrollados para la Ciudad de México no sean aplicables a otras regiones
- Los datos de actividad y los factores de emisión basados en censos son muy inciertos
  - Los datos de diversas regiones geográficas pueden variar debido a diferencias socio-económicas y culturales

Influencias Geográficas y Otras, en México

- La carencia de factores de emisión específicos para México
  - Se desconoce la aplicabilidad de los factores de emisión de los EE.UU. en México
- Existen fuentes características de México que nunca antes han sido inventariadas:
  - Tortillerías
  - Quema de basura a cielo abierto en tiraderos
  - Baños públicos
  - Vendedores ambulantes
  - Ladrilleras

Recolección de Datos

- Investigar categorías para elaborar factores de emisión
- Identificar factores de emisión y factores de actividad para esas fuentes de emisión
- Investigar categorías para obtener información de actividad
- Recolectar datos de actividad, eficiencias de control y otra información que sea necesaria

Jerarquizar los Esfuerzos para la Recolección de Datos

- Concentrarse en recolectar información detallada sobre las categorías de fuentes que :
  - Sean las mayores contribuyentes individuales de emisiones
  - Tengan datos locales de actividad rápidamente disponibles
- Generalizar cuando:
  - Las emisiones de las diferentes categorías de fuentes, como un todo, sean pequeñas

Factores de Emisión

- Factores nacionales de emisión
  - Se basan en "promedios nacionales" calculados a partir de una amplia gama de evaluaciones en la fuente así como de estimaciones nacionales de consumos
  - Las emisiones reales pueden diferir considerablemente de los valores que se calculan usando factores nacionales de emisión debido a las diferencias geográficas
  - Cuando están disponibles, siempre se prefieren los datos de evaluaciones en fuentes específicas

Factores de Emisión (continuación)

- Los factores nacionales de emisión pueden usarse cuando:
  - No existen factores locales de emisión
  - La mezcla local de fuentes individuales en la categoría es semejante al "promedio nacional"
  - La categoría de la fuente es de baja prioridad

Factores de Emisión (continuación)

- Los factores locales de emisión se prefieren cuando:
  - Un factor de emisión a nivel nacional no explica las variaciones locales
  - La categoría es de alta prioridad para el área local
- La disponibilidad de factores locales de emisión en México es muy limitada

Factores de Emisión (continuación)

- Para obtener factores locales de emisión:
  - Usar mediciones o encuestas para estimar tasas de emisión para todas las fuentes en una categoría particular
  - Un Estado o una localidad pueden desarrollar un protocolo de pruebas para medir una fuente y a partir de esas mediciones desarrollar un factor de emisión
  - Desarrollar estimaciones basadas en los consumos locales para la categoría de solventes
  - Adaptar información de otros inventarios

Factores de Emisión (continuación)

- Actualización de los factores de emisión
  - Los factores de emisión deben actualizarse cuando la tasa de emisiones de una fuente ha cambiado respecto a la actividad
    - Por ejemplo, si el uso de un solvente industrial por empleado se ha reducido durante los 80's a causa del aumento en el uso de productos de base agua, un factor de emisión viejo basado en la actividad de los empleados no reflejará el cambio

Factores de Emisión (continuación)

- Para desarrollar un factor de emisión actualizado :
  - Identificar el cambio (p. ej., aumento reducción)
  - Estimar la magnitud del cambio en las emisiones
  - Ajustar el factor de emisión para reflejar el cambio

Datos de Actividad

- Actividad es la medida de una categoría de fuentes que constituye un indicador directo o sustituto de las emisiones
  - La actividad puede ser una medida directa de la producción o del uso de un material (p. ej., la cantidad de combustible quemado, de gasolina vendida, o de solvente usado)
  - La actividad puede ser una medida sustituta, basada en promedios nacionales (p. ej., población, empleo en la industria)

Datos de Actividad (continuación)

- Ejemplos de datos de actividad sustitutos :
  - Población
  - Número de empleados
  - Número de hogares
  - Número de instalaciones

Datos de Actividad (continuación)

- Recolectar datos de actividad:
  - Usar las encuestas para obtener información de las fuentes
  - Recolectar la información a partir de referencias, de autoridades gubernamentales, de asociaciones comerciales
  - Ajustar los datos de nivel nacional, estatal o regional para usarlos a nivel municipal
  - Usar los factores sustitutos para estimar la actividad

Datos de Actividad (continuación)

- Fuentes potenciales para obtener información de actividad
  - Instituto Nacional de Estadística, Geografía e Informática (INEGI)
    - Datos de población y vivienda
    - Datos de empleo por municipio y por sector económico
  - Cámara Nacional de la Industria de la Transformación (CANACINTRA)
  - Datos de empleo en la industria manufacturera, específicos para cada instalación (por sector económico)

Eficiencias de Control

- Los controles para una categoría de fuentes de área puede variar ampliamente
- La eficiencia de control para las fuentes de área representa el control promedio ponderado para la categoría

Eficacia de la Regla

- La eficacia de la Regla (ER) es una medida de la capacidad de un programa de regulación para lograr reducciones de las emisiones, lo que es posible a través del cumplimiento pleno de las regulaciones aplicables por todas las fuentes, en todo momento
- La ER refleja la suposición de que, por lo general, las regulaciones no son 100 por ciento efectivas
- Las fuentes totalmente sin control deberían tener una ER igual a cero

Eficacia de la Regla (continuación)

- Los cambios irreversibles que eliminan el uso de COV's en los procesos deberían dar como resultado una ER de 100 por ciento
- Métodos para calcular la ER de los inventarios:
  - Usar un valor por omisión
  - La Agencia de Protección Ambiental de los Estados Unidos sugiere un valor por omisión de 80%
  - Usar un estudio específico para una categoría y área geográfica

Eficacia de la Regla (continuación)

- Ejemplo: Emisiones no controladas = 50 kg / día
  - > Eficiencia estimada del equipo de control = 90%
  - > Eficacia de la regla = 80%
  - > Emisión después del control = 50 kg / día x [1-(0.90) x (0.80)] = 14 kg / día

Penetración de la Regla

- La penetración de la regla (PR) es el porcentaje de la categoría de fuentes de área cubierto por la regulación aplicable
- Ambos ER y PR se aplican a la totalidad de categorías de fuentes
- Las categorías de fuentes para las que no existe regulación no tendrían un factor ER o uno PR asociado con ellas

Otros Parámetros

- Rendimiento del período
  - > Determinar si hay variación estacional en los datos de actividad
  - > Las variaciones estacionales son importantes para las estaciones con niveles altos de ozono (meses más cálidos)
- Horarios de Operación
  - > Horas de operación en días por semana, semanas por año
  - > Necesarios para calcular las emisiones diarias
- Carga de Combustible
  - > A partir de información de agencias locales y estatales
  - > AP-42
  - > Boletín electrónico CHIEF

Métodos para la Estimación de Emisiones

- A corto plazo:
  - > Factores de emisión basados en censos y datos de actividad
    - – Recubrimiento de superficies (no industrial)
    - – Tintorerías
    - – Solventes comerciales usados por consumidores
    - – tortillerías
- Por Encuestas
  - – Cuando el enfoque basado en censos no está disponible
  - – Cuando es muy probable que el enfoque basado en censos introduzca un muy alto grado de incertidumbre si se aplica en México (p. ej., polvo de carreteras no pavimentadas, incendios)

Métodos para la Estimación de Emisiones

- A corto plazo (continuación):
  - Balances de materiales
    - Consumo de combustible, comercial e industrial
    - Para apoyar el modelado de emisiones provenientes del almacenamiento y transporte de materiales
    - Para verificar si son razonables las estimaciones de emisiones basadas en extrapolaciones en el caso del recubrimiento de superficies y del uso de solventes
  - Modelos mecanísticos
    - Almacenamiento y transporte de líquidos orgánicos
    - Rellenos sanitarios
  - Extrapolación
    - Recubrimiento de superficies y uso de solventes (industrial)

Métodos para la Estimación de Emisiones

- A largo plazo
  - Balance de materiales
    - consumo de combustible, comercial e industrial
    - para apoyar en la modelación de emisiones provenientes del almacenamiento y transporte de materiales

Métodos para la Estimación de Emisiones

- A largo plazo (continuación)
  - Modelos mecanísticos
    - almacenamiento y transporte de líquidos orgánicos
    - rellenos sanitarios
  - Modelos de variable múltiple
    - la mayoría de tipos de fuentes fijas de área
    - fomentan el desarrollo de modelos basados en datos específicos de México
    - se requieren encuestas para recolectar los datos para el desarrollo de los modelos

Ejemplo de Balance de Materiales Destacando las Emisiones Fugitivas

Cálculos de Emisiones

- Modelos mecanísticos
  - Se utilizan principios de química y física, así como la comprensión de la tecnología del proceso
  - Se usan con mayor frecuencia para el almacenamiento de líquidos orgánicos
  - La EPA de los EE.UU. ha desarrollado métodos estándar que están disponibles como software para computadora

Cálculos de Emisiones

- Modelos mecanísticos (continuación)
  - Modelos de la EPA (EE.UU.) disponibles para computadora :
    - Sistema de modelado de embalses superficiales (SIMS)
    - TANKS: Programa para la estimación de emisiones de tanques de almacenamiento
    - Modelo para la Estimación de emisiones al aire de rellenos sanitarios (LAEEM)

Ejemplo de Modelo Mecanístico

Cálculos de Emisiones

- Extrapolación
    - Los datos de muestreo en la fuente para una instalación o tipo de proceso pueden extrapolarse para otros tipos de fuentes o de instalaciones
    - Si las condiciones socioeconómicas entre dos o más regiones geográficas son comparables, entonces los datos disponibles de emisiones de una fuente de área para una región pueden ser extrapolados a las regiones restantes
    - Basados en datos de población o datos de empleo

Ejemplos de Extrapolación

Cálculos de Emisiones

- Modelos de variable múltiple
  - *Primer paso*: Identificar las variables que caracterizan el sistema global
  - Ejemplos:
    - Actividades agrícolas (tipo de cultivo, área de cultivo, cantidad de cosecha)
    - Actividades de construcción (tipo de construcción, tamaño de construcción, valor monetario)

Cálculos de Emisiones

- Modelos de variable múltiple (continuación)
  - *Segundo paso*: Determinar qué tipos de fuente de emisión se incluirán en el modelo
  - Ejemplos:
    - Actividades agrícolas (cultivos agrícolas)
    - Actividades de construcción (remoción de tierra, manejo de materiales, escapes de los equipos)

Cálculos de Emisiones

- Modelos de variable múltiple (continuación)
  - > *Tercer paso*: Determinar emisiones para un número de sitios
  - > *Cuarto paso*: Graficar las emisiones totales estimadas de cada sitio versus cada variable que caracteriza al sistema
    - – El “Mejor-Ajuste” del factor de emisión para cada variable de sitio (p. ej., kg de PM_{10} / $ de construcción de edificios)
  - > *Quinto paso*: Estimar las emisiones regionales multiplicando los datos de actividad regional por el mejor ajuste de los factores de emisión

Ajustes en las Fuentes de Área

- Ajustes temporales
- Reconciliación con las fuentes puntuales

Ajustes Temporales

- Ajustes estacionales
  - > Se basan en factores estacionales que afectan a las emisiones: temperatura, horas de luz solar, actividad estacional
- Distribución temporal
  - > Ajustes estacionales para valores anuales
  - > Ajustes por día de semana / fin de semana / diarios
  - > Ajustes horarios/diurnos

Reconciliación con las Fuentes de Puntuales

- Métodos de reconciliación con las fuente puntuales
  - > Ajustar niveles de actividad antes de aplicar los factores de emisión
  - > Ajustar las emisiones no controladas de fuentes de área después de que se han calculado substrayendo las emisiones no controladas de fuentes puntuales
- En ambos casos, aplicar la eficacia de la regla, la penetración de la regla y la eficiencia del control después de hacer el ajuste de las fuentes puntuales

Reconciliación con las Fuentes de Puntuales

- Ejemplo: Operaciones de recubrimiento de superficies
  - > Determinar el número total y cantidad de recubrimientos de superficies usados en un área geográfica dada
  - > Determinar el número y cantidad de recubrimientos de superficies usados por las fuentes puntuales
  - > Restar las cantidades correspondientes a las fuentes puntuales por cada recubrimiento:
    - – Uso total (litros / año) - Uso de fuentes puntuales (litros / año) = uso de fuentes de área (litros / año)

Terminación de las Estimaciones de Emisiones

- Calcular las emisiones
- Corregir por emisiones de fuente puntuales
- Verificar todos los cálculos y documentar suposiciones
- Dar toda la información al equipo de AC para su revisión (parámetros, cálculos, documentación)
- Corregir cualquier error
- Documentar

Fuentes Móviles que no Circulan por Carreteras

- Categorías de fuentes móviles que no circulan por carreteras
  - > Aeronaves
  - > Locomotoras
  - > Embarcaciones marinas comerciales
  - > Otras máquinas y vehículos que no circulan por carreteras

Aeronaves

- De preferencia, las emisiones se estiman por tipo de aeronave y de motor
- Se pueden usar factores de emisión a nivel de flotilla para taxis aéreos y aviación general
- Se basan en emisiones por ciclo de aterrizaje y despegue (AD)

Estimación de Emisiones de Aeronaves

- Enfoque General:
  - > Tiempo en un modo específico del motor (min) x uso de combustible (lb combustible/min) x Factor de emisión [lb/lb combustible)
- Modos del motor considerados:
  - > Aterrizaje /despegue
  - > Desplazamiento en tierra de la aeronave a la llegada y a la salida
  - > Ascenso
  - > Acercamiento

Ciclo de Aterrizaje y Despegue (AD)

Estimación de Emisiones de Aeronaves

- Fuentes de factores de emisión:
  - > Desarrollo de Inventarios de Emisiones: Fuentes de Área (Volumen V)
  - > Procedimientos para preparar Inventarios de Emisiones, Volumen IV: Fuentes Móviles, Sección 5.0
  - > AP-42, EPA de los EEUU
  - > Metodología alterna:
    - – Base de datos de emisiones de motores de aeronaves de la Administración Federal de Aviación (FAEED) de los EE.UU.

Estimación de las Emisiones de Aeronaves

- Identificar todos los aeropuertos que se incluirán en el inventario
- Definir la composición de la flotilla para cada categoría de aeronaves en cada aeropuerto
- Determinar la actividad del aeropuerto en términos del número de ciclos de aterrizaje y despegue (AD) para cada tipo de aeronave
  - Obtener información en las publicaciones de Aeropuertos y Servicios Auxiliares
  - De la autoridad del aeropuerto local
  - De encuestas

Estimación de Emisiones de Aeronaves (Continuación)

- Seleccionar factores de emisión para cada tipo de aeronave
- Estimar un modo en tiempo (MET) para cada tipo de aeronave en cada aeropuerto
- Calcular un inventario basado en las actividades del aeropuerto, el MET y los factores de emisión de las aeronaves

Modelo FAAED

- Procedimiento de cálculo computarizado
- El usuario selecciona de la base de datos las tasas de emisión de motores y aeronaves
- El modulo solicita del usuario el aporte de información clave, tal como:
  - AD's por tipo de aeronave
  - TIMs (opción para seleccionar valores iniciales supuestos)
- Es un enfoque conveniente cuando se conoce el tipo de aeronave
- Referirse al manual del usuario del FAEED

Fuentes de Datos AD

- Aeropuertos y Servicios Auxiliares
- Autoridad del aeropuerto local
- Encuestas
- Comandante de la base militar local para campos aéreos militares

Documentación de las Emisiones de Aeronaves

- Identificar todos los aeropuertos en el inventario
- Reportar tipo de aeronave, datos DA, suposiciones para TIM y factores de ajuste estacional
- Si se calcula manualmente indicar el factor de emisión por tipo de motor y flujo de combustible usado
- Si se usa el modelo FAAED, documentar las opciones seleccionadas y dar el disquete del archivo correspondiente para el programa
- Documentar la correspondencia con las bases aéreas militares y con los aeropuertos civiles

Locomotoras

- Tres tipos distintos de locomotoras:
  - Clase I de remolque
  - Clase II & III de remolque
  - Locomotoras de patio
- Las emisiones se basan en el consumo de combustible y en factores de emisión
- Fuentes de factores de emisión:
  - AP-42 , EPA de los EE.UU.
  - Procedimientos para la preparación de Inventarios de Emisiones , Volumen IV: Fuentes Móviles, Sección 6 . (En Inglés)

Estimación de las Emisiones de Locomotoras

- Las emisiones de locomotoras de patio se calculan en base al número de locomotoras que operen
  - Ponerse en contacto con los patios locales
  - Encuestar/observar el número de locomotoras en uso
- Emisión (kg/año) = FE x DA
- Donde:
  - FE = Factor de emisión (kg/litro)
  - DA = Datos de actividad = Uso de combustible (litro / año)
  - Para las clases I, II, y III de locomotoras de arrastre, obtener los datos de consumo de combustible de las compañías individuales de ferrocarril
  - Usar las millas recorridas en vía para distribuir las estimaciones que cubran varias regiones geográficas

Documentación de las Emisiones de Ferrocarriles

- Documentar correspondencia con las compañías de ferrocarril
- Documentar resultados de las encuestas
- Reportar índice de consumo de combustible, consumo de combustible y número de locomotoras de patio por cada compañía de ferrocarril
- Documentar cualesquiera suposiciones respecto a la distribución, ajuste estacional, etc.

Embarcaciones Marinas Comerciales

- Se consideran tres tipos de embarcaciones
  - De puerto
  - Que vayan al océano
  - De pesca
- Se deben incluir las embarcaciones comerciales, militares y gubernamentales

Estimación de las Emisiones de Embarcaciones

- Las emisiones se basan en el consumo de combustible y en factores de emisión
- Las emisiones varían dependiendo de los movimientos del barco
  - En tránsito, en maniobra y paradas en puertos y resguardos
- Fuentes de factores de emisión:
  - AP-42, EPA de los EE.UU.
  - Procedures for Emission Inventory Preparation, Volume IV: Mobile Sources Section 6

Estimación de las Emisiones de Embarcaciones

- Realizar encuestas para determinar el número de embarcaciones y el consumo de combustible de aquellas con motor fuera de borda y a bordo
- Emisión (kg/año) = FE x DA
  - FE = Factor de emisión (kg/litro)
  - DA = Datos de actividad = Consumo de combustible (litro/año)

Documentación de las Emisiones de Embarcaciones

- Documentar resultados de las encuestas, otras fuentes de consumo de combustible y actividad de embarcaciones
- Reportar consumo de combustible y las emisiones en base, cuando menos, a un puerto específico
- Describir cualesquier métodos de distribución espacial que se hayan usado

Maquinaria y Vehículos que no Circulan por Carreteras

- Las categorías más importantes de equipo son:
  - Equipo agrícola
  - Equipo de jardín y cortadoras de césped
  - Equipo de construcción
  - Equipo recreativo
  - Equipo industrial
  - Botes recreativos
  - Equipo comercial ligero

Maquinaria y Vehículos que no Circulan por Carreteras

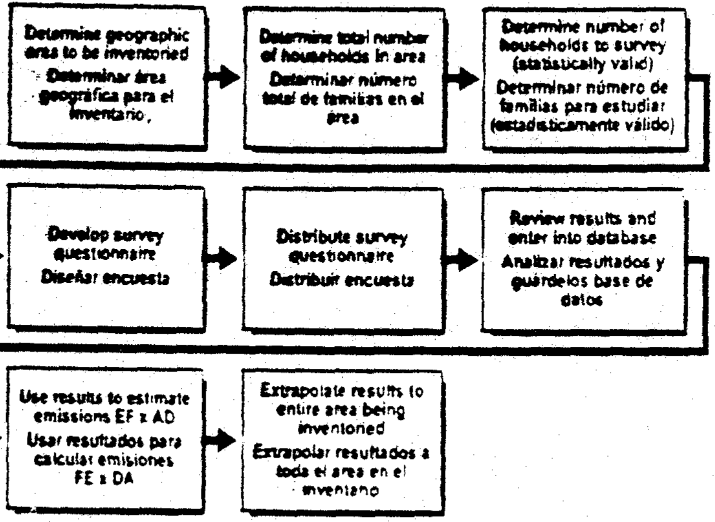
- Emplean tres tipos de motores
  - Diesel
  - Motores de gasolina de cuatro tiempos
  - Motores de gasolina de dos tiempos

Maquinaria y Vehículos que no Circulan por Carreteras

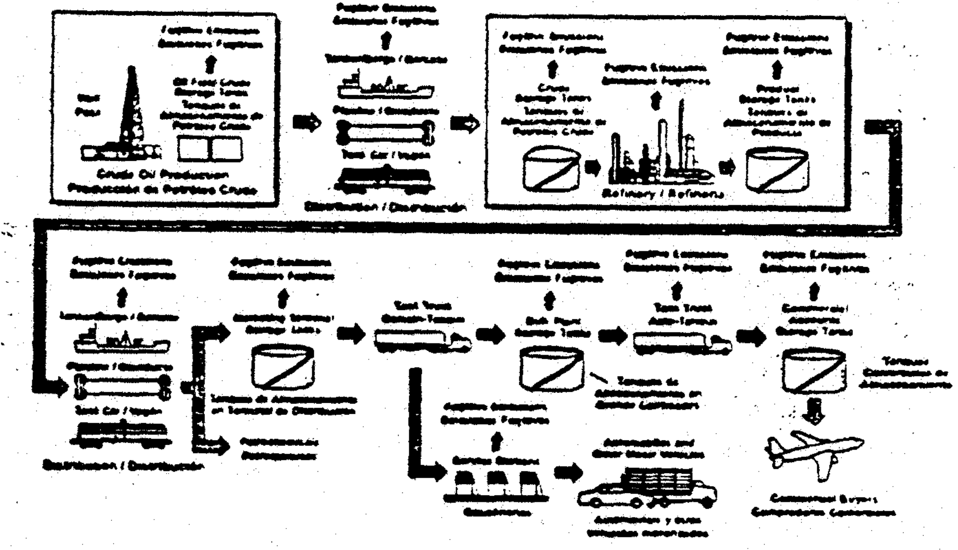
- Realizar encuestas para determinar el número y tipo de vehículos así como el consumo de combustible
- Desarrollar un modelo de variable múltiple basado en los datos de las encuestas
- El modelo relaciona los datos de actividad con la población, hogares, o con otro factor apropiado

Graficación de Emisiones de PM_{10}, vs. Variables del Sistema

Diagrama de flujo para determinar el uso doméstico de Gas LP por medio de encuestas



Ejemplo de Balance de Materiales Destacando las Emisiones Fugitivas



Ejemplo de Modelo Mecanístico

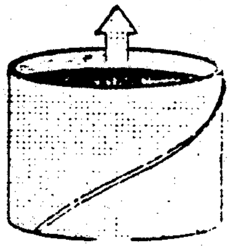
COV's emitidos por la expansión y contracción del vapor debidas a los cambios en la temperatura y la presion.

Emisiones = $f(V_V, W_V, \Delta P_V, P_{VA}, P_A, \Delta T_V, T_{LA})$

Donde:

V_V = volumen del espacio de vapor en el tanque
W_V = densidad del vapor del líquido almacenado
ΔP_V = variación diaria de la presión de vapor del líquido almacenado
P_{VA} = presión de vapor a la temperatura promedio diaria de la superficie del líquido
P_A = presión atmosférica
ΔT_V = variación diaria de la temperatura del líquido almacenado
T_{LA} = temperatura promedio diaria de la superficie del líquido

Pérdidas por Respiración de los Tanques de Almacenamiento de Productos Orgánicos



Ejemplos de Extrapolación

Producción de Petróleo Crudo de la Refinería A

Producción de Petróleo Crudo de la Refinería B

Emisiones de la Refinería A

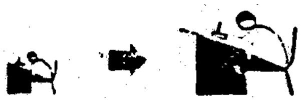
Emisiones de la Refinería B

Terrenos Agrícolas en el Estado A

Terrenos Agrícolas en el Estado B

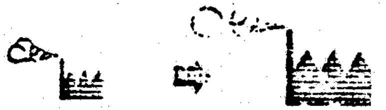
Emisiones de químicos agrícolas en el Estado A

Emisiones de químicos agrícolas en el Estado B



Número de Empleados en Instalaciones de Artes Gráficas encuestadas

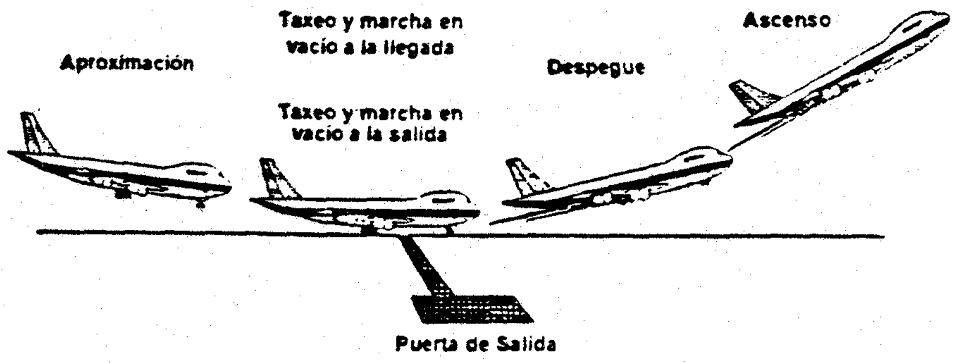
Número Total de empleados en instalaciones de Artes Gráficas en el Área



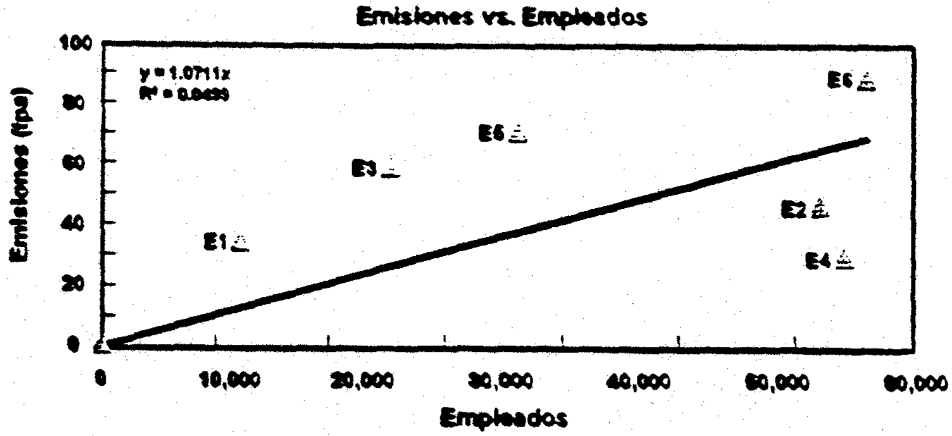
Emisiones de las Instalaciones de Artes Gráficas Encuestadas

Emisiones del número total de instalaciones de Artes Gráficas en el Área

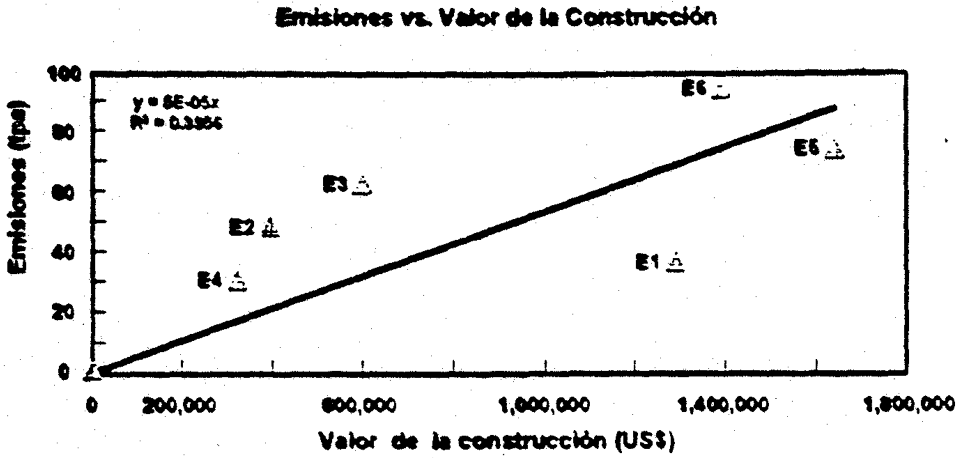
Ciclo de Aterrizaje y Despegue (AD)



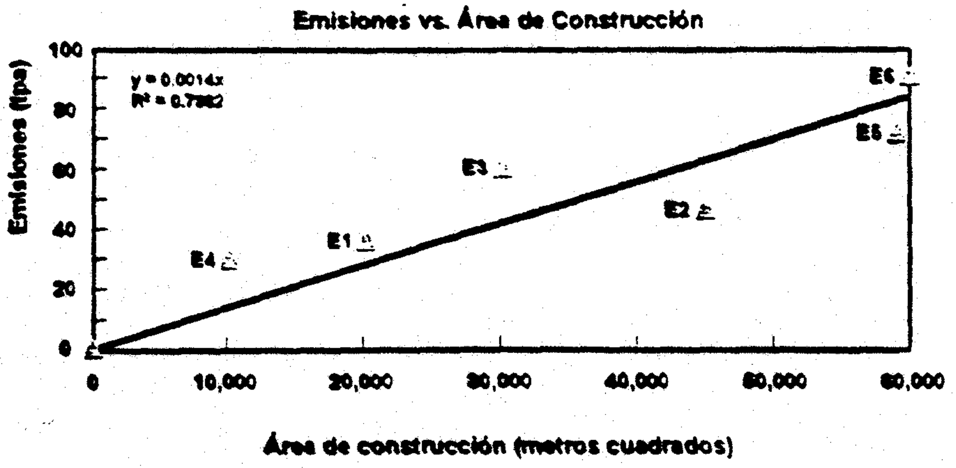
Graficación de Emisiones de PM_{10} vs. Variables del Sistema



Graficación de Emisiones de PM_{10} vs. Variables del Sistema



Graficación de Emisiones de PM_{10} vs. Variables del Sistema



IV. Fuentes Naturales

Notas

Emisiones de Fuentes Naturales

- Emisiones resultantes de procesos naturales
- Emisiones biogénicas

Fuentes Naturales

- Vegetación
- Microorganismos del suelo
- Actividad meteorológica
  - Relámpagos
  - Inyección estratosférica

Fuentes Naturales (continuación)

- Actividad agrícola
- Polvo dispersado por el viento
- Actividad volcánica
- Incendios silvestres
- Ganado
- Fuentes indirectas

Contaminantes Provenientes de Fuentes Naturales

- COV's
  - Vegetación
  - Ganado

Contaminantes Provenientes de Fuentes Naturales (continuación)

- NO_x
  - Relámpagos
  - Desnitrificación del suelo
  - Inyección estratosférica
  - Estiércol
  - Oxidación del NH_3

Contaminantes Provenientes de Fuentes Naturales (continuación)

- Compuestos de azufre
  - Erupciones volcánicas (SO_2)
  - Rocío marino (sulfatos)
  - Procesos biogénicos (especies reducidas de azufre que pueden ser oxidadas en la atmósfera)

Contaminantes Provenientes de Fuentes Naturales (continuación)

- Partículas
  - Fuentes primarias
    - polvo arrastrado por el viento
    - rocío marino
    - erupciones volcánicas
    - incendios silvestres
  - Fuentes secundarias
    - reacciones atmosféricas de emisiones de COV's biogénicos (especialmente terpenos)
- El tamaño de las partículas es importante

Contaminantes Provenientes de Fuentes Naturales (continuación)

- CO
  - Oxidación del CH_4 y otros hidrocarburos
  - Actividad microbiana en los océanos
  - Emisiones provenientes de plantas

Contaminantes Provenientes de Fuentes Naturales (continuación)

- Gases de invernadero
  - Compuestos de Carbono - CO_2, CH_4, CO
  - Compuestos de Nitrógeno - N_2O, NO, NO_x, NH_3

Importancia para el Inventario de Emisiones

- Es importante incluír estas emisiones en un inventario
- Son difíciles de cuantificar
  - Las tasas de emisión pueden ser afectadas por la luz y por la temperatura
  - Contribuyen a la incertidumbre del inventario de emisiones

Estimación de las Emisiones de Fuentes Naturales

- BEIS - Sistema de Inventario de Emisiones Biogénicas (Biogenic Emissions Inventory System)
- Otros modelos
  - BIOME
- Extrapolación de emisiones

Modelo PC-BEIS

- Sistema BEIS usado en computadoras personales
- Calcula emisiones de COV's en base horaria
- Limitaciones de PC-BEIS

Entradas para el Modelo BEIS

- Información sobre el uso de suelo
  - Basada en datos del Departamento de Agricultura y del Servicio Forestal de los EEUU y clasificaciones de datos de satélite
  - Se puede necesitar experiencia local para el uso del suelo en áreas urbanas

Entradas para el Modelo BEIS

- Factores de emisión
  - Tres tasas de emisión de COV's para bosques
  - 23 tasas de emisión de COV's para las categorías agrícola y diversas
- Tasas de emisión de NO_X para las siguientes clasificaciones de uso del suelo: forestal, pastizales, urbano y agrícola

Entradas del Modelo BEIS

- Factores de corrección ambiental
  - El flujo solar tiene efecto sobre la fotosíntesis
  - La temperatura ambiente determina la temperatura foliar
  - Factores de densidad foliar

Método de Cálculo BEIS

- La ecuación general usada para calcular emisiones biogénicas es:
- $ER_i = S_j [A_j FF_j \times EF_{ij} \times F(S,T)]$
- ER = Tasa de emisión
  - Especies químicas (por ejemplo isopreno o monoterpeno)
  - Tipo de vegetación

Método de Cálculo BEIS (continuación)

- A_j = Area de vegetación
- FF = Factor de densidad foliar
- EF = Factor de emisión biogénica
- F(S,T) = Factor ambiental para tomar en cuenta la radiación solar (S) y la temperatura de las hojas (T)

Entradas al Modelo PC-BEIS

- La información es para la zona de interés
  - Datos del sitio
    - código municipal
    - latitud, longitud
    - zona de tiempo
    - mes, día, año, hora

Entradas al Modelo PC-BEIS

- Datos meteorológicos
  - Velocidad de viento en la superficie
  - Temperatura del aire ambiente
  - Humedad relativa
  - Cubierta opaca del cielo
- El modelo proporciona:
  - Emisiones biogénicas de COV's en toneladas por día
  - Estimaciones horarias de emisiones biogénicas de COV's

Documentación Requerida para Resultados UAM-BEIS

- Los campos UAM-BEIS usados como entradas para el BEIS
- UAM-BEIS crea BIBN, un archivo binario de emisiones que es una entrada a para el UAM
- Cambios a archivos de uso de suelo y la base de los cambios

Documentación

- Bases para la selección del día modelado
- Entradas al modelo - meteorología e información del sitio
- Resultados del modelo
- Cambios a archivos de uso de suelo y la base de los cambios

Modelo BIOME

- Software de dominio público
- Usa el mismo algoritmo que BEIS2 para calcular emisiones
  - $ER_i = S_j [A_j FF_j \times EF_{ij} \times F(S,T)]$
  - Será necesario desarrollar datos, tanto para BEIS2 como para BIOME

Modelo BIOME (continuación)

- Ventajas sobre BEIS2
  - Puede usar mas datos específicos para cada sitio
    - Ejemplo: se construyen las comunidades de plantas a partir de especies existentes en vez de usar el enfoque de arriba hacia abajo para seleccionar el tipo LULC
  - El adaptar BEIS2 a México requerirá mucha programación

Modelo BIOME (continuación)

- Desventajas comparado con BEIS2
  - BIOME requiere una estación de trabajo de cómputo
  - BEIS2 se puede correr en una computadora personal

Estimación de Emisiones de Fuentes Naturales en México

  - Mejorar los datos referentes al uso y cobertura del suelo (LULC) para México
  - Aumentar la investigación de campo para determinar la aplicabilidad de los modelos en uso

V. Vehículos Automotores

Notas

Fuentes Vehiculares de Emisión

- Automóviles, camiones y motocicletas
- Fuentes de partículas (P), compuestos orgánicos volátiles (COV's), óxidos de nitrógeno (NO_X), monóxido de carbono (CO), óxidos de azufre (SO_X) , gases de invernadero y contaminantes atmosféricos tóxicos.

Fuentes Móviles de Emisión

- Tipos de Emisiones
  - > Monóxido de carbono del escape(CO)
  - > Óxidos de nitrógeno del escape (NO_X)
  - > Óxidos de azufre del escape (So_X)
  - > Partículas del escape (P)
  - > Hidrocarburos
    - – del escape
    - – de emisiones evaporativas
    - – durante el abastecimiento de combustible
    - – pérdidas en operación y pérdidas en reposo

Fuentes Vehiculares de Emisión

Emisiones de Hidrocarburos en la Ciudad de México

Emisiones de NO_X en la Ciudad de México

Emisiones de Monóxido de Carbono en la Ciudad de México

Técnicas de Estimación Disponibles

- Factor de emisión (g/km) x datos de actividad (km/año)
- Datos de actividad
  - > Datos de actividad basados en el recorrido (kilómetros recorridos por vehículo; KRV)
  - > Datos de actividad basados en el consumo de combustible
  - > Balances de combustible (para emisiones de SO_X)
  - > El método seleccionado depende del alcance geográfico del inventario y de los datos disponibles

Factores que Afectan las Emisiones Vehiculares

- Actividad de la flota vehicular (p.ej. KRV)
- Factores de Emisión (obtenidos de modelos)
  - > Características de la flota
  - > Características del combustible
  - > Programas de control de emisiones vehiculares
  - > Factores de corrección por velocidad, modos de operación, temperatura, etc.

Datos Necesarios

- Datos primarios necesarios
  - Kilómetros recorridos por vehículo (KRV)
  - Distribución del registro vehicular
  - Consumo de combustible

Efectos de la Distribución del Año Modelo del Automóvil en las Emisiones de Monóxido de Carbono

Datos Necesarios

- Datos primarios necesarios (continuación):
  - Composición del combustible (% de azufre, % de plomo)
  - Información sobre las tecnologías de control de las emisiones
  - Velocidad vehicular promedio
  - Datos de temperatura ambiente

Datos Necesarios

- Datos secundarios necesarios :
  - Información de los programas de Inspección y Mantenimiento (I/M)
  - Datos de alteraciones de dispositivos y uso de combustible indebido
  - Número de vehículos estadounidenses presentes en la flota (especialmente aplicable a las áreas fronterizas)

Datos Necesarios

- Datos secundarios necesarios (continuación):
  - Número de vehículos sin registro presentes en la flota
  - Tasas de acumulación de kilometraje

Datos Necesarios

- Datos adicionales necesarios:
  - Estudios en las carreteras
  - Estudios de patrones de manejo

Fuentes de Factores de Emisión

- Basados en pruebas realizadas a los vehículos
- Fuentes disponibles de factores de emisión
  - MOBILE5a
  - MOBILE5c
  - MOBILE-México City Metropolitan Area (MCMA)
  - MOBILE-Monterrey Metropolitan Area preliminary (MMAp)

Fuentes de Factores de Emisión (continuación)

- Fuentes disponibles de factores de emisión (continuación)
  - PART5
  - Programa de computadora para la estimación de emisiones a partir del tránsito en carretera (Computer Programme to Estimate Emissions from Road Traffic COPERT)
  - Técnicas rápidas para elaborar inventarios de fuentes

Modelos de Factores de Emisión

- Modelo de Factores de Emisión MOBILE
  - Usado para determinar factores de emisión de NO_X, CO, VOC's
  - La versión actual usada por la U.S. EPA es el MOBILE5a
  - MOBILE5c
    - Modelo basado en el U.S. EPA MOBILE para ser usado en cualquier área geográfica
  - MOBILE-MCMA (modelo para la Ciudad de México)
    - en proceso de actualización
  - MOBILE-MMAp (desarrollado utilizando metodología similar a la del MCMA)

Modelos de Factores de Emisión

- Factores de Emisión
- Factores de emisión de base provenientes de pruebas realizadas a vehículos
- Factores de emisión de base provenientes de datos de pruebas realizadas en Cd. Juárez
- La nueva versión usará datos de la prueba IM240
- Factores de emisión de base ajustados usando una matriz de equivalencia de tecnología

Modelo de Factores de Emisión MOBILE

- Componentes primarios del modelo:
  - Factores básicos de emisión
  - Características de la flota vehicular
  - Características del combustible
  - Condiciones de operación de los vehículos

Modelo de Factores de Emisión MOBILE

- Componentes adicionales del modelo:
  - Efecto de los programas de inspección y mantenimiento (I/M)
  - Efecto de la alteración de dispositivos de control de emisiones
  - Efecto de las condiciones climatológicas locales
- El usuario específica los datos para alimentar al modelo para una área de estudio dada
- Las guías del usuario proporcionan instrucciones detalladas para establecer los datos a introducir en el modelo

Modelo de Factores de Emisión MOBILE

- Características de la flota
  - Mezcla de vehículos
  - Distribución del registro
  - Tasas de acumulación de kilometraje

Modelo de Factores de Emisión MOBILE

- Tipos de vehículos en el modelo MOBILE
  - VLG: Vehículos Ligeros que usan Gasolina (p. ej. automóviles de pasajeros)
  - VLD: Vehículos Ligeros que usan Diesel (p. ej. automóviles de pasajeros que usan Diesel)
  - CLG1: Camiones Ligeros que usan Gasolina, tipo 1 (p. ej., camionetas pickup y vans que tienen un peso vehicular bruto de 8,500 lbs, tipos 1 y 2)

Modelo de Factores de Emisión MOBILE

- Tipos de vehículos en el modelo MOBILE
  - CLD: Camiones Ligeros que usan Diesel , tipos 1 y 2)
  - VPG: Vehículos Pesados que usan Gasolina (p. ej., todos los vehículos accionados por gasolina con un peso bruto superior a 8,500 lbs)
  - VPD: Vehículos Pesados que usan Diesel (p. ej. , todas las camionetas y camiones accionados por diesel con un peso bruto superior a 8,500 lbs)
  - MC: Motocicletas

MOBILE5a

Tasa de Emisión de NO_X vs. Tipo de Vehículo

Año Calendario = 1990, 9.0 PVR, 19.6 mph, 87.5^{o} F

MOBILE5a

Tasa de Emisión de COV’S Totales vs. Tipo de vehículo

Año Calendario = 1990, 9.0 PVR, 19.6 mph, 87.5^{o} F

MOBILE5a

Tasa de Emisión de CO vs. Tipo de Vehículo

Año Calendario = 1990, 9.0 PVR, 19.6 mph, 87.5^{o} F

Modelo de Factores de Emisión MOBILE

- Características del Combustible
  - Presión de Vapor Reid (PVR)
    - usar datos de encuestas locales
    - los valores de PVR se encuentran en *Procedures for Emission Inventory Preparation, Volume IV: Mobile Sources, Section 3.3.3*
  - Combustibles oxigenados
    - mezclas gasolina/alcohol (p.ej. mezclas con etanol)
    - mezclas gasolina/éter (p.ej. mezclas con MTBE)

Modelo de Factores de Emisión MOBILE

- Características del combustible
  - Gasolinas reformuladas
    - a partir de 1995 se exigió gasolina reformulada en las nueve zonas más contaminadas por ozono en los EUA
  - Componentes reformulados
    - benceno
    - azufre
    - presión de vapor
    - T_{90}

Modelo de Factores de Emisión MOBILE

- Programa de I/M
  - Especificar tipo de programa de inspección y mantenimiento (I/M) vigente o planeado
  - Estimación de tasas de cumplimiento
  - ver Sección 3.3.6.2 de *Procedures for Emission Inventory Preparation, Volume IV: Mobile Sources*, para otros requerimientos
  - Incluir programas de I/M “mejorados” y puntos de corte específicos de los programas, según sea apropiado

Modelo de Factores de Emisión MOBILE

- Programas Contra la Alteración de Dispositivos de Control de Emisiones
  - Especificar tipo de programa anti-alteración, vigente o planeado
  - Determinar tipo de inspecciones llevadas a cabo por tipos de vehículo
    - sistema de bomba de aire
    - catalizador (convertidor catalítico)
    - restrictor de la entrada de combustible
    - prueba de detección de plomo en el escape

Modelo de Factores de Emisión MOBILE

- Programas Contra la Alteración de Dispositivos de Control de Emisiones
  - Tipos de inspección (continuación)
    - sistema de recirculación de gases de escape (sistema EGR)
    - sistema de control evaporativo
    - sistema de ventilación positiva del carter (sistema PCV)
    - tapón del tanque de la gasolina
  - Especificar tasas de alteración
    - existen tasas de alteración predeterminadas incluídas en el MOBILE5a

Modelo de Factores de Emisión MOBILE

- Emisiones durante el abastecimiento de combustible
  - MOBILE puede modelar las emisiones durante el abastecimiento con alguno o con ambos de los siguientes controles:
  - "Etapa II" (en la bomba de gasolina)
    - el modelo requiere el año de inicio del programa, el período de entrada a éste y el porcentaje de eficiencia
    - ver Sección 3.3.6.1 de *Procedures for Emission Inventory Preparation,Volume IV: Mobile Sources*, para la descripción de otros requerimientos.

Modelo de Factores de emisión MOBILE

- Emisiones durante el abastecimiento de combustible
  - "A bordo" (en el vehículo)
    - actualmente el uso de los sistemas a bordo no es general
    - la EPA requiere que los automóviles de pasajeros entren e este sistema empezando con el modelo 1998 y los camiones ligeros empezando con el modelo 2001

Modelo de Factores de Emisión MOBILE

- Velocidad de los Vehículos
  - Los cambios en la velocidad tienen un gran impacto sobre los factores de emisión calculados por MOBILE
  - Las velocidades deben ser estimadas separadamente por tipo de camino
  - La estrategia preferida es usar datos generados por un modelo local de demanda de viajes para estimar velocidades vehiculares

Modelo de Factores de Emisión MOBILE

- Velocidad de los Vehículos
  - Referirse a los siguientes documentos guía para más información:
  - *Highway Vehicle Speed Estimation Procedures for Use in Emission Inventories*
  - *A Study of Highway Vehicle Emission Inventory Procedures in Selected Urban Area*

MOBILE5a

Velocidad vs. NOx

Año calendario = 1990, 9.0 PVR, 19.6 mph, 87.5^{o} F

MOBILE5a

Velocidad vs. VOC

Año Calendario = 1990, 9.0 PVR, 19.6 mph, 87.5^{o} F

MOBILE5a

Velocidad vs. CO

Año Calendario = 1990, 9.0 RVP, 19.6 mph, 87.5^{o} F

Modelo de Factores de Emisión MOBILE

- Modos de Operación
  - Corrección basada en el porcentaje de KRV (no vehículos) acumulado en cada uno de los siguientes modos de operación
    - PCCN = Porcentaje de KRV acumulado por vehículos sin catalizador en el modo de etapa de encendido en frío
    - PCHC = Porcentaje de KRV acumulado por vehículos equipados con catalizador en el modo de encendido caliente
    - PCCC = Porcentaje de KRV acumulado por vehículos equipados con catalizador en el modo de etapa de encendido en frío

Modelo de Factores de Emisión MOBILE

- Modos de Operación (continuación)

  Cuando se modela un área geográfica amplia y/o un período de tiempo largo, el usuario puede optar por usar los valores correspondientes al ciclo de manejo del Procedimiento de Prueba Federal (Federal Test Procedure [FTP], EPA de los EE.UU.):
    - PCCN: 20.6%
    - PCHC: 27.3%
    - PCCC: 20.6%

Modelo de Factores de Emisión MOBILE

- Modos de Operación
  - El usuario puede considerar valores alternos si:
    - el ciclo de manejo FTP no se ajusta a las características del área (es decir áreas rural o residencial); o
    - el modelo intenta representar condiciones altamente localizadas (es decir, tramos de rutas específicas durante ciertas horas del día)

Modelo de Factores de Emisión MOBILE

- Temperatura
  - Dos temperaturas en el modelo MOBILE
    - Temperatura ambiente
    - Temperaturas mínima y máxima diarias

Modelo de Factores de Emisión MOBILE

- Temperatura
  - Temperatura ambiente
    - el usuario puede usar para el modelado datos directos de temperatura o calcularla a partir de las temperaturas mínima y máxima
    - la temperatura ambiente se usa para corregir las emisiones de escape, la estabilización en caliente, el abastecimiento de combustible, las pérdidas en operación y las pérdidas en reposo obtenidas bajo condiciones estándar FTP

Modelo de Factores de Emisión MOBILE

- Temperatura
  - Temperaturas mínima y máxima
    - deben ser proporcionadas por el usuario
    - usadas directamente para calcular la porción diurna de las emisiones por evaporación
    - ver la Seccion 3.3.5. de *Procedures for Emission Inventory Preparation,Volume IV: Mobile Sources,* para procedimientos específicos para el cálculo de las temperaturas mínima y máxima

Modelo de Factores de Emisión MOBILE

- Cálculo de las Emisiones de COV
  - El modelo MOBILE proporciona tres opciones para obtener los factores de emisión de COV:
    - suma de todos los componentes COV en g/km
    - suma y componentes (escape, evaporativo, abastecimiento, pérdidas en operación y pérdidas en reposo) en g/km
    - suma y factores de emisión de los componentes, más el desglose detallado del factor de emisión evaporativo.

Modelo de Factores de Emisión MOBILE

- Cálculo de las Emisiones de COV's
  - Usa un desglose detallado del componente evaporativo para obtener el factor de emisión de COV debido a abastecimiento de combustible en g/l
  - Puede reportar emisiones debidas a abastecimiento dentro de la categoría de fuentes fijas regionales

Modelo de Factores de Emisión MOBILE

- Cálculo de Emisiones de Fuentes Móviles
  - Factores de emisión asociados con tipos de caminos basándose en asociaciones con variables relevantes (es decir, velocidad, modo de operación, etc.)
  - Calcula emisiones para cada combinación "tipo de vehículo/tipo de camino"

Modelo de Factores de Emisión MOBILE

- Cálculo de emisiones de fuentes móviles
  - Ejemplo:
  - El número de cálculos dependerá del número de asociaciones únicas de las variables relevantes

Modelo de Factores de Emisión PART5

- Modelo de factor de emisión de partículas de la EPA de los EE.UU.
  - > Calcula factores de emisión de partículas por distribución de tamaño de partícula para vehículos de gasolina y diesel
  - > Los factores incluyen emisión de partículas provenientes de:
    - – partículas en el escape y sus componentes (plomo, óxidos de azufre)
    - – desgaste de los frenos
    - – desgaste de las llantas
    - – polvo de resuspensión del camino (caminos pavimentados y no pavimentados)

Modelo de Factores de Emisión PART5

- Generalmente emplea muchos de los parámetros usados por el modelo MOBILE
  - > Mezclas KRV, distribución de registros, tasa de acumulación de kilometraje
- Las categorías VPD son mucho más detalladas que aquellas del modelo MOBILE

Modelo de Factores de Emisión PART5

- PART5 proporciona valores iniciales supuestos para muchos de los parámetros basándose en promedios nacionales de los EUA
- También permite el uso de datos proporcionados por el usuario para muchos de los parámetros
- Los datos básicos usados en el modelo PART5 son limitados

Modelo de Factores de Emisión PART5

- La información basada en datos estadounidenses debe ser modificada para poder aplicarse a México
- Puede usar técnicas similares a las desarrolladas para el modelo MOBILE-MCMA

Modelo de Factores de Emisión COPERT

- Programa de computadora para calcular emisiones a partir de tráfico en los caminos (Computer Programme to Calculate Emissions from Road Traffic)
  - > Usa un método iterativo que calcula el consumo total de combustible y las emisiones
  - > No requiere datos de tráfico extensos

Modelo de Factores de Emisión COPERT

- Programa de computadora para calcular emisiones a partir de tráfico en los caminos
  - > No incluye el efecto de volatilidad del combustible, la altitud, o rendimientos altos del motor
  - > Provee únicamente estimaciones gruesas de las emisiones por evaporación
  - > Metodología y datos relacionados menos desarrollados que para el modelo MOBILE

Técnicas Rápidas de Inventario de Fuentes

- Dos métodos para estimar emisiones
  - Factores de emisión únicos basados en la cantidad de combustible consumido
  - Método adicional para vehículos automotores basado en gráficas y ecuaciones obtenidas del modelo COPERT

Técnicas Rápidas de Inventario de Fuentes

- El uso de factores de emisión únicos no provee suficiente detalle
- Tratamiento insuficiente de emisiones evaporativas
- Falta de habilidad para describir condiciones locales
- Datos insuficientemente desarrollados

Recolección de Datos

- Considerar los siguientes factores cuando se dediquen recursos a la recolección de datos para modelos de factores de emisión:
  - Sensibilidad de las tasas de emisión
  - Disponibilidad de datos
  - Exactitud de los datos disponibles

Documentando el Uso de Modelos de Factores de Emisión

- Descripción paso por paso de como fueron desarrollados los elementos a introducir en el modelo
- Copias impresas o archivos electrónicos de todos los archivos de entrada usados y de los resultados de modelo
- Resumen de los factores de emisión para cada combinación tipo de vehículo/tipo de camino para cada designación geográfica similar
- Descripción de como los factores de emisión fueron usados al calcular emisiones (especialmente factores de emisión de COV)

Datos de Actividad de Fuentes Móviles

- Estimaciones detalladas de kilómetros recorridos por vehículo (KRV)
- Estimaciones regionales de KRV
- Estimaciones regionales de uso de combustibles
- Datos regionales de población y registro de vehículos

Estimaciones Detalladas de KRV

- Representa la estimación más exacta de actividad vehicular
- En general, requiere del uso de
  - Modelos de transporte
  - Programas extensos de contabilidad de tráfico y encuestas
  - Registro detallado de resultados
- Usualmente están disponibles para regiones metropolitanas grandes
  - Ciudad de México, Monterrey y Ciudad Juárez

Estimaciones Detalladas de KRV

- Los de demanda de viajes y pueden ser usados para desarrollar factores de crecimiento para proyectar KRV y para localización espacial y temporal
- Ver *Procedures for Emission Inventory Preparation,Volume IV: Mobile Sources*, Secciones 3.4.1 y 3.4.2 para una descripción más amplia de modelos de demanda de viajes

Estimaciones Detalladas de KRV

- Tipos de caminos
  - Areas Urbanas
    - Interestatal
    - Otras vías rápidas
    - **O**tras arterias principales
    - Arteria Menor
    - Colector
    - Local

Estimaciones Detalladas de KRV

- Tipos de caminos
  - Areas Rurales
    - Interestatal
    - Otra arteria principal
    - Arteria Menor
    - Colector Mayor
    - Colector Menor
    - Local

Estimaciones Detalladas de KRV

- Ajustes Temporales de KRV
  - Los inventarios de emisiones deben ser calculados para un día-entre-semana típico de verano/invierno; los KRV necesitan reflejar este nivel de detalle
  - Si KRV es compilado en base a un promedio diario anual, necesita ser ajustado por estimación diaria estacional

Estimaciones Detalladas de KRV

- Ajustes Temporales de KRV
  - Usar el inverso de los factores que son usados para convertir cuentas de tráfico de períodos de 24- y 48-horas a cuentas de tráfico promedio diario anual
  - Las cuentas de períodos de 24- y 48-horas se ajustan, basándose en el día-entre-semana y en la estación del año, a promedios anuales usando información obtenida por medio de registradores de tráfico contínuos

Estimaciones Detalladas de KRV

- Ajustes Temporales de KRV
- Para convertir a un día-entre-semana estacional apropiado para propósitos de inventario, use el inverso de los factores aplicados a las cuentas de 24- y 48-horas durante la estación del año de interés

Estimaciones Detalladas de KRV

- KRV Mixto
  - KRV mixto es un dato a introducir al modelo MOBILE; especifica la fracción del KRV total de vía rápida que es acumulado por cada uno de los 8 vehículos tipo regulados
  - Agencias de transportación y planeación deben ser consultadas para obtener KRV mixtos locales
  - El Capítulo 6 del reporte, *Techniques for Estimating MOBILE2 Variables* proporciona metodologías para calcular KRV mixtos

Estimaciones Detalladas de KRV

- Modelos de Transporte
  - Modelos de planeación de transporte, si están disponibles, pueden proporcionar información de viajes, clave para el modelo MOBILE
    - velocidades vehiculares para caminos-tipo
    - puntos de inicio de viajes
    - puntos de término de viajes

Estimaciones Detalladas de KRV

- Modelos de Transporte
  - La información de la distribución de la longitud de viaje obtenida de los modelos de transporte puede ser analizada para estimar las fracciones correspondientes a cada modo de operación
  - Factores de crecimiento de KRV pueden ser desarrollados a partir de escenarios proyectados anualmente
  - Factores de localización espacial y temporal pueden ser usados en el modelado de inventarios

Estimaciones Detalladas de KRV

- Modelos de Transporte
  - En la mayoría de los modelos de demanda de viajes, las velocidades son usadas para situar los viajes a través de la red, y no como una salida del modelo por si mismo
  - Un método básico es ajustar la estimación de la velocidad específica por tramo proporcionada por el modelo, usando cocientes volumen de vía rápida a capacidad

Estimaciones Detalladas de KRV

- Modelos de Transporte
  - Los métodos básicos y sus mejoras están descritas en el reporte, *Highway Vehicle Speed Estimation Procedures for Use in Emission Inventories*

Estimaciones Detalladas de KRV

- Documentación de KRV
  - > Referirse a los siguientes documentos para descripción de metodologías de KRV
    - – EPA´s *Quality Review Guidelines for the 1990 base year Emission Inventories*, Apéndice C, Tabla C-1
    - – Sección 7.0 del documento guía. Example Documentation Report for 1990 base year Ozone and Carbon Monoxide State Implementation Plan Emission Inventories

Estimaciones Regionales del KRV

- Cubre áreas geográficas grandes, más que estimaciones detalladas (estados completos)
- Usualmente se basa en programas de conteo de tráfico
- Aplicación de características conocidas de la flota vehicular

Estimaciones Regionales del Uso de Combustible para Vehículos en Carreteras

- Para áreas donde no están disponibles estimaciones directas de KRV
- Datos de uso de combustible provenientes de:
  - > Gobierno Federal o Estatal a través de recibos de impuestos a los combustibles
  - > Instituto Mexicano del Petróleo (IMP)

Estimaciones Regionales de Uso de Combustible

- KRV regional es estimado a partir de datos de uso y economía de combustible por medio de la siguiente ecuación

KRV gasolina, diesel = Uso de combustible regional gasolina, diesel / Economía de combustible de la flota normal vehículo gasolina, diesel

  > Donde:

Economía de Combustible de la Flota Promedio =

  ∑ = Economía de combustible tipo de vehículo X Fracción registrada tipo de vehículo X Tasa de acumulación de Kilometraje tipo de vehículo) / ∑(Fracción Registrada tipo de vehículo X Tasa de Acumulación de Kilometraje tipo de vehículo)

Estimaciones Regionales de Uso de Combustible

- Los datos de uso de combustible se separan por tipo de combustible (gasolina o diesel) para una región
- No incluir combustible usado por aviones, locomotoras

Estimaciones Regionales de Uso de Combustible

- Fuentes de datos de economía de combustible para cada tipo de vehículos
  - > Fuentes locales de datos
  - > Resultados de encuestas
  - > Datos registrados durante las pruebas de calificación de emisiones
- Datos de registros regionales
- Estimaciones de acumulación de kilometraje

Datos de Población Regional y Registro de Vehículos

- Datos de población o registro de vehículos se combinan con factores de emisión per capita o ,por vehículo
- Método menos exacto
- Útil como control de calidad para verificar la exactitud de las emisiones estimadas por otros métodos

Diferencias México-EUA

- Tipo de vehículos
- Edad de los vehículos
- Composición del combustible
- Tecnologías para el control de emisiones

Diferencias México-EUA

- Programas de inspección y mantenimiento(I/M)
- Tasa de alteración de equipos de control de emisiones vehiculares y perdidas durante el abastecimiento de combustible
- Tasa de acumulación de kilometraje

- Patrones de manejo

Diferencias Geográficas en México

- Disponibilidad de datos
- Factores que afectan las emisiones de los vehículos
  - > Ejemplo: Ciudad de México
  - – Eficiencia de combustión menor debido a la altitud
  - – Presiones atmosféricas más bajas e intervalos más bajos de temperaturas diurnas resulta en emisiones más altas de COV debidas a estabilización en caliente en los carburadores y a evaporación directa en los tanques de combustible
  - – Patrones de manejo

Diferencias Geográficas en México

- Se espera que las áreas rurales tengan emisiones menores de fuentes móviles
- Las áreas fronterizas pudieran tener un número importante de vehículos estadounidenses en la flota
- Extrapolación de emisiones calculada en base al uso regional de combustibles en carreteras pudiera resultar en una incertidumbre alta

Desarrollo de Inventarios de Fuentes Móviles Metodología Potencial a Corto Plazo

- El modelo MOBILE4 fue usado previamente para estimar las emisiones debidas a fuentes móviles en la Ciudad de México
  - Este modelo esta descontinuado actualmente
- Metodología a corto plazo para estimar emisiones de fuentes móviles
  - Usa el modelo MOBILE5a como base
  - Ajusta factores de emisión básicos a la flota vehicular mexicana (para un área dada) basándose en una matriz de equivalencia de tecnología para el control de emisiones
  - Este método se usó para el modelo MOBILE-MMAp

Desarrollo de Inventarios de Fuentes Móviles (continuación)

- Una metodología similar podría ser usada para el modelo PART5
  - El modelo PART5 esta basado en datos limitados y podría necesitar mejoras antes de ser usado en México
- Las emisiones de SO_x están basadas en un balance de material
  - Determina las emisiones basándose en el uso del combustible y en su contenido de azufre

Desarrollo de Inventarios de Fuentes Móviles Metodología Potencial a Largo Plazo

- Se necesita desarrollar un modelo de factor de emisiones específico para México
  - Remplazar factores de emisión básicos estadounidenses en el modelo MOBILE con datos específicos de México
  - Basado en datos de pruebas vehiculares -- medir emisiones obtenidas con una mezcla de vehículos representativos
  - Necesita desarrollar datos específicos de la región

Desarrollo de Inventarios de Fuentes Móviles (continuación)

- Describir patrones de manejo típicos de México
  - Usar datos de patrones de manejo para obtener un ciclo de manejo específico de México para usarse en pruebas vehiculares
  - Alternativamente, se puede considerar el desarrollo de un modelo modal

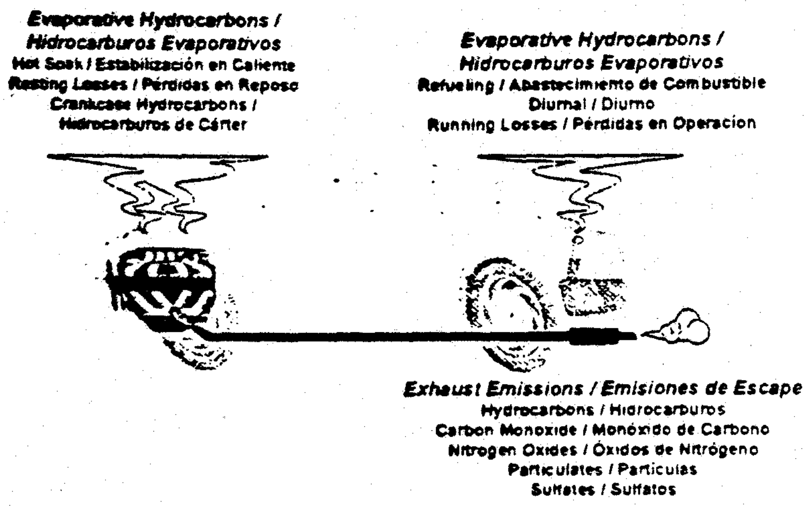
Desarrollo de Inventarios de Fuentes Móviles (continuación)

- Desarrollar factores de ajuste específicos para México para tomar en cuenta las diferencias entre factores de emisión básicos y varias condiciones no-ideales
  - Encuestar datos de registro de vehículos a nivel local
  - Efectuar un estudio para confirmar el alcance de la tecnología del control de emisiones en diferentes tipos de vehículos

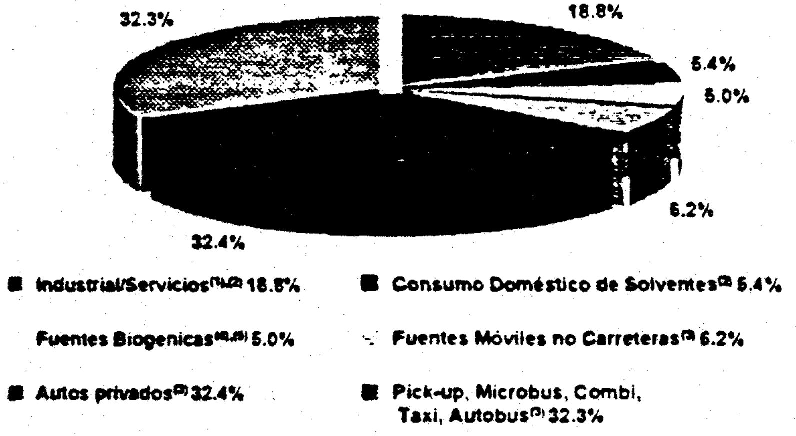
Desarrollo de Inventarios de Fuentes Móviles (continuación)

- Desarrollar factores de ajuste específicos para México
  - Efectuar un estudio para determinar la efectividad real de los programas I/M
  - Efectuar un estudio para determinar el nivel de alteración y pérdidas en el abastecimiento de combustible entre aquellos vehículos que tienen tecnología de control de emisiones
  - Efectuar un estudio para cuantificar el número de vehículos no registrados presentes en la flota vehicular de México

Fuentes Vehiculares de Emisión

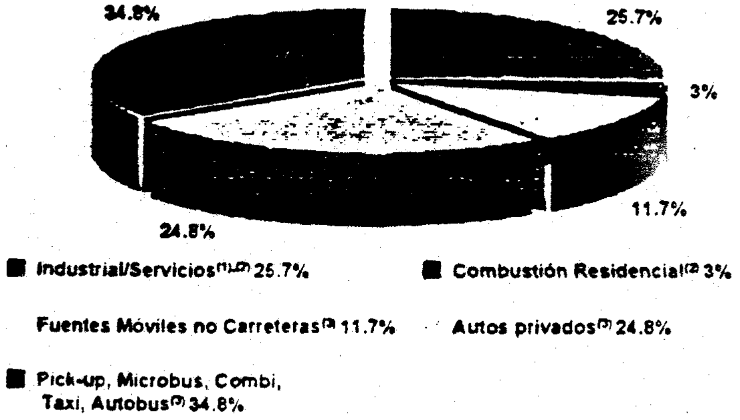


Emisiones de Hidrocarburos en la Ciudad de México



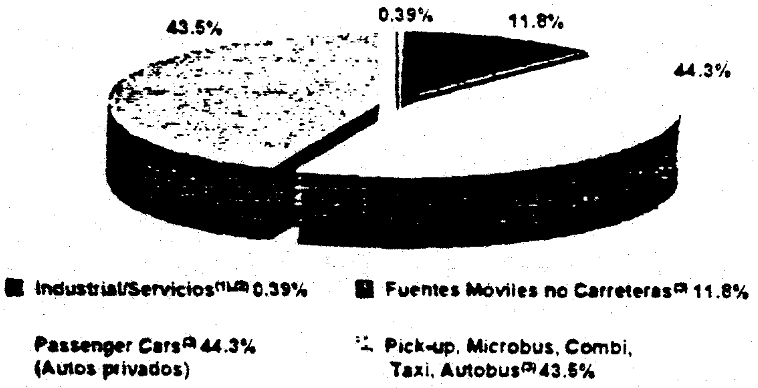
Fuentes:
(1) Instituto Nacional de Ecología. Sistema Nacional de Fuentes Fijas. 1994
(2) Departamento del Distrito Federal. Dirección General de Ecología. Subdirección de Inventario de Emisiones y Atención a Contingencias
(3) Departamento del Distrito Federal. Subdirección General de Ecología. Dirección de Estudios y Proyectos Ambientales. 1994
(4) UNAM. Centro de Ciencias de la Atmósfera. Reporte final de Cálculos y mediciones de hidrocarburos naturales en el valle de México. 1990
(5) UNAM. Manual de Inventario de Emisiones Contaminantes a la Atmósfera. Estudio de Emisión de Partículas Generadas por Fuentes Naturales. 1990

Emisiones de NOx en la Ciudad de México



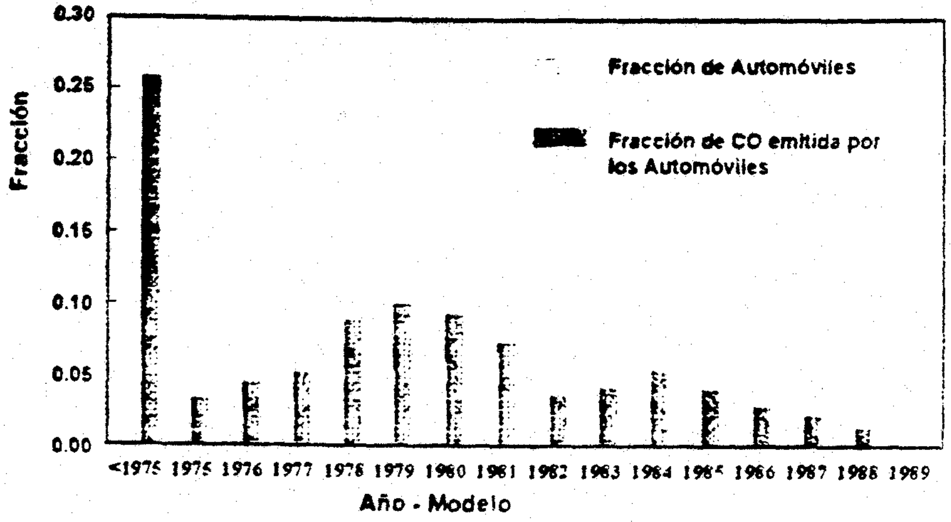
Fuentes:
(1) Instituto Nacional de Ecología. Sistema Nacional de Fuentes Fijas. 1994
(2) Departamento del Distrito Federal. Dirección General de Ecología. Subdirección de Inventario de Emisiones y Atención a Contingencias
(3) Departamento del Distrito Federal. Subdirección General de Ecología. Dirección de Estudios y Proyectos Ambientales. 1994
(4) UNAM. Centro de Ciencias de la Atmósfera. Reporte final de Cálculos y mediciones de hidrocarburos naturales en el Valle de México. 1990
(5) UNAM. Manual de Inventario de Emisiones Contaminantes a la Atmósfera. Estudio de Emisión de Partículas Generadas por Fuentes Naturales. 1990

Emisiones de Monóxido de Carbono en la Ciudad de México



Fuentes:
(1) Instituto Nacional de Ecología. Sistema Nacional de Fuentes Fijas. 1994
(2) Departamento del Distrito Federal. Dirección General de Ecología. Subdirección de Inventario de Emisiones y Atención a Contingencias
(3) Departamento del Distrito Federal. Subdirección General de Ecología. Dirección de Estudios y Proyectos Ambientales. 1994
(4) UNAM. Centro de Ciencias de la Atmósfera. Reporte final de Cálculos y mediciones de hidrocarburos naturales en el Valle de México. 1990
(5) UNAM. Manual de Inventario de Emisiones Contaminantes a la Atmósfera. Estudio de Emisión de Partículas Generadas por Fuentes Naturales. 1990

Efectos de la Distribución del Año Modelo del Automóvil en las Emisiones de Monóxido de Carbono

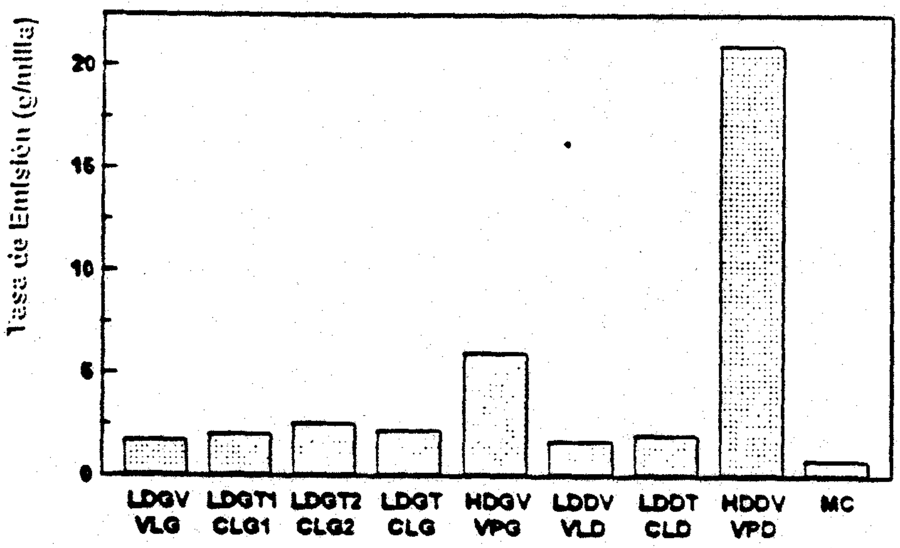


* Fuente South Coast Air Quality Management District, Los Angeles, CA

MOBILE5a

Tasa de Emisión de NO_x vs. Tipo de Vehiculo

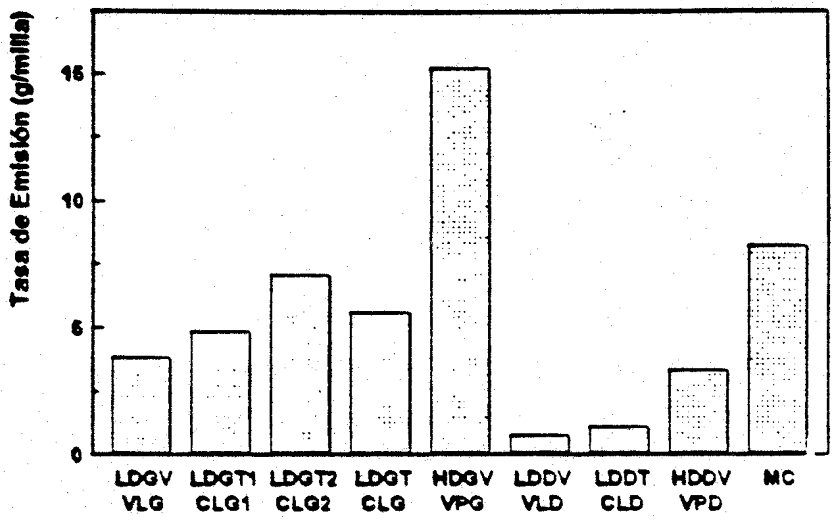
Año Calendario= 1990, 9.0 PVR, 19.6 mph, 87.5° F



MOBILE5a

Tasa de Emisión de COV'sTotales vs. Tipo de Vehiculo

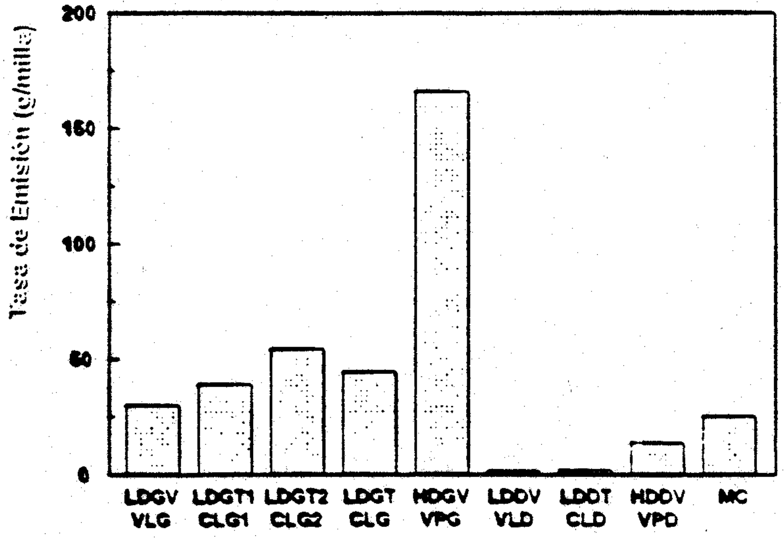
Año Calendario= 1990, 9.0 PVR, 19.6 mph, 87.5° F



MOBILE5a

Tasa de Emisión de CO vs. Tipo de Vehiculo

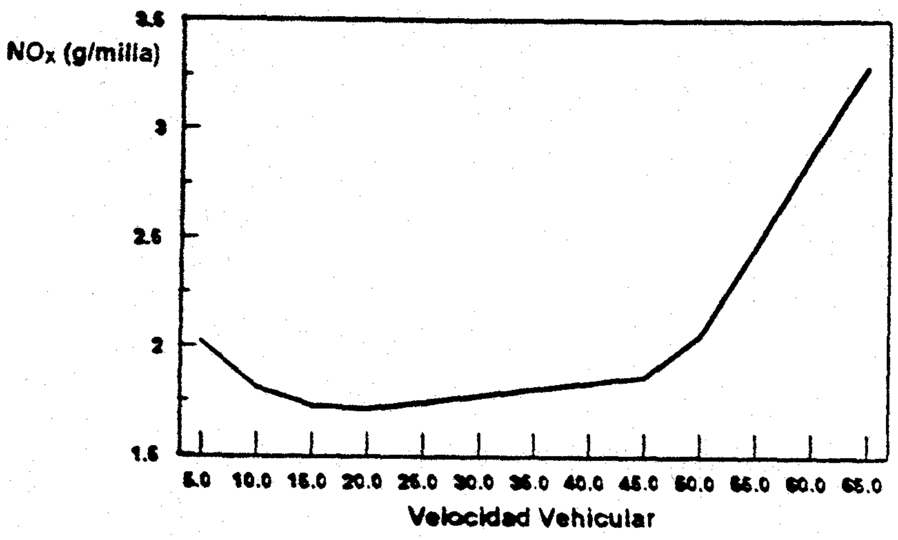
Año Calendario = 1990, 9.0 PVR, 19.6 mph, 87.5° F



MOBILE5a

Velocidad vs. NO_X

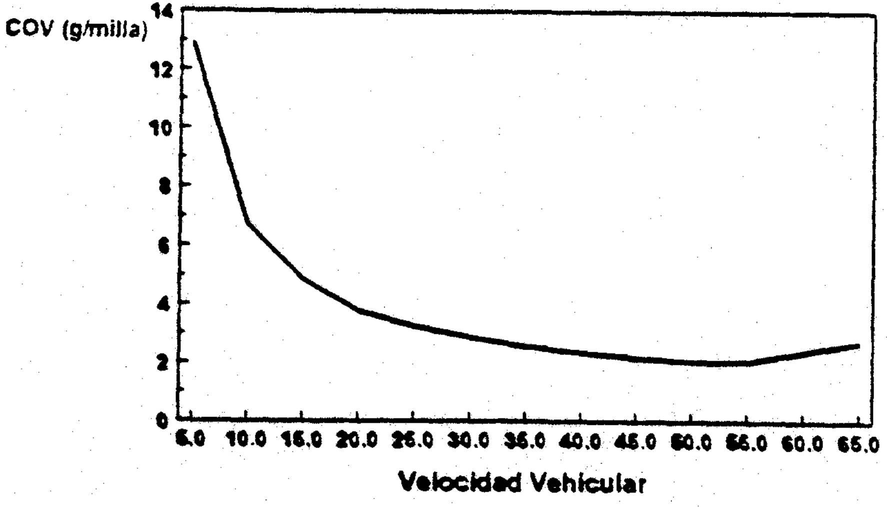
Año calendario = 1990, 9.0 RVP, 19.6 mph, 87.5° F



MOBILE5a

Velocidad vs. COV

Año Calendario = 1990, 9.0 PVR, 19.6 mph, 87.5° F



MOBILE5a

Velocidad vs. CO

Año Calendario = 1990, 9.0 PVR, 19.6 mph, 87.5° F