



# ELIP Volume II

## Point Sources Preferred and Alternative Methods



## **PREFACE**

As a result of the more prominent role given to emission inventories in the 1990 Clean Air Act Amendments (CAAA), inventories are receiving heightened priority and resources from the U.S. Environmental Protection Agency (EPA), state/local agencies, and industry. More than accountings of emission sources, inventory data are now providing the prime basis for operating permit fee systems, State Implementation Plan (SIP) development (including attainment strategy demonstrations), regional air quality dispersion modeling assessments, and control strategy development. This new emphasis on the use of emissions data will require significantly increased effort by state/local agencies to provide adequate, accurate, and transferrable information to meet various agency and regional program needs.

Existing emission inventory data collection, calculation, management, and reporting procedures are not sufficient or of high enough quality to meet all of these needs into the next century. To address these concerns, the Emission Inventory Improvement Program (EIIP) was created. The EIIP is a jointly sponsored endeavor of the State and Territorial Air Pollution Program Administrators/Association of Local Air Pollution Control Officials (STAPPA/ALAPCO) and the U.S. EPA, and is an outgrowth of recommendations put forth by the Standing Air Emissions Work Group (SAEWG) of STAPPA/ALAPCO. The EIIP Steering Committee and technical committees are composed of state/local agency, EPA, industry, consultant, and academic representatives. In general, technical committee participation is open to anyone.

The EIIP is defined as a program to develop and use standard procedures to collect, calculate, store, and report emissions data. Its ultimate goal is to provide cost-effective, reliable, and consistent inventories through the achievement of the following objectives:

- Produce a coordinated system of data measurement/calculation methods as a guide for estimating current and future source emissions;
- Produce consistent quality assurance/quality control (QA/QC) procedures applicable to all phases of all inventory programs;
- Improve the EPA/state/local agency/industry system of data collection, reporting, and transfer; and
- Produce an integrated source data reporting procedure that consolidates the many current reporting requirements;

EIIP goals and objectives are being addressed through the production of seven guidance and methodology volumes. These seven are:

- Volume I: Introduction and Use of EIIP Guidance for Emissions Inventory Development
- Volume II: Point Sources Preferred and Alternative Methods
- Volume III: Area Sources Preferred and Alternative Methods
- Volume IV: Mobile Sources Preferred and Alternative Methods
- Volume V: Biogenics Sources Preferred and Alternative Methods
- Volume VI: Quality Assurance Procedures
- Volume VII: Data Management Procedures

The purpose of each volume is to evaluate the existing guidance on emissions estimation techniques, and, where applicable, to identify the preferred and alternative emission estimation procedures. Another important objective in each volume is to identify gaps in existing methods, and to recommend activities necessary to fill the gaps. The preferred and alternative method findings are summarized in clear, consistent procedures so that both experienced and entry-level inventory personnel can execute them with a reasonable amount of time and effort. Sufficiently detailed references are provided to enable the reader to identify any supplementary information. Users should note that the number of source categories or topics covered in any volume is constantly expanding as a function of EIIP implementation and availability of new information.

It is anticipated that the EIIP materials will become the guidance standard for the emission inventory community. For this reason, the production of EIIP volumes will be a dynamic, iterative process where documents are updated over time as better data and scientific understanding support improved estimation, QA, and data management methods. The number of individual source categories addressed by the guidance will grow as well over time. The EIIP welcomes input and suggestion from all groups and individuals on how the volumes could be improved.

**VOLUME II: CHAPTER 1**

# **INTRODUCTION TO STATIONARY POINT SOURCE EMISSION INVENTORY DEVELOPMENT**

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## DISCLAIMER

This document was furnished to the Point Sources Committee, Emission Inventory Improvement Program and the U.S. Environmental Protection Agency by Eastern Research Group, Inc., Morrisville, North Carolina. This report is intended to be a final document and has been reviewed and approved for publication. The opinions, findings, and conclusions expressed represent a consensus of the members of the Emission Inventory Improvement Program.

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# ABBREVIATIONS, ACRONYMS, AND SYMBOLS

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## ABBREVIATIONS

ACT	Alternative Control Technology Guideline
AFS	AIRS Facility Subsystem
AFSEF	AIRS Facility Subsystem Emission Factors Database
AIRS	Aerometric Information Retrieval System
ALAPCO	Association of Local Air Pollution Control Officials
AMS	AIRS Area and Mobile Subsystem
APA	Air Pathway Analysis
API	American Petroleum Institute
APPCD	Air Pollution Prevention and Control Division
APTI	Air Pollution Training Institute
AQS	AIRS Quality Subsystem
ARDS	Acid Rain Data System
ASTM	American Society for Testing and Materials
BACT	best available control technology
BTU	British thermal unit
CAA	Clean Air Act
CAS	Chemical Abstract Services
CD-ROM	compact disc read-only memory
CEM	Continuous Emissions Monitoring
CFC	Chlorofluorocarbon
CFR	Code of Federal Regulations
CERCLA	Comprehensive Environmental Recovery and Comprehensive Liability Act
CHIEF	Clearinghouse for Inventories and Emission Factors

# ABBREVIATIONS, ACRONYMS, AND SYMBOLS (CONTINUED)

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CMS	Continuous Monitoring System
CO	carbon monoxide
CTC	Control Technology Center
CTG	Control Techniques Guideline
DARS	Data Attribute Rating System
DECIM	Defense Corporate Information Management
DoD	Department of Defense
DOE	Department of Energy
EA	Environmental assessment
EFIG	Emission Factor and Inventory Group
EIIP	Emission Inventory Improvement Program
EIS	Environmental Impact Statement
EMTIC	Emission Measurement Technical Information Center
EPA	U.S. Environmental Protection Agency
FIP	Federal Implementation Plan
FR	Federal Register
FIRE	Factor Information Retrieval System
HAP	hazardous air pollutant
HCFC	hydrochlorofluorocarbon
ID	identification
JEIOG	Joint Emission Inventory Oversight Group
LAER	lowest achievable emission rate
LAEEM	Landfill Air Emissions Estimation Model
lb	pound
LDP	locational data policy

# ABBREVIATIONS, ACRONYMS, AND SYMBOLS (CONTINUED)

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MACT	maximum achievable control technology
MSDS	material safety data sheets
MWC	municipal waste combustors
NAAQS	National Ambient Air Quality Standard
NEC	not elsewhere classified
NEDS	National Emissions Database System
NEPA	National Environmental Policy Act
NATICH	National Air Toxics Information Clearinghouse
NADB	National Allowance Database
NO <sub>x</sub>	nitrogen oxides
NPL	national priority list
NSPS	New Source Performance Standard
NSR	new source review
NTIS	National Technical Information Service
OAQPS	Office of Air Quality Planning and Standards
OMB	Office of Management and Budget
ORD	Office of Research and Development
PC	personal computer
PC-BEIS	Personal Computer-Biogenic Emissions Inventory System
PL	Public Law
PM	particulate matter
PM <sub>10</sub>	particulate matter of aerodynamic diameter less than or equal to 10 micrometers
PM <sub>2.5</sub>	particulate matter of aerodynamic diameter less than or equal to 2.5 micrometers
POTW	publicly owned treatment works
PPM	parts per million

# ABBREVIATIONS, ACRONYMS, AND SYMBOLS (CONTINUED)

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PSD	prevention of significant deterioration
QA	quality assurance
QC	quality control
RACT	reasonably available control technology
RCRA	Resource Conservation and Recovery Act
RE	rule effectiveness
RFP	reasonable further progress
RVP	Reid vapor pressure
SARA	Superfund Amendments and Reauthorization Act
SAEWG	Standing Air Emissions Work Group
STAPPA	State and Territorial Air Pollution Program Administrators
SCC	Source Classification Code
SIC	Standard Industrial Classification
SIP	state implementation plan
SO <sub>2</sub>	sulfur dioxide
TAP	toxic air pollutant
tpy	tons per year
TRAC	Tracking Responses to Acid Rain Compliance
TRIS	Toxic Chemical Release Inventory System
TSDF	treatment, storage, and disposal facility
U.S.	United States
U.S.C.	United States Code
UTM	universal transverse mercator
VOC	volatile organic compound



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# DEFINITIONS OF COMMONLY USED TERMS

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**Actual Emissions** are the actual rate of emissions of a pollutant from an emissions unit calculated using the unit's actual operating hours, production rates, and types of materials processed, stored, or combusted during the selected time period.

**Allowable Emissions** are the emissions rate that represents a limit on the emissions that can occur from an emissions unit. This limit may be based on a federal, state, or local regulatory emission limit determined from state or local regulations and/or 40 Code of Federal Regulations (CFR) Parts 60, 61, and 63.

**Ambient Standards** limit the concentration of a given pollutant in the ambient air. Ambient standards are not emissions limitations on sources, but usually result in such limits being placed on source operation as part of a control strategy to achieve or maintain an ambient standard.

**Area Sources** are smaller sources that do not qualify as point sources under the relevant emissions cutoffs. Area sources encompass more widespread sources that may be abundant, but that, individually, release small amounts of a given pollutant. These are sources for which emissions are estimated as a group rather than individually. Examples typically include dry cleaners, residential wood heating, auto body painting, and consumer solvent use. Area sources generally are not required to submit individual emissions estimates.

**Carbon Monoxide (CO)** is a colorless, odorless gas that depletes the oxygen-carrying capacity of blood. Major sources of CO emissions include industrial boilers, incinerators, and motor vehicles.

**Class I Substances** as defined in Title VI of the Clean Air Act Amendments include chlorofluorocarbons (CFCs), halons, carbon tetrachloride, and methyl chloroform. According to the CAAA, all of these compounds must be phased out of production by the year 2000 with the exception of methyl chloroform, which must be phased out of production by the year 2002. Provisions are also made that allow for acceleration of this phaseout.

**Class II Substances** as defined in Title VI of the Clean Air Act Amendments include hydrochlorofluorocarbons (HCFCs). These substances must be phased out of production by the year 2015.

**Continuous Emissions Monitoring (CEM)** is any monitoring effort that "continuously" measures (i.e., measures with very short averaging times) and records emissions. In addition to measuring and recording actual emissions during the time of monitor operation, CEM data can be used to estimate emissions for different operating periods and longer averaging times.

**Criteria Pollutants** are carbon monoxide (CO), lead (Pb), nitrogen oxides (NO<sub>x</sub>), sulfur dioxide (SO<sub>2</sub>), volatile organic compounds (VOCs), and particulate matter of aerodynamic diameter less than or equal to 10 micrometers (PM<sub>10</sub>). The National Ambient Air Quality Standards (NAAQS) were mandated by the Clean Air Act of 1970, and are based on criteria including adverse health or welfare effects. NAAQS are currently used to establish air pollutant concentration limits for the six air pollutants listed above that are commonly referred to as **criteria pollutants**.

**Design Standards** impose certain hardware requirements. For example, a design standard might require that leaks from compressors be collected and diverted to a control device. Design standards are typically used when an emissions limit is not feasible.

**Emission Concentration Standards** limit the mass emissions of a pollutant per volume of air. Emission concentration standards are expressed in terms such as grams per dry standard cubic meter (g/dscm) or other similar units.

**Emission Factors** are ratios that relate emissions of a pollutant to an activity level at a plant that can be easily measured, such as an amount of material processed, or an amount of fuel used. Given an emission factor and a known activity level, a simple multiplication yields an estimate of the emissions. Emission factors are developed from separate facilities within an industry category, so they represent typical values for an industry, but do not necessarily represent a specific source. Published emission factors are available in numerous sources.

**Emissions Reduction Standards** limit the amount of current emissions relative to the amount of emissions before application of a pollution control measure. For example, an emission reduction standard may require a source to reduce, within a specified time, its emissions to 50 percent of the present value.

**Emission Standards** are a general type of standard that limit the mass of a pollutant that may be emitted by a source. The most straightforward emissions standard is a simple limitation on mass of pollutant per unit time (e.g., pounds of pollutant per hour).

**Engineering Estimate** is a term commonly applied to the best approximation that can be made when the specific emission estimation techniques such as stack testing, material balance, or emission factor age are not possible. This estimation is usually made by an engineer familiar with the specific process, and is based on whatever knowledge may be available.

**Equipment Standards** require a specific type of equipment to be used in certain processes. Equipment standards are typically used when an emissions limit is not feasible.

**Fugitive Emissions** are emissions from sources that are technically infeasible to collect and control (e.g., storage piles, wastewater retention ponds).

**Hazardous Air Pollutants (HAPs)** are listed in Section 112(b) of the 1990 Clean Air Act Amendments (CAAA). These pollutants are generally emitted in smaller quantities than criteria pollutants but may be reasonably anticipated to cause cancer, developmental effects, reproductive dysfunctions, neurological disorders, inheritable gene mutations, or other chronically or acutely toxic effects in humans. The CAAA specifies an initial list of 189 HAPs to be subject to further regulation. The list of HAPs includes relatively common pollutants such as formaldehyde, chlorine, methanol, and asbestos, as well as numerous less-common substances. Pollutants may, under certain circumstances, be added to or deleted from the list.

**Lead (Pb)** is an element that causes several types of developmental effects in children including anemia, neurobehavioral alterations, and metabolic alterations. Lead is emitted from industries such as battery manufacturing, lead smelters, and incineration. Although regulated in highway fuels, lead may also be emitted from unregulated off-highway mobile sources.

**Material Balance** or **Mass Balance** is a method for estimating emissions that attempts to account for all the inputs and outputs of a given pollutant. If inputs of a material to a given process are known and all outputs except for air emissions can be reasonably well quantified, then the remainder can be assumed to be an estimate of the amount lost to the atmosphere for the process.

**Maximum Achievable Control Technology (MACT) Standards** in addition to National Emissions Standards for Hazardous Air Pollutants (NESHAP), are promulgated under Section 112 of the Clean Air Act Amendments (CAAA). Technically NESHAP and MACT standards are separate programs. MACT standards differ from older NESHAPs because MACT standards are mandated by law to require the maximum achievable control technology. MACT standards are source category-specific, and each standard covers all the pollutants listed in Section 112 of the CAAA that are emitted by that source category. The first MACT standard promulgated (for the Synthetic Organic Chemical Manufacturing Industries) was

originally developed as a NESHAP and is still referred to as the Hazardous Organic NESHAP (HON).

**Means of Release to the Atmosphere** is the mechanism by which emissions enter the atmosphere. Environmental agencies usually classify release mechanisms into three categories: process emissions, fugitive emissions, and process fugitive emissions. This characteristic of an emission source is important because emission factors and other estimation methods are specific to the type of release.

**Mobile Sources** include all nonstationary sources, such as automobiles, trucks, aircraft, trains, construction and farm equipment, and others. Mobile sources are a subcategory of area sources, and are generally not required to submit individual emissions estimates.

**National Ambient Air Quality Standards (NAAQS)** are the main ambient standards for the following six criteria pollutants: carbon monoxide (CO), lead (Pb), nitrogen oxides ( $\text{NO}_x$ ), sulfur oxides ( $\text{SO}_x$ ), ozone ( $\text{O}_3$ ), and particulate matter of aerodynamic diameter less than or equal to 10 micrometers ( $\text{PM}_{10}$ ).

**National Emissions Standards for Hazardous Air Pollutants (NESHAP)** are a class of standards limiting emissions of HAPs. The common usage of NESHAP actually refers to two different sets of standards. First, there are 22 emissions standards promulgated prior to the 1990 Clean Air Act Amendments (CAAA). Some of these standards are pollutant-specific (e.g., the NESHAP for vinyl chloride), others are source-category specific (e.g., the NESHAP for benzene waste operations), and still others are both pollutant- and source-category specific (e.g., the NESHAP for inorganic arsenic emissions from glass manufacturing plants).

**New Source Performance Standards (NSPS)** are promulgated for criteria, hazardous, and other pollutant emissions from new, modified, or reconstructed sources that the U.S. Environmental Protection Agency (EPA) determines contribute significantly to air pollution. These are typically emission standards, but may be expressed in other forms such as concentration and opacity. The NSPS are published in 40 Code of Federal Regulations (CFR) Part 60.

**Nitrogen Oxides ( $\text{NO}_x$ )** are a class of compounds that are respiratory irritants and that react with volatile organic compounds (VOCs) to form ozone ( $\text{O}_3$ ). The primary combustion product of nitrogen is nitrogen dioxide ( $\text{NO}_2$ ). However, several other nitrogen compounds are usually emitted at the same time (nitric oxide [NO], nitrous oxide [ $\text{N}_2\text{O}$ ], etc.), and these may or may not be distinguishable in available test data. They are usually in a rapid state of flux, with  $\text{NO}_2$  being, in the short term, the ultimate product emitted or formed shortly downstream of the stack. The convention followed in emission factor documents is to report the distinctions wherever possible, but to report total  $\text{NO}_x$  on the basis of the molecular weight

of  $\text{NO}_2$ .  $\text{NO}_x$  compounds are also precursors to acid rain. Motor vehicles, power plants, and other stationary combustion facilities emit large quantities of  $\text{NO}_x$ .

**Opacity Standards** limit the opacity (in units of percent opacity) of the pollutant discharge rather than the mass of pollutant.

**Operational Standards** impose some requirements on the routine operation of the unit. Such standards include maintenance requirements or operator training certification requirements. Operational standards are typically used when an emission limit is not feasible.

**Ozone ( $\text{O}_3$ )** is a colorless gas that damages lungs and can damage materials and vegetation. It is the primary constituent of smog, and is formed primarily when nitrogen oxides ( $\text{NO}_x$ ) and volatile organic compounds (VOCs) react in the presence of sunlight. It is also emitted in insignificant quantities from motor vehicles, industrial boilers, and other minor sources.

**Particulate Matter of aerodynamic diameter less than or equal to 10 micrometers ( $\text{PM}_{10}$ )** is a measure of small solid matter suspended in the atmosphere. Small particles can penetrate deeply into the lung where they can cause respiratory problems. Emissions of  $\text{PM}_{10}$  are significant from fugitive dust, power plants, commercial boilers, metallurgical industries, mineral industries, forest and residential fires, and motor vehicles.

**Particulate Matter of aerodynamic diameter less than or equal to 2.5 micrometers ( $\text{PM}_{2.5}$ )** is a measure of fine particles of particulate matter that come from fuel combustion, agricultural burning, woodstoves, etc. On November 27, 1996 the U.S. Environmental Protection Agency proposed to revise the current primary (health-based) PM standards by adding a new annual  $\text{PM}_{2.5}$  standard.

**Plant Level Emissions** are consolidated for an entire plant or facility. A plant may contain one or many pollutant-emitting sources.

**Plant Level Reporting** is generally required if total emissions from a plant (which may be composed of numerous individual emission points) meet the point source cutoff. These data can be used by the state to conduct a detailed estimate of emissions from that plant. The plant level reporting used by most air pollution control agencies generally requires that the facility provide data that apply to the facility as a whole. Such data include number of employees and the Standard Industrial Classification (SIC) code designation for the plant. A plant usually has only one SIC code denoting the principal economic activity of the facility. For the purpose of clearly identifying and tracking emissions data, each plant is generally assigned a plant (alternatively, "facility") name and number. The plant is also identified by geographic or jurisdictional descriptors such as air quality control region, county, address, and universal transverse mercator (UTM) grid coordinates (or latitude/longitude) that identify a coterminous

location. An owner or operator engaged in one or more related activities is also identified. In some cases, plantwide emissions may be reported at the plant level.

**Point Level Emissions** typically represent single stacks or vents individually large enough to be considered point sources.

**Point Level Reporting** includes specific data for individual emission points (typically stacks). These data are more detailed than that submitted in Plant Level Reporting and may include emission-related and modeling information such as stack height of the release point, diameter of the stack, emission rate, method of determination, fugitive emissions, gas exit velocity from a stack, gas temperature, and operating schedule. Source identification information, as previously described under Plant Level Reporting, is usually also required at the point level to ensure that emission data for a single plant remain clearly identified. Regulatory agencies generally maintain individual emission-related records at the point level.

**Point Sources** are large, stationary, identifiable sources of emissions that release pollutants into the atmosphere. Sources are often defined by state or local air regulatory agencies as point sources when they annually emit more than a specified amount of a given pollutant, and how state and local agencies define point sources can vary. Point sources are typically large manufacturing or production plants. They typically include both confined "stack" emission points as well as individual unconfined "fugitive" emission sources.

Within a given point source, there may be several **emission points** that make up the point source. Emissions point refers to a specific stack, vent, or other discrete point of pollution release. This term should not be confused with point source, which is a regulatory distinction from area and mobile sources. The characterization of point sources into multiple emissions points is useful for allowing more detailed reporting of emissions information.

For point sources, the emission estimate reporting system used by most state and local air regulatory agencies groups emission sources into one of three categories and maintains emission-related data in a different format for each. The three categories are plant level, point level, and process or segment level.

**Potential Emissions** are the potential rate of emissions of a pollutant from an emissions unit calculated using the unit's maximum design capacity. Potential emissions are a function of the unit's physical size and operational capabilities.

It is important to note that annual potential emissions from a unit are not necessarily the product of 8760 hours per year times the hourly potential emissions. For most processes, the operation of one piece of equipment is limited in some way by the operation of another piece of equipment upstream or downstream. For example, consider a batch process involving

vessels X, Y, and Z in series (i.e., the output from Vessel X is the feed to Vessel Y, and the output from Vessel Y is the feed to Vessel Z) where the residence time for each vessel is different. In this process, Vessel Y may not operate 8760 hours per year because either the output from Vessel X is not feeding Vessel Y at all times or Vessel Z may not always be available to accept the output from Vessel Y.

It is also possible for the emission rate to vary over time. For instance, if a reaction requires 6 hours to reach completion, the emissions from the reaction vessel during the first hour will be different than those during the last hour. Thus, the highest hourly emission rate is not sustained during the entire cycle or for the entire year.

**Process-based Emission Standards** limit the mass emissions per unit of production. These standards may limit mass emissions per unit of material processed or mass emissions per unit of energy used. As process rate increases (e.g., an increase in tons of ore processed per hour), the allowable emissions increase (e.g., an increase in pounds of pollutant per hour).

**Process Emissions** are emissions from sources where an enclosure, collection system, ducting system, and/or stack (with or without an emission control device) is in place for a process. Process emissions represent emissions from process equipment (other than leaks) where the emissions can be captured and directed through a controlled or uncontrolled stack for release into the atmosphere.

**Process Fugitive Emissions** occur as leaks from process equipment including compressors, pump seals, valves, flanges, product sampling systems, pressure relief devices, and open-ended lines. Emissions from the process that are not caught by the capture system are also classified as process fugitive emissions.

**Process or Segment Level Emissions** usually represent a single process or unit of operation.

**Process or Segment Level Reporting** involves each process within a plant being identified by a U.S. Environmental Protection Agency (EPA) source classification code (SCC). For point sources, reporting guidelines may require that a plant identify, for each process or operation (designated by SCC), the periods of process operation (daily, weekly, monthly, annually); operating rate data including actual, maximum, and design operating rate or capacity; fuel use and fuel property data (ash, sulfur, trace elements, heat content, etc.); identification of all pollution control equipment and their associated control efficiencies (measured or design); and emissions rates. Source identification information, as previously described under Plant Level Reporting, is usually also required at the process level to ensure that emissions data for a single plant are clearly identified.



**Process-specific Empirical Relationships** are similar to emission factors in that they relate emissions to easily identifiable process parameters. However, these relationships are represented by more detailed equations that relate emissions to several variables at once, rather than a simple ratio. An example is the estimate for volatile organic compound (VOC) emissions from storage tanks that is based on tank size and throughput, air temperature, vapor pressure, and other variables.

**Reported Emissions** are those emission estimates that are submitted to a regulatory agency. Emissions inventories can be used for a variety of purposes such as State Implementation Plan (SIP) base year inventories, environmental compliance audits, air quality rule applicability, and reporting information in an air quality permit application. Emissions can be reported on an actual, potential, or maximum basis. Many state and local air pollution control agencies have rules and regulations that define an allowable emission value for a particular piece of equipment. Because of this, a facility should first define the purpose of the inventory and then choose the appropriate means of reporting emissions to the regulatory agency. For example, SIP base year inventories for point sources would contain actual emissions. However, regulatory applicability and air quality permit applications can require that actual, allowable, and potential emissions be reported.

**Source Tests** are short-term tests used to collect emissions data that can then be extrapolated to estimate long-term emissions from the same or similar sources. Uncertainties arise when source test results are used to estimate emissions under process conditions that differ from those under which the test was performed.

**Stratospheric Ozone-depleting Compounds** are chlorofluorocarbons (CFCs), halons, carbon tetrachloride, methyl chloroform, and hydrochlorofluorocarbons (HCFCs). These pollutants are regulated by Title VI of the Clean Air Act Amendments (CAAA) because they may destroy stratospheric ozone. Title VI is primarily designed to limit the manufacture of these materials, not their use. The pollutants are divided into two classes (Class I and Class II) based on the dates by which their manufacture must be discontinued. Methods to estimate emissions of ozone-depleting compounds are not discussed in Emission Inventory Improvement Program (EIIP) documents. Information on emissions of ozone-depleting compounds can be obtained from the U.S. Environmental Protection Agency (EPA) Office of Atmospheric and Indoor Air Programs, Global Climate Change Division, located at EPA Headquarters in Washington, D.C.

**Sulfur Oxides ( $SO_x$ )** are a class of colorless, pungent gases that are respiratory irritants and precursors to acid rain. Sulfur oxides are emitted from various combustion or incineration sources, particularly from coal combustion.

**Volatile Organic Compounds (VOCs)** react with nitrogen oxides ( $\text{NO}_x$ ) in the atmosphere to form ozone ( $\text{O}_3$ ). Although not criteria pollutants, VOC emissions are regulated under criteria pollutant programs because they are ozone precursors. Large amounts of VOCs are emitted from motor vehicle fuel distribution, chemical manufacturing, and a wide variety of industrial, commercial, and consumer solvent uses.

The use of certain photochemical models requires estimation of methane, ethane, and several other less photochemically reactive compounds and particulates. While not regulated as VOCs, these compounds may need to be estimated for certain modeling inventories or to meet certain state inventory requirements. For this reason, the term **total organic compounds (TOCs)** is used to refer to this broader class of chemicals.

**Work Practice Standards** require some action during the routine operation of the unit. For example, volatile organic compound (VOC) monitoring of a compressor might be required on a quarterly basis to ensure no leaks are occurring. Work practice standards are typically used when an emission limit is not practical.

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# INTRODUCTION

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## 1.1 BACKGROUND

The Clean Air Act, as amended in 1990 (hereafter referred to as the CAA), has expanded the continuing role of the U.S. Environmental Protection Agency (EPA) in its effort to improve air quality in the United States. Among the mandates set forth in the CAA is the requirement that the EPA improve the quality of emission estimates of air pollutants.

Over the last two decades, the CAA and numerous other federal, state, and local programs have required industry to report the amount of air pollutants emitted. With the CAA in place, it is useful for industry to understand the methods used to estimate emissions in order to comply with regulations.

The Emission Inventory Improvement Program (EIIP) is a joint program of the EPA, Standing Air Emissions Work Group (SAEWG), and the State and Territorial Air Pollution Program Administrators and the Association of Local Air Pollution Control Officials (STAPPA/ALAPCO). The ultimate goal of the EIIP is to provide cost-effective, reliable inventories by improving the quality of emissions data collected and provide for uniform reporting of this information. These emissions-related data will be made available to state and local agencies, the regulated community, the public, and EPA. The EIIP has been designed to increase the likelihood that acceptable quality emission inventory data will be available. The use of these procedures will promote consistency in these activities among the emission inventory reporting groups.

Using standardized approaches enables federal, state, and local agencies to generate data of known quality at acceptable or reasonable costs. The EIIP has implemented this concept by selecting preferred and alternative methods for use in determining emissions for various source categories of interest. Their findings are reported in the following series of guidance documents:

- Volume I: *Introduction and Use of EIIP Guidance for Emissions Inventory Development*
- Volume II: *Point Sources Preferred and Alternative Methods*
- Volume III: *Area Sources Preferred and Alternative Methods*
- Volume IV: *Mobile Sources Preferred and Alternative Methods*

- Volume V: *Biogenic Sources Preferred and Alternative Methods*
- Volume VI: *Quality Assurance Procedures*
- Volume VII: *Data Management Procedures*

Volume II in the series of EIIP guidance documents is intended to familiarize the private and government sectors with the basic concepts and procedures involved in estimating air pollutant emissions from point sources. Volume II should also be used to provide state agencies with instructional guidance on preferred methods for developing emission inventories for point sources.

Point sources are those facilities/plants/activities for which individual source records are maintained in the inventory. Under ideal circumstances, all sources would be considered point sources. However, in practical applications, only sources that emit (or have the potential to emit) more than some specified cutoff level of emissions are considered point sources.

Area sources, in contrast, are those activities for which aggregated source and emissions information is maintained for entire source categories rather than for an individual source. Sources not treated as point sources should be included in an area source inventory. Area sources are addressed in Volume III of the EIIP series of guidance documents.

Volume II consists of various combustion, manufacturing, and production activities that comprise point sources. The major chapters within Volume II at various stages of production are as follows:

- Chapter 1: *Introduction to Stationary Point Source Emission Inventory Development*
- Chapter 2: *Preferred and Alternative Methods for Estimating Air Emissions from Boilers*
- Chapter 3: *Preferred and Alternative Methods for Estimating Air Emissions from Hot-Mix Asphalt Plants*
- Chapter 4: *Preferred and Alternative Methods for Estimating Fugitive Air Emissions from Equipment Leaks*
- Chapter 5: *Preferred and Alternative Methods for Estimating Air Emissions from Wastewater Collection and Treatment*
- Chapter 6: *Preferred and Alternative Methods for Estimating Air Emissions from Semiconductor Manufacturing Facilities*

- Chapter 7: *Preferred and Alternative Methods for Estimating Air Emissions from Surface Coating Operations*
- Chapter 8: *Preferred and Alternative Methods for Estimating Air Emissions from Paint and Ink Manufacturing Facilities*
- Chapter 9: *Preferred and Alternative Methods for Estimating Air Emissions from Metal Production Facilities*
- Chapter 10: *Preferred and Alternative Methods for Estimating Air Emissions from Oil and Gas Field Production and Processes*
- Chapter 11: *Preferred and Alternative Methods for Estimating Air Emissions from Plastic Products Manufacturing*

Each industry- or source-specific document contains a brief process description; identification of emission points; an overview of methods available for estimating emissions; example calculations for each technique presented; a brief discussion on quality assurance and quality control; and the source classification codes (SCCs) needed for entry of the data into a database management system. The SCCs included in each volume apply to the process emission points, in-process fuel use, storage tank emissions, fugitive emissions, and control device fuel (if applicable).

## 1.2 PURPOSE OF CHAPTER 1

Chapter 1 provides an introduction to air pollutant emission assessment, the basic procedures involved in estimating emissions, and industry-specific techniques for estimating emissions. This introductory chapter of Volume II is intended to introduce the information applicable to all stationary point sources as well as identify basic concepts of emission estimation techniques. Practical, detailed calculations and procedures applicable to a specific category are found within subsequent chapters (documents). These later chapters present several different estimation scenarios and provide example calculations to aid in actual emission estimation. Figure 1.1-1 is included to assist readers tasked with inventory preparation in decision making and to refer them to the applicable chapters within this volume and other volumes in the EIIP series. Cumulatively, the chapters of Volume II provide a comprehensive series of manuals which should successfully serve the user in generating a point source emissions inventory.

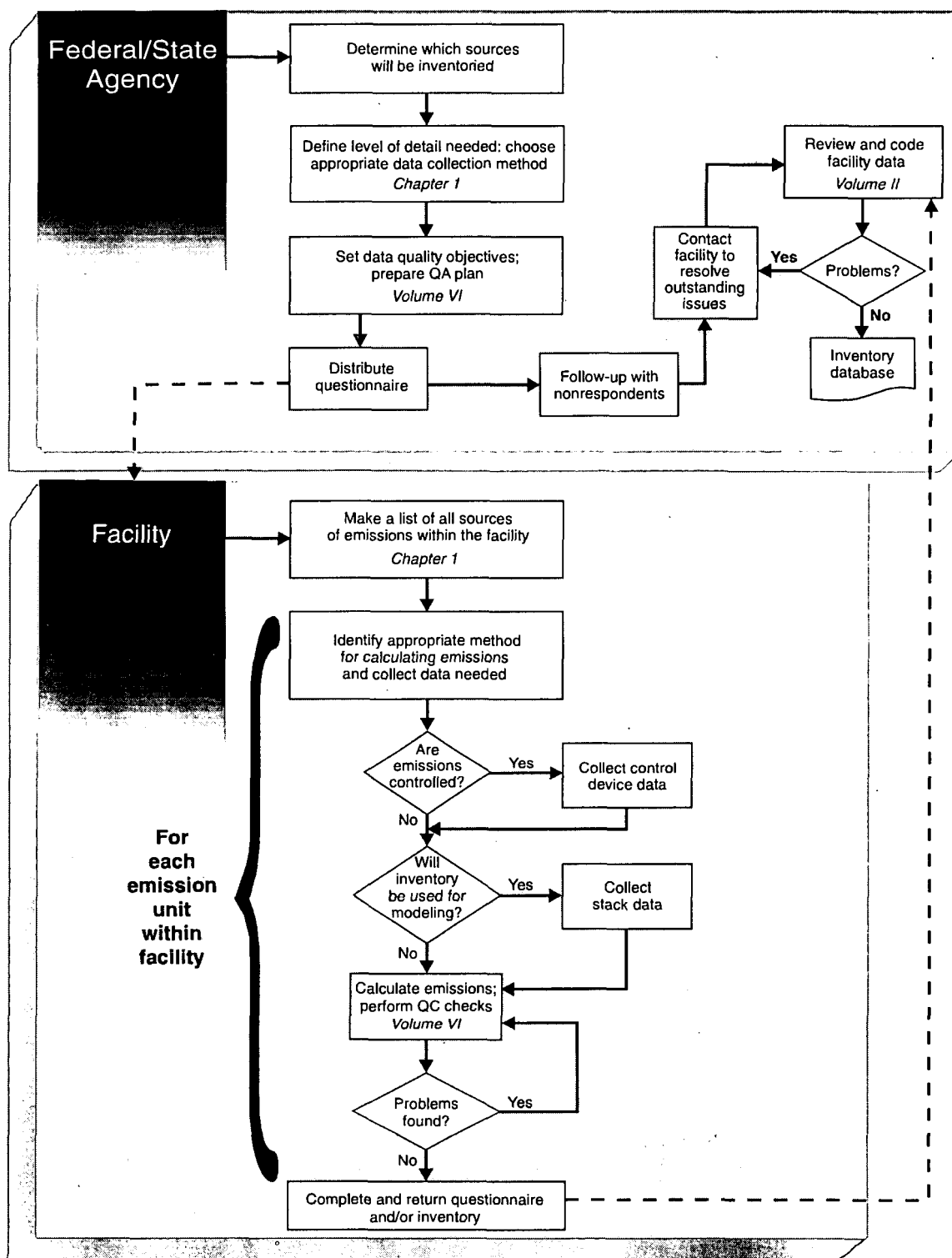


FIGURE 1.1-1. POINT SOURCE INVENTORY DEVELOPMENT PROCESS

## 1.3 ORGANIZATION OF CHAPTER 1

Section 2 of this chapter identifies several purposes for industry to generate emissions estimates including federal and state regulations, and plant initiatives. Section 3 discusses the emission inventory planning effort, including data handling and documentation requirements. Section 4 describes the basic techniques employed to estimate emissions, including emission factors, source tests, models, and material balances. Section 5 describes the basic procedures followed for data collection and the types of data available for estimating emissions. Section 7 describes quality assurance and quality control procedures and Volume VI of the EIIP series describes quality assurance and quality control procedures in detail. References are provided in Section 8.

Appendix A includes the table of contents from *AP-42, 5th Edition* and Appendix B provides useful conversion factors. Appendix C provides various contact and resource information, and Appendix D presents an example checklist to use to guarantee the completeness of the emissions inventory. Appendix E provides a brief description of the test methods described in individual chapters throughout Volume II. Information on emission estimation tools are presented in Appendix F.



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# PURPOSES FOR ASSESSING EMISSIONS

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In order to comply with various federal and state regulations, sources must initiate an emissions estimation effort. This section primarily focuses on the federal requirements for reporting emissions, while typical state requirements are also briefly discussed. Figure 1.2-1 provides an overview of some of the key emissions estimation relationships among industry, and state and federal agencies (EPA, 1993a).

## 2.1 FEDERAL REQUIREMENTS

Various federal requirements are linked to emissions estimation requirements. The major federal requirements for both sources and states, with emphasis on those requirements that are likely to lead to emissions estimation requirements for industry, are discussed in this section. Requirements discussed stem mainly from the Clean Air Act, and from other legislation such as the National Environmental Policy Act (NEPA), the Comprehensive Environmental Recovery and Comprehensive Liability Act (CERCLA), the Superfund Amendments and Reauthorization Act (SARA), the Resource Conservation and Recovery Act (RCRA), and the Pollution Prevention Act. Additional requirements stem from policy issued by the EPA, the Department of Energy (DOE), and the Department of Defense (DoD). The form and content of the specific emissions information varies with each requirement. A useful source for identifying which specific data elements are necessary under each requirement is the document entitled *Integrated Reporting Issues: Preliminary Findings* (EPA, 1992e). Table 1.2-1 provides an overview of the key federal emissions estimation requirements. In addition, Table 1.2-2, taken from the *Integrated Reporting Issues* document, provides an overview of the data elements contained in the major emissions reporting programs described in this section.

### 2.1.1 CLEAN AIR ACT REQUIREMENTS

The Clean Air Act is the major legislation addressing air pollution in the United States. It mandates a wide variety of programs to manage air quality. The federal air quality management effort begins with the national ambient air quality standards (NAAQS). The NAAQS set nationwide minimum air quality goals. Each state must assess all areas' air

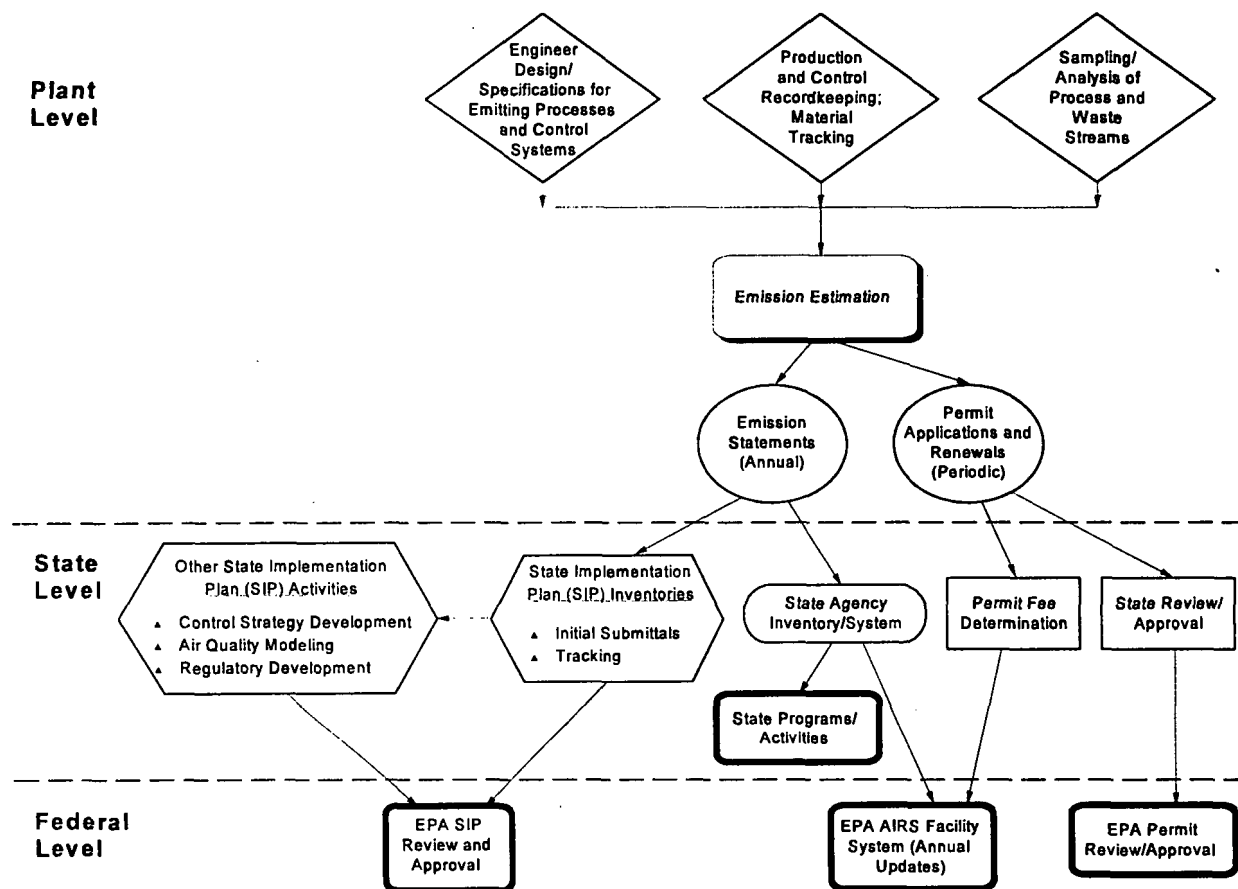


FIGURE 1.2-1. KEY RELATIONSHIPS FOR INDUSTRY AIR POLLUTANT EMISSION ESTIMATION

TABLE 1.2-1

## OVERVIEW OF KEY FEDERAL EMISSION ESTIMATION REQUIREMENTS

Statutory Requirement and Agency	Pollutant	Due Date	Size Cutoff	Data Requirements
<b>Annual AIRS Update</b>				
40 CFR 51.321 Agency: State to EPA	PM <sub>10</sub> , sulfur oxides, VOC, NO <sub>x</sub> , CO, and lead	July 1, annually	Facility-100 tpy PM <sub>10</sub> , sulfur oxides, VOC, and NO <sub>x</sub> ; 100 tpy CO; 5 tpy lead. Point-25 tpy PM <sub>10</sub> , sulfur oxides, VOC, and NO <sub>x</sub> ; 250 tpy CO; and 5 tpy lead	General plant information, year of inventory, general operating parameters, emissions data, and control equipment data
<b>Emission Inventory (base year and periodic)</b>				
Clean Air Act Section 172(c)(3) Section 182(a)(1)a Section 182(a)(3)(A)a Section 187(a)(1)b Agency: State to EPA	All criteria pollutants	November 15, 1992 and every 3 years thereafter	Point sources-10 tpy VOC; 100 tpy PM <sub>10</sub> moderate; 70 tpy PM <sub>10</sub> serious	General plant information, year of inventory, source operating data, physical data (i.e., stack height, process rate data, source emissions data, and emission limitation data)
<b>Emission Statement</b>				
Clean Air Act Section 182(a)(3)(B)c Agency: Source to state	VOC, NO <sub>x</sub>	April 15, annually;	25 tpy VOC or NO <sub>x</sub> in nonattainment area; 50 tpy VOC or 100 tpy NO <sub>x</sub> in attainment portion of transport region	Source identification, source emissions data (annual and typical summer day), control equipment data, process rate data and a certification that the data are accurate

TABLE 1.2-1

(CONTINUED)

Statutory Requirement and Agency	Pollutant	Due Date	Size Cutoff	Data Requirements
<b>Title V Operating Permits</b>				
Clean Air Act Title V Agency: Source to state	All criteria pollutants, all HAPs, CFCs, HCFCs	At time of initial Title V permit application submittal, which is generally one year after EPA approval of state permit program. Annual submission according to state schedule to determine fee basis.	Potential to emit "major" amounts of regulated air pollutants <sup>d,e</sup>	General company information, plant description, emissions information, regulatory requirements and compliance information
<b>New Source Review</b>				
Clean Air Act Section 172(c)(5) Agency: Source to state	Criteria pollutants, fluorides, sulfuric acid mist, hydrogen sulfide, total reduced sulfur, reduced sulfur compounds, MWC organics, metals and gases, ozone-depleting substances <sup>f</sup>	Prior to construction or operation of a new or modified major source	Potential to emit "major" amounts for new sources, significant net emissions increase for modified sources	Legal authority, technical specifications, potential emissions, emission compliance demonstration, definition of excess emissions, administrative and other conditions
<b>Economic Incentive Programs (EIP)</b>				
40 CFR Part 51 (some required, some optional) Agency: Source to state	All criteria pollutants	Specific to individual EIP	Major <sup>d</sup>	Specific to individual EIP. Emissions must be "quantifiable."

TABLE 1.2-1

(CONTINUED)

Statutory Requirement and Agency	Pollutant	Due Date	Size Cutoff	Data Requirements
<b>Early Reductions Program</b>				
Clean Air Act Section 112(i)(5)  Agency: Source to state	All HAPs as defined in Section 112(b)	Reduction must be achieved before January 1, 1994, therefore demonstration must come before then	Any stationary source	Same as permit with the early reduction demonstration
<b>Urban Air Toxics Program</b>				
Clean Air Act Section 112(k)  Agency: EPA to Congress	All HAPs as defined in Section 112(b) or (k)	EPA must report by November 15, 1993	Any source of HAPs contributing to urban concentrations, with emphasis on area sources	Data as necessary to characterize emissions of HAPs and prioritize threats to public health in urban areas
<b>Great Lakes and Coastal Waters Program</b>				
Clean Air Act Section 112(m)  Agency: EPA to Congress	All HAPs as defined in Section 112(b)	EPA must report by November 15, 1993, and biennially thereafter	Any source contributing to deposition of HAPs	Data as necessary to determine sources and deposition rates of HAPs
<b>Accidental Release Program</b>				
Clean Air Act Section 112(r)	All extremely hazardous substances as defined in regulation developed under Section 112(r)	As specified in Section 112(r) regulations to be published	Sources emitting amounts above threshold quantities as specified in Section 112(r) regulations to be published	Risk management plan including estimate of potential release quantities, determination of downwind effects, previous release history, and an evaluation of the worst case accidental release

TABLE 1.2-1

(CONTINUED)

Statutory Requirement and Agency	Pollutant	Due Date	Size Cutoff	Data Requirements
<b>New Source Performance Standards</b>				
40 CFR Part 60  Agency: Source to state agency or EPA	SO <sub>2</sub> , NO <sub>x</sub> , total reduced sulfur, hydrogen sulfide, CO, opacity, VOC, PM	30 days after reporting period ends	As specified in standard	Pollutant, reporting period, general company information, emission limitation, monitor manufacturer and model number, data of last CMS certification or audit, process units description, total source operating time, emissions data, CMS performance data
<b>Acid Rain Allowance Trading (Title IV)</b>				
Title IV Clean Air Act	SO <sub>2</sub> , NO <sub>x</sub>	30 days after end of quarter (beginning January 30, 1994 for Phase I and April 30, 1995 for Phase II)	Any facility listed in Table A or B of Title IV or any facility that opts-in (Phase I approx. 110 sources, Phase II approx. 800 sources). Also applies to any new fossil-fuel combustion device that supplies electricity for sale or serves an electricity-generating device that supplies electricity for sale.	General plant information, emissions data, fuel use data
<b>Section 114 General Requirements (i.e., "Section 114 letter")</b>				
Clean Air Act Section 114  Agency: Source to EPA	As specified by EPA	As specified by EPA	Determined case-by-case by EPA	General company information, pollutant, compliance information, operating information

TABLE 1.2-1

(CONTINUED)

Statutory Requirement and Agency	Pollutant	Due Date	Size Cutoff	Data Requirements
<b>Section 114 Compliance Certification</b>				
Clean Air Act Section 114(a)(3)  Agency: source to EPA	All criteria pollutants and all hazardous air pollutant as defined in Section 112(a)(1)	30 days after quarter ends, on a quarterly or annual basis	Major	General company information, pollutant, emission information, description of enhanced monitoring system, summary of compliance demonstration, deviation description, violation information, and operation data
<b>National Air Toxics Information Clearinghouse (NATICH)</b>				
Clean Air Act Section 112(1)(3)  Agency: State/local agency to EPA	Any hazardous air pollutant (i.e., any noncriteria air pollutant)	Voluntary	Voluntary	Agency name, general plant information, year permit issued, control equipment data, pollutant names, emission limit data, actual emission rate data, source testing data
<b>Best Available Control Technology (BACT)/Lowest Achievable Emission Rate (LAER) Clearinghouse</b>				
N.A.  Agency: State/local agency to EPA	Criteria pollutants	Voluntary - after issuance of a BACT or LAER determination	Voluntary	General company information, plant description, year permit issued, emissions data, control technology data, compliance data
<b>National Environmental Policy Act (NEPA)</b>				
PL 91-190  Agency: EPA	Anything that may result in a "significant environmental impact"	Prior to implementation of any federal agency action	NA	Description of the proposed action, alternatives to the action, and environmental, social, and economic impacts of the proposed action and alternatives. May lead to specific requests from EPA to industry



TABLE 1.2-1

(CONTINUED)

Statutory Requirement and Agency	Pollutant	Due Date	Size Cutoff	Data Requirements
<b>Comprehensive Environmental Recovery and Comprehensive Liability Act (CERCLA)</b>				
PL 96-510, amended SARA 42 U.S.C. Section 9601  Agency: Source to state	Chemicals listed in Sections 307, 311 of Clean Water Act, Section 3001 of RCRA, Section 112 of CAA, Section 7 of Toxic Substances Control Act, others designated by EPA under Superfund	Upon release	Releases to the environment that exceed the reportable quantity for that material	Report on release of the toxic substance, including substance and quantity released. (See SARA Section 304.)
<b>Superfund Amendments and Reauthorization Act (SARA)</b>				
SARA Title III Section 313 ("right to know")  Agency: EPA and states	EPA designated "toxic chemicals" (329 on original list; 284 added 1995)	July 1, annually	Chemicals used $\geq 10,000$ lb/yr, chemical manufactured or processed $\geq 25,000$ lb/yr	Chemical identify, name, location and principal business identity, certification by senior officials of business, use of each listed chemical, maximum on-site quantity at any time, amount (lb/yr) released to the environment of each chemical, amount (lb/yr) transferred offsite, method of waste treatment and disposal including treatment efficiency, release data (fugitive air emissions in lb/yr, stack/point air emissions in lb/hr, wastewater discharges, releases to land, transfers to off-site locations, underground injection)
SARA Section 304 (hazardous releases)  Agency: Source to public	Hazardous substances as defined by CERCLA, extremely hazardous substances as defined by EPA	Immediately upon release	Any episode that releases more than published reportable quantity	Chemical name or identity, quantity released, time and duration of release, media into which released, anticipated health risks, medical attention requirements, precautions, evacuation information, name of person to contact for more information

TABLE 1.2-1

(CONTINUED)

Statutory Requirement and Agency	Pollutant	Due Date	Size Cutoff	Data Requirements
<b>Resource Conservation and Recovery Act (RCRA)</b>				
40 CFR Subtitle C Agency: Source to EPA	Hazardous waste as defined by 40 CFR 261.31, acutely defined by 40 CFR 261.33	Biennially	Small generators: 100-1000 kg non-acutely hazardous waste/month; large generators >1 kg acutely hazardous waste, >1000 kg non-acutely hazardous waste/month	EPA ID number, record of hazardous waste transfers (manifests), records of any test results, waste analyses, etc., waste minimization plan
<b>Pollution Prevention Act</b>				
PL 101-508 Section 6607 Agency: Source to EPA	EPA designated "toxic chemicals"	Annually	Chemicals used $\geq 10,000$ lb/yr, chemical manufactured or processed $\geq 25,000$ lb/yr	Toxic chemical source reduction and recycling report

Source: EPA, 1993a.

<sup>a</sup> For ozone.<sup>b</sup> For CO.<sup>c</sup> The periodic inventory requirement is only for ozone nonattainment areas.<sup>d</sup> Definition of major and significant net emissions increase depends on pollutant (e.g., for ozone it depends on an area's classification).<sup>e</sup> Additional nonmajor sources may be added by EPA rule expected in late 1990s.<sup>f</sup> Applicability determination is based on emissions of all pollutants regulated under the Act. However, emission inventory submitted to the state is generally on pollutants listed to determine control technology requirements.

CMS = Continuous Monitoring System.

NADB = National Allowance Database.

ARDS = Acid Rain Data System.

TRAC = Tracking Responses to Acid Rain Compliance.

NA = Not applicable.

TABLE 1.2-2

## COMPARISON OF EMISSIONS REPORTING PROGRAM DATA ELEMENTS

Data Element	Triennial Inventory (State to EPA)	AIRS Annual Update (State to EPA)	Permit Program <sup>a</sup> (Source to State)	Emission Statement (Source to State)
<b>Plant - General Level</b>				
FIP State Code	✓	✓	✓	✓
FIP County Code	✓	✓	✓	✓
Year of Record	✓	✓	✓	✓
Plant AFS/NEDS ID	✓	✓	✓	✓
Plant Name	✓	✓		✓
Plant Address	✓	✓	✓	✓
FIP City Code	✓	✓	✓	✓
Plant Zip Code	✓	✓	✓	✓
UTM Zone, Easting, and Northing or Latitude and Longitude	✓	✓		✓
Primary SIC Code	✓	✓	✓	✓
Type of Inventory	✓			
Annual Nonbanked Emissions (Estimated Actual)			✓	
<b>Point - General Level</b>				
FIP State Code	✓	✓		✓
FIP County Code	✓	✓		✓
Plant AFS ID	✓	✓		✓
Point AFS ID	✓	✓		✓
Operating hours/day	✓	✓		✓
Operating days/week	✓	✓		✓

TABLE 1.2-2

(CONTINUED)

Data Element	Triennial Inventory (State to EPA)	AIRS Annual Update (State to EPA)	Permit Program <sup>a</sup> (Source to State)	Emission Statement (Source to State)
Operating hours/year	✓	✓		✓
Percent throughput: Dec-Feb	✓	✓		✓
Percent throughput: Mar-May	✓	✓		✓
Percent throughput: Jun-Aug	✓	✓		✓
Percent throughput: Sep-Nov	✓	✓		✓
<b>Stack Level</b>				
FIP State Code	✓	✓		
FIP County Code	✓	✓		
Plant AFS ID	✓	✓		
Stack AFS ID	✓	✓		
Stack Height	✓	✓		
Stack Diameter	✓	✓		
Plume Height	✓	✓		
<b>Segment - General Level</b>				
FIP State Code	✓	✓		✓
FIP County Code	✓	✓		✓
Plant AFS ID	✓	✓		✓
Point AFS ID	✓	✓		✓
Segment AFS ID	✓	✓		✓
SCC Number	✓	✓		✓
Process Rate Units	✓			✓
Actual Annual Process Rate	✓			✓

TABLE 1.2-2

(CONTINUED)

Data Element	Triennial Inventory (State to EPA)	AIRS Annual Update (State to EPA)	Permit Program <sup>a</sup> (Source to State)	Emission Statement (Source to State)
Ozone Season Daily Process Rate	✓			✓
CO Season Daily Process Rate	✓			
Stack ID for Segment	✓			
<b>Segment - Pollutant Level</b>				
FIP State Code	✓	✓	✓	✓
FIP County ID	✓	✓	✓	✓
Plant AFS ID	✓	✓	✓	✓
Point AFS ID	✓	✓		✓
Segment AFS ID	✓	✓		✓
Pollutant/CAS Number	✓	✓	✓	✓
Primary Control Device Code	✓	✓		✓
Secondary Control Device Code	✓	✓		✓
Control Efficiency	✓	✓		✓
SIP Regulation in Place	✓			
Compliance Year for Segment	✓			
Emission Limitation Description	✓			
Emission Limitation Value	✓			
Emission Limitation Units	✓			
Emission Estimation Method	✓	✓		✓

TABLE 1.2-2

(CONTINUED)

Data Element	Triennial Inventory (State to EPA)	AIRS Annual Update (State to EPA)	Permit Program <sup>a</sup> (Source to State)	Emission Statement (Source to State)
Emission Factor	✓	✓		✓
Annual Nonbanked Emissions (Estimated Actual)	✓	✓		✓
Rule Effectiveness	✓			✓
Ozone Season Daily Emissions	✓			✓
CO Season Daily Emissions	✓			

Source: EPA, 1992e.

<sup>a</sup> Proposed AFS permit enhancements.

quality relative to the NAAQS. For those areas meeting the standard, the state is required to submit plans showing prevention of significant deterioration (PSD).

For nonattainment areas, the state must develop and submit to EPA a detailed, comprehensive and legally binding plan to meet the NAAQS by a specified date and to continue to meet the NAAQS beyond that date. This legally binding plan is called a state implementation plan (SIP). In the SIP, each state has the responsibility for selecting a control strategy that determines which sources must control emissions and the degree of control needed to achieve and/or maintain the NAAQS. States that have been totally or partially designated as nonattainment areas must develop emissions inventories as part of their SIP to reduce emissions. If the state fails to submit an adequate plan, the EPA will impose its own plan, called a federal implementation plan (FIP).

In addition to those requirements related to maintenance of the NAAQS, other federal-state programs addressing emissions of various air pollutants have also been established to improve air quality. These include emissions standards for hazardous air pollutants (HAPs), emission and fuel standards for motor vehicles, provisions for control of acid deposition, requirements for operating permit programs, and stratospheric ozone protection. The following sections briefly describe these programs.

### ***SIP Requirements (CAA Amendments, Title I)***

The CAA requires that the base year SIP inventories be prepared according to a set of minimum standards. The requirements for ozone and CO SIP inventories are listed in Table 1.2.3.

### ***Operating Permits Program (CAA Amendments, Title V)***

Title V of the Clean Air Act mandates that states establish operating permits programs requiring the owners or operators of major and other sources to obtain permits addressing all applicable pollution control obligations under the CAA. These obligations include emissions limitations and standards, and monitoring, recordkeeping, and reporting requirements. Such requirements are to be contained in an operating permit which is issued to the source for a period of no more than five years, before renewal. EPA has published its final regulations on operating permits in a new Part 70 of Title 40 of the *Code of Federal Regulations*. In general, the operating permits program as defined in the Part 70 regulations includes the following sources regulated under the Clean Air Act:

- Major sources of air toxics as defined in Section 112 with the potential to emit 10 tpy or more of any single HAP listed in Section 112(b); or 25 tpy or more of any combination of HAPs; or a lesser quantity if specified by the EPA.

TABLE 1.2-3

**INVENTORY REQUIREMENTS OF THE CLEAN AIR ACT AMENDMENTS  
FOR OZONE AND CO**

<b>Activity</b>	<b>Requirement</b>	<b>Date</b>
Ozone Base Year Inventory--Basis For All Other Inventories	<ul style="list-style-type: none"> <li>• Comprehensive, accurate inventory for 1990</li> <li>• Include VOC, NO<sub>x</sub>, and CO from point, area, and mobile sources</li> <li>• Include anthropogenic and biogenic sources</li> <li>• Same requirements for all nonattainment classifications</li> </ul>	11/15/92
Adjusted Ozone Base Year Inventory	<ul style="list-style-type: none"> <li>• Needed to demonstrate 15% VOC reduction by 1996</li> <li>• Excludes biogenic emissions and emissions reductions required before CAAA</li> </ul>	11/15/93
CO Base Year Inventory	<ul style="list-style-type: none"> <li>• Comprehensive, accurate inventory for 1990</li> <li>• Include CO emissions from point, area, and mobile sources for a 24-hour period</li> <li>• For moderate and serious areas</li> </ul>	11/15/92
PM <sub>10</sub>	<ul style="list-style-type: none"> <li>• Comprehensive, accurate inventory due with the attainment plan</li> <li>• Most significant inventory will be for serious areas--due later</li> </ul>	11/15/92
Inventory Work Plan	<ul style="list-style-type: none"> <li>• The EPA requires states to submit plans to explain how they will develop, document, and submit their inventories</li> </ul>	10/01/91



(CONTINUED)

Activity	Requirement	Date
Periodic Inventories for Ozone and CO	<ul style="list-style-type: none"> <li>• Same information as base year</li> <li>• 1993 base for first year</li> <li>• Purpose is to track emissions reductions for all nonattainment classifications</li> </ul>	Ozone - 11/15/96 CO-09/30/95 Update every 3 years until attainment
Ozone Modeling Inventory	<ul style="list-style-type: none"> <li>• Required for all areas using photochemical grid model and other moderate areas making an attainment demonstration</li> <li>• Requires base year and projected inventory</li> <li>• Photochemical grid model requires allocated, speciated, and spatially gridded inventory</li> </ul>	Areas using a photochemical grid model--inventory due 11/15/94. Other modeling approaches--inventory due 11/15/93.
CO Modeling	<ul style="list-style-type: none"> <li>• Needed for nonattainment areas with design values exceeding 12.7 ppm</li> <li>• Requires base year and projected inventory</li> <li>• Detail will reflect model used (proportional rollback or gridded dispersion model)</li> <li>• Used for determining whether proposed SIP control strategies are adequate to reach attainment by specified date.</li> <li>• Moderate areas demonstration plan for attainment.</li> <li>• Serious areas demonstration plan for attainment.</li> </ul>	11/15/93          12/31/95  12/31/00

TABLE 1.2-3

(CONTINUED)

Activity	Requirement	Date
RFP Projection Inventory for 3% per year VOC Reduction	<ul style="list-style-type: none"> <li>◦ Serious and above areas show 3% per year VOC reduction after 1996</li> <li>◦ Continue until attainment</li> <li>◦ Base year will be final year of demonstration (i.e., 1999, 2002, 2005, 2008, 2010)</li> <li>◦ Based on allowable emissions reflecting regulatory limits</li> </ul>	11/15/94
Emission Statements	<ul style="list-style-type: none"> <li>◦ For all nonattainment classifications</li> <li>◦ Annual statements from owners of stationary sources showing actual emissions of NO<sub>x</sub> or VOCs</li> <li>◦ Certify information is accurate</li> <li>◦ Sources less than 25 tpy can be waived if included in inventory and the EPA emission factors used</li> </ul>	11/15/93

- Any other source, including an area source, subject to the HAP provisions of Section 112. An area source is any source not considered to be a major source.
- Major sources in nonattainment areas as defined in Part D of Title I with potential to emit pollutants in the amounts shown in Table 1.2-4.
- Any source subject to the new source performance standards (NSPS) under Section 111.
- Sources subject to the preconstruction permits requirements of the Prevention of Significant Deterioration (PSD) program under Title I, Part C or the nonattainment area NSR program under Title I, Part D.
- Major sources as defined in Section 302 of the Act with the potential to emit 100 tpy or more of any pollutant.
- Sources subject to the acid rain provisions contained in Title IV.
- Any source designated by the EPA in whole or in part, by regulation, after notice and comment.

The Part 70 regulations specify the requirements under Title V of the Act for permittees, as well as the administrative duties required of state air permitting agencies. The minimum requirements for information to be submitted by subject sources in the permit application, which include certain emissions-related information, are listed in 40 CFR 70.5(c). Emissions-related information required to be in the application includes the following: (1) all emissions of pollutants for which the source is major [including unregulated Section 112(b) pollutants], and all emissions of regulated air pollutants from all emissions units; (2) identification and description of all emissions points; (3) emissions rate in tpy and in any other units necessary to establish compliance with standards; (4) fuels, fuel use, raw materials, production rates, and operating conditions used to determine emissions, fees, or compliance; (5) pollution control and compliance monitoring activities; (6) limitations on source operation affecting emissions; (7) other relevant information, including stack height limitations; and (8) calculations on which any of the above are based. A state's permit program may also require additional information under its own laws.

TABLE 1.2-4

**EMISSION CUTOFFS FOR DETERMINING APPLICABILITY OF  
TITLE V OPERATING PERMITS PROGRAM IN NONATTAINMENT AREAS**

Pollutant	tpy
Ozone (VOC and NO <sub>x</sub> ):	
Serious nonattainment area	≤ 50
Transport region not severe extreme in nonattainment	≤ 50
Severe nonattainment area	≤ 25
Extreme nonattainment area	≤ 10
Carbon monoxide - serious nonattainment area	≤ 50
Particulate matter - (PM <sub>10</sub> ) serious nonattainment area	≤ 70

***New Source Review (CAA Amendments, Title I)***

Section 172(c)(5) of the CAA states that SIPs for nonattainment areas will require preconstruction permits for the construction and operation of new or modified major stationary sources anywhere within the nonattainment area. Likewise, Section 165(a)(1) of the CAA requires that new or modified sources in attainment areas must also secure preconstruction permits. These permits must contain certain basic elements, including legal authority, technical specifications (including an estimate of emissions of each pollutant that the source would have the potential to emit in significant amounts), emission compliance methods, a definition of excess emissions, and other administrative and miscellaneous conditions (EPA, 1992e). Once the source begins operation it will be necessary to determine source emissions under design operating conditions in order to demonstrate compliance or noncompliance with the allowable levels of emissions. Sources obtaining permits for new sources often use trading transactions, which also require emissions estimations.

***Emissions Statements (CAA Amendments, Title I)***

Section 182(a)(3)(B) of the CAA requires that states with areas designated as nonattainment for ozone obtain emissions statement data from VOC and NO<sub>x</sub> sources in the nonattainment areas. Emissions statements are derived from point source data through plant contacts. A revision to a state's SIP to include emissions statements should have been submitted within 2 years of the CAA Amendments enactment date.

The emissions statement requirement applies to all ozone nonattainment areas, regardless of their classification, and to stationary sources that emit, or have the potential to emit, 50 tons per year (tpy) or more of VOC or 100 tpy or more of NO<sub>x</sub> in attainment areas within ozone transport regions. A state may, with the EPA's approval, waive the requirement for emissions statements for classes or categories of sources with less than 25 tpy of actual plantwide NO<sub>x</sub> or VOC emissions in nonattainment areas if the class or category is included in the base year and periodic inventories and emissions are calculated using emission factors established by the EPA (such as those found in *AP-42*) or other methods acceptable to the EPA. Whatever minimum reporting level is established, if either VOC or NO<sub>x</sub> is emitted at or above this level, the other pollutant should be included in the emissions statement, even if it is emitted at levels below the specified cutoffs.

At a minimum, emissions statements should include: (1) certification of data accuracy, (2) operating schedule, (3) emissions information (to include annual and typical ozone season day emissions), (4) control equipment information, and (5) process data. Agencies are responsible for reviewing the consistency of the emissions statement data with other available data sources and resolving any inconsistencies (EPA, 1992c).

The emissions statement reporting format provides for two data collection mechanisms. Traditional sources (i.e., those with emissions data already in the AIRS database) should review and/or correct their Aerometric Information Retrieval System (AIRS) AFP644 report. Nontraditional sources (i.e., those that do not have emissions data in AIRS) should submit an "Emissions Statement Initial Reporting Form." In both cases, an explanatory letter and detailed instructions should be included. Agencies have the option of developing their own emissions statement reporting format, in which case care should be taken to ensure that the minimum emissions statement data elements are requested and that the emissions statement data are provided to the EPA via the AIRS system.

Facilities must submit their first emissions statement within three years of the CAA Amendments enactment date, and annually thereafter. The first emissions statement will be based on 1992 emissions. The EPA strongly recommends that agencies require a submittal date of April 15 to allow use of the emissions statement data in the preparation of the annual point source inventory. Adequate records of emissions statement data and source certifications of emissions should be maintained by an agency for at least three years to allow for review or verification of the information, as needed.

Agencies should provide the EPA with a status report that outlines the degree of compliance with the emissions statement program. Since July 1, 1993, agencies are required to report the total number of sources affected by the emissions statement provisions, the number that have complied with the emissions statement provisions, and the number that have not. This report is a quarterly submittal until all the regulated sources have complied for the reporting year.

The status report also includes the total annual and typical ozone season day emissions from all reporting sources, both corrected and non-corrected for rule effectiveness. Agencies should include in their status report a list of sources that emit 500 tpy or more of VOC or 2,500 tpy or more of NO<sub>x</sub> and that are delinquent in submitting their emissions statements.

Agencies are recommended to enter emissions statement data into AFS by July 1 of each year, as of 1993. This activity should be coordinated with other reporting requirements to avoid deleting valuable data in the AIRS database.

The emissions statement data elements were developed to be consistent with other source and agency reporting requirements. This consistency is essential to assist agencies with an avenue to check emissions estimates and to facilitate consolidation of all EPA reporting requirements. Thus, emissions statement data will provide information useful for the development, quality assurance, and completion of several emissions reporting requirements, including tracking of RFP, periodic inventories, annual AFS submittals, the operating permit program of the CAA, emissions trends, and compliance certifications. The goal of emissions statement reporting in the future is to consolidate all these reporting requirements into one annual effort.

### ***Hazardous Air Pollutants (CAA Amendments, Title III)***

Section 112 of the CAA requires EPA to promulgate regulations for reducing the emissions of HAPs. Section 112(b) contains a list of 189 pollutants which are to be regulated as HAPs. Section 112(d) requires that emissions standards be established for each source category listed. A draft schedule for issuance of these standards was published on September 24, 1992 (57 FR 44147) and the emissions standards must be technology-based and must require the maximum achievable degree of reduction possible in emissions of HAPs from the source category. This technology is referred to as maximum achievable control technology (MACT) and the emissions standards are called MACT standards. In general, MACT standards may include process changes; material substitutions; reuse or recycling; enclosure of systems or processes to eliminate emissions; pollution collection, capture or treatment systems; design, equipment, work practice or operational methods; operator training requirements; or a combination of these methodologies.

Section 112 may lead to additional emission estimation or inventory requirements for sources. All sources subject to Section 112 are also subject to the Title V requirements. As such, sources of HAPs must include emissions estimates in their operating permits. In addition, four special programs under Section 112 may lead to additional requirements for emissions estimates. These are: the early reductions program under Section 112(i)(5), the Urban Air Toxics Study under Section 112(k), the Great Lakes and Coastal Waters program under Section 112(m), and the accidental releases program under Section 112(r).

Under Section 112(s), EPA is required to maintain a database on pollutants and sources subject to Section 112. This database will be required to contain information from all of the programs described above, as well as information from standard development projects under Section 112(d). EPA is planning to consolidate this data into a "MACT database." Information and guidance on this database will be available in future rulemakings pertaining to Section 112.

**Early Reduction Program.** Under the early reduction program, existing sources may opt to apply for a 6-year extension of the regular 3-year MACT compliance deadline if such sources can demonstrate a 90 percent reduction (or 95 percent reduction for particulate emissions) or more of HAPs prior to the proposal of the applicable MACT standard. As a condition of the compliance extension, states may require additional emission reductions from such sources. Such reductions generally must be based on actual and verifiable emissions in a base year no earlier than 1987. The source must provide a one-time demonstration of the required reduction, which will require estimation and comparison of current emissions and emissions during the relevant base year. It should be noted that the emissions reductions used to qualify under this extension will be federally enforceable, and hence also require a Title V permit revision.

**Urban Air Toxics Study.** Under the Urban Air Toxics Study, EPA is required to conduct a program of research on sources of HAPs in urban areas. This program must include an analysis to characterize sources of such pollution with a focus on area sources. EPA, in implementing this program, may request specific emissions estimates and other relevant information from sources.

**Great Lakes and Coastal Waters Program.** Under the Great Lakes and Coastal Waters program (often referred to as the Great Waters Program), EPA is required to assess the extent of atmospheric deposition of HAPs into the Great Lakes, Chesapeake Bay, Lake Champlain, and coastal waters. In addition to numerous monitoring and sampling efforts, this assessment will include an investigation of the deposited chemicals and their precursors and sources. This investigation will likely lead to emissions estimation requirements for sources which emit HAPs that could be deposited into these waters.

**Accidental Release Program.** Under the accidental release program, sources which emit HAPs above certain threshold quantities must submit risk management plans designed to detect and prevent accidental releases of HAPs. The risk management plan must assess the potential effects of an accidental release, which will include an estimate of potential release quantities, determination of downwind effects, previous release history and an evaluation of the worst case accidental release. The plan must also include an accidental release prevention program

and an emergency response program to be implemented in the event of such a release. Such plans must be submitted to EPA, the Chemical Safety and Hazard Investigation Board, and state and local air pollution control agencies.

**Section 114 Reporting Requirements, Compliance Certifications and Compliance Monitoring.** Section 114 of the CAA gives EPA the authority to require sources to, on a one-time, periodic, or continuous basis, report to EPA information which EPA deems necessary for developing standards or SIPs, determining compliance, or meeting other provisions of the Act. Under Section 114, EPA can require sources to establish recordkeeping; make reports; sample emissions; keep production, control technology, or other operations data; or provide other necessary information. The EPA may include emissions estimates as part of these information requirements. Information collected under Section 114 is publicly available except non-emissions-related data which may be held as confidential by the EPA, rather than divulging proprietary product information.

#### ***Allowance Trading (CAA Amendments, Title IV)***

In order to control sources of acid deposition, Title IV of the CAA Amendments establishes the allowance trading program. This program seeks to reduce emissions of SO<sub>2</sub> by 10 million tpy, relative to 1980 levels. Three databases, National Allowance Database (NADB), Acid Rain Data System (ARDS) and Tracking Responses to Acid Rain Compliance (TRAC), are set up under this program to track emissions, allowance trading, and compliance, respectively. Sources affected by Title IV (i.e., those listed in Table A, Title IV, of the CAA Amendments), or those that opt in will be responsible for reporting to these databases. These reports will include general plant information, emissions data, and fuel use data. It should also be noted that sources subject to Title IV requirements are also subject to Title V operating permit provisions (EPA, 1993a).

### **2.1.2 REQUIREMENTS UNDER OTHER EPA REGULATIONS**

A number of other EPA requirements which are not directly related to the CAA require some form of emissions estimation. These requirements are a result of the following federal laws: NEPA, CERCLA, SARA, RCRA, and the Pollution Prevention Act. This subsection briefly highlights these requirements.

#### ***National Environmental Policy Act (NEPA) of 1969***

The National Environmental Policy Act (NEPA) requires that, where a federal agency action may result in a significant environmental impact, an environmental assessment be prepared before such policy can be implemented. An environmental assessment (EA) is a study that provides background information and preliminary analyses of the potential impact of a new



policy. If the results of an EA indicate that significant environmental impact may result, EPA will prepare an Environmental Impact Statement (EIS). The EIS examines, in detail, the potential impact of a proposed agency action. Generally, industries are not required to prepare EISs, but EPA may require industry input, including emissions estimates, for its evaluation of the impact of proposed rulings (EPA, 1993a).

### ***Comprehensive Environmental Recovery and Comprehensive Liability Act of 1980***

Under CERCLA, facility managers are required to perform an Air Pathway Analysis (APA) in order to assess the potential for exposure of personnel to toxics in the ambient air at National Priority List (NPL) sites and to provide input to the Superfund risk assessment process. Air pathway analysis involves a combination of modeling and monitoring methods to assess actual or potential emissions from a hazardous waste site. The APA has three major components: (1) characterization of air emission sources (e.g., estimation of contaminant emission rates) for the control and recordkeeping process; (2) determination of the effects of atmospheric processes (e.g., transport and dilution) on the personnel at a site; and (3) evaluation of receptor exposure potential (i.e., what air contaminant concentrations are expected at receptors of interest for various exposure periods) (EPA, 1989).

### ***Superfund Amendments and Reauthorization Act (SARA) of 1986***

SARA, which was passed in 1986 to amend CERCLA, contains two requirements likely to lead to emissions estimation. First, Section 313 of SARA requires that companies that process, manufacture, or otherwise use toxic compounds listed in Section 313 of the Act report to EPA the annual quantities used of those compounds and any releases to the environment (including air emissions) that result from their use. The Section 313 "Right-to-Know" requirements were enacted by Congress to increase public awareness and information on toxic emissions. The EPA has made Section 313 data publicly available. A database has been established, known as the Toxic Release Inventory System (TRIS), which contains information from SARA toxic chemical release reports (EPA, 1993a).

Second, Section 304 of SARA requires that any source which emits amounts in excess of threshold levels of any "hazardous" or "extremely hazardous" substance as defined by EPA pursuant to CERCLA must report the quantities of the substance(s) released. These reports are to be filed with the National Response Center, and are due immediately upon release of the substance (EPA, 1993a).

### ***Resource Conservation and Recovery Act (RCRA) of 1976***

RCRA was established to minimize the generation of hazardous waste, and to aid in the management of such hazardous waste. Sections 3001 and 3002 of RCRA require hazardous

waste generating facilities to report and analyze their generation of certain hazardous wastes. Such an analysis could include estimation of emissions of certain substances. These facilities must report biennially to EPA.

### ***Pollution Prevention Act of 1990***

The Pollution Prevention Act is designed to facilitate the reduction of pollution at the source, rather than to mandate "end-of-pipe" controls. In general, this Act requires several EPA activities to facilitate pollution prevention, including establishing a clearinghouse for pollution prevention information, a grants program, reports to Congress, and others. It also imposes a specific reporting requirement on certain sources. Specifically, sources that are required to file an annual toxic release form under Section 313 of SARA must also file an annual toxic chemical source reduction and recycling report. Section 6607 of the Pollution Prevention Act describes the specific requirements for this report. For many sources, meeting these requirements will require some form of emissions estimation (EPA, 1991c).

### **2.1.3 FEDERAL REQUIREMENTS OUTSIDE OF EPA**

In addition to EPA, two other federal agencies have requirements that may lead to emissions estimates for certain sources. The Department of Energy (DOE) requires electric power plants to report information on fuels, cooling equipment, environmental control equipment, and other information from which air emissions may be estimated. The Department of Defense (DoD) is in the process of establishing a central air emissions database which is to be part of the Defense Corporate Information Management (DECIM) system. This database may require additional emissions reporting. It should also be noted that each facility subject to any DOE or DoD requirements is also subject to any relevant EPA requirements.

## **2.2 STATE REQUIREMENTS**

As previously described, the EPA places several requirements on states which may indirectly lead to reporting requirements for sources. These include the requirements that the states update emissions inventories on an annual basis for AIRS, that the states submit base year and periodic inventories for SIP development, and that the states develop Title V Operating Permits programs.

Although states must comply with federal requirements, states are not restricted from establishing their own, more stringent requirements. While the federal laws and regulations identify a minimum set of requirements, states may choose to develop additional estimating and reporting requirements. Individual state agencies can provide assistance to sources on identifying and complying with individual state requirements.

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# 3

## EMISSIONS INVENTORY PLANNING

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### 3.1 PRELIMINARY PLANNING ACTIVITIES

Prior to initiating the actual compilation of an emissions inventory, an agency or facility must plan a basic approach for collecting, handling, and reporting emissions data. Careful consideration of the approach to be used in developing the emissions inventory program will greatly facilitate the inventory process and can prevent major revisions to the inventory during review. As part of the preliminary planning activities, the inventory preparer should consider the following:

- End use of the data;
- Scope of the inventory;
- Availability and usefulness of existing data; and
- Strategy for data collection and management.

Each of these issues is discussed in more detail below.

#### 3.1.1 END USE OF THE DATA

A basic consideration in planning the inventory is establishing the end uses of the completed inventory. For the regulatory agency, the end uses of all inventories fall into three general categories: (1) air quality control strategy development, (2) air quality maintenance, and (3) air quality research. For an individual facility, the inventory may be the measure of progress towards a corporate goal for emission reductions and/or a means of identifying opportunities for process improvements. Possible future use of the inventory, as well as immediate objectives, should be considered in determining inventory procedures and data needs.

#### 3.1.2 SCOPE OF THE INVENTORY

In defining the scope of the inventory, the primary considerations are the desired level of detail, the desired number of sources, and the pollutant(s) of interest. Point sources can be

inventoried at three levels of detail: (1) the plant level, which denotes a plant or facility that could contain several pollutant-emitting activities; (2) the point/stack level, where emissions to the ambient air from stacks, vents, or other points of emission are characterized; and (3) the process/segment level, representing the unit operations of specific source categories. The appropriate level of detail will be a function of the intended use of the data.

Under ideal circumstances, all stationary sources would be considered point sources for purposes of emission inventories. In practical applications, however, only sources that emit more than a specified cutoff level of pollutant are considered point sources. In general, the higher the cutoff level, the fewer the facilities that are included in an inventory of point sources; a lower cutoff level would result in the inclusion of more sources. As a rule, the lower the cutoff level, the greater the cost to develop the inventory. However, a low cutoff level will increase user confidence in the source and emissions data, and the inventory will have a greater number of applications.

The pollutants to be inventoried are a major element in determining the scope of the inventory. The pollutants of interest for ozone inventories are VOCs, NO<sub>x</sub>, and CO. For other criteria pollutants, only the criteria pollutant itself is of interest in the inventory. For HAP inventories on the federal level, the CAA list of 189 HAPs determines the pollutants to be inventoried.<sup>a</sup> States and local agencies may have additional toxic pollutants on their state/local toxic air pollutant (TAP) lists.

Table 1.3-1 presents source categories that should be considered for inclusion in point source emission inventories. The table also indicates the types of pollutants emitted from these categories. In defining the scope of an inventory, the emphasis should be on those source categories that are located in the geographic area covered by the inventory and that are addressed by regulations applicable to point sources. The selected sources and source categories should be compatible with available information and be of sufficient detail to facilitate control strategy projections.

### 3.1.3 AVAILABILITY AND USEFULNESS OF EXISTING DATA

A major inventory planning consideration is whether, and to what extent, existing information can be used. Existing inventories should be examined to determine whether the appropriate sources have been included and whether the emissions data represent current conditions. Existing inventories can serve as a starting point for developing extensive data and support information, such as documentation of procedures. Information may also be drawn from other regulatory agency operations such as permitting, compliance, and source inspections and from

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<sup>a</sup> Caprolactam was delisted as a HAP (*Federal Register*, Vol. 61, page 30816, June 18, 1996).

TABLE 1.3-1

## POTENTIAL POINT SOURCES AND POLLUTANTS

Source Name	Description	POLLUTANTS						
		VOC	CO	NO <sub>x</sub>	SO <sub>2</sub>	PM <sub>10</sub>	Lead	HAPs
Fuel Combustion, Electric Utilities	Coal			X	X	X	X	X
	Oil			X	X	X	X	X
	Gas			X				X
	Other						X	
	Internal Combustion							X
Fuel Combustion, Industrial	Coal			X	X	X	X	X
	Oil			X	X	X	X	X
	Gas			X		X		X
	Other			X		X	X	
	Internal Combustion							X
Fuel Combustion, Other	Commercial/Institutional Coal			X	X	X	X	X
	Commercial/Institutional Oil			X	X	X	X	X
	Commercial/Institutional Gas			X				X
	Misc. Fuel Comb. (Except Residential)						X	X
	Residential Wood	X	X			X		
	Residential Other			X	X			X
Chemical and Allied Product Mfg.	Organic Chemical Mfg.	X	X					X
	Inorganic Chemical Mfg.		X				X	X
	Polymer and Resin Mfg.	X						X
	Agricultural Chemical Mfg.							X
	Paint, Varnish, Lacquer, Enamel Mfg.	X						X
	Pharmaceutical Mfg.	X						X
	Other Chemical Mfg.	X	X					X

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TABLE 1.3-1

(CONTINUED)

Source Name	Description	POLLUTANTS						
		VOC	CO	NO <sub>x</sub>	SO <sub>2</sub>	PM <sub>10</sub>	Lead	HAPs
Metals Processing	Non-Ferrous Metals Processing		X		X	X	X	X
	Ferrous Metals Processing	X	X			X	X	X
	Metals Processing Not Else Classified (NEC)						X	X
Petroleum and Related Industries	Oil and Gas Production	X			X			X
	Petroleum Refineries and Related Industries	X	X		X	X		X
	Asphalt Manufacturing	X				X		X
Other Industrial Processes	Agriculture, Food, and Kindred Products	X				X		X
	Textiles, Leather, and Apparel Products	X				X		X
	Wood, Pulp and Paper, and Publishing Products	X	X			X		X
	Rubber and Miscellaneous Plastic Products	X						X
	Mineral Products			X	X	X	X	X
	Machinery Products					X		X
	Electronic Equipment					X		X
	Transportation Equipment					X		X
	Construction					X		X
	Miscellaneous Industrial Processes	X				X		X
Solvent Utilization	Degreasing	X						X
	Graphic Arts	X						X
	Dry Cleaning	X						X
	Surface Coating	X						X
	Other Industrial	X						X
	Nonindustrial	X			X			X

TABLE 1.3-1  
(CONTINUED)

Source Name	Description	POLLUTANTS						
		VOC	CO	NO <sub>x</sub>	SO <sub>2</sub>	PM <sub>10</sub>	Lead	HAPs
Storage and Transport	Bulk Terminals and Plants	X			X			X
	Petroleum and Petroleum Product Storage	X						X
	Petroleum and Petroleum Product Transport	X						X
	Service Stations: Stage I	X						X
	Service Stations: Stage II	X						X
	Service Stations: Breathing and Emptying	X						X
	Organic Chemical Storage	X						X
	Organic Chemical Transport	X						X
	Inorganic Chemical Storage					X		X
	Inorganic Chemical Transport					X		X
	Bulk Materials Storage					X	X	X
	Bulk Materials Transport					X	X	X
Waste Disposal and Recycling	Incineration		X			X	X	X
	Open Burning	X	X			X		X
	Publicly Owned Treatment Works (POTW)	X						X
	Industrial Waste Water	X						X
	Treatment, Storage, and Disposal Facility (TSDF)	X				X		X
	Landfills	X				X		X
	Other	X				X	X	X
	Agriculture and Forestry			X		X		X
Miscellaneous	Other Combustion	X	X			X		X
	Catastrophic/Accidental Releases	X			X	X		X
	Repair Shops	X						X
	Health Services	X						X
	Cooling Towers	X						X
	Fugitive Dust					X		X



other facility resources such as corporate reporting or compliance report submittals. For effective use of resources, an agency or facility should plan to fulfill specific emissions inventory requirements by building upon and improving the quality of regularly collected data.

For effective use of resources, an agency or facility should plan to fulfill specific emissions inventory requirements by building upon and improving the quality of regularly collected data.

### **3.1.4 STRATEGY FOR DATA COLLECTION**

Another key decision in inventory planning regards what particular data collection procedures will be followed. Alternatives include questionnaires, plant inspections, and review of existing agency permit and compliance files. Depending on the approach selected, the data available may be in various forms such as source tests, material balances, purchasing records, or actual emission estimates. The amount of staff and budget that will be needed to actually gather the data and then manipulate it into the desired inventory will also vary depending on the selected approach. The inventory preparer must keep these considerations in mind during the preliminary planning phase in order to decide on the strategy that best matches the data needs and the available resources.

Because it is not always certain whether a category will be considered a point or an area source for the purpose of the inventory, data collection efforts should always include as much detailed information as possible. For example, employment by standard industrial classification code may not be used in a point source inventory, but would be helpful for preparing an area source inventory.

Once the strategy for data collection is known, the inventory preparer needs to consider how these data will be handled and managed, including QA/QC procedures. Emissions inventory data for a single point source or area source category may be minimal enough to be handled using spreadsheets or by hand calculations. For large sets of data, some type of electronic database will be needed to organize, manipulate, and simply store the collected data. There are a wide variety of available software packages designed for the tracking of environmentally related emissions and release information. The system used should be able to handle the types of information being collected as well as have the ability to export information for state and federal reporting requirements.

## **3.2 INVENTORY WORK PLAN**

The inventory work plan is a concise, to-the-point document that declares how an agency or plant intends to develop and present its inventory. It allows a line of communication between the inventory preparer, his/her management, and the receiving agency to ensure that the inventory is conducted effectively. The work plan should include inventory objectives and

general procedures and should address all sources (regardless of size) of all the target pollutants.

Although no specific format is usually required, the work plan should, at a minimum:

- Define how the inventory work plan is structured and what it contains;
- Define the inventory area by nonattainment status;
- Provide the background/basis for the inventory (i.e., previous efforts that are viable and related);
- Specify who is responsible for the inventory, with a detailed organization chart of key personnel/consultants;
- Specify the quality assurance (QA) coordinator (who must be different than the inventory management or technical staff);
- Describe the approach to be used to estimate emissions, including plans for data collection, analysis, and storage; and
- Describe how the plant or agency plans to present and document the inventory for submittal.

For point sources, an agency must define how all pertinent emissions sources will be identified and located. The work plan should describe how point source activity levels and associated parameters will be developed, and how these data are used to calculate emissions estimates. It should also describe the type of source surveys that are planned and the use of existing data contained in systems such as the Aerometric Information Retrieval System (AIRS), state emission inventory systems, or state permitting files.

### 3.3 TRAINING

Training is an important component of the facility's or agency's preliminary planning activities. The extent of training needed will depend on the staff chosen to prepare the inventory and the number of new procedures required by the inventory process.

Training courses for the critical components of an emissions inventory are provided annually by the EPA's Air Pollution Training Institute (APTI). These courses provide detailed instruction in:

- Inventory planning;
- Inventory management;
- Point source emissions;
- Emissions calculations;
- Projection techniques; and,
- Data reporting.

These courses are available to any individuals with the education, experience, or employment responsibilities involving enforcement or compliance with regulatory programs for achievement of air quality standards. Further information can be obtained by contacting the APTI (see Appendix C).

### 3.4 DATA HANDLING

Inventory data can be managed almost entirely by computer. During the inventory planning stages, the inventory preparer 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 the inventory preparer must deal with large amounts of data, maximizing the use of computerized inventory data-handling systems will allow them to spend more time gathering, analyzing, and validating the inventory data, as opposed to manipulating the data.

Computerized data handling becomes significantly more cost-effective as the database, the variety of tabular summaries, or the number of iterative tasks increases. In these cases, the computerized inventory requires less overall time and has the added advantage of forcing organization, consistency, and accuracy.

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

- Printing mailing lists and labels;
- 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.

Additional information on data handling is presented in Volume VII of the EIIP series of guidance documents.

### **3.5 DOCUMENTATION REQUIREMENTS**

Documentation is an integral part of an emissions inventory. Before submittal, internal review of the written documentation provides an opportunity to uncover and correct errors in assumptions, calculations, or methods. Following submittal of the inventory, the documentation allows the results of the inventory to be clearly understood and the quality of the inventory to be effectively judged.

Although documentation requirements may evolve during data collection, the calculation and reporting steps of the emissions inventory development process should be anticipated during planning. Planning the level of documentation required will: (1) ensure that important supporting information is properly developed and maintained; (2) allow extraneous information to be identified and discarded, thereby reducing the paperwork burden; (3) help determine data storage requirements; and (4) aid in identifying aspects of the inventory on which to concentrate the QA efforts.

### **3.6 SCHEDULE**

If the development and maintenance of an emissions inventory is conceptualized as a network of activities or events with a definite start and end, various techniques can be used to formulate a project schedule. One method is to graphically present the inventory tasks, their estimated completion times, major project milestones, and labor requirements. This is a useful way to visualize the activities and their relationships to one another. By identifying the "critical path" events at this early point in the schedule-planning activities, the inventory preparer can anticipate potential bottlenecks in the process and avoid delays that might affect the timely submittal of the final inventory.

It is important to remember that a schedule must be frequently compared to the actual progress of the inventory effort. By closely tracking the activities, the preparer can: (1) ensure that each task is being completed expeditiously; (2) revise labor commitments to reflect schedule and data changes; and (3) learn from experience so that this knowledge can be applied towards future inventory efforts.

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# 4

## EMISSION ESTIMATION PROCEDURES

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Air pollutant emissions may be released from numerous sources within a facility. Depending on the facility size, the nature and number of processes, and the emission control equipment in place, emission estimation may be very simple or extremely difficult. The inventory preparer should consider the types of emissions to be reported (i.e., actual, potential, or allowable), the availability of data, and the cost when selecting which method of emissions estimation is appropriate.

Figure 1.4-1 (from *AP-42*) depicts various approaches to emission estimation that should be considered when analyzing the costs versus the quality of the results (EPA, 1995a). Ideally, plants needing emissions estimates would use continuous emissions monitoring (CEM) to obtain actual emissions measurements over very short time intervals. Some facilities currently do this. The CEM concentration data can be easily converted to mass emission rates provided the air volume through the monitor is also known. In cases where CEM or parametric monitoring data are unavailable, however, another method must be used to estimate emissions. The three principal methods for estimating emissions in such cases are source tests, material balances, and emission factors. If none of these three methods can be employed to estimate emissions for a specific process, an approximation or engineering estimate based on available process, physical, chemical, and emission knowledge may be used.

Where risks of adverse environmental or regulatory effects are high, the more sophisticated and costly emission determination methods such as CEM or source tests may be necessary. Conversely, where the risks are low, less expensive estimation methods such as the use of emission factors and emission models may be acceptable.

### 4.1 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. Typically, a source test uses two instruments: one to collect the pollutant in the emission stream and one to measure the emission stream flow rate. The essential difference between a source test and CEM is the duration of time over which

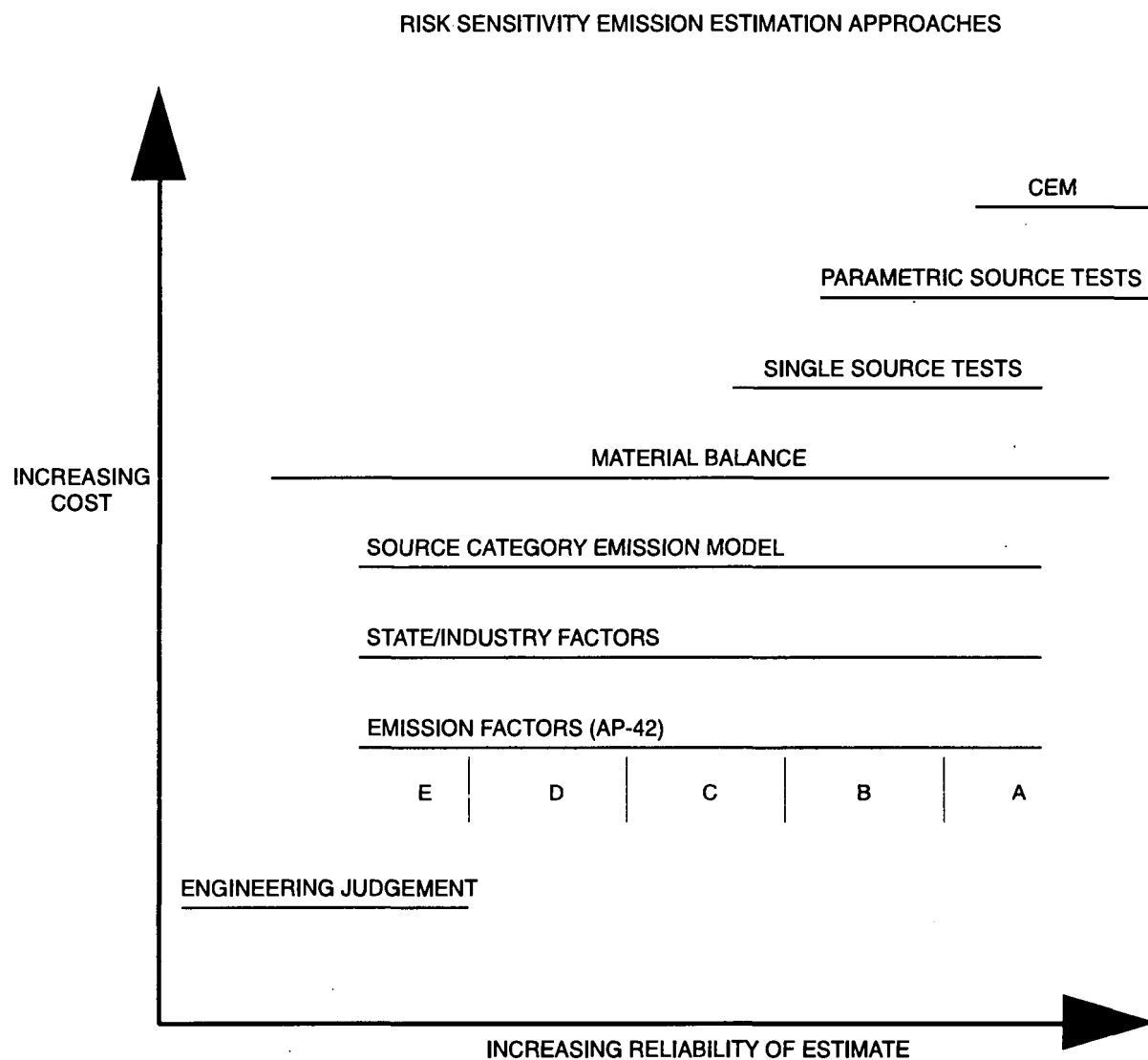


FIGURE 1.4-1. EMISSION ESTIMATION HIERARCHY

measurements are conducted. A source test is conducted over a discrete, finite period of time, while CEM is continuous.

If the use of source test data reduces the number of assumptions regarding the applicability of emissions data to a source (a common consideration when emission factors are used), as well as the control device efficiency, equipment variations, and fuel characteristics. Thus, source tests typically provide better emission estimates than emission factors or material balances, if correctly applied (Southerland, 1991). However, source test data should be used for emission estimation purposes only if the data were obtained under conditions which are representative of or related to operating conditions normally encountered at the source in question.

Two items should be noted when using source test data to calculate emissions. First, because most source tests are only conducted over several hours or days at most, adjustments may need to be made when using these data to estimate emissions over longer time intervals. Emission data from a one-time source test can be extrapolated to estimate annual emissions only if the process stream does not vary and if the process and control devices are operated uniformly.

Second, a source test may not adequately describe a given facility's annual or seasonal operating pattern. For example, there may be variations in process operation throughout the year or the efficiency of control device performance may vary due to fluctuations in ambient temperature or humidity. In such cases, multiple tests must be conducted for source testing to be useful in generating an emission estimate for extended periods that are longer than the test period. 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 or test data taken from literature. The reliability of the data may be affected by factors such as the number of tests conducted and the test methodology used.

The EPA has published reference methods for measuring emissions of PM, SO<sub>2</sub>, NO<sub>x</sub>, CO, and VOC. The reference methods, given in Title 40, Code of Federal Regulations, Part 60, Appendix A, define and describe the test equipment, materials, and procedures to be used in stack tests for the various criteria pollutants. Reference methods for estimating HAP emissions are published in Title 40, Code of Federal Regulations, Part 61, Appendix B (EPA, 1986; EPA, 1988). The EPA publication, *Screening Methods for the Development of Air Toxics Emission Factors*, presents an overview of the use of these reference methods for specific HAPs (EPA, 1992d). A brief description of several EPA methods is given in Appendix E. For further information, the reader can consult with the Emission Measurement Technical Information Center (EMTIC), which provides technical guidance on stationary



source emission testing. Industry personnel may access EMTIC on the EPA's Technology Transfer Network bulletin board system, or by calling EMTIC staff directly. Appendix C contains EMTIC contact information.

Most source test reports summarize emissions for each pollutant by expressing them in terms of: (1) a mass loading rate (weight of pollutant emitted per unit of time); (2) an emission factor (weight of pollutant emitted per unit of process activity); or (3) a flue gas concentration (weight 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 emission factor can easily be calculated with knowledge of equipment size or operating parameters, as in the example below (EPA, 1993a):

- **Example.** A single-line paper coating plant has been subjected to an emission test for 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 ( $Q_s$ )	= 10,000 scf
Emission concentration ( $C_e$ )	= 96 ppm (as toluene)
Fugitive emission capture ( $Eff_{cap}$ )	= 0.90 (90 percent, as required by reasonably available control technology (RACT))

Other information needed to complete the calculations include:

Plant operation	= 16 hour/day, 312 days/year
Solvent input rate ( $M_i$ )	= 500 ton/year
Rule effectiveness (RE)	= 0.80 (80 percent)
Molecular weight (toluene)	= 92
Unit correction factor ( $f$ )	= $1.58 \times 10^{-7}$ (lb-mole-min)/(hr-ppm-scf)

The emission calculation begins with determination of the average mass loading rate ( $M_o$ ):

$$\begin{aligned}
 M_o &= (f)(MW)(C_e)(Q_s) \\
 &= (1.58 \times 10^{-7})(92)(96)(10,000) \\
 &= 14 \text{ lb/hr}
 \end{aligned}$$

The emission control efficiency ( $Eff_{con}$ ) is calculated:

$$\begin{aligned}
 Eff_{con} &= (M_i - M_o)/M_i \\
 &= [500 - ((14)(16)(312)/2,000)]/500 \\
 &= 0.93 \text{ (93 percent control)}
 \end{aligned}$$

## 4.2 MATERIAL BALANCES

The material balance (also known as a mass balance) is a method commonly used for estimating emissions from many source categories. In this method, emissions are estimated as the difference between material input and material output across a vessel, process, or entire facility. The material balance method can be used where source test data, emission factors, or other developed methods are not available. For example, emissions from evaporation sources are commonly estimated using this approach as are sources where testing of low-level, intermittent, or fugitive exhaust streams would be very difficult, costly, and uncertain. 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 compounds.

Use of material balances involves the examination of a process to determine whether emissions can be estimated solely on knowledge of operating parameters, material compositions, and total material usage. The simplest material balance assumes that all solvent used in a process will evaporate to become air emissions somewhere at the facility. For instance, for many surface coating operations, it can be assumed that all of the solvent in the coating evaporates to the atmosphere during the application and drying processes. In such cases, emissions equal the amount of solvent contained in the surface coating plus any added thinners.

Material balances are greatly simplified and very accurate in cases where all of the consumed solvent is emitted to the atmosphere. But many situations exist where a portion of the evaporated solvent is captured and routed to a control device such as an afterburner (incinerator) or condenser. In these cases, the captured portion must be measured or estimated by other means and the disposition of any recovered material must be accounted for. As a second example, in degreasing operations, emissions will not equal solvent consumption if waste solvent is removed from the unit for recycling or incineration. A third example is cutback asphalt paving where some fraction of the diluent used to liquefy the asphalt is believed to be retained in the substrate (pavement) rather than evaporated after application. In these examples, a method of accounting for the non-emitted solvent is required to avoid an overestimation of emissions.

Material balances cannot be accurately employed at a reasonable cost for some evaporation processes because the amount of material lost is too small to be determined accurately. As an example, applying material balances to petroleum product storage tanks is not generally feasible because the losses are too small relative to the uncertainty of any metering devices. In these cases, *AP-42* emission factors or equations can be used (EPA, 1995a).

The material balance method should not be used for processes where material is reacted to form products or where the material otherwise undergoes significant chemical change. If a

material balance method is used to estimate emissions and if the actual emissions are a small fraction of the throughput, the throughput estimate or measurement can be even more critical. 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 much larger percentage error in the emission estimate. For this reason, material balances are sometimes inappropriate for estimating small losses.

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):

$$\text{VOC}_{\text{added to mixing vessel}} (\text{lb/gal}) - \text{VOC}_{\text{in final paint mixture}} (\text{lb/gal}) = \text{VOC}_{\text{emitted}} (\text{lb/gal}) \quad (1.4-1)$$

### 4.3 EMISSION FACTORS

One of the most useful tools available for estimating emissions from point sources is the emission factor. An emission factor is a ratio that relates the quantity of a pollutant released to the atmosphere to the activity level associated with the release of that pollutant (e.g., production rate or amount of fuel combusted). If the emission factor and the corresponding activity level for a process are known, an estimate of the emissions can be made. In most cases, emission factors are expressed simply as a single number, with the underlying assumption that a linear relationship exists between emissions and the specified activity level over the probable range of application. The use of emission factors is straightforward when the relationship between process data and emissions is direct and relatively uncomplicated. The primary reference for criteria pollutant emission factors for industrial sources is *AP-42* (EPA, 1995a).

Because emission factors are averages obtained from data of wide range and varying degrees of accuracy, emissions calculated this way for a given facility are likely to differ from that facility's actual emissions; factors will indicate higher emission estimates than are actual for some sources, and lower for others. Only specific source measurement can determine the actual pollutant contribution from a source, under conditions existing at the time of the test. For the most accurate emissions estimate, it is recommended that source-specific data be obtained whenever possible. If factors are used to predict emissions from new or proposed sources, the latest literature and technology should be reviewed to determine whether such sources would likely exhibit emission characteristics different from those sources from which the emission factors were derived.

In addition to presenting emission factors, *AP-42* gives a quality indicator for each emission factor rated "A" through "E," with "A" being the best; and U1 through U5, published with varying degrees of uncertainty (EPA, 1995a). The lower the quality indicator, the more likely that a given emission factor may not be representative of the source type. When an emission factor for a specific source or source category may not provide a reasonably adequate emission estimate, it is always better to rely on actual stack test data, where available. Conversely, if an emission factor does provide reasonably adequate emission estimates, stack testing may represent an ineffective use of time and resources.

The EPA continues to update and expand the factors in *AP-42*, including a more detailed speciation of VOC and other organic emissions by compound or compound class, where data are available (EPA, 1995a). The EPA databases and documents that contain emission factors for use in inventory development are discussed in more detail in Appendix F. The EPA's procedure for assigning emission factor quality ratings is described in the document, *Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections* (EPA, 1993b).

#### 4.3.1 CALCULATION OF EMISSIONS USING EMISSION FACTORS

In order to calculate emissions using emission 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 device and control device efficiencies to provide the basis for estimation of emissions to the atmosphere after passage through the control device(s) if using an uncontrolled emission factor ("Controlled" emission factors already take this into account).

The basic emission estimation algorithm for an uncontrolled emission factor is:

$$E = A * EF * (1 - ER/100) \quad (1.4-2)$$

where:

E	=	emission estimate for source (at the process level)
A	=	activity level (such as throughput)
EF	=	"uncontrolled" emission factor (such as lb emitted/throughput)
ER	=	overall emission reduction efficiency, expressed in percent; equal to the capture device efficiency multiplied by the control device efficiency

If a controlled emission factor is being used, the emission factor already incorporates the control system effectiveness term  $(1 - ER/100)$ ; therefore, the form of the algorithm is:

$$E = A * EF \quad (1.4-3)$$

where:

E	=	emission estimate for source (at the process level)
A	=	activity level (such as throughput)
EF	=	controlled emission factor (such as lb emitted/throughput)

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.

#### 4.3.2 ROLE OF THROUGHPUT IN EMISSION FACTOR ESTIMATES

The activity level (also referred to as throughput rate) is the second component of an estimate developed using an emission factor. For industrial processes, activity data are generally reported as process weight rates (e.g., pound, ton, gallon or barrel per hour). Similarly, for fuel-burning equipment, activity data are reported as fuel consumption rates (tons,  $10^3$  gallons,  $10^6$  ft<sup>3</sup>, or  $10^6$  Btu per hour). The optimum activity data are hourly values, although in some cases only shift, daily, weekly or even monthly data are available. If hourly values are not known, the hourly average value can be calculated from the actual operating schedule.

In many instances, conversion factors must be applied to convert reported consumption or production values into units that correspond to the emission factor throughput units (tons, barrels, etc.). For example, an emission factor for fuel oil consumption may be given in lbs per MMBtu while the activity data are available only in gallons of oil per hour. In order to estimate emissions, a conversion factor is needed. The heating value of the fuel in MMBtu per gallon provides the necessary conversion. In this case, the emission equation would be:

$$E = A \times EF \times C \quad (1.4-4)$$

where:

E	=	emission estimate in lbs/hr
A	=	activity level = fuel consumption in gal/hr
EF	=	emission factor in lbs/MMBtu
C	=	conversion factor = heating value in MMBtu/gal

If the emission factor or activity data involve electrical power output or steam generation, an additional correction factor (i.e., the fractional efficiency of the fuel burning equipment) must be applied to account for conversion of heat input to power output (electrical) or steam production (thermal).

Occasionally, additional process data are required to ensure that the correct conversion factors are applied. For example, a production rate for plywood boards might be given as the number of boards manufactured per hour, while an emission factor relates emissions to the number of tons manufactured, rather than the number of boards. In this case, the weight of the product per board must be known. Errors associated with the conversion of activity data to emission factor units can be avoided by clearly specifying the required units throughout a calculation (EPA, 1993a; EPA, 1991d).

#### **4.3.3 ROLE OF CAPTURE AND CONTROL DEVICE EFFICIENCIES IN EMISSION FACTOR ESTIMATES**

Control effectiveness is the third element of the emission factor approach. Control effectiveness is a product of the capture device efficiency (including the duct system between the capture device and the control device) 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 (EPA, 1993a; EPA, 1991d).

Control device efficiency may be determined for specific equipment by source tests measuring pollutant concentrations before and after application of the control device. However, because of possible variation in control device operation, control device malfunction, and deterioration over time, etc., the measurement is subject to the potential limitations of all source tests. Capture device efficiency can be quantified by more complex methods. Often, capture device efficiency is estimated on the basis of tests performed on similar equipment at other facilities, rather than by tests performed at the facility for which emissions are being estimated.

When test data are not available for a specific control device, a second approach using literature values to estimate control efficiency is often employed. *AP-42* includes efficiencies

for control devices which are commonly encountered in industrial applications (EPA, 1995a). However, these control efficiency estimates may not be precisely applicable to specific control devices. In addition, a control device may be improperly sized for effective control of the process under consideration. Therefore, knowledge of the process and engineering judgement should be used along with the literature value.

A third method of obtaining a control device efficiency is to employ the manufacturer's design specification or guaranteed performance specification subject to field verification. However, the design efficiency reported by manufacturers is the efficiency obtainable under optimum conditions and may not represent actual conditions. Some assessment of design efficiency may be required to adjust for source-specific conditions.

It may also be necessary to modify the control device efficiency estimate based on considerations such as downtime or gradually deteriorating conditions (e.g., degradation of fabric filter bags). If the 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 account for excess emissions resulting from downtime and deteriorated efficiency can be a large source of error in the emission estimate. Although regulations and permitting conditions often exempt emissions occurring when control equipment is inoperative or malfunctioning, these emissions should be quantified and reported for emission inventory purposes.

#### **4.3.4 PROCESS-SPECIFIC EMPIRICAL RELATIONSHIPS**

In addition to the emission factors described above, *AP-42* also provides empirically developed process equations for estimating emissions from certain sources (EPA, 1995a). These equations, like emission factors, are based on throughput and control efficiency. However, they are often more complex than the simple ratio used for emission factors. Typically, these equations include such variables as air temperature, vapor pressure, and others. For example, VOC emissions from some sources, including storage tanks, vary as a function of tank size, tank color, temperature, barometric pressure, throughput, and properties of the material stored.

### **4.4 EMISSION MODELS**

Emission models may be used to estimate emissions in cases where the calculational approach is burdensome, or in cases where a combination of parameters have been identified which affect emissions but, individually, do not provide a direct correlation. For example, the TANKS program incorporates variables such as tank color, temperature, and windspeed to obtain an emissions estimate.

Emission models may be based on measured or empirical values. The computer model may be based on theoretical equations that have been calibrated using actual data, or they may be purely empirical, in which case the equations are usually based on statistical correlations with independent variables.

Appendix F provides information on some of the more commonly used emission estimation models.

## **4.5 BEST APPROXIMATION OR ENGINEERING JUDGEMENT**

A best approximation or engineering judgement is a final option for estimating emissions, although it is considered the least desirable method. A best approximation or engineering judgement is an emission estimate based on available information and assumptions.

If emissions must be estimated by best approximation, a few guidelines may be used to reduce the potential error. Published emission factors may be used to place order-of-magnitude boundaries on possible emissions from the process in question.

## **4.6 OTHER CONSIDERATIONS**

### **4.6.1 RULE EFFECTIVENESS**

Inventories performed before 1987 assumed that regulatory programs would be implemented with full effectiveness, achieving all required or intended emissions reductions and maintaining the reduction level over time. However, experience has shown regulatory programs to be less than 100 percent effective for most source categories in most areas of the country.

Rule effectiveness (RE), expressed as a fraction or percent, is an adjustment which reflects the ability of a regulatory program to achieve the required emissions reductions. The intent behind the RE 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, and that some intentional noncompliance exists. 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.

Rule effectiveness is especially important for VOC and CO control programs because of the small size, large number, and relative complexity of most regulated sources. It is necessary to apply rule effectiveness when preparing emissions inventories because the effectiveness of existing regulations is directly related to emissions levels. Rule effectiveness must also be



considered in planning for the expected effect of further regulations. Rule effectiveness should be applied for all applicable regulations: federal, state, and local.

A default fraction of 0.80 (equal to 80 percent effectiveness) has been established by the EPA to estimate rule effectiveness in the base year inventories. This fraction is a representative estimate of the average effectiveness values, based on a survey of selected state and local personnel on the perceived effectiveness of their regulatory programs for a wide range of source categories. The 80 percent default value or local category-specific rule effectiveness factor is applied if the emissions data were determined using emission factors, results of emissions tests, or estimated control efficiencies, even if the data were obtained from a survey of the source.

Although the 80-percent rule effectiveness value may generally be valid, it can vary significantly among source categories and can have a dramatic impact on sources assumed to be controlled at a high efficiency (e.g., 99.9 percent). Use of the default rule effectiveness factor should be carefully reviewed under these circumstances. A rule effectiveness of 100 percent may be applicable in some cases, but sources should be sure that no equipment downtime or emergency releases have occurred during the inventory period.

For the purpose of base year inventories under the CAA, the EPA allows the use of the 80-percent default value, but also gives agencies the option to derive local category-specific rule effectiveness factors through the use of a survey. Also, if rule effectiveness can be determined for a source category in a particular region using the protocol defined by the EPA's Office of Enforcement and Compliance Assurance, this rule effectiveness can be used. If a particular facility disagrees with the rule effectiveness factor used in an inventory, a case-by-case assessment of emissions can be performed to determine whether there is adequate data for emissions to be directly determined. If a facility can provide the explicit source data required by EPA, such as continuous source monitoring and control equipment functioning records for the inventory period, then emissions can be determined directly.

Where controls are not used, there is no need to apply rule effectiveness. The rule effectiveness factor should be applied to the estimated control efficiency in the calculation of emissions from a source. However, if emissions are estimated properly, there is no need to apply rule effectiveness. An example of the application is given below.

- Example:

Uncontrolled emissions	= 50 pounds (lb) per day
Estimated control equipment efficiency	= 0.90 (90 percent)
Rule effectiveness factor	= 0.80 (80 percent)

$$\begin{aligned}\text{Emissions after control} &= 50[1-(0.90)(0.80)] \\ &= 50(1-0.72) \\ &= 14 \text{ lb per day}\end{aligned}$$

Note: The EIIP Point Sources Committee is currently evaluating the application of the rule effectiveness policy. The committee will present their findings in an issues paper to the EIIP Steering Committee upon completion of their study.

#### 4.6.2 CONTROL DEVICES

A basic description of the techniques typically used by industry to control PM<sub>10</sub>, VOCs, SO<sub>2</sub>, NO<sub>x</sub>, and HAPs can be found in the *Handbook: Control Technologies for Hazardous Air Pollutants* (EPA, 1991d). The handbook briefly describes the efficiencies commonly achieved by major types of control devices in current use and describes how to estimate emission reductions using control systems. Table 1.4-1 lists several control devices commonly used for emission reduction at stationary point sources. For each control device listed, the table identifies the pollutants controlled by the device and presents expected efficiency ranges.

In order to determine removal efficiencies of HAPs from the air stream, it is necessary to know the nature of the HAPs involved, including such parameters as particle size, volatility, or combustibility. Control techniques guidelines (CTG) documents have been written for numerous VOC-emitting source categories; some of these documents contain information relevant to the control of HAPs. A list of several CTGs is presented in Table 1.4-2. Information on available CTG documents can also be obtained via the Control Technology Center (CTC) assistance line (see Appendix C). Another source of information on control devices for a particular source is a series of documents collectively referred to as alternative control techniques (ACT) documents. These documents provide background information on controls, but do not provide reasonably available control technology (RACT) analysis information as do the CTGs. A list of available ACT documents is presented in Table 1.4-3.

TABLE 1.4-1

## AIR POLLUTION CONTROL TECHNOLOGIES

Method	Pollutant Type			Efficiency (%)
	Organic Vapors	Inorganic Vapors	Particulates	
Cyclones			X	98 <sup>a</sup>
Fabric filter			X	80-99
Wet scrubbers	X <sup>b</sup>	X	X	95
Electrostatic precipitators			X	99.5-99.9
Carbon adsorption	X <sup>c</sup>	X		50 - 99
Fluidized-bed systems	X <sup>d</sup>			--
Absorption	X <sup>e</sup>			90 - 99
Condensation	X	X <sup>f</sup>		50 - 95 <sup>g</sup>
Thermal incineration	X			≥99
Catalytic incineration	X			95 - 99

Sources: EPA, 1991d; and Cooper, et al., 1994.

<sup>a</sup> The greatest amount of control would be achieved for particles larger than 5  $\mu\text{m}$ .

<sup>b</sup> Depends on material, should be miscible in water.

<sup>c</sup> Carbon adsorption or fired-bed systems.

<sup>d</sup> Not widely used.

<sup>e</sup> Material must be readily soluble in water or other solvents.

<sup>f</sup> Depends on vaporization point of material.

<sup>g</sup> Highly dependent on the emission stream characteristics.

-- No data available.

**TABLE 1.4-2**  
**CONTROL TECHNIQUES GUIDELINES DOCUMENTS**  
**(GROUPS I, II, III)**

Source Description	EPA Report Number	NTIS Report Number	Date of Publication
Surface Coating Operations	450/2-76-028	PB-260 386	1976
Coating of Cans, Coils, Paper, Fabrics, Automobiles, and Light-Duty Trucks	450/2-77-008	PB-272 445	1977
Surface Coating of Metal Furniture	450/2-77-032	PB-278-257	1977
Surface Coating of Insulation of Magnet Wire	450/2-77-033	PB-278-258	1977
Surface Coating of Large Appliances	450/2-77-034	PB-278-259	1978
Surface Coating of Miscellaneous Metal Parts and Products	450/2-78-015	PB-286-157	1978
Factory Surface Coating of Flat Wood Paneling	450/2-78-032	PB-292-490	1978
Graphic Arts - Rotogravure and Flexography	450/2-78-033	PB-292-490	1978
Bulk Gasoline Plants	450/2-77-035	PB-276-722	1977
Storage of Petroleum Liquids in Fixed Roof Tanks	450/2-77-036	PB-276-749	1977
Refinery Vacuum Producing Systems, Wastewater Separators, and Process Unit Turnarounds	450/2-77-025	PB-275-662	1977

TABLE 1.4-2

(CONTINUED)

Source Description	EPA Report Number	NTIS Report Number	Date of Publication
Use of Cutback Asphalt	450/2-77-037	PB-278-185	1977
Tank Truck Gasoline Loading Terminals	450/2-77-026	PB-275-060	1977
Design Criteria for Stage I Vapor Control Systems-Gasoline Service Stations	--	--	1975
Control of Volatile Organic Compound Leaks from Petroleum Refinery Equipment	450/78-036	PB-286-158	1978
Petroleum Liquid Storage in External Floating Roof Tanks	450/2-78-047	PB-290-579	1978
Perchloroethylene Dry Cleaning Systems	450/2-78-050	PB-290-613	1978
Leaks from Gasoline Tank Trucks and Vapor Collection Systems	450/2-78-051	PB-290-568	1978
Volatile Organic Liquid Storage in Floating and Fixed Roof Tanks, Draft	--	--	1981
Large Petroleum Dry Cleaners	450/3-82-009	PB 83-124-875	1982
Synthetic Organic Chemical Polymer and Resin Manufacturing Equipment	450/3-83-006	PB-84-161-520	1984

TABLE 1.4-2

(CONTINUED)

Source Description	EPA Report Number	NTIS Report Number	Date of Publication
Equipment Leaks from Natural Gas/Gasoline Processing Plants	450/2-83-007	PB-84-161-520	1983
Solvent Metal Cleaning	450/2-77-022	PB-274-557	1977
Manufacture of Synthesized Pharmaceutical Products	450/2-78-029	PB-290-580	1978
Manufacture of Pneumatic Rubber Tires	450/2-78-030	PB-290-557	1978
Control Techniques for Volatile Organic Emissions from Stationary Sources	450/2-78-022	PB-284-804	1978
Air Oxidation Processes in Synthetic Organic Chemical Manufacturing Industry	450/3-84-015	PB-85-164-275	1984
Manufacture of High-Density Polyethylene, Polypropylene, and Polystyrene Resins	450/3-83-008	PB-84-134-600	1983
Fugitive Emissions Sources of Organic Compounds - Additional Information on Emissions, Emissions Reductions, and Costs	450/3-82-010	PB-82-217-126	1982

TABLE 1.4-3

## ALTERNATIVE CONTROL TECHNIQUES DOCUMENTS

Source Description	EPA Report Number	NTIS Report Number	Date of Publication
Halogenated Solvent	450/3-89-030	PB 90-103268	1989
Reduction of Volatile Organic Compound Emissions from the Application of Traffic Markings	--	PB 89-148274	1988
Ethylene Oxide Sterilization/Fumigation Operations	450/3-89-007	PB 90-131434	1989
Reduction of Volatile Organic Compound Emissions from Automobile	450/3-88-009	PB 89-148282	
Organic Waste Process Vents	450/3-91-007	PB 91-148270	1990
Industrial Wastewater Volatile Organic Compound Emissions-Background Information for BACT/LAER Determinations	450/3-90-004	PB 90-194754	1990
Polystyrene Foam Manufacturing	450/3-90-020	PB 91-102111	1990

# 5

## DATA COLLECTION

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This section describes effective procedures for obtaining data for emissions inventories. Questionnaires, plant inspections, and agency air pollution files are some of the methods that are useful in collecting emissions data as well as source activity and control data. Selection of the appropriate method of data collection should include consideration of the desired level of detail of the inventory.

### 5.1 LEVEL OF DETAIL

Point sources can be inventoried at three levels of detail: (1) the plant level, which denotes a plant or facility that could contain several pollutant-emitting activities; (2) the point/stack level, where emissions to the ambient air from stacks, vents, or other points of emission are characterized; and (3) the process/segment level, representing the unit operations of specific source categories. A discussion of these three levels follows and includes the minimum information that will be needed for the inventory regardless of the method selected for collecting the data.

#### 5.1.1 PLANT LEVEL

In a plant-level survey, each plant within the area should be identified and assigned a plant number. The plant should be further identified by geographic descriptors such as nonattainment area, state, county, city, street and/or mailing address, and UTM grid coordinates (or latitude/longitude). A plant contact should also be identified to facilitate communication and interaction with the plant. Additional information gathered regarding the facility should include annual fuel consumption, process throughput, hours of operation, number of employees, and the plant's standard industrial classification (SIC) code. The SIC codes are prepared and published by the U.S. Office of Management and Budget (OMB). A facility can have more than one SIC code denoting the secondary economic activities of the facility.

#### 5.1.2 POINT/STACK LEVEL

In an inventory conducted at the point/stack level, each stack, vent, or other release point that meets or exceeds a specified minimum emission rate should be identified as an emission point. Information obtained at the point/stack level is used in application of mathematical models to



correlate air pollutant emissions with ambient air quality. Thus, in addition to the facility identification, location, and plant contact, release characteristics for each emission point are necessary for establishing a comprehensive inventory and performing evaluations with modeling programs. The necessary emission point parameters include location (latitude/longitude), stack height, stack diameter, emission rate, and gas exit velocity.

It is recommended that the location of point sources be reported with a resolution of  $\pm 1$  second at 30 meters. This level of resolution is consistent with existing data specifications in EPA emissions inventory databases. However, such a high degree of precision in specifying location may only be necessary in a limited number of applications

### **5.1.3 PROCESS/SEGMENT LEVEL**

A plant may include various processes or operations. Each process can usually be identified by an SCC that is used to enter emissions data into a database management system. The information necessary to establish an inventory at this level includes facility identification; facility location; plant contact; process identification information; point level data; applicable regulations; operating rate data, including actual, maximum, and design operating rate or capacity; fuel use and properties data (e.g., ash content, sulfur content, level of trace elements, heat content, etc.); and identification of all pollution control equipment and its associated control efficiency (measured or design).

## **5.2 AVAILABILITY AND USEFULNESS OF EXISTING DATA**

A major inventory planning consideration is whether, and to what extent, existing information can be used. Existing inventories can serve as a starting point for developing extensive data and support information, such as documentation of procedures. Information may also be drawn from other regulatory agency operations such as permitting, compliance, and source inspections and from other facility resources such as corporate reporting or compliance report submittals. For effective use of resources, an agency or facility should plan to fulfill specific emissions inventory requirements by building upon and improving the quality of regularly collected data.

## **5.3 DATA COLLECTION METHODS**

### **5.3.1 QUESTIONNAIRES**

The survey questionnaire is a technique commonly used by state and local agencies for gathering point source emissions inventory data. Figure 1.5-1 shows an example of point

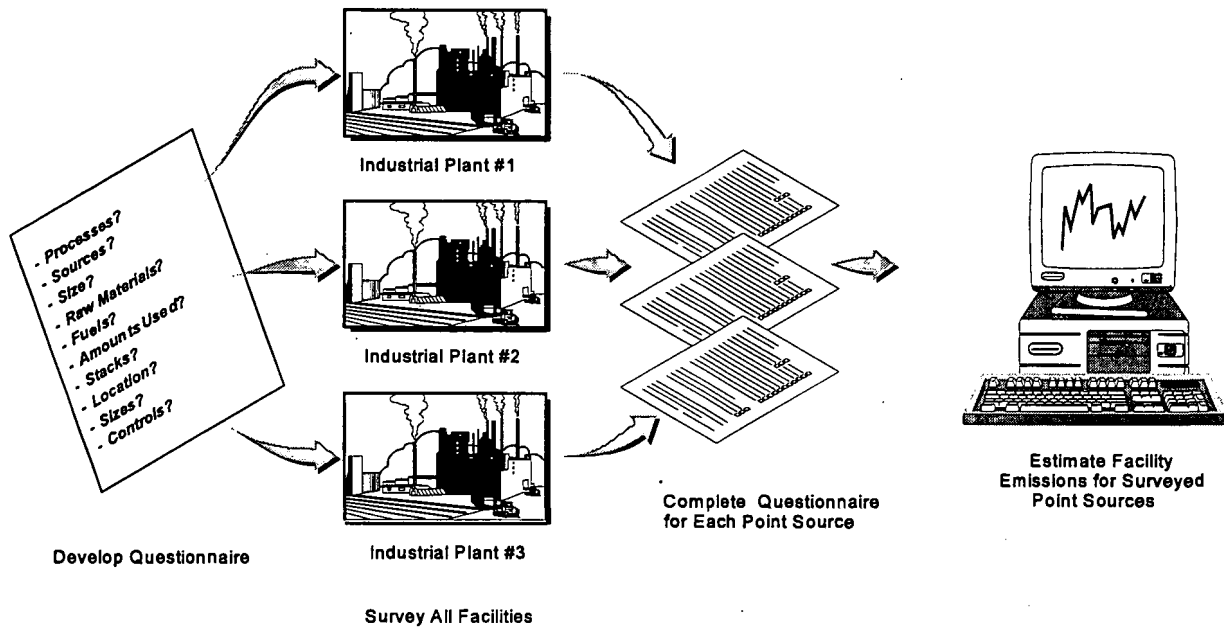


FIGURE 1.5-1. EXAMPLE OF POINT SOURCE SURVEYING

source surveying. The primary purpose of a survey is to obtain source and emissions data by means of a questionnaire that can be mailed or otherwise delivered to each facility. In order to conduct this type of data-gathering operation, the facilities to be surveyed must be identified; mailing lists must be prepared; questionnaires must be designed, assembled, and either mailed or delivered; data-handling procedures must be prepared and organized; and response-receiving systems must be established. Recently, it has become common to use computer media (floppy disks or electronic transmission) instead of paper to return questionnaire responses to the regulatory 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.

The sections below provide additional detail regarding the steps involved in collecting data via questionnaires. The information is applicable regardless of whether the data is collected on paper or electronic media. See the document *Development of Questionnaires for Various Emission Inventory Uses* for more information about questionnaires (Holman and Collins, 1979).

### ***Preparing the Mailing List***

A necessary step in the mail survey is the preparation of a mailing list that tabulates the name, address, and general process category of each facility to be surveyed. The basic function of the mailing list is to identify those sources to which questionnaires will be sent. The mailing list may also serve other functions. For example, the general process category information obtained from the mailing list can assist an agency in determining those categories for which questionnaires must be designed. In addition, the size of the resulting mailing list gives an agency an indication of the numbers and types of sources that can effectively be considered in the point source inventory within resource limitations. In this regard, the mailing list can be used to help an agency determine whether the resources allocated for the compilation effort will be sufficient.

The mailing list is compiled from a variety of information sources, including:

- Existing inventories;
- Other inventories such as the Toxic Chemical Release Inventory System (TRIS);
- Air pollution control agency files;
- Other government agency files; and

- Other local information sources such as local industrial directories, yellow pages, manufacturers and suppliers, and national publications such as those listed below;
  - Dun and Bradstreet,<sup>b</sup> Million Dollar Directory: Companies with sales over \$1,000,000 per year are compiled by SIC and county.
  - Dun and Bradstreet,<sup>a</sup> Middle Market Directory: Companies with sales between \$50,000 and \$1,000,000 per year are compiled by SIC and county.
  - Dun and Bradstreet,<sup>a</sup> *Industrial Directory*.
  - National Business Lists: Companies are listed by SIC and county with information on financial strength and number of employees.
  - Trade and professional society publications: Names and addresses of members are listed along with their type of business.

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 city or county, then by SIC, 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.

### ***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. One way is to limit the mailout to only those sources believed to be above certain emissions levels.

The cutoff level distinction is especially important in the VOC inventory because there are so many more small sources of VOC than of most other pollutants. The cutoff level for NO<sub>x</sub> and CO is less critical because of the usually significant contribution from the larger emitters. In general, if too high a cutoff level is chosen, many facilities will not be considered individually as point sources, and, if care is not taken, emissions from these sources may not be included in the inventory at all. Techniques are available for "scaling up" the inventory to account for missing sources; however, such procedures are invariably less accurate than point source methods. If too low a cutoff level is chosen, the result will be a significant increase in the

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<sup>a</sup> Dun and Bradstreet data can be accessed through the FACTS database on the EPA mainframe National Computing Center. Contact (919) 541-4506 to set up an account.

number of plant contacts of various sorts that must be made and the size of the point source file that must be maintained. While a low cutoff level may increase the accuracy of the inventory, the tradeoff is that many more resources are needed to compile and maintain the inventory.

### ***Designing the Questionnaires***

A questionnaire should be prepared for each source category type to be contacted. This can be done either by preparing industry-specific questionnaires for each source category or by preparing more general questionnaires that encompass many source categories. The use of general questionnaires may be advisable if the mailing list is long, if an agency is unfamiliar with many of the sources on the list, or if an agency's resources are limited. Often in practice, a general questionnaire is merely a collection of process-specific questionnaires. If sufficient resources are available, the use of industry-specific questionnaires is advantageous for certain sources.

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 be designed to be understood by persons without specialized technical training. 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. In addition to general source information such as location, ownership, and nature of business, the request should include the following:

- Process information-Because activity levels, including indicators of production and fuel consumption, are generally used with emission factors, appropriate activity levels must be obtained for each type of source. The types of activity levels needed to calculate emissions from point sources are defined for sources in *AP-42, 5th Edition*.
- Source information-Some of the emission equations in *AP-42* require information on the operation or physical characteristics of the individual point source. For example, emissions from petroleum product storage and handling operations are dependent on a number of variables, including liquid temperature, tank size, tank color, roof type, and product vapor pressure.

Appropriate values for these variables should be obtained to allow an agency to use the emission equations given in *AP-42, 5th Edition*.

- Control device information-Many of the emission factors in *AP-42* represent emissions in the absence of any controls. Thus, data on control devices is helpful for determining potential emission reductions resulting from applying various control strategies, especially for those source categories for which CTG documents have been published.
- Modeling data-Application of dispersion and photochemical models requires input data characterizing the emission stream as it exits the stack or vent. These parameters include stack height, stack diameter, exit temperature, exit velocity, and geographic location in the form of latitude/longitude or UTM coordinates. [NOTE: These example parameters are appropriate for dispersion modeling but may not be representative of the types of information needed for photochemical models. Please review carefully.]

### ***Mailing and Tracking the Questionnaires and Logging Returns***

Each questionnaire sent out 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.

After the final mailing list has been compiled and questionnaire packages are assembled (including mailing label, cover letter, instructions, questionnaires, and self-addressed stamped envelope), an agency should proceed with the mailout activities. It is important to develop a tracking system to determine the status of each step 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; (3) the dates that each response was returned; (4) corrected name, address, and SIC information; (5) preliminary information on the type of the source; (6) whether recontacting is necessary; and (7) 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.

### **5.3.2 PLANT INSPECTIONS**

During plant inspections, agency personnel usually examine the various processes at a particular facility and interview appropriate plant personnel. If an agency's resources allow, source testing may be conducted as a part of the plant inspection.

The major advantage of the plant inspection is that it should provide more thorough and accurate information about an emitter than does the questionnaire alone. Errors resulting from a company's misinterpretation of the questionnaire, or an agency's misinterpretation of the response, are also minimized. Finally, in cases where a process is unique or complex, the only realistic way for an agency to gain an adequate understanding of the emitting points and the variables affecting emissions is to observe the plant equipment personally and to review the operations and process schematics with the appropriate plant personnel.

### **5.3.3 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 dealing with each source on enforcement matters. 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. Such information may be helpful in the preparation of an inventory.

### **5.3.4 EMISSIONS ESTIMATES CONDUCTED BY PLANT PERSONNEL**

The number and complexity of processes within a given plant, in addition to the difficulty of accessing all the data necessary to complete emission calculations, can make emissions estimation a complex task, with significant opportunity for error. A few general guidelines for conducting overall emissions estimates for a plant are listed below:

- Identify and document the emission sources;
- Identify the types of pollutants and quantify the emissions;

- Compile the source and emissions data into a useable format;
- Design and implement a quality assurance plan; and
- Seek assistance from EPA, state, and local agencies.



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# 6

## INVENTORY REPORTING AND DOCUMENTATION

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Documentation is an integral part of an emissions inventory. Before submittal, internal review of the written documentation of an inventory's data sources and procedures may uncover errors in assumptions, calculations, or methods. Early correction of these errors will result in a more reliable and technically defensible database, which is essential in some critical aspects of the inventory such as source impact assessments and development of emissions control strategies.

Following submittal of the inventory, the documentation allows the quality of the inventory to be effectively judged. An emissions inventory that is documented according to standardized guidelines enables the receiving agency to review the inventory in a consistent manner. Because it is recognized that some variability is needed to meet the specific needs of each inventory region, standardization is emphasized for the types of data reported, but not the format in which they are reported. Inventories not meeting the minimum data reporting and documentation standards may be deemed unacceptable and returned to the preparer for modification before any further review of technical quality is performed.

The reporting steps of the emissions inventory development process should be anticipated during planning. Planning the level of documentation required will: (1) ensure that important supporting information is properly developed and maintained; (2) allow extraneous information to be identified and discarded, thereby reducing the paperwork burden; (3) help determine data storage requirements; and (4) aid in identifying aspects of the inventory on which to concentrate the QA efforts.

### 6.1 WRITTEN DOCUMENTATION

Written documentation should include summary tables and a report discussing the inventory development procedures and point source results. Large volumes of detailed data should be put into appendices but clearly linked to the text discussion in terms of how they were used to determine emissions.

For inventories prepared by a plant, emissions may be summarized by pollutant, equipment/source, and/or stack. For larger inventories prepared by a state or local agency, the

presentation may be more broadly focussed by source category and/or county. Graphics may be useful to illustrate the contribution of point sources to areawide emissions.

The report should address data collection methods and tools, how the inventoried sources were identified, the completeness of source coverage, and procedures for estimating emissions. If any source categories are excluded, they should be listed and a reason for the exclusion should be provided. If applicable, an explanation should be included on how emissions were temporally allocated and on what basis. The methodology by which activity levels and emissions were determined for each plant should also be explained.

The appendices should contain the results of all information surveys that have been conducted. All sources inventoried should be listed according to their source category type (e.g., storage tank, process vent, petroleum refinery, graphic arts, degreasing, etc.). All references and other data sources should also be included or, if they are too voluminous, they should be clearly cited in the inventory submittal and kept in a readily accessible location on site.

For a more detailed discussion of documentation requirements, consult the EPA document *Example Documentation Report for 1990 Base Year Ozone and Carbon Monoxide SIP Emissions Inventories* (EPA, 1992b).

## 6.2 COMPUTERIZED DATA REPORTING

Along with the written documentation of the inventory, an electronic submittal inventory is also recommended. State and local agencies may submit their data to EPA, using one of the data transfer options available. Specific information on the data transfer options may be located on the EPA's 1996 Emission Inventory World Wide Website (expected to be available mid-July 1997).

# QUALITY ASSURANCE/ QUALITY CONTROL

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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. The main objective of the QA and QC for emissions inventories is the development of accurate, useful, and reliable data. These procedures should be applied consistently by the state or local agency in preparing or reviewing inventories.

Prior to establishing a quality program or plan, the meaning of quality as it relates to the inventory should be clarified. 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. Quality assurance is an integrated system or program 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.

## 7.1 QUALITY CONTROL

Quality control is the performance of standardized activities during the course of inventory preparation to ensure data quality. Quality control activities include technical reviews, accuracy checks, and the use of approved standardized procedures for emissions calculations. These internal activities are designed to provide the first level of quality checking and should be included in inventory development planning, data collection, data analysis, emissions calculation, and reporting. Quality control is best implemented through the use of standardized checklists that assess the adequacy of the data and procedures at various intervals in the inventory process. Specifically, QC checklists are used to monitor the following procedures and tasks:

- Data collection;
- Data calculation;
- Emission estimates;

- Data validity;
- Data reasonableness;
- Data completeness;
- Data coding and recording; and
- Data tracking.

The checklist can aid the preparer in finalizing the inventory prior to submittal to a reviewing agency. An example QC checklist for stationary point sources is included in Appendix D. This checklist includes questions concerning completeness (e.g., questions whether all the VOC point sources  $\geq 10$  tpy have been accounted for); use of approved procedures (e.g., questions as to which model was used to estimate wastewater treatment emissions); and reasonableness (e.g., questions whether all stack heights are greater than 50 feet and all stack diameters between 0.5 and 30 feet). For additional information and guidance on applying reasonableness or reality checks to an inventory, please refer to Chapter 3, Volume VI of the EIIP series.

## 7.2 QUALITY ASSURANCE

Quality assurance activities include helping inventory preparers identify critical phases of the inventory development process that will affect the technical soundness, accuracy, and completeness of the inventory. After identifying these phases of the process, QC procedures are developed to monitor the quality of the data and work to help ensure the generation of an accurate and complete inventory. Other QA activities include the evaluation of the effectiveness of these QC procedures by conducting data and procedural audits at critical phases of the inventory development process.

If quality concerns are found during QA audits, they should be discussed with the personnel involved so that actions can be taken immediately to resolve the issues. The quality concerns, recommendations for corrective actions, and satisfactory aspects of the QC program should be summarized in an audit report. Inventory development personnel are responsible for the resolution of the quality concerns in a timely fashion so that the work progresses as planned and the quality of the data is always being optimized.

The keys to the success of a QA/QC program are proper planning and the involvement of QA personnel to help design the QC program. An essential part of proper planning is the specification of the data quality objectives. Much of the data used for inventories are not sufficient to establish quantitative goals. Therefore, qualitative goals must be specified.

Table 1.7-1 lists six important quality goals for inventories and gives general methods for achieving those goals.

## **7.3 QA/QC PROCEDURES FOR SPECIFIC EMISSION ESTIMATION METHODS**

### **7.3.1 SOURCE TESTS AND CONTINUOUS EMISSIONS MONITORING (CEM)**

The main objective of any QA/QC effort for any program is to independently assess and document the precision, accuracy, and adequacy of data. In an emissions inventory developed from source tests and CEM, the data of interest will be that generated during sampling and analysis. As a first step, a QA Plan should be developed by the team conducting the test prior to each specific field test. Next, it is essential to the production of valid test data that the emissions measurement program be performed by qualified personnel using appropriate and properly functioning test equipment. Sampling equipment, such as flow meters and gauges, must be properly calibrated and maintained. Emphasis is placed upon these standard practices as means of ensuring the validity of results. Deviations from standard procedures must be kept to a minimum and applied only when absolutely necessary to obtain representative samples. For compliance testing, deviations from standard procedures may be used only with approval of the regulatory agency. Any changes in methodology must be based on sound engineering judgement and must be thoroughly documented.

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 *Quality Assurance Handbook for Air Pollution Measurement Systems: Volume III. Stationary Source Specific Methods* (EPA, 1984). This document also contains a detailed discussion of interpretations of CEM data, required accuracy calculations, specific criteria for unacceptable CEM data, and indications that a CEM is out of control.

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.

Quality control procedures for all instruments used to continuously collect emissions data are identical. The primary control check for precision of the continuous monitors is daily analysis of control standards.

TABLE 1.7-1

## METHODS FOR ACHIEVING EMISSION INVENTORY DATA QUALITY OBJECTIVES

Data Quality Objectives	Methods
Ensure correct implementation of EPA guidance.	<ul style="list-style-type: none"> <li>• Review inventory documentation, comparing actual procedures used to those required.</li> </ul>
Where EPA guidance was not used or unavailable, assess bias by evaluating the reasonableness of the approach used.	<ul style="list-style-type: none"> <li>• Technical review of approach used.</li> <li>• Compare with results from other methods.</li> </ul>
Ensure accuracy of input data.	<ul style="list-style-type: none"> <li>• Check accuracy of transcription of data.</li> <li>• Check any conversion factors used.</li> <li>• Assess validity of assumptions used to calculate input data.</li> <li>• Verify that the data source was current and the best available.</li> </ul>
Ensure accuracy of calculations.	<ul style="list-style-type: none"> <li>• Reconstruct a representative sample (or all) by hand.</li> </ul>
Assess comparability and representativeness of inventory.	<ul style="list-style-type: none"> <li>• Compare emissions to those from similar inventories.</li> <li>• Cross-check activity data by comparing it to surrogates.</li> </ul>
Assess completeness of inventory.	<ul style="list-style-type: none"> <li>• Compare list of source categories or emission points to those listed in EPA guidance.</li> <li>• Cross-check against other published inventories, business directories, etc.</li> </ul>

The emission rates of a particular pollutant are a function of a number of stack gas parameters such as concentration and flow rate which are measured during testing. Sensitivity and error analyses illustrate the extent to which the emission estimate may be affected by variability in the measured values. See Volume VI of the EIIP series of guidance documents for additional information on evaluating how the quality of the calculated emission rates are affected by the accuracy of the measurements.

### 7.3.2 MATERIAL BALANCES

The accuracy and reliability of emission values calculated using the material balance approach are related to the quality of material usage and speciation data, and knowledge of the different fate pathways for the material.

The quantity of material used in an operation is often "eye-balled," a procedure that can easily result in an error of as great as 25 percent. This level of uncertainty can be reduced by using a standardized method of measuring quantities such as a gravimetric procedure (e.g., weighing a container before and after using the material) or use of a stick or gauge to measure the level of liquid in a container. For certain applications (e.g., those where very small quantities of materials are used), it may be more accurate to make these types of measurements monthly or annually, rather than after each application event. Another technique for determining usage quantities would be to use purchase and inventory records.

Uncertainty of emissions using the material balance approach is also related to the quality of material speciation data, which is typically extracted from Material Safety Data Sheets (MSDSs). If speciation data are not available on the MSDS, the material manufacturer should be contacted. Finally, a thorough knowledge of the amount of a material exiting a process through each fate pathway is needed. Typical fate pathways include product, recycle/reuse, solid waste, liquid waste, and air emissions.

### 7.3.3 EMISSION FACTORS

Realizing that site specific test or CEM data are not always available or the most cost effective means for estimating air emissions from a facility, emission factors are often used as an alternative method for calculating emissions. Data used to develop emission factors available in *AP-42* or the FIRE system, for example, are obtained from source tests, material balance studies, and engineering estimates. *AP-42* and FIRE identify any qualifications or limitations of the data. *AP-42* and FIRE emission factors represent the best available information on average emissions from the identified source categories as of the date of factor publication.

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 quality of the emission



factor. When using existing emission factors, the user should be familiar with the criteria for assigning both 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* (EPA, 1993b).

The data quality ratings for source tests are as follows:

- A-Rated Test - Excellent - The test(s) was performed by a sound methodology and reported in enough detail for adequate validation. These tests are not necessarily EPA reference test methods, although such reference methods are certainly to be used as a guide.
- B-Rated Test - Above Average - The test(s) was performed by a generally sound methodology but lacked enough detail for adequate validation.
- C-Rated Test - Average - The test(s) was based on a nonvalidated or draft methodology or lacked a significant amount of background data.
- D-Rated Test - Below Average - 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 factor quality ratings are used for the emission factors found in AP-42, FIRE, or any 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.

### 7.3.4 MODELING

When a model or other software program is used to calculate emissions, manual verification (by hand) of each type of calculation should be performed. If the calculations are complex and can not be easily reconstructed, an alternative approach is to try to duplicate the results using another calculation method. The input data should also be verified for accuracy. For additional guidance on QA/QC procedures for using models, refer to Chapter 3, *General QA/QC Methods* (EHP, 1996).

## 7.4 DATA ATTRIBUTE RATING SYSTEM (DARS)

The EPA has developed a Data Attribute Rating System (DARS) to assist in evaluating data associated with emission inventories (Beck, et al., 1994). The system disaggregates emission inventories into emission factors and activity data, then assigns a numerical score to each of these two components. Each score is based on what is known about the factor and activity parameters, such as the specificity to the source category and the measurement or estimation techniques employed. The resulting emission factor and activity data scores are combined to arrive at an overall confidence rating for the inventory.

The DARS defines certain classifying attributes that are believed to influence the accuracy, appropriateness, and reliability of an emission factor or activity and derived emission estimates. This approach is semiquantitative in that it uses numeric scores; however, scoring is based on qualitative and often subjective assessments. The proposed approach, when applied systematically by inventory analysts, can be used to provide a measure of the merits of one emission estimate relative to another.

The DARS provides the means for determining the comparability and transparency of rated inventories. The inventory with the higher overall rating is likely to be a better estimate given the techniques and methodologies employed in its development. Several methods of combining the values are discussed and compared in the paper entitled *A Data Attribute Rating System* (Beck, et al., 1994).

The DARS is currently being developed into a PC-based system which will enable users to import emissions inventories for scoring.

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# **APPENDIX A**

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# **APPENDIX B**

## **CONVERSION FACTORS FROM *AP-42*, 5TH EDITION, APPENDIX A**

Source: EPA. January 1995. *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources, Fifth Edition and Supplements A-B*, AP-42. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park, North Carolina.

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**APPENDIX A**  
**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 <sup>3</sup>
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 <sup>2</sup>	0.16	inches <sup>2</sup>
inch <sup>2</sup>	6.45	centimeters <sup>2</sup>
foot <sup>2</sup>	0.09	meters <sup>2</sup>
meter <sup>2</sup>	1.2	yards <sup>2</sup>
yard <sup>2</sup>	0.84	meters <sup>2</sup>
mile <sup>2</sup>	2.59	kilometers <sup>2</sup>
centimeter <sup>3</sup>	0.061	inches <sup>3</sup>
inch <sup>3</sup>	16.39	centimeters <sup>3</sup>
foot <sup>3</sup>	283.17	centimeters <sup>3</sup>
foot <sup>3</sup>	1728	inches <sup>3</sup>

### SOME USEFUL WEIGHTS AND MEASURES (cont.)

Unit Of Measure	Equivalent	
meter <sup>3</sup>	1.31	yards <sup>3</sup>
yard <sup>3</sup>	0.77	meters <sup>3</sup>
cord	128	feet <sup>3</sup>
cord	4	meters <sup>3</sup>
peck	8	quarts
bushel (dry)	4	pecks
bushel	2150.4	inches <sup>3</sup>
gallon (U. S.)	231	inches <sup>3</sup>
barrel	31.5	gallons
hogshead	2	barrels
township	36	miles <sup>2</sup>
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<sup>a</sup>

Type Of Fuel	Heating Value		Sulfur % (by weight)	Ash % (by weight)
	kcal	Btu		
<b>Solid Fuels</b>				
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 <sup>b</sup>
Coke, Byproduct	7,380/kg	13,300/lb	0.5-1.0	0.5-5.0
<b>Liquid Fuels</b>				
Residual Oil	9.98 x 10 <sup>6</sup> /m <sup>3</sup>	150,000/gal	0.5-4.0	0.05-0.1
Distillate Oil	9.30 x 10 <sup>6</sup> /m <sup>3</sup>	140,000/gal	0.2-1.0	N
Diesel	9.12 x 10 <sup>6</sup> /m <sup>3</sup>	137,000/gal	0.4	N
Gasoline	8.62 x 10 <sup>6</sup> /m <sup>3</sup>	130,000/gal	0.03-0.04	N
Kerosene	8.32 x 10 <sup>6</sup> /m <sup>3</sup>	135,000/gal	0.02-0.05	N
Liquid Petroleum Gas	6.25 x 10 <sup>6</sup> /m <sup>3</sup>	94,000/gal	N	N
<b>Gaseous Fuels</b>				
Natural Gas	9,341/m <sup>3</sup>	1,050/SCF	N	N
Coke Oven Gas	5,249/m <sup>3</sup>	590/SCF	0.5-2.0	N
Blast Furnace Gas	890/m <sup>3</sup>	100/SCF	N	N

<sup>a</sup> N = negligible.

<sup>b</sup> Ash content may be considerably higher when sand, dirt, etc., are present.



### THERMAL EQUIVALENTS FOR VARIOUS FUELS

Type Of Fuel	kcal	Btu (gross)
<b>Solid fuels</b>		
Bituminous coal	$(5.8 \text{ to } 7.8) \times 10^6/\text{Mg}$	$(21.0 \text{ to } 28.0) \times 10^6/\text{ton}$
Anthracite coal	$7.03 \times 10^6/\text{Mg}$	$25.3 \times 10^6/\text{ton}$
Lignite	$4.45 \times 10^6/\text{Mg}$	$16.0 \times 10^6/\text{ton}$
Wood	$1.47 \times 10^6/\text{m}^3$	$21.0 \times 10^6/\text{cord}$
<b>Liquid fuels</b>		
Residual fuel oil	$10 \times 10^3/\text{liter}$	$6.3 \times 10^6/\text{bbl}$
Distillate fuel oil	$9.35 \times 10^3/\text{liter}$	$5.9 \times 10^6/\text{bbl}$
<b>Gaseous fuels</b>		
Natural gas	$9,350/\text{m}^3$	$1,050/\text{ft}^3$
Liquefied petroleum gas		
Butane	$6,480/\text{liter}$	$97,400/\text{gal}$
Propane	$6,030/\text{liter}$	$90,500/\text{gal}$

### 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	
<b>Fuels</b>		
Crude Oil	874 kg/m <sup>3</sup>	7.3 lb/gal
Residual Oil	944 kg/m <sup>3</sup>	7.88 lb/gal
Distillate Oil	845 kg/m <sup>3</sup>	7.05 lb/gal
Gasoline	739 kg/m <sup>3</sup>	6.17 lb/gal
Natural Gas	673 kg/m <sup>3</sup>	1 lb/23.8 ft <sup>3</sup>
Butane	579 kg/m <sup>3</sup>	4.84 lb/gal (liquid)
Propane	507 kg/m <sup>3</sup>	4.24 lb/gal (liquid)
<b>Wood (Air dried)</b>		
Elm	561 kg/m <sup>3</sup>	35 lb/ft <sup>3</sup>
Fir, Douglas	513 kg/m <sup>3</sup>	32 lb/ft <sup>3</sup>
Fir, Balsam	400 kg/m <sup>3</sup>	25 lb/ft <sup>3</sup>
Hemlock	465 kg/m <sup>3</sup>	29 lb/ft <sup>3</sup>
Hickory	769 kg/m <sup>3</sup>	48 lb/ft <sup>3</sup>
Maple, Sugar	689 kg/m <sup>3</sup>	43 lb/ft <sup>3</sup>
Maple, White	529 kg/m <sup>3</sup>	33 lb/ft <sup>3</sup>
Oak, Red	673 kg/m <sup>3</sup>	42 lb/ft <sup>3</sup>
Oak, White	769 kg/m <sup>3</sup>	48 lb/ft <sup>3</sup>
Pine, Southern	641 kg/m <sup>3</sup>	40 lb/ft <sup>3</sup>
<b>Agricultural Products</b>		
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
<b>Mineral Products</b>		
Brick	2.95 kg/brick	6.5 lb/brick
Cement	170 kg/bbl	375 lb/bbl
Cement	1483 kg/m <sup>3</sup>	2500 lb/yd <sup>3</sup>

# DENSITIES OF SELECTED SUBSTANCES (cont.).

Substance	Density	
Concrete	2373 kg/m <sup>3</sup>	4000 lb/yd <sup>3</sup>
Glass, Common	2595 kg/m <sup>3</sup>	162 lb/ft <sup>3</sup>
Gravel, Dry Packed	1600 - 1920 kg/m <sup>3</sup>	100 - 120 lb/ft <sup>3</sup>
Gravel, Wet	2020 kg/m <sup>3</sup>	126 lb/ft <sup>3</sup>
Gypsum, Calcined	880 - 960 kg/m <sup>3</sup>	55 - 60 lb/ft <sup>3</sup>
Lime, Pebble	850 - 1025 kg/m <sup>3</sup>	53 - 64 lb/ft <sup>3</sup>
Sand, Gravel (Dry, loose)	1440 - 1680 kg/m <sup>3</sup>	90 - 105 lb/ft <sup>3</sup>

## 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<sup>a</sup>

To Convert From	To	Multiply By
<b>Area</b>		
Acres	Sq feet	$4.356 \times 10^4$
Acres	Sq kilometers	$4.0469 \times 10^{-3}$
Acres	Sq meters	$4.0469 \times 10^3$
Acres	Sq miles (statute)	$1.5625 \times 10^{-3}$
Acres	Sq yards	$4.84 \times 10^3$
Sq feet	Acres	$2.2957 \times 10^{-5}$
Sq feet	Sq cm	929.03
Sq feet	Sq inches	144.0
Sq feet	Sq meters	0.092903
Sq feet	Sq miles	$3.587 \times 10^{-8}$
Sq feet	Sq yards	0.111111
Sq inches	Sq feet	$6.9444 \times 10^{-3}$
Sq inches	Sq meters	$6.4516 \times 10^{-4}$
Sq inches	Sq mm	645.16
Sq kilometers	Acres	247.1
Sq kilometers	Sq feet	$1.0764 \times 10^7$
Sq kilometers	Sq meters	$1.0 \times 10^6$
Sq kilometers	Sq miles	0.386102
Sq kilometers	Sq yards	$1.196 \times 10^6$
Sq meters	Sq cm	$1.0 \times 10^4$
Sq meters	Sq feet	10.764
Sq meters	Sq inches	$1.55 \times 10^3$
Sq meters	Sq kilometers	$1.0 \times 10^{-6}$
Sq meters	Sq miles	$3.861 \times 10^{-7}$
Sq meters	Sq mm	$1.0 \times 10^6$
Sq meters	Sq yards	1.196
Sq miles	Acres	640.0
Sq miles	Sq feet	$2.7878 \times 10^7$
Sq miles	Sq kilometers	2.590

# CONVERSION FACTORS (cont.).

To Convert From	To	Multiply By
Sq miles	Sq meters	$2.59 \times 10^6$
Sq miles	Sq yards	$3.0976 \times 10^6$
Sq yards	Acres	$2.0661 \times 10^{-4}$
Sq yards	Sq cm	$8.3613 \times 10^3$
Sq yards	Sq ft	9.0
Sq yards	Sq inches	$1.296 \times 10^3$
Sq yards	Sq meters	0.83613
Sq yards	Sq miles	$3.2283 \times 10^{-7}$
Density		
Dynes/cu cm	Grams/cu cm	$1.0197 \times 10^{-3}$
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.)	$8.345 \times 10^{-3}$
Kilograms/cu meter	Grams/cu cm	0.001
Kilograms/cu meter	Pounds/cu ft	0.0624
Kilograms/cu meter	Pounds/cu in	$3.613 \times 10^{-5}$
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	$2.768 \times 10^{-4}$

# CONVERSION FACTORS (cont.).

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
<b>Energy</b>		
Btu	Cal. gm (IST.)	251.83
Btu	Ergs	$1.05435 \times 10^{10}$
Btu	Foot-pounds	777.65
Btu	Hp-hours	$3.9275 \times 10^{-4}$
Btu	Joules (Int.)	1054.2
Btu	kg-meters	107.51
Btu	kW-hours (Int.)	$2.9283 \times 10^{-4}$
Btu/hr	Cal. kg/hr	0.252
Btu/hr	Ergs/sec	$2.929 \times 10^6$
Btu/hr	Foot-pounds/hr	777.65
Btu/hr	Horsepower (mechanical)	$3.9275 \times 10^{-4}$
Btu/hr	Horsepower (boiler)	$2.9856 \times 10^{-5}$
Btu/hr	Horsepower (electric)	$3.926 \times 10^{-4}$
Btu/hr	Horsepower (metric)	$3.982 \times 10^{-4}$
Btu/hr	Kilowatts	$2.929 \times 10^{-4}$
Btu/lb	Foot-pounds/lb	777.65
Btu/lb	Hp-hr/lb	$3.9275 \times 10^{-4}$
Btu/lb	Joules/gram	2.3244
Calories, kg (mean)	Btu (IST.)	3.9714
Calories, kg (mean)	Ergs	$4.190 \times 10^{10}$
Calories, kg (mean)	Foot-pounds	$3.0904 \times 10^3$
Calories, kg (mean)	Hp-hours	$1.561 \times 10^{-3}$
Calories, kg (mean)	Joules	$4.190 \times 10^3$
Calories, kg (mean)	kg-meters	427.26
Calories, kg (mean)	kW-hours (Int.)	$1.1637 \times 10^{-3}$
Ergs	Btu	$9.4845 \times 10^{-11}$
Ergs	Foot-poundals	$2.373 \times 10^{-6}$

# CONVERSION FACTORS (cont.).

To Convert From	To	Multiply By
Ergs	Foot-pounds	$7.3756 \times 10^{-8}$
Ergs	Joules (Int.)	$9.99835 \times 10^{-8}$
Ergs	kW-hours	$2.7778 \times 10^{-14}$
Ergs	kg-meters	$1.0197 \times 10^{-8}$
Foot-pounds	Btu (IST.)	$1.2851 \times 10^{-3}$
Foot-pounds	Cal. kg (IST.)	$3.2384 \times 10^{-4}$
Foot-pounds	Ergs	$1.3558 \times 10^7$
Foot-pounds	Foot-poundals	32.174
Foot-pounds	Hp-hours	$5.0505 \times 10^{-7}$
Foot-pounds	Joules	1.3558
Foot-pounds	kg-meters	0.138255
Foot-pounds	kW-hours (Int.)	$3.76554 \times 10^{-7}$
Foot-pounds	Newton-meters	1.3558
Foot-pounds/hr	Btu/min	$2.1432 \times 10^{-5}$
Foot-pounds/hr	Ergs/min	$2.2597 \times 10^5$
Foot-pounds/hr	Horsepower (mechanical)	$5.0505 \times 10^{-7}$
Foot-pounds/hr	Horsepower (metric)	$5.121 \times 10^{-7}$
Foot-pounds/hr	Kilowatts	$3.766 \times 10^{-7}$
Horsepower (mechanical)	Btu (mean)/hr	$2.5425 \times 10^3$
Horsepower (mechanical)	Ergs/sec	$7.457 \times 10^9$
Horsepower (mechanical)	Foot-pounds/hr	$1.980 \times 10^6$
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	$3.3446 \times 10^4$
Horsepower (boiler)	Ergs/sec	$9.8095 \times 10^{10}$
Horsepower (boiler)	Foot-pounds/min	$4.341 \times 10^5$
Horsepower (boiler)	Horsepower (mechanical)	13.155



# CONVERSION FACTORS (cont.).

To Convert From	To	Multiply By
Horsepower (boiler)	Horsepower (electric)	13.15
Horsepower (boiler)	Horsepower (metric)	13.337
Horsepower (boiler)	Joules/sec	$9.8095 \times 10^3$
Horsepower (boiler)	Kilowatts	9.8095
Horsepower (electric)	Btu (mean)/hr	$2.5435 \times 10^3$
Horsepower (electric)	Cal. kg/hr	641.87
Horsepower (electric)	Ergs/sec	$7.46 \times 10^9$
Horsepower (electric)	Foot-pounds/min	$3.3013 \times 10^4$
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	$2.5077 \times 10^3$
Horsepower (metric)	Ergs/sec	$7.355 \times 10^9$
Horsepower (metric)	Foot-pounds/min	$3.255 \times 10^4$
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)	$2.5425 \times 10^3$
Horsepower-hours	Foot-pounds	$1.98 \times 10^6$
Horsepower-hours	Joules	$2.6845 \times 10^6$
Horsepower-hours	kg-meters	$2.73745 \times 10^5$
Horsepower-hours	kW-hours	0.7457
Joules (Int.)	Btu (IST.)	$9.4799 \times 10^{-4}$
Joules (Int.)	Ergs	$1.0002 \times 10^7$
Joules (Int.)	Foot-poundals	12.734
Joules (Int.)	Foot-pounds	0.73768
Joules (Int.)	kW-hours	$2.778 \times 10^{-7}$

# CONVERSION FACTORS (cont.).

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	$1.341 \times 10^{-3}$
Kilogram-meters	Btu (mean)	$9.2878 \times 10^{-3}$
Kilogram-meters	Cal. kg (mean)	$2.3405 \times 10^{-3}$
Kilogram-meters	Ergs	$9.80665 \times 10^7$
Kilogram-meters	Foot-pounds	232.715
Kilogram-meters	Foot-pounds	7.233
Kilogram-meters	Hp-hours	$3.653 \times 10^{-6}$
Kilogram-meters	Joules (Int.)	9.805
Kilogram-meters	kW-hours	$2.724 \times 10^{-6}$
Kilogram-meters/sec	Watts	9.80665
Kilowatts (Int.)	Btu (IST.)/hr	$3.413 \times 10^3$
Kilowatts (Int.)	Cal. kg (IST.)/hr	860.0
Kilowatts (Int.)	Ergs/sec	$1.0002 \times 10^{10}$
Kilowatts (Int.)	Foot-pounds/min	$1.424 \times 10^6$
Kilowatts (Int.)	Foot-pounds/min	$4.4261 \times 10^4$
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	$3.6 \times 10^6$
Kilowatts (Int.)	kg-meters/hr	$3.6716 \times 10^5$
Kilowatt-hours (Int.)	Btu (mean)	$3.41 \times 10^3$
Kilowatt-hours (Int.)	Foot-pounds	$2.6557 \times 10^6$
Kilowatt-hours (Int.)	Hp-hours	1.341
Kilowatt-hours (Int.)	Joules (Int.)	$3.6 \times 10^6$
Kilowatt-hours (Int.)	kg-meters	$3.6716 \times 10^5$
Newton-meters	Gram-cm	$1.01972 \times 10^4$
Newton-meters	kg-meters	0.101972

# CONVERSION FACTORS (cont.).

To Convert From	To	Multiply By
Newton-meters	Pound-feet	0.73756
Force		
Dynes	Newtons	$1.0 \times 10^{-5}$
Dynes	Poundals	$7.233 \times 10^{-5}$
Dynes	Pounds	$2.248 \times 10^{-6}$
Newtons	Dynes	$1.0 \times 10^5$
Newtons	Pounds (avdp.)	0.22481
Poundals	Dynes	$1.383 \times 10^4$
Poundals	Newtons	0.1383
Poundals	Pounds (avdp.)	0.03108
Pounds (avdp.)	Dynes	$4.448 \times 10^5$
Pounds (avdp.)	Newtons	4.448
Pounds (avdp.)	Poundals	32.174
Length		
Feet	Centimeters	30.48
Feet	Inches	12
Feet	Kilometers	$3.048 \times 10^{-4}$
Feet	Meters	0.3048
Feet	Miles (statute)	$1.894 \times 10^{-4}$
Inches	Centimeters	2.540
Inches	Feet	0.08333
Inches	Kilometers	$2.54 \times 10^{-5}$
Inches	Meters	0.0254
Kilometers	Feet	$3.2808 \times 10^3$
Kilometers	Meters	1000
Kilometers	Miles (statute)	0.62137
Kilometers	Yards	$1.0936 \times 10^3$
Meters	Feet	3.2808
Meters	Inches	39.370
Micrometers	Angstrom units	$1.0 \times 10^4$

# CONVERSION FACTORS (cont.).

To Convert From	To	Multiply By
Micrometers	Centimeters	$1.0 \times 10^{-3}$
Micrometers	Feet	$3.2808 \times 10^{-6}$
Micrometers	Inches	$3.9370 \times 10^{-5}$
Micrometers	Meters	$1.0 \times 10^{-6}$
Micrometers	Millimeters	0.001
Micrometers	Nanometers	1000
Miles (statute)	Feet	5280
Miles (statute)	Kilometers	1.6093
Miles (statute)	Meters	$1.6093 \times 10^3$
Miles (statute)	Yards	1760
Millimeters	Angstrom units	$1.0 \times 10^7$
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	$1.0 \times 10^{-7}$
Nanometers	Inches	$3.937 \times 10^{-8}$
Nanometers	Micrometers	0.001
Nanometers	Millimeters	$1.0 \times 10^{-6}$
Yards	Centimeters	91.44
Yards	Meters	0.9144
<b>Mass</b>		
Grains	Grams	0.064799
Grains	Milligrams	64.799
Grains	Pounds (apoth. or troy)	$1.7361 \times 10^{-4}$
Grains	Pounds (avdp.)	$1.4286 \times 10^{-4}$
Grains	Tons (metric)	$6.4799 \times 10^{-8}$
Grams	Dynes	980.67

# CONVERSION FACTORS (cont.).

To Convert From	To	Multiply By
Grams	Grains	15.432
Grams	Kilograms	0.001
Grams	Micrograms	$1 \times 10^6$
Grams	Pounds (avdp.)	$2.205 \times 10^{-3}$
Grams	Tons, metric (megagrams)	$1 \times 10^{-6}$
Kilograms	Grains	$1.5432 \times 10^4$
Kilograms	Poundals	70.932
Kilograms	Pounds (apoth. or troy)	2.679
Kilograms	Pounds (avdp.)	2.2046
Kilograms	Tons (long)	$9.842 \times 10^{-4}$
Kilograms	Tons (metric)	0.001
Kilograms	Tons (short)	$1.1023 \times 10^{-3}$
Megagrams	Tons (metric)	1.0
Milligrams	Grains	0.01543
Milligrams	Grams	$1.0 \times 10^{-3}$
Milligrams	Ounces (apoth. or troy)	$3.215 \times 10^{-5}$
Milligrams	Ounces (avdp.)	$3.527 \times 10^{-5}$
Milligrams	Pounds (apoth. or troy)	$2.679 \times 10^{-6}$
Milligrams	Pounds (avdp.)	$2.2046 \times 10^{-6}$
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)	$4.4643 \times 10^{-4}$

# CONVERSION FACTORS (cont.).

To Convert From	To	Multiply By
Pounds (avdp.)	Tons (metric)	$4.5359 \times 10^{-4}$
Pounds (avdp.)	Tons (short)	$5.0 \times 10^{-4}$
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	$1.016 \times 10^3$
Tons (long)	Pounds (apoth. or troy)	$2.722 \times 10^3$
Tons (long)	Pounds (avdp.)	$2.240 \times 10^3$
Tons (long)	Tons (metric)	1.016
Tons (long)	Tons (short)	1.12
Tons (metric)	Grams	$1.0 \times 10^6$
Tons (metric)	Megagrams	1.0
Tons (metric)	Pounds (apoth. or troy)	$2.6792 \times 10^3$
Tons (metric)	Pounds (avdp.)	$2.2046 \times 10^3$
Tons (metric)	Tons (long)	0.9842
Tons (metric)	Tons (short)	1.1023
Tons (short)	Kilograms	907.18
Tons (short)	Pounds (apoth. or troy)	$2.4301 \times 10^3$
Tons (short)	Pounds (avdp.)	2000
Tons (short)	Tons (long)	0.8929
Tons (short)	Tons (metric)	0.9072
Pressure		
Atmospheres	cm of H <sub>2</sub> O (4°C)	$1.033 \times 10^3$
Atmospheres	Ft of H <sub>2</sub> O (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.).

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 <sub>2</sub> O (4°C)	Atmospheres	$2.458 \times 10^{-3}$
Inches of H <sub>2</sub> O (4°C)	In. of Hg (32°F)	0.07355
Inches of H <sub>2</sub> O (4°C)	kg/sq meter	25.399
Inches of H <sub>2</sub> O (4°C)	Pounds/sq ft	5.2022
Inches of H <sub>2</sub> O (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 <sub>2</sub> O (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	$1.3158 \times 10^{-3}$
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 <sub>2</sub> O (4°C)	70.309
Pounds/sq inch	In. of Hg (32°F)	2.036
Pounds/sq inch	In. of H <sub>2</sub> O (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.).

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	$5.08 \times 10^{-3}$
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	$3.2808 \times 10^3$
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	$7.2765 \times 10^3$



# CONVERSION FACTORS (cont.).

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	$3.5315 \times 10^{-5}$
Cubic centimeters	Cu inches	0.06102
Cubic centimeters	Cu meters	$1.0 \times 10^{-6}$
Cubic centimeters	Cu yards	$1.308 \times 10^{-6}$
Cubic centimeters	Gallons (U. S., liq.)	$2.642 \times 10^{-4}$
Cubic centimeters	Quarts (U. S., liq.)	$1.0567 \times 10^{-3}$
Cubic feet	Cu centimeters	$2.8317 \times 10^4$
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	$5.787 \times 10^{-4}$
Cubic inches	Cu meters	$1.6387 \times 10^{-5}$
Cubic inches	Cu yards	$2.1433 \times 10^{-5}$
Cubic inches	Gallons (U. S., liq.)	$4.329 \times 10^{-3}$
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	$1.0 \times 10^6$
Cubic meters	Cu feet	35.315
Cubic meters	Cu inches	$6.1024 \times 10^4$
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	$7.6455 \times 10^5$

# CONVERSION FACTORS (cont.).

To Convert From	To	Multiply By
Cubic yards	Cu feet	27
Cubic yards	Cu inches	$4.6656 \times 10^4$
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	$3.7854 \times 10^3$
Gallons (U. S., liq.)	Cu feet	0.13368
Gallons (U. S., liq.)	Cu inches	231
Gallons (U. S., liq.)	Cu meters	$3.7854 \times 10^{-3}$
Gallons (U. S., liq.)	Cu yards	$4.951 \times 10^{-3}$
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.).

To Convert From	To	Multiply By
<b>Volumetric Rate</b>		
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	$6.309 \times 10^{-5}$
Gallons (U. S.)/hr	Cu yd/min	$8.2519 \times 10^{-5}$
Gallons (U. S.)/hr	Liters/hr	3.7854
Liters/min	Cu ft/min	0.0353
Liters/min	Gal (U. S., liq.)/min	0.2642

<sup>a</sup> 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	$283.2 \times 10^{-6}$
	Grams/cu m	0.001
	Micrograms/cu m	1000.0
	Micrograms/cu ft	28.32
	Pounds/1000 cu ft	$62.43 \times 10^{-6}$
Grams/cu ft	Milligrams/cu m	$35.3145 \times 10^3$
	Grams/cu m	35.314
	Micrograms/cu m	$35.314 \times 10^6$
	Micrograms/cu ft	$1.0 \times 10^6$
	Pounds/1000 cu ft	2.2046
Grams/cu m	Milligrams/cu m	1000.0
	Grams/cu ft	0.02832
	Micrograms/cu m	$1.0 \times 10^6$
	Micrograms/cu ft	$28.317 \times 10^3$
	Pounds/1000 cu ft	0.06243
Micrograms/cu m	Milligrams/cu m	0.001
	Grams/cu ft	$28.317 \times 10^{-9}$
	Grams/cu m	$1.0 \times 10^{-6}$
	Micrograms/cu ft	0.02832
	Pounds/1000 cu ft	$62.43 \times 10^{-9}$
Micrograms/cu ft	Milligrams/cu m	$35.314 \times 10^{-3}$
	Grams/cu ft	$1.0 \times 10^{-6}$
	Grams/cu m	$35.314 \times 10^{-6}$
	Micrograms/cu m	35.314
	Pounds/1000 cu ft	$2.2046 \times 10^{-6}$
Pounds/1000 cu ft	Milligrams/cu m	$16.018 \times 10^3$
	Grams/cu ft	0.35314
	Micrograms/cu m	$16.018 \times 10^6$
	Grams/cu m	16.018
	Micrograms/cu ft	$353.14 \times 10^3$

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)	$73.48 \times 10^{-3}$

# 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 <sup>-9</sup>
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 <sup>-6</sup>
	Pounds/cu ft	62.43 x 10 <sup>-12</sup>
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 <sup>-9</sup>
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 <sup>6</sup>
ppm by weight	Milligrams/cu m	1.198
	Micrograms/cu m	1.198 x 10 <sup>-3</sup>
	Micrograms/liter	1.198
	ppm by volume (20°C)	28.8/M
	Pounds/cu ft	7.48 x 10 <sup>-6</sup>
Pounds/cu ft	Milligrams/cu m	16.018 x 10 <sup>6</sup>
	Micrograms/cu m	16.018x 10 <sup>9</sup>
	Micrograms/liter	16.018x 10 <sup>6</sup>
	ppm by volume (20°C)	385.1 x 10 <sup>6</sup> /M
	ppm by weight	133.7 x 10 <sup>3</sup>

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	$1.316 \times 10^{-3}$
	Inches of mercury	$39.37 \times 10^{-3}$
	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 =  $10.5 \times 10^6$  BTU/hr  
(8 to  $14 \times 10^6$  BTU/hr)

1 Megawatt =  $8 \times 10^3$  lb steam/hr  
(6 to  $11 \times 10^3$  lb steam/hr)

1 BHP = 34.5 lb steam/hr

1 BHP =  $45 \times 10^3$  BTU/hr  
(40 to  $50 \times 10^3$  BTU/hr)

1 lb steam/hr =  $1.4 \times 10^3$  BTU/hr  
(1.2 to  $1.7 \times 10^3$  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 values.

VOLUME	cu. in.	ml.	liters	ounces (U. S. fl.)	gallons (U. S.)	barrels (U. S.)	cu. ft.
Cubic inches .....	.....	16.3868	.0163868	0.3541	$4.3290 \times 10^{-3}$	$1.37429 \times 10^{-4}$	$5.78704 \times 10^{-4}$
Milliliters .....	0.061024	.....	0.001	0.03381	$2.6418 \times 10^{-4}$	$8.387 \times 10^{-6}$	$3.5316 \times 10^{-5}$
Liters .....	61.024	1000	.....	33.8147	0.26418	$8.387 \times 10^{-3}$	0.035316
Ounces (U. S. fl.)	1.80469	29.5729	0.029573	.....	$7.8125 \times 10^{-3}$	$2.48 \times 10^{-4}$	$1.0443 \times 10^{-3}$
Gallons (U. S.) <sup>a</sup> ..	231	3785.3	3.7853	128	.....	0.031746	0.13368
Barrels (U. S.)...	7276.5	$1.1924 \times 10^5$	119.2369	4032.0	31.5	.....	4.2109
Cubic feet .....	1728	$2.8316 \times 10^4$	28.316	957.568	7.481	0.23743	.....

<sup>a</sup>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	$3.527 \times 10^{-2}$	$2.205 \times 10^{-3}$	15.432	$1.102 \times 10^{-6}$	1000
Kilograms .....	1000	.....	35.274	2.2046	15432	$1.102 \times 10^{-3}$	$1 \times 10^6$
Ounces (avoir.)...	28.350	0.028350	.....	0.0625	437.5	$3.125 \times 10^{-5}$	$2.8350 \times 10^4$
Pounds (avoir.) <sup>a</sup> ..	453.59	0.45359	16.0	.....	7000	$5.0 \times 10^{-4}$	$4.5359 \times 10^5$
Grains .....	0.06480	$6.480 \times 10^{-5}$	$2.286 \times 10^{-3}$	$1.429 \times 10^{-4}$	.....	$7.142 \times 10^{-8}$	64.799
Tons (U. S.) .....	$9.072 \times 10^5$	907.19	$3.200 \times 10^4$	2000	$1.4 \times 10^7$	.....	$9.0718 \times 10^8$
Milligrams .....	0.001	$1 \times 10^{-6}$	$3.527 \times 10^{-5}$	$2.205 \times 10^{-6}$	0.015432	$1.102 \times 10^{-9}$	.....

<sup>a</sup>Mass of 27.692 cubic inches water weighed in air at 4.0°C, 760 mm mercury pressure.



## EMISSION FACTORS

(Reformatted 1/95) 9/85

WORK AND ENERGY	g. cal.	kg. cal.	ergs	Joules	BTU	ft. lb.	kg. meters	L-Atm	HP Hours	ft. pounds	KWH	WH
Gram Calories (mean).....	0.001	4.186x10 <sup>-7</sup>	4.186	3.9680x10 <sup>-3</sup>	3.0874	0.42683	0.041311	1.5593x10 <sup>-6</sup>	99.334	1.1628x10 <sup>-6</sup>	1.1628x10 <sup>-3</sup>	
Kilogram Calories.....	1000	4.186x10 <sup>10</sup>	4186	3.9480	3087.4	426.85	41.311	1.5593x10 <sup>-3</sup>	99334	1.1628x10 <sup>-3</sup>	1.1628	
Ergs.....	2.3889x10 <sup>-8</sup>	2.3889x10 <sup>-11</sup>	1x10 <sup>-7</sup>	9.4805x10 <sup>-11</sup>	7.3756x10 <sup>-8</sup>	1.0197x10 <sup>-8</sup>	9.8689x10 <sup>-10</sup>	3.7251x10 <sup>-14</sup>	2.3730x10 <sup>-6</sup>	2.7778x10 <sup>-14</sup>	2.7778x10 <sup>-11</sup>	
Joules.....	0.23889	2.3889x10 <sup>-4</sup>	1x10 <sup>7</sup>	9.4805x10 <sup>-4</sup>	0.73756	0.10197	9.8689x10 <sup>-3</sup>	3.7251x10 <sup>-7</sup>	23.730	2.7778x10 <sup>-7</sup>	2.7778x10 <sup>-4</sup>	
BTU (mean).....	251.98	0.23198	1.0548x10 <sup>10</sup>	1054.8	777.98	107.56	10.409	3.9292x10 <sup>-4</sup>	2.5030x10 <sup>4</sup>	2.930x10 <sup>-4</sup>	0.2930	
Foot Pounds.....	0.32189	3.2389x10 <sup>-4</sup>	1.35382x10 <sup>7</sup>	1.3538	1.2834x10 <sup>-3</sup>	0.13825	0.013361	5.0505x10 <sup>-7</sup>	32.174	3.7662x10 <sup>-7</sup>	3.7662x10 <sup>-4</sup>	
Kilogram meters ..	2.3427	2.3427x10 <sup>-3</sup>	9.8046x10 <sup>7</sup>	9.8064	9.2967x10 <sup>-3</sup>	.....	0.096781	3.6529x10 <sup>-6</sup>	232.71	2.7241x10 <sup>-6</sup>	2.7241x10 <sup>-3</sup>	
Liter Atmospheres (normal).....	24.206	2.4206x10 <sup>-2</sup>	1.0133x10 <sup>9</sup>	101.328	0.09406	10.333	.....	3.7745x10 <sup>-5</sup>	2404.5	2.8164x10 <sup>-5</sup>	2.8164x10 <sup>-2</sup>	
Horsepower Hours ..	6.4130x10 <sup>3</sup>	641.30	2.6845x10 <sup>13</sup>	2.6843x10 <sup>6</sup>	2434.0	2.7374x10 <sup>3</sup>	26494	.....	6.3705x10 <sup>7</sup>	0.7437	743.7	
Foot pounds.....	0.010067	10.067x10 <sup>-6</sup>	4.21402x10 <sup>5</sup>	0.04214	3.9932x10 <sup>-5</sup>	4.2972x10 <sup>-3</sup>	4.1558x10 <sup>-4</sup>	1.5697x10 <sup>-8</sup>	.....	1.17055x10 <sup>-8</sup>	1.17055x10 <sup>-5</sup>	
Kilowatt Hours ...	8.6001x10 <sup>3</sup>	860.01	3.6000x10 <sup>13</sup>	3.6000x10 <sup>6</sup>	3413.0	3.6709x10 <sup>-3</sup>	3.5529x10 <sup>6</sup>	1.3440	8.3430x10 <sup>7</sup>	.....	1000	
Watt Hours.....	860.01	0.86001	3.6000x10 <sup>10</sup>	3600	3.4130	367.09	3.5529x10 <sup>3</sup>	1.3410x10 <sup>-3</sup>	8.3430x10 <sup>1</sup>	0.001	.....	

POWER	watts	kw	ft. lb./sec	erg/sec	BTU/min	g. cm/sec	kg. cal/min	HP	Lumens	Joules/sec	BTU/hr.
Watts .....	.....	0.001	0.73756	$1 \times 10^7$	0.056884	$1.0197 \times 10^4$	0.01433	$1.341 \times 10^{-3}$	668	1	3.41304
Kilowatts .....	1000	.....	737.56	$1 \times 10^{10}$	56.884	$1.0197 \times 10^7$	14.3334	1.3410	$6.68 \times 10^5$	1000	3413.04
Foot pounds per second .....	1.35582	$1.3558 \times 10^{-3}$	.....	$1.3558 \times 10^7$	0.077124	$1.3826 \times 10^4$	0.019433	$1.8182 \times 10^{-3}$	906.28	1.3558	4.6274
Ergs per second ..	$1 \times 10^{-7}$	$1 \times 10^{-10}$	$7.3756 \times 10^{-8}$	.....	$5.688 \times 10^{-9}$	$1.0197 \times 10^{-3}$	$1.4333 \times 10^{-9}$	$1.3410 \times 10^{-10}$	$6.6845 \times 10^{-5}$	$1 \times 10^{-7}$	$3.4130 \times 10^{-7}$
BTU* per minute ..	17.580	0.017580	12.9600	$1.7580 \times 10^8$	.....	$1.7926 \times 10^5$	0.2520	0.023575	11751	17.580	60
Gram Centimeters per second .....	$9.8067 \times 10^{-5}$	$9.8067 \times 10^{-8}$	$7.2330 \times 10^{-5}$	980.665	$5.5783 \times 10^{-6}$	.....	$1.4056 \times 10^{-6}$	$1.3151 \times 10^{-7}$	0.065552	$9.8067 \times 10^{-5}$	$3.3470 \times 10^{-4}$
Kilogram calories per minute .....	69.767	.069767	51.457	$6.9770 \times 10^8$	3.9685	$7.1146 \times 10^5$	.....	0.093557	46636	69.769	238.11
Horsepower (U. S.)	745.7	0.7457	550	$7.457 \times 10^9$	42.4176	$7.6042 \times 10^6$	10.688	.....	498129	745.7	2545.1
Lumens .....	$1.496 \times 10^{-3}$	$1.496 \times 10^{-6}$	$1.0034 \times 10^{-3}$	$1.496 \times 10^4$	$8.5096 \times 10^{-5}$	15.254	$2.1437 \times 10^{-5}$	$2.0061 \times 10^{-6}$	.....	$1.496 \times 10^{-3}$	$5.1069 \times 10^{-3}$
Joules per second	1	0.001	0.73756	$1 \times 10^7$	0.056884	$1.0197 \times 10^4$	0.01433	$1.341 \times 10^{-3}$	668	.....	3.41304
BTU* per hour .....	0.29299	$2.9299 \times 10^{-4}$	0.21610	$2.9299 \times 10^6$	0.01667	$2.9878 \times 10^3$	$4.1997 \times 10^{-3}$	$3.9291 \times 10^{-4}$	195.80	0.29299	.....

\*British Thermal Units (Mean)

# CONVERSION FACTORS FOR VARIOUS SUBSTANCES<sup>a</sup>

Type Of Substance	Conversion Factors
<b>Fuel</b>	
Oil	1 bbl = 159 liters (42 gal)
Natural gas	1 therm = 100,000 Btu (approx. 25,000 kcal)
<b>Gaseous Pollutants</b>	
O <sub>3</sub>	1 ppm, volume = 1960 µg/m <sup>3</sup>
NO <sub>2</sub>	1 ppm, volume = 1880 µg/m <sup>3</sup>
SO <sub>2</sub>	1 ppm, volume = 2610 µg/m <sup>3</sup>
H <sub>2</sub> S	1 ppm, volume = 1390 µg/m <sup>3</sup>
CO	1 ppm, volume = 1.14 mg/m <sup>3</sup>
HC (as methane)	1 ppm, volume = 0.654 mg/m <sup>3</sup>
<b>Agricultural products</b>	
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
<b>Mineral products</b>	
Brick	1 brick = 2.95 kg = 6.5 lb
Cement	1 bbl = 170 kg = 375 lb
Cement	1 yd <sup>3</sup> = 1130 kg = 2500 lb
Concrete	1 yd <sup>3</sup> = 1820 kg = 4000 lb
<b>Mobile sources, fuel efficiency</b>	
Motor vehicles	1.0 mi/gal = 0.426 km/liter
Waterborne vessels	1.0 gal/naut mi = 2.05 liters/km
<b>Miscellaneous liquids</b>	
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

<sup>a</sup> 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 C**

## **CONTACT AND RESOURCE INFORMATION**

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# **1. Office of Air Quality Planning and Standards Technology Transfer Network (TTN) Electronic Bulletin Board (OAQPS TTN)**

The OAQPS TTN provides access to the *Emission Measurement Technical Information Center (EMTIC)* and *Clearinghouse for Inventories and Emission Factors (CHIEF)* bulletin boards.

## **OAQPS TTN System Operators:**

Herschel Rorex, System Manager  
Phil Dickerson, Assistant System Manager  
Research Triangle Park, NC 27711  
(919) 541-5384

## **TTN Telephone:**

(919) 541-5742 (1200, 2400, or 9600 baud)

## **FTP site:**

[ttnftp.rtpnc.epa.gov](ftp://ttnftp.rtpnc.epa.gov)

## **Internet:**

[ttnwww.rtpnc.epa.gov](http://ttnwww.rtpnc.epa.gov)

## **Telenet:**

[ttnbbs.rtpnc.epa.gov](telnet://ttnbbs.rtpnc.epa.gov)

## **Hardware and Software Requirements:**

Computer  
Communications software package  
Modem  
Communications software parameters:  
    8 data bits  
    1 stop bit  
    no parity  
    full duplex  
    terminal emulation VT100 or VT/ANSI

The OAQPS TTN is down every Monday morning from 8:00 a.m. to 12:00 p.m. EST for maintenance.

2. **Emission Factor Assistance Line (InfoCHIEF) for questions pertaining to SPECIATE, FIRE, AIRS SCC/SIC file, Air CHIEF CD-ROM, Fax CHIEF, CHIEF Bulletin Board, TANKS, L&E documents, or AP-42**

Address:

Emission Factor and Inventory Group (MD-14)  
U.S. Environmental Protection Agency  
Research Triangle Park, NC 27711

Contact:

InfoCHIEF Help Line

Telephone:

(919) 541-5285

Fax CHIEF:

(919) 541-0548  
(919) 541-5626

3. **New SCC Assignments**

Address:

Emission Factor and Inventory Group (MD-14)  
U.S. Environmental Protection Agency  
Research Triangle Park, NC 27711

Contact:

Ron Ryan

Telephone:

(919) 541-4330

4. **Air Pollution Training Institute**

Address:

Environmental Research Center  
U.S. Environmental Protection Agency  
Research Triangle Park, NC 27711

Contact:  
J. Nunn, Training Coordinator

Telephone:  
(919) 541-3724

**5. Information on CHEMDAT8 and WATER8**

Address:  
Emission Standards Division  
U.S. Environmental Protection Agency  
Research Triangle Park, NC 27711

Contact:  
Elaine Manning

Telephone:  
(919) 541-5499

**6. Information on LAEEM**

Address:  
Air Pollution Prevention and Control Division  
Office of Research and Development  
U.S. Environmental Protection Agency  
Research Triangle Park, NC 27711

Contact:  
Susan Thorneloe

Telephone:  
(919) 541-2709

**7. U.S. Environmental Protection Agency Library**

Single copies of some EPA documents and personal computer tools are available free to government and non-profit organizations from the EPA library. For-profit organizations should order from the Government Printing Office (GPO) or from the National Technical Information Service (NTIS).



Address:

U.S. Environmental Protection Agency Library  
MD-35  
Research Triangle Park, NC 27711

Telephone:

(919) 541-2777

**8. Government Printing Office (GPO)**

Address:

Government Printing Office  
Superintendent of Documents  
P.O. Box 371954  
Pittsburgh, PA 15250-795420402

Telephone:

(202) 512-1800  
(202) 512-2250 (Fax)

**9. National Technical Information Service (NTIS)**

Address:

National Technical Information Service  
5285 Port Royal Road  
Springfield, VA 22161

Ordering and Catalog Information:

(703) 487-4650  
(703) 321-8547 (fax)  
(800) 553-6847 (rush orders only)

Telecommunications Devices for the Deaf (TDD):

(703) 487-4639

NTIS documents are generally available on paper or microfiche.

**10. Pollution Prevention Information Clearinghouse**

Telephone:

(202) 260-1023

Pollution Prevention Information Exchange System (PIES)

(access via computer)

(703) 506-1025

**Hardware and Software Requirements**

Computer

Communications software package

Modem

Communications software parameters:

8 data bits

1 stop bit

no parity

**11. Control Technology Center**

Address:

U.S. Environmental Protection Agency

ORD/APPCD (MD-91) or

OAQPS/ITPID (MD-12)

Air Pollution Prevention and Control Division

MD-91

Research Triangle Park, NC 27711

Telephone:

(919) 541-0800

**12. Emergency Planning and Community Right-to-Know Act Hotline**

(703) 412-9810

(800) 424-9346

Telecommunications Devices for the Deaf (TDD): (800) 553-7672

**13. EIIP Point Sources Committee****Co-chairs**

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## **APPENDIX D**

# **ANNUAL EMISSIONS INVENTORY CHECKLIST FOR STATIONARY POINT SOURCES**



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## ANNUAL EMISSIONS INVENTORY CHECKLIST FOR STATIONARY POINT SOURCES

Completeness Checks - Point Sources	Yes	No	Comments
Have all VOC point sources with actual emissions $\geq 10$ tpy been included in the inventory?			
Have process, point, and segment level data been provided for all VOC point sources with actual emissions $\geq 10$ tpy?			
Have all VOC sources in the 25-mile zone outside of the nonattainment area with emissions $> 100$ tpy been addressed in the inventory?			
Have all $\text{NO}_x$ and CO sources in the nonattainment area and 25-mile zone outside of the nonattainment area with emissions $> 100$ tpy been addressed in the inventory?			
Have all process, point, and segment level documentation data required for the 100-ton $\text{NO}_x$ and CO sources been provided?			
Does the inventory include point sources for VOCs in the 10 - 25 tpy (actual) range?			
Are the following VOC point source categories represented among the 10 - 25 tpy plant listings?			
<i>Note: Provide documentation if any are "no."</i>			
• Graphic Arts			
• Commercial/Institutional Boilers			
• Industrial Boilers			
• Gasoline Bulk Plants			

## ANNUAL EMISSIONS INVENTORY CHECKLIST FOR STATIONARY POINT SOURCES

(CONTINUED)

Completeness Checks - Point Sources	Yes	No	Comments
• Degreasing Operations			
• Waste Disposal/Treatment			
Are the following broad source categories represented among the >25 tpy VOC plant listing?			
• Storage, transportation and marketing of petroleum products and volatile organic liquids			
• Industrial Processes			
• Industrial Surface Coating			
Are the following CO and NO <sub>x</sub> source categories represented among the plant listings?			
• Utility Boilers			
• Industrial Boilers			
• Commercial/Institutional External Fuel Combustion			
• Waste Disposal/Combustion			
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 state) and is it accurate: source addresses, contact information, and SIC code(s)?			

## ANNUAL EMISSIONS INVENTORY CHECKLIST FOR STATIONARY POINT SOURCES

(CONTINUED)

Procedures Checks(Continued)	Yes	No	Comments
Have you made a copy of the inventory and report you are mailing to the state 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, AFS, and permit files) to develop the point source inventory listing?			
Does the point source inventory reflect a base year of 1990? <i>Note: If another inventory was used as a starting point, documentation should be provided to show what adjustments were made to reflect the 1990 base year.</i>			
Were emissions estimates adjusted to reflect the O <sub>3</sub> season and rule effectiveness?			
Does the inventory documentation describe the methodology used to define months of the O <sub>3</sub> season?			
Indicate which of the following basic options were used to submit data for point sources:			
• EIIP data transfer format			
• AFS batch transaction format			
• Interactive direct entry to AFS			
Was a computer model used to estimate emissions from waste treatment/disposal sources? If yes, which model?			

## ANNUAL EMISSIONS INVENTORY CHECKLIST FOR STATIONARY POINT SOURCES

(CONTINUED)

Procedures Checks (Continued)	Yes	No	Comments
Was a rule effectiveness factor of 80 percent used for all categories?			
Does the point source inventory documentation include the contact person(s) for referring questions?			
Was rule effectiveness applied to emission estimates for the following point source categories?			
• Surface Coating of Cans			
• Surface Coating of Metal Coils			
• Surface Coating of Fabric and Vinyl			
• Surface Coating of Paper Products			
• Coating of Automobiles and Light-duty Trucks in Assembly Plants			
• Surface Coating of Metal Furniture			
• Surface Coating of Magnetic Wire			
• Tank Truck Gasoline Loading Terminals			
• Bulk Gasoline Plants			

## ANNUAL EMISSIONS INVENTORY CHECKLIST FOR STATIONARY POINT SOURCES

(CONTINUED)

Procedures Checks (Continued)	Yes	No	Comments
<p>Select a subset that represents at least 10 percent of the listed point sources (in the &gt; 25 tpy range) and determine if the following data are compiled and presented for each source.</p> <p><i>Note: Identify in the comment column the record number of those plants that were checked.</i></p>			
<ul style="list-style-type: none"> <li>Plant name and location (including latitude, longitude, and zip code)</li> </ul>			
<ul style="list-style-type: none"> <li>AFS point ID</li> </ul>			
<ul style="list-style-type: none"> <li>SIC code(s)</li> </ul>			
<ul style="list-style-type: none"> <li>Operating schedule</li> </ul>			
<ul style="list-style-type: none"> <li>Applicable regulations</li> </ul>			
<ul style="list-style-type: none"> <li>Current environmental permits</li> </ul>			
<ul style="list-style-type: none"> <li>UTM zone</li> </ul>			
<ul style="list-style-type: none"> <li>FIP State, city, and county codes</li> </ul>			
<ul style="list-style-type: none"> <li>Plot plan of the facility</li> </ul>			
<ul style="list-style-type: none"> <li>Pollutant code or CAS code</li> </ul>			
<ul style="list-style-type: none"> <li>Inventory of vents and stacks (for point pollutant data)</li> </ul>			
<ul style="list-style-type: none"> <li>Stack parameter data</li> </ul>			
<ul style="list-style-type: none"> <li>Emission limitations (only if subject to SIP regulation)</li> </ul>			

## ANNUAL EMISSIONS INVENTORY CHECKLIST FOR STATIONARY POINT SOURCES

(CONTINUED)

Reasonableness Checks	Yes	No	Comments
• Compliance year (only if subject to SIP Regulation)			
• SCC for process unit			
• Daily process rate and units			
• Listing and description of processes and support activities			
• Listing of cooling units and air conditioners using CFCs			
• Type and volume of CFC used			
• Control equipment type			
• Control efficiency			
• Date of equipment installation and latest modification			
• Emissions estimation method			
• Emission factors			
• List, description, and volume of wastes generated			
• Chemical and fuel storage tank data			
• Current emission source testing results			
• Material safety data sheets for production and maintenance-related raw materials			
• Rule effectiveness			
• Seasonal adjustment factor			

## ANNUAL EMISSIONS INVENTORY CHECKLIST FOR STATIONARY POINT SOURCES

(CONTINUED)

Reasonableness Checks (Continued)	Yes	No	Comments
<ul style="list-style-type: none"> <li>O<sub>3</sub> season daily emissions</li> </ul>			
Does the sum of emission estimates from small VOC point sources represent at least 5 percent of the total point source VOC contribution?			
<p>If point source VOC emissions are attributed to the synthetic organic chemical manufacturing industry (SOCMI), are fugitive leaks also quantified?</p> <p><i>Note: Fugitive equipment leak emissions should be 1 to 10 times larger than emissions from vents, reactors, etc.</i></p>			
Are unadjusted annual emissions estimates for VOC, CO, and NO <sub>x</sub> from point sources within 25 percent of the values reported in AFS?			
Are the following data elements within the ranges listed below for general point sources data?			
<ul style="list-style-type: none"> <li>Hours per day <math>\leq 24</math></li> </ul>			
<ul style="list-style-type: none"> <li>Days per week <math>\leq 7</math></li> </ul>			
<ul style="list-style-type: none"> <li>Hours per year <math>\leq 8,760</math></li> </ul>			
<ul style="list-style-type: none"> <li>Seasonal throughputs 0 - 100</li> </ul>			
<ul style="list-style-type: none"> <li>Boiler capacity 80 - 120 percent of hourly maximum rate x fuel heat content</li> </ul>			
<ul style="list-style-type: none"> <li>Is percent space heat for winter greater than summer</li> </ul>			



## ANNUAL EMISSIONS INVENTORY CHECKLIST FOR STATIONARY POINT SOURCES

(CONTINUED)

Reasonableness Checks (Continued)	Yes	No	Comments
Are the following data elements within the ranges listed below for point pollutant data?			
• Stack height > 50 Feet			
• Stack diameter 0.5 and 30 Feet			
• Plume height > 200 Feet			
• Temperature of exit gases between 60°F and 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 and velocity within expected range?			
Are the following data elements within the ranges listed below for general segment data?			
• For control devices, is the control efficiency between 0 - 100 percent?			
• Are emission estimates within the ranges expected?			

# **APPENDIX E**

## **TEST METHODS**

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This appendix describes available pollutant monitoring and fuel analysis methodologies. Table 1.E-1 contains a listing of the published and approved methodologies available for determining pollutant emissions using stack test data. Continuous emission monitoring (CEM), manual monitoring, and fuel analysis are included. A description of each method listed in Table 1.E-1 is discussed below. Section E.1 summarizes EPA methods and section E.2 addresses other (i.e., non-EPA methods).

## **E.1 EPA METHODS**

### **E.1.1 EPA METHOD 2 (STACK SAMPLING)**

This method is applicable for measurement of the average velocity of a gas stream and for quantifying gas flow rate. The average gas velocity is determined from the gas density and from measurement of the average velocity head with a Type S (Staustscheibe or reverse type) pitot tube. Gas velocity is then multiplied by the cross-sectional area of the stack or duct to determine volumetric gas flow rate. This method cannot be used for direct measurement in cyclonic or swirling gas streams.

### **E.1.2 EPA METHOD 3 (STACK SAMPLING)**

This method is used to determine oxygen ( $O_2$ ) and carbon dioxide ( $CO_2$ ) concentrations in flue gas from fossil-fuel-fired combustion processes. A gas sample is extracted from the stack either from a single point or by multipoint integrated sampling. The sample is passed through an Orsat analyzer containing a solution of 45-percent potassium hydroxide (KOH) in one impinger and a solution of pyrogallol in the second impinger. The  $CO_2$  is absorbed by KOH, and the  $O_2$  is absorbed by pyrogallol. The decrease in sample volume due to this absorption is directly proportional to the concentration in the sample.

### **E.1.3 EPA METHOD 3A (CEM)**

This method may be used to determine  $O_2$  and  $CO_2$  concentrations when CEM systems are in place. A gas sample is extracted continuously from the stack and conveyed to the  $O_2$  and  $CO_2$  analyzers. The sample can be wet or dry depending on the type of analyzer used.

$CO_2$  can only be measured using infrared analyzers such as nondispersive infrared (NDIR) systems or gas filter correlation (GFC) analyzers.

NDIR analyzers consist of sample and reference optical cells through which a beam of infrared light passes. This beam of light is modulated so that the infrared light passing through the optical cell pulses. The modulated infrared light then enters a two-chambered detector that is

TABLE 1.E-1

## SUMMARY OF AVAILABLE MONITORING AND FUEL ANALYSIS METHODS

Parameter	Monitoring Methods		Fuel Analysis Method
	Stack Sampling	CEM	
SO <sub>2</sub>	EPA Method 6	EPA Method 6C	ASTM D-1552-83/ D4507-81 <sup>a</sup>
SO <sub>3</sub>	EPA Method 8	NA	
NO <sub>x</sub>	EPA Method 7	EPA Method 7E	
O <sub>2</sub> /CO <sub>2</sub>	EPA Method 3	EPA Method 3A	
CO	EPA Method 10B	EPA Method 10	
VOC	EPA Method 25	NA	
THC	EPA Method 25	EPA Method 25A	
Speciated organics	EPA Method 0030	NA	
Heavy metals	EPA Method 29	NA	SW 846 Methods 3040/7090 <sup>b</sup>
PM	EPA Method 5	NA	
PM <sub>10</sub>	EPA Method 201/202	NA	
Sulfuric acid mist	EPA Method 8	NA	
Flow rate	EPA Method 2	EPA Method 19, CFRM <sup>c</sup>	

Sources: EPA, 1986; *Test Methods for Evaluating Solid Waste*, SW-846, Third Edition; ASTM, 1992; Title 40 CFR, Appendices A and B, September 1992. Title 40 CFR Part 60, Appendix A and Part 61, Appendix B.

<sup>a</sup> For liquid fuels. ASTM D3177-75/D4239-85 is used for coal.

<sup>b</sup> For liquid fuels.

<sup>c</sup> Continuous flow rate monitoring.

NA = Not applicable; no CEM method exists.

filled with the same gas that is being analyzed. The gas in the detector chambers absorbs the infrared light and heats up, causing it to expand. Separating the two chambers is a thin diaphragm which flexes as the pressure between the two chambers varies. Since the sample has absorbed some of the infrared light, the detector chamber associated with the sample cell does not heat up as much as the reference side. This causes a pressure differential between the two chambers, deflecting the diaphragm. Because the infrared light is modulated, the diaphragm pulses. This degree of deflection in conjunction with the pulsing is converted into an electrical signal proportional to gas concentration.

O<sub>2</sub> analyzers generally use electrochemical cells. Porous platinum electrodes are attached to the inside and outside of the cell to provide the instrument voltage response. Zirconium oxide contained in the cell conducts electrons when it is hot due to the mobility of O<sub>2</sub> ions in its crystal structure. A difference in O<sub>2</sub> concentration between the sample side of the cell and the reference (outside) side of the cell produces a voltage. This response is proportional to the logarithm of the O<sub>2</sub> concentration ratio. The reference gas is ambient air at 20.9 percent O<sub>2</sub> by volume.

#### **E.1.4 EPA METHOD 5 OR 17 (STACK SAMPLING)**

EPA Method 5 or 17 may be used to monitor emissions of particulate matter (PM) from boilers. In Method 5, PM is withdrawn isokinetically from the source and collected externally on a heated glass fiber filter maintained at 248°F ± 25°F. Method 17 employs an in-stack filter and particulate matter is collected at source temperature and pressure. The particulate mass is determined gravimetrically.

#### **E.1.5 EPA METHOD 6 (STACK SAMPLING)**

Method 6 is used to measure SO<sub>2</sub> emissions. A gas sample is extracted from the sampling point in the stack. The sample passes through a filter to remove PM and the sulfuric acid (including sulfur trioxide) and sulfur dioxide (SO<sub>2</sub>) are separated in a series of impingers containing 80 percent isopropanol and 3 percent hydrogen peroxide. The SO<sub>2</sub> is then measured by barium-thorin titration.

#### **E.1.6 EPA METHOD 6C (CEM)**

Method 6 is used to measure SO<sub>2</sub> emissions when CEM systems are in place. A gas sample is continuously extracted from a stack, and a portion of the sample is conveyed to a continuous analyzer for determination of SO<sub>2</sub> gas concentration using an NDIR, ultraviolet (UV), or fluorescence analyzer.

NDIR analyzers were discussed in section E.1.3.

UV analyzers work very similarly to NDIR instruments. A beam of UV light passes through the gas sample, which absorbs some of the light. The remaining light passes through the sample cell and is measured by the detector.

Fluorescence analyzers are typically used in ambient monitoring. The analyzer works by exposing the sample to a pulse of ultraviolet light.  $\text{SO}_2$  molecules absorb this light, which "excites" the molecule into a higher energy state. The molecule loses some of this excess energy by fluorescing (detected by a photomultiplier tube), which in turn provides an  $\text{SO}_2$  concentration value.

### **E.1.7 EPA METHOD 7 (STACK SAMPLING)**

Method 7 is used to measure  $\text{NO}_x$  emissions. A grab sample is collected in an evacuated flask containing a dilute sulfuric acid-hydrogen peroxide absorbing solution, and the  $\text{NO}_x$ , except nitrous oxide ( $\text{N}_2\text{O}$ ), are measured colorimetrically using phenoldisulfonic acid (PDS).

### **E.1.8 EPA METHOD 7E (CEM)**

When CEM systems are in place, Method 7E is used. A gas sample is continuously extracted from the stack and a portion of the sample is conveyed to an instrumental chemiluminescent analyzer for determination of  $\text{NO}_x$  concentration. This measurement technique uses a chemical reaction (ozone combining with nitric oxide [ $\text{NO}$ ]) to cause light to be emitted. This light is measured with a photomultiplier tube, similar to the  $\text{SO}_2$  fluorescence analyzer.

### **E.1.9 EPA METHOD 8 (STACK SAMPLING)**

This method is applicable for the determination of sulfuric acid mist (including  $\text{SO}_3$ ) and  $\text{SO}_2$  emissions from stationary sources. A gas sample is extracted isokinetically from the stack. The sulfuric acid mist and  $\text{SO}_2$  are separated, and both fractions are measured separately by the barium-thorium titration method.

### **E.1.10 EPA METHOD 10 (CEM)**

When CEM systems are in place, Method 10 may be used to measure CO concentration. A gas sample is continuously extracted from the stack and a portion of the sample is conveyed to an instrumental NDIR analyzer for determination of CO concentration. The principle of operation is similar to the NDIR  $\text{SO}_2$  analyzer.

### **E.1.11 EPA METHOD 10B (STACK SAMPLING)**

An integrated bag sample is extracted from the sampling point and analyzed for CO. The sample is passed through a conditioning system to remove interferences and collected in a Tedlar<sup>®</sup> bag. The CO is separated from the sample by a gas chromatograph (GC) and catalytically reduced to methane (CH<sub>4</sub>) prior to analysis by flame ionization detection (FID).

### **E.1.12 EPA METHOD 19**

This method is applicable for:

- Determining PM, SO<sub>2</sub>, and NO<sub>x</sub> emission rates;
- Determining sulfur removal efficiencies of fuel pretreatment and SO<sub>2</sub> control devices;
- Determining overall reduction of potential SO<sub>2</sub> emissions; and
- Determining SO<sub>2</sub> rates based on fuel sampling and analysis procedures.

Pollutant emission rates and SO<sub>2</sub> control device efficiencies are determined from concentrations of PM, SO<sub>2</sub>, or NO<sub>x</sub>, and O<sub>2</sub> or CO<sub>2</sub>, along with F factors (ratios of combustion gas volumes to heat inputs).

### **E.1.13 EPA METHOD 25 (STACK SAMPLING)**

This method is applicable for the determination of total gaseous nonmethane organic (TGNMO) emissions as carbon. A gas sample is extracted from the stack at a constant rate through a heated filter and a chilled condensate trap by means of an evacuated sample tank. After sampling is completed, the TGNMO emissions are determined by independent analysis of the condensate trap and the sample tank fractions and combining the analytical results. The organic content of the condensate trap fraction is determined by oxidizing the nonmethane organics to CO<sub>2</sub> and quantitatively collecting the effluent in an evacuated vessel; then, a portion of the CO<sub>2</sub> is reduced to CH<sub>4</sub> and measured by FID. The organic content of the sample tank fraction is measured by injecting a portion of the sample into a GC equipped with a capillary column capable of separating the nonmethane organic emissions from CO, CO<sub>2</sub> and CH<sub>4</sub>.



### **E.1.14 EPA METHOD 25A (CEM)**

This method applies to the measurement of total gaseous organic concentrations of vapors consisting primarily of alkanes, alkenes, and aromatic hydrocarbons. A gas sample is extracted continuously from the source through a heated sample line and directed to the total hydrocarbon analyzer that uses FID. The sample gas enters the detector and is combusted in a hydrogen flame. The ions and electrons formed in the flame enter an electrode gap, decrease the gas resistance, and allow a current to flow in an external circuit. The resulting current is proportional to the instantaneous concentration of total hydrocarbons. The concentration is expressed in terms of methane or propane.

### **E.1.15 EPA METHOD 29 (STACK SAMPLING)**

This method is applicable for the determination of chromium, cadmium, arsenic, nickel, manganese, beryllium, copper, lead, selenium, silver, antimony, and mercury emissions from stationary sources. The stack gas sample is withdrawn isokinetically. Particulate emissions are collected in the probe and on a heated filter while gaseous emissions are collected in solutions of acidic hydrogen peroxide and acidic potassium permanganate. The recovered samples are digested and the appropriate fractions are analyzed by atomic absorption spectrophotometry.

### **E.1.16 EPA METHOD 0030 (STACK SAMPLING)**

Method 0030 is a manual method for collecting VOCs which are defined for purposes of this method as those organics with boiling points less than 100°C. The gas sample is collected from the sampling point and cooled to 20°C by passing through a water-cooled condenser and the volatile organics are collected on a pair of sorbent resin traps. The resin traps are then analyzed in the laboratory using a gas chromatograph equipped with an electron capture detector (ECD), flame ionization detector (FID), or mass spectrometer to determine speciated organics.

### **E.1.17 EPA METHODS 201 AND 202 (STACK SAMPLING)**

In this method, a gas sample is isokinetically extracted from the source. An in-stack cyclone is used to separate PM with a diameter greater than 10 micrometers, and an in-stack glass fiber filter is used to collect the PM<sub>10</sub>. The particulate mass is determined gravimetrically after removal of uncombined water. Method 202 is used to determine the condensable PM. The condensable PM is determined gravimetrically by analysis of the impinger fractions.

## **E.2 OTHER METHODS**

### **E.2.1 CONTINUOUS FLOW RATE MONITORS**

A new monitoring requirement under Acid Rain regulations (Title IV of the CAAA) is the measurement of exhaust gas velocities. There are three velocity monitoring techniques applicable to utility stacks or exhaust ducts. These are: (1) ultrasonic flow monitors, (2) thermal flow monitors, and (3) differential pressure monitors.

Ultrasonic monitors operate by passing a pulse of ultrasonic sound diagonally through the moving stack gas. The frequency of the ultrasonic pulse is changed in proportion to the velocity of the stack gas. This frequency shift is measured and gas velocity is then calculated.

Thermal flow monitors operate by inserting a heated element into the exhaust stream. As gas moves over the probe, the heated element is cooled thus requiring additional power to be supplied to the heater in order to maintain a constant temperature. This additional power is proportional to the gas velocity being measured.

Differential pressure monitors measure the difference between the velocity head and static pressure. This difference is proportional to the velocity of the gas stream. The gas flow rate is then calculated using this pressure difference.

### **E.2.2 FUEL ANALYSIS (ASTM D1552-83/D4507-81)**

SO<sub>2</sub> emissions from combustion sources can also be estimated by fuel analysis. The fuel is analyzed for sulfur content and emissions are calculated based on the assumption that all of the sulfur is converted to SO<sub>2</sub>. Depending on the characteristics of the fuel ash, a portion of the SO<sub>2</sub> may be absorbed onto the ash (generally less than 5 percent). The remainder is emitted.

### **E.2.3 FUEL ANALYSIS (SW 846 METHODS 3040/7090)**

Metal emissions from combustion sources can also be estimated by fuel analysis. The fuel is analyzed for the metals of interest and emissions are calculated assuming all of the metals are emitted. Because most of the metals are associated with either boiler ash or PM (which may be collected by an air pollution control system), this approach will provide a conservative emission estimate.

### **E.2.4 FLUX CHAMBER MEASUREMENT**

Flux chamber measurement is a direct measurement technique used to estimate emissions from area sources of fugitive emissions such as contaminated soil, landfills, and lagoons. The

approach employs an emission isolation flux chamber to obtain an estimate of the amount of pollutant, or pollutants, being emitted from a given surface area per unit time. A variety of flux chamber equipment designs and operating procedures have been employed. EPA has issued guidance identifying flux chamber measurement as a recommended method of estimating baseline air emissions from Superfund sites (EPA, 1990).

### E.2.5 OPTICAL REMOTE MEASUREMENT

Another method used to estimate emissions from open areas or otherwise inaccessible sources (e.g., plumes from smoke stacks, hazardous waste landfills) is the use of optical remote sensing (ORS). ORS is an open-path method of determining pollutant concentration using optical absorption spectroscopy. Pollutant concentration data combined with on-site meteorological data may then be used to estimate emissions. ORS techniques include Fourier transform spectroscopy, differential optical absorption spectroscopy, laser long-path absorption, differential absorption lidar, and gas cell correlation spectroscopy.

## E.3 REFERENCE

EPA. 1986. *Test Methods for Evaluating Solid Waste*, SW-846, Third Edition, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. Washington, D.C.

EPA. 1990. *Procedures for Conducting Air Pathway Analyses for Superfund Activities, Interim Final Documents: Volume 2 -- Estimation of Baseline Air Emissions at Superfund Sites*. EPA-450/1-89-002a (NTIS PB90-270588), August.

ASTM. *Annual Book of ASTM Standards*, Volumes 06.01 and 15.05. September 1992.

# **APPENDIX F**

## **EMISSION ESTIMATION TOOLS**

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This appendix describes emission factor databases, models, and other data tools that may be useful or required for inventory preparation. Specific emissions measurement are generally the best and most accurate method to quantify emissions; however, source data are not always available. As an alternative, emission factors and models can be used as tools to estimate air pollutant emissions for inventory purposes.

An emission factor relates a quantity of air pollutant to a process parameter, so that if the process parameter is known, an estimate of emissions can be made. For example, an emission factor in the form of pounds of volatile organic compound (VOC) per ton of product can be used to estimate VOC emissions from a source, if the weight of product is known or can be determined.

A more complex model is used to estimate emissions when emissions are not directly related to any one parameter. Models may use computers so that a large number of equations and interactions can be easily calculated. The data requirements for such 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. The reader should refer to Appendix C for contact information or to request the most current version available for each of the tools discussed below.

## **F.1 LOCATING AND ESTIMATING EMISSIONS OF . . . DOCUMENTS**

In addition to AP-42, EPA has published about 40 reports, each with the title, *Locating and Estimating Air (Toxic) Emissions From (or of) Source Category (or Substance)*. These reports (also known as L&Es) identify the source categories for which emissions of a substance have been characterized. The reports include general process descriptions of the emitting processes identifying potential release points and emission factors. Table 1.F-1 lists the available L&E documents, which are available by contacting the EPA's Emission Factors and Inventory Group (EFIG), downloading from the EPA Clearinghouse for Inventories and Emission Factors Bulletin Boards System (CHIEF BBS), or ordering through the National Technical Information Service (NTIS).

## **F.2 EMISSION FACTOR DATABASE SYSTEMS**

### **F.2.1 DATABASES AND SYSTEMS**

The most comprehensive compilation of emission factors for hazardous air pollutants (HAPs) is available in the Factor Information Retrieval (FIRE) System, which is available from EPA on one 5.25 inch high density diskette [via request from the Info CHIEF helpline (see Appendix C)] or by downloading from the CHIEF BBS. FIRE contains emission factors for 106 toxic and criteria pollutants from various source categories (EPA, 1995).

TABLE 1.F-1

## LOCATING AND ESTIMATING DOCUMENT SERIES

Substance or Source Category	EPA Publication Number
1,3-Butadiene (revised)	EPA-454/R-96-008
Acrylonitrile	EPA-450/4-84-007a
Arsenic	In Production - 1997
Benzene (under revision)	EPA-450/4-84-007q
Cadmium	EPA-454/R-93-040
Carbon Tetrachloride (under revision)	EPA-450/4-84-007b
Chlorobenzenes	EPA-454/R-93-044
Chloroform (under revision)	EPA-450/4-84-007c
Chromium	EPA-450/4-84-007g
Chromium, supplement	EPA-450/2-89-002
Coal and Oil Combustion Sources	EPA-450/2-89-001
Cyanide Compounds	EPA-454/R-93-041
Dioxins/Furans	In Production - 1997
Epichlorohydrin	EPA-450/4-84-007j
Ethylene Oxide	EPA-450/4-84-007i
Ethylene Dichloride	EPA-450/4-84-007d
Formaldehyde (under revision)	EPA-450/2-91-012
Lead	In Production - 1997
Manganese	EPA-450/4-84-007h
Medical Waste Incinerators	EPA-454/R-93-053
Mercury and Mercury Compounds (under revision)	EPA-453/R-93-023
Methyl Chloroform	EPA-454/R-93-045
Methyl Ethyl Ketone	EPA-454/R-93-046
Methylene Chloride	EPA-454/R-93-006
Municipal Waste Combustors	EPA-450/2-89-006
Nickel	EPA-450/4-84-007f
Organic Liquid Storage Tanks	EPA-450/4-88-004
Perchloroethylene and Trichloroethylene (under revision)	EPA-450/2-89-013
Phosgene	EPA-450/4-84-007i
Polychlorinated Biphenyls (PCBs) (under revision)	EPA-450/4-84-007n
Polycyclic Organic Matter (POM) (under revision)	EPA-450/4-84-007p
Sewage Sludge Incinerators	EPA-450/2-90-009
Styrene	EPA-454/4-93-011
Toluene	EPA-454/R-93-047
Vinylidene Chloride	EPA-450/4-84-007k
Xylenes	EPA-454/R-93-048

### **Factor Information Retrieval System**

The EPA's Factor Information Retrieval System (FIRE) is a user friendly, menu driven system. FIRE is a consolidation of emission factors for criteria pollutants and HAPs found in older EPA databases such as Crosswalk/Air Toxic Emission Factor (XATEF), and Aerometric Information Retrieval System (AIRS) Facility Subsystem Emission Factors (AFSEF), as well as emission factors from EPA documents such as *AP-42* and the L&Es. FIRE also contains emission factors for some sources based on single source tests or literature-reported values, where no *AP-42* or L&E data are available. These factors are primarily for HAPs.

Additional and updated emission factors from *AP-42* supplements and new L&Es are entered into FIRE annually. Each emission factor in FIRE also includes information about the pollutant (Chemical Abstract Services [CAS] numbers and chemical synonyms) and about the Source Classification Codes [SCCs] and descriptions). Each emission factor entry includes supporting data such as process parameters, source test methods, control devices, emission factor ranges and/or source conditions, as well as the references where the data were obtained. The emission factor also includes a factor quality rating.

The FIRE database has been designed to be very "user friendly." Data can be searched in many different ways and can be downloaded to print standard reports, or can be printed in a report format that is designed by the user. The FIRE database can be accessed on the EPA's CHIEF electronic bulletin board system.

### **SPECIATE**

The VOC/PM Speciation Database Management System (SPECIATE, Version 1.5) is a clearinghouse for speciation profiles (not emission factors) for both VOCs and PM used primarily for photochemical modeling and source-receptor modeling (EPA, 1993). Each profile lists the elements or compounds identified as being emitted by a source category or process according to the weight percent of each compound as a function of total organic compounds or PM emissions. The SPECIATE PM profiles include three particle size range distributions and total measured PM data for each species. SPECIATE is designed to search for profiles based on a user-provided SCC, pollutant name, or a source category description. Because this system represents a compilation from available literature for use in EPA's photochemical modeling efforts, it will not address toxic compounds with any degree of completeness or accuracy.

The SPECIATE database is updated annually, and is accompanied by a user's manual. The SPECIATE database is available for downloading from the CHIEF BBS or website. All user related questions should be directed to the InfoCHIEF help line.



## **F.3 CLEARINGHOUSE FOR INVENTORIES AND EMISSION FACTORS BULLETIN BOARD**

CHIEF is maintained by the EPA's Emission Factor and Inventory Group in Research Triangle Park, North Carolina. As a clearinghouse, CHIEF is the repository of the most up-to-date information on inventories and emission estimation tools, such as emission factors.

The CHIEF bulletin board contains all of the *AP-42* stationary source volumes and draft revisions, the SPECIATE database, the MOBILE5a model, the AFS database, e-mail from other users of CHIEF. Other information may be available in the future. CHIEF may be accessed on the internet at the following address: [ttnwww.rtpnc.epa.gov](mailto:ttnwww.rtpnc.epa.gov).

## **F.4 AEROMETRIC INFORMATION RETRIEVAL SYSTEM BULLETIN BOARD**

The AIRS bulletin board is an electronic bulletin board maintained by the EPA that holds information useful to AIRS users. The AIRS bulletin board can be accessed through a telephone line modem and provides information on utility information, file transfers, communications, and public communications.

### **F.4.1 ACCESSING THE SYSTEMS**

Most of the EPA materials described in this section are available through the CHIEF BBS or on Air CHIEF CD-ROM. Any user accessing the CHIEF BBS can download *AP-42* chapters, *Locating and Estimating Emissions of...* documents, FIRE, SPECIATE, TANKS, Surface Impoundment Modeling System (SIMS), the AIRS Facility Subsystem Emission Factors (AFSEF) database, and many more tools for estimating emissions. The CHIEF BBS is a subpart of the EPA's Office of Air Quality Planning and Standards (OAQPS) Technology Transfer Network (TTN).

The Air CHIEF CD-ROM for accessing many of EPA's documents and databases is available for purchase from the Government Printing Office (GPO) for about \$20 or from InfoCHIEF (see Appendix C). Users need an IBM™ - compatible personal computer (PC) with a VGA monitor, MS-DOS version 3.0 or later, 8 megabytes (MB) random access memory (RAM), a CD-ROM drive, an interface card, and MS-DOS CD-ROM extensions. Version 4.0 of Air CHIEF CD-ROM includes Volume I of *AP-42, 5th Edition* (criteria pollutant emission factors for point and area sources, not including mobile sources), FIRE, SPECIATE, and 32 documents in the *Locating and Estimating Emissions of...* series. The Air CHIEF CD-ROM is updated annually.

## **F.5 GEOGRAPHIC MODELING SYSTEMS SUPPORT**

Computerized modeling systems can be used in many facets of the emissions inventory to locate emissions sources and track the progress of a control strategy. The most common of these systems are the Geographic Information System and the Global Positioning System.

### **F.5.1 GEOGRAPHIC INFORMATION SYSTEM**

The Geographical Information System uses modern computer technology to store, retrieve, analyze, update, and display spatially arranged data (maps). Because the characterization of emissions is enhanced by knowledge of the location and spatial arrangement of all identified sources, the Geographical Information System can be a useful tool for emissions inventories. Locating each point source, defining the boundaries around each area source, and mapping all road networks can provide valuable information for formulating, evaluating, and implementing emissions reduction strategies. Mapping point and area sources is also important in defining, and subsequently modifying, nonattainment area boundaries. Map features are available in digital formats from transportation departments, tax offices, planning/zoning offices, and emergency response agencies.

Further information about the potential applications of the Geographical Information System technologies in emissions inventory preparation can be obtained from the EPA's OAQPS, and Office of Research and Development (ORD), Research Triangle Park, North Carolina; local colleges or universities with geography, civil engineering, or natural sciences departments; state and local land/resource management or environmental protection agencies; and private organizations that provide mapping services.

### **F.5.2 GLOBAL POSITIONING SYSTEM**

The Global Positioning System performs map feature registration using banks of geosynchronous Earth-orbiting satellites that act as known reference points in triangulation calculations. The coordinates of the unknown Earth surface location can be calculated from the known coordinates of orbiting satellites. This can serve as a valuable quality assurance/quality control (QA/QC) check for locating point source data. Geographical positioning units offer a cost-effective alternative for locating emissions sources, assuming that a registration accuracy of plus or minus three meters will provide adequate mapping resolution within a nonattainment area that covers tens or hundreds of square miles. It is anticipated that as Global Positioning Systems become cheaper and more common, they will be the standard method of determining coordinate locations, if the required accuracy goal can be achieved. Other methods, such as map reading, address matching, and zip code centroids may then decrease in popularity.

The EPA locational data policy (LDP), which became effective in 1995, prescribes that latitude/longitude coordinates be maintained for all EPA facility data (i.e., all media, not just air). The coordinates are to have an accuracy goal of  $\pm 1$  second.

## F.6 WATER AND WASTEWATER AIR EMISSIONS MODELS

### F.6.1 CHEMDAT8

CHEMDAT8 is a Lotus 1-2-3® spreadsheet prepared by the EPA's Emission Standards Division that includes analytical models for estimating VOCs from treatment, storage, and disposal facility (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 aerated impoundment model may be used for predicting emissions from surface treatment impoundments and aerated wastewater treatment tanks. 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 example calculations. However, the input parameters can be changed to reflect different TSDF characteristics and then recalculate emissions under these modified conditions. 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.

## F.6.2 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.

## F.7 LANDFILL AIR EMISSIONS ESTIMATION MODEL

The Landfill Air Emissions Estimation Model (LAEEM) is a computer program specifically designed for use by state and local regulatory agencies to monitor the emissions of HAPs 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 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. 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 kb of memory, and can be used with a monochrome or color graphics adaptor. It is recommended that the user's guide be thoroughly read before using the model.

## F.8 TANKS

The TANKS program is designed to estimate emissions of organic chemicals from storage tanks. After the user provides specific information concerning the storage tank and its contents, the TANKS program estimates the annual or seasonal emissions and produces a report. The emissions can be separated into standing storage and working losses.

The TANKS program has a chemical database of over 100 organic liquids and meteorology data from over 250 cities in the U.S. The user may add new chemicals and cities to their version of the database. The tank types 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-component liquid or a multicomponent mixture.

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 are needed to use other approximation techniques. If storage tank emissions are expected to be small relative to emissions from other sources in the inventory, 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.

TANKS version 3.0 is currently available. The program is written in FoxPro™, a dBase-compatible language, and is distributed by the EPA through the CHIEF BBS or through the mail on diskette.

## F.9 TRADE ASSOCIATIONS

Trade associations are another information resource regarding emission estimation tools and software for a specific industry. The larger trade associations (e.g., the Aluminum Association or the American Iron and Steel Institute) often serve as liaisons between government and industry. As such, they sometimes support environmental research and negotiations with EPA and other federal agencies. Trade associations may be able to provide emission factor information, test data, control system performance data, and other useful information to industry personnel. Many relevant associations are listed in the *National Trade and Professional Associations of the United States* directory (Russell 1992).

## F.10 REFERENCES

EPA. 1993. *VOC/PM Speciation Data System Documentation and User's Guide, Version 1.5*. EPA-450/4-92-027. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park, North Carolina.

EPA. 1995. *Factor Information Retrieval System (FIRE), Version 4.0*. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park, North Carolina.

Russell, John J., Managing Editor. 1992. *National Trade and Professional Associations of the United States*. 27th Annual Edition. Columbia Books, Inc., Washington, DC.

**VOLUME II: CHAPTER 2**

# **PREFERRED AND ALTERNATIVE METHODS FOR ESTIMATING AIR EMISSIONS FROM BOILERS**

**June 1996**



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Prepared for:  
Point Sources Committee  
Emission Inventory Improvement Program

## DISCLAIMER

This document was furnished to the Emission Inventory Improvement Program and the U.S. Environmental Protection Agency by Radian Corporation, Research Triangle Park, North Carolina. This report is intended to be a final document and has been reviewed and approved for publication. The opinions, findings, and conclusions expressed represent a consensus of the members of the Emission Inventory Improvement Program.

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# INTRODUCTION

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The purposes of the preferred methods guidelines are to describe emission estimation techniques for stationary point sources in a clear and unambiguous manner and to provide concise example calculations to aid in the preparation of emission inventories. This chapter describes the procedures and recommended approaches for estimating emissions from external combustion sources (i.e., boilers).

Section 2 of this chapter contains a general description of the boiler source category, a listing of emission sources commonly associated with boilers, and an overview of the available control technologies for various boiler types. Section 3 of this chapter provides an overview of available emission estimation methods. It should be noted that the use of site-specific emission data is often preferred over the use of industry-averaged data such as AP-42 emission factors. However, depending upon available resources, site-specific data may not be cost effective to obtain. Section 4 presents the preferred emission estimation methods for boilers by pollutant, and Section 5 presents the alternative emission estimation techniques. Quality assurance (QA) and quality control (QC) procedures are described in Section 6, and data coding procedures are discussed in Section 7. Section 8 lists references. Appendix A provides an example data collection form for boilers to assist in information gathering prior to emissions calculations. Refer to Chapter 1 of this volume, *Introduction to Stationary Point Source Emission Inventory Development*, for general concepts and technical approaches.

This chapter does not specifically discuss State Implementation Plans (SIPs) or base year, periodic, and planning inventories. However, the reader should be aware that the U.S. Environmental Protection Agency (EPA) procedures manuals pertaining to the preparation of emission inventories for carbon monoxide and precursors of ozone are available (EPA, May 1991).

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## GENERAL SOURCE CATEGORY DESCRIPTION

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### 2.1 SOURCE CATEGORY DESCRIPTION

This section provides a brief overview discussion of boilers. The reader is referred to the *Air Pollution Engineering Manual* (sometimes referred to as *AP-40*) and *AP-42* for a more detailed discussion on boilers, boiler designs, boiler operations and their influences on emissions (Buonicore and Davis, 1992; EPA, January 1995).

The boiler source category comprises sources that combust fuels to produce hot water and/or steam. Utility boilers utilize steam to generate electricity. Industrial boilers often generate steam for electrical power as well as process steam. Space heaters use the hot water for heating commercial and residential building space. Fuels typically used in boilers include coal, oil, and natural gas. In addition, liquified petroleum gas (LPG), process and waste gases, and wood wastes may be used. In general, boilers are categorized as follows:

Types of Boilers	Size
Utility	> 100 MMBtu/hr
Industrial	10 - 250 MMBtu/hr
Commercial	< 10 MMBtu/hr
Residential	< < 10 MMBtu/hr

#### 2.1.1 COAL-FIRED BOILERS

Coal is broadly classified into one of four types (anthracite, bituminous, subbituminous, or lignite) based on differences in heating values and amounts of fixed carbon, volatile matter, ash, sulfur, and moisture. The following sections discuss the four main types of coal boilers (pulverized coal, cyclone, spreader stoker, and fluidized bed) and the processes that occur at all four types of coal-fired boilers. Pulverized coal and cyclone boilers employ a technique known as suspension firing; they are sometimes categorized by this technique.



### ***Pulverized Coal Furnaces***

Pulverized coal furnaces are used primarily in utility and large industrial boilers (Buonicore and Davis, 1992; EPA, January 1995). In a pulverized coal system, the coal is pulverized in a mill to the consistency of talcum powder. The pulverized coal is then entrained in primary air before being fed through the burners to the combustion chamber, where it burns in suspension. Pulverized coal furnaces are classified as either dry or wet bottom, depending on the ash removal technique. Dry-bottom furnaces may either be tangential- or nontangential-fired units. Some examples of nontangential-fired pulverized coal furnaces are wall-fired, turbo, cell-fired, vertical, and arch. Dry-bottom furnaces fire coal with high ash fusion temperatures, whereas wet-bottom furnaces fire coal with low ash fusion temperatures. Wet-bottom furnace designs have higher nitrogen oxides ( $\text{NO}_x$ ) emission rates and are no longer being built, though many remain in service.

### ***Cyclone Furnaces***

Cyclone furnaces are used mostly in utility and large industrial applications (Buonicore and Davis, 1992). Cyclone furnaces burn coal that has a low ash fusion temperature and has been crushed to a four-mesh size (larger than pulverized coal). Coal in a cyclone furnace is fed tangentially with primary air to a horizontal cylindrical combustion chamber. In this chamber, small coal particles are burned in suspension, while the larger particles are forced against the outer wall. Because of the high temperatures developed in the relatively small combustion chamber and because of the low fusion temperature of the coal ash, much of the ash forms a liquid slag that is drained from the bottom of the furnace through a slag tap opening (EPA, January 1995).

### ***Spreader Stokers***

In spreader stokers, a rotating flipping mechanism throws the coal into the furnace and onto a moving fuel bed. Combustion occurs partly in suspension and partly on the grate. Because of significant amounts of carbon in the particulate, fly ash reinjection from mechanical collectors is commonly employed to improve boiler efficiency. Ash residue in the fuel bed is deposited in a receiving pit at the end of the grate (EPA, January 1995). Anthracite coal is not used in spreader stokers because of its low volatile matter content and relatively high ignition temperature.

### ***Fluidized Bed Combustors***

In a fluidized bed combustor (FBC), coal is introduced to a bed of either sorbent (limestone or dolomite) or inert material (usually sand) that is fluidized by an upward flow of air. Combustion takes place in the bed at lower temperatures than other boiler

types. Key benefits to this relatively new process are fuel flexibility and reduced emissions. FBCs are typically used for industrial-sized boilers and may be emerging as a competitive design for electric power generation (Stultz and Kitto, 1992).

### 2.1.2 OIL-FIRED BOILERS

There is little variation between the design of oil-fired units and the design of coal-fired units; almost all are either tangential-fired or wall-fired. Fuel oils are broadly classified into two major types: distillate and residual. Distillate oils (fuel oil grade Nos. 1 and 2) are used mainly in domestic and small commercial applications in which easy fuel burning is required. Distillates are more volatile and less viscous than residual oils. Being more refined, they have negligible ash content, and usually contain less than 0.3 weight percent sulfur. Residual oils (grade Nos. 4, 5, and 6) are used mainly in utility, industrial, and large commercial applications with sophisticated combustion equipment. Residual No. 4 oil is sometimes classified as a distillate, and No. 6 is sometimes referred to as Bunker C. The heavier residual oils (grade Nos. 5 and 6) are more viscous and less volatile than distillate oils and, therefore, must be heated to facilitate handling and proper atomization. Because residual oils are produced from the crude oil residue after lighter fractions (gasoline, kerosene, and distillate oils) have been removed, these oils contain significant quantities of ash, nitrogen, and sulfur (EPA, January 1995). However, low-sulfur residual oil is becoming more commonplace.

### 2.1.3 NATURAL GAS-FIRED BOILERS

Natural gas is used for power generation, industrial process steam and production activities, and domestic and commercial space heating. The primary component of natural gas is methane, although small amounts of ethane, nitrogen, helium, and carbon dioxide ( $\text{CO}_2$ ) can also be present (EPA, January 1995).

Natural gas boilers are considered clean relative to coal- or oil-fired boilers, but improper operating conditions (such as poor air-fuel mixing) may still result in smoke (unburned carbon) in the exhaust, as well as carbon monoxide (CO) and perhaps small amounts of unburned hydrocarbons.  $\text{NO}_x$  emissions are usually the major pollutants of concern in a well-operated natural gas boiler.  $\text{NO}_x$  emissions are primarily a function of the combustion chamber temperature.

Several modifications can be made to natural gas boilers to reduce  $\text{NO}_x$  emissions. Staged combustion can reduce  $\text{NO}_x$  emissions by 5 to 20 percent (EPA, January 1995); low excess air levels and flue gas recirculation also often lower  $\text{NO}_x$  emissions.

### 2.1.4 BOILERS USING OTHER TYPES OF FUEL

Other fuels such as LPG, process gas, wood and/or bark, and solid/liquid waste may be used in boilers.

LPG is either butane, propane, or a mixture of the two. This gas is often called bottled gas. Grade A LPG is mostly butane and Grade F is mostly propane, with Grades B through E consisting of varying mixtures of butane and propane. Although LPG is considered a clean fuel, gaseous pollutants such as CO, organic compounds (including volatile organic compounds or VOCs), and NO<sub>x</sub> are emitted as are small amounts of sulfur dioxide (SO<sub>2</sub>).

Process gases that are used for fuel include petroleum refinery gas, blast furnace gas, coke oven gas, landfill gas, and any other process gases with sufficient and economically recoverable heating values.

The burning of wood and/or bark in boilers is mostly confined to situations where steady supplies of wood or bark are available as a byproduct or in close proximity to the boiler. In most cases, the wood is waste that would otherwise present a solid waste disposal problem. The common types of boilers used to burn wood/bark are Dutch ovens, fuel cell ovens, spreader stokers, vibrating grate stokers, and cyclone (tangential-fired) boilers (EPA, January 1995).

Solid or liquid waste may consist of general waste solids or liquids, refuse-derived fuel, or waste oil. Waste oil, or used oil, refers to spent lubrication and other industrial oils that would otherwise present a liquid waste disposal problem. The most common type of waste oil is used vehicle crankcase oil. Other oils include metalworking lubricants, animal and vegetable oils and fats, and transformer and other heat transfer fluids. Waste oils may have higher emissions of SO<sub>2</sub> and particulates than refined fuel oils, but will have similar levels of emissions for NO<sub>x</sub>, CO, and organic compounds (EPA, January 1995). Heavy metal emissions may be greater from crankcase oil combustion.

### 2.1.5 COGENERATION UNITS

Cogeneration is the production of more than one useful form of energy (such as process heat and electric power) from the same energy source. Cogeneration plants produce electric power and also meet the process heat requirements of industrial processes (Cengel and Boles, 1989). A steam turbine, gas-cycle turbine, or combined-cycle turbine can be used to produce power in a cogeneration plant.

In a typical cogeneration plant, energy is transferred to water by burning coal, oil, natural gas, or other (nonfossil) fuels in a boiler. The high-pressure, high-temperature steam leaving the boiler is expanded in a turbine that drives a generator to produce electric power. The low-pressure, low-temperature steam leaving the turbine is used as process heat. Industries likely to use cogenerated process heat are the chemical, pulp and paper, oil production and refining, steel making, food processing, and textile industries. Besides the steam-turbine cycle described above, a gas-cycle or a combined-cycle turbine can be used to produce power in a cogeneration plant (Cengel and Boles, 1989). Combustion turbines are also commonly used for cogeneration.

### **2.1.6 AUXILIARY SOURCES**

Auxiliary sources associated with boilers include fuel storage piles, fuel storage tanks, materials handling, and other sources of fugitive emissions. These sources are often overlooked and not reported as a part of the emission inventory. However, it is essential that these sources be considered in the emission inventory to develop a complete record of the emissions coming from the facility.

Coal storage piles are used to store coal at the boiler site. Material handling involves the receipt of coal, movement of coal to the preparation (crushing) facility, and movement of coal to the boilers, which may result in the release of particulate matter (PM) emissions. A coal-fired boiler may also use fuel oil or gas for the initial light-off of the boilers. In this case, as well as for oil-fired boilers, VOC losses from fuel oil storage tanks should be considered (EPA, January 1995).

Because coal crushing operations can generate a significant amount of fine PM, they should be included in the inventory. Because of the potential for explosion from this fine particulate, crushing operations are typically well controlled (EPA, January 1995).

## **2.2 EMISSION SOURCES**

Air pollutant emissions associated with boilers can occur at the following points/processes. Section 7 lists the source classification codes (SCCs) for these emission points.

### **2.2.1 MATERIAL HANDLING (FUGITIVE EMISSIONS)**

Material handling includes the receipt, movement, and processing of fuel and materials to be used at the boiler facility. Coal, limestone, wood, bark, and solid waste may all be included, and their handling may result in particulate emissions. Organic compound emissions can also result from the transfer of liquid and gaseous fuels. This source category includes storage bins and open stockpiles, as well as the processes used to transfer these materials (e.g., unloading, loading, and conveying).

### 2.2.2 STORAGE TANKS

Storage tanks are used to store fuel oils at boiler facilities, and should be inventoried as a source of organic compound emissions. Storage tanks at boiler facilities are usually one of two types: fixed roof or floating roof. Emissions at fixed-roof tanks are typically divided into two categories: working losses and breathing losses. Working losses refer to the combined loss from filling and emptying the tank. Filling losses occur when the organic compounds and VOCs contained in the saturated air are displaced from a fixed-roof vessel during loading. Emptying losses occur when air drawn into the tank becomes saturated and expands, exceeding the capacity of the vapor space. Breathing losses are the expulsion of vapor from a tank through vapor expansion caused by changes in temperature and pressure.

Emissions at floating roof tanks are reported in two categories: standing losses and withdrawal losses. Withdrawal loss is the vaporization of liquid that clings to the tank wall and that is exposed to the atmosphere when a floating roof is lowered by withdrawal of liquid. Standing losses result from wind-induced mechanisms and occur at rim seals, deck fittings, and deck seams (EPA, January 1995).

The TANKS program is commonly used to quantify emissions from oil-fired boilers. Its use at boiler installations should be carefully evaluated because it is a complicated program with a great number of input parameters. It is commonly used at large oil-burning facilities where VOC emissions may be significant. Check with your local or state authority as to whether TANKS is required for your facility. The use of the TANKS program for calculating emissions from storage tanks is discussed in Chapter 1 of Volume II, *Introduction to Stationary Point Source Emissions Inventory Development*.

### 2.2.3 PROCESS EMISSIONS

For boilers, emissions resulting from the process (combustion of fuel to generate hot water and steam) are typically vented to the atmosphere via a stack or vent. The major pollutants of concern from boiler stacks are PM, sulfur oxides ( $\text{SO}_2$  and sulfur trioxide [ $\text{SO}_3$ ]), and  $\text{NO}_x$ . CO and unburned combustibles, including numerous organic compounds (e.g., benzene) can also be emitted under certain boiler operating conditions. Most of the carbon in fossil fuels is emitted as  $\text{CO}_2$  during combustion, and may be inventoried due to its role as a greenhouse gas. Trace metals, such as arsenic and cadmium, may also be emitted as a result of combustion of coal and oil. Additionally, organic pollutants such as formaldehyde and polycyclic organic matter (POM) may be formed during combustion and emitted (EPA, April 1989).

## 2.3 FACTORS AND DESIGN CONSIDERATIONS INFLUENCING EMISSIONS

### 2.3.1 PROCESS OPERATING FACTORS

The combustion process is defined as the rapid oxidation of substances (fuels) with the evolution of heat. Boilers utilize the heat generated by combustion to produce hot water, steam, or both. The fuel types discussed in this chapter include coal, oil, natural gas, and other fuels such as wood, LPG, and process gases. When these burn, they are converted into  $\text{CO}_2$  and water, referred to as the combustion products. The noncombustible portion of a fuel remains as a solid residue or ash. The coarser, heavier portion remains within the combustion chamber and is called "bottom ash." The finer portion, referred to as "fly ash," exits the furnace with the flue gas.

Combustion products from boiler operation can also include partially oxidized hydrocarbons,  $\text{CO}$ ,  $\text{SO}_2$ ,  $\text{SO}_3$ ,  $\text{NO}_x$ , acids such as hydrochloric acid, and organohalides such as dioxins and furans. The generation of undesirable combustion products is strongly influenced by fuel type, furnace type, firing configuration, and boiler operating conditions. Although a detailed discussion of boiler operations cannot be presented here, some general observations are included to assist in understanding the relative impact of various boilers and fuel types on air emissions.

The discussion on coal-fired boilers introduced the four primary classifications of coal: lignite, anthracite, bituminous, and subbituminous. Fuel is ranked based on American Society for Testing and Materials (ASTM) 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 also be used to calculate fuel factors ( $F_d$ ) for determining exhaust gas flow rates (see Equation 2.4-4). Sections 3 and 4 discuss how fuel analysis can be used to estimate emissions of sulfur oxides and metals from fuel combustion. Generally, boiler size, firing configuration, and operation have 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.

By contrast,  $\text{NO}_x$  formation is highly dependent on boiler conditions, especially temperature and air/fuel ratios near the burner.  $\text{NO}_x$  is produced by two mechanisms: conversion of fuel-bound nitrogen in fuel and oxidation of molecular nitrogen from combustion air (referred to as thermal  $\text{NO}_x$  formation). Thermal  $\text{NO}_x$  formation is highly temperature dependent and becomes rapid as temperatures exceed  $3,000^\circ\text{F}$  (Buonicore and Davis, 1992). Lower operating temperatures result in decreased thermal

NO<sub>x</sub> production. Shorter residence time also lowers thermal NO<sub>x</sub> generation. Fuel NO<sub>x</sub> will generally account for over 50 percent of the total NO<sub>x</sub> generated by oil- and coal-fired boilers. NO<sub>x</sub> emissions from tangential-fired oil boilers are typically lower than those from horizontally opposed units. Many boilers employ combustion modifications to reduce NO<sub>x</sub> emissions. These include staged combustion, off-stoichiometric firing, flue gas recirculation, and low-NO<sub>x</sub> burners with overfire air (OFA). These control strategies can reduce NO<sub>x</sub> emissions by 5 to 50 percent (Buonicore and Davis, 1992).

The utility sector is dominated by pulverized dry-bottom, coal-fired units. Stoker boilers, currently accounting for a small percentage of total national capacity, are less common. Coal-fired pulverized wet-bottom and cyclone boilers are no longer sold due to their inability to meet NO<sub>x</sub> standards, although many are still in use.

In the industrial sector, more natural gas is used relative to coal and oil. The commercial/institutional sector consumes a greater proportion of oil and natural gas relative to coal consumption than the other two sectors.

### 2.3.2 CONTROL TECHNIQUES

Table 2.2-1, "Boiler Controls," lists the control technologies associated with boiler operations, along with their typical efficiencies. Control efficiency for a specific piece of equipment will vary depending on the age of the equipment and quality of the maintenance/repair program at a particular facility.

#### *Particulate Control*

In addition to PM and PM with an aerodynamic diameter of less than 10  $\mu\text{m}$  (PM<sub>10</sub>) emissions, particulate control also serves to remove trace metals, as well as metals (such as mercury) that are vaporized in the combustion chamber and condensed onto fly ash in the exhaust. However, the PM control efficiencies listed in Table 2.2-1 may not correspond to actual removal efficiencies of specific hazardous air pollutants (HAPs) or metals, due to the phenomena of fine particle enrichment. This phenomena may be especially important for metals with relatively high vapor pressures such as mercury (EPA, April 1989).

**Electrostatic Precipitators (ESPs).** ESPs are widely used to control emissions from coal-fired boilers and account for 95 percent of all utility particulate controls in the United States (Buonicore and Davis, 1992). ESPs are PM control devices that employ electrical forces to remove particles from the flue gas onto collecting plates (EPA, June 1991). The accumulated particles are then knocked or washed off the plates and into collecting hoppers.

**TABLE 2.2-1**  
**BOILER CONTROLS**

Fuel	Pollutant	Device/Technique	Typical Efficiency (%)
Coal	NO <sub>x</sub>	SCR	80
		SNCR	50
		LEA	5 - 25
		LNB and OFA	5 - 25
	SO <sub>2</sub>	Spray drying	70 - 90
		Wet scrubber	80 - 95
		Low-sulfur coal	50
		Coal washing	30
	PM and PM <sub>10</sub>	ESP	99
		Fabric filter (in conjunction with dry scrubber)	99
		Multiple cyclones	90
		Venturi scrubbers	97
Oil	NO <sub>x</sub>	SCR	40 - 90
		SNCR	50
		LNB and OFA	20 - 50
		LEA	0 - 28
	SO <sub>2</sub>	Spray drying	70 - 90
		Wet scrubber	80 - 98
		Low-sulfur oil	80
	PM and PM <sub>10</sub>	Good combustion	---



TABLE 2.2-1

(CONTINUED)

Fuel	Pollutant	Device/Technique	Typical Efficiency (%)
Natural Gas	NO <sub>x</sub>	SCR	80
		SNCR	50
		LNB	50
Wood Waste	PM	Wet scrubber	---
		ESP	---
		Fabric filter	---

Source: EPA, January 1995; Cooper and Alley, 1994.

ESP = Electrostatic precipitator.  
 LEA = Low excess air.  
 LNB = Low NO<sub>x</sub> burner.  
 OFA = Overfire air.  
 SCR = Selective catalytic reduction.  
 SNCR = Selective noncatalytic reduction.  
 --- Means data not available.

**Fabric Filters.** Fabric filter systems (also called baghouses) filter particles through fabric filtering elements (bags). Particles are caught on the surface of the bags, while the cleaned flue gas passes through. To minimize pressure drop, the bags must be cleaned periodically as the dust layer builds up. Fabric filters can achieve the highest particulate collection efficiency of all particulate control devices. A trend toward using more fabric filters in the electric utility industry is expected because of increasing restrictions on emissions of  $PM_{10}$  and the growing use of dry  $SO_2$  control technologies, such as dry injection and spray drying (Buonicore and Davis, 1992).

**Multiple Cyclones.** The cyclone (also known as a "mechanical collector") is a particulate control device that uses gravity, inertia, and impaction to remove particles from the flue gas. A multiple cyclone consists of numerous small-diameter cyclones operating in parallel. Multiple cyclones are less expensive to install and operate than ESPs and fabric filters, but are not as effective at removing particulates. They are often used as precleaners to remove the bulk of heavier particles from the flue gas before it enters the main control device. They are often used on wood-fired boilers in series with scrubbers, ESPs, or fabric filters (Buonicore and Davis, 1992).

**Venturi Scrubbers.** Venturi scrubbers (sometimes referred to as high-energy wet scrubbers) are used to remove coarse and fine PM. Flue gas passes through a venturi tube while low-pressure water is added at the throat. The turbulence in the venturi tube promotes intimate contact between the particles and the water. The wetted particles and droplets are collected in a cyclone spray separator (sometimes called a cyclonic demister). Venturi scrubbers are often used on wood-fired boilers. Venturi scrubbers have a relatively high pressure drop, often ranging from 25 to 50 inches of water.

### ***Sulfur Dioxide Control***

**Dry Scrubbers.** Dry scrubbing is sometimes referred to as spray drying or spray absorption. It involves spraying a highly atomized slurry of an alkaline reagent (slaked lime) into the hot flue gas to absorb the  $SO_2$ . Unlike wet scrubbers, the dry scrubber is positioned before the dust collector. Dry scrubbers are often applied on smaller industrial boilers, waste-to-energy plants, and units burning low-sulfur fuels (Stultz and Kitto, 1992).

**Wet Scrubbers.** In wet scrubbers, an alkaline liquid solution is introduced into the flue gas. Wet scrubbing results in the generation of wet waste, which typically must be treated and disposed of in accordance with landfill and wastewater regulations. Limestone scrubbing is widely used on coal-fired utility boilers. Less common are regenerable systems that treat the absorber product to recover reagents, sometimes producing salable gypsum, elemental sulfur, or sulfuric acid.

**Low-Sulfur Fuel.** This approach to reducing  $\text{SO}_2$  emissions reduces the sulfur fed to the combustor by burning low-sulfur coals or oils. Fuel blending is the process of mixing high-sulfur-content fuels with low-sulfur-content fuels. The goal of effective fuel blending is to meet the blend specification, including sulfur content, heating value, moisture content, and (for coal) grindability. This practice is highly effective since most studies estimate that over 95 percent of the fuel sulfur is converted to  $\text{SO}_2$  during combustion. The minor amount of sulfur not converted is typically bound in the ash. High-alkali coal tends to bind more  $\text{SO}_2$  in the ash.

### ***Nitrogen Oxides Control***

**Selective Catalytic Reduction.** SCR is an add-on control technology that catalytically promotes the reaction between ammonia and  $\text{NO}_x$  to form nitrogen ( $\text{N}_2$ ) and water. SCR is currently used primarily with natural gas- and oil-fired boilers. In addition, several SCR systems have recently been installed on coal-fired boilers. If sulfur is present in the fuel, ammonium sulfate and bisulfate can form at around  $500^\circ\text{F}$  and can deposit on and foul the catalyst. If chlorine is present, ammonium chloride can form at around  $250^\circ\text{F}$  and result in a visible plume.

**Selective Noncatalytic Reduction.** SNCR technologies inject a reducing agent into  $\text{NO}_x$ -laden flue gas to reduce the  $\text{NO}_x$  to  $\text{N}_2$  and water ( $\text{H}_2\text{O}$ ). Two basic processes are currently available, one based on ammonia injection (Thermal De $\text{NO}_x$ ®), and one based on urea injection (sponsored by the Electric Power Research Institute [EPRI]). Both systems require careful attention to the problem of unreacted ammonia, which can form corrosive ammonia salts that damage downstream equipment.

**Low  $\text{NO}_x$  Burners and Overfire Air.** LNB and OFA have been demonstrated to be effective means of lowering  $\text{NO}_x$  production at utility boilers. These are combustion control methods that reduce peak temperatures in the combustion zone, reduce the gas residence time in the high-temperature zone, and provide a rich fuel/air ratio in the primary flame zone. This is considered a design change although it results in a reduction of emissions.

**Low Excess Air.** LEA is another combustion modification designed to lower  $\text{NO}_x$  emissions by inhibiting the creation of thermal  $\text{NO}_x$ . This is accomplished by limiting the amount of free nitrogen in the combustion zone. Excess air must be present to ensure good fuel use and to prevent smoke formation.

***VOC Control***

Boilers do not have controls for organics or VOCs since the combustion process destroys most organic pollutants. Boilers do have residual amounts of organics and HAPs in their exhaust streams, which may be reduced by some add-on controls such as scrubbers used to control other pollutants.

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# 3

## OVERVIEW OF AVAILABLE METHODS FOR ESTIMATING EMISSIONS

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### 3.1 EMISSION ESTIMATION METHODOLOGIES

Several methodologies are available for calculating emissions from boilers. The method used is dependent upon available data, available resources, and the degree of accuracy required in the estimate. In general, site-specific data that are representative of normal operation at that site are preferred over industry-averaged data such as *AP-42* emission factors. For purposes of calculating peak season daily emissions for SIP inventories, refer to the *EPA Procedures* manual (EPA, May 1991)

This section discusses the methods available for calculating emissions from boilers and identifies the preferred method of calculation on a pollutant basis. This discussion focuses on estimating emissions from fuel combustion. Emission estimation approaches for auxiliary processes, such as using EPA's TANKS program to calculate storage tank emissions, are briefly discussed in Chapter 1 of this volume.

#### 3.1.1 CONTINUOUS EMISSION MONITORING SYSTEM (CEMS)

A CEMS provides a continuous record of emissions over an extended and uninterrupted period of time. Various principles are employed to measure the concentration of pollutants in the gas stream; they are usually based on photometric measurements. Once the pollutant concentration is known, emission rates are obtained by multiplying the pollutant concentration by the volumetric stack gas flow rate. The accuracy of this method may be problematic at low pollutant concentrations.

#### 3.1.2 PREDICTIVE EMISSION MONITORING (PEM)

PEM is based on developing a correlation between pollutant emission rates and process parameters and could be considered a hybrid of continuous monitoring, emission factors, and stack tests. A correlation test must first be performed to develop this relationship. Emissions at a later time can then be estimated or predicted using process parameters to predict emission rates based on the results of the initial source test. For example, emissions from a boiler controlled by an SO<sub>2</sub> scrubber could be predicted, based on the correlation of the scrubbing solution to the pH and flow rate.

### 3.1.3 STACK SAMPLING

Stack sampling provides a "snapshot" of emissions during the period of the test. Samples are collected using probes inserted into the stack, and pollutants are collected in or on various media and sent to a laboratory for analysis or analyzed on-site by continuous analysis. Pollutant concentrations are obtained by dividing the amount of pollutant collected during the test by the volume of the sample. Emission rates are then determined by multiplying the pollutant concentration by the volumetric stack flow rate. Only experienced stack testers should perform the stack tests. The accuracy of this method may be problematic at low pollutant concentrations.

### 3.1.4 FUEL ANALYSIS

Fuel analysis data can be used to predict emissions by applying mass conservation laws. For example, if the concentration of a pollutant, or pollutant precursor, in a fuel is known, emissions of that pollutant can be calculated by assuming that all of the pollutant is emitted. This approach is appropriate for pollutants such as metals, SO<sub>2</sub>, and CO<sub>2</sub>. It should be noted, however, that some of the pollutant may end up in physical or chemical states (ash, unburned hydrocarbons, etc.) not emitted to the atmosphere.

### 3.1.5 EMISSION FACTORS

Emission factors are available for many source categories and are based on the results of source tests performed at one or more facilities within an industry. Basically, an emission factor is the pollutant emission rate relative to the level of source activity. Chapter 1 of this volume contains a detailed discussion of the reliability, or quality, of available emission factors. EPA provides compiled emission factors for criteria and HAPs in *AP-42*, the locating and estimating (L&E) series of documents, and the Factor Information Retrieval (FIRE) System.

## 3.2 COMPARISON OF AVAILABLE EMISSION ESTIMATION METHODOLOGIES

Table 2.3-1 identifies the preferred and alternative emission estimation approach for selected pollutants. For many of the pollutants emitted from boilers, several of the previously defined emission estimation methodologies can be used.

TABLE 2.3-1

**SUMMARY OF PREFERRED AND ALTERNATIVE EMISSION  
ESTIMATION METHODS FOR BOILERS**

Parameter	Preferred Emission Estimation Approach	Alternative Emission Estimation Approach <sup>a</sup>
SO <sub>2</sub>	Fuel analysis <sup>b</sup>	1. CEMS/PEM 2. Stack sampling data 3. EPA/state published emission factors
NO <sub>x</sub>	CEMS/PEM data	1. Stack sampling data 2. EPA/state published emission factors
CO	CEMS/PEM data	1. Stack sampling data 2. EPA/state published emission factors
CO <sub>2</sub>	CEMS/PEM data	1. Stack sampling data 2. Fuel analysis 3. EPA/state published emission factors
VOC	Stack sampling data	EPA/state published emission factors
THC <sup>c</sup>	CEMS/PEM data	1. Stack sampling data 2. EPA/state published emission factors
PM	Stack sampling data	EPA/state published emission factors
PM <sub>10</sub>	Stack sampling data	EPA/state published emissions factors



TABLE 2.3-1

(CONTINUED)

Parameter	Preferred Emission Estimation Approach	Alternative Emission Estimation Approach <sup>a</sup>
Heavy metals	Fuel analysis <sup>d</sup>	1. Stack sampling data 2. EPA/state published emission factors
Speciated organics	Stack sampling data	EPA/state published emission factors
Sulfuric acid mist	Stack sampling data	EPA/state published emission factors
Flow rate	CFRM <sup>e</sup> data/stack sampling data	1. Stack sampling data 2. EPA/state published emission factors

<sup>a</sup> In most cases, there are several alternative emission estimation approaches.

<sup>b</sup> Use when no control device is present; otherwise use CEMS.

<sup>c</sup> THC = Total hydrocarbons.

<sup>d</sup> Use when no control device is present; otherwise use stack sampling data.

<sup>e</sup> CFRM = Continuous flow rate monitor.

The preferred method for estimating boiler emissions is to use some form of direct or indirect measurement. This includes stack samples using a standard EPA reference method or other method of known quality, CEMS, or PEM. None of these approaches is inherently better than the other. The preferred method is determined by the time specificity of the emission estimate (i.e., is an average acceptable or is the value on a given day needed?) and the data quality; the quality of the data will depend on a variety of factors including the number of data points generated, the representativeness of those data points, and the proper operation and maintenance of the equipment being used to record the measurements.

The main use of CEMS/PEM is to show compliance on an hourly or daily (or other short-term) basis. Therefore, average estimates of emissions are not acceptable for this purpose. If the objective is to estimate annual emissions or average daily emissions, CEMS/PEM do not necessarily produce better results than stack sampling data. Although CEM data are expected to provide a continuous record of emissions, malfunctions in the CEMS or the data recording may provide an incomplete record. If the data capture does not cover a representative set of operating conditions of the boiler, using the CEMS data to estimate annual emissions may give poor results.

In general, stack samples using an EPA reference method will give the highest quality (most accurate) data for any given point in time. The performance of CEMS and PEM is measured with respect to the EPA reference method using an index known as relative accuracy (RA). The RA for CEMS or PEM is generally expressed as a percentage, and should have been quantified for any CEMS/PEM installed for regulatory compliance purposes. Also, the stack sampling data used to establish RA should be available; if the standard error of the sample data is greater than the RA, and if the CEMS is known to be adequately maintained, the CEMS data should be used to calculate emissions for any averaging period. Otherwise, the most recent stack sampling data may give results that are as good as the CEMS data. The same discussion applies to PEM. For more discussion of statistical measures of uncertainty and data quality, refer to the *Quality Assurance Source Document* (Chapter 3, Section 7, and Chapter 4).

### 3.2.1 CEMS

The use of site-specific CEMS data is preferred for estimating NO<sub>x</sub>, CO, CO<sub>2</sub>, and total hydrocarbon (THC) emissions because it provides a detailed record of emissions over time. SO<sub>2</sub> is the only pollutant that can be measured using CEMS where a CEMS may not be the preferred method. This is due to the fact that if the amount of sulfur in the fuel is monitored, SO<sub>2</sub> emissions may be calculated using the results of fuel analysis. Other alternative methods available to estimate emissions of these pollutants provide

only short-term emissions data (in the case of stack sampling) or industry averages (in the case of emission factors) that may not be accurate or representative for a specific source.

Instrument calibration drift can be problematic for CEMS and uncaptured data can create long-term incomplete data sets. However, it is misleading to assert that a snapshot (stack sampling) can better predict long-term emission characteristics. It is the responsibility of the source owner to properly operate, calibrate, and validate the monitoring equipment and the corresponding emission data.

The preferred approach for obtaining stack gas flow rate is through the use of continuous monitoring. While flow rate can be measured using short-term stack sampling measurements, continuous monitoring provides more accurate long-term data.

### 3.2.2 PEM

PEM is a predictive emission estimation methodology whereby emissions are correlated to process parameters based on demonstrated correlations between emissions and process parameters. For example, testing may be performed on a boiler stack while the boiler is operated at various loads. Parameters such as fuel usage, steam production, and furnace temperature are monitored during the tests. These data are then used to produce emission curves. Periodic stack sampling may be required to verify that the emission curves are still accurate or to develop new curves based on the test results.

### 3.2.3 STACK SAMPLING

Stack sampling is the preferred emission estimation methodology for PM, PM<sub>10</sub>, speciated organics, and sulfuric acid mist. There are currently no CEMS methods for measuring these pollutants so the use of short-term, site-specific information is preferred over using emission factors that provide averaged emission data for a particular industry.

### 3.2.4 FUEL ANALYSIS

Site-specific fuel analysis is the preferred emission estimation methodology for SO<sub>2</sub> and metals when air pollution control equipment (e.g., scrubber, ESP) are not installed. In cases where control equipment is installed, fuel analysis may be preferred if accurate data are available on pollutant-specific collection efficiencies and the amount of pollutant present in bottom ash and fly ash are known. Once the concentrations of sulfur and metals in a fuel are known, their emissions can be calculated based on mass conservation laws. While emission factors are available for SO<sub>2</sub> and most metals, the use of site-specific fuel analysis data provides a more accurate emission estimate. Fuel

analysis may also be used to calculate CO<sub>2</sub> emissions by assuming complete conversion of the carbon in the fuel to CO<sub>2</sub>.

### **3.2.5 EMISSION FACTORS**

Due to their availability and acceptance in the industry, emission factors are commonly used to prepare emission inventories. However, the emission estimate obtained from using emission factors is based upon emission testing performed at similar facilities and may not accurately reflect emissions at a single source. Thus, the user should recognize that, in most cases, emission factors are averages of available industry-wide data with varying degrees of quality and may not be representative for an individual facility within that industry.

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## PREFERRED METHODS FOR ESTIMATING EMISSIONS

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The preferred method for estimating emissions of most pollutants emitted from boilers is usually the use of site-specific information (either CEMS data, PEM data, or recent stack tests). This section provides an outline for calculating emissions from boilers based on raw data collected by the CEMS and stack tests. The CEMS is usually used to measure  $\text{SO}_2$ ,  $\text{NO}_x$ , THC, CO, flow rate, and a diluent, which can be either oxygen ( $\text{O}_2$ ) or  $\text{CO}_2$ .

While CEMS data may be used to estimate  $\text{SO}_2$  emissions, the preferred emission estimation method for  $\text{SO}_2$  is the use of fuel analysis data for the reasons stated in Section 3. Fuel analysis is also the preferred method for estimating emissions of metals.

For PM, sulfuric acid mist, and speciated organic emissions, the preferred emission estimation method is the use of stack sampling test data. Table 2.4-1 lists the variables and symbols used in the following discussion.

### 4.1 EMISSION CALCULATIONS USING CEMS DATA

To monitor  $\text{SO}_2$ ,  $\text{NO}_x$ , THC, and CO emissions using a CEMS, a facility uses a pollutant concentration monitor, which measures concentration in parts per million by volume dry air (ppmvd). Flow rates are measured using a volumetric flow rate monitor or they can be estimated based on heat input using fuel factors.

Table 2.4-2 presents an example output from a boiler using a CEMS consisting of  $\text{SO}_2$ ,  $\text{NO}_x$ , CO,  $\text{O}_2$ , and flow rate monitors. The output usually includes pollutant concentration in parts per million (ppm) and emission rates in pounds per hour (lb/hr).

The measurements presented in Table 2.4-2 represent a "snapshot" of a boiler's operation; in this case, over a time period of 1 hour and 45 minutes. From these data, it is possible to determine that between 11:00 a.m. and noon, emissions of  $\text{SO}_2$  totaled 6,525 lb. Assuming the CEMS operates properly all year long, an accurate emission estimate can be made by summing the hourly emission estimates.

TABLE 2.4-1

## LIST OF VARIABLES AND SYMBOLS

Variable	Symbol	Units
Concentration	C	parts per million by volume dry air (ppmvd)
Molecular weight	MW	lb/lb-mole
Molar volume	V	cubic feet (ft <sup>3</sup> )/lb-mole
Flow rate	Q	dry standard cubic feet per minute (dscfm) or actual cubic feet per minute (acfm)
Hourly emissions	E <sub>x</sub>	typically lb/hr of pollutant x
Heat input rate	H <sub>in</sub>	million British thermal units (Btu) per hour (MMBtu/hr) <sup>a</sup>
Annual heat input rate	H <sub>in,ann</sub>	MMBtu/yr
Annual emissions	E <sub>tpy,x</sub>	tons per year (tpy) of pollutant x
Higher heating value	HHV	Btu/lb
Fuel factor (dry)	F <sub>d</sub>	dscf/MMBtu at 0% O <sub>2</sub>
Filter catch	C <sub>f</sub>	g
Metered volume	V <sub>m</sub>	ft <sup>3</sup>
Fuel flow	Q <sub>f</sub>	typically, lb/hr
Annual fuel use	Q <sub>f,ann</sub>	lb/yr
Emission factor	EF <sub>x</sub>	typically lb/MMBtu, lb/ft <sup>3</sup> , or lb/gal of pollutant x
Annual Op hours	OpHrs	annual operating hours (hr/yr)

<sup>a</sup> MMBtu = 10<sup>6</sup> Btu.

TABLE 2.4-2

## EXAMPLE CEMS OUTPUT FOR A BOILER BURNING NO. 6 FUEL OIL

Period	O <sub>2</sub> (%V)	SO <sub>2</sub> (C) (ppmvd)	NO <sub>x</sub> (C) (ppmvd)	CO (C) (ppmvd)	Fuel Rate (Q <sub>F</sub> ) (10 <sup>3</sup> lb/hr)	Stack Gas Flow Rate (Q) (dscfm)	Emissions			
							SO <sub>2</sub> <sup>a</sup> (lb/MMBtu)	NO <sub>x</sub> <sup>a</sup> (lb/MMBtu)	SO <sub>2</sub> (lb/hr)	NO <sub>x</sub> (lb/hr)
11:00	2.1	1,004.0	216.2	31.5	46.0	155,087	1.9	0.4	1,551	334
11:15	2.0	1,100.0	200.6	25.5	46.5	155,943	2.0	0.4	1,709	312
11:30	2.1	1,050.0	216.7	25.1	46.0	155,087	2.0	0.4	1,622	335
11:45	1.9	1,070.0	220.5	20.8	46.2	154,122	2.0	0.4	1,643	338
12:00	1.9	1,070.0	213.8	19.4	46.8	156,123	2.0	0.4	1,664	332
12:15	1.8	1,050.0	214.0	19.4	46.3	153,647	1.9	0.4	1,607	328
12:30	2.0	1,100.0	209.1	21.5	46.3	155,273	2.0	0.4	1,701	323
12:45	2.0	1,078.0	210.8	50.3	46.5	155,943	2.0	0.4	1,675	327

<sup>a</sup> Based on a fuel heating value of 18,000 Btu/lb.



### 4.1.1 CALCULATING HOURLY EMISSIONS FROM CONCENTRATION MEASUREMENTS

Although CEMS can report real-time hourly emissions automatically, it may be necessary to manually estimate predicted annual emissions from hourly concentration data. This section describes how to calculate emissions from raw CEMS concentration data.

Hourly emissions can be based on concentration measurements as shown in Equation 2.4-1.

$$E_x = \frac{(C * MW * Q * 60)}{(V * 10^6)} \quad (2.4-1)$$

where:

60	=	60 min/hr
$E_x$	=	Hourly emissions in lb/hr of pollutant x
C	=	Pollutant concentration in ppmvd
MW	=	Molecular weight of the pollutant (lb/lb-mole)
Q	=	Stack gas volumetric flow rate in dscfm
V	=	Volume occupied by 1 mole of ideal gas at standard temperature and pressure (385.5 ft <sup>3</sup> /lb-mole @ 68°F and 1 atm)

### 4.1.2 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) according to EPA Method 19 as shown below.

$$Q = F_d * \frac{20.9}{(20.9 - \%O_2)} * \frac{H_{in}}{60} \quad (2.4-2)$$

where:

$F_d$	=	Fuel factor, dry basis (from EPA Method 19)
$\%O_2$	=	Measured oxygen concentration, dry basis expressed as a percentage
$H_{in}$	=	Heat input rate in MMBtu/hr

The F factor is the ratio of the gas volume of the products of combustion to the heat content of the fuel.  $F_d$  includes all components of combustion less water.  $F_d$  can be calculated from fuel analysis results using the following equation:

$$F_d = \frac{10^6 [3.64(\%H) + 1.53(\%C) + 0.57(\%S) + 0.14(\%N) - 0.46(\%O)]}{HHV} \quad (2.4-3)$$

where:

H, C, S, N, and O = Concentrations of hydrogen, carbon, sulfur, nitrogen, and oxygen in the fuel expressed as a percentage as determined by a fuel analysis

HHV = Higher heating value of the fuel in Btu/lb

Fuel heating values are available in publications such as *Steam, Its Generation and Use* (Stultz and Kitto, 1992). The average  $F_d$  factors are provided in EPA Reference Method 19 for different fuels and are shown in Table 2.4-3.

#### 4.1.3 CALCULATING EMISSION FACTORS FROM HEAT INPUT

Sometimes it is desirable to calculate emissions in terms of pounds of pollutant per unit of heat combusted. For regulatory purposes, heat input is calculated based on the HHV of the fuel as measured by analysis. The heat input in terms of MMBtu/hr is calculated using:

$$H_{in} = \frac{(Q_f * HHV)}{10^6} \quad (2.4-4)$$

where:

$H_{in}$  = Heat input rate in MMBtu/hr

$Q_f$  = Mass fuel flow rate in lb/hr

HHV = Higher heating value in Btu/lb

An emission factor relating emissions to the heat input rate for the boiler is expressed as:

$$EF_x = E_x / H_{in} \quad (2.4-5)$$

where:

$EF_x$  = Emission factor in lb/MMBtu of pollutant x

$E_x$  = Emissions of pollutant x in lb/hr

**TABLE 2.4-3**  
**F<sub>d</sub> FACTORS FOR VARIOUS FUELS<sup>a</sup>**

Fuel Type	F <sub>d</sub>	
	dscm/J <sup>b</sup>	dscf/MMBtu
Coal		
Anthracite <sup>c</sup>	$2.71 \times 10^{-7}$	10,100
Bituminous <sup>c</sup>	$2.62 \times 10^{-7}$	9,780
Lignite	$2.65 \times 10^{-7}$	9,860
Oil <sup>d</sup>	$2.65 \times 10^{-7}$	9,190
Gas		
Natural	$2.34 \times 10^{-7}$	8,710
Propane	$2.34 \times 10^{-7}$	8,710
Butane	$2.34 \times 10^{-7}$	8,710
Wood	$2.48 \times 10^{-7}$	9,240
Wood Bark	$2.58 \times 10^{-7}$	9,600

<sup>a</sup> Determined at standard conditions: 20°C (68°F) and 760 mm Hg (29.92 in. Hg).

<sup>b</sup> dscm/J = Dry standard cubic meters per joule.

<sup>c</sup> As classified according to ASTM Method D 388-77.

<sup>d</sup> Crude, residual, or distillate.

#### 4.1.4 CALCULATING ACTUAL ANNUAL EMISSIONS

Emissions in tons per year can be calculated either by multiplying the average hourly emission rate by the number of annual operating hours (Equation 2.4-6) or by multiplying the average emission factor in lb/MMBtu by the annual heat input (Equation 2.4-8). Equation 2.4-7 shows how to calculate the annual heat input. Example 2.4-1 depicts the use of these equations.

$$E_{tpy,x} = E_x * OpHrs/2,000 \quad (2.4-6)$$

where:

$E_{tpy,x}$  = Actual annual emissions in ton/yr of pollutant x  
 $E_x$  = Emissions of pollutant x in lb/hr  
 $OpHrs$  = Operating hours per year  
 $2,000$  = lb/ton

Annual heat input may be calculated from annual fuel use using:

$$H_{in,ann} = \frac{(Q_{f,ann} * HHV)}{10^6} \quad (2.4-7)$$

where:

$H_{in,ann}$  = Annual heat input rate in MMBtu/yr  
 $Q_{f,ann}$  = Annual fuel flow rate in lb/yr  
 $HHV$  = Higher heating value in Btu/lb

$$E_{tpy,x} = EF_x * H_{in,ann} \quad (2.4-8)$$

where:

$E_{tpy,x}$  = Actual annual emissions of pollutant x in ton/yr  
 $EF_x$  = Emission factor in lb/MMBtu of pollutant x

Example 2.4-1

This example shows how SO<sub>2</sub> emissions can be calculated based on the raw CEMS data for 11:00 shown in Table 2.4-2. Hourly emissions are calculated using Equation 2.4-1:

$$\begin{aligned} E_{\text{SO}_2} &= (C * MW * Q * 60)/(V * 10^6) \\ &= 1,004 * 64 * 155,087 * 60/(385.5 * 10^6) \\ &= 1,551 \text{ lb/hr} \end{aligned}$$

Heat input is calculated using Equation 2.4-4:

$$\begin{aligned} H_{\text{in}} &= (Q_f * \text{HHV})/10^6 \\ &= 46,000 * 18,000/10^6 \\ &= 828 \text{ MMBtu/hr} \end{aligned}$$

An emission factor, in terms of lb/MMBtu, is calculated using Equation 2.4-5:

$$\begin{aligned} \text{EF}_{\text{SO}_2} &= E_{\text{SO}_2}/H_{\text{in}} \\ &= 1,551/828 \\ &= 1.9 \text{ lb/MMBtu} \end{aligned}$$

Emissions in tpy (based on a 5,840 hr/yr operating schedule) can then be calculated using Equation 2.4-6:

$$\begin{aligned} E_{\text{tpy,SO}_2} &= E_{\text{SO}_2} * \text{OpHrs}/2,000 \\ &= 1,551 * (5,840/2,000) \\ &= 4,529 \text{ tpy} \end{aligned}$$

Emissions in tpy (based on  $2.69 * 10^8$  lb annual fuel use) can then be calculated by first using Equation 2.4-7 to calculate annual heat input:

$$\begin{aligned} H_{\text{in,ann}} &= (Q_{\text{f,ann}} * \text{HHV})/10^6 \\ &= (2.69 * 10^8 * 18,000)/10^6 \\ &= 4.84 * 10^6 \text{ MMBtu/yr} \end{aligned}$$

(Continued)

**Example 2.4-1 (Continued)**

Emissions in tpy (based on  $4.84 \times 10^6$  MMBtu/yr) can then be calculated using Equation 2.4-8:

$$\begin{aligned} E_{\text{tpy}, \text{SO}_2} &= EF_{\text{SO}_2} \times H_{\text{in,ann}} / 2,000 \\ &= 1.9 \times 4.84 \times 10^6 / 2,000 \\ &= 4,598 \text{ tpy} \end{aligned}$$

Note that the last two calculations in Example 2.4-1 show an actual annual emission estimate based on a single 1-hour test point and are provided as an example only. Average values of  $E_x$  should be used to obtain a representative annual emissions estimate.

## 4.2 PEM

This section outlines an example of  $\text{SO}_2$  emission monitoring that could be used to develop a PEM protocol for a boiler equipped with a wet scrubber. Boiler and scrubber parameters that affect emissions and that are most likely to be included in the testing algorithm are scrubber water pH and flow rate, and fuel combustion rate.

To develop this algorithm, correlation testing of the stack gas, scrubber, and boiler process variables could be conducted over a range of potential operating conditions using EPA Method 6A or Method 6C to measure  $\text{SO}_2$  emissions. Potential testing conditions are shown in Table 2.4-4. Based on the test data, a mathematical correlation can be developed that predicts  $\text{SO}_2$  emissions using these parameters.

## 4.3 EMISSION CALCULATIONS USING STACK SAMPLING DATA

Stack sampling test reports often provide emissions in terms of lb/hr or lb/MMBtu. Annual emissions may be calculated from these data using Equations 2.4-6 or 2.4-8 as shown in Example 2.4-1. Stack tests performed under a proposed permit condition or a maximum emissions rate may not accurately reflect the emissions that would result under normal operating conditions. Therefore, when using stack sampling test data to estimate emissions, tests should be conducted under "normal" operating conditions.

TABLE 2.4-4

PREDICTIVE EMISSION MONITORING ANALYSIS<sup>a</sup>

Test Number	Scrubber Water Flow Rate	Scrubber Water pH	Fuel Firing Rate
1	B	H	H
2	B	H	M
3	B	H	L
4	B	M	H
5	B	M	M
6	B	M	L
7	B	L	H
8	B	L	M
9	B	L	L

- <sup>a</sup> H = High.  
M = Medium.  
L = Low.  
B = Baseline.

This section shows how to calculate emissions in lb/hr based on raw stack sampling data. Calculations involved in determining SO<sub>2</sub> and PM<sub>10</sub> emissions from raw EPA Method 201 data are presented in Examples 2.4-2 and 2.4-3, respectively. Because PM<sub>10</sub> emissions cannot be measured continuously, the best method available for measuring PM<sub>10</sub> emissions is Method 201.

An example summary of a Method 201 test is shown in Table 2.4-5. The table shows the results of three different sampling runs conducted during one test event. The source parameters measured as part of a Method 201 run include gas velocity and moisture content, which are used to determine exhaust gas flow rates in dscfm. The filter weight gain is determined gravimetrically and divided by the volume of gas sampled as shown in Equation 2.4-11 to determine the PM concentration in lb/dscf. Pollutant concentration is then multiplied by the volumetric flow rate to determine the emission rate in pounds per hour, as shown in Equation 2.4-1.

Example 2.4-2

This example shows how to calculate SO<sub>2</sub> emissions when the stack gas flow rate, Q, is not available.

The F factor for No. 6 fuel oil, based on Table 2.4-3, is 9,190 dscf/MMBtu. The oxygen content is 2.1 percent. From Example 2.4-1, H<sub>in</sub> is 828 MMBtu/hr. The stack gas flow rate is calculated using Equation 2.4-9:

$$\begin{aligned} Q &= F_d * (20.9)/(20.9 - \%O_2) * (H_{in}/60) \\ Q &= 9,190 * (20.9)/(20.9 - 2.1) * (828/60) \\ Q &= 140,988 \text{ dscfm} \end{aligned} \quad (2.4-9)$$

Using the CEMS data from Table 2.4-2 (for 11:00) and the calculated flow rate, hourly emissions can now be calculated using Equation 2.4-1:

$$\begin{aligned} E_{SO_2} &= (C * MW * Q * 60)/(V * 10^6) \\ E_{SO_2} &= (1,004 * 64 * 140,988 * 60)/(385.5 * 10^6) \\ E_{SO_2} &= 1,410 \text{ lb/hr} \end{aligned} \quad (2.4-1)$$

To express the emissions in terms of pounds per unit of heat combusted, use Equation 2.4-10:

$$\begin{aligned} EF_{SO_2} &= E_{SO_2}/H_{in} \\ EF_{SO_2} &= 1,410/828 \\ EF_{SO_2} &= 1.7 \text{ lb/MMBtu} \end{aligned} \quad (2.4-10)$$

Note that E<sub>SO<sub>2</sub></sub> and EF<sub>SO<sub>2</sub></sub> calculated using F factors is slightly different than the emissions calculated using flow rate measurements. This difference is due to different estimation approaches; depending on the use of the data, either approach may be acceptable.



**TABLE 2.4-5**  
**SAMPLE TEST RESULTS - METHOD 201**

Parameter	Run 1	Run 2	Run 3
Total sampling time (minutes)	180.00	180.00	180.00
Corrected barometric pressure (in. Hg)	30.56	30.56	30.56
Absolute stack pressure, $P_s$ (in. Hg)	30.49	30.49	30.49
Stack static pressure (in. $H_2O$ )	-0.89	-0.89	-0.89
Average stack temperature ( $^{\circ}F$ )	328.00	330.00	335.00
Stack area ( $ft^2$ )	113.09	113.09	113.09
Metered volume of sample, $V_m$ ( $ft^3$ )	116.51	110.20	115.30
Average meter pressure (in. $H_2O$ )	0.81	0.81	0.81
Average meter temperature ( $^{\circ}F$ )	69.28	71.00	70.20
Moisture collected (g)	258.50	265.00	261.00
Carbon dioxide concentration (%V)	15.50	15.40	15.30
Oxygen concentration (%V)	2.30	2.30	2.30
Nitrogen concentration (%V)	82.20	82.30	82.40
Dry gas meter factor	1.01080	1.01080	1.01080
Pitot constant	0.84	0.84	0.84
$PM_{10}$ filter catch (g)	0.003	0.004	0.003
Average sampling rate (dscfm)	0.67	0.67	0.67
Standard metered volume, $V_m$ (std) (dscf)	120.23	121.30	118.50
Standard volume water vapor, $V_w$ (scf)	12.19	13.00	12.50
Stack moisture (%V)	9.20	9.50	9.60
Mole fraction dry stack gas	0.908	0.908	0.908
Dry molecular weight (g)	29.37	29.37	29.37
Wet molecular weight (g)	28.32	28.32	28.32
Stack gas velocity, $V_s$ (ft/min)	3000.00	2950.00	2965.00
Volumetric flow rate (acfm)	339270	333616	335312
Volumetric flow rate (dscfm)	206404	201791	201319
Percent isokinetic	96.48	97.00	98.00
Concentration of particulate (g/dscf)	0.00002	0.00003	0.00003
$PM_{10}$ emission rate (lb/hr)	0.68	0.90	0.69

$$E_x = (C_f/V_m) * Q * 60/453.6 \quad (2.4-11)$$

where:

$E_x$	=	Emissions of pollutant x in lb/hr
$C_f$	=	Filter catch (g)
$V_m$	=	Metered volume of sample (ft <sup>3</sup> )
$Q$	=	Stack gas volumetric flow rate (dscfm)
60	=	60 min/hr
453.6	=	453.6 g/lb

#### Example 2.4-3

This example shows how PM<sub>10</sub> emissions may be calculated using Equation 2.4-11 and the stack sampling data for Run 1 (presented in Table 2.4-5).

$$\begin{aligned} E &= (C_f/V_m) * Q * 60/453.6 \\ &= (0.003/120.23) * 206,404 * 60/453.6 \\ &= 0.68 \text{ lb/hr} \end{aligned}$$

## 4.4 EMISSION CALCULATIONS USING FUEL ANALYSIS DATA

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 that may be converted to other compounds during the combustion process.

The basic equation used in fuel analysis emission calculations is:

$$E = Q_f * \text{Pollutant concentration in fuel} * \left[ \frac{MW_p}{MW_f} \right] \quad (2.4-12)$$

where:

$$\begin{aligned} Q_f &= \text{Fuel flow rate (lb/hr)} \\ MW_p &= \text{Molecular weight of pollutant emitted (lb/lb-mole)} \\ MW_f &= \text{Molecular weight of pollutant in fuel (lb/lb-mole)} \end{aligned}$$

For example, SO<sub>2</sub> 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<sub>2</sub>. Therefore, for every pound of sulfur (MW = 32 g) burned, 2 lb of SO<sub>2</sub> (MW = 64 g) are emitted. The application of this emission estimation technique is shown in Example 2.4-4.

#### Example 2.4-4

This example shows how SO<sub>2</sub> emissions can be calculated from oil combustion based on fuel analysis results and the fuel flow information provided in Table 2.4-2.

E<sub>SO<sub>2</sub></sub> may be calculated using Equation 2.4-12.

$$\begin{aligned} Q_f &= 46,000 \text{ lb/hr} \\ \text{Percent sulfur (\%S) in fuel} &= 1.17 \end{aligned}$$

$$\begin{aligned} E_{\text{SO}_2} &= Q_f * \text{Pollutant concentration in fuel} * (MW_p/MW_f) \\ &= (46,000) * (1.17/100) * (64/32) \\ &= 1,076 \text{ lb/hr} \end{aligned}$$

# 5

## ALTERNATIVE METHODS FOR ESTIMATING EMISSIONS

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### 5.1 EMISSION FACTOR CALCULATIONS

Emission factors are commonly used to calculate emissions when site-specific stack monitoring data are unavailable. The EPA maintains a compilation of emission factors in *AP-42* (EPA, January 1995) for criteria pollutants and HAPs. The most comprehensive source for toxic air pollutant emission factors is the FIRE data system (EPA, June 1995). FIRE also contains emission factors for criteria pollutants.

Much work has been done recently on developing emission factors for HAPs and recent *AP-42* revisions have included these factors. In addition, many states have developed their own HAP emission factors for certain source categories and may require their use in any inventories including HAPs. Refer to Chapter 1 of Volume II for a complete discussion of available information sources for locating, developing, and using emission factors as an estimation technique.

Emission factors developed from measurements for a specific boiler may sometimes be used to estimate emissions at other sites. For example, a company may have several boilers of a similar model and size; if emissions were measured from one boiler, a factor can be developed and applied to the other boilers. It is advisable to have the factor approved by state/local agencies or by the EPA.

The basic equation used in emission factor emissions calculations is:

$$E_x = EF_x * \text{Activity Rate} \quad (2.5-1)$$

where:

$$\begin{array}{ll} E_x & = \text{Emissions of pollutant } x \\ EF_x & = \text{Emission factor} \end{array}$$

In cases where more than one fuel type is used, annual emissions should be calculated using appropriate emission factors and proportioned based on the amount of each type

In cases where more than one fuel type is used, annual emissions should be calculated using appropriate emission factors and proportioned based on the amount of each type of fuel used. Examples 2.5-1 and 2.5-2 show the use of Equations 2.5-1.

#### Example 2.5-1

This example shows how CO emissions may be calculated for No. 6 oil combustion based on the boiler fuel rate information provided in Table 2.4-2 and a CO emission factor from AP-42, Table 1.3-2, for No. 6 fuel oil.

$$\begin{aligned} E_x &= EF_x * \text{Activity Rate } (Q_f) \\ EF_{CO} &= 5 \text{ lb}/10^3 \text{ gal} \\ Q_f &= (46.0 * 10^3 \text{ lb/hr}) * 1 \text{ gal}/8 \text{ lb} \\ &= 5,750 \text{ gal/hr} \\ E_{CO} &= EF_{CO} * Q_f \\ &= 5/10^3 * 5,750 \end{aligned}$$

## 5.2 EMISSION CALCULATIONS USING RULE EFFECTIVENESS

Some emission inventories, such as SIP Base Year inventories, may require incorporation of the concept of rule effectiveness (RE). RE is an adjustment to estimated emission data to account for emission underestimates due to compliance failures. The RE adjustment accounts for known underestimates due to noncompliance with existing rules, control equipment downtime, operating problems, and/or process upsets. The concepts and philosophy behind RE are discussed in Chapter 1, Section 6, of this volume, *Introduction to Stationary Point Source Emission Inventory Development*. Additional information on the application of RE can be found in *Guidelines for Estimating and Applying Rule Effectiveness for Ozone/CO State Implementation Plan Base Year Inventories* (EPA, November 1992). Example 2.5-3 presents an application of RE to boiler emission estimates.

Example 2.5-2

This example shows how chromium emissions may be calculated for No. 6 oil combustion based on a heat input rate of 828 MMBtu/hr and a chromium emission factor from FIRE for SCC 1-01-004-01.

$$\begin{aligned}
 \text{EF(chromium)} &= 6.31 \cdot 10^{-6} \text{ lb/MMBtu} \\
 \text{Chromium emissions} &= \text{EF(chromium)} \cdot H_{\text{in}} \\
 &= (6.31 \cdot 10^{-6}) \cdot 828 \\
 &= 5.22 \cdot 10^{-3} \text{ lb/hr}
 \end{aligned}$$

Example 2.5-3

This example shows how the application of RE can affect the emission estimate. This example is based on a pulverized coal-fired, dry-bottom, wall-fired boiler. The firing rate is 6.9 ton/hr, and the SO<sub>2</sub> emission factor is from AP-42, Table 1.1-1. The boiler is subject to a regulation that requires that it be equipped with a sodium carbonate wet scrubber with a control efficiency (CE) of 90 percent. RE is set equal to 80 percent, the default value.

$$\begin{aligned}
 \text{EF}_{\text{(SO}_x\text{)}} &= 38 \text{ (S) lb/ton, where S = weight percent sulfur} \\
 \text{S} &= 0.70 \text{ percent} \\
 \text{Firing rate} &= 6.9 \text{ ton/hr}
 \end{aligned}$$

$$\begin{aligned}
 \text{Uncontrolled SO}_x \text{ emissions} &= (\text{EF}_{\text{SO}_x})(\text{Activity rate}) \\
 &= (38)(0.7)(6.9) \\
 &= 183.5 \text{ lb/hr}
 \end{aligned}$$

$$\begin{aligned}
 \text{Controlled SO}_x &= (\text{EF}_{\text{SO}_x})(\text{Activity rate})(1 - [\text{CE}]) \\
 &= (38)(0.7)(6.9)(1 - [0.9]) \\
 &= 18 \text{ lb/hr}
 \end{aligned}$$

$$\begin{aligned}
 \text{Controlled SO}_x \text{ including RE} &= (\text{EF}_{\text{SO}_x})(\text{Activity rate})(1 - [\text{CE}][\text{RE}]) \\
 &= (38)(0.7)(6.9)(1 - [0.9][0.8])
 \end{aligned}$$

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# 6

## QUALITY ASSURANCE/QUALITY CONTROL

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The consistent use of standardized methods and procedures is essential in the compilation of reliable emission inventories. QA and QC of an inventory is accomplished through a set of procedures that ensure the quality and reliability of data collection and analysis. These procedures include the use of appropriate emission estimation techniques, applicable and reasonable assumptions, accuracy/logic checks of computer models, checks of calculations, and data reliability checks. Chapter 3 of Volume VI of this series describes additional QA/QC methods and tools for performing these procedures.

Chapter 1, *Introduction to Stationary Point Source Emission Inventory Development*, of this volume presents recommended standard procedures to follow that ensure the reported inventory of this volume data are complete and accurate. Chapter 1, Section 9, should be consulted for current EIIP guidance for QA/QC checks for general procedures, recommended components of a QA plan, and recommended components for point source inventories. The QA plan discussion includes recommendations for data collection, analysis, handling, and reporting. The recommended QC procedures include checks for completeness, consistency, accuracy, and the use of approved standardized methods for emission calculations, where applicable. Chapter 1, Section 9, also describes guidelines to follow in order to assure the quality and validity of the data from manual and continuous emission monitoring methodologies used to estimate emissions.

### 6.1 GENERAL FACTORS INVOLVED IN EMISSION ESTIMATION TECHNIQUES

#### 6.1.1 STACK TESTS AND CEMS

Data collected via CEMS, PEM, or stack tests must meet quality objectives. Stack test data must be reviewed to ensure that the test was conducted under normal operating conditions and that data were generated according to an acceptable method for each pollutant of interest. Calculation and interpretation of accuracy for stack testing methods and CEMS are described in detail in *Quality Assurance Handbook for Air Pollution Measurements Systems: Volume III. Stationary Source Specific Methods (Interim Edition)* (EPA, April 1994).

The acceptance criteria, limits, and values for each control parameter associated with



The acceptance criteria, limits, and values for each control parameter associated with manual sampling methods, such as dry gas meter calibration and leak rates, are summarized in of Chapter 1 of this volume. Continuous monitoring for NO<sub>x</sub>, CO, CO<sub>2</sub>, and THCs using various instruments is discussed in Section 3 of this chapter. QC procedures for all instruments used to continuously collect emissions data are similar. The primary control check for precision of the continuous monitors is daily analysis of control standards. The CEMS acceptance criteria and control limits are also listed in Chapter 1.

### 6.1.2 EMISSION FACTORS

The use of emission factors is straightforward when the relationship between process data and emissions is direct and relatively uncomplicated. When using emission factors, the user should be aware of the quality indicator associated with the value. Emission factors published within EPA documents and electronic tools have a quality rating applied to them. The lower the quality indicator, the more likely that a given emission factor may not be representative of the source type. When an emission factor for a specific source or category may not provide a reasonably adequate emission estimate, it is always better to rely on actual stack test or CEMS data, where available. The reliability and uncertainty of using emission factors as an emission estimation technique are discussed in detail in Chapter 1 of this volume.

## 6.2 DATA ATTRIBUTE RATING SYSTEM (DARS) SCORES

One measure of emission inventory data quality is the DARS score (Beck et al. 1994). Four examples are given here to illustrate DARS scoring using the preferred and alternative methods. The DARS provides a numerical ranking on a scale of 1 to 10 for individual attributes of the emission factor and the activity data. Each score is based on what is known about the factor and the activity data, such as the specificity to the source category and the measurement technique employed. The composite attribute score for the emissions estimate can be viewed as a statement about the confidence that can be placed in the data. For a complete discussion of DARS and other rating systems, see the *QA Source Document* (Volume VI, Chapter 4) and Volume II, Chapter 1, *Introduction to Stationary Point Source Emission Inventory Development*.

Each of the examples below is hypothetical. A range is given where appropriate to cover different situations. The scores are assumed to apply to annual emissions from a boiler. Table 2.6-1 gives a set of scores for an estimate based on CEMS/PEM data. A perfect score of 1.0 is achievable using this method if data quality is very good. Note that maximum scores of 1.0 are automatic for the source definition and spatial congruity attributes. Likewise, the temporal congruity attribute receives a 1.0 if data capture is greater than 90 percent; this assumes that data are sampled adequately throughout the

year. The measurement attribute score of 1.0 assumes that the pollutants of interest were measured directly. A lower score is given if the emissions are speciated using a profile, or if the emissions are used as a surrogate for another pollutant. Also, the measurement/method score can be less than 1.0 if the relative accuracy is poor (e.g., > 10 percent), if the data are biased, or if data capture is closer to 90 percent than to 100 percent.

TABLE 2.6-1

DARS SCORES: CEMS/PEM DATA<sup>a</sup>

Attribute	Emission Factor Score	Activity Data Score	Composite Scores		Comment
			Range	Midpoint	
Measurement/method	0.9 - 1	0.9 - 1	0.81 - 1	0.905	Lower scores given if relative accuracy poor (e.g., > 10 percent) or data capture closer to 90 percent.
Source definition	1.0	1.0	1.0	1.0	
Spatial congruity	1.0	1.0	1.0	1.0	
Temporal congruity	1.0	1.0	1.0	1.0	
Weighted Score	0.98 - 1	0.98 - 1	0.95 - 1	0.98	

<sup>a</sup> Assumes data capture is 90 percent or better, and representative of entire year; monitors, sensors, and other equipment properly maintained.

The use of stack sample data can give DARS scores as high as those for CEMS/PEM data. However, the sample size is usually too low to be considered completely representative of the range of possible emissions making a score of 1.0 for measurement/method unlikely. A typical DARS score is generally closer to the low end of the range shown in Table 2.6-2.

Two examples are given for emissions calculated using emission factors. For both of these examples, the activity data are assumed to be measured directly or indirectly. Table 2.6-3 applies to an emission factor developed from CEMS/PEM data from one boiler and then applied to a different boiler of similar design and age. Table 2.6-4 gives

TABLE 2.6-2

DARS SCORES: STACK SAMPLE DATA<sup>a</sup>

Attribute	Emission Factor Score	Activity Data Score	Composite Scores		Comment
			Range	Midpoint	
Measurement/method	0.7 - 1	0.7 - 1	0.49 - 1	0.745	
Source definition	1 - 1	1 - 1	1 - 1	1	
Spatial congruity	1 - 1	1 - 1	1 - 1	1	
Temporal congruity	0.7 - 1	0.7 - 1	0.49 - 1	0.745	Lower scores given if emissions vary temporally and sample does not cover range.
Weighted Score	0.85 - 1	0.85 - 1	0.75 - 1	0.87	

<sup>a</sup> Assumes use of an EPA reference method, high quality data.

an example for an estimate made with an *AP-42* emission factor. *AP-42* factors are defined for classes of boilers (based on size and fuel type); for some pollutants, the variability in emissions among this population may be high. The *AP-42* factor is a mean and could overestimate or underestimate emissions for any single boiler in the population. Also, the data on which some of these factors are based are often limited in numbers and may be 10-20 years old. Thus, the confidence that can be placed in emissions estimated for a specific boiler with a general *AP-42* factor is lower than emissions based on source-specific data.

The example in Table 2.6-3 shows that emission factors based on high-quality data from a similar unit will typically give better results than a general factor. The main criterion affecting the score is how similar the boiler used to generate the factor is to the target boiler.

If sufficient data are available, the uncertainty in the estimate should be quantified. QA methods are described in the (Volume VI, Chapter 4).

TABLE 2.6-3

**DARS SCORES: SOURCE-SPECIFIC EMISSION FACTOR<sup>a</sup>**

Attribute	Emission Factor Score	Activity Data Score	Composite Scores		Comment
			Range	Midpoint	
Measurement/method	0.9 - 1	0.8 - 1	0.72 - 1	0.86	Factor score for this attribute depends entirely on data quality.
Source definition	0.5 - 0.9	0.8 - 0.9	0.4 - 0.81	0.61	Factor score lowest if unit differs much from original source of data.
Spatial congruity	1 - 1	1 - 1	1 - 1	1	
Temporal congruity	1 - 1	0.5 - 0.9	0.5 - 0.9	0.7	
Weighted Score	0.85 - 0.98	0.78 - 0.95	0.66 - 0.93	0.79	

<sup>a</sup> Assumes factor developed from PEM or CEMS data from an identical emission unit (same manufacturer, model).

TABLE 2.6-4

DARS SCORES: AP-42 EMISSION FACTOR<sup>a</sup>

Attribute	Emission Factor Score	Activity Data Score	Composite Scores		Comment
			Range	Midpoint	
Measurement/method	0.6 - 0.8	0.8 - 1	0.48 - 0.7	0.59	Score depends on quality and quantity of data points used to develop factor.
Source definition	0.5 - 0.9	0.8 - 0.9	0.4 - 0.81	0.605	Emission factor score will be low if variability in source population is high.
Spatial congruity	0.6 - 0.8	1 - 1	0.6 - 0.8	0.7	Factor score lower if geographic location has significant effect on emissions.
Temporal congruity	0.5 - 0.9	0.5 - 0.9	0.25 - 0.81	0.53	Lower scores given if emissions vary temporally and sample does not cover range.
Weighted Score	0.55 - 0.85	0.78 - 0.95	0.43 - 0.78	0.61	

<sup>a</sup> Assumes activity data (e.g., fuel use) or surrogate is measured directly in some manner.

## DATA CODING PROCEDURES

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This section describes the methods and codes available for characterizing emission sources at boiler facilities using SCC and Aerometric Information Retrieval System (AIRS) control device codes. Consistent categorization and coding will result in greater uniformity among inventories. The SCCs are the building blocks on which point source emissions data are structured. Each SCC represents a unique process or function within a source category that is logically associated with an emission point. Without an appropriate SCC, a process cannot be accurately identified for retrieval purposes. In addition, the procedures described here will assist the reader preparing data for input to a database management system. For example, the use of the SCCs provided in Table 2.7-1 are recommended for describing boiler operations. Refer to the Clearinghouse for Inventories and Emission Factors (CHIEF) bulletin board for a complete listing of SCCs for boilers. While the codes presented here are currently in use, they may change based on further refinement by the emission inventory user community. As part of the Emission Inventory Improvement Program (EIIP), a common emissions data exchange format is being developed to facilitate data transfer between industry, states, and EPA.

### 7.1 PROCESS EMISSIONS

Use of the codes in Table 2.7-1 are recommended for describing boilers that burn anthracite, bituminous, subbituminous, or lignite coal; oil- or natural gas-fired electric utility boilers; peaking plants; cogeneration units; and electric utility boilers that burn other types of fuel. More than one code may be necessary for each boiler if auxiliary fuel is used. Auxiliary fuels such as oil are used during start-up of utility boilers, or to sustain combustion (such as coal, oil, or natural gas used at utility boilers that predominantly burn wood/bark or waste).

### 7.2 STORAGE TANKS

The codes in Table 2.7-1 are recommended to describe emissions related to fuel storage.

### 7.3 FUGITIVE EMISSIONS

Fugitive emissions at boiler facilities may result from coal, wood/bark, and solid/liquid waste handling and storage. Limestone handling and storage emissions may also occur if the facility uses limestone in control devices such as scrubbers. There are undoubtedly sources of fugitive emissions within the facility or sources that have not been specifically

sources of fugitive emissions within the facility or sources that have not been specifically discussed thus far; these should be included. Conditions vary from plant to plant, so each specific case cannot be discussed within the context of this document.

Codes that may be used to describe fugitive emissions at boiler facilities are also presented in Table 2.7-1. It may be necessary to use a miscellaneous fugitive emission code for sources without a unique code. Many database systems used for inventory management contain a comment field that may be used to describe the fugitive emissions.

## 7.4 CONTROL DEVICES

The codes found in Table 2.7-2 are recommended for describing control devices used at electric utilities and may also be applicable to control devices used at commercial and institutional boilers. The "099" control code may be used to handle miscellaneous control devices that do not have a unique control equipment identification code. For a complete listing, the reader may consult the *AIRS User's Guide Volume XI: AFS Data Dictionary* (AFS is AIRS Facility Subsystem) (EPA, January 1992).

**TABLE 2.7-1**  
**SOURCE CLASSIFICATION CODES FOR BOILERS<sup>a</sup>**

Source Description	Process Description	SCC	Units
<b>Process Emissions</b>			
Anthracite Coal	Pulverized Coal	1-01-001-01	Tons Burned
	Pulverized Coal	1-03-001-01	Tons Burned
	Traveling Grate (Overfeed) Stoker	1-01-001-02	Tons Burned
	Traveling Grate (Overfeed) Stoker	1-03-001-02	Tons Burned
	Hand-fired	1-03-001-03	Tons Burned
Bituminous Coal	Pulverized Coal: Wet Bottom	1-01-002-01	Tons Burned
	Pulverized Coal: Wet Bottom	1-03-002-05	Tons Burned
	Pulverized Coal: Dry Bottom/Nontangential	1-01-002-02	Tons Burned
	Pulverized Coal: Dry Bottom/Nontangential	1-03-002-06	Tons Burned
	Pulverized Coal: Dry Bottom/Tangential	1-01-002-12	Tons Burned
	Pulverized Coal: Dry Bottom/Tangential	1-03-002-16	Tons Burned
	Atmospheric Fluidized Bed Combustion: Bubbling Bed	1-03-002-17	Tons Burned
	Cyclone Furnace	1-01-002-03	Tons Burned
	Cyclone Furnace	1-03-002-03	Tons Burned
	Spreader Stoker	1-01-002-04	Tons Burned
	Spreader Stoker	1-03-002-09	Tons Burned
	Overfeed Stoker	1-03-002-11	Tons Burned
	Traveling Grate (Overfeed) Stoker	1-01-002-05	Tons Burned
	Overfeed Stoker	1-03-002-07	Tons Burned
	Underfeed Stoker	1-03-002-08	Tons Burned
	Hand-fired	1-03-002-14	Tons Burned
	Atmospheric Fluidized Bed Combustion	1-01-002-17	Tons Burned



TABLE 2.7-1

(CONTINUED)

Source Description	Process Description	SCC	Units
<b>Process Emission (Continued)</b>			
Bituminous Coal (Continued)	Atmospheric Fluidized Bed Combustion: Circulating Bed	1-03-002-18	Tons Burned
Subbituminous Coal	Pulverized Coal: Wet Bottom	1-01-002-21	Tons Burned
	Pulverized Coal: Wet Bottom	1-03-002-21	Tons Burned
	Pulverized Coal: Dry Bottom/Nontangential	1-01-002-22	Tons Burned
	Pulverized Coal: Dry Bottom/Nontangential	1-03-002-22	Tons Burned
	Pulverized Coal: Dry Bottom/Tangential	1-01-002-26	Tons Burned
	Pulverized Coal: Dry Bottom/Tangential	1-03-002-26	Tons Burned
	Cyclone Furnace	1-01-002-23	Tons Burned
	Cyclone Furnace	1-03-002-23	Tons Burned
	Spreader Stoker	1-01-002-24	Tons Burned
	Spreader Stoker	1-03-002-24	Tons Burned
	Traveling Grate (Overfeed) Stoker	1-01-002-25	Tons Burned
	Traveling Grate (Overfeed) Stoker	1-03-002-25	Tons Burned
Lignite Coal	Pulverized Coal: Nontangential Firing	1-01-003-01	Tons Burned
	Pulverized Coal: Nontangential Firing	1-03-003-05	Tons Burned
	Pulverized Coal: Tangential Firing	1-01-003-02	Tons Burned
	Pulverized Coal: Tangential Firing	1-03-003-06	Tons Burned
	Cyclone Furnance	1-01-003-03	Tons Burned
	Traveling Grate (Overfeed) Stoker	1-01-003-04	Tons Burned
	Traveling Grate (Overfeed) Stoker	1-03-003-07	Tons Burned
	Spreader Stoker	1-01-003-06	Tons Burned
	Spreader Stoker	1-03-003-09	Tons Burned

TABLE 2.7-1

(CONTINUED)

Source Description	Process Description	SCC	Units
<b>Process Emission (Continued)</b>			
Residual Oil	Grade No. 6 Oil: Normal Firing	1-01-004-01	1000 Gallons Burned
	Grade No. 6 Oil	1-03-004-01	1000 Gallons Burned
	10-100 Million Btu/hr	1-03-004-02	1000 Gallons Burned
	<10 Million Btu/hr	1-03-004-03	1000 Gallons Burned
	Grade No. 6 Oil: Tangential Firing	1-01-004-04	1000 Gallons Burned
	Grade No. 5 Oil: Normal Firing	1-01-004-05	1000 Gallons Burned
	Grade No. 5 Oil	1-03-004-04	1000 Gallons Burned
	Grade No. 5 Oil: Tangential Firing	1-01-004-06	1000 Gallons Burned
Distillate Oil	Grades Nos. 1 and 2 Oil	1-01-005-01	1000 Gallons Burned
	Grades Nos. 1 and 2 Oil	1-03-005-01	1000 Gallons Burned
	10-100 Million Btu/hr	1-03-005-02	1000 Gallons Burned
	<10 Million Btu/hr	1-03-005-03	1000 Gallons Burned
	Grade No. 4 Oil: Normal Firing	1-01-005-04	1000 Gallons Burned
	Grade No. 4 Oil	1-03-005-04	1000 Gallons Burned
	Grade No. 4 Oil: Tangential Firing	1-01-005-05	1000 Gallons Burned
Natural Gas	Boilers > 100 Million Btu/hr (Nontangential)	1-01-006-01	Million ft <sup>3</sup> Burned
	Boilers > 100 Million Btu/hr	1-03-006-01	Million ft <sup>3</sup> Burned
	10-100 Million Btu/hr	1-03-006-02	Million ft <sup>3</sup> Burned
	Boilers < 100 Million Btu/hr (Nontangential)	1-01-006-02	Million ft <sup>3</sup> Burned
	Boilers < 100 Million Btu/hr	1-03-006-03	Million ft <sup>3</sup> Burned
	Boiler - Tangential	1-01-006-04	Million ft <sup>3</sup> Burned
Coke	All Boiler Sizes	1-01-008-01	Tons Burned

TABLE 2.7-1

(CONTINUED)

Source Description	Process Description	SCC	Units
<b>Process Emission (Continued)</b>			
Liquefied Petroleum Gas	Butane	1-01-010-01	1000 Gallons Burned
	Butane	1-03-010-01	1000 Gallons Burned
	Propane	1-01-010-02	1000 Gallons Burned
	Propane	1-03-010-02	1000 Gallons Burned
	Butane/Propane Mixture: Specify Percent Butane in Comments	1-01-010-03	1000 Gallons Burned
	Butane/Propane Mixture: Specify Percent Butane in Comments	1-03-010-03	1000 Gallons Burned
Process Gas	Boilers > 100 Million Btu/hr	1-01-007-01	Million ft <sup>3</sup> Burned
	POTW <sup>b</sup> Digester Gas-fired Boiler	1-03-007-01	Million ft <sup>3</sup> Burned
	Boilers < 100 Million Btu/hr	1-01-007-02	Million ft <sup>3</sup> Burned
	Other Not Classified	1-03-007-99	Million ft <sup>3</sup> Burned
Landfill Gas	Landfill Gas	1-03-008-11	Million ft <sup>3</sup> Burned
Wood/Bark	Bark Only	1-01-009-01	Tons Burned
	Bark-fired Boiler	1-03-009-01	Tons Burned
	Wood/Bark	1-01-009-02	Tons Burned
	Wood/Bark-fired Boiler	1-03-009-02	Tons Burned
	Wood-fired Boiler	1-03-009-03	Tons Burned
	Wood Only	1-01-009-01	Tons Burned
Solid/Liquid Waste	Solid Waste/Specify in Comments	1-01-012-01	Tons Burned
	Specify Waste Material in Comments	1-03-012-01	Tons Burned
	Refuse-derived Fuel	1-01-012-02	Tons Burned
	Refuse-derived Fuel	1-03-012-02	Tons Burned
	Liquid Waste/Specify in Comments	1-01-013-01	1000 Gallons Burned

TABLE 2.7-1

(CONTINUED)

Source Description	Process Description	SCC	Units
<b>Process Emission (Continued)</b>			
Solid/Liquid Waste (Continued)	Specify Waste Material in Comments	1-03-013-01	1000 Gallons Burned
	Waste Oil	1-01-013-02	1000 Gallons Burned
	Waste Oil	1-03-013-02	1000 Gallons Burned
	Sewage Grease Skimmings	1-03-013-03	1000 Gallons Burned
Cogeneration Units	Bituminous Coal	To Be Added	Tons Burned
	Subbituminous Coal	To Be Added	Tons Burned
	Lignite	To Be Added	Tons Burned
	Residual Oil	To Be Added	1000 Gallons Burned
	Distillate Oil	To Be Added	1000 Gallons Burned
	Natural Gas	To Be Added	Million ft <sup>3</sup> Burned
	Process Gas	To Be Added	Million ft <sup>3</sup> Burned
	Coke	To Be Added	Tons Burned
	Wood	To Be Added	Tons Burned
<b>Storage Tanks</b>			
Fixed-Roof 67,000-Barrel Fuel Tanks: Breathing Loss	Fixed-Roof Tanks (67,000 bbl): Grade No. 6 Oil <sup>c</sup>	4-03-010-25	1000 Gallons Storage Capacity
	Fixed-Roof Tanks (67,000 bbl): Grade No. 5 Oil	4-03-010-26	1000 Gallons Storage Capacity
	Fixed-Roof Tanks (67,000 bbl): Grade No. 4 Oil	4-03-010-27	1000 Gallons Storage Capacity
	Fixed-Roof Tanks (67,000 bbl): Grade No. 2 Oil	4-03-010-28	1000 Gallons Storage Capacity
	Fixed-Roof Tanks (67,000 bbl): Grade No. 1 Oil	4-03-010-29	1000 Gallons Storage Capacity

TABLE 2.7-1

(CONTINUED)

Source Description	Process Description	SCC	Units
<b>Storage Tanks (Continued)</b>			
Fixed-Roof 250,000-Barrel Fuel Tanks: Breathing Loss	Fixed-Roof Tanks (250,000 bbl): Grade No. 6 Oil	4-03-010-65	1000 Gallons Storage Capacity
	Fixed-Roof Tanks (250,000 bbl): Grade No. 5 Oil	4-03-010-66	1000 Gallons Storage Capacity
	Fixed-Roof Tanks (250,000 bbl): Grade No. 4 Oil	4-03-010-67	1000 Gallons Storage Capacity
	Fixed-Roof Tanks (250,000 bbl): Grade No. 2 Oil	4-03-010-68	1000 Gallons Storage Capacity
	Fixed-Roof Tanks (250,000 bbl): Grade No. 1 Oil	4-03-010-69	1000 Gallons Storage Capacity
Fixed-Roof Fuel Tanks: Working Loss	Fixed-Roof Tanks: Grade No. 6 Oil	4-03-010-75	1000 Gallons Throughput
	Fixed-Roof Tanks: Grade No. 5 Oil	4-03-010-76	1000 Gallons Throughput
	Fixed-Roof Tanks: Grade No. 4 Oil	4-03-010-77	1000 Gallons Throughput
	Fixed-Roof Tanks: Grade No. 2 Oil	4-03-010-78	1000 Gallons Throughput
	Fixed-Roof Tanks: Grade No. 1 Oil	4-03-010-79	1000 Gallons Throughput
Floating-Roof 67,000-Barrel Fuel Tanks: Standing Loss	Floating-Roof Tanks (67,000 bbl): Grade No. 6 Oil	4-03-011-25	1000 Gallons Storage Capacity
	Floating-Roof Tanks (67,000 bbl): Grade No. 5 Oil	4-03-011-25	1000 Gallons Storage Capacity
	Floating-Roof Tanks (67,000 bbl): Grade No. 4 Oil	4-03-011-67	1000 Gallons Storage Capacity
	Floating-Roof Tanks (67,000 bbl): Grade No. 2 Oil	4-03-011-68	1000 Gallons Storage Capacity

TABLE 2.7-1

(CONTINUED)

Source Description	Process Description	SCC	Units
<b>Storage Tanks (Continued)</b>			
Floating-Roof 67,000-Barrel Fuel Tanks: Standing Loss (Continued)	Floating-Roof Tanks (67,000 bbl): Grade No. 1 Oil	4-03-011-69	1000 Gallons Storage Capacity
Floating-Roof Fuel Tanks: Withdrawal Loss	Floating-Roof Tanks: Grade No. 6 Oil	4-03-011-75	1000 Gallons Throughput
	Floating-Roof Tanks: Grade No. 5 Oil	4-03-011-76	1000 Gallons Throughput
	Floating-Roof Tanks: Grade No. 4 Oil	4-03-011-77	1000 Gallons Throughput
	Floating-Roof Tanks: Grade No. 2 Oil	4-03-011-78	1000 Gallons Throughput
	Floating-Roof Tanks: Grade No. 1 Oil	4-03-011-79	1000 Gallons Throughput
<b>Fugitive Emissions</b>			
Coal	Storage Bins - Coal	3-05-102-03	Tons Processed
	Open Stockpiles - Coal	3-05-103-03	Tons Processed
	Unloading - Coal	3-05-104-03	Tons Processed
	Loading - Coal	3-05-105-03	Tons Processed
	Conveyors	3-05-101-03	Tons Processed
Limestone	Storage Bins - Limestone	3-05-102-05	Tons Processed
	Open Stockpiles - Limestone	3-05-103-05	Tons Processed
	Unloading - Limestone	3-05-104-05	Tons Processed
	Loading - Limestone	3-05-105-05	Tons Processed
	Conveyors - Limestone	3-05-101-05	Tons Processed
Wood/Bark	Storage Bins - Wood/Bark	3-07-040-01	Tons Processed

TABLE 2.7-1

(CONTINUED)

Source Description	Process Description	SCC	Units
<b>Fugitive Emissions (Continued)</b>			
Wood/Bark (Continued)	Stockpiles - Wood/Bark	3-07-040-02	Tons Processed
	Unloading - Wood/Bark	3-07-040-03	Tons Processed
	Loading - Wood/Bark	3-07-040-04	Tons Processed
	Conveyors - Wood/Bark	3-07-040-05	Tons Processed
Solid and Liquid Waste	Storage Bins - Solid Waste	5-04-003-20	Tons Processed
	Storage Bins - Liquid Waste	5-04-003-50	Tons Processed
	Stockpile - Solid Waste	5-04-003-01	Tons Processed
	Loading - Solid Waste	5-04-003-03	Tons Processed
	Transfer - Liquid Waste	5-04-003-51	Tons Processed
	Unloading - Solid Waste	5-04-003-02	Tons Processed
Miscellaneous	Miscellaneous Fugitive Emissions	3-05-888-01 to 05	Tons Burned

<sup>a</sup> To determine which SCC is most appropriate, more detailed information can be found on the CHIEF bulletin board.

<sup>b</sup> POTW = Publicly owned treatment works.

<sup>c</sup> bbl = Barrel.

**TABLE 2.7-2**  
**AIRS CONTROL DEVICE CODES<sup>a</sup>**

Control Device	Code
Wet Scrubber - High-Efficiency	001
Wet Scrubber - Medium-Efficiency	002
Wet Scrubber - Low-Efficiency	003
Gravity Collector - High-Efficiency	004
Gravity Collector - Medium-Efficiency	005
Gravity Collector - Low-Efficiency	006
Centrifugal Collector - High-Efficiency	007
Centrifugal Collector - Medium-Efficiency	008
Centrifugal Collector - Low-Efficiency	009
Electrostatic Precipitator - High-Efficiency	010
Electrostatic Precipitator - Medium-Efficiency	011
Electrostatic Precipitator - Low-Efficiency	012
Fabric Filter - High-Efficiency	016
Fabric Filter - Medium-Efficiency	017
Fabric Filter - Low-Efficiency	018
Mist Eliminator - High-Velocity	014
Mist Eliminator - Low-Velocity	015
Modified Furnace or Burner Design	024
Staged Combustion	025
Flue Gas Recirculation	026
Reduced Combustion-Air Preheating	027
Steam or Water Injection	028
Low-Excess Air Firing	029



TABLE 2.7-2

(CONTINUED)

Control Device	Code
Use of Fuel with Low Nitrogen Content	030
Catalytic Reduction	065
Selective Noncatalytic Reduction for NO <sub>x</sub>	107
Catalytic Oxidation - Flue Gas Desulfurization	039
Dry Limestone Injection	041
Wet Limestone Injection	042
Venturi Scrubber	053
Wet Lime Slurry Scrubbing	067
Alkaline Fly Ash Scrubbing	068
Sodium Carbonate Scrubbing	069
Miscellaneous Control Device	099

<sup>a</sup> Source: EPA, January 1992. Control device efficiency ranges are defined for individual pollutants in AP-42 (EPA, January 1995).

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## **APPENDIX A**

# **EXAMPLE DATA COLLECTION FORM AND INSTRUCTIONS - BOILER**

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**EXAMPLE DATA COLLECTION FORM INSTRUCTIONS - BOILER**

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 methods (described in Sections 3 and 4) 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 you want to modify the form to better serve your needs, an electronic copy of the form may be obtained through the EIIP on the CHIEF bulletin board system (BBS).
5. If rated capacity is not documented in MMBtu/hr, please enter the capacity in lb/hr steam produced, or other appropriate units of measure.
6. 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.
7. 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 - BOILER****GENERAL INFORMATION**

Facility/Plant Name: \_\_\_\_\_

SIC Code: \_\_\_\_\_

SCC: \_\_\_\_\_

SCC 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: \_\_\_\_\_

**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<sup>a</sup>:**

Year:

Maximum Hourly Fuel Use (units):

Monthly Fuel Use (units):

January:

February:

March:

April:

May:

June:

July:

August:

September:

October:

November:

December:

Total Annual Fuel Use (units):

<sup>a</sup> This form should be completed for each fuel type used.



---

**FIRING CONFIGURATION (Check the appropriate type)**

---

Tangential Fired ☐    Horizontally Fired ☐    Vertically Fired ☐    Pulverized Coal Fired ☐

Dry Bottom ☐    Wet Bottom ☐

Cyclone Furnace ☐

Spreader Stoker ☐    Uncontrolled ☐    Controlled ☐

Overfeed Stoker ☐    Uncontrolled ☐    Controlled ☐

Underfeed Stoker ☐    Uncontrolled ☐    Controlled ☐

Hand-fired Units ☐

---

**POLLUTION CONTROL EQUIPMENT (Enter control efficiency and source of information)**

---

ESP:

Baghouse:

Wet Scrubber:

Dry Scrubber:

Spray Dryer:

Cyclone:

Other:

---

**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 (acsf/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):

## EMISSION ESTIMATION RESULTS

Unit ID: \_\_\_\_\_  
Fuel Type: \_\_\_\_\_

Pollutant	Emission Estimation Method <sup>a</sup>	Emissions	Emissions Units	Emission Factor <sup>b</sup>	Emission Factor Units	Comments
VOC						
NO <sub>x</sub>						
CO						
SO <sub>2</sub>						
PM <sub>10</sub>						
Total Particulate						
Hazardous Air Pollutants (list individually)						

<sup>a</sup> Use the following codes to indicate which emission estimation method is used for each pollutant:

CEMS/PEM = CEMS/PEM

Emission Factor = EF

Stack Test Data = ST

Other (indicate) = O

Fuel Analysis = FA

<sup>b</sup> Where applicable, enter the emission factor and provide the full citation of the reference or source of information from where the emission factor was obtained. If the emission factor is from a published source, include the name of the source, the year, and the page number. If the emission factor is from a proprietary source, include the name of the source and the year.

**VOLUME II: CHAPTER 3**

# **PREFERRED AND ALTERNATIVE METHODS FOR ESTIMATING AIR EMISSIONS FROM HOT-MIX ASPHALT PLANTS**

**July 1996**



Prepared by:  
Eastern Research Group, Inc.

Prepared for:  
Point Sources Committee  
Emission Inventory Improvement Program

## DISCLAIMER

This document was furnished to the Emission Inventory Improvement Program and the U.S. Environmental Protection Agency by Eastern Research Group, Inc., Morrisville, North Carolina. This report is intended to be a final document and has been reviewed and approved for publication. The opinions, findings, and conclusions expressed represent a consensus of the members of the Emission Inventory Improvement Program.

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# INTRODUCTION

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The purposes of the preferred methods guidelines are to describe emission estimation techniques for stationary point sources in a clear and unambiguous manner and to provide concise example calculations to aid in the preparation of emission inventories. While emissions estimates are not provided, this information may be used to select an emission estimation technique best suited to a particular application. This chapter describes the procedures and recommends approaches for estimating emissions from hot-mix asphalt (HMA) plants.

Section 2 of this chapter contains a general description of the HMA plant source category, common emission sources, and an overview of the available control technologies used at HMA plants. Section 3 of this chapter provides an overview of available emission estimation methods.

Section 4 presents the preferred methods for estimating emissions from HMA plants, while Section 5 presents the alternative emission estimation techniques. It should be noted that the use of site-specific emission data is preferred over the use of industry-averaged data such as *AP-42* emission factors (EPA, 1995a). Depending upon available resources, site-specific data may not be cost effective to obtain. However, this site-specific data may be a requirement of the state implementation plan (SIP) and may preclude the use of other data. Quality assurance and control procedures are described in Section 6. Coding procedures used for data input and storage are discussed in Section 7. Some states use their own unique identification codes, so individual state agencies should be contacted to determine the appropriate coding scheme to use. References are cited in Section 8. Appendix A provides an example data collection form to assist in information gathering prior to emissions calculations.

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## GENERAL SOURCE CATEGORY DESCRIPTION

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This section provides a brief overview of HMA plants. The reader is referred to the *Air Pollution Engineering Manual* (referred to as AP-40) and AP-42, 5th Edition, January 1995, for a more detailed discussion on these facilities (AWMA, 1992; EPA, 1995a).

### 2.1 PROCESS DESCRIPTION

HMA paving materials are a mixture of well graded, high quality aggregate (which can include reclaimed or recycled asphalt pavement [RAP]) and liquid asphalt cement, which is heated and mixed in measured quantities to produce HMA. Aggregate and RAP (if used) constitute over 92 percent by weight of the total HMA mixture. Aside from the relative amounts and types of aggregate and RAP used, mix characteristics are determined by the amount and grade of asphalt cement used. Additionally, the asphalt cement may be blended with petroleum distillates or emulsifiers to produce "cold mix" asphalt, sometimes referred to as cutback or emulsified asphalt, respectively (EPA, 1995a; Gunkel, 1992; TNRCC, 1994).

The process of producing HMA involves drying and heating the aggregate to prepare them for the asphalt cement coating. In the drying process, the aggregate are dried in a rotating, slightly inclined, direct-fired drum dryer. The aggregate is introduced into the higher end of the dryer. The interior of the dryer is equipped with flights that veil the aggregate through the hot exhaust as the dryer rotates. After drying, the aggregate is typically heated to temperatures ranging from 275 to 325°F and then coated with asphalt cement in one of two ways. In most drum mix plants, the asphalt is introduced directly into the dryer chamber to coat the aggregate. In batch mix plants, the mixing of aggregate and asphalt takes place in a separate mixing chamber called a pug mill.

The variations in the HMA manufacturing process are primarily defined by the following types of plants:

- Batch mix plants;
- Parallel flow drum mix plants; and

- Counterflow drum mix plants.

(Continuous mix plants, which represent a very small fraction of the plants presently operating, are not discussed here [EPA, 1995a]. The estimation techniques described for the batch mixing process should be followed when estimating emissions from continuous mix plant operations.).

### **2.1.1 BATCH MIXING PROCESS**

In the batch mixing process, the aggregate is transported from storage piles and is placed in the appropriate hoppers of a cold feed unit. The material is metered from the hoppers onto a conveyor belt and is transported into a rotary dryer (typically gas- or oil-fired) (Gunkel, 1992; NAPA, 1995).

As hot aggregate leave the dryer, it drops into a bucket elevator and is transferred to a set of vibrating screens, that drop the aggregate into individual "hot" bins according to size. To control aggregate size distribution in the final batch mix, the operator opens various hot bins over a weigh hopper until the desired mix and weight for individual components are obtained. RAP may also be added at this point. Concurrent with the aggregate being weighed, liquid asphalt cement is pumped from a heated storage tank to an asphalt bucket, where it is weighed to achieve the desired mix.

Aggregate from the weigh hopper is dropped into the mixer (pug mill) and dry-mixed for 6 to 10 seconds. The liquid asphalt is then dropped into the pug mill where it is wet-mixed until homogeneous. The hot-mix is conveyed to a hot storage silo or dropped directly into a truck and hauled to a job site.

### **2.1.2 PARALLEL FLOW DRUM MIXING PROCESS**

The parallel flow drum mixing process is a continuous mixing type process that uses proportioning cold feed controls for the process materials. The major difference between this process and the batch process is that the dryer is used not only to dry aggregate but also to mix the heated and dried aggregate with the liquid asphalt cement. Aggregate, which has been proportioned by size gradations, is introduced to the drum at the burner end. As the drum rotates, the aggregate, as well as the combustion products, move toward the other end of the drum in parallel (EPA, 1995). The asphalt cement is introduced into approximately the lower third of the drum. The aggregate are is coated with asphalt cement as it veils to the end of the drum. The RAP is introduced at some point along the length of the drum, as far away from the combustion zone as possible (about the midpoint of the drum), but with enough drum length remaining to dry and heat the material adequately before it reaches the coating zone (Gunkel, 1992). The flow of liquid asphalt cement is controlled by a variable flow pump electronically linked to the aggregate and RAP weigh scales (EPA, 1995a).

### 2.1.3 COUNTERFLOW DRUM MIXING PROCESS

In the counterflow drum mixing process, the aggregate is proportioned through a cold feed system prior to introduction to the drying process. As opposed to the parallel flow drum mixing process though, the aggregate moves opposite to the flow of the exhaust gases. After drying and heating take place, the aggregate is transferred to a part of the drum that is not exposed to the exhaust gas and coated with asphalt cement. This process prevents stripping of the asphalt cement by the hot exhaust gas. If RAP is used, it is usually introduced into the coating chamber.

## 2.2 EMISSION SOURCES

Emissions from HMA plants derive from both controlled (i.e., ducted) and uncontrolled sources. Section 7 lists the source classification codes (SCCs) for these emission points.

### 2.2.1 MATERIAL HANDLING (FUGITIVE EMISSIONS)

Material handling includes the receipt, movement, and processing of fuel and materials used at the HMA facility. Fugitive particulate matter (PM) emissions from aggregate storage piles are typically caused by front-end loader operations that transport the aggregate to the cold feed unit hoppers. The amount of fugitive PM emissions from aggregate piles will be greater in strong winds (Gunkel, 1992). Piles of RAP, because RAP is coated with asphalt cement, are not likely to cause significant fugitive dust problems. Other pre-dryer fugitive emission sources include the transfer of aggregate from the cold feed unit hoppers to the dryer feed conveyor and, subsequently, to the dryer entrance. Aggregate moisture content prior to entry into the dryer is typically 3 percent to 7 percent. This moisture content, along with aggregate size classification, tend to minimize emissions from these sources, which contribute little to total facility PM emissions. PM less than or equal to 10  $\mu\text{m}$  in diameter ( $\text{PM}_{10}$ ) emissions from these sources are reported to account for about 19 percent of their total PM emissions (NAPA, 1995).

If crushing, breaking, or grinding operations occur at the plant, these may result in fugitive PM emissions (TNRCC, 1994). Also, fine particulate collected from the baghouses can be a source of fugitive emissions as the overflow PM is transported by truck (enclosed or tarped) for on-site disposal. At all HMA plants there may be PM and slight process fugitive volatile organic compound (VOC) emissions from the transport and handling of the hot-mix from the mixer to the storage silo and also from the load-out operations to the delivery trucks (EPA, 1994a). Small amounts of VOC emissions can also result from the transfer of liquid and gaseous fuels, although natural gas is normally transported in a pipeline (Gunkel, 1992, Wiese, 1995).



### 2.2.2 GENERATORS

Diesel generators may be used at portable HMA plants to provide electricity. Maximum electricity generation during process operations is typically less than 500 kilowatts per hour (kW/hr) with rates of 20-50 kW/hr at other times (Fore, 1995). (Note that 1 kW equals 1.34 horsepower.) Emissions from these generators are likely uncontrolled and are correlated with fuel usage, as determined by engine size, load factor, and hours of operation. Emissions primarily include criteria pollutants—particularly  $\text{NO}_x$  and CO (EPA, 1995b).

### 2.2.3 STORAGE TANKS

Storage tanks are used to store fuel oils, heated liquid asphalts, and asphalt cement at HMA plants, and may be a source of VOC emissions. Storage tanks at HMA plants are usually fixed roof (closed or enclosed) due to the smaller size of the tanks, usually less than 30,000 gallons (Fore, 1995; Patterson, 1995). Emissions from fixed-roof tanks (closed or enclosed) are typically divided into two categories: working losses and breathing losses. Working losses refer to the combined loss from filling and emptying the tank. Filling losses occur when the VOC contained in the saturated air are displaced from a fixed-roof vessel during loading. Emptying losses occur when air drawn into the tank becomes saturated and expands, exceeding the capacity of the vapor space. Breathing losses are the expulsion of vapor from a tank through vapor expansion caused by changes in temperature and pressure. Because of the small tank sizes and fuel usage, total VOC emissions would typically be less than 1 ton per year. Emissions from tanks used for No. 5 or 6 oils or for asphalt cement may be increased when they are heated to control oil viscosity. Emissions from asphalt cement tanks are particularly low, due to its low vapor pressure.

The TANKS computer program, available from the EPA, is commonly used to quantify emissions; however, its use should be carefully evaluated since it is a complicated program with a great number of input parameters. Check with your local or state authority as to whether TANKS is required for your facility. The use of the TANKS program for calculating emissions from storage tanks is discussed in Chapter 1 of this volume, *Introduction to Stationary Point Source Emissions Inventory Development*.

### 2.2.4 PROCESS EMISSIONS

The most significant source of emissions from HMA plants is the dryer (EPA, 1995a; Gunkel, 1992; NAPA, 1995). Dryer burners capacities are usually less than 100 million British thermal units per hour (100 MMBtu/hr), but may be as large as 200 MMBtu/hr (NAPA, 1995; Wiese, 1995). Combustion emissions from the dryer include products of complete combustion and products of incomplete combustion. Products of complete

combustion include carbon dioxide ( $\text{CO}_2$ ), water, oxides of nitrogen ( $\text{NO}_x$ ), and, if sulfur is present in the fuel, oxides of sulfur ( $\text{SO}_x$ ), for example sulfur dioxide ( $\text{SO}_2$ ). Products of incomplete combustion include carbon monoxide ( $\text{CO}$ ), VOC, including smaller quantities of hazardous air pollutants (HAP) (e.g., benzene, toluene, and xylene), and other organic particulate matter. These incomplete combustion emissions result from improper air and fuel mixtures (e.g., poor mixing of fuel and air), inadequate fuel air residence time and temperature, and quenching of the burner flame. Depending on the fuel, small amounts of ash may also be emitted. In addition to combustion emissions, emissions from a dryer include water and PM from the aggregate. Non-combustion emissions from rotary drum dryers may include small amounts of VOC, polynuclear aromatic hydrocarbons (PAH), aldehydes, and HAP from the volatile fraction of the asphalt cement and organic residues that are commonly found in recycled asphalt (i.e., gasoline and engine oils) (EPA, 1995a; Gunkel, 1992; TNRCC, 1994; EPA, 1991a; NAPA, 1995).

For drum mix processes, the dryer contributes most of the facility's total PM emissions (NAPA, 1995). At these plants, PM emissions from post-dryer processes are minimal due to the mixing with asphalt cement.

In batch mix plants, post-dryer PM emission sources include hot aggregate screens, hot bins, weigh hoppers, and pug mill mixers (NAPA, 1995, TNRCC, 1994). Uncontrolled PM emissions from these sources will be greater than emissions from pre-dryer sources primarily due to the lower aggregate moisture content in addition to the greater number of transfer points (NAPA, 1995). Post-dryer emission sources at batch plants are usually controlled by venting to the primary dust collector (along with the dryer gas) or sometimes to a separate dust collection system. Captured emissions are mostly aggregate dust, but they may also contain gaseous VOC and a fine aerosol of condensed liquid particles. This liquid aerosol is created by the condensation of gas into particles during the cooling of organic vapors volatilized from the asphalt cement and RAP in the pug mill. The aerosol emissions are primarily dependent upon the temperatures of the materials entering the mixing process. This problem appears to be more acute when the RAP has not been preheated prior to entering the pug mill or boot of the hot elevator. This results in a sudden, rapid release of steam resulting from evaporation of the moisture in the RAP upon mixing it into the superheated (often above  $400^\circ\text{F}$ ) aggregate (EPA, 1995a; Gunkel, 1992).

Recycled tires, which are sometimes used in the production of asphalt concrete, may be a source of VOC and PM emissions. When heated, ground up tire pieces (referred to as crumb rubber) have been shown to emit VOC. These emissions are a function of the quantity of crumb rubber used in the liquid asphalt and the temperature of the mix (TNRCC, 1994).

If cutback or emulsions are used to make cold mix asphalt concrete, VOC emissions can be significant. These emissions can occur as stack emissions from mixing of asphalt batches and as fugitives from handling areas. Emission levels depend on the type and quantity of the cold mix produced. VOC emissions associated with cutback asphalt production may include naphtha, kerosene, or diesel vapors.

In some states (e.g., Wisconsin) asphalt drum dryers are used for soil remediation. In this practice, the contaminated soil may be run through the dryer as an aggregate, cut with virgin aggregate at ratios ranging from 1:1 to 1:10 (contaminated soil to virgin aggregate) depending on the clay content of the material. The dried material is coated with asphalt and "RAP" is produced. The manufactured RAP can then be fed into the hot mix asphalt process normally, as any RAP would be, and incorporated into the final mix. This practice can result in HAP emissions, which are a function of the HAP content and quantity of the soil as well as the dryer temperature and residence time. There is significant control of VOC/HAPs in the dryer drum. Based on testing performed by the asphalt industry, a control on the average of 75 percent with numbers ranging from 45 to 98 percent control depending on the plant type (parallel flow versus counterflow drum designs) have been recorded. (Wiese, 1995).

## 2.3 PROCESS DESIGN AND OPERATING FACTORS INFLUENCING EMISSIONS

There are two methods of introducing combustion air to the dryer burners and two types of combustion chambers, with the combination resulting in four types of burner systems that can be found at HMA plants. The type of burner system employed has a direct effect on gaseous combustion emissions, including VOC, HAP, CO, and NO<sub>x</sub>. The two types of burners related to the introduction of combustion air include the induced draft burner and the forced draft burner. Forced draft burners are usually more fuel efficient under proper operating and maintenance conditions and, consequently, have lower emissions (Gunkel, 1992). The two types of burners related to the use of combustion chambers include those with refractory-lined combustion chambers and those without combustion chambers. While most older burners had combustion chambers, today's burners generally do not (Gunkel, 1992).

Incomplete combustion in the dryer burner increases emissions of CO and organics (e.g., VOC). This may be caused by: (1) improper air and fuel mixtures (e.g., poor mixing prior to combustion); (2) inadequate residence time (i.e., too short) and temperature (i.e., too low); and (3) flame quenching. The primary cause of CO and organic emissions in chamberless burners is quenching of the flame caused by improper lighting. This occurs when the flame temperature is reduced by contact with cold surfaces or cold material dropping through the flame (NAPA, 1995). In addition, the

moisture content of the aggregate in the dryer may contribute to the formation of CO and unburned fuel emissions by reducing the temperature (Gunkel, 1992). A secondary cause of these gaseous pollutants may be excess air entering the combustion process, particularly in the case of an induced draft burner. The use of a precombustion chamber to promote better fuel air mixing may reduce VOC and CO emissions.

NO<sub>x</sub> is primarily formed from nitrogen in the combustion air, thermal NO<sub>x</sub>, and from nitrogen in the fuel, fuel NO<sub>x</sub>. Thermal NO<sub>x</sub> is negligible below 1300°C and increases with combustion temperature (Nevers, 1995). Fuel NO<sub>x</sub>, which is likely lower than thermal NO<sub>x</sub> from dryer burners, is formed by conversion of some of the nitrogen in the burner fuel. While No. 4, 5 and 6 fuel oils may contain significant amounts of nitrogen, No. 1 and 2 oils and natural gas contain very little (Nevers, 1995).

Dryer burners can be designed to operate on almost any type of fuel; natural gas, liquefied petroleum gas (LPG), light fuel oils, heavy fuel oils, and waste fuel oils (Gunkel, 1992). The type of fuel and its sulfur content will affect SO<sub>x</sub>, VOC, and HAP emissions and, to a lesser extent, NO<sub>x</sub> and CO emissions. Sulfur in the burner fuel will convert to SO<sub>x</sub> during combustion; burner operation will have little effect on the percent of this conversion (TNRCC, 1994; EIIP, 1995). VOC emissions from natural gas combustion are less than emissions from LPG or fuel oil combustion, which are lower than emissions from waste-blended fuel combustion (TNRCC, 1994). Ash levels and concentrations of most of the trace elements in waste oils are normally much higher than those in virgin oils, producing higher emission levels of PM and trace metals. Chlorine in waste oils also typically exceeds the levels in virgin oils. High levels of halogenated solvents are often found in waste oil as a result of the additions of contaminant solvents to the waste oils.

When cold mix asphalt cement is heated, organic fumes (i.e., VOC) may be released as visible emissions if the asphalt is cut with lighter ends or other additives needed for a specification; however, these emissions are not normally seen when heating asphalt cement, as the boiling point of asphalt cement is much higher (Patterson, 1995). In drum mix plants, hydrocarbon (e.g., aldehydes) and PAH emissions may result from the heating and mixing of liquid asphalt inside the drum as hot exhaust gas in the drum strips light ends from the asphalt. The magnitude of these emissions is a function of the process temperatures and constituents of the asphalt being used. The mixing zone temperature in parallel flow drums is largely a function of drum length and flighting. The processing of RAP materials, particularly in parallel flow plants, may also increase VOC emissions, because of an increase in mixing zone temperature during processing. In counterflow drum mix plants, the liquid asphalt cement, aggregate, and sometimes RAP, are mixed in a zone not in contact with the hot exhaust gas stream. Consequently, counterflow drum mix plants will likely have lower VOC emissions than parallel flow drum mix plants. In batch mix plants, the amount of hydrocarbons (i.e., liquid aerosol) produced depends to a large extent on the temperature of the asphalt cement and aggregate entering the pug mill (EPA, 1995a; Gunkel, 1992).

Particulate emissions from parallel flow drum mix plants are reduced because the aggregate and asphalt cement mix for a longer time. The amount of PM generated within the dryer in this process is usually lower than that generated within batch dryers, but because the asphalt is heated to higher temperatures for a longer period of time, organic emissions (gaseous and liquid aerosol) are typically greater than in conventional batch plants (EPA, 1991a).

## 2.4 CONTROL TECHNIQUES

Control techniques and devices typically used at HMA facilities are described below and presented in Table 3.2-1. Control efficiency for a specific piece of equipment will vary depending not only on the type of equipment and quality of the maintenance/repair program at a particular facility, but also the velocity of the air through the dryer.

### 2.4.1 PROCESS AND PROCESS FUGITIVE PARTICULATE CONTROL (INCLUDING METALS)

Process and process fugitive particulates at HMA plants are typically controlled using primary and secondary collection devices. Primary devices typically include cyclone and settling chambers to remove larger PM. Smaller PM is typically collected by secondary devices, including fabric filters and venturi scrubbers. PM from the dry control devices is usually collected and mixed back into the process near the entry point of the asphalt cement in drum-mix plants. In addition to PM and PM<sub>10</sub> emissions, particulate control also serves to remove trace metals emitted as particulate. These controls are primarily used to reduce PM emissions from the dryer; however at batch mix plants, these controls are also used for post-dryer sources, where fugitive emissions may be scavenged at an efficiency of 98 percent (NAPA, 1995).

#### *Cyclones*

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 precleaners to remove the bulk of heavier particles from the flue gas before it enters a secondary or final collection system. A secondary collection device, which is more effective at removing particulates than a primary collector, is used to capture remaining PM from the primary collector effluent.

In batch plants, cyclones are often used to return collected material to the hot elevator and to combine it with the drier virgin aggregate (EPA, 1995a; Gunkel, 1992; Khan, 1977; NAPA, 1995).

TABLE 3.2-1

## TYPICAL HOT-MIX ASPHALT PLANT EMISSION CONTROL TECHNIQUES

Emission Source	Pollutant	Control Technique	Typical Efficiency (%)
Process	PM and PM <sub>10</sub>	Cyclones	50 - 75 <sup>a,b</sup>
		Multiple cyclones	90 <sup>c</sup>
		Settling chamber	<50 <sup>b</sup>
		Baghouse	99 - 99.97 <sup>a,d</sup>
		Venturi scrubber	90 - 99.5 <sup>d,e</sup>
	VOC	Dryer and combustion process modifications	37 - 86 <sup>f,g</sup>
	SO <sub>x</sub>	Limestone	50 <sup>b,e</sup>
		Low sulfur fuel	80 <sup>c</sup>
Fugitive dust	PM and PM <sub>10</sub>	Paving and maintenance	60 - 99 <sup>g</sup>
		Wetting and crusting agents	70 <sup>b</sup> - 80 <sup>c</sup>
		Crushed RAP material, asphalt shingles	70 <sup>h</sup>

<sup>a</sup> Control efficiency dependent on particle size ratio and size of equipment.

<sup>b</sup> Source: Patterson, 1995c.

<sup>c</sup> Source: EIIP, 1995.

<sup>d</sup> Typical efficiencies at a hot-mix asphalt plant.

<sup>e</sup> Source: TNRCC, 1995.

<sup>f</sup> Source: Gunkel, 1992.

<sup>g</sup> Source: TNRCC, 1994.

<sup>h</sup> Source: Patterson, 1995a.

### ***Multiple Cyclones***

A multiple cyclone consists of numerous small-diameter cyclones operating in parallel. Multiple cyclones are less expensive to install and operate than fabric filters, but are not as effective at removing smaller particulates. They are often used as precleaners to remove the bulk of heavier particles from the flue gas before it enters the main control device (EPA, 1995a; Gunkel, 1992; Khan, 1977).

### ***Settling Chambers***

Settling chambers, also referred to as knock-out boxes, are used at HMA plants as primary dust collection equipment. To capture remaining PM, the primary collector effluent is ducted to a secondary collection device such as a baghouse, which is more effective at removing particulates (EPA, 1995a, Khan, 1977).

### ***Baghouses***

Baghouses, or fabric filter systems, filter particles through fabric filtering elements (bags). Particles are caught on the surface of the bags, while the cleaned flue gas passes through. To minimize pressure drop, the bags must be cleaned periodically as the dust layer builds up. Fabric filters can achieve the highest particulate collection efficiency of all particulate control devices. Most HMA plants with baghouses use them for process and process fugitive emissions control. The captured dust from these devices is usually returned to the production process (EPA, 1995a; Gunkel, 1992).

### ***Venturi Scrubbers***

Venturi scrubbers (sometimes referred to as high energy wet scrubbers) are used to remove coarse and fine particulate matter. Flue gas passes through a venturi tube while low pressure water is added at the throat. The turbulence in the venturi promotes intimate contact between the particles and the water. The wetted particles and droplets are collected in a cyclone spray separator (sometimes called a cyclonic demister). Venturi scrubbers are often used in similar applications to baghouses (EPA, 1995a; Gunkel, 1992).

In addition to controlling particulate emissions, the venturi scrubber is likely to remove some of the process organic emissions from the exhaust gas (Gunkel, 1992). While the high-pressure venturi scrubber is reliable at controlling PM, it requires considerable attention and daily maintenance to maintain a high degree of PM removal efficiency (Gunkel, 1992).

## 2.4.2 FUGITIVE PARTICULATE EMISSIONS CONTROL

### *Driving Surfaces*

Unpaved driving surfaces are commonly maintained by utilizing wet-down techniques using water, or other agents. In some areas unpaved roadways may alternatively be covered with crushed recycled material (e.g., tires, asphalt shingles) with equal success. In recent years, there has been a trend toward paving the driving surfaces to eliminate fugitive particulates. Facilities with paved surfaces may additionally employ sweeping or vacuuming as maintenance measures to reduce PM emissions (EPA, 1995a; Gunkel, 1992; TRNCC, 1994).

### *Aggregate Stockpiles*

Watering of the stockpiles is not typically used because of the burden it puts on the heating and drying process (Gunkel, 1992). Occasionally, crusting agents may be applied to aggregate piles. These crusting agents have served fairly well to mitigate fugitive dust emissions in these instances (TNRCC, 1994). There are many variables that affect the fugitive dust emissions from stockpiles including moisture content of the material, amount of fines (< 200 mesh), and age of pile (i.e., older piles tend to loose their surface fines). Pre-washed aggregate, from which fines have been removed, may be used for additional PM control (Patterson, 1995a).

## 2.4.3 VOC (INCLUDING HAP) CONTROL

VOCs are the total organic compounds emitted by the process minus the methane constituent. Once the exhaust stream cools after discharge from the process stack, some VOCs condense to form a fine liquid aerosol or "blue smoke" plume. A number of process modifications or restrictions have been introduced to reduce blue smoke, including installation of flame shields, rearrangement of flights inside the drum, adjustments of the asphalt injection point, and other design changes (EPA, 1995a; Gunkel, 1992). Periodic burner tune-ups may reduce VOC emissions by about 38 percent (Patterson, 1995a). Burner combustion air can be optimized to reduce emissions by monitoring the pressure drop across induced draft burners with a photohelic device tied to an automatic damper that adjusts the exhaust fan (Patterson, 1995a).

Organic vapors from heated asphalt cement storage tanks can be reduced by condensing the vapors with air-cooled vent pipes. In some cases, tank emissions may be routed back to combustion units. Organic emissions from heated asphalt storage tanks may also be controlled with carbon canisters on the vents or by other measures such as



condensing precipitation or stainless steel shaving condensers (Wiese, 1995). Although not common, organic emissions from truck-loading of asphaltic concrete can be controlled by venting into the dryer (EPA, 1995a). This is usually practiced in non-attainment areas.

#### **2.4.4 SULFUR OXIDES CONTROL**

##### ***Low Sulfur Fuel***

This approach to reducing  $\text{SO}_x$  emissions reduces the sulfur fed to the combustor by burning low sulfur fuels. Fuel blending is the process of mixing higher sulfur content fuels with lower sulfur fuels (e.g., low sulfur oil). The goal of effective fuel blending is to provide a fuel supply with reasonably uniform properties that meet the blend specification, typically including sulfur content, heating value, and moisture content (EIIP, 1995).

##### ***Aggregate Adsorption***

Alkaline aggregate (i.e., limestone) may adsorb sulfur compounds from the exhaust gas. In exhaust streams controlled by baghouses,  $\text{SO}_x$  may be reduced by limestone dust that coats the baghouse filters (Patterson, 1995). Consequently, limestone aggregate may maximize the removal of sulfur compounds (Gunkel, 1992). Sulfur compounds from the exhaust gas may also be adsorbed by a venturi scrubber with recirculated water containing limestone (Wiese, 1995).

#### **2.4.5 NITROGEN OXIDES CONTROL**

##### ***Low Nitrogen Fuels***

Fuels lower in nitrogen content may reduce some  $\text{NO}_x$  emissions (NAPA, 1995). At temperatures above  $1300^\circ\text{C}$ , however, conversion from high-nitrogen fuels to low-nitrogen fuels may not substantially reduce  $\text{NO}_x$  emissions, as thermal  $\text{NO}_x$  contributions will be more significant (Nevers, 1995). Consequently,  $\text{NO}_x$  emissions are generally inversely related to CO emissions (NAPA, 1995).

Staged combustion systems such as low  $\text{NO}_x$  burners that are used to reduce  $\text{NO}_x$  emissions in other industries, are not typically employed in the HMA industry due to economic and engineering considerations (NAPA, 1995). Recirculation of the exhaust gas may be precluded by the relatively high moisture content (e.g., 30 percent) of the gas stream. Exhaust recirculation in these instances may cause some flame quenching around the edges and could contribute to higher VOC and CO emissions when sealed burners are not used (Patterson, 1995a).

## OVERVIEW OF AVAILABLE METHODS

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### 3.1 DESCRIPTION OF EMISSION ESTIMATION METHODOLOGIES

There are several methodologies available for calculating emissions from HMA plants. The method used is dependent upon available data, available resources, and the degree of accuracy required in the estimate. In general, site-specific data is preferred over industry averaged data such as *AP-42* emission factors for more accurate emissions estimates (EPA, 1995a). (Each state may have a different preference or requirement and so it is suggested that the reader contact the nearest state or local air pollution agency before deciding on which emission estimation methodology to use.) This document evaluates emission estimation methodologies with respect to accuracy and does not mandate any emission estimation method. For purposes of calculating peak season daily emissions for State Implementation Plan inventories, refer to the EPA *Procedures* manual (EPA, May 1991).

This section discusses the methods available for calculating emissions from HMA plants and identifies the preferred method of calculation on a pollutant basis. These emission estimation methodologies are listed in no particular order and the reader should not infer a preference based on the order they are listed in this section. A discussion of the sampling and analytical methods available for monitoring each pollutant is provided in Chapter 1, *Introduction to Stationary Point Source Emissions Inventory Development*.

Emission estimation techniques for auxiliary processes, such as using EPA's TANKS program to calculate storage tank emissions, are also discussed in Chapter 1.

#### 3.1.1 STACK SAMPLING

Stack sampling provides a "snapshot" of emissions during the period of the stack test. Stack tests are typically performed during either representative (i.e., normal) or worst case conditions, depending upon the requirements of the state. Samples are collected from the stack using probes inserted through a port in the stack wall, and pollutants are collected in or on various media and sent to a laboratory for analysis. Pollutant concentrations are obtained by dividing the amount of pollutant collected during the test by the volume of the sample. Emission rates are then determined by multiplying the pollutant concentration by the volumetric stack gas flow rate. Because there are many steps in the stack sampling procedures where errors can occur, only experienced stack testers should perform such tests.

### 3.1.2 EMISSION FACTORS

Emission factors are available for many source categories and are based on the results of source tests performed at an individual plant or at one or more facilities within an industry. Basically, an emission factor is the pollutant emission rate relative to the level of source activity. Chapter 1 of this volume of documents contains a detailed discussion of the reliability, or quality, of available emission factors. EPA-developed emission factors for criteria and hazardous air pollutants are available in *AP-42*, the *Locating and Estimating Series* of documents, and the Factor Information Retrieval (FIRE) System.

### 3.1.3 FUEL ANALYSIS

Fuel analysis data can sometimes be used to predict emissions by applying mass conservation laws. For example, if the concentration of a pollutant, or pollutant precursor, in a fuel is known, emissions of that pollutant can be calculated by assuming that all of the pollutant is emitted or by adjusting the calculated emissions by the control efficiency. This approach is appropriate for SO<sub>2</sub>.

### 3.1.4 CONTINUOUS EMISSION MONITORING SYSTEM (CEMS) AND PREDICTIVE EMISSION MONITORING (PEM)

A CEMS provides a continuous record of emissions over time. Various principles are employed to measure the concentration of pollutants in the gas stream and are usually based on photometric measurements. Once the pollutant concentration is known, emission rates are obtained by multiplying the pollutant concentration by the volumetric gas flow rate. Stack gas flow rate can also be measured by continuous monitoring instruments; but it is more typically determined using manual methods (e.g., pitot tube traverse). At low pollutant concentrations, the accuracy of this method may decrease. Instrument drift can be problematic for CEMS and uncaptured data can create long-term, incomplete data sets.

PEM is based on developing a correlation between pollutant emission rates and process parameters. A PEM may be considered a specialized usage of an emission factor. Correlation tests must first be performed to develop this relationship. At a later time emissions can then be calculated using process parameters to predict emission rates based on the results of the initial source test.

## **3.2 COMPARISON OF AVAILABLE EMISSION ESTIMATION METHODOLOGIES**

Table 3.3-1 identifies the preferred and alternative emission estimation approach(s) for selected pollutants. Table 3.3-1 is ordered according to the accuracy of the emission estimation approach. The reader and the local air pollution agency must decide which emission estimation approach is applicable based on costs and air pollution control requirements in their area. The preferred method chosen should also recognize the time specificity of the emission estimate and the data quality. The quality of the data will depend on a variety of factors including the number of data points generated, the representativeness of those data points, and the proper operation and maintenance of the equipment being used to record the measurements.

### **3.2.1 STACK SAMPLING**

Without considering cost, stack sampling is the preferred emission estimation methodology for process  $\text{NO}_x$ , CO, VOC, THC, PM,  $\text{PM}_{10}$ , metals and speciated organics. EPA reference methods and other methods of known quality can be used to obtain accurate estimates of emissions at a given time for a particular facility.

### **3.2.2 EMISSION FACTORS**

Due to their availability and acceptance in the industry, emission factors are commonly used to prepare emission inventories. However, the emission estimate obtained from using emission factors is based upon emissions testing performed at similar facilities and may not accurately reflect emissions at a single source. Thus, the user should recognize that, in most cases, emission factors are averages of available industry-wide data with varying degrees of quality and may not be representative of averages for an individual facility within that industry. Emission factors are the preferred technique for estimating fugitive dust emissions for aggregate stockpiles and driving surfaces, as well as process fugitives.

### **3.2.3 FUEL ANALYSIS**

Fuel analysis can be used as an approximation if no emission factors or site specific stack test data are available. Once the concentration of sulfur in a fuel is known,  $\text{SO}_2$  emissions can be calculated based on mass conservation laws, assuming negligible adsorption by alkaline aggregates.

TABLE 3.3-1

**SUMMARY OF PREFERRED EMISSION  
ESTIMATION METHODS FOR HOT-MIX ASPHALT PLANTS**

Parameter	Preferred Emission Estimation Approach Ordered by Accuracy <sup>a</sup>
SO <sub>2</sub>	<ol style="list-style-type: none"> <li>1. Stack sampling data</li> <li>2. CEMS/PEM</li> <li>3. Fuel analysis</li> <li>4. EPA/state published emission factors<sup>b</sup></li> </ol>
NO <sub>x</sub>	<ol style="list-style-type: none"> <li>1. Stack sampling data</li> <li>2. CEMS/PEM data</li> <li>3. EPA/state published emission factors<sup>b</sup></li> </ol>
CO	<ol style="list-style-type: none"> <li>1. Stack sampling data</li> <li>2. CEMS/PEM data</li> <li>3. EPA/state published emission factors<sup>b</sup></li> </ol>
VOC	<ol style="list-style-type: none"> <li>1. Stack sampling data</li> <li>2. EPA/state published emission factors</li> </ol>
THC <sup>c</sup>	<ol style="list-style-type: none"> <li>1. Stack sampling data</li> <li>2. CEMS/PEM data</li> <li>3. EPA/state published emission factors<sup>b</sup></li> </ol>
PM	<ol style="list-style-type: none"> <li>1. Stack sampling data<sup>d</sup></li> <li>2. EPA/state published emission factors<sup>e</sup></li> </ol>
PM <sub>10</sub>	<ol style="list-style-type: none"> <li>1. Stack sampling data<sup>d</sup></li> <li>2. EPA/state published emission factors<sup>e</sup></li> </ol>
Heavy metals	<ol style="list-style-type: none"> <li>1. Stack sampling data</li> <li>2. EPA/state published emission factors<sup>b</sup></li> </ol>

TABLE 3.3-1

(CONTINUED)

Parameter	Preferred Emission Estimation Approach Ordered by Accuracy <sup>a</sup>
Speciated organics	1. Stack sampling data 2. EPA/state published emission factors <sup>b</sup>

<sup>a</sup> Preferred emission estimation approaches do not include considerations such as cost. The costs, benefits, and relative accuracy should be considered prior to method selection. Readers are advised to check with local air pollution control agency before choosing a preferred emission estimation approach.

<sup>b</sup> Assumes emission factors are not based on site-specific fuel analysis.

<sup>c</sup> THC = total hydrocarbons.

<sup>d</sup> Preferred method for process and process fugitive emissions.

<sup>e</sup> Preferred method for fugitive dust.

### 3.2.4 CEMS AND PEM

HMA plants would not likely estimate emissions using CEMS and PEM. HMA plants have conditions unfavorable to generating accurate CEM data including, high vibrations, high moisture content of the stack gas, and dust. Nightly shutdown of CEMS would also adversely affect their performance. In some instances, however, CEMS may be used to estimate emissions of  $\text{NO}_x$ , CO, and THC. This method may be used, for example, when detailed records of emissions are needed over time. Similarly, stack gas flow rate may be monitored using a continuous flow rate monitor, including pitot tubes, ultrasonic, and thermal monitors (Patterson, 1995a).

PEM is a predictive emission estimation methodology whereby emissions are correlated to process parameters based on an initial series of stack tests at a facility. For example, VOC emissions may occur from asphalt mixtures produced at various temperatures with different combustion fuels and varying quantities of asphalt cement, aggregates, RAP, and crumb rubber. Similarly, sulfur dioxide emissions may be controlled by scrubbers that operate at variable pressure drops, alkalinity, and recirculation rates. These parameters may be monitored during the tests and correlated to the pollutant emission rates. Following the correlation development, parameters would be monitored to periodically predict emission rates. Periodic stack sampling may be required to verify that the predictive emission correlations are still accurate; if not, new correlations are developed.

## PREFERRED METHODS FOR ESTIMATING EMISSIONS

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Without consideration of cost, the preferred method for estimating emissions of most pollutants emitted from HMA plants is the use of site-specific recent stack tests. Each state may have a different preference or requirement and so it is suggested that the reader contact the nearest state or local air pollution agency before deciding on which emission estimation methodology to use. This section provides an outline for calculating emissions from HMA plants based on raw data collected by stack tests.

Table 3.4-1 lists the variables and symbols used in the following discussions.

### 4.1 EMISSION CALCULATIONS USING STACK SAMPLING DATA

Stack sampling test reports often provide emissions data in terms of lb/hr or grain/dscf. Annual emissions may be calculated from these data using Equations 3.4-1 or 3.4-2. Stack tests performed under a proposed permit condition or a maximum emissions rate are likely to be higher than the emissions which would result under normal operating conditions. The emission testing should only be completed after the purpose of the testing is known. For example, emission testing for particulate emissions may be different than emission testing for New Source Performance Standards (NSPS) because the back-half catch portion is not considered.

This section shows how to calculate emissions in lb/hr based on stack sampling data. Calculations involved in determining particulate emissions from Method 5 data are used as an example. Because continuous PM monitors have not been demonstrated for this industry, the only available methods for measuring PM emissions are EPA Methods 5 or 17 and EPA Method 201A for PM<sub>10</sub>. EPA Method 5 is used for NSPS testing. If condensible PM is needed in the emissions estimate, the test method selected must be configured accordingly.



TABLE 3.4-1

## LIST OF VARIABLES AND SYMBOLS

Variable	Symbol	Units
Concentration	C	parts per million volume dry (ppmvd)
Molecular weight	MW	lb/lb-mole
Molar volume	V	385.5 ft <sup>3</sup> /lb-mole @ 68°F and 1 atmosphere
Flow rate	Q <sub>a</sub>	actual cubic feet per minute (acfm)
Flow rate	Q <sub>d</sub>	dry standard cubic feet per minute (dscfm)
Emissions	E <sub>x</sub>	typically lb/hr of pollutant x
Annual emissions	E <sub>tpy,x</sub>	ton/year of pollutant x
Filter catch	C <sub>f</sub>	grams (g)
Fuel use	Q <sub>f</sub>	typically, lb/hr
PM concentration	C <sub>PM</sub>	grain/dscf
Metered volume at standard temperature and pressure	V <sub>m,STP</sub>	dscf
Moisture	R	percent
Temperature	T	degrees fahrenheit
Asphalt production	A	ton/hr
Annual operating hours	OpHrs	hr/yr

An example summary of a Method 5 test is shown in Table 3.4-2. The table shows the results of three different sampling runs conducted during one test event. The source parameters measured as part of a Method 5 run include gas velocity and moisture content, which are used to determine exhaust gas flow rates in dscfm. The filter weight gain is determined gravimetrically and divided by the volume of gas sampled (as shown in Equation 3.4-1) to determine the PM concentration in grains per dscf. Note that this example does not present the condensible PM emissions.

Pollutant concentration is then multiplied by the volumetric flow rate to determine the emission rate in pounds per hour, as shown in Equation 3.4-2 and Example 3.4-1.

$$C_{PM} = C_f / V_{m,STP} * 15.43 \quad (3.4-1)$$

where:

$C_{PM}$	=	concentration of PM or grain loading (grain/dscf)
$C_f$	=	filter catch (g)
$V_{m,STP}$	=	metered volume of sample at STP (dscf)
15.43	=	15.43 grains per gram

$$E_{PM} = C_{PM} * Q_d * 60/7000 \quad (3.4-2)$$

where:

$E_{PM}$	=	hourly emissions in lb/hr of PM
$Q_d$	=	stack gas volumetric flow rate (dscfm)
60	=	60 min/hr
7000	=	7000 grains per pound

**TABLE 3.4-2**  
**TEST RESULTS - METHOD 5**

Parameter	Symbol	Run 1	Run 2	Run 3
Total sampling time (minutes)	min	120	120	120
Moisture collected (grams)	g	395.6	372.6	341.4
Filter catch (grams)	$C_f$	0.0851	0.0449	0.0625
Average sampling rate (dscfm)	dscfm	0.34	0.34	0.34
Standard metered volume, (dscf)	$V_{m,STP}$	41.83	40.68	40.78
Volumetric flow rate (acfm or dscfm)	$Q_a$ or $Q_d$	17,972	17,867	17,914
Concentration of particulate (grains/dscf)	$C_{PM}$	0.00204	0.00110	0.00153
Particulate emission rate (lb/hr)	$E_{PM}$	4.84	2.61	3.63

**Example 3.4-1**

PM emissions calculated using Equations 3.4-1 and 3.4-2 and the stack sampling data for Run 1 (presented in Table 3.4-2 are shown below).

$$\begin{aligned}
 C_{PM} &= C_f / V_{m,STP} * 15.43 \\
 &= (0.085 / 41.83) * 15.43 \\
 &= 0.03 \text{ grain/dscf} \\
 E_{PM} &= C_{PM} * Q_d * 60 / 7000 \\
 &= 0.03 * 17,972 * (60 \text{ min/hr}) * (1 \text{ lb/7000 grains}) \\
 &= 4.84 \text{ lb/hr}
 \end{aligned}$$

The information from some stack tests may be reported in pounds of particulate per pounds of exhaust gas (wet). Use Equation 3.4-3 to calculate the dry particulate emissions in lb/hr.

$$E_{PM} = Q_a / 1000 * 60 * 0.075 (1 - R) * (528 / 460 + T) \quad (3.4-3)$$

where:

$$\begin{aligned}
 E_{PM} &= \text{hourly emissions in lb/hr PM} \\
 Q_a &= \text{actual cubic feet of exhaust gas per minute (acfm)} \\
 1000 &= 1000 \text{ lb exhaust gas per lb of PM} \\
 60 &= 60 \text{ min/hr} \\
 0.075 &= 0.075 \text{ lb/ft}^3 \\
 R &= \text{moisture percent (\%)} \\
 528 &= 528^\circ\text{F} \\
 460 &= 460^\circ\text{F} \\
 T &= \text{stack gas temperature in } ^\circ\text{F}
 \end{aligned}$$

## 4.2 EMISSION FACTOR CALCULATIONS

Emission factors are commonly used to calculate emissions for fugitive dust sources and when site-specific monitoring data are unavailable. EPA maintains a compilation of emission factors in *AP-42* for criteria pollutants and HAPs (EPA, 1995a). A supplementary source for toxic air pollutant emission factors is the Factor Information

and Retrieval (FIRE) data system (EPA, 1994). FIRE also contains emission factors for criteria pollutants.

Much work has been done recently on developing emission factors for HAPs and recent AP-42 revisions have included these factors (EPA, 1995a,b). In addition, many states have developed their own HAP emission factors for certain source categories and require their use in any inventories including HAPs. Refer to Chapter 1 of Volume III for a complete discussion of available information sources for locating, developing, and using emission factors as an estimation technique.

Emission factors developed from measurements for a specific mixer or dryer may sometimes be used to estimate emissions at other sites. For example, a company may have several units of similar model and size; if emissions were measured from one dryer or mixer, an emission factor could be developed and applied other similar units. It is advisable to have the emission factor reviewed and approved by state/local agencies or the EPA prior to its use.

The basic equation for using an emission factor to calculate emissions is the following:

$$E_x = EF_x * \text{Activity or Production Rate} \quad (3.4-4)$$

where:

$$\begin{array}{ll} E_x & = \text{emissions of pollutant } x \\ EF_x & = \text{emission factor of pollutant } x \end{array}$$

Calculations using emission factors are presented in Examples 3.4-2 and 3.4-3.

### 4.3 EMISSION CALCULATIONS USING FUEL ANALYSIS DATA

Fuel analysis can be used to predict SO<sub>2</sub> and other emissions based on application of conservation laws, if fuel rate (Q<sub>f</sub>) is measured. The presence of certain elements in fuels may be used to predict their presence in emission streams. This includes elements such as sulfur which may be converted to other compounds during the combustion process.

Example 3.4-2

Example 3.4-2 shows how potential hourly VOC combustion emissions may be calculated for a parallel flow drum mixer using a total organic compound (TOC) emission factor from AP-42, Table 11.1-8, for an oil-fired dryer. The asphalt plant is assumed to operate 1,200 hours per year.

$$\begin{aligned}
 EF_{\text{TOC}} &= 0.069 \text{ lb/ton asphalt produced} \\
 \text{Maximum asphalt production rate} &= 350 \text{ ton/hr} \\
 \text{TOC emissions} &= EF_{\text{TOC}} * \text{asphalt production rate} \\
 &= 0.069 * 350 \\
 &= 24.15 \text{ lb/hr} * 1 \text{ ton/2000 lb} * 1200 \text{ hr/yr} \\
 &= 14.5 \text{ ton/yr}
 \end{aligned}$$

Example 3.4-3

Example 3.4-3 shows how potential hourly xylene emissions may be calculated for a batch mix HMA plant with a natural gas-fired dryer based on a xylene emission factor from AP-42, Table 11.1-9. The HMA plant is assumed to operate 1,200 hours per year.

$$\begin{aligned}
 EF_{\text{xylene}} &= 0.0043 \text{ lb/ton asphalt produced} \\
 \text{Xylene emissions} &= EF_{\text{xylene}} * \text{maximum asphalt production rate} \\
 &= (0.0043 \text{ lb/ton}) * 350 \text{ ton/hr} \\
 &= 1.5 \text{ lb/hr} * 1 \text{ ton/2000 lb} * 1200 \text{ hr/yr} \\
 &= 0.9 \text{ ton/yr}
 \end{aligned}$$

The basic equation used in fuel analysis emission calculations is the following:

$$E_x = Q_f * \text{Pollutant concentration in fuel} * \left[ \frac{MW_p}{MW_f} \right] \quad (3.4-4)$$

where:

E	=	emissions of pollutant x
$Q_f$	=	fuel use (lb/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. The application of this emission estimation technique is shown in Example 3.4-4.

#### Example 3.4-4

This example shows how  $SO_2$  emissions can be calculated from oil combustion based on fuel analysis results and the fuel flow information, if available. The asphalt plant is assumed to operate 1,200 hours per year.

$E_{SO_2}$  may be calculated using Equation 3.4-4.

Assume a given $Q_f$	=	5,000 lb/hr
Given percent weight sulfur (% S) in fuel	=	1.17

$$\begin{aligned}
 E_{SO_2} &= Q_f * \text{pollutant concentration in fuel} * (MW_p/MW_f) \\
 &= (5,000) * (1.17/100) * (64/32) \\
 &= 117 \text{ lb/hr} * \text{ton}/2000 \text{ lb} * 1,200 \text{ hr/yr} \\
 &= 70.2 \text{ ton/yr}
 \end{aligned}$$

## ALTERNATIVE METHODS FOR ESTIMATING EMISSIONS

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### 5.1 EMISSION CALCULATIONS USING CEMS DATA

To monitor SO<sub>2</sub>, NO<sub>x</sub>, THC, and CO emissions using a CEMS, a facility uses a pollutant concentration monitor, which measures concentration in parts per million by volume dry air (ppmvd). Note that a CEMS would not likely be used to monitor emissions for an extended period due to the unfavorable conditions at an HMA plant. Flow rates should be measured using a volumetric flow rate monitor. Flow rates estimated based on heat input using fuel factors may be inaccurate because these systems typically run with high excess air to remove the moisture out of the drum (Patterson, 1995). Emission rates (lb/hr) are then calculated by multiplying the stack gas concentrations by the stack gas flow rates.

Table 3.5-1 presents example CEMS data output averaged for three periods for a parallel flow drum mixer. The output includes pollutant concentrations in parts per million dry basis (ppmvd), diluent (O<sub>2</sub> or CO<sub>2</sub>) concentrations in percent by volume dry basis (%v,d), and emission rates in pounds per hour (lb/hr). These data represent a "snapshot" of a drum mixer operation. While it is possible to determine total emissions of an individual pollutant over a given time period from these data assuming the CEM operates properly all year long, an accurate emission estimate can be made by summing the hourly emission estimates if the CEMS data are representative of typical operating conditions.

Although CEMS can report real-time hourly emissions automatically, it may be necessary to manually estimate annual emissions from hourly concentration data. This section describes how to calculate emissions from CEMS concentration data. The selected CEMS data should be representative of operating conditions. When possible, data collected over longer periods should be used. It is important to note that prior to using CEMS to estimate emissions, a protocol should be developed for collecting and averaging the data.



TABLE 3.5-1

## EXAMPLE CEM OUTPUT AVERAGED FOR A PARALLEL FLOW DRUM MIXER FIRING WASTE FUEL OIL

Period	O <sub>2</sub> (%V)	Concentration (C) (ppmvd)				Stack Gas Flow Rate (Q) (dscfm)	Emission Rate (E) (lb/hr)				Asphalt Production Rate (A) (ton/hr)
		SO <sub>2</sub>	NO <sub>x</sub>	CO	THC		SO <sub>2</sub>	NO <sub>x</sub>	CO	THC	
0830-1039	10.3	150.9	142.9	42.9	554.2	18,061	27.15	25.71	3.38	24.93	287
1355-1606	10.1	144.0	145.7	41.8	582.9	17,975	25.78	26.09	3.27	26.09	290
1236-1503	11.8	123.0	112.7	128.4	515.1	18,760	22.99	21.06	10.50	24.06	267

Source: EPA, 1991b.

Hourly emissions can be based on concentration measurements as shown in Equation 3.5-1 and Example 3.5-1.

$$E_x = \frac{(C * MW * Q * 60)}{(V * 10^6)} \quad (3.5-1)$$

where:

$E_x$	=	hourly emissions in lb/hr of pollutant x
$C$	=	pollutant concentration in ppmvd
$MW$	=	molecular weight of the pollutant (lb/lb-mole)
$Q$	=	stack gas volumetric flow rate in dscfm
60	=	60 min/hr
$V$	=	volume occupied by one mole of ideal gas at standard temperature and pressure (385.5 ft <sup>3</sup> /lb-mole @ 68°F and 1 atm)

Actual emissions in tons per year can be calculated by multiplying the emission rate in lb/hr by the number of actual annual operating hours (OpHrs) as shown in Equation 3.5-2 and Example 3.5-1.

$$E_{tpy,x} = E_x * OpHrs/2000 \quad (3.5-2)$$

where:

$E_{tpy,x}$	=	annual emissions in ton/yr of pollutant x
$E_x$	=	hourly emissions in lb/hr of pollutant x
OpHrs	=	annual operating hours in hr/yr

Emissions in pounds of pollutant per ton of asphalt produced can be calculated by dividing the emission rate in lb/hr by the asphalt production in rate (ton/hr) during the same period (Equation 3.5-3) as shown below. It should be noted that the emission factor calculated below assumes that the selected period (i.e., hour) is representative of annual operating conditions and longer time periods should be used when available. Use of the calculation is shown in Example 3.5-1.

$$E_{tpy,x} = E_x/A \quad (3.5-3)$$

where:

$$\begin{aligned} E_{tpy,x} &= \text{emissions of pollutant } x \text{ (lb/ton) per ton of asphalt produced} \\ E_x &= \text{hourly emissions in lb/hr of pollutant } x \\ A &= \text{asphalt production (ton/hr)} \end{aligned}$$

### Example 3.5-1

This example shows how SO<sub>2</sub> emissions can be calculated using Equation 3.5-1 based on the average CEMS data for 8:30-10:39 shown in Table 3.5-1.

$$\begin{aligned} E_{SO_2} &= (C * MW * Q * 60) / (V * 10^6) \\ &= 150.9 * 64 * 18,061 * 60 / (385.5 * 10^6) \\ &= 27.15 \text{ lb/hr} \end{aligned}$$

Emissions in ton/yr (based on a 1,200 hr/yr operating schedule) can then be calculated using Equation 3.5-2; however, based on the above period this estimate should be calculated from the average CEMS data for year using Equation 3.5-1:

$$\begin{aligned} E_{tpy,SO_2} &= E_{SO_2} * \text{OpHrs} / 2,000 \\ &= 27.15 * (1,200 / 2,000) \\ &= 16.29 \text{ ton/yr} \end{aligned}$$

Emissions, in terms of lb/ton asphalt produced, are calculated using Equation 3.5-3:

$$\begin{aligned} E_{tpy,SO_2} &= E_{SO_2} / A \\ &= 9.46 * 10^{-2} \text{ lb SO}_2 / \text{ton asphalt produced} \end{aligned}$$

## 5.2 PREDICTIVE EMISSION MONITORING

Emissions from the HMA process depend upon several variables, which are discussed in Section 3 of this chapter. For example, VOC process emissions for a given plant may vary with several parameters, including: the type of fuel burned; the relative quantities of asphalt constituents (e.g., RAP, crumb rubber, and emulsifiers); aggregate type and moisture content; the temperature of the asphalt constituents; the mixing zone temperature; and, fuel combustion rate. An example emissions monitoring that could be

used to develop a PEM protocol would need to account for the variability in these parameters and, consequently, may require a complex testing algorithm.

To develop this algorithm, correlation testing of the process variables could be conducted over a range of potential operating conditions using EPA Method 25 or Method 25A to measure THC emissions and EPA Method 6A or Method 6C to measure SO<sub>2</sub> emissions. Potential testing conditions covering several parameters are shown in Table 3.5-2. Based on the test data, a mathematical correlation can be developed which predicts emissions using these parameters. This method may be cost prohibitive for a single source.

TABLE 3.5-2

PREDICTIVE EMISSION MONITORING ANALYSIS<sup>a</sup>

Test Number	Temperature of Asphalt Constituents	Mixing Zone Temperature	Fuel Firing Rate
1	B	H	H
2	B	H	M
3	B	H	L
4	B	M	H
5	B	M	M
6	B	M	L
7	B	L	H
8	B	L	M
9	B	L	L

- <sup>a</sup> H = high.  
M = medium.  
L = low.  
B = baseline.

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# QUALITY ASSURANCE/QUALITY CONTROL

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The consistent use of standardized methods and procedures is essential in the compilation of reliable emission inventories. QA and QC of an inventory is accomplished through a set of procedures that ensure the quality and reliability of data collection and analysis. These procedures include the use of appropriate emission estimation techniques, applicable and reasonable assumptions, accuracy/logic checks of computer models, checks of calculations, and data reliability checks. Figure 3.6-1 provides an example checklist that could aid the inventory preparer at a HMA plant. Volume VI, *QA Procedures* of this series describes additional QA/QC methods and tools for performing these procedures.

Volume II, Chapter 1, *Introduction to Stationary Point Source Emission Inventory Development*, presents recommended standard procedures to follow that ensure the reported inventory data are complete and accurate. The QA/QC section of Chapter 1 should be consulted for current EIIP guidance for QA/QC checks for general procedures, recommended components of a QA plan, and recommended components for point source inventories. The QA plan discussion includes recommendations for data collection, analysis, handling, and reporting. The recommended QC procedures include checks for completeness, consistency, accuracy, and the use of approved standardized methods for emission calculations, where applicable. Chapter 1 also describes guidelines to follow in order to ensure the quality and validity of the data from manual and continuous emission monitoring methodologies used to estimate emissions.

## 6.1 CONSIDERATIONS FOR USING STACK TEST AND CEMS DATA

Data collected via CEMS, PEM, or stack tests must meet quality objectives. Stack test data must be reviewed to ensure that the test was conducted under normal operating conditions, or under maximum operating conditions in some states, and that it was generated according to an acceptable method for each pollutant of interest. Calculation and interpretation of accuracy for stack testing methods and CEMS are described in detail in *Quality Assurance Handbook for Air Pollution Measurements Systems: Volume III. Stationary Source Specific Methods (Interim Edition)*.

Item	Y/N	Corrective Action (complete if "N"; describe, sign, and date)
1. Have the toxic emissions been calculated and reported using approved stack test methods or using the emission factors provided from AP-42, FIRE, and/or NAPA (National Asphalt Pavement Association)? Have asphalt production rates been included? Each facility should request from their state agency guidance on which test methods or emission factors should be used.		
2. Fugitive emissions are required for the inventory, but will not count towards a Title V determination unless the facility is NSPS affected. Presently, in the case of the asphalt plants, only particulate emissions for the process as defined in 40 CFR 60.90 are NSPS affected. Have fugitive emissions been calculated?		
3. If emission factors are used to calculate fuel usage emissions, have fuel usage rates been determined for the dryer and for the asphalt heater separately? If the AP-42 dryer emission factors are used, they already contain emissions from fuel combustion in the dryer.		
4. Again, request guidance from the state regulatory agency on whether or not to calculate toxic emissions from fuel usage. Most toxic emission factors usually are inclusive of the asphalt and the fuel. Has the state agency been contacted for guidance?		
5. Have stack parameters been provided for each stack or vent which emits criteria or toxic pollutants? This includes the fabric filter or scrubber installed on the asphalt dryer/mixer, the asphalt cement heaters, and any storage silos other than asphalt concrete storage.		

**FIGURE 3.6-1. EXAMPLE EMISSION INVENTORY DEVELOPMENT  
CHECKLIST FOR ASPHALT PLANTS**

Item	Y/N	Corrective Action (complete if "N"; describe, sign, and date)
<p>6. Check with the state regulatory agency to determine whether emissions should be calculated using AP-42 emission factors:</p> <p><u>Dryer/Mix Type:</u></p> <p>Rotary Dryer (Batch Mix): Conventional Plant (3-05-002-01) Drum (Mix) Dryer: Hot Asphalt Plant (3-05-002-05)</p> <p><u>Diesel Generators:</u> Industrial diesel reciprocating (2-02-001-02)</p> <p><u>Asphalt Heaters:</u></p> <p>"In Process Fuel Use Factors" (Residual, 3-05-002-07; Distillate, 3-05-002-08; Natural Gas, 3-05-002-06; LPG, 3-05-002-09).</p>		
<p>7. Have you considered storage piles (3-05-002-03)(includes handling of piles) from both Batch and Drum Plants?</p>		
<p>8. If required by the state, has a site diagram been included with the emission inventory? This should be a detailed plant drawing showing the location of sources/stacks with ID numbers for all processes, control equipment, and exhaust points.</p>		
<p>9. Have examples of all calculations been included?</p>		
<p>10. Have all conversions and units been reviewed and checked for accuracy?</p>		

FIGURE 3.6-1. (CONTINUED)



The acceptance criteria, limits, and values for each control parameter associated with manual sampling methods, such as dry gas meter calibration and leak rates, are summarized within the tabular format of the QA/QC section of Chapter 1. QC procedures for all instruments used to continuously collect emissions data are similar. The primary control check for precision of the continuous monitors is daily analysis of control standards. The CEMS acceptance criteria and control limits are listed within the tabular format of the QA/QC section of Chapter 1.

Quality assurance should be delineated in a Quality Assurance Plan (QAP) by the team conducting the test prior to each specific test. The main objective of any QA/QC effort for any program is to independently assess and document the precision, accuracy, and adequacy of emission data generated during sampling and analysis. It is essential that the emissions measurement program be performed by qualified personnel using proper test equipment. Also, valid test results require the use of appropriate and properly functioning test equipment and use of appropriate reference methods.

The QAP should be developed to assure that all testing and analytical data generated are scientifically valid, defensible, comparable, and of known and acceptable precision and accuracy. EPA guidance, is available for assistance in preparing any QAP (EPA, October, 1989).

## 6.2 CONSIDERATIONS FOR USING EMISSION FACTORS

The use of emission factors is straightforward when the relationship between process data and emissions is direct and relatively uncomplicated. When using emission factors, the user should be aware of the quality indicator associated with the value. Emission factors published within EPA documents and electronic tools have a quality rating applied to them. The lower the quality indicator, the more likely that a given emission factor may not be representative of the source type. When an emission factor for a specific source or category may not provide a reasonably adequate emission estimate, it is always better to rely on actual stack test or CEMS data, where available. The reliability and uncertainty of using emission factors as an emission estimation technique are discussed in detail in the QA/QC Section of Chapter 1.

## 6.3 DATA ATTRIBUTE RATING SYSTEM (DARS) SCORES

One measure of emission inventory data quality is the DARS score. Four examples are given here to illustrate DARS scoring using the preferred and alternative methods. The DARS provides a numerical ranking on a scale of 1 to 10 for individual attributes of the emission factor and the activity data. Each score is based on what is known about the factor and the activity data, such as the specificity to the source category and the

measurement technique employed. The composite attribute score for the emissions estimate can be viewed as a statement of the confidence that can be placed in the data. For a complete discussion of DARS and other rating systems, see the *QA Source Document* (Volume VI, Chapter 4) and the QA/QC Section within Volume II Chapter 1, *Introduction to Stationary Point Sources Emission Inventory Development*.

Each of the examples below is hypothetical. A range is given where appropriate to cover different situations. The scores are assumed to apply to annual emissions from an HMA plant. Table 3.6-1 gives a set of scores for an estimate based on CEMS/PEM data. A perfect score of 1.0 is achievable using this method if data quality is very good. Note that maximum scores of 1.0 are automatic for the source definition and spatial congruity attributes. Likewise, the temporal congruity attribute receives a 1.0 if data capture is greater than 90 percent; this assumes that data are sampled adequately throughout the year. The measurement attribute score of 1.0 assumes that the pollutants of interest were measured directly. A lower score is given if the emissions are speciated using a profile, or if the emissions are used as a surrogate for another pollutant. Also, the measurement/method score can be less than 1.0 if the relative accuracy is poor (e.g., > 10 percent), if the data are biased, or if data capture is closer to 90 percent than to 100 percent.

The use of stack sample data can give DARS scores as high as those for CEMS/PEM data. However, the sample size is usually too low to be considered completely representative of the range of possible emissions making a score of 1.0 for measurement/method unlikely. A typical DARS score for stack sample data is generally closer to the low end of the range shown in Table 3.6-2.

Two examples are given for emissions calculated using emission factors. For both of these examples, the activity data is assumed to be measured directly or indirectly. Table 3.6-3 applies to an emission factor developed from CEMS/PEM data from one dryer or mixer and then applied to a different dryer or mixer of similar design and age. Table 3.6-4 gives an example for an estimate made with an *AP-42* emission factor. The *AP-42* factor is a mean and could overestimate or underestimate emissions for any single unit in the population. Thus, the confidence that can be placed in emissions estimated for a specific unit with a general *AP-42* factor is lower than emissions based on source-specific data. This assumes that the source-specific data were developed while the HMA plant was operating under normal conditions. If it was not operated under normal conditions then the *AP-42* emission factor may be a better characterization of the emissions from the HMA plant.

The example in Table 3.6-3 shows that emission factors based on high-quality data from a similar unit will typically give better results than a general factor. The main criterion affecting the score is how similar the unit used to generate the factor is to the target dryer or mixer.

TABLE 3.6-1

DARS SCORES: CEMS/PEM DATA<sup>a</sup>

Attribute	Emission Factor Score	Activity Data Score	Composite Scores		Comment
			Range	Midpoint	
Measurement/ method	0.9 - 1.0	0.9 - 1.0	0.81 - 1.0	0.91	Lower scores given if relative accuracy poor (e.g., >10 percent) or data capture closer to 90 percent.
Source definition	1.0	1.0	1.0 - 1.0	1.0	
Spatial congruity	1.0	1.0	1.0 - 1.0	1.0	
Temporal congruity	1.0	1.0	1.0 - 1.0	1.0	
Weighted Score	0.98 - 1.0	0.98 - 1.0	0.95 - 1.0	0.98	

<sup>a</sup> Assumes data capture is 90 percent or better, representative of entire year, monitors sensors, and other equipment is properly maintained.

TABLE 3.6-2

DARS SCORES: STACK SAMPLE DATA<sup>a</sup>

Attribute	Emission Factor Score	Activity Data Score	Composite Scores		Comment
			Range	Midpoint	
Measurement/ method	0.7 - 1.0	0.7 - 1.0	0.49 - 1.0	0.745	
Source definition	1.0 - 1.0	1.0 - 1.0	1.0 - 1.0	1.0	
Spatial congruity	1.0 - 1.0	1.0 - 1.0	1.0 - 1.0	1.0	
Temporal congruity	0.7 - 1.0	0.7 - 1.0	0.49 - 1.0	0.745	Lower scores given if emissions vary temporally and sample does not cover range.
Weighted Score	0.85 - 1.0	0.85 - 1.0	0.75 - 1.0	0.878	

<sup>a</sup> Assumes use of EPA Reference Method, high quality data.

TABLE 3.6-3

DARS SCORES: SOURCE-SPECIFIC EMISSION FACTOR<sup>a</sup>

Attribute	Emission Factor Score	Activity Data Score	Composite Scores		Comment
			Range	Midpoint	
Measurement/method	0.9 - 1.0	0.8 - 1.0	0.72 - 1.0	0.86	Factor score for this attribute depends entirely on data quality.
Source definition	0.5 - 0.9	0.8 - 0.9	0.4 - 0.81	0.61	Factor score lowest if unit differs much from original source of data.
Spatial congruity	1.0 - 1.0	1.0 - 1.0	1.0 - 1.0	1.0	
Temporal congruity	1.0 - 1.0	0.5 - 0.9	0.5 - 0.9	0.7	
Weighted Score	0.85 - 0.98	0.78 - 0.95	0.66 - 0.93	0.79	

<sup>a</sup> Assumes factor developed from PEM or CEMS data from an identical emission unit (same manufacturer, model).

TABLE 3.6-4

DARS SCORES: AP-42 EMISSION FACTOR<sup>a</sup>

Attribute	Emission Factor Score	Activity Data Score	Composite Scores		Comment
			Range	Midpoint	
Measurement/method	0.6 - 0.8	0.8 - 1.0	0.48 - 0.7	0.59	Score depends on quality and quantity of data points used to develop factor.
Source definition	0.5 - 0.9	0.8 - 0.9	0.4 - 0.81	0.605	Emission factor score will be low if variability in source population is high.
Spatial congruity	0.6 - 0.8	1.0 - 1.0	0.6 - 0.8	0.7	Factor score lower if geographic location has significant effect on emissions.
Temporal congruity	0.5 - 0.9	0.5 - 0.9	0.25 - 0.81	0.53	Lower scores given if emissions vary temporally and sample does not cover range.
Weighted Score	0.55 - 0.85	0.78 - 0.95	0.43 - 0.78	0.61	

<sup>a</sup> Assumes activity data (e.g., fuel use) or surrogate is measured directly in some manner.

If sufficient data are available, the uncertainty in the estimate should be quantified. If sufficient data are not available, a qualitative analysis of uncertainty is still recommended. Some methods and examples are described in *QA Procedures* (Volume VI, Chapter 3).

The reader should note that the presentation of the DARS scores here is shown as a hypothetical example, only. Although the highest DARS score results from the use of CEMS, this estimation technique will not practically be applied or used by the majority of facilities operating. Due to technical feasibility issues and costs incurred by applying CEMS to a HMA plant, stack testing or emission factors may provide the best choice when selecting an appropriate method for estimating emissions (even though stack testing or emission factors did not receive the highest DARS score). The reader should always contact their state regulatory agency for approval of selected methodologies or techniques. Also, it should be noted that this hypothetical application of DARS does not mandate any emission estimation method, but only offers the reader a means for selecting any one method over another.

## DATA CODING PROCEDURES

---

This section describes the methods and codes available for characterizing emission sources at HMA facilities. Consistent categorization and coding will result in greater uniformity among inventories. The SCCs are the building blocks on which point source emissions data are structured. Each SCC represents a unique process or function within a source category that is logically associated with an emission point. Without an appropriate SCC, a process cannot be accurately identified for retrieval purposes. In addition, the procedures described here will assist the reader preparing data for input to the Aerometric Information Retrieval System (AIRS) or a similar database management system. For example, the use of the SCCs provided in Table 3.7-1 are recommended for describing HMA operations. Refer to the CHIEF bulletin board for a complete listing of SCCs for HMA plants. While the codes presented here are currently in use, they may change based on further refinement by the emission inventory user community. As part of the EIIP, a common emissions data exchange format is being developed to facilitate data transfer between industry, states, and EPA. Details on SCCs for specific emission sources are as follows:

- **Process Emissions:** For asphaltic concrete production processes, be careful to use only one SCC for each process. Use the codes for either the batch or continuous process or for the drum mix process, depending on which process is used. The process-specific codes should be used as often as possible; however, "Entire Unit" and "General" codes are available. If the "Entire Unit" code is used, do not use the chemical-specific or process-specific codes as this would double-count emissions. *AP-42* emission factors for dryer emissions include all stack emissions (including products of combustion from the dryer burner).
- **In-Process Fuel:** In-process fuel includes SCCs for asphalt cement heaters. These emissions are separate and apart from dryer emissions.
- **Generators:** Diesel generators may be used at portable HMA plants to generate electricity. These emissions are not included in emission factors for process emissions.



- **Storage Tanks:** Storage tanks may be used in the asphaltic concrete production process to store fuel such as oil. Potential emissions from storage tanks will likely be insignificant. The codes in Table 3.7-1 are recommended to describe fuel storage emissions.
- **Fugitive Emissions:** Fugitive emissions from asphaltic concrete production result primarily from the storage and handling of raw materials and finished product. The miscellaneous codes may be used for fugitive emission sources without a unique code. Remember to use the comment section to describe the emissions.

Control device codes applicable to asphaltic concrete production are presented in Table 3.7-2. These should be used to enter the type of applicable emissions control device into the AIRS Facility Subsystem (AFS). The "099" control code may be used for miscellaneous control devices that do not have a unique identification code.

If there are significant sources of fugitive emissions within the facility, or sources that have not been specifically discussed thus far, they should be included in the emissions estimates if required by the state. Conditions vary from plant to plant, thus, each specific case cannot be discussed within the context of this document.

TABLE 3.7-1

**SOURCE CLASSIFICATION CODES FOR ASPHALTIC CONCRETE  
PRODUCTION (SIC CODE 2951)**

Source Description	Process Description	SCC	Units
<b>Process Emissions</b>			
Batch or continuous mix process	Rotary dryer	3-05-002-01	Tons HMA produced
	Hot elevators, screens, bins, and mixer	3-05-002-02	Tons aggregate processed
Drum mix process	Drum mixer: hot asphalt plants	3-05-002-05	Tons HMA produced
General process	General process/specify in comments	3-05-002-99	Tons produced
	In-place recycling - propane	3-05-002-15	Tons produced
<b>In-Process Fuel</b>			
Asphalt heater fuel use	Residual oil	3-05-002-07	1000 gallons burned
	Distillate oil	3-05-002-08	1000 gallons burned
	Natural gas	3-05-002-06	Million ft <sup>3</sup> burned
	Waste oil	3-05-002-10	1000 gallons burned
	Liquid petroleum gas	3-05-002-09	1000 gallons burned
<b>Generators</b>			
Diesel	Reciprocating	2-02-001-02	Horsepower hours
<b>Fugitive Emissions</b>			
Fugitive emissions	Raw material storage piles	3-05-002-03	Tons aggregate processed
	Cold aggregate handling	3-05-002-04	Tons aggregate processed
	Storage silo	3-05-002-13	Tons HMA produced
	Truck load-out	3-05-002-14	Tons HMA loaded
	Miscellaneous fugitive emissions	3-05-888-01 to 05	Vehicle miles travelled
	Haul roads - general	3-05-002-90	Tons product

TABLE 3.7-2

## AIRS CONTROL DEVICE CODES

Control Device	Code
Settling chamber: high-efficiency	004
Settling chamber: medium-efficiency	005
Settling chamber: low-efficiency	006
Single cyclone	075
Multiple cyclone	076
Centrifugal collector: high-efficiency	007
Centrifugal collector: medium-efficiency	008
Centrifugal collector: low-efficiency	009
Fabric filter: high temperature	016
Fabric filter: medium temperature	017
Fabric filter: low temperature	018
Wet fan	085
Spray tower	052
Venturi scrubber	053
Baffle spray tower	052
Miscellaneous control device	099

Source: EPA, January 1992.

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## **APPENDIX A**

# **EXAMPLE DATA COLLECTION FORM AND INSTRUCTIONS FOR HOT-MIX ASPHALT PLANTS**



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## EXAMPLE DATA COLLECTION FORM INSTRUCTIONS

1. This form may be used as a work sheet to aid the plant engineer in collecting the information necessary to calculate emissions from HMA plants. The information requested on the form relates to the methods (described in Sections 3 through 5) 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 requested on these forms is needed to complete emission calculations. If the information requested does not apply to a particular dryer, mixer, or unit, write "NA" in the blank.
4. If you want to modify the form to better serve your needs, an electronic copy of the form may be obtained through the EIIP on the CHIEF bulletin board system (BBS).
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 - HOT-MIX ASPHALT PLANTS

## GENERAL INFORMATION

Facility/Plant Name:

SIC Code:

SCC:

SCC Description:

Location:

County:

City:

State:

Parent Company Address:

Plant Geographical Coordinates (if portable, state so):

Latitude:

Longitude:

UTM Zone:

UTM Easting:

UTM Northing:

Contact Name:

Title:

Telephone Number:

Source ID Number:

AIRS or FID?

Type of Plant (i.e., batch, drum):

Permit Number:

Permitted Hours of Operation (per year):

Actual Hours of Operation (per year):

Hours/Day:

Days/Weeks:

Weeks/Year:

**EXAMPLE DATA COLLECTION FORM - HOT-MIX ASPHALT PLANTS****COMBUSTION OPERATIONS****ASPHALT CEMENT HEATERS:**

Unit ID No.:	Fuel A	Fuel B	Fuel C	Comments
Fuel Type:				
Year:				
Maximum Hourly Fuel Use (units):				
Total Annual Fuel Use (units):				
Maximum Capacity of Heater(s) (Million Btu/hr):				

Note: Complete this form for each type of fuel used and for each unit.

## EXAMPLE DATA COLLECTION FORM - HOT-MIX ASPHALT PLANTS

COMBUSTION OPERATIONS				
DRYERS:				
Unit ID No.:	Fuel A	Fuel B	Fuel C	Comments
Fuel Type:				
Year:				
Composition (% sulfur)				
Composition (metals)				
Maximum Hourly Fuel Use (units):				
Monthly Fuel Use (units):				
January:				
February:				
March:				
April:				
May:				
June:				
July:				
August:				
September:				
October:				
November:				
December:				
Total Annual Fuel Use (units):				

## EXAMPLE DATA COLLECTION FORM - HOT-MIX ASPHALT PLANTS

## GENERATORS:

Size: Horsepower or kilowatts:

Unit ID:	Fuel A	Fuel B	Fuel C	Comments
Fuel Type:				
Year:				
Maximum Hourly Fuel Use (units):				
Total Annual Fuel Use (units):				

## STACK/VENT INFORMATION

Please fill out the following information for each stack/vent. Attach additional sheets as needed.

STACK PARAMETER	STACK ID NUMBER	STACK ID NUMBER	STACK ID NUMBER
Source(s) Vented:			
Latitude/Longitude:			
UTM Zone:			
UTM Easting:			
UTM Northing:			
Height (feet):			
Diameter (feet):			
Temperature (°F):			
Velocity (FPS):			
Flow Rate (ACFM):			
Stack/Vent Direction: (vert./horiz./fugitive)	(circle one) V H F	(circle one) V H F	(circle one) V H F
Stack Capped (yes/no):			

## EXAMPLE DATA COLLECTION FORM - HOT-MIX ASPHALT PLANTS

PRODUCTION OPERATIONS			COMMENTS
Year:			
Asphalt Produced (tons):			
Maximum Design Capacity of Plants (tons/hr) (This should be standardized at 5% moisture):			
Liquid Asphaltic Cement Used (tons):			
Tons of RAP Processed:			
Tons of Mineral Filler Used from Silos:			
AIR POLLUTION CONTROL EQUIPMENT			
Please fill out the following information for each control device. Attach additional sheets as needed			
Control Type	Location	Efficiency (%)	How calculated?
EXAMPLE: Fabric Filter	Dryer Exhaust	99	Vendor's specs

## EMISSION ESTIMATION RESULTS

Unit ID No.: \_\_\_\_\_

Pollutant	Emission Estimation Method <sup>a</sup>	Emission Factor Throughput	Emission Factor <sup>b</sup>	Emissions Factor Units	Annual Emissions	Emission Units	Comments
VOC							
NO <sub>x</sub>							
CO							
SO <sub>2</sub>							
PM <sub>10</sub>							
Total Particulate							
Hazardous Air Pollutants (list individually)							

<sup>a</sup> Use the following codes to indicate which emission estimation method is used for each pollutant:

CEMS/PEM = CEM/PEM

Emission Factor = EF

Stack Test Data = ST

Other (indicate) = O

Fuel Analysis = FA

<sup>b</sup> Where applicable, enter the emission factor and provide the full citation of the reference or source of information from where the emission factor came. Include edition, version, table, and page numbers if AP-42 is used.



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**VOLUME II: CHAPTER 4**

# **PREFERRED AND ALTERNATIVE METHODS FOR ESTIMATING FUGITIVE EMISSIONS FROM EQUIPMENT LEAKS**

**November 1996**



Prepared by:  
Eastern Research Group

Prepared for:  
Point Sources Committee  
Emission Inventory Improvement Program

## DISCLAIMER

This document was furnished to the Emission Inventory Improvement Program and the U.S. Environmental Protection Agency by Eastern Research Group, Inc., Morrisville, North Carolina. This report is intended to be a final document and has been reviewed and approved for publication. The opinions, findings, and conclusions expressed represent a consensus of the members of the Emission Inventory Improvement Program. Any mention of company or product names does not constitute an endorsement of the company or product; rather the names are used as examples.

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# INTRODUCTION

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The purposes of this document are to present general information on methodologies and/or approaches for estimating air emissions from equipment leaks in a clear and concise manner and to provide specific example calculations to aid in the preparation and review of emission inventories.

Because documents describing procedures for estimating emissions from equipment leaks are readily available, duplication of detailed information will be avoided in this document. The reader is referred to the following reports that were used to develop this document:

- Environmental Protection Agency (EPA). November 1995. *Protocol for Equipment Leak Emission Estimates*. EPA-453/R-95-017; U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina;
- Chemical Manufacturers Association (CMA). 1989. *Improving Air Quality: Guidance for Estimating Fugitive Emissions*. Second Edition. Washington, DC; and,

During the development of this guideline document, results of recent studies developed by the EPA for the petroleum industry were incorporated (Epperson, January, 1995). This information is available on the Office of Air Quality Planning and Standards (OAQPS) Technology Transfer Network (TTN) bulletin board (under the Clearinghouse for Inventories and Emission Factors [CHIEF]).

Section 2 of this chapter contains a general description of the equipment leak sources, such as valves, pumps, and compressors and also includes information on equipment leak control techniques and efficiencies. Section 3 of this chapter provides an overview of available approaches for estimating emissions from equipment leaks. Four main approaches are discussed and compared in Section 3: (1) average emission factor; (2) screening ranges; (3) EPA correlation equation; and (4) unit-specific correlation equations. Also included in this section are descriptions of available procedures for collecting equipment leaks data and a comparison of available emission estimation approaches. Section 4 presents the preferred method for estimating emissions, while Section 5 presents alternative emission estimation methods. Quality assurance and control procedures are described in Section 6 and data coding procedures are discussed in Section 7. References are listed in Section 8.

Appendix A presents information on how to estimate the control effectiveness of leak detection and repair (LDAR) programs. Appendix B presents additional information on response factors (RFs) and some guidelines on how to evaluate whether an RF correction to a screening value should be made. Appendix C of this chapter presents general information on methods and calculation procedures for mass emissions sampling (bagging). Appendix D presents an example data collection form that can be used for gathering information to estimate fugitive emissions from equipment leaks.

# GENERAL SOURCE CATEGORY DESCRIPTION

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## 2.1 SOURCE CATEGORY DESCRIPTION

Emissions occur from process equipment whenever components in the liquid or gas stream leak. 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. There are several potential sources of equipment leak emissions. Components such as pumps, valves, pressure relief valves, flanges, agitators, and compressors are potential sources that can leak due to seal failure. 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 for estimating equipment leak emissions has been for total organic compounds and non-methane organic compounds. Equipment leak emission data have been collected from the following industry segments:

- Synthetic Organic Chemical Manufacturing Industry (SOCMI);
- Petroleum Refineries;
- Petroleum Marketing Terminals; and
- Oil and Gas Production Facilities.

Each of these emission sources is briefly described in this section. A more detailed discussion of these sources can be found in the *Protocol for Equipment Leak Emission Estimates* (EPA, November 1995) and the *Equipment Leaks Enabling Document* (EPA, July 1992).

### 2.1.1 PUMPS

Pumps are used extensively in the petroleum and chemical industries for the movement of liquids. The centrifugal pump is the most widely used pump type in the chemical industry; however, other types, such as the positive displacement (reciprocating) pump, are also used. Chemicals transferred by pump can leak at the point of contact between the moving shaft and the stationary casing. Consequently, all pumps except the sealless type, such as canned-motor, magnetic drive, and diaphragm pumps, require a seal at the point where the shaft penetrates the housing in order to isolate the pumped fluid from the environment.

Two generic types of seals, packed and mechanical, are used on pumps. Packed seals can be used on both reciprocating and centrifugal pumps. A packed seal consists of a cavity ("stuffing box") in the pump casing filled with packing gland to form a seal around the shaft. Mechanical seals are limited in application to pumps with rotating shafts. There are single and dual mechanical seals, with many variations to their basic design and arrangement, but all have a lapped seal face between a stationary element and a rotating seal ring.

### **2.1.2 VALVES**

Except for connectors, valves are the most common and numerous process equipment type found in the petroleum and chemical industries. Valves are available in many designs, and most contain a valve stem that operates to restrict or allow fluid flow. Typically, the stem is sealed by a packing gland or O-ring to prevent leakage of process fluid to the atmosphere. Emissions from valves occur at the stem or gland area of the valve body when the packing or O-ring in the valve fails.

### **2.1.3 COMPRESSORS**

Compressors provide motive force for transporting gases through a process unit in much the same way that pumps transport liquids. Compressors are typically driven with rotating or reciprocating shafts. Thus, the sealing mechanisms for compressors are similar to those for pumps (i.e., packed and mechanical seals).

### **2.1.4 PRESSURE RELIEF DEVICES**

Pressure relief devices are safety devices commonly used in petroleum and chemical facilities to prevent operating pressures from exceeding the maximum allowable working pressures of the process equipment. Note that it is not considered an equipment leak-type emission when a pressure relief device functions as designed during an over pressure incident allowing pressure to be reduced. Equipment leaks from pressure relief devices occur when material escapes from the pressure relief device during normal operation. The most common pressure relief valve (PRV) is spring-loaded. The PRV is designed to open when the operating pressure exceeds a set pressure and to reseal after the operating pressure has decreased to below the set pressure. Another pressure relief device is a rupture disk (RD) which does not result in equipment leak emissions. The disks are designed to remain whole and intact, and burst at a set pressure.

### **2.1.5 CONNECTORS AND FLANGES**

Connectors and flanges are used to join sections of piping and equipment. They are used wherever pipes or other equipment (such as vessels, pumps, valves, and heat exchangers) require isolation or removal. Flanges are bolted, gasket-sealed connectors and are normally

used for pipes with diameters of 2.0 inches or greater. The primary causes of flange leakage are poor installation, aging and deterioration of the sealant, and thermal stress. Flanges can also leak if improper gasket material is chosen.

Threaded fittings (connectors) are made by cutting threads into the outside end of one piece (male) and the inside end of another piece (female). These male and female parts are then screwed together like a nut and bolt. Threaded fittings are normally used to connect piping and equipment having diameters of 2.0 inches or less. Seals for threaded fittings are made by coating the male threads with a sealant before joining it to the female piece. The sealant may be a polymeric tape, brush-on paste, or other spreadable material that acts like glue in the joint. These sealants typically need to be replaced each time the joint is broken. Emissions can occur as the sealant ages and eventually cracks. Leakage can also occur as the result of poor assembly or sealant application, or from thermal stress on the piping and fittings.

In the 1993 petroleum industry studies, flanges were analyzed separately from connectors. Non-flanged connectors (or just connectors) were defined as plugs, screwed or threaded connectors, and union connectors that ranged in diameter from 0.5 to 8.0 inches, but were typically less than 3.0 inches in diameter. Flanged connectors (flanges) were larger, with diameters in some cases of 22.0 inches or more.

### **2.1.6 AGITATORS**

Agitators are used in the chemical industry to stir or blend chemicals. Four seal arrangements are commonly used with agitators: packed seals, mechanical seals, hydraulic seals, and lip seals. Packed and mechanical seals for agitators are similar in design and application to packed and mechanical seals for pumps. In a hydraulic seal, an annular cup attached to the process vessel contains a liquid that contracts an inverted cup attached to the rotating agitator shaft. Although the simplest agitator shaft seal, the hydraulic seal, is limited to low temperature/low pressure applications, and can handle only very small pressure changes. A lip seal consists of a spring-loaded, nonlubricated elastomer element, and is limited in application to low-pressure, top-entering agitators.

### **2.1.7 OPEN-ENDED LINES**

Some valves are installed in a system so that they function with the downstream line open to the atmosphere. A faulty valve seat or incompletely closed valve on such an open-ended line would result in a leakage through the open end.

### 2.1.8 SAMPLING CONNECTIONS

Sampling connections are used to obtain samples from within the process. Emissions occur as a result of purging the sampling line to obtain a representative sample of the process fluid.

## 2.2 POLLUTANT COVERAGE

### 2.2.1 TOTAL ORGANIC COMPOUNDS

The majority of data collected for estimating equipment leaks within the petroleum and gas industries and the SOCM has been for total organic compounds and non-methane organic compounds. Therefore, the emission factors and correlations developed for emission estimation approaches are intended to be used for estimating total organic compound (TOC) emissions.

### 2.2.2 SPECIATED ORGANICS/HAZARDOUS AND TOXIC AIR POLLUTANTS

Because material in equipment within a process unit is often a mixture of several chemicals, equipment leak emission estimates for specific volatile organic compounds (VOCs), hazardous air pollutants (HAPs), and/or pollutants under Section 112(r) of the Clean Air Act, as amended can be obtained by multiplying the TOC emissions from a particular equipment times the ratio of the concentration of the specific VOC/pollutant to the TOC concentration, both in weight percent. An assumption in the above estimation is that the weight percent of the chemicals in the mixture contained in the equipment will equal the weight percent of the chemicals in the leaking material. In general, this assumption should be accurate for single-phase streams containing any gas/vapor material or liquid mixtures containing constituents of similar volatilities. Engineering judgement should be used to estimate emissions of individual chemical species, in cases when:

- The material in the equipment piece is a liquid mixture of constituents with varying volatilities; or
- It is suspected that the leaking vapor will have different concentrations than the liquid.

### 2.2.3 INORGANIC COMPOUNDS

The emission estimation approaches developed for estimating TOC emissions may be used to estimate emissions of inorganic compounds--particularly for volatile compounds or those present as a gas/vapor. Also, in the event that there is no approach available to estimate the concentration of the inorganic compound at the leak interface, the average emission factors

developed for organic compounds can be used; however, the accuracy of the emission estimate will be unknown.

## 2.3 ESTIMATION OF CONTROL EFFICIENCIES FOR EQUIPMENT LEAK CONTROL TECHNIQUES

Two primary techniques are used to reduce equipment leak emissions: (1) modifying or replacing existing equipment, and (2) implementing an LDAR program. Equipment modifications are applicable for each of the leaking equipment described in this section. An LDAR program is a structured program to detect and repair equipment that are identified as leaking; however, it is more effective on some equipment than others.

The use of equipment modifications and equipment included in an LDAR program are predicated by state and federal regulations that facilities/process units are required to meet. In most equipment leak regulations, a combination of equipment modifications and LDAR requirements are used. Table 4.A-1 in Appendix A of this chapter summarizes requirements in several federal equipment leak control regulations.

### 2.3.1 REPLACEMENT/MODIFICATION OF EXISTING EQUIPMENT

Controlling emissions by modifying existing equipment is achieved by either installing additional equipment that eliminates or reduces emissions, or replacing existing equipment with sealless types. Equipment modifications that can be used for each type of equipment described in this section, and their corresponding emission control efficiencies are presented in Table 4.2-1. A closed-vent system is a typical modification for pumps, compressors, and pressure relief devices. A closed-vent system captures leaking vapors and routes them to a control device. The control efficiency of a closed-vent system depends on the efficiency of the vapor transport system and the efficiency of the control device. A closed-vent system can be installed on a single piece of equipment or on a group of equipment pieces. A description of the controls by equipment type are briefly presented below.

#### ***Pumps***

Equipment modifications that are control options for pumps include: (1) routing leaking vapors to a closed-vent system, (2) installing a dual mechanical seal containing a barrier fluid, or (3) replacing the existing pump with a sealless type. Dual mechanical seals and sealless pumps are discussed in detail in Chapter 5 of the *Equipment Leaks Enabling Document* (EPA, July 1992). The control efficiency of sealless pumps and a dual mechanical seal with a barrier fluid at a higher pressure than the pumped fluid is essentially 100 percent, assuming both the inner and outer seal do not fail simultaneously.



TABLE 4.2-1

## SUMMARY OF EQUIPMENT MODIFICATIONS

Equipment Type	Modification	Approximate Control Efficiency (%)
Pumps	Sealless design	100 <sup>a</sup>
	Closed-vent system	90 <sup>b</sup>
	Dual mechanical seal with barrier fluid maintained at a higher pressure than the pumped fluid	100
Valves	Sealless design	100 <sup>a</sup>
Compressors	Closed-vent system	90 <sup>b</sup>
	Dual mechanical seal with barrier fluid maintained at a higher pressure than the compressed gas	100
Pressure relief devices	Closed-vent system	<sup>c</sup>
	Rupture disk assembly	100
Connectors	Weld together	100
Open-ended lines	Blind, cap, plug, or second valve	100
Sampling connections	Closed-loop sampling	100

<sup>a</sup> Sealless equipment can be a large source of emissions in the event of equipment failure.

<sup>b</sup> Actual efficiency of a closed-vent system depends on percentage of vapors collected and the efficiency of the control device to which the vapors are routed.

<sup>c</sup> Control efficiency of closed vent-systems installed on a pressure relief device may be lower than other closed-vent systems because they must be designed to handle both potentially large and small volumes of vapor.

### ***Valves***

Emissions from process valves can be eliminated if the valve stem can be isolated from the process fluid, (i.e., using sealless valves). Two types of sealless valves, diaphragm valves and sealed bellows, are available. The control efficiency of both diaphragm and sealed bellowed valves is essentially 100 percent.

### ***Compressors***

Emissions from compressors may be reduced by collecting and controlling the emissions from the seal using a closed-vent system or by improving seal performance by using a dual mechanical seal system similar to pumps. The dual mechanical seal system has an emissions control efficiency of 100 percent, assuming both the inner and outer seal do not fail simultaneously.

### ***Pressure Relief Valves***

Equipment leaks from pressure relief valves (PRVs) occur as a result of improper reseating of the valve after a release, or if the process is operating too close to the set pressure of the PRV and the PRV does not maintain the seal. There are two primary equipment modifications that can be used for controlling equipment leaks from pressure relief devices: (1) a closed-vent system, or (2) use of a rupture disk in conjunction with the PRV.

The equipment leak control efficiency for a closed-vent system installed on a PRV may not be as high as what can be achieved for other pieces of equipment because emissions from PRVs can have variable flow during an overpressure situation and it may be difficult to design a control device to efficiently handle both high and low flow emissions. Rupture disks can be installed upstream of a PRV to prevent fugitive emissions through the PRV seat. The control efficiency of a rupture disk/PRV combination is essentially 100 percent when operated and maintained properly.

### ***Connectors and Flanges***

In cases where connectors are not required for safety, maintenance, process modification, or periodic equipment removal, emissions can be eliminated by welding the connectors together.

### ***Open-Ended Lines***

Emissions from open-ended lines can be controlled by properly installing a cap, plug, or second valve to the open end. The control efficiency of these measures is essentially 100 percent.

### ***Sampling Connections***

Emissions from sampling connections can be reduced by using a closed-loop sampling system or by collecting the purged process fluid and transferring it to a control device or back to the process. The efficiency of a closed-loop system is 100 percent.

### **2.3.2 LEAK DETECTION AND REPAIR (LDAR) PROGRAMS**

An LDAR program is a structured program to detect and repair equipment that is identified as leaking. A portable screening device is used to identify (monitor) pieces of equipment that are emitting sufficient amounts of material to warrant reduction of the emissions through simple repair techniques. These programs are best applied to equipment types that can be repaired on-line, resulting in immediate emissions reduction.

An LDAR program may include most types of equipment leaks; however, it is best-suited to valves and pumps and can also be implemented for connectors. For other equipment types, an LDAR program is not as applicable. Compressors are repaired in a manner similar to pumps; however, because compressors ordinarily do not have a spare for bypass, a process unit shutdown may be required for repair. Open-ended lines are most easily controlled by equipment modifications. Emissions from sampling connections can only be reduced by changing the method of collecting the sample, and cannot be reduced by an LDAR program. Safety considerations may preclude the use on an LDAR program on pressure relief valves.

The control efficiency of an LDAR program is dependent on three factors: (1) how a leak is defined, (2) the monitoring frequency of the LDAR program, and (3) the final leak frequency after the LDAR program is implemented. The leak definition is the screening value measured by a portable screening device at which a leak is indicated if a piece of equipment screens equal to or greater than that value. Screening values are measured as concentrations in parts per million by volume (ppmv). The leak definition is a given part of an LDAR program and can either be defined by the facility implementing the program or by an equipment standard to which the facility must comply. Table 4.A-1 in Appendix A of this document provides equipment leak screening values for several equipment leak control programs. The monitoring frequency is the number of times a year (daily, weekly, monthly, quarterly, yearly) that equipment are monitored with a portable screening device. The monitoring frequency may be estimated from the initial leak frequency before the LDAR program is implemented, and the final leak frequency after the LDAR program is implemented. The leak frequency is the fraction of equipment with screening values equal to or greater than the leak definition. The LDAR program control efficiency approach is based on the relationship between the percentage of equipment pieces that are leaking and the corresponding average leak rate for all of the equipment.

Most federal equipment leak control programs have quarterly or monthly monitoring requirements. However, the LDAR monitoring frequency and leak definitions at some state equipment leak control programs may be different from federal programs. During the planning of a LDAR program, it is recommended to contact the local environmental agency to find out about their LDAR program guidelines and/or requirements.

The EPA has developed control efficiencies for equipment monitored at specified leak definitions and frequencies. Tables 4.2-2 and 4.2-3 summarize the control efficiencies for equipment that are monitored quarterly and monthly at a leak definition of 10,000 ppmv, and equipment meeting the LDAR requirements of the National Emission Standard for Hazardous Air Pollutants (NESHAP) for hazardous organics known as the Hazardous Organic NESHAP (HON). Although it was developed for the SOCMI, it is the basis for most new equipment leak regulations for other industries. Appendix A presents information on how to develop process/facility-specific control efficiencies.

TABLE 4.2-2

## CONTROL EFFECTIVENESS FOR AN LDAR PROGRAM AT A SOCFI PROCESS UNIT

Equipment Type and Service	Control Effectiveness (%)		
	Monthly Monitoring 10,000 ppmv Leak Definition	Quarterly Monitoring 10,000 ppmv Leak Definition	HON <sup>a</sup>
Valves - gas	87	67	92
Valves - light liquid	84	61	88
Pumps - light liquid	69	45	75
Compressors - gas	b	b	93
Connectors - gas and light liquid	b	33	b
Pressure relief devices - gas	b	44	b

<sup>a</sup> Control effectiveness attributed to the requirements of the HON equipment leak regulation is estimated based on equipment-specific leak definitions and performance levels.

<sup>b</sup> Data are not available to estimate control effectiveness.

TABLE 4.2-3

**CONTROL EFFECTIVENESS FOR LDAR COMPONENT MONITORING FREQUENCIES FOR  
PETROLEUM REFINERIES**

Equipment Type and Service	Control Effectiveness (%)		
	Monthly Monitoring 10,000 ppmv Leak Definition <sup>a</sup>	Quarterly Monitoring 10,000 ppmv Leak Definition <sup>a,b</sup>	HON <sup>a,c</sup>
Valves - gas	88	70	96
Valves - light liquid	76	61	95
Pumps - light liquid	68	45	88
Compressors - gas	d	33	e
Connectors - gas and light liquid	f	f	81
Pressure relief devices - gas	d	44	e

<sup>a</sup> Source: EPA, July 1992.

<sup>b</sup> Source: EPA, April 1982.

<sup>c</sup> Control effectiveness attributed to the requirements of the HON equipment leak regulation is estimated based on equipment-specific leak definitions and performance levels.

<sup>d</sup> Monthly monitoring of component is not required in any control program.

<sup>e</sup> Rule requires equipment modifications instead of LDAR.

<sup>f</sup> Information not available.

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# 3

## OVERVIEW OF AVAILABLE METHODS

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This section contains general information on the four basic approaches for estimating equipment leak emissions. The approach used is dependent upon available data, available resources to develop additional data, and the degree of accuracy needed in the estimate.

Regulatory considerations should also be taken into account in selecting an emission estimation approach. These considerations may include air toxic evaluations, nonattainment emission inventory reporting requirements, permit reporting requirements, and employee exposure concerns.

Each approach is briefly described including its corresponding data requirements. Since data collection procedures will impact the accuracy of the emission estimate, this section also includes a general description of the two variable procedures for collecting equipment leaks data, screening and bagging procedures, and available monitoring methods. Finally, a general description for estimating control efficiencies for equipment leak control techniques is presented. Table 4.3-1 lists the variables and symbols used in the following discussions on emissions estimates.

### 3.1 EMISSION ESTIMATION APPROACHES

There are four basic approaches for estimating emissions from equipment leaks in a specific processing unit. The approaches, in order of increasing refinement, are:

- Average emission factor approach;
- Screening ranges approach;
- EPA correlation approach; and
- Unit-specific correlation approach.

The approaches increase in complexity and in the amount of data collection and analysis required. All the approaches require some data collection, data analysis and/or statistical evaluation.

These approaches range from simply applying accurate equipment counts to average emission factors to the more complex project of developing unit-specific correlations of mass emission



TABLE 4.3-1

## LIST OF VARIABLES AND SYMBOLS

Variable	Symbol	Units
TOC mass emissions	$E_{\text{TOC}}$	kg/hr of TOC
VOC mass emissions	$E_{\text{VOC}}$	kg/hr of VOC
Mass emissions of organic chemical x	$E_x$	kg/hr of organic chemical x
Concentration of TOCs	$WP_{\text{TOC}}$	weight percent of TOCs
VOC concentration	$WP_{\text{VOC}}$	weight percent of VOCs
Concentration of organic chemical x	$WP_x$	weight percent of organic chemical x
Average emission factor	$F_A$	typically, kg/hr per source
Emission factor for screening value $\geq 10,000$ ppmv	$F_G$	kg/hr per source
Emission factor for screening value $< 10,000$ ppmv	$F_L$	kg/hr per source
Concentration from screening value	SV	ppmv

rates and screening values. In general, the more refined approaches require more data and provide more accurate emission estimates for a process unit. Also, the more refined approaches, especially the unit-specific correlation approach which requires bagging data, require a larger budget to implement the program and develop the correlation equations.

Figure 4.3-1 shows an overview of the data collection and analysis required to apply each of the above approaches. All of the approaches require an accurate count of equipment components by the type of equipment (e.g., valves, pumps, connectors), and for some of the equipment types, the count must be further described by service (e.g., heavy liquid, light liquid, and gas).

The chemical industry has developed alternative methods for estimating equipment component count (CMA, 1989). One of the methods calls for an accurate count of the number of pumps in the process and the service of the pumps. Equipment components in the entire process are then estimated through use of the number of pumps. Another method calls for an accurate count of valves directly associated with a specific piece of equipment using process flow sheets; and then based on the number of valves, the number of flanges and fittings are estimated using ratios (e.g., flanges/valves). A careful selection/development of the methodology used to quantify the equipment component count should be made to accurately reflect the equipment leak emission estimates for any facilities and/or process units.

Except for the average emission factor approach, all of the approaches require screening data. Screening data are collected by using a portable monitoring instrument to sample air from potential leak interfaces on individual pieces of equipment. A screening value is a measure of the concentration of leaking compounds in the ambient air that provides an indication of the leak rate from an equipment piece, and is measured in units of parts per million by volume (ppmv). See "Source Screening" in this section for details about screening procedures.

In addition to equipment counts and screening data, the unit-specific correlation approach requires bagging data. Bagging data consist of screening values and their associated measured leak rates. A leak rate is measured by enclosing an equipment piece in a bag to determine the actual mass emission rate of the leak. The screening values and measured leak rates from several pieces of equipment are used to develop a unit-specific correlation. The resulting leak rate/screening value correlation predicts the mass emission rate as a function of the screening value. See "Mass Emissions Sampling (Bagging)" in this section for details about bagging procedures.

These approaches are applicable to any chemical- and petroleum-handling facility. However, more than one set of emission factors or correlations have been developed by the EPA and other regulatory agencies, depending upon the type of process unit being considered.

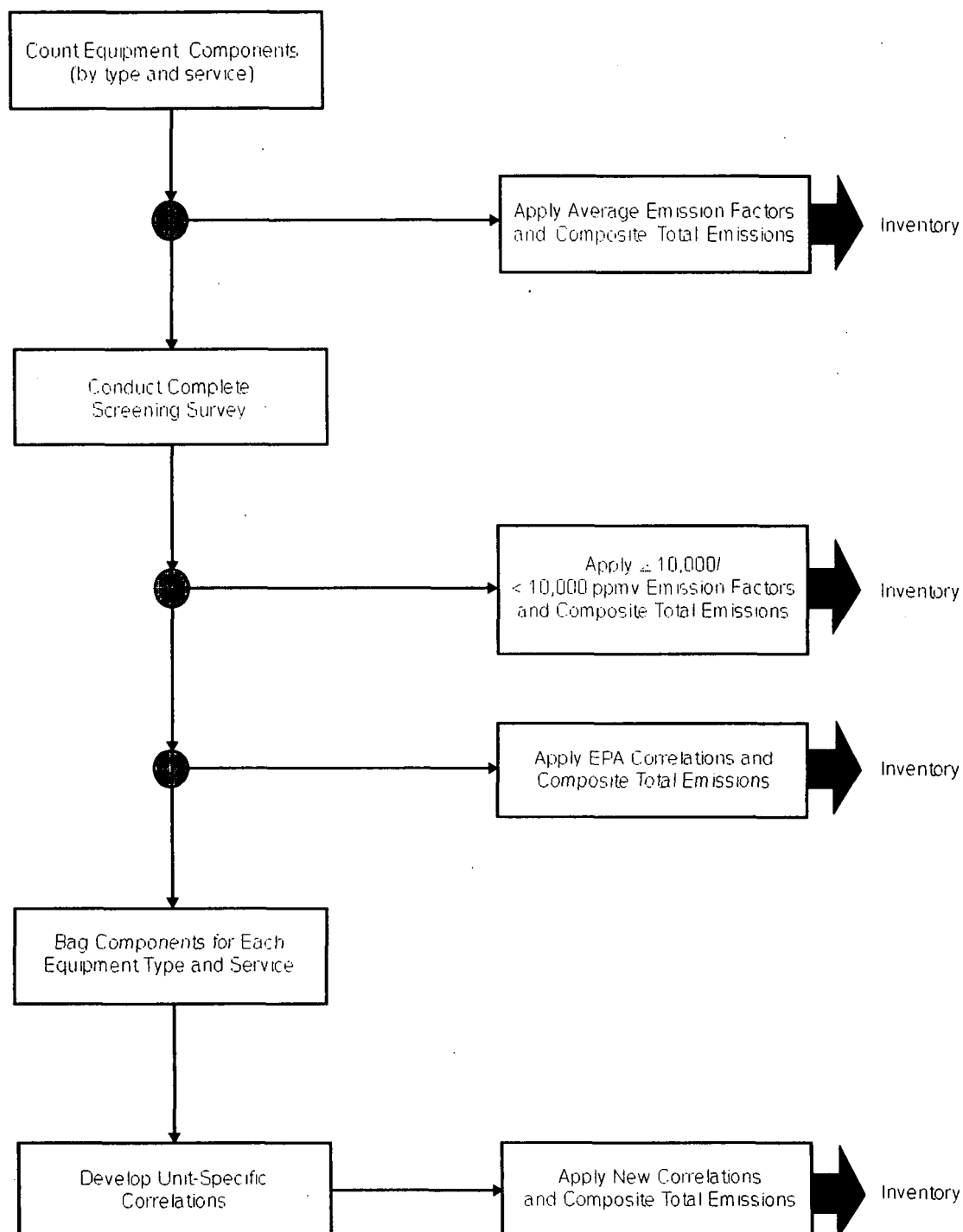


Figure 4.3-1. Overview of Data Collection and Analysis Approaches For Developing Equipment Leak Emissions Inventory

EPA data collection on emissions from equipment leaks in SOCOMI facilities, refineries, oil and gas production operations, and marketing terminals has yielded emission factors and correlations for these source categories. Emission factors and correlations for oil and gas production facilities, including well heads, have also been developed by regulatory agencies and the American Petroleum Institute (CARB, August 1989; API, 1993).

For process units in source categories for which emission factors and/or correlations have not been developed, the factors and/or correlations already developed can be utilized. However, appropriate evidence should indicate that the existing emission factors and correlations are applicable to the source category in question. Criteria for determining the appropriateness of applying existing emission factors and correlations to another source category may include one or more of the following: (1) process design; (2) process operation parameters (i.e., pressure and temperature); (3) types of equipment used; and, (4) types of material handled. For example, in most cases, SOCOMI emission factors and correlations are applicable for estimating equipment leak emissions from the polymer and resin manufacturing industry. This is because, in general, these two industries have comparable process design and comparable process operations; they use the same types of equipment and they tend to use similar feedstock with similar operations, molecular weight, density, and viscosity. Therefore, response factors should also be similar for screening values.

In estimating emissions for a given process unit, all equipment components must be screened for each class of components. However, in some cases, equipment is difficult or unsafe to screen or it is not possible to screen every equipment piece due to cost considerations. The latter is particularly true for connectors. The *Protocol for Equipment Leak Emission Estimates* (EPA, November 1995) provides criteria for determining how many connectors must be screened to constitute a large enough sample size to identify the screening value distribution for connectors. However, if the process unit to be screened is subject to a standard which requires the screening of connectors, then all connectors must be screened. If the criteria presented in the *Protocol* document are met, the average emission rate for connectors that were connected can be applied to connectors that were not screened. For equipment types other than connectors, including difficult or unsafe-to-screen equipment, that are not monitored, the average emission factor approach or the average emission rate for the equipment components that were screened can be used to estimate emissions.

Also, screening data collected at several different times can be used for estimating emissions, as long as the elapsed time between values obtained is known. For example, if quarterly monitoring is performed on a valve, four screening values will be obtained from the valve in an annual period. The annual emissions from the valve should be calculated by determining the emissions for each quarter based on the operational hours for the quarter, and summing the quarterly emission together to get entire year emissions.

### 3.2 SPECIATING EMISSIONS

In some cases, it may be necessary to estimate emissions of a specific VOC in a mixture of several chemicals. The equations developed for each one of the approaches (see Sections 4 and 5) are used to estimate total VOC emissions; the following equation is used to speciate emissions from a single equipment piece:

$$E_x = E_{\text{TOC}} \times \text{WP}_x / \text{WP}_{\text{TOC}} \quad (4.3-1)$$

where:

$E_x$	=	The mass emissions of organic chemical "x" from the equipment (kg/hr);
$E_{\text{TOC}}$	=	The TOC mass emissions from the equipment (kg/hr) calculated from either the Average Emission Factor, Screening Ranges, EPA Correlation, or Unit-Specific Correlation approaches;
$\text{WP}_x$	=	The concentration of organic chemical x in the equipment in weight percent; and
$\text{WP}_{\text{TOC}}$	=	The TOC concentration in the equipment in weight percent.

An assumption in the above equation is that the weight percent of the chemicals in the mixture contained in the equipment will equal the weight percent of the chemicals in the leaking material. In general, this assumption should be accurate for single-phase streams containing any gas/vapor material or liquid mixtures containing constituents of similar volatilities.

Engineering judgement should be used to estimate emissions of individual chemical species from liquid mixtures of constituents with varying volatilities or in cases where it is suspected that the leaking vapor has different concentrations than the liquid.

### 3.3 ORGANIC COMPOUND EMISSION ESTIMATES FROM EQUIPMENT CONTAINING NON-VOCs

A very similar approach to the one used to speciate emissions can be used to estimate organic compound emissions from equipment containing organic compounds not classified as VOCs. Because the concentrations of these compounds (such as methane or ethane) are included with VOC concentrations in the screening value, the emissions associated with the screening value will include emissions of the "non-VOCs."

Once TOC emissions have been estimated, the organic compound emissions from a group of equipment containing similar composition can be calculated using the equation:

$$E_{\text{VOC}} = E_{\text{TOC}} \times \text{WP}_{\text{VOC}}/\text{WP}_{\text{TOC}} \quad (4.3-2)$$

where:

$E_{\text{VOC}}$	=	The VOC mass emissions from the equipment (kg/hr);
$E_{\text{TOC}}$	=	The TOC mass emissions from the equipment (kg/hr) calculated from either the Average Emission Factor, Screening Ranges, EPA Correlation, or Unit-Specific Correlation approaches;
$\text{WP}_{\text{VOC}}$	=	The concentration of VOC in the equipment in weight percent; and
$\text{WP}_{\text{TOC}}$	=	The TOC concentration in the equipment in weight percent.

### 3.4 INORGANIC COMPOUND EMISSION ESTIMATES

The emission factors and correlations presented in this document are intended to be applied to estimate emissions of total organic compounds. However, in some cases, it may be necessary to estimate equipment leak emissions of inorganic compounds, particularly for those existing as gas/vapor or for volatile compounds.

Equipment leak emission estimates of inorganic compounds can be obtained by the following methods:

- Develop unit-specific correlations;
- Use a portable monitoring instrument to obtain actual concentrations of the inorganic compounds and then enter the screening values obtained into the applicable correlations developed by the EPA;
- Use the screening values obtained above and apply the emission factors corresponding to that screening range; or
- Multiply the average emission factor by the component count to estimate the leak rate.

Also, surrogate measurements can be used to estimate emissions of inorganic compounds. For example, potassium iodide (KI) or a similar salt solution is an indicator for equipment leaks from acid (hydrochloric acid [HCl], hydrofluoric acid [HF]) process lines.

### 3.5 DESCRIPTION OF AVAILABLE PROCEDURES FOR COLLECTING EQUIPMENT LEAKS DATA

The *Protocol* document (EPA, November 1995) provides a consistent approach for collecting equipment leaks data, which will ensure the development of acceptable emission factors and/or correlation equations for emission estimation purposes. Recognizing the importance of the above statement, general information on the two available procedures for collecting equipment leaks data, screening and bagging, is presented in this section.

#### 3.5.1 SOURCE SCREENING

This part of the section provides general information for conducting a screening program on-site and provides a short description of the type of portable analyzers that can be used when conducting screening surveys.

Source screening is performed with a portable organic compound analyzer (screening device). The *Protocol* document (EPA, November 1995) requires that the portable analyzer probe opening be placed at the leak interface of the equipment component to obtain a "screening" value. The screening value is an indication of the concentration level of any leaking material at the leak interface.

Some state and local agencies may require different screening procedures with respect to the distance between the probe and the leak interface. The reader should contact their state or local agency to determine the appropriate screening guidelines. However, use of the leak rate correlations require screening values gathered as closely as practicable to the leak interface.

The main objective of a screening program is to measure organic compound concentration at any potential leak point associated with a process unit. A list of equipment types that are potential sources of equipment leak emissions is provided in Table 4.3-2.

The first step is to define the process unit boundaries and obtain a component count of the equipment that could release fugitive emissions. A process unit can be defined as the smallest set of process equipment that can operate independently and includes all operations necessary to achieve its process objective. The use of a simplified flow diagram of the process is recommended to note the process streams. The actual screening data collection can be done efficiently by systematically following each stream.

The procedures outlined in EPA Reference Method 21 — *Determination of Volatile Organic Compound Leaks* (40 CFR 60, Appendix A) should be followed to screen each equipment type that has been identified. The *Protocol* document (EPA, November 1995) describes the location on each type of equipment where screening efforts should be concentrated. For

**TABLE 4.3-2**  
**EQUIPMENT LEAK EMISSION SOURCES**

<b>Equipment Types</b>
Pump seals
Compressor seals
Valves
Pressure relief devices
Flanges
Connectors
Open-ended lines
Agitator seals
Other <sup>a</sup>
<b>Services</b>
Gas/vapor
Light liquid
Heavy liquid

<sup>a</sup> Includes instruments, loading arms, stuffing boxes, vents, dump lever arms, diaphragms, drains, hatches, meters, polished rods, and vents.



equipment with no moving parts at the leak interface, the probe should be placed directly on the leak interface (perpendicular, not tangential, to the leak potential interface). On the other hand, for equipment with moving parts, the probe should be placed approximately 1 centimeter off from the leak interface (EPA, November 1995). The Chemical Manufacturers Association has also made some suggestions to maintain good screening practices (CMA, 1989). Recent ongoing efforts by the American Petroleum Institute have also been focused on increasing the accuracy of screening readings.

Various portable organic compound detection devices can be used to measure concentration levels at the equipment leak interface. Any analyzer can be used provided it meets the specifications and performance criteria set forth in EPA Reference Method 21.

Reference Method 21 requires that the analyzer meet the following specifications:

- The VOC detector should respond to those organic compounds being processed (determined by the response factor [RF]);
- Both the linear response range and the measurable range of the instrument for the VOC to be measured and the calibration gas must encompass the leak definition concentration specified in the regulation;
- The scale of the analyzer meter must be readable to  $\pm 2.5$  percent of the specified leak definition concentration;
- The analyzer must be equipped with an electrically driven pump so that a continuous sample is provided at a nominal flow rate of between 0.1 and 3.0 liters per minute;
- The analyzer must be intrinsically safe for operation in explosive atmospheres; and
- The analyzer must be equipped with a probe or probe extension for sampling not to exceed 0.25 inch in outside diameter, with a single end opening for admission of sample.

Note that the suction flow rate span allowed by Reference Method 21 is intended to accommodate a wide variety of instruments, and manufacturers guidelines for appropriate suction flow rate should be followed.

In addition to the specifications for analyzers, each analyzer must meet instrument performance criteria, including instrument response factor, instrument response time, and calibration precision. Table 4.3-3 presents the performance criteria requirements that portable organic compound detectors must meet to be accepted for use in a screening program.

TABLE 4.3-3

**EPA REFERENCE METHOD 21 PERFORMANCE CRITERIA FOR PORTABLE ORGANIC  
COMPOUND DETECTORS<sup>a</sup>**

Criteria	Requirement	Time Interval
Instrument response factor <sup>b</sup>	Must be <10 unless correction curve is used	One time, before detector is put in service.
Instrument response time <sup>c</sup>	Must be ≤30 seconds	One time, before detector is put in service. If modification to sample pumping or flow configuration is made, a new test is required.
Calibration precision <sup>d</sup>	Must be ≤10 percent of calibration gas value	Before detector is put in service and at 3-month intervals or next use, whichever is later.

<sup>a</sup> Source: 40 CFR Part 60, Appendix A, EPA Reference Method 21. These performance criteria must be met in order to use the portable analyzer in question for screening.

<sup>b</sup> The response factor is the ratio of the known concentration of a VOC to the observed meter reading when measured using an instrument calibrated with the reference compound specified in the applicable regulation.

<sup>c</sup> The response time is the time interval from a step change in VOC concentration at the input of the sampling system to the time at which 90 percent of the corresponding final value is reached as displayed on the instrument readout meter.

<sup>d</sup> The precision is the degree of agreement between measurements of the same known value, expressed as the relative percentage of the average difference between the meter readings and the known concentration to the known concentration; i.e., between two meter readings of a sample of known concentration.

Table 4.3-4 lists several portable organic compound detection instruments, their manufacturers, model number, pollutants detected, principle of operation, and range. Figure 4.3-2 shows the HW-101 (HNU Systems, Inc.) instrument, Figure 4.3-3 shows the Foxboro OVA-108, and Figure 4.3-4 shows the Foxboro TVA-1000. When a monitoring device does not meet all of the EPA Reference Method 21 requirements, it can still be used for the purpose of estimating emissions if its reliability is documented. For information on operating principles and limitations of portable organic compound detection devices, as well as specifications and performance criteria, please refer to the *Protocol for Equipment Leak Emission Estimates* document (EPA, November 1995).

Data loggers are available for use with portable organic compound detection devices to aid in the collection of screening data and in downloading the data to a computer. Database management programs are also available to aid in screening data inventory management and compiling emissions. Contact the American Petroleum Institute or state and local agencies for more information about data loggers and database management programs.

As mentioned earlier, screening values are obtained by using a portable monitoring instrument to detect TOCs at an equipment leak interface. However, portable monitoring instruments used to detect TOC concentrations do not respond to different organic compounds equally. To correct screening values to compensate for variations in a monitor's response to different compounds, response factors (RFs) have been developed. An RF relates measured concentrations to actual concentrations for specific compounds using specific instruments.

Appendix B of this chapter presents additional information on response factors and includes some guidelines on how to evaluate whether an RF correction to a screening value should be made.

### 3.5.2 MASS EMISSIONS SAMPLING (BAGGING)

An equipment component is bagged by enclosing the component to collect leaking vapors. A bag (or tent) made of material that is impermeable to the compound(s) of interest is constructed around the leak interface of the piece of the equipment.

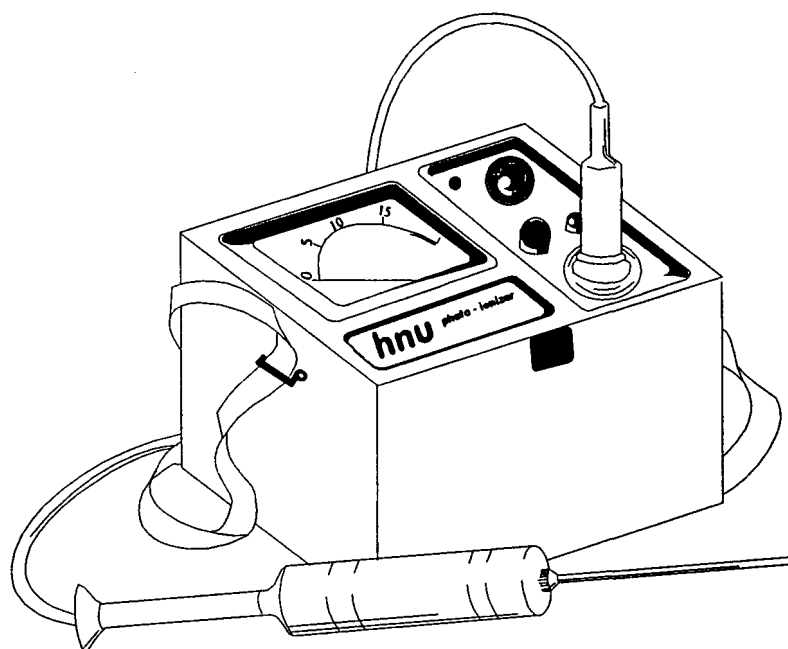
A known rate of carrier gas is introduced into the bag. A sample of the gas from the bag is collected and analyzed to determine the concentration (in parts per million by volume [ppmv]) of leaking material. The concentration is measured using laboratory instrumentation and procedures. The use of analytical instrumentation in a laboratory is critical to accurately estimate mass emissions. A gas chromatograph (GC) equipped with a flame ionization detector or electron capture detector is commonly used to identify individual constituents of a sample (EPA, November 1995).

TABLE 4.3-4

## PORTABLE ORGANIC COMPOUND DETECTION INSTRUMENTS

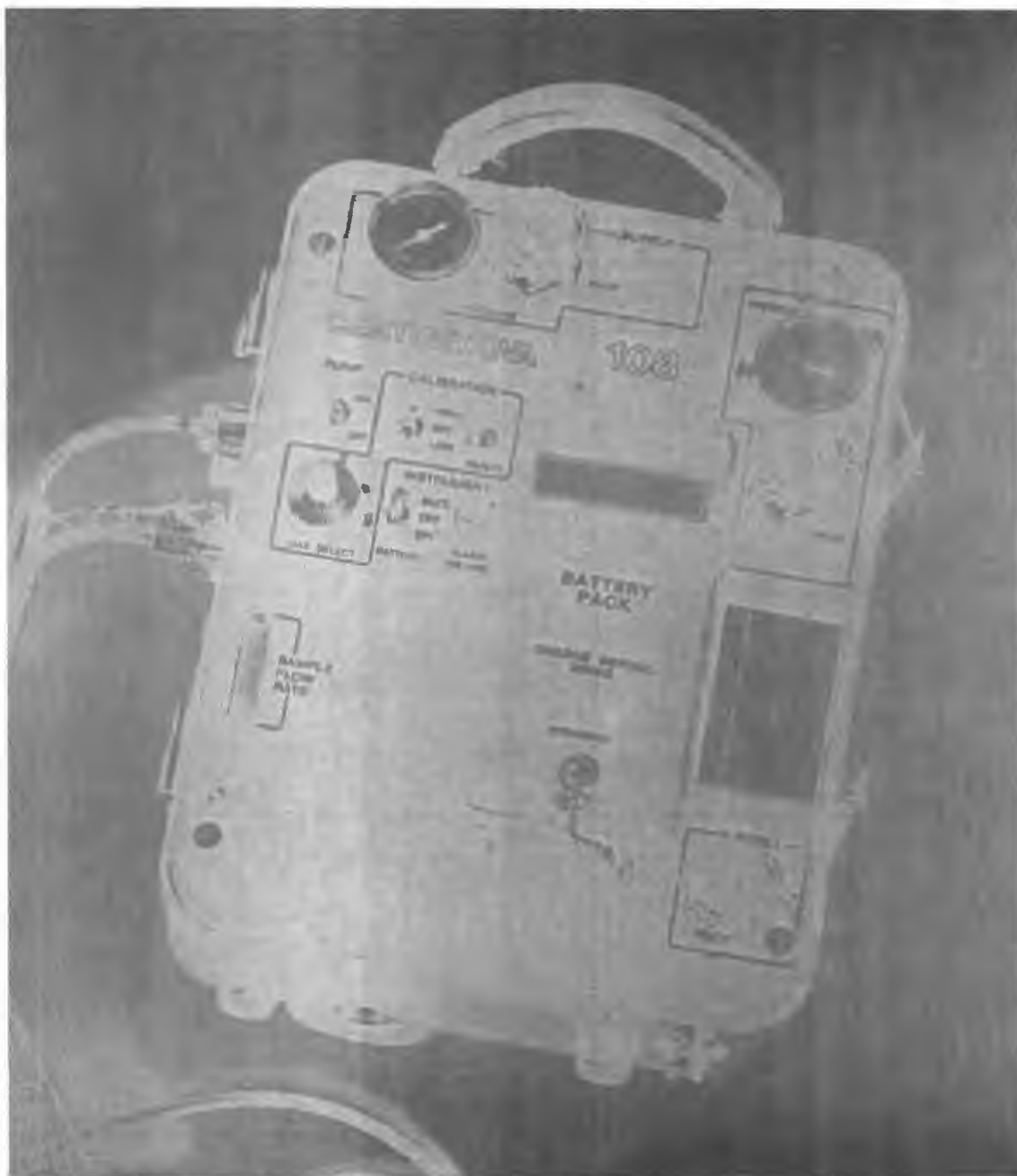
Manufacturer	Model Number	Pollutant(s) Detected	Detection Technique	Range
Bacharach Instrument Co., Santa Clara, California	L	Combustible gases	Catalytic combustion	0 - 100% LEL <sup>a</sup>
	TLV Sniffer	Combustible gases	Catalytic combustion	0 - 1,000 and 0 - 10,000 ppm
Foxboro S. Norwalk, Connecticut	OVA-128	Most organic compounds	FID/GC <sup>b</sup>	0 - 1,000 ppm
	OVA-108	Most organic compounds	FID/GC	0 - 10,000 ppm
	Miran IBX	Compounds that absorb infrared radiation	NDIR <sup>c</sup>	Compound specific
	TVA-1000	Most organic and inorganic compounds	Photoionization and FID/GC	0.5-2,000 ppm (photoionization) 1-50,000 ppm (FID/GC)
Health Consultants	Detecto- PAK III	Most organic compounds	FID/GC	0 - 10,000 ppm
HNU Systems, Inc. Newton Upper Falls, Massachusetts	HW-101	Chlorinated hydrocarbons, aromatics, aldehydes, ketones, any substance that ultraviolet light ionizes	Photoionization	0 - 20, 0 - 200 and 0 - 2,000 ppm
Mine Safety Appliances Co., Pittsburgh, Pennsylvania	40	Combustible gases	Catalytic combustion	0 - 10% and 0 - 100% LEL
Survey and Analysis, Inc., Northboro, Massachusetts	On Mark Model 5	Combustible gases	Thermal conductivity	0 - 5% and 0 - 100% LEL
Rae Systems Sunnyvale, California	MiniRAE PGM-75K	Chlorinated hydrocarbons, aromatics, aldehydes, ketones, any substance that ultraviolet light ionizes	Photoionization	0 - 1,999 ppm

<sup>a</sup> LEL = Lower explosive limit.<sup>b</sup> FID/GC = Flame ionization detection/gas chromatography.<sup>c</sup> NDIR = Nondispersive infrared analysis.



950236-LN-CRTP

**FIGURE 4.3-2. HW-101 PORTABLE ORGANIC COMPOUND DETECTION INSTRUMENT  
(HNU SYSTEM, INC.)**



**FIGURE 4.3-3. OVA-108 PORTABLE ORGANIC COMPOUND DETECTION INSTRUMENT (FOXBORO)**



**FIGURE 4.3-4. TVA-1000 PORTABLE ORGANIC/INORGANIC COMPOUND DETECTION INSTRUMENT (FOXBORO)**

Appendix C of this chapter presents general information on the methods generally employed in sampling source enclosures (vacuum and blow-through methods) and presents the calculation procedures for leak rates when using both methods.

The *Protocol for Equipment Leak Emission Estimates* document provides detailed information on sampling methods for bagging equipment, considerations for bagging each equipment type and analytical techniques (EPA, November 1995).

### **3.6 COMPARISON OF AVAILABLE EMISSION ESTIMATION METHODOLOGIES/APPROACHES**

Table 4.3-5 identifies the preferred and alternative emission estimation approaches for equipment leaks, and presents their advantages and disadvantages. All four emission estimation approaches presented are more appropriately applied to the estimation of emissions from equipment population rather than individual equipment pieces.

The preferred approach for estimating fugitive emissions from equipment leaks is to use the EPA correlation equations that relate screening values to mass emission rates. The selection of the preferred method for emission estimation purposes is based on the degree of accuracy obtained and the amount of resources and cost associated with the method.

Because the equipment leak emissions may occur randomly, intermittently, and vary in intensity over time, the "snapshot" of emissions from a given leak indicated by screening and/or bagging results, which are used either to develop or apply all of the approaches, may or may not be representative of the individual leak. However, by taking measurements from several pieces of a given equipment type, the snapshots of individual deviations from the actual leaks offset one another such that the ensemble of leaks should be representative. All of these approaches are imperfect tools for estimating fugitive emissions from equipment leaks; however, they are the best tools available. The best of these tools, the preferred method, can be expected to account for approximately 50 to 70 percent of the variability of the snapshot ensemble of equipment leak emissions.



TABLE 4.3-5

**SUMMARY OF THE ADVANTAGES AND DISADVANTAGES OF PREFERRED AND  
ALTERNATIVE EMISSION ESTIMATION APPROACHES FOR EQUIPMENT LEAKS**

<b>Preferred Emission Estimation Approach</b>	<b>Alternative Emission Estimation Approach</b>	<b>Advantages</b>	<b>Disadvantages</b>
EPA Correlation Equations		<p>Provides a refined emission estimate when actual screening values are available.</p> <p>Provides a continuous function over the entire range of screening values instead of discrete intervals.</p>	<p>Screening value measurements used with these correlations should have the same format as the one followed to develop the correlations (OVA<sup>a</sup>/methane).</p> <p>The development of an instrument response curve may be needed to relate screening values to actual concentration.</p>
	Average Emission Factors	In the absence of screening data, offers good indication of equipment leak emission rates from equipment in a process unit.	<p>They are not necessarily an accurate indication of the mass emission rate from an individual piece of equipment. Average emission factors do not reflect different site-specific conditions among process units within a source category.</p> <p>May present the largest potential error (among the other approaches) when applied to estimate emissions from equipment populations.</p>
	Screening Ranges	<p>Offers some refinement over the Average Emission Factor approach.</p> <p>Allows some adjustment for individual unit conditions and operation.</p>	Available data indicate that measured mass emission rates can vary considerably from the rates predicted by the use of these emission factors.
	Process- Unit Specific Correlation	The correlations are developed on a process unit basis to minimize the error associated with different leak rate characteristics between units.	High cost.

<sup>a</sup> Organic vapor analyzer.

## PREFERRED METHOD FOR ESTIMATING EMISSIONS

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The EPA correlation equation approach is the preferred method when actual screening values are available. This approach involves entering the screening value into the correlation equation, which predicts the mass emission rate based on the screening value. For new sources, when no actual screening values are available, average emission factors can be used temporarily to determine fugitive emissions from equipment leaks until specific and/or better data are available. However, it is recommended that the local environmental agency be contacted to discuss the best approach and assumptions when data are not available.

This approach offers a good 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. This approach is most valid for estimating emissions from a population of equipment and is not intended for estimating emissions from an individual equipment piece over a short time period (i.e., 1 hour). EPA correlation equations relating screening values to mass emission rates have been developed by the EPA for SOCFI process units and for the petroleum industry (EPA, November 1995).

Correlations for SOCFI are available for: (1) gas valves; (2) light liquid valves; (3) connectors; (4) single equation for light liquid pump seals. Correlation equations, for the petroleum industry that apply to refineries, marketing terminals, and oil and gas production operations data are available for: (1) valves; (2) connectors; (3) flanges; and (4) pump seals; (5) open-ended lines; and (6) other. The petroleum industry correlations apply to all services for a given equipment type.

An example of the EPA correlation equation approach is demonstrated for Streams A and B described in Table 4.4-1. This example is for a hypothetical chemical processing facility and is shown for the sole purpose of demonstrating the emission estimating techniques described in this chapter. As mentioned before, the correlation approach involves entering screening values into a correlation equation to generate an emission rate for each equipment piece. In Table 4.4-2, example screening values and the resulting emissions for each individual equipment piece are presented. Emissions from the pump that was not screened are estimated using the corresponding average emission factor.

TABLE 4.4-1

SAMPLE DATA FOR EXAMPLE CALCULATIONS<sup>a</sup>

Stream ID	Equipment Type/Service	Equipment Count	Hours of Operation <sup>b</sup> (hr/yr)	Stream Composition	
				Constituent	Weight Fraction
A	Pumps/light liquid	15	8,760	Ethyl acrylate	0.80
				Water	0.20
B	Pumps/light liquid	12	4,380	Ethyl acrylate	0.10
				Styrene	0.90
C	Valves/gas	40	8,760	Ethyl acrylate	0.65
				Ethane	0.25
				Water vapor	0.10

<sup>a</sup> Source: EPA, November 1995, Table A-1.

<sup>b</sup> Hours of operation include all of the time in which material is contained in the equipment.

TABLE 4.4-2

EPA CORRELATION EQUATION METHOD<sup>a</sup>

Equipment ID <sup>b</sup>	Screening Value (ppmv)	VOC Mass Emissions <sup>c</sup> (kg/yr)
A-1	0	0.066
A-2	0	0.066
A-3	0	0.066
A-4	0	0.066
A-5	0	0.066
A-6	20	2.0
A-7	50	4.2
A-8	50	4.2
A-9	100	7.4
A-10	100	7.4
A-11	200	13
A-12	400	23
A-13	1,000	49
A-14	2,000	87
A-15	5,000	190
<b>Total Stream A Emissions:</b>		<b>390</b>
B-1	0	0.033
B-2	0	0.033
B-3	0	0.033
B-4	10	0.55
B-5	30	1.4
B-6	250	7.9
B-7	500	14
B-8	2,000	44
B-9	5,000	93
B-10	8,000	140
B-11	25,000	350
B-12 (100% VOC) <sup>d</sup>	Not screened	87
<b>Total Stream B Emissions:</b>		<b>740</b>
<b>Total Emissions</b>		<b>1,130</b>

<sup>a</sup> Source: EPA, November, 1995, Table A-4.

<sup>b</sup> Equipment type: Light liquid pumps.

Correlation equation: Leak rate (kg/hr) =  $1.90 \times 10^{-5} \times (\text{Screening Value})^{0.824}$ ; Default-zero mass emission rate:  $7.49 \times 10^{-6}$  kg/hr.

Hours of operation: Stream A = 8,760; Stream B = 4,380.

<sup>c</sup> VOC Emissions = (correlation equation or default-zero emission rate)  $\times$  (WP<sub>VOC</sub>/WP<sub>TOC</sub>)  $\times$  (hours of operation).

<sup>d</sup> VOC Emissions = (average emission factor)  $\times$  (wt. fraction of TOC)  $\times$  (WP<sub>VOC</sub>/WP<sub>TOC</sub>)  $\times$  (hours of operation).

VOC emission estimates using the EPA correlation equation approach are 1,130 kg/yr. On the other hand, VOC emission estimates using the average emission factor approach and screening value range for the same Streams A and B included in Table 4.4-1 are 3,138 and 1,480 kg/yr, respectively (see Section 5, Tables 4.5-3 and 4.5-4).

The leak rate/screening value correlations, default zero emission rates, and pegged emission rates are presented in Table 4.4-3 for SOCM and in Table 4.4-4 for the petroleum industry. Example calculations utilizing the information presented in Tables 4.4-2 through 4.4-3 are demonstrated in Example 4.4-1.

The EPA correlation equations can be used to estimate emissions when the adjusted screening value (adjusted for the background concentration) is not a "pegged" screening value (the screening value that represents the upper detection limit of the monitoring device) or a "zero" screening value (the screening value that represents the minimum detection limit of the monitoring device). All non-zero and non-pegged screening values can be entered directly into the EPA correlation equation to predict the mass emissions (kg/hr) associated with the adjusted screening value (ppmv) measured by the monitoring device.

The correlation equations mathematically predict zero emissions for zero screening values (note that any screening value that is less than or equal to ambient [background] concentration is considered a screening value of zero). However, data collected by EPA show this prediction to be incorrect. Mass emissions have been measured from equipment having a screening value of zero. This is because the lower detection limit of the monitoring devices used is larger than zero and because of the difficulty in taking precise measurements close to zero. The default-zero emission rates are applicable only when the minimum detection limit of the portable monitoring device is 1 ppmv or less above background. In cases where a monitoring device has a minimum detection limit greater than 1 ppmv, the available default-zero emission leak rates presented in Tables 4.4-3 and 4.4-4 of this section are not applicable. For these cases, an alternative approach for determining a default-zero leak rate is to (1) determine one-half the minimum screening value of the monitoring device, and (2) enter this screening value into the applicable correlation to determine the associated default-zero leak rate.

In instances of pegged screening values, the true screening value is unknown and use of the correlation equation is not appropriate. Pegged emission rates have been developed using mass emissions data associated with known screening values of 10,000 ppmv or greater and for known screening values of 100,000 ppmv or greater. When the monitoring device is pegged at either of these levels, the appropriate pegged emission rate should be used to estimate the mass emissions of the component.

TABLE 4.4-3

**CORRELATION EQUATIONS, DEFAULT ZERO EMISSION RATES, AND PEGGED EMISSION RATES FOR ESTIMATING SOCM I TOC EMISSION RATES<sup>a</sup>**

Equipment Type	Default Zero Emission Rate (kg/hr per source)	Pegged Emission Rates (kg/hr per source)		Correlation Equation (kg/hr per source) <sup>b</sup>
		10,000 ppmv	100,000 ppmv	
Gas valves	6.6E-07	0.024	0.11	Leak Rate = $1.87\text{E-}06 \times (\text{SV})^{0.873}$
Light liquid valves	4.9E-07	0.036	0.15	Leak Rate = $6.41\text{E-}06 \times (\text{SV})^{0.797}$
Light liquid pumps <sup>c</sup>	7.5E-06	0.14	0.62	Leak Rate = $1.90\text{E-}05 \times (\text{SV})^{0.824}$
Connectors	6.1E-07	0.044	0.22	Leak Rate = $3.05\text{E-}06 \times (\text{SV})^{0.885}$

<sup>a</sup> Source: EPA, November 1995, Tables 2-9, 2-11, and 2-13. To estimate emissions: Use the default zero emission rates only when the screening value (adjusted for background) equals 0.0 ppmv; otherwise use the correlation equations. If the monitoring device registers a pegged value, use the appropriate pegged emission rate.

<sup>b</sup> SV is the screening value (ppmv) measured by the monitoring device.

<sup>c</sup> The emission estimates for light liquid pump seals can be applied to compressor seals, pressure relief valves, agitator seals, and heavy liquid pumps.

TABLE 4.4-4

**CORRELATION EQUATIONS, DEFAULT ZERO EMISSION RATES, AND PEGGED EMISSION RATES FOR ESTIMATING PETROLEUM INDUSTRY TOC EMISSION RATES<sup>a</sup>**

Equipment Type/Service	Default Zero Emission Rate (kg/hr per source) <sup>b</sup>	Pegged Emission Rates (kg/hr per source) <sup>c</sup>		Correlation Equation (kg/hr per source) <sup>d</sup>
		10,000 ppmv	100,000 ppmv	
Connector/All	7.5E-06	0.028	0.030	Leak Rate = $1.51\text{E-}06 \times (\text{SV})^{0.735}$
Flange/All	3.1E-07	0.085	0.084	Leak Rate = $4.44\text{E-}06 \times (\text{SV})^{0.703}$
Open-Ended Line/All	2.0E-06	0.030	0.079	Leak Rate = $2.16\text{E-}06 \times (\text{SV})^{0.704}$
Pump/All	2.4E-05	0.074	0.160 <sup>e</sup>	Leak Rate = $4.82\text{E-}05 \times (\text{SV})^{0.610}$
Valve/All	7.8E-06	0.064	0.140	Leak Rate = $2.28\text{E-}06 \times (\text{SV})^{0.746}$
Other <sup>f</sup> /All	4.0E-06	0.073	0.110	Leak Rate = $1.32\text{E-}05 \times (\text{SV})^{0.589}$

- <sup>a</sup> Source: EPA, November 1995, Tables 2-10, 2-12, and 2-14. Developed from the combined 1993 refinery, marketing terminal, and oil and gas production operations data. To estimate emissions: use the default zero emission rates only when the screening value (adjusted for background) equals 0.0 ppmv; otherwise use the correlation equations. If the monitoring device registers a pegged value, use the appropriate pegged emission rate.
- <sup>b</sup> Default zero emission rates were based on the combined 1993 refinery and marketing terminal data only (default zero data were not collected from oil and gas production facilities).
- <sup>c</sup> The 10,000 ppmv pegged emission rate was based on components screened at greater than 10,000 ppmv; however, in some cases, most of the data could have come from components screened at greater than 100,000 ppmv, thereby resulting in similar pegged emission rates for both the 10,000 and 100,000 ppmv pegged levels (e.g., connector and flanges).
- <sup>d</sup> SV is the screening value (ppmv) measured by the monitoring device.
- <sup>e</sup> Only two data points were available for the pump 100,000 ppmv pegged emission rate; therefore, the ratio of the pump 10,000 ppmv pegged emission rate to the overall 10,000 ppmv pegged emission rate was multiplied by the overall 100,000 ppmv pegged emission rate to approximate the pump 100,000 ppmv pegged emission rate.
- <sup>f</sup> The other equipment type includes instruments, loading arms, pressure relief valves, stuffing boxes, vents, compressors, and dump lever arms.

Example 4.4-1:

- Stream A, Equipment IDs: A-1, A-2, A-3, A-4, and A-5  
 Equipment Type: Light-liquid Pumps  
 Hours of Operation: 8,760 hours  
 SV (Screening value) = 0 ppmv  
 SOCM default-zero TOC emission rate (kg/hr/source)  

$$= 7.5 \times 10^{-6} \quad \text{(from Table 4.4-3)}$$
 VOC emissions per equipment ID (kg/yr)  

$$= 7.5 \times 10^{-6} \text{ kg/hr} \times (0.80/0.80) \times 8,760 \text{ hr}$$

$$= 0.066$$
- Stream A, Equipment ID: A-6  
 Equipment Type: Light-liquid Pumps  
 Hours of Operation: 8,760 hours  
 SV (Screening value) = 20 ppmv  
 SOCM Correlation Equation:  
 TOC Leak Rate (kg/hr)  

$$= 1.90 \times 10^{-5} (\text{SV})^{0.824} \quad \text{(from Table 4.4-3)}$$

$$= 1.90 \times 10^{-5} (20)^{0.824}$$

$$= 2.24 \times 10^{-4}$$
 VOC emissions (kg/yr)  

$$= 2.24 \times 10^{-4} \text{ kg/hr} \times 8,760 \text{ hr} \times (0.80/0.80)$$

$$= 2.0$$
- Stream A, Equipment IDs: A-7 and A-8  
 Equipment Type: Light-liquid Pumps  
 SV (Screening value) = 50 ppmv  
 SOCM Correlation Equation:  
 TOC Leak Rate (kg/hr)  

$$= 1.90 \times 10^{-5} (\text{SV})^{0.824} \quad \text{(from Table 4.4-3)}$$

$$= 1.90 \times 10^{-5} (50)^{0.824}$$

$$= 4.77 \times 10^{-4}$$
 VOC emissions (kg/yr)  

$$= 4.77 \times 10^{-4} \text{ kg/hr} \times 8,760 \text{ hr} \times (0.80/0.80)$$

$$= 4.2$$



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# 5

## ALTERNATIVE METHODS FOR ESTIMATING EMISSIONS

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The alternative methods for estimating emissions from equipment leaks are the following (in no specific order of preference):

- Average emission factor approach;
- Screening ranges approach; and
- Unit-specific correlation approach.

### 5.1 EMISSION CALCULATIONS USING THE AVERAGE EMISSION FACTOR APPROACH

The average emission factor approach is commonly used to calculate emissions when site-specific screening data are unavailable.

To estimate emissions using the average emission factor approach, the TOC concentration in weight percent within the equipment is needed. The TOC concentration in the equipment is important because equipment (and VOC or HAP concentrations if speciation is to be performed) with higher TOC concentrations tend to have higher TOC leak rates. The various equipment should be grouped into "streams," such that all equipment within a stream has approximately the same TOC weight percent.

This 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 of the stream; and (4) the time period each component was in that service.

EPA average emission factors have been developed for SOCMI process units, refineries, marketing terminals, and oil and gas production operations (EPA, November 1995). The method used by the EPA to develop emission factors for individual equipment leak emission sources is described in the *Protocol for Equipment Leak Emission Estimates* (EPA, November 1995). Tables 4.5-1 and 4.5-2 show the average emission factors for SOCMI process units and refineries, respectively.

**TABLE 4.5-1**  
**SOCMI AVERAGE EMISSION FACTORS<sup>a</sup>**

Equipment Type	Service	Emission Factor (kg/hr per source) <sup>b</sup>
Valves	Gas	0.00597
	Light liquid	0.00403
	Heavy liquid	0.00023
Pump seals <sup>c</sup>	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

<sup>a</sup> Source: EPA, November 1995, Table 2-1.

<sup>b</sup> These factors are for TOC emission rates.

<sup>c</sup> The light liquid pump seal factor can be used to estimate the leak rate from agitator seals.

**TABLE 4.5-2**  
**REFINERY AVERAGE EMISSION FACTORS<sup>a</sup>**

<b>Equipment Type</b>	<b>Service</b>	<b>Emission Factor (kg/hr per source)<sup>b</sup></b>
Valves	Gas	0.0268
	Light liquid	0.0109
	Heavy liquid <sup>d</sup>	0.00023
Pump seals <sup>c</sup>	Light liquid	0.114
	Heavy liquid <sup>d</sup>	0.021
Compressor seals	Gas	0.636
Pressure relief valves	Gas	0.16
Connectors	All	0.00025
Open-ended lines	All	0.0023
Sampling connections	All	0.0150

<sup>a</sup> Source: EPA, November 1995, Table 2-2. Based on data gathered in the 1970's.

<sup>b</sup> These factors are for non-methane organic compound emission rates.

<sup>c</sup> The light liquid pump seal factor can be used to estimate the leak rate from agitator seals.

<sup>d</sup> The American Petroleum Institute is conducting a program to develop revised emission factors for components in heavy liquid service. Contact state or local agencies to determine the appropriate application of heavy liquid emission factors.

Although the average emission factors are in units of kilogram per hour per individual source, it is important to note that these factors are most valid for estimating emissions from a population of equipment. However, the average emission factor approach may present the largest potential error, among the other approaches, when applied to estimate emissions from equipment populations. The average factors are not intended to be used for estimating emissions from an individual piece of equipment over a short time period (i.e., 1 hour).

When the average emission factors are used to estimate TOC mass emissions from refineries, it is necessary to adjust the refinery emission factors because they represent only non-methane emissions. To estimate TOC emissions, methane and non-methane organic compounds must be included. Two guidelines for adjusting the refinery emission factors are as follows:

- The adjustment should be applied only to equipment containing a mixture of organic and methane, and
- The maximum adjustment 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 (EPA, April and July 1980) typically contained 10 weight percent or less methane).

Because the average emission factors for refineries must be adjusted when estimating TOC emissions, there is one equation (Equation 4.5-1) for using the average emission factors to estimate emissions from SOCFI marketing terminals, and oil and gas production operations and a second equation (Equation 4.5-2) for using the emission factors to estimate emissions from refinery operations.

These equations can be used to estimate TOC emission from all of the equipment of a given equipment type in a stream:

$$E_{\text{TOC}} = F_A \times \text{WF}_{\text{TOC}} \times N \quad (4.5-1)$$

$$E_{\text{TOC}} = F_A \times \frac{\text{WF}_{\text{TOC}}}{\text{WF}_{\text{TOC}} - \text{WF}_{\text{methane}}} \times \text{WF}_{\text{TOC}} \times N \quad (4.5-2)$$

where:

$E_{\text{TOC}}$  = Emission rate of TOC from all equipment in the stream of a given equipment type (kg/hr);

$F_A$	=	Applicable average emission factor <sup>1</sup> for the equipment type (kg/hr per source);
$WF_{TOC}$	=	Average weight fraction of TOC in the stream;
$WF_{methane}$	=	Average weight fraction of methane in the stream;
$WF_{TOC}$	=	Average weight fraction of TOC in the stream; and
$N$	=	Number of pieces of the applicable equipment type in the stream.

If there are several streams at a process unit, the total VOC emission rate for an equipment type is the sum of VOC emissions from each of the streams. The total emission rates for all of the equipment types are summed to generate the process unit total VOC emission rate from leaking equipment.

An example of the average emission factor approach is demonstrated for Streams A and B included in Table 4.4-1. Note that Stream A contains water, which is not a TOC. Therefore, this is accounted for when total TOC emissions are estimated from Stream A. Table 4.5-3 summarizes the average emission factor approach calculations.

TABLE 4.5-3

## AVERAGE EMISSION FACTOR METHOD

Stream ID	Equipment Count	TOC Emission Factor (kg/hr per source)	Weight Fraction of TOC	Hours of Operation (hr/yr)	VOC Emissions <sup>a</sup> (kg/yr)
A	15	0.0199	0.80	8,760	2,092
B	12	0.0199	1.00	4,380	1,046
<b>Total Emissions</b>					<b>3,138</b>

<sup>a</sup> VOC Emissions = (no. of components) × (emission factor) × (wt. fraction TOC) × (WP<sub>VOC</sub>/WP<sub>TOC</sub>) × (hours of operation).

<sup>1</sup> Emission factors presented in the *1995 Protocol for Equipment Leak Emission Estimates* (EPA, November 1995) are for TOC emission rates, except for refineries that are for non-methane organic compound emission rates.

## 5.2 EMISSION CALCULATIONS USING THE SCREENING RANGES APPROACH

The screening ranges approach requires screening data to be collected for the equipment in the process unit. This approach is applied in a similar manner as the average emission factor approach in that equipment counts are multiplied by the applicable emission factor. However, because the screening value on which emissions are based is a measurement of only organic compound leakage, no adjustment is made for inorganic compounds.

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." As with the average factors, the SOCFI, marketing terminal, and oil and gas production operations screening range factors predict TOC emissions, whereas the refinery screening range factors predict non-methane organic compound emissions. Thus, when using the average refinery screening range factors to estimate TOC emissions from refineries, an adjustment must be made to the factors to include methane emissions. The maximum adjustment for the methane weight factors should not exceed 0.10, even if the equipment contains greater than 10 weight percent methane.

Because the average screening range factors for refineries must be adjusted when estimating TOC emissions, there is one equation (Equation 4.5-3) for using the average screening range factors to estimate emissions from SOCFI, marketing terminals, and oil and gas production operations and a second equation (Equation 4.5-4) for using the screening range factors to estimate emissions from refinery operations. These equations are described below:

$$E_{\text{TOC}} = (F_G \times N_G) + (F_L \times N_L) \quad (4.5-3)$$

$$E_{\text{TOC}} = \frac{WF_{\text{TOC}}}{WF_{\text{TOC}} - WF_{\text{methane}}} [(F_G \times N_G) + (f_L \times N_L)] \quad (4.5-4)$$

where:

$E_{\text{TOC}}$  = TOC emission rate for an equipment type (kg/hr);  
 $F_G$  = Applicable emission factor<sup>1</sup> for sources with screening values greater than or equal to 10,000 ppmv (kg/hr per source);

<sup>1</sup> Emission factors presented in the *1995 Protocol for Equipment Leak Emission Estimates* (EPA, November 1995) are for TOC emission rates, except for refineries that are for non-methane organic compound emission rates.

$WP_{TOC}$	=	Average weight percent of TOC in the stream;
$WP_{methane}$	=	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 per source); 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 VOCs, the total VOC emission for each stream is calculated as the sum of TOC emissions associated with each specific equipment type in the stream.

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.

An example of the screening value ranges approach is demonstrated in Table 4.5-4 using the example of a hypothetical chemical processing facility presented in Section 4 for Streams A and B (Table 4.4-1). The calculations are similar to those used for the average emission factor approach, except that a TOC emission factor for each screening value range is used. Emissions from equipment that could not be screened are calculated using average emission factors. VOC emissions using the screening value range approach are 1,480 kg/yr. In comparison, VOC emissions using the average emission factor approach for the same Streams A and B are 3,138 kg/yr, as shown in Table 4.5-3.

### 5.3 EMISSION CALCULATIONS USING UNIT-SPECIFIC CORRELATION APPROACH

Correlation equations may be developed for specific units rather than using correlation equations developed by the EPA. Once the correlations are developed, they are applied in the same way as described for the EPA correlations.

Before developing unit-specific correlations it is recommended that the validity of the EPA correlations to a particular process unit be evaluated because of the high cost of bagging. This can be done measuring as few as four leak rates of a particular equipment type in a particular service. The measured emission rate can be compared with the predicted rates obtained using the EPA correlations. If there is a consistent trend (i.e., all measured values are less than values predicted by the EPA correlation equation or all measured values are larger) the EPA correlation equation may not provide reasonable emission estimates for the



**TABLE 4.5-4**  
**SCREENING VALUE RANGES METHOD<sup>a</sup>**

Stream ID	Equipment Count <sup>b</sup>	Emission Factor (kg/hr per source)	Hours of Operation (hr/yr)	VOC Emissions (kg/yr)
Components screening $\geq 10,000$ ppmv <sup>c</sup>				
B	1	0.243	4,380	1,060
Components screening $< 10,000$ ppmv <sup>c</sup>				
A	15	0.00187	8,760	246
B	10	0.00187	4,380	82
Components not screened <sup>d</sup>				
B (TOC wt. fraction equal to 1.0)	1	0.0199	4,380	87
Total emissions				1,480

<sup>a</sup> Source: EPA, November, 1995, Table A-3.

<sup>b</sup> It was assumed that none of the light liquid pumps in Stream A have a screening value greater than or equal to 10,000 ppmv, one of the light liquid pumps in Stream B screens greater than 10,000 ppmv, and one of the pumps in Stream B could not be screened.

<sup>c</sup> VOC emissions = (no. of components)  $\times$  (TOC emission factor)  $\times$  (WP<sub>voc</sub>/WP<sub>TOC</sub>)  $\times$  (hours of operation).

<sup>d</sup> VOC emissions = (no. of components)  $\times$  (average TOC emission factor)  $\times$  (WP<sub>voc</sub>)  $\times$  (hours of operation).

process unit. There is a more formal comparison, the Wilcoxon signed-rank test, which can be performed by comparing the logarithm of the measured mass emission rates to the logarithm of the corresponding rates predicted by the EPA correlation.

In developing new unit-specific correlations, a minimum number of leak rate measurements and screening value pairs must be obtained. The *Protocol for Equipment Leak Emission Estimates* (EPA, November 1995) provides detailed information on the methodology to be followed. In general, the following consideration should be observed:

- Process unit equipment should be screened to know the distribution of screening values at the unit;
- Mass emission data must be collected from individual sources with screening values distributed over the entire range; and
- A random sample of a minimum of six components from each of the following screening value ranges (in ppmv) should be selected for bagging: 1-100; 101-1,000; 1,001-10,000; 10,001-100,000; and > 100,000. Therefore, a minimum of 30 emissions rate/screening value pairs should be obtained to estimate emissions across the entire range of screening values.

The *Protocol* document (EPA, November 1995) provides some alternatives to developing a correlation equation with fewer than 30 bags. These alternatives are based on experience in measuring leak rates and developing leak rate/screening value correlations. However, other source selection strategies can be used if an appropriate rationale is given.

Methodologies for generating leak rate/screening value correlations with mass emissions data and screening values are presented in Appendix B of the 1995 *Protocol* document. Once correlations are developed using the methodologies outlined in Appendix B, they are applied in the same manner as described in the example for the EPA correlations.

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# QUALITY ASSURANCE/QUALITY CONTROL PROCEDURES

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The consistent use of standardized methods and procedures is essential in the compilation of reliable emission inventories. Quality assurance (QA) and quality control (QC) of an inventory are accomplished through a set of procedures that ensure the quality and reliability of data collection and analysis. These procedures include the use of appropriate emission estimation techniques, applicable and reasonable assumptions, accuracy/logic checks of computer models, checks of calculations, and data reliability checks. Chapter 4 of Volume VI (the *QA Source Document*) of this series describes some QA/QC methods for performing these procedures.

Volume II, Chapter 1, *Introduction to Stationary Point Source Emission Inventory Development*, presents recommended standard procedures to follow that ensure the reported inventory data are complete and accurate. Chapter 1, should be consulted for current EIIP guidance for QA/QC checks for general procedures, recommended components of a QA plan, and recommended components for point source inventories. The QA plan discussion includes recommendations for data collection, analysis, handling, and reporting. The recommended QC procedures include checks for completeness, consistency, accuracy, and the use of approved standardized methods for emission calculations, where applicable.

## 6.1 SCREENING AND BAGGING DATA COLLECTION

To ensure that data quality is maintained while screening and data collection take place, it is recommended that data be recorded on prepared data sheets. Figures 4.6-1 provides an example data sheet that may be used to log measurements taken during a screening program.

To ensure highest quality of the data collected during the bagging program, QA/QC procedures must be followed. Quality assurance requirements include accuracy checks of the instrumentation used to perform mass emission sampling. Quality control requirements include procedures to be followed when performing equipment leak mass emissions sampling.

Figures 4.6-2 and 4.6-3 present examples of data collection forms to be used when collecting data in the field. Accuracy checks on the instrumentation and monitoring devices used to perform mass emission sampling include a leak rate check performed in the laboratory, blind standards to be analyzed by the laboratory instrumentation, and drift checks on the portable monitoring device.

## **CHAPTER 4 - EQUIPMENT LEAKS**

Operator Name: \_\_\_\_\_

Date: \_\_\_\_\_

[illegible]

**FIGURE 4.6-1. EXAMPLE FIELD SHEET FOR EQUIPMENT SCREENING DATA**

### EXAMPLE DATA COLLECTION FORM FOR FUGITIVE EMISSIONS BAGGING TEST (VACUUM METHOD)

Equipment Type _____	Component ID _____
Equipment Category _____	Plant ID _____
Line Size _____	Date _____
Stream Phase (G/V, LL, HL) _____	Analysis Team _____
Barometric Pressure _____	
Ambient Temperature _____	Instrument ID _____
Stream Temperature _____	Stream Pressure _____
Stream Composition (Wt. %) _____	

TimeBagging Test Measurement Data

_____	Initial Screening (ppmv) Equipment Piece <sup>a</sup> _____ Bkgd. _____	_____
_____	Background Bag Organic Compound Conc. (ppmv) <sup>b</sup> _____	_____
_____	Sample Bag 1 Organic Compound Conc. (ppmv) _____	_____
_____	Dry Gas Meter Reading (L/min) _____	_____
_____	Vacuum Check in Bag (Y/N) (Must be YES to collect sample.) _____	_____
_____	Dry Gas Meter Temperature <sup>c</sup> (°C) _____	_____
_____	Dry Gas Meter Pressure <sup>c</sup> (mmHg) _____	_____
_____	Sample Bag 2 Organic Compound Conc. (ppmv) _____	_____
_____	Dry Gas Meter Reading (L/min) _____	_____
_____	Vacuum Check in Bag (Y/N) (Must be YES to collect sample.) _____	_____
_____	Dry Gas Meter Temperature <sup>c</sup> (°C) _____	_____
_____	Dry Gas Meter Pressure <sup>c</sup> (mmHg) _____	_____
Condensate Accumulation: Starting Time _____ Final Time _____		
Organic Condensate Collected (mL) _____		
Density of Organic Condensate (g/mL) _____		
_____	Final Screening (ppmv) Equip. Piece <sup>a</sup> _____ Bkgd. _____	_____

<sup>a</sup> The vacuum method is not recommended if the screening value is approximately 10 ppmv or less.

<sup>b</sup> Collection of a background bag is optional.

<sup>c</sup> Pressure and temperature are measured at the dry gas meter.

**FIGURE 4.6-2. EXAMPLE DATA COLLECTION FORM FOR FUGITIVE EMISSIONS  
BAGGING TEST (VACUUM METHOD)**

### EXAMPLE DATA COLLECTION FORM FOR FUGITIVE EMISSIONS BAGGING TEST (BLOW-THROUGH METHOD)

Equipment Type _____	Component ID _____
Equipment Category _____	Plant ID _____
Line Size _____	Date _____
Stream Phase (G/V, LL, HL) _____	Analysis Team _____
Barometric Pressure _____	_____
Ambient Temperature _____	Instrument ID _____
Stream Temperature _____	Stream Pressure _____
Stream Composition (Wt. %) _____	
_____	
_____	

<u>Time</u>	<u>Bagging Test Measurement Data</u>
_____	Initial Screening (ppmv) Equipment Piece ____ Bkgd. _____
_____	Background Bag Organic Compound Conc. (ppmv) <sup>a</sup> _____
_____	Sample Bag 1 Organic Compound Conc. (ppmv) _____
_____	Dilution Gas Flow Rate (L/min) _____
_____	O <sub>2</sub> Concentration (volume %) _____
_____	Bag Temperature (°C) _____
_____	Sample Bag 2 Organic Compound Conc. (ppmv) _____
_____	Dilution Gas Flow Rate (L/min) _____
_____	O <sub>2</sub> Concentration (volume %) _____
_____	Bag Temperature (°C) _____
Condensate Accumulation: Starting Time ____ Final Time _____	
Organic Condensate Collected (mL) _____	
Density of Organic Condensate (g/mL) _____	
_____	Final Screening (ppmv) Equipment Piece ____ Bkgd. _____

<sup>a</sup> Collection of a background bag is optional. However, it is recommended in cases where the screening value is less than 10 ppmv and there is a detectable oxygen level in the bag.

**FIGURE 4.6-3. EXAMPLE DATA COLLECTION FORM FOR FUGITIVE EMISSIONS  
BAGGING TEST (BLOW-THROUGH METHOD)**

## 6.2 OTHER QA/QC ISSUES

At a minimum, the approach and data used to estimate emissions should be peer reviewed to assure correctness. In addition, some sample calculations should be performed to verify that calculations were done correctly.

If any of the methods that require screening or bagging data were used, the sample design should be reviewed to assure that all relevant equipment types were sampled. Furthermore, the adequacy of sample sizes should be verified.

## 6.3 DATA ATTRIBUTE RATING SYSTEM (DARS) SCORES

One measure of emission inventory data quality is the DARS score. Three examples are given here to illustrate DARS scoring using the preferred and alternative methods. The DARS provides a numerical ranking on a scale of 1 to 10 for individual attributes of the emission factor and the activity data. Each score is based on what is known about the factor and activity data, such as the specificity to the source category and the measurement technique employed. The composite attribute score for the emissions estimate can be viewed as a statement of the confidence that can be placed in the data. For a complete discussion of DARS and other rating systems, see the *QA Source Document* (Volume VI, Chapter 4), and Volume II, Chapter 1, *Introduction to Stationary Point Sources Emission Inventory Development*.

For each example, assume emissions are being estimated for a petroleum marketing terminal. Table 4.6-1 gives a set of scores for the preferred method, the EPA correlation approach. Note that a perfect score (1.0) is not possible with any of the methods described in this chapter because all are based on the use of surrogates rather than direct measurement of emissions. The spatial congruity attribute is not particularly relevant for this category, and thus is given a score of 1.0. Both measurement and specificity scores are relatively high (0.8) because the correlation equation is based on a representative sample from the specific category. The measurement attribute score assumes that the pollutants of interest were measured directly. The temporal attribute scores are 0.7 because the data (for the correlation equation and for the screening values) are presumed to be one time samples, but the throughputs are assumed not to vary much over time.

Tables 4.6-2 and 4.6-3 give DARS scores for the average emission factor approach and the unit-specific correlation approach respectively. Not surprisingly, the first approach gets lower DARS scores, while the second gets higher scores.



TABLE 4.6-1

## DARS SCORES: EPA CORRELATION APPROACH

Attribute	Scores		
	Factor	Activity	Emissions
Measurement	0.8	0.8	0.64
Specificity	0.8	1.0	0.80
Spatial	1.0	1.0	1.0
Temporal	0.7 <sup>a</sup>	0.7 <sup>a</sup>	0.49
Composite Scores	0.83	0.88	0.73

<sup>a</sup> Assumes a one-time sampling of equipment and little variation in throughput.

TABLE 4.6-2

## DARS SCORES: AVERAGE EMISSION FACTOR APPROACH

Attribute	Scores		
	Factor	Activity	Emissions
Measurement	0.6	0.5	0.3
Specificity	0.5	1.0	0.5
Spatial	1.0	1.0	1.0
Temporal	0.7	0.7	0.49
Composite Scores	0.7	0.8	0.57

TABLE 4.6-3

## DARS SCORES: UNIT-SPECIFIC CORRELATION APPROACH

Attribute	Scores		
	Factor	Activity	Emissions
Measurement	0.9	0.9	0.81
Specificity	1.0	1.0	1.0
Spatial	1.0	1.0	1.0
Temporal	0.7	0.7	0.49
Composite Scores	0.90	0.90	0.83

These examples are given as an illustration of the relative quality of each method. If the same analysis were done for an actual real site, the scores could be different but the relative ranking of methods should stay the same. Note, however, that if the source is not truly a member of the population used to develop the EPA correlation equations or the emission factors, these approaches are less appropriate and the DARS scores will probably drop.

If sufficient data are available, the uncertainty in the estimate should be evaluated. Qualitative and quantitative methods for conducting uncertainty analyses are described in the *QA Source Document* (Volume VI, Chapter 4).

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## DATA CODING PROCEDURES

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This section describes the methods and codes available for characterizing fugitive emissions from equipment leaks using Source Classification Codes (SCCs) and Aerometric Information Retrieval System (AIRS) control device codes. Consistent categorization and coding will result in greater uniformity among inventories. The SCCs are the building blocks on which point source emissions data are structured. Each SCC represents a unique process or function within a source category that is logically associated with an emission point. Without an appropriate SCC, a process cannot be accurately identified for retrieval purposes. In addition, the procedures described here will assist the reader preparing data for input into a database management system. For example, the SCCs provided in Table 4.7-1 are typical of the valid codes recommended for describing equipment leaks. This table does not include all fugitive source SCCs, but does include those commonly used to identify equipment leaks. Refer to the CHIEF bulletin board for a complete listing of SCCs.

While the codes presented here are currently in use, they may change based on further refinement by the emission inventory community. As part of the EIIP, a common data exchange format is being developed to facilitate data transfer between industry, states, and EPA.

For equipment leaks, be careful to use only one SCC for each process or source category. Many of these are designated for the entire process unit on an annual basis. In some cases, the user may need to calculate emissions for multiple pieces of equipment and then sum up to the unit total. The process-specific codes should be used as often as possible.

TABLE 4.7-1

**SOURCE CLASSIFICATION CODES AND DESCRIPTIONS FOR FUGITIVE EMISSIONS  
FROM EQUIPMENT LEAKS**

Source Description	Process Description	SCC	Units
<b>Industrial Processes</b>			
<b>Chemical Manufacturing</b>	Adipic Acid - Fugitive Emissions: General	3-01-001-80	Process Unit-Year
	Carbon Black Production; Furnace Process: Fugitive Emissions	3-01-005-09	Tons Produced
	Chlorine: Carbon Reactivation/Fugitives	3-01-007-05	Tons Produced
	Sulfuric Acid (Contact Process): Process Equipment Leaks	3-01-023-22	Tons 100% H <sub>2</sub> SO <sub>4</sub>
	Terephthalic Acid/ Dimethyl Terephthalate: Fugitive Emissions	3-01-031-80	Process Unit-Year
	Aniline/Ethanolamines: Fugitive Emissions	3-01-034-06	Process Unit-Year
	Aniline/Ethanolamines: Fugitive Emissions	3-01-034-14	Process Unit-Year
	Pharmaceutical Preparations: Miscellaneous Fugitives	3-01-060-22	Tons Processed
	Pharmaceutical Preparations: Miscellaneous Fugitives	3-01-060-23	Tons Processed
	Inorganic Chemical Manufacturing (General): Fugitive Leaks	3-01-070-01	Tons Product
	Acetone/Ketone Production: Fugitive Emissions (Acetone)	3-01-091-80	Process Unit-Year
	Maleic Anhydride: Fugitive Emissions	3-01-100-80	Process Unit-Year
	Fugitive Emissions (Formaldehyde)	3-01-120-07	Process Unit-Year

TABLE 4.7-1

(CONTINUED)

Source Description	Process Description	SCC	Units
<b>Industrial Processes</b>			
<b>Chemical Manufacturing</b>	Fugitive Emissions (Acetaldehyde)	3-01-120-17	Process Unit-Year
	Fugitive Emissions (Acrolein)	3-01-120-37	Process Unit-Year
	Chloroprene: Fugitive Emissions	3-01-124-80	Process Unit-Year
	Chlorine Derivatives: Fugitive Emissions (Ethylene Dichloride)	3-01-125-09	Process Unit-Year
	Chlorine Derivatives: Fugitive Emissions (Chloromethanes)	3-01-125-14	Process Unit-Year
	Chlorine Derivatives: Fugitive Emissions (Perchloroethylene)	3-01-125-24	Process Unit-Year
	Chlorine Derivatives: Fugitive Emissions (Trichloroethane)	3-01-125-29	Process Unit-Year
	Chlorine Derivatives: Fugitive Emissions (Trichloroethylene)	3-01-125-34	Process Unit-Year
	Chlorine Derivatives: Fugitive Emissions (Vinyl Chloride)	3-01-125-50	Process Unit-Year
	Chlorine Derivatives: Fugitive Emissions (Vinylidene Chloride)	3-01-125-55	Process Unit-Year
	Fluorocarbons/ Chloroflourocarbons: Fugitive Emissions	3-01-127-80	Process Unit-Year
	Organic Acid Manufacturing: Fugitive Emissions	3-01-132-27	Process Unit-Year

TABLE 4.7-1

(CONTINUED)

Source Description	Process Description	SCC	Units
<b>Industrial Processes</b>			
<b>Chemical Manufacturing</b>	Acetic Anhydride: Fugitive Emissions	3-01-133-80	Process Unit-Year
	Butadiene: Fugitive Emissions	3-01-153-80	Process Unit-Year
	Cumene: Fugitive Emissions	3-01-156-80	Process Unit-Year
	Cyclohexane: Fugitive Emissions	3-01-157-80	Process Unit-Year
	Cyclohexanone/ Cyclohexanol: Fugitive Emissions	3-01-158-80	Process Unit-Year
	Vinyl Acetate: Fugitive Emissions	3-01-167-80	Process Unit-Year
	Ethyl Benzene: Fugitive Emissions	3-01-169-80	Process Unit-Year
	Ethylene Oxide: Fugitive Emissions	3-01-174-80	Process Unit-Year
	Glycerin (Glycerol): Fugitive Emissions	3-01-176-80	Process Unit-Year
	Toluene Diisocyanate: Fugitive Emissions	3-01-181-80	Process Unit-Year
	Methyl Methacrylate: Fugitive Emissions	3-01-190-80	Process Unit-Year
	Nitrobenzene: Fugitive Emissions	3-01-195-80	Process Unit-Year
	Olefin Prod.: Fugitive Emissions (Propylene)	3-01-197-09	Process Unit-Year
	Olefin Prod.: Fugitive Emissions (Ethylene)	3-01-197-49	Process Unit-Year
	Phenol: Fugitive Emissions	3-01-202-80	Process Unit-Year
	Propylene Oxide: Fugitive Emissions	3-01-205-80	Process Unit-Year
	Styrene: Fugitive Emissions	3-01-206-80	Process Unit-Year

TABLE 4.7-1

(CONTINUED)

Source Description	Process Description	SCC	Units
<b>Industrial Processes</b>			
Chemical Manufacturing	Caprolactam: Fugitive Emissions	3-01-210-80	Process Unit-Year
	Linear Alkylbenzene: Fugitive Emissions	3-01-211-80	Process Unit-Year
	Methanol/Alcohol Production: Fugitive Emissions (Methanol)	3-01-250-04	Process Unit-Year
	Ethylene Glycol: Fugitive Emissions	3-01-251-80	Process Unit-Year
	Glycol Ethers: Fugitive Emissions	3-01-253-80	Process Unit-Year
	Nitriles, Acrylonitrile, Adiponitrile Prod.: Fugitive Emissions	3-01-254-09	Process Unit-Year
	Nitriles, Acrylonitrile, Adiponitrile Prod.: Fugitive Emissions	3-01-254-20	Process Unit-Year
	Benzene/Toluene/Aromatics/Xylenes: Fugitive Emissions (Aromatics)	3-01-258-80	Process Unit-Year
	Chlorobenzene: Fugitive Emissions	3-01-301-80	Process Unit-Year
	Carbon Tetrachloride: Fugitive Emissions	3-01-302-80	Tons Product
	Allyl Chloride: Fugitive Emissions	3-01-303-80	Process Unit-Year
	Allyl Alcohol: Fugitive Emissions	3-01-304-80	Process Unit-Year
	Epichlorohydrin: Fugitive Emissions	3-01-305-80	Process Unit-Year
	General Processes: Fugitive Leaks	3-01-800-01	Process Unit-Year



TABLE 4.7-1

(CONTINUED)

Source Description	Process Description	SCC	Units
<b>Industrial Processes</b>			
Chemical Manufacturing	Fugitive Emissions: Specify In Comments Field	3-01-888-02	Tons Product
	Fugitive Emissions: Specify In Comments Field	3-01-888-01	Tons Product
	Fugitive Emissions: Specify In Comments Field	3-01-888-03	Tons Product
	Fugitive Emissions: Specify In Comments Field	3-01-888-04	Tons Product
	Fugitive Emissions: Specify In Comments Field	3-01-888-05	Process Unit-Year
Primary Metal Production	By-Product Coke Manufacturing-Equipment Leaks	3-03-003-61	Process Unit-Year
	Primary Metal Production - Equipment Leaks	3-03-800-01	Facility-Annual
Secondary Metal Production	Secondary Metal Production-Equipment Leaks	3-04-800-01	Facility-Annual
Petroleum Industry	Pipeline Valves And Flanges	3-06-008-01	1000 Barrels Refined
	Vessel Relief Valves	3-06-008-02	1000 Barrels Refined
	Pump Seals Without Controls	3-06-008-03	1000 Barrels Refined
	Compressor Seals	3-06-008-04	1000 Barrels Refined
	Misc: Sampling/Non-Asphalt Blowing/Purging/Etc.	3-06-008-05	1000 Barrels Refined
	Pump Seals With Controls	3-06-008-06	1000 Barrels Refined

TABLE 4.7-1

(CONTINUED)

Source Description	Process Description	SCC	Units
<b>Industrial Processes</b>			
Petroleum Industry	Blind Changing	3-06-008-07	1000 Barrels Refined
	Pipeline Valves: Gas Streams	3-06-008-11	Valves In Operation
	Pipeline Valves: Light Liquid/Gas Stream	3-06-008-12	Valves In Operation
	Pipeline Valves: Heavy Liquid Stream	3-06-008-13	Valves In Operation
	Pipeline Valves: Hydrogen Streams	3-06-008-14	Valves In Operation
	Open-Ended Valves: All Streams	3-06-008-15	Valves In Operation
	Flanges: All Streams	3-06-008-16	Flanges In Operation
	Pump Seals: Light Liquid/Gas Streams	3-06-008-17	Seals In Operation
	Pump Seals: Heavy Liquid Streams	3-06-008-18	Seals In Operation
	Compressor Seals: Gas Streams	3-06-008-19	Seals In Operation
	Compressor Seals: Heavy Liquid Streams	3-06-008-20	Seals In Operation
	Drains: All Streams	3-06-008-21	Drains In Operation
	Vessel Relief Valves: All Streams	3-06-008-22	Valves In Operation
	Fugitive Emissions - Specify In Comments Field	3-06-888-01	1000 Barrels Refined
	Fugitive Emissions - Specify In Comments Field	3-06-888-02	1000 Barrels Refined
	Fugitive Emissions - Specify In Comments Field	3-06-888-03	1000 Barrels Refined

TABLE 4.7-1

(CONTINUED)

Source Description	Process Description	SCC	Units
<b>Industrial Processes</b>			
Petroleum Industry	Fugitive Emissions - Specify In Comments Field	3-06-888-04	1000 Barrels Refined
	Fugitive Emissions - Specify In Comments Field	3-06-888-05	1000 Barrels Refined
Rubber And Miscellaneous Plastics Products	Rubber And Miscellaneous Plastic Parts - Equipment Leaks	3-08-800-01	Facility-Annual
Oil And Gas Production	Crude Oil Production - Complete Well	3-10-001-01	Wells/Year In Operation
	Crude Oil Production - Oil Well Cellars	3-10-001-08	Sq Ft Of Surface Area
	Crude Oil Production - Compressor Seals	3-10-001-30	Number Of Seals
	Crude Oil Production - Drains	3-10-001-31	Number Of Drains
	Natural Gas Production - Valves	3-10-002-07	Million Cubic Feet
	Natural Gas Production - Drains	3-10-002-31	Number Of Drains
	Fugitive Emissions - Specify In Comments Field	3-10-888-01	Process-Unit/Year
	Fugitive Emissions - Specify In Comments Field	3-10-888-02	Process-Unit/Year
	Fugitive Emissions - Specify In Comments Field	3-10-888-03	Process-Unit/Year
	Fugitive Emissions - Specify In Comments Field	3-10-888-04	Process-Unit/Year
	Fugitive Emissions - Specify In Comments Field	3-10-888-05	100 Barrel Feed Prod.
	Fugitive Emissions - Specify In Comments Field	3-10-888-11	Million Cubic Feet

TABLE 4.7-1

(CONTINUED)

Source Description	Process Description	SCC	Units
<b>Industrial Processes</b>			
Transportation Equipment	Transportation Equipment - Equipment Leaks	3-14-800-01	Facility-Annual
<b>Petroleum &amp; Solvent Evaporation</b>			
Organic Solvent Evaporation	Dry Cleaning - Misc. Trichloroethylene Fugitives	4-01-001-63	Tons Clothes Cleaned
	Fugitive Emissions - Specify In Comments Field	4-01-888-01	Tons Product
	Fugitive Emissions - Specify In Comments Field	4-01-888-02	Tons Product
	Fugitive Emissions - Specify In Comments Field	4-01-888-03	Tons Product
	Fugitive Emissions - Specify In Comments Field	4-01-888-04	Tons Product
	Fugitive Emissions - Specify In Comments Field	4-01-888-05	Tons Product
	Fugitive Emissions - Specify In Comments Field	4-01-888-98	Gallons
Surface Coating Operations	Surface Coating Operations - Equipment Leaks	4-02-800-01	Facility-Annual
Organic Chemical Transportation	Organic Chemical Transportation - Equipment Leaks	4-08-800-01	Facility-Annual
Organic Solvent Evaporation	Waste Solvent Recovery Operations - Fugitive Leaks	4-90-002-06	Process-Unit/Year
<b>Waste Disposal</b>			
Solid Waste Disposal - Government	Solid Waste Disposal: Govt. - Equipment Leaks	5-01-800-01	Facility-Annual
Solid Waste Disposal - Commercial/Institutional	Solid Waste Disposal: Comm./Inst. - Equipment Leaks	5-02-800-01	Facility-Annual
Solid Waste Disposal - Industrial	Solid Waste Disposal: Indus. - Equipment Leaks	5-03-800-01	Facility-Annual

TABLE 4.7-1

(CONTINUED)

Source Description	Process Description	SCC	Units
<b>Waste Disposal</b>			
Site Remediation	Site Remediation - Equipment Leaks	5-04-800-01	Facility-Annual
<b>MACT Source Categories</b>			
Styrene Or Methacrylate-based Resins	Styrene Or Methacrylate-based Resins - Equipment Leaks	6-41-800-01	Facility-Annual
Cellulose-based Resins	Cellulose-based Resins - Equipment Leaks	6-44-800-01	Facility-Annual
Miscellaneous Resins	Miscellaneous Resins - Equipment Leaks	6-45-800-01	Facility-Annual
Vinyl-based Resins	Vinyl-based Resins - Equipment Leaks	6-46-800-01	Facility-Annual
Miscellaneous Polymers	Miscellaneous Polymers - Equipment Leaks	6-48-800-01	Facility-Annual
MACT Miscellaneous Processes (Chemicals)	MACT Misc. Processes (Chemicals) - Equipment Leaks	6-84-800-01	Facility-Annual
MACT Miscellaneous Processes (Chemicals)	MACT Misc. Processes (Chemicals) - Equipment Leaks	6-85-800-01	Facility-Annual

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## **APPENDIX A**

# **ESTIMATING LEAK DETECTION AND REPAIR (LDAR) CONTROL EFFECTIVENESS**



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## ESTIMATING LDAR CONTROL EFFECTIVENESS

Some process units/facilities may want to develop control efficiencies specific to their process/facility if they have different leak definitions than what is in the federal programs. The LDAR monitoring frequency and leak definitions at some state equipment leak control programs may also be significantly different from federal programs. Table 4.A-1 presents a summary of controls required by federal requirement leak control programs.

The control efficiency of monitoring equipment at various leak definitions and monitoring frequencies may be estimated from the leak frequency before and after an LDAR program is implemented. Tables 4.A-2, and 4.A-3 present equations relating average leak rate to fraction leaking at SOCOMI facilities and petroleum refineries. Once the initial and final leak frequencies are determined, they can be entered into the applicable equation to calculate the corresponding average leak rates at these leak frequencies. The control effectiveness for an LDAR program can be calculated from the initial leak rate and the final leak rate.

$$\text{Eff} = (\text{ILR} - \text{FLR})/\text{ILR} \times 100 \quad (4.A-1)$$

where:

- Eff = Control effectiveness (percent)
- ILR = Initial leak rate (kg/hr per source)
- FLR = Final leak rate (kg/hr per source)

The methodology for estimating leak frequencies is discussed in detail in Chapter 5 of the *Equipment Leaks Enabling Document* (EPA, July 1992). The methodology requires knowledge of screening data and equipment repair times.

### REFERENCE

EPA. July 1992. *Equipment Leaks Enabling Document*. Final Report. Internal Instruction Manual for ESD Regulation Development. U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina.

TABLE 4.A-1

## CONTROLS REQUIRED BY EQUIPMENT LEAK CONTROL PROGRAMS

Equipment Type	Service	Petroleum Refinery CTG <sup>a</sup>	SOCMI CTG	Petroleum Refinery NSPS <sup>b</sup>	HON
Valves	Gas	Quarterly LDAR at 10,000 ppm	Quarterly LDAR at 10,000 ppm	Monthly LDAR at 10,000 ppm; decreasing frequency with good performance	Monthly LDAR with >2% leakers; quarterly LDAR with <2% leakers; decreasing frequency with good performance. Initially at 10,000 ppm, annually at 500 ppm
	Light liquid	Annual LDAR at 10,000 ppm	Quarterly LDAR at 10,000 ppm	Monthly LDAR at 10,000 ppm; decreasing frequency with good performance	Monthly LDAR with >2% leakers; quarterly LDAR with <2% leakers; decreasing frequency with good performance. Initially at 10,000 ppm, annually at 500 ppm
Pumps	Light liquid	Annual LDAR at 10,000 ppm; weekly visual inspection	Quarterly LDAR at 10,000 ppm; weekly visual inspection	Monthly LDAR at 10,000 ppm; weekly visual inspection; or dual mechanical seals with controlled degassing vents	Monthly LDAR; weekly visual inspection. Leak definition decreases from 10,000 ppm; or dual mechanical seals or closed-vent system
Compressors	Gas	Quarterly LDAR at 10,000 ppm	Quarterly LDAR at 10,000 ppm	Daily visual inspection; dual mechanical seal with barrier fluid and closed-vent system or maintained at a higher pressure than the compressed gas	Daily visual inspection. Dual mechanical seal with barrier fluid and closed-vent system or maintained at a higher pressure than the compressed gas
Connectors	Gas and light liquid	None	None	None	Annual LDAR at 500 ppm with >0.5% leakers; decreasing frequency with good performance

TABLE 4.A-1

(CONTINUED)

Equipment Type	Service	Petroleum Refinery CTG <sup>a</sup>	SOCMI CTG	Petroleum Refinery NSPS <sup>b</sup>	HON
Pressure relief devices	Gas	Quarterly LDAR at 10,000 ppm	Quarterly LDAR at 10,000 ppm	No detectable emissions	No detectable emissions or closed-vent system
Sampling connections	All	None	None	Closed-loop or in situ sampling	Closed-loop, closed-purge, closed vent or in situ sampling
Open-ended lines	All	Cap, blind flange, plug, or second valve	Cap, blind flange, plug, or second valve	Cap, blind flange, plug, or second valve	Cap, blind flange, plug, or second valve

<sup>a</sup> CTG = Control Techniques Guidelines.<sup>b</sup> NSPS = New Source Performance Standard.

TABLE 4.A-2

**EQUATIONS RELATING AVERAGE LEAK RATE TO FRACTION  
LEAKING AT SOCMI UNITS**

Equipment Type	Leak Definition (ppmv)	Equations <sup>a,b</sup>
Gas valve	500	$ALR = (0.04372) \times (Lk\text{ Frac.}) + 0.000017$
	1000	$ALR = (0.04982) \times (Lk\text{ Frac.}) + 0.000028$
	2000	$ALR = (0.05662) \times (Lk\text{ Frac.}) + 0.000043$
	5000	$ALR = (0.06793) \times (Lk\text{ Frac.}) + 0.000081$
	10000	$ALR = (0.07810) \times (Lk\text{ Frac.}) + 0.000131$
Light liquid valve	500	$ALR = (0.04721) \times (Lk\text{ Frac.}) + 0.000027$
	1000	$ALR = (0.05325) \times (Lk\text{ Frac.}) + 0.000039$
	2000	$ALR = (0.06125) \times (Lk\text{ Frac.}) + 0.000059$
	5000	$ALR = (0.07707) \times (Lk\text{ Frac.}) + 0.000111$
	10000	$ALR = (0.08901) \times (Lk\text{ Frac.}) + 0.000165$
Light liquid pump	500	$ALR = (0.09498) \times (Lk\text{ Frac.}) + 0.000306$
	1000	$ALR = (0.11321) \times (Lk\text{ Frac.}) + 0.000458$
	2000	$ALR = (0.13371) \times (Lk\text{ Frac.}) + 0.000666$
	5000	$ALR = (0.19745) \times (Lk\text{ Frac.}) + 0.001403$
	10000	$ALR = (0.24132) \times (Lk\text{ Frac.}) + 0.001868$
Connector	500	$ALR = (0.04684) \times (Lk\text{ Frac.}) + 0.000017$
	2000	$ALR = (0.07307) \times (Lk\text{ Frac.}) + 0.000035$
	5000	$ALR = (0.09179) \times (Lk\text{ Frac.}) + 0.000054$
	10000	$ALR = (0.11260) \times (Lk\text{ Frac.}) + 0.000081$

<sup>a</sup> ALR = Average TOC leak rate (kg/hr per source).

<sup>b</sup> Lk Frac. = Fraction leaking.

**TABLE 4.A-3**  
**EQUATIONS RELATING AVERAGE LEAK RATE TO FRACTION LEAKING**  
**AT REFINERY PROCESS UNITS**

Equipment Type	Leak Definition (ppmv)	Equation <sup>a,b</sup>
Gas valve	500	$ALR = (0.11140) \times (Lk \text{ Frac.}) + 0.000088$
	1000	$ALR = (0.12695) \times (Lk \text{ Frac.}) + 0.000140$
	10000	$ALR = (0.26200) \times (Lk \text{ Frac.}) + 0.000600$
Light liquid valve	500	$ALR = (0.03767) \times (Lk \text{ Frac.}) + 0.000195$
	1000	$ALR = (0.04248) \times (Lk \text{ Frac.}) + 0.000280$
	10000	$ALR = (0.08350) \times (Lk \text{ Frac.}) + 0.001700$
Light liquid pump	500	$ALR = (0.19579) \times (Lk \text{ Frac.}) + 0.001320$
	1000	$ALR = (0.23337) \times (Lk \text{ Frac.}) + 0.001980$
	10000	$ALR = (0.42500) \times (Lk \text{ Frac.}) + 0.012000$
Connector	500	$ALR = (0.01355) \times (Lk \text{ Frac.}) + 0.000013$
	1000	$ALR = (0.01723) \times (Lk \text{ Frac.}) + 0.000018$
	10000	$ALR = (0.03744) \times (Lk \text{ Frac.}) + 0.000060$

<sup>a</sup> ALR = Average non-methane organic compound leak rate (kg/hr per source).

<sup>b</sup> Lk Frac. = Fraction leaking.

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## **APPENDIX B**

# **SOURCE SCREENING — RESPONSE FACTORS**



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## SOURCE SCREENING — RESPONSE FACTORS

This appendix presents additional information on response factors and includes some guidelines on how to evaluate whether a RF correction to a screening value should be made.

An RF is a correction factor that can be applied to a screening value to relate the actual concentration to the measured concentration of a given compound. The RF is calculated using the equation:

$$RF = AC/SV \quad (4.B-1)$$

where:

RF	=	Response factor
AC	=	Actual concentration of the organic compound (ppmv)
SV	=	Screening value (ppmv)

The value of the RF is a function of several parameters. These parameters include the monitoring instrument, the calibration gas used to calibrate the instrument, the compound(s) being screened, and the screening value.

The EPA recommends that if a compound (or mixture) has an RF greater than 3, then the RF should be used to adjust the screening value before it is used in estimating emissions. When a compound has an RF greater than three for the recalibrated instrument, the emissions estimated using the unadjusted screening value will, generally, underestimate the actual emissions.

A detailed list of published RFs is presented in Appendix C of the *Protocol* document (EPA, November 1995). These RFs, developed for pure compounds, can be used to estimate the RF for a mixture by using the equation:

$$RF_m = \frac{1}{\sum_{i=1}^n (x_i/RF_i)} \quad (4.B-2)$$

where:

$RF_m$	=	Response factor of the mixture
$n$	=	Number of components in the mixture
$x_i$	=	Mole fraction of constituent "i" in the mixture

$RF_i$  = Response factor of constituent i in the mixture

For more detail on the derivation of this equation, please refer to Appendix A of the *Protocol* document (EPA, November 1995).

In general, RFs can be used to correct all screening values, if so desired. The following steps can be carried out to evaluate whether an RF correction to a screening value should be made.

1. For the combination of monitoring instrument and calibration gas used, determine the RFs of a given material at an actual concentration of 500 ppmv and 10,000 ppmv. When it may not be possible to achieve an actual concentration of 10,000 ppmv for a given material, the RF at the highest concentration that can be safely achieved should be determined.
2. If the RFs at both actual concentrations are below 3, it is not necessary to adjust the screening values.
3. If either of the RFs are greater than 3, then the EPA recommends an RF be applied for those screening values for which the RF exceeds 3.

One of the following two approaches can be applied to correct screening values:

1. Use the higher of either the 500 ppmv RF or the 10,000 ppmv RF to adjust all screening values; or
2. Generate a response factor curve to adjust the screening values.

When it is necessary to apply RFs, site personnel should use engineering judgement to group process equipment into streams containing similar compounds. All components associated with a given stream can then be assigned the same RF, as opposed to calculating an RF for each individual equipment piece. Appendix A of the *Protocol* document (EPA, November 1995) presents an example about the application of response factors.

## REFERENCE

EPA. November 1995. *Protocol for Equipment Leak Emission Estimates*. U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Air Quality Planning and Standards, 453/R-95-017. Research Triangle Park, North Carolina.

## **APPENDIX C**

# **MASS EMISSIONS SAMPLING — METHODS AND CALCULATION PROCEDURES**

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## MASS EMISSIONS SAMPLING (BAGGING)

When bagging an equipment piece, two methods are generally employed in sampling source enclosures: the vacuum method (Figure 4.C-1) and the blow-through method (Figure 4.C-2). These two methods differ in the ways that the carrier gas is conveyed through the bag. In the vacuum method, a vacuum pump is used to pull air through the bag. In the blow-through method, a carrier gas such as nitrogen is blown into the bag. In general, the blow-through method has advantages over the vacuum method. These advantages are as follows:

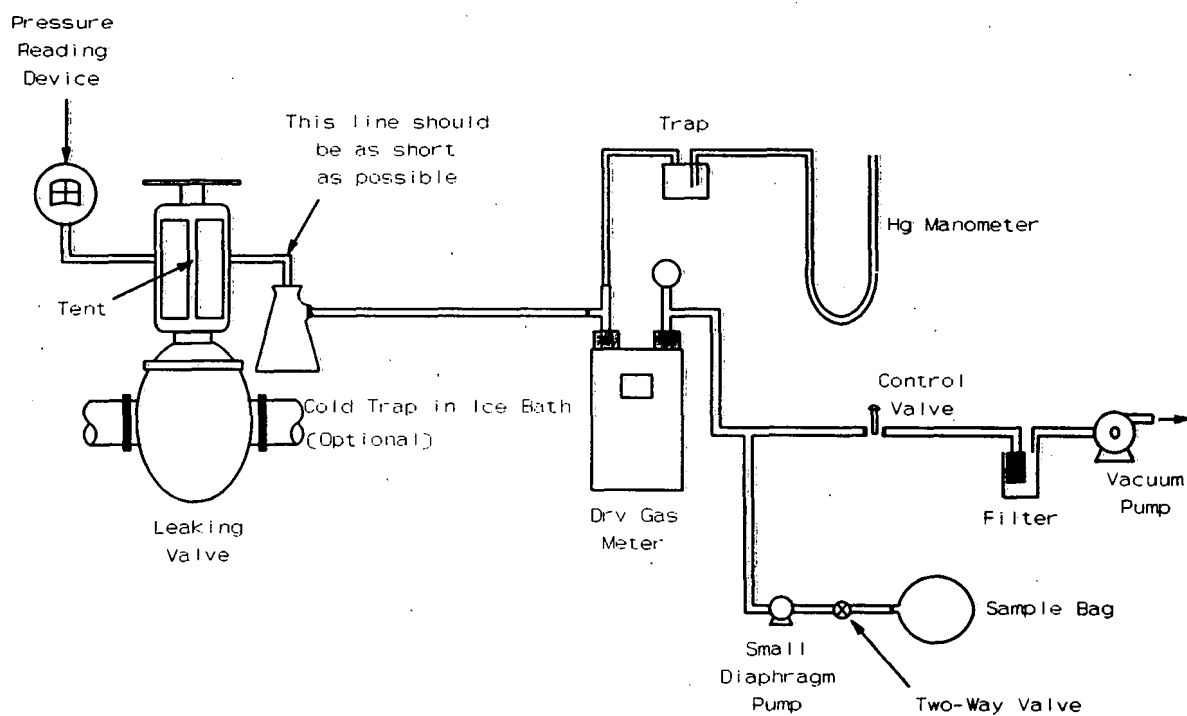
- The blow-through method is more conducive to better mixing in the bag.
- The blow-through method minimizes ambient air in the bag and thus reduces potential error associated with background organic compound concentrations. (For this reason the blow-through method is especially preferable when measuring the leak rate from components with zero or very low screening values.)
- The blow-through method minimizes oxygen concentration in the bag (assuming air is not used as the carrier gas) and the risk of creating an explosive environment.
- In general, less equipment is required to set up the blow-through method sampling train.

However, the blow-through method does require a carrier gas source, and preferably the carrier gas should be inert and free of any organic compounds and moisture. The vacuum method does not require a special carrier gas.

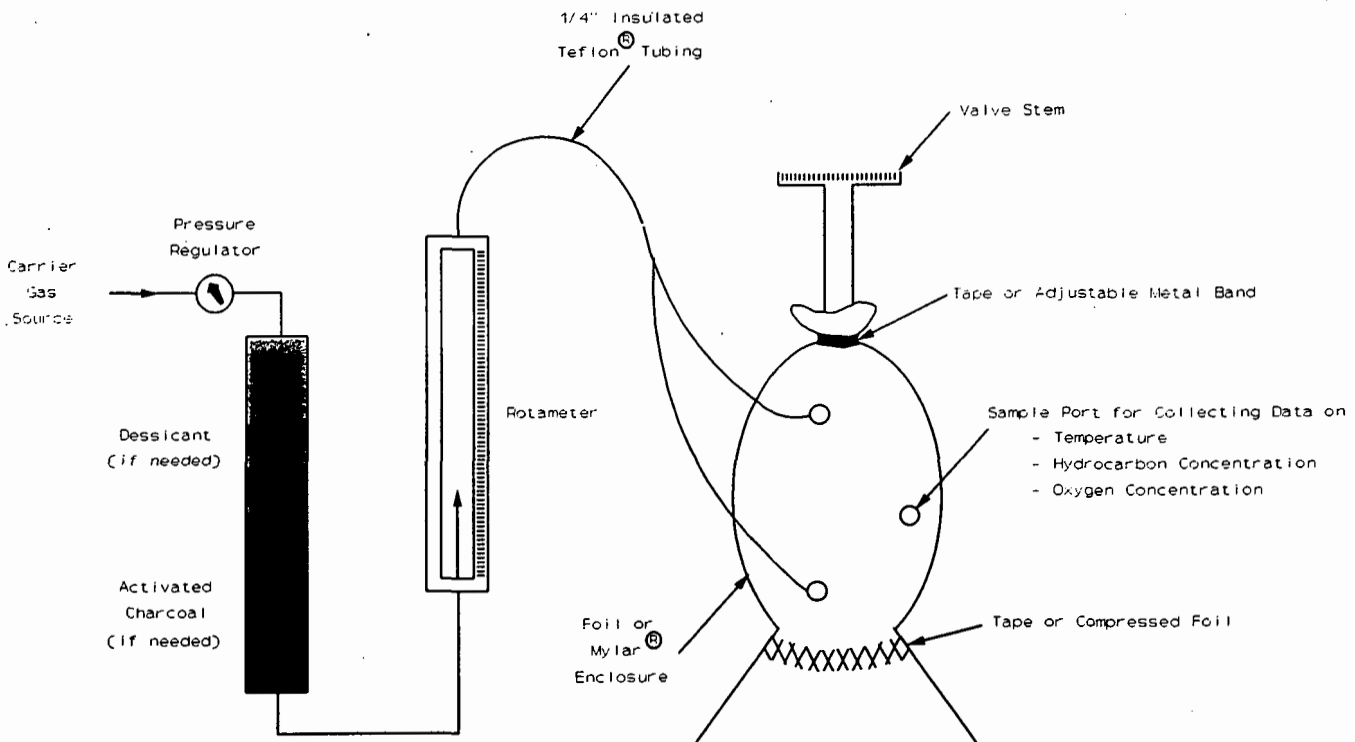
Figures 4.C-3 and 4.C-4 present the calculation procedures for leak rates when using the vacuum and blow-through methods, respectively.

When choosing the bagging material, an important criteria is that it is impermeable to the specific compounds being emitted from the equipment piece.

Example 4.C-1, for the vacuum method, and Example 4.C-2, for the blow-through method, are presented in two parts. Part 1 shows the data sheets that were presented in Section 6 (Figures 4.6-2 and 4.6-3) filled out with the appropriate information, and Part 2 shows how that information is used to calculate the mass emission rates, using the equations shown in Figures 4.C-3 and 4.C-4.



**FIGURE 4.C-1. SAMPLING TRAIN FOR BAGGING A SOURCE USING THE VACUUM METHOD**



**FIGURE 4.C-2. EQUIPMENT REQUIRED FOR THE BLOW-THROUGH SAMPLING TECHNIQUE**



### CALCULATION PROCEDURES FOR LEAK RATE WHEN USING THE VACUUM METHOD

$$\text{Leak Rate (kg/hr)} = \frac{9.63 \times 10^{-10} (Q)(MW)(GC)(P)}{T + 273.15} + \frac{(\rho)(v_L)}{16.67(t)}$$

where:

$9.63 \times 10^{-10}$  = A conversion factor using the gas constant:

$$\frac{^{\circ}\text{K} \times 10^6 \times \text{kg-mol} \times \text{min}}{\text{L} \times \text{hour} \times \text{mmHg}}$$

$Q$  = Flow rate out of bag (L/min)

$MW^a$  = Molecular weight of organic compound(s) in the sample bag or alternatively in the process stream contained within the equipment piece being bagged (kg/kg-mol)

$GC^b$  = Sample bag organic compound concentration (ppmv) minus background bag organic compound concentration (ppmv)

$P$  = Absolute pressure at the dry gas meter (mmHg)

$T$  = Temperature at the dry gas meter ( $^{\circ}\text{C}$ )

$\rho$  = Density of organic liquid collected (g/mL)

$V_L$  = Volume of liquid collected (mL)

$16.67$  = A conversion factor to adjust term to units of kilograms per hour (g  $\times$  hr)/(kg  $\times$  min)

$t$  = Time in which liquid is collected (min)

<sup>a</sup> For mixtures, calculate MW as:

$$\frac{\sum_{i=1}^n MW_i X_i}{\sum_{i=1}^n X_i}$$

where:

$MW_i$  = Molecular weight of organic compound "i"

$X_i$  = Mole fraction of organic compound i

$n$  = Number of organic compounds in mixture.

<sup>b</sup> For mixtures, the value of GC is the total concentration of all the organic compounds in the mixture.

<sup>c</sup> Collection of a background bag is optional. If a bag of background air is not collected, assume the background concentration is zero.

**FIGURE 4.C-3. CALCULATION PROCEDURES FOR LEAK RATE WHEN USING THE VACUUM METHOD**

### CALCULATION PROCEDURES FOR LEAK RATE WHEN USING THE BLOW-THROUGH METHOD

$$\text{Leak Rate (kg/hr)} = \left[ \frac{1.219 \times 10^{-5}(Q)(MW)(GC)}{T + 273.15} + \frac{(\rho)(V_L)}{16.67(t)} \right] \times \left[ \frac{10^6 \text{ ppmv}}{10^6 \text{ ppmv} - GC} \right]$$

where:

$1.219 \times 10^{-5}$  = A conversion factor taking into account the gas constant and assuming a pressure in the bag of 1 atmosphere:

$$\frac{^{\circ}\text{K} \times 10^6 \times \text{kg-mol}}{\text{m}^3}$$

$Q$  = flow rate out of bag ( $\text{m}^3/\text{hr}$ );

$$= \frac{N_2 \text{ Flow Rate (L/min)}}{1 - [\text{Bag Oxygen Conc. (volume \%)/21]} \times \frac{[0.06 (\text{m}^3/\text{min})]}{(\text{L/hr})}$$

$MW^a$  = Molecular weight of organic compounds in the sample bag or alternatively in the process stream contained within the equipment piece being bagged ( $\text{kg/kg-mol}$ )

$GC^b$  = Sample bag organic compound concentration (ppmv), corrected for background bag organic compound concentration (ppmv)<sup>c</sup>

$T$  = Temperature in bag ( $^{\circ}\text{C}$ )

$\rho$  = Density of organic liquid collected ( $\text{g/mL}$ )

$V_L$  = Volume of liquid collected ( $\text{mL}$ )

$16.67$  = A conversion factor to adjust term to units of kilograms per hour ( $\text{g} \times \text{hr}/(\text{kg} \times \text{min})$ )

$t$  = Time in which liquid is collected ( $\text{min}$ )

**FIGURE 4.C-4. CALCULATION PROCEDURES FOR LEAK RATE WHEN USING THE  
BLOW-THROUGH METHOD**

**CALCULATION PROCEDURES FOR LEAK RATE WHEN USING THE  
BLOW-THROUGH METHOD (CONTINUED)**

<sup>a</sup> For mixtures, calculate MW as:

$$\frac{\sum_{i=1}^n MW_i X_i}{\sum_{i=1}^n X_i}$$

where:

MW<sub>i</sub> = Molecular weight of organic compound "i"  
X<sub>i</sub> = Mole fraction of organic compound i  
n = Number of organic compounds in mixture

<sup>b</sup> For mixtures, the value of GC is the total concentration of all the organic compounds in the mixture.

<sup>c</sup> Collection of a background bag is optional. If a bag of background air is not collected, assume the background concentration is zero. To correct for background concentration, use the following equation:

$$GC_{(ppmv)} = SB - \left[ \frac{BAG}{21} \times BG \right]$$

where:

SB = Sample bag concentration (ppmv);  
BAG = Tent oxygen concentration (volume %); and  
BG = Background bag concentration (ppmv)

**FIGURE 4.C-4. (CONTINUED)**

## EXAMPLE 4.C-1: PART 1

EXAMPLE DATA COLLECTION FORM FOR FUGITIVE EMISSIONS  
BAGGING TEST (VACUUM METHOD)

Equipment Type <u>Valve</u>	Component ID <u>V0101</u>
Equipment Category _____	Plant ID <u>P012</u>
Line Size _____	Date <u>10-15-95</u>
Stream Phase (G/V, LL, HL) <u>LL</u>	Analysis Team _____
Barometric Pressure _____	
Ambient Temperature _____	Instrument ID <u>I01</u>
Stream Temperature _____	Stream Pressure _____
Stream Composition (Wt. %) <u>100% TOC MW = 25.4735 kg/kg-mol</u>	

<u>Time</u>	<u>Bagging Test Measurement Data</u>
_____	Initial Screening (ppmv) Equipment Piece <sup>a</sup> <u>450</u> Bkgd. <u>9</u>
_____	Background Bag Organic Compound Conc. (ppmv) <sup>b</sup> _____
_____	Sample Bag 1 Organic Compound Conc. (ppmv) <u>268</u>
_____	Dry Gas Meter Reading (L/min) <u>2.806</u>
_____	Vacuum Check in Bag (Y/N) (Must be YES to collect sample.) _____
_____	Dry Gas Meter Temperature <sup>c</sup> (°C) <u>17</u>
_____	Dry Gas Meter Pressure <sup>c</sup> (mmHg) <u>668</u>
_____	Sample Bag 2 Organic Compound Conc. (ppmv) _____
_____	Dry Gas Meter Reading (L/min) _____
_____	Vacuum Check in Bag (Y/N) (Must be YES to collect sample.) _____
_____	Dry Gas Meter Temperature <sup>c</sup> (°C) _____
_____	Dry Gas Meter Pressure <sup>c</sup> (mmHg) _____
Condensate Accumulation: Starting Time _____ Final Time _____	
Organic Condensate Collected (mL) _____	
Density of Organic Condensate (g/mL) _____	
_____	Final Screening (ppmv) Equip. Piece <sup>a</sup> <u>450</u> Bkgd. <u>9</u>

<sup>a</sup> The vacuum method is not recommended if the screening value is approximately 10 ppmv or less.

<sup>b</sup> Collection of a background bag is optional.

<sup>c</sup> Pressure and temperature are measured at the dry gas meter.

## EXAMPLE 4.C-1: PART 2

## EQUATION FOR CALCULATING THE LEAK RATE USING THE DATA FROM PART 1

$$\begin{aligned}
 \text{Leak Rate} &= \left[ \frac{9.63\text{E-}10 (Q)(MW)(GC)(P)}{T + 273.15} \right] \\
 &= \left[ 9.63\text{E-}10 \frac{^{\circ}\text{K} \times 10^6 \times \text{kg-mol} \times \text{min}}{\text{L} \times \text{hr} \times \text{mmHg}} \right] \left[ 2.806 \frac{\text{L}}{\text{min}} \right] \left[ 25.4735 \frac{\text{kg}}{\text{kg-mol}} \right] \\
 &\quad \left[ \frac{(268 \text{ ppmv})(668 \text{ mmHg})}{(17 + 273.15)^{\circ}\text{K}} \right] \\
 &= 4.25\text{E-}05 \text{ kg/hr}
 \end{aligned}$$

## EXAMPLE 4.C-2: PART 1

EXAMPLE DATA COLLECTION FORM FOR FUGITIVE EMISSIONS BAGGING TEST  
(BLOW-THROUGH METHOD)

Equipment Type <u>Valve</u>	Component ID <u>V0102</u>
Equipment Category _____	Plant ID <u>P012</u>
Line Size _____	Date <u>10-15-95</u>
Stream Phase (G/V, LL, HL) <u>LL</u>	Analysis Team _____
Barometric Pressure _____	Instrument ID <u>I01</u>
Ambient Temperature _____	Stream Pressure _____
Stream Temperature _____	
Stream Composition (Wt. %) <u>100% TOC MW=28.12 kg/kg-mol</u>	

<u>Time</u>	<u>Bagging Test Measurement Data</u>
_____	Initial Screening (ppmv) Equipment Piece <u>8</u> Bkgd. <u>4</u>
_____	Background Bag Organic Compound Conc. (ppmv) <sup>a</sup> _____
_____	Sample Bag 1 Organic Compound Conc. (ppmv) <u>29.3</u>
_____	Dilution Gas Flow Rate (L/min) <u>5.21</u>
_____	O <sub>2</sub> Concentration (volume %) <u>2.55</u>
_____	Bag Temperature (°C) <u>23.89</u>
_____	Sample Bag 2 Organic Compound Conc. (ppmv) _____
_____	Dilution Gas Flow Rate (L/min) _____
_____	O <sub>2</sub> Concentration (volume %) _____
_____	Bag Temperature (°C) _____
Condensate Accumulation: Starting Time _____ Final Time _____	
Organic Condensate Collected (mL) _____	
Density of Organic Condensate (g/mL) _____	
_____	Final Screening (ppmv) Equipment Piece <u>8</u> Bkgd. <u>4</u>

<sup>a</sup> Collection of a background bag is optional. However, it is recommended in cases where the screening value is less than 10 ppmv and there is a detectable oxygen level in the bag.

**EXAMPLE 4.C-2: PART 2****EQUATION FOR CALCULATING THE LEAK RATE USING THE DATA FROM PART 1**

$$\begin{aligned}
 Q &= \frac{\text{Dilution Gas Flow Rate}}{\left[ 1 - \frac{\text{Bag O}_2 \text{ conc (vol\%)}}{21\%} \right]} \times \frac{[0.06 \text{ m}^3/\text{min}]}{\text{L/hr}} \\
 &= \frac{5.21 \frac{\text{L}}{\text{min}}}{1 - \left[ \frac{2.55\%}{21\%} \right]} \times \frac{[0.06 \text{ m}^3/\text{min}]}{\text{L/hr}} \\
 &= 0.36 \text{ m}^3/\text{hr}
 \end{aligned}$$

$$\begin{aligned}
 \text{Leak Rate} &= \left[ \frac{1.219\text{E-}05 (Q) (\text{MW}) (\text{GC})}{T + 273.15} \right] \times \left[ \frac{10^6}{10^6 - \text{GC}} \right] \\
 &= \frac{\left[ 1.219\text{E-}05 \frac{^\circ\text{K} \times 10^6 \times \text{kg-mol} \times \text{min}}{\text{m}^3} \right] \left[ 0.36 \frac{\text{m}^3}{\text{hr}} \right] \left[ 28.12 \frac{\text{kg}}{\text{kg-mol}} \right] (29.3\text{ppmv})}{(23.89+273.15)^\circ\text{K}} \times \left[ \frac{10^6}{10^6 - 29} \right] \\
 &= 1.22\text{E-}05 \text{ kg/hr}
 \end{aligned}$$

## **APPENDIX D**

# **EXAMPLE DATA COLLECTION FORM FOR FUGITIVE EMISSIONS FROM EQUIPMENT LEAKS**



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## EXAMPLE DATA COLLECTION FORM INSTRUCTIONS

### GENERAL

- 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.
- The form is divided into five sections: General Information; Stream Composition Data; Equipment Counts; Screening Data; and Equipment Leaks Controls.
- 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.
- If you want to modify the form to better serve your needs, an electronic copy of the form may be obtained through the EIIP on the CHIEF bulletin board system (BBS) of the OAQPS TTN.

### STREAM COMPOSITION DATA SECTION

- Weight percents may not need to be provided for constituents present in concentrations less than 1.0 weight percent.
- 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.

### SCREENING DATA SECTION

- Complete the information/data for each screened stream.

## EQUIPMENT COUNT SECTION

- Complete each blank form for each stream in the facility.
- The LDAR trigger concentration refers to the concentration level that the component is considered to be leaking.
- 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 the attached table.
- 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.
- Indicate any secondary control devices to which the closed vent system transports the process fluid.

Example 4.D-1 shows how all of the sections of this form would be filled out for the example presented in Section 4 (Tables 4.4-1 and 4.4-2) for a hypothetical chemical processing facility, which is subject to an LDAR program.

**Note:** Complete this form for each type of fuel used and for each unit.

### EXAMPLE DATA COLLECTION FORM - FUGITIVE EMISSIONS FROM EQUIPMENT LEAKS

GENERAL INFORMATION						
Process Unit Capacity (lb/yr)						
Portable VOC Monitoring Instrument Used <sup>a</sup>						
Calibration Gas of Monitoring Instrument <sup>a</sup>						
STREAM COMPOSITION DATA						
CAS Number	Chemical Name	Concentration (wt.%)				
		Stream 1	Stream 2	Stream 3	Stream 4	Stream 5
--	OTHER					
--	Total HAPs					
--	Total VOCs					
--	Source <sup>c</sup>					
Amount of Time Fluid in Stream (hr/yr)						

<sup>a</sup> Collect information if screening data have been gathered at the process unit.

<sup>b</sup> CAS = Chemical Abstract Service.

<sup>c</sup> EJ = Engineering judgement; TD = Test data; LV = Literature values.

# EXAMPLE DATA COLLECTION FORM - FUGITIVE EMISSIONS FROM EQUIPMENT LEAKS

EQUIPMENT COUNTS					
Component	Service	Count Source <sup>b</sup>	Stream 1 (A)	Stream 2 (B)	Stream 3 (C)
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				

<sup>a</sup> Do not include equipment in vacuum service.

<sup>b</sup> D = Design specifications; I = Inspection and maintenance tags; C = Actual count; and R = Ratio; if ratio, specify (i.e., 25 valves per pump).

## CHAPTER 4 - EQUIPMENT LEAKS

[illegible]

## 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 <sup>a</sup> :									
Leak Detection and Repair Parameters					Control Parameters				
Equipment	Quantity in Program	LDAR Trigger Conc.	Monitoring Frequency	Response Time <sup>b</sup>	Percent with Control A <sup>c</sup>	Percent with Control B <sup>c</sup>	Percent with Control C <sup>c</sup>	Other	Closed Vent Secondary Control
Valves							NA <sup>d</sup>	/	
Pumps								/	
Compressors							NA	/	
Connectors						NA	NA	/	
Open-ended lines							NA	/	
Sampling Connections	NA	NA	NA	NA				/	
Pressure Relief Valves							NA	/	

<sup>a</sup> V = Visual; P = Portable; F = Fixed point; If other, please specify.

<sup>b</sup> IM = Immediately; D = 1 day; D3 = 3 days; W = 1 week; W2 = 2 weeks; and M = 1 month.

<sup>c</sup> See attached table, Controls by Equipment Type.

<sup>d</sup> NA = Not applicable.

# EXAMPLE DATA COLLECTION FORM - FUGITIVE EMISSIONS FROM EQUIPMENT LEAKS

## TABLE OF CONTROLS BY EQUIPMENT TYPE

Control Option	Equipment	Controls
A	All	Closed vent system
B	Valves Pumps Compressors Open-ended lines Sampling Connections PRVs	Sealless Dual mechanical seal with barrier fluid Mechanical seals with barrier fluid Capped, plugged, blind-flagged <i>In-situ</i> sampling Rupture disk
C	Pumps Sampling connections	Sealless Closed loop sampling

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CHAPTER 4 - EQUIPMENT LEAKS



## EXAMPLE DATA COLLECTION FORM - FUGITIVE EMISSIONS FROM EQUIPMENT FROM EQUIPMENT LEAKS

<sup>b</sup> Engine [redacted] jud [redacted] nt; Test [redacted] LV [redacted] eratur [redacted] lues [redacted]

## EXAMPLE 4.D-1

(CONTINUED)

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CHAPTER 4 - EQUIPMENT LEAKS

EQUIPMENT COUNTS					
Component	Service	Count Source <sup>b</sup>	Stream 1 (A)	Stream 2 (B)	Stream 3 (C)
Valves	gas/vapor	<i>C</i>			<i>40</i>
	light liquid				
	heavy liquid				
Connectors	all				
Pumps	light liquid	<i>C</i>	<i>15</i>	<i>12</i>	
	heavy liquid				
Compressor	gas/vapor				
Open Lines	all				
Sample Connections	all				
Pressure Relief Valve	gas/vapor				

<sup>a</sup> Do not include equipment in vacuum service.<sup>b</sup> D = Design specifications; I = Inspection and maintenance tags; C = Actual count; and R = Ratio; if ratio, specify (i.e., 25 valves per pump).

## EXAMPLE 4.D-1

(CONTINUED)

SCREENING DATA	
Stream ID: <i>A</i>	Component Type: <i>Light Liquid Pump</i>
Date Components Screened: <i>7-15-95</i>	Total Number of Components Screened: <i>15</i>
Component ID	Screening Value (ppmv)
<i>A-1</i>	<i>0</i>
<i>A-2</i>	<i>0</i>
<i>A-3</i>	<i>0</i>
<i>A-4</i>	<i>0</i>
<i>A-5</i>	<i>0</i>
<i>A-6</i>	<i>20</i>
<i>A-7</i>	<i>50</i>
<i>A-8</i>	<i>50</i>
<i>A-9</i>	<i>100</i>
<i>A-10</i>	<i>100</i>
<i>A-11</i>	<i>200</i>
<i>A-12</i>	<i>400</i>
<i>A-13</i>	<i>1000</i>
<i>A-14</i>	<i>2000</i>
<i>A-15</i>	<i>5000</i>

## EXAMPLE 4.D-1

(CONTINUED)

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CHAPTER 4 - EQUIPMENT LEAKS

SCREENING DATA	
Stream ID: <i>B</i>	Component Type: <i>Light Liquid Pump</i>
Date Components Screened: <i>7-15-95</i>	Total Number of Components Screened: <i>11</i>
Component ID	Screening Value (ppmv)
<i>B-1</i>	<i>0</i>
<i>B-2</i>	<i>0</i>
<i>B-3</i>	<i>0</i>
<i>B-4</i>	<i>10</i>
<i>B-5</i>	<i>30</i>
<i>B-6</i>	<i>250</i>
<i>B-7</i>	<i>500</i>
<i>B-8</i>	<i>2000</i>
<i>B-9</i>	<i>5000</i>
<i>B-10</i>	<i>8000</i>
<i>B-11</i>	<i>25,000</i>

## EXAMPLE 4.D-1

(CONTINUED)

SCREENING DATA	
Stream ID: <i>C</i>	Component Type: <i>Gas/Vapor Valve</i>
Date Components Screened: <i>7-15-95</i>	Total Number of Components Screened: <i>40</i>
Component ID	Screening Value (ppmv)
<i>C-1</i>	<i>0</i>
<i>C-2</i>	<i>0</i>
<i>C-3</i>	<i>0</i>
<i>C-4</i>	<i>0</i>
<i>C-5</i>	<i>0</i>
<i>C-6</i>	<i>0</i>
<i>C-7</i>	<i>15</i>
<i>C-8</i>	<i>20</i>
<i>C-9</i>	<i>20</i>
<i>C-10</i>	<i>35</i>
<i>C-11</i>	<i>50</i>
<i>C-12</i>	<i>50</i>
<i>C-13</i>	<i>120</i>
<i>C-14</i>	<i>150</i>
<i>C-15</i>	<i>200</i>

## EXAMPLE 4.D-1

(CONTINUED)

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CHAPTER 4 - EQUIPMENT LEAKS

SCREENING DATA	
Stream ID: <i>C</i>	Component Type: <i>Gas/Vapor Valve</i>
Date Components Screened: <i>7-15-95</i>	Total Number of Components Screened: <i>40</i>
Component ID	Screening Value (ppmv)
<i>C-16</i>	<i>500</i>
<i>C-17</i>	<i>550</i>
<i>C-18</i>	<i>575</i>
<i>C-19</i>	<i>600</i>
<i>C-20</i>	<i>610</i>
<i>C-21</i>	<i>700</i>
<i>C-22</i>	<i>800</i>
<i>C-23</i>	<i>1010</i>
<i>C-24</i>	<i>1200</i>
<i>C-25</i>	<i>1500</i>
<i>C-26</i>	<i>1550</i>
<i>C-27</i>	<i>1700</i>
<i>C-28</i>	<i>2000</i>
<i>C-29</i>	<i>5000</i>
<i>C-30</i>	<i>5100</i>

## EXAMPLE 4.D-1

(CONTINUED)

SCREENING DATA	
Stream ID: <i>C</i>	Component Type: <i>Gas/Vapor Valve</i>
Date Components Screened: <i>7-15-95</i>	Total Number of Components Screened: <i>40</i>
Component ID	Screening Value (ppmv)
<i>C-31</i>	<i>6100</i>
<i>C-32</i>	<i>7000</i>
<i>C-33</i>	<i>8000</i>
<i>C-34</i>	<i>8100</i>
<i>C-35</i>	<i>8150</i>
<i>C-36</i>	<i>8300</i>
<i>C-37</i>	<i>9000</i>
<i>C-38</i>	<i>10,000</i>
<i>C-39</i>	<i>15,000</i>
<i>C-40</i>	<i>50,000</i>

## EXAMPLE 4.D-1

(CONTINUED)

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CHAPTER 4 - EQUIPMENT LEAKS

EQUIPMENT LEAKS CONTROLS									
Stream ID: <i>A</i>									
Is the equipment in this stream subject to a LDAR program? (Yes/No) <i>Yes</i>									
Type of Monitoring System <sup>a</sup> : <i>P</i>									
Leak Detection and Repair Parameters					Control Parameters				
Equipment	Quantity in Program	LDAR Trigger Conc.	Monitoring Frequency	Response Time <sup>b</sup>	Percent with Control A <sup>c</sup>	Percent with Control B <sup>c</sup>	Percent with Control C <sup>c</sup>	Other	Closed Vent Secondary Control
Valves							NA <sup>d</sup>	/	
Pumps	<i>15</i>	<i>10,000 ppm</i>	<i>monthly</i>	<i>W</i>	<i>53%</i>	<i>7%</i>	<i>40%</i>	/	
Compressors							NA	/	
Connectors						NA	NA	/	
Open-ended lines							NA	/	
Sampling Connections	NA	NA	NA	NA				/	
Pressure Relief Valves							NA	/	

<sup>a</sup> V = Visual; P = Portable; F = Fixed point; If other, please specify.<sup>b</sup> IM = Immediately; D = 1 day; D3 = 3 days; W = 1 week; W2 = 2 weeks; and M = 1 month.<sup>c</sup> See attached table, Controls by Equipment Type.<sup>d</sup> NA = Not applicable.



## EXAMPLE 4.D-1

(CONTINUED)

EQUIPMENT LEAKS CONTROLS									
Stream ID: <i>B</i>									
Is the equipment in this stream subject to a LDAR program? (Yes/No) <i>Yes</i>									
Type of Monitoring System <sup>a</sup> : <i>P</i>									
Leak Detection and Repair Parameters					Control Parameters				
Equipment	Quantity in Program	LDAR Trigger Conc.	Monitoring Frequency	Response Time <sup>b</sup>	Percent with Control A <sup>c</sup>	Percent with Control B <sup>c</sup>	Percent with Control C <sup>c</sup>	Other	Closed Vent Secondary Control
Valves							NA <sup>d</sup>	/	
Pumps	<i>12</i>	<i>10,000 ppm</i>	<i>monthly</i>	<i>W</i>	<i>67%</i>	<i>33%</i>	<i>0%</i>	/	
Compressors							NA	/	
Connectors						NA	NA	/	
Open-ended lines							NA	/	
Sampling Connections	NA	NA	NA	NA				/	
Pressure Relief Valves							NA	/	

<sup>a</sup> V = Visual; P = Portable; F = Fixed point; If other, please specify.<sup>b</sup> IM = Immediately; D = 1 day; D3 = 3 days; W = 1 week; W2 = 2 weeks; and M = 1 month.<sup>c</sup> See attached table, Controls by Equipment Type.<sup>d</sup> NA = Not applicable.

## EXAMPLE 4.D-1

(CONTINUED)

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CHAPTER 4 - EQUIPMENT LEAKS

EQUIPMENT LEAKS CONTROLS									
Stream ID: <i>C</i>									
Is the equipment in this stream subject to a LDAR program? (Yes/No) <i>Yes</i>									
Type of Monitoring System <sup>a</sup> : <i>P</i>									
Leak Detection and Repair Parameters					Control Parameters				
Equipment	Quantity in Program	LDAR Trigger Conc.	Monitoring Frequency	Response Time <sup>b</sup>	Percent with Control A <sup>c</sup>	Percent with Control B <sup>c</sup>	Percent with Control C <sup>c</sup>	Other	Closed Vent Secondary Control
Valves	<i>40</i>	<i>10,000 ppm</i>	<i>monthly</i>	<i>W</i>	<i>50%</i>	<i>50%</i>	<i>NA<sup>d</sup></i>	<i>/</i>	
Pumps								<i>/</i>	
Compressors							<i>NA</i>	<i>/</i>	
Connectors						<i>NA</i>	<i>NA</i>	<i>/</i>	
Open-ended lines							<i>NA</i>	<i>/</i>	
Sampling Connections	<i>NA</i>	<i>NA</i>	<i>NA</i>	<i>NA</i>				<i>/</i>	
Pressure Relief Valves							<i>NA</i>	<i>/</i>	

<sup>a</sup> V = Visual; P = Portable; F = Fixed point; If other, please specify.<sup>b</sup> IM = Immediately; D = 1 day; D3 = 3 days; W = 1 week; W2 = 2 weeks; and M = 1 month.<sup>c</sup> See attached table, Controls by Equipment Type.<sup>d</sup> NA = Not applicable.

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**VOLUME II: CHAPTER 5**

# **PREFERRED AND ALTERNATIVE METHODS FOR ESTIMATING AIR EMISSIONS FROM WASTEWATER COLLECTION AND TREATMENT**

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Prepared for:  
Point Sources Committee  
Emission Inventory Improvement Program

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# INTRODUCTION

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The purposes of the preferred methods guidelines are to describe emissions estimation techniques for stationary point sources in a clear and unambiguous manner and to provide concise example calculations to aid in the preparation of emission inventories. This chapter describes the procedures and recommended approaches of estimating volatile organic compound (VOC) emissions from wastewater collection and treatment (WWCT).

Section 2 of this chapter contains a general description of the WWCT source category, a listing of common emission sources associated with WWCT, and an overview of the available air pollution control technologies for WWCT. Section 3 of this chapter provides an overview of available emission estimation methods. It should be noted that the use of site-specific emissions data is always preferred over the use of industry-averaged data such as default data, available in several of the current WWCT air emissions models. However, depending upon available resources, obtaining site-specific data may not be cost effective. Section 4 presents the preferred emission estimation methods for WWCT, while Section 5 presents alternative emission estimation techniques. Quality assurance and quality control procedures are described in Section 6, and Section 7 lists references. Appendix A contains an example data collection form for WWCT sources, and Appendix B contains the *AP-42* WWCT equations and example calculations (Environmental Protection Agency [EPA], 1995). Appendix C contains a list of references that may be consulted for more detailed, technical evaluations and comparisons of the emission estimation techniques and emissions software models discussed in this chapter.

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# 2

## GENERAL SOURCE CATEGORY DESCRIPTION

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### 2.1 SOURCE CATEGORY DESCRIPTION

This section provides a brief overview discussion of the WWCT category. In addition to wastewater generated at the municipal level, many industries generate large quantities of contaminated water as a byproduct of production processes. These wastewaters typically pass through a series of on-site collection and treatment units before discharge to a receiving water body or publicly owned treatment works (POTW). Many of these collection and treatment units are open to the atmosphere and allow for volatilization of VOCs from the wastewater.

The information presented in this document is applicable to any source, municipality, or industry treating wastewater on-site.

The following sections describe the various types of wastewater collection and treatment devices. The type of unit (collection or treatment) is provided, as is a brief description of each. Table A-1, Appendix A lists approximate physical dimensions of several units.

### 2.2 WWCT DEVICES

#### 2.2.1 DRAINS (COLLECTION UNIT)

Wastewater streams from various sources throughout a given process are normally introduced into the collection system through process drains. Drains may be of a trapped or untrapped design. Individual drains are usually connected directly to the main process sewer line. However, they may also drain to trenches, sumps, or ditches. Some drains are dedicated to a single piece of equipment such as a scrubber, decanter, or stripper. Others serve several sources. These types of drains are located centrally between the pieces of equipment they serve and are referred to as area drains (EPA, 1990).

### **2.2.2 MANHOLES (COLLECTION UNIT)**

Manholes are service entrances into sewer lines that permit inspection and cleaning of the sewer line. They are normally placed at periodic lengths along the sewer line. They may also be located where sewers intersect or where there is a significant change in direction, grade, or sewer line diameter. The lower portion of the manhole is usually cylindrical, with a typical inside diameter of 4 feet to allow adequate space for workers. The upper portion tapers to the diameter of the opening at ground level. The opening is normally about 2 feet in diameter and covered with a heavy cast-iron plate with two to four holes for ventilation and for cover removal.

### **2.2.3 REACHES (COLLECTION UNIT)**

A reach is a segment of sewer channel that conveys wastewater between two manholes or other sewer components such as lift stations or junction boxes. Sanitary sewers are naturally ventilated through holes in manhole covers, gooseneck vents (which are sometimes included to enhance ventilation), and vent risers on buildings that are connected to sewers. (Sanitary sewers are sometimes mechanically ventilated; i.e., fans or blowers are used to remove hydrogen sulfide.) Combined sanitary/storm sewers are generally well-ventilated, and include openings associated with street-level storm drains.

### **2.2.4 JUNCTION BOXES (COLLECTION UNIT)**

A junction box normally serves several process sewer lines. Process lines meet at the junction box to combine the multiple wastewater streams into one stream that flows downstream from the junction box. Liquid level in the junction box depends on the flow rate of the wastewater. Junction boxes are either square or rectangular and are sized based on the flow rate of the entering streams. They may also be water-sealed or covered and vented.

### **2.2.5 LIFT STATIONS (COLLECTION UNIT)**

Lift stations are usually the last collection unit prior to the treatment system, accepting wastewater from one or several sewer lines. The main function of the lift station is to provide sufficient head pressure to transport the collected wastewater to the treatment system. A pump is used to provide the head pressure and is generally designed to operate or cut off based on preset high and low liquid levels.

### **2.2.6 TRENCHES (COLLECTION UNIT)**

Trenches are used to transport wastewater from the point of process equipment discharge to subsequent wastewater collection units such as junction boxes and lift stations. This mode of transport replaces the drain scenario as a method for introducing process wastewater into the downstream collection system. In older plants, trenches are often the primary mode of wastewater transportation in the collection system. Trenches are often interconnected throughout the process area to accommodate pad water runoff, water from equipment washes and spill cleanups, as well as process wastewater discharges. Normally, the length of the trench is determined by the general locations of the process equipment and the downstream collection system units. This length typically ranges from 50 to 500 feet. Trench depth and width are dictated by the wastewater flow rate discharged from process equipment. The depth and width of the trench must be sufficient to accommodate expected as well as emergency wastewater flows from the process equipment.

### **2.2.7 SUMPS (COLLECTION UNIT)**

Sumps are typically used for collection and equalization of wastewater flow from trenches prior to treatment. They are usually quiescent and open to the atmosphere. Typical diameters and depths are approximately 1.5 meters.

### **2.2.8 WEIRS (COLLECTION UNIT)**

Weirs act as dams in open channels in order to maintain constant water level upstream. The weir face is normally aligned perpendicular to the bed and walls of the channel. Water from the channel normally overflows the weir but may pass through a notch, or opening, in the weir face. Because of this configuration, weirs provide some control of the level and flow rate through the channel. This control, however, may be insignificant compared to upstream factors that influence the supply of water to the channel.

### **2.2.9 OIL/WATER SEPARATORS (TREATMENT UNIT)**

Oil/water separators are often the first step in the wastewater treatment plant but may also be found in the process area. The purpose of these units is to separate liquid phases of different specific gravities; they also serve to remove free oil and suspended solids contained in the wastewater. Most of the separation occurs as the wastewater stream passes through a quiescent zone in the unit. Oils and scum with specific gravities less than water float to the top of the aqueous phase. Heavier solids sink to the bottom. Most of the organics contained in the wastewater tend to partition to the oil phase. For this reason, most of these organic compounds are removed with the skimmed oil leaving



the separator. The wastewater stream leaving the separator, therefore, is reduced in organic loading.

### **2.2.10 EQUALIZATION BASINS (TREATMENT UNIT)**

Equalization basins are used to reduce fluctuations in the wastewater flow rate and organic content to the downstream treatment processes and may be covered, stirred, or aerated. Equalization of wastewater flow rate results in more uniform effluent quality from downstream settling units such as clarifiers. Biological treatment performance can also benefit significantly from the damping of concentration and flow fluctuations. This damping protects biological processes from upset or failure due to shock loadings of toxic or treatment-inhibiting compounds.

### **2.2.11 CLARIFIERS (TREATMENT UNIT)**

The primary purpose of a clarifier is to separate any oils, grease, scum, and solids contained in the wastewater. Most clarifiers are equipped with surface skimmers to clear the water of floating oil deposits and scum. Clarifiers also have sludge raking arms that prevent accumulation of organic solids collected at the bottom of the tank.

### **2.2.12 BIOLOGICAL TREATMENT BASINS (TREATMENT UNIT)**

Biological waste treatment is normally accomplished through the use of aeration basins. Microorganisms that metabolize aerobically require oxygen to carry out the biodegradation of organic compounds that results in energy and biomass production. The aerobic environment in the basin is normally achieved by the use of diffused or mechanical aeration. This aeration also serves to maintain the biomass in a well-mixed regime. The goal is to maintain the biomass concentration at a level where the treatment is efficiently optimized and proper growth kinetics are induced.

### **2.2.13 SLUDGE DIGESTERS (TREATMENT UNIT)**

Sludge digesters are used to treat organic sludges produced from various treatment operations. Two types of digesters are used: anaerobic digesters and aerobic digesters.

In the anaerobic digestion process, the organic material in mixtures of primary settled and biological sludges is converted biologically, under anaerobic conditions, to a variety of byproducts including methane ( $\text{CH}_4$ ), carbon dioxide ( $\text{CO}_2$ ), and hydrogen sulfide ( $\text{H}_2\text{S}$ ). The process is carried out in an airtight reactor. Sludge, introduced continuously or intermittently, is retained in the reactor for varying periods of time. The stabilized

sludge, withdrawn continuously or intermittently from the reactor, is reduced in organic and pathogen content and is nonputrescible.

In aerobic digestion, the sludge is aerated for an extended period of time in an open, unheated tank using conventional air diffusers or surface aeration equipment. The process may be operated in a continuous or batch mode. Smaller plants use the batch system in which sludge is aerated and completely mixed for an extended period of time, followed by quiescent settling and decantation. In continuous systems, a separate tank is used for decantation and concentration. High-purity oxygen aerobic digestion is a modification of the aerobic digestion process in which high-purity oxygen is used in lieu of air. The resultant sludge is similar to conventional aerobically digested sludge (Burton and Tchobanoglous, 1991).

#### **2.2.14 TREATMENT TANKS (TREATMENT UNIT)**

Flocculation tanks and pH adjustment tanks may be used for treatment of wastewater after and before biological treatment, respectively. In flocculation tanks, flocculating agents are added to the wastewater to promote formation of large-particle masses from the fine solids formed during biological treatment. These large particles will then precipitate out of the wastewater in the clarifier that typically follows. Tanks designed for pH adjustment typically precede the biological treatment step. In these tanks, the wastewater pH is adjusted, using acidic or alkaline additives, to prevent shocking of the biological system downstream.

#### **2.2.15 SURFACE IMPOUNDMENTS (TREATMENT UNIT)**

Surface impoundments are typically used for evaporation, polishing, equalization, storage prior to further treatment or disposal, leachate collection, and as emergency surge basins. They may be either quiescent or mechanically agitated.

#### **2.2.16 AIR AND STEAM STRIPPING (TREATMENT UNIT)**

Air stripping and steam stripping may be used to remove organic constituents in industrial wastewater streams prior to secondary and tertiary treatment devices.

Air stripping involves the contact of wastewater and air to strip out volatile organic constituents. As the volume of air contacting the contaminated water increases, an increase in the transfer rate of the organic compounds into the vapor phase is achieved. Removal efficiencies vary with volatility and solubility of organic impurities. For highly volatile compounds, average removal ranges from 90 to 99 percent, for medium- to low-volatility compounds, removal ranges from less than 50 to 90 percent, though a higher air flow rate may be needed (EPA, 1995).

Steam stripping is the distillation of wastewater to remove volatile organic constituents, with the basic operating principle being the direct contact of steam with wastewater. The steam provides the heat of vaporization for the more volatile organic constituents. Removal efficiencies vary with the amount of steam applied for a given wastewater flow rate and the volatility and solubility of the organic impurities. For highly volatile compounds (Henry's Law constant [HLC] greater than  $10^{-3}$  atm-m<sup>3</sup>/gmol), VOC removal ranges from 95 to 99 percent and can easily be achieved with a sufficient amount of steam. For medium-volatility compounds (HLC between  $10^{-5}$  and  $10^{-3}$  atm-m<sup>3</sup>/gmol), average VOC removal ranges from 90 to 95 percent and would require more steam than needed for more volatile compounds. For low-volatility compounds (HLC less than  $10^{-5}$  atm-m<sup>3</sup>/gmol), average removal ranges from less than 50 to 90 percent (EPA, 1995).

## 2.3 EMISSION SOURCES

Wastewater streams are collected and treated in a variety of ways. Many of these collection and treatment system units are open to the atmosphere and allow organic-containing wastewaters to contact ambient air. Whenever this happens, there is a potential for VOC emissions. The organic pollutants volatilize in an attempt to exert their equilibrium partial pressure above the wastewater. In doing so, the organics are emitted to the ambient air surrounding the collection and treatment units. The magnitude of VOC emissions depends greatly on many factors such as the physical properties of the pollutants, pollutant concentration, flow rate, the temperature of the wastewater, and the design of the individual collection and treatment units. All of these factors, as well as the general scheme used to collect and treat facility wastewater, have a major effect on VOC emissions.

Collection and treatment schemes are facility specific. The flow rate and organic composition of wastewater streams at a particular facility are functions of the processes used. The wastewater flow rate and composition, in turn, influence the sizes and types of collection and treatment units that must be employed at a given facility.

Figure 5.2-1 illustrates a typical scheme for collecting and treating process wastewater generated at a facility and the opportunity for volatilization of organics.

Drains are often open to the atmosphere and provide an opportunity for volatilization of organics in the wastewater. The drain is normally connected to the process sewer line that carries the wastewater to the downstream collection and treatment units.

Figure 5.2-1 illustrates the wastewater being carried past a manhole and on to a junction box where two process wastewater streams are joined. The manhole provides an escape route for organics volatilized in the sewer line. In addition, the junction box may also be open to the atmosphere, allowing organics to volatilize. Wastewater is discharged from



**FIGURE 5.2-1. TYPICAL WASTEWATER COLLECTION AND TREATMENT SYSTEM**

the junction box to a lift station where it is pumped to the treatment system. The lift station is also likely to be open to the atmosphere, allowing volatilization of organics.

The equalization basin, the first treatment unit shown in Figure 5.2-1, regulates the wastewater flow and pollutant compositions to the remaining treatment units. The equalization basin also typically provides a large area for wastewater contact with ambient air. For this reason, emissions may be relatively high from this unit. Suspended solids are removed in the clarifier, and the wastewater then flows to the aeration basin where microorganisms act on the organic constituents. Both the clarifier and the aeration basin may be open to the atmosphere. In addition, the aeration basin is normally aerated either mechanically or with diffused air. Wastewater leaving the aeration basin normally flows through a secondary clarifier for solids removal before it is discharged from the facility. The secondary clarifier is also likely to be open to the atmosphere. The solids that settle in the clarifier are discharged partly to a sludge digester and partly recycled to the aeration basin. Finally, waste sludge from the sludge digester is generally hauled off for land treatment or to a landfill.

In addition to VOC emissions from volatilization, sulfur oxides ( $\text{SO}_x$ ) emissions from the thermal destruction of hydrogen sulfide can occur if methane gas from digesters is used in on-site combustion equipment. Chlorine and chlorinated compounds may be released if the wastewater stream is disinfected using chlorine prior to discharge.

## 2.4 FACTORS AND DESIGN CONSIDERATIONS INFLUENCING EMISSIONS

### 2.4.1 PROCESS OPERATING FACTORS

During wastewater treatment, the fate mechanisms of volatilization/stripping, sorption, and biotransformation primarily determine the fate of VOCs (Mihelcic et al., 1993). Of these, it is volatilization and stripping that result in air emissions. Biodegradation and sorption onto sludge serve to suppress air emissions.

Stripping may be defined as pollutant loss from the wastewater due to water movement caused by mechanical agitation, head loss, or air bubbles, while volatilization may be defined as quiescent or wind-driven loss (Mihelcic et al., 1993). The magnitude of emissions from volatilization/stripping depends on factors such as the physical properties of the pollutants (vapor pressure, Henry's Law constants, solubility in water, etc.), the temperature of the wastewater, and the design of the individual collection and treatment units. WWCT unit design is important in determining the surface area of the air-water interface and the degree of mixing occurring in the wastewater.

Biodegradation by microorganisms occurs in biological treatment devices such as aeration basins. Due to the high level of biomass present in aeration basins, organic compounds may also be removed via sorption mechanisms. Parameters important in determining the rate of biodegradation and sorption occurring in aeration basins include the degree of biodegradability of the compound, the affinity of the compound for the organic or aqueous phase, and the biomass concentration in the basin (EPA, 1990). EPA has developed several methods for determining site-specific biodegradation rates for regulatory purposes. These include batch tests (aerated reactor and sealed reactor), as well as EPA Test Methods 304A and 304B. However, if site-specific rate constants are not available, default biodegradation rates are available for many pollutants in several of the emissions models used to estimate emissions. The use of site-specific biodegradation rates will result in a more accurate emission estimate.

Detailed information on the rates of organic removal through biodegradation, sorption, and volatilization are required for accurate emission estimates.

#### **2.4.2 CONTROL TECHNIQUES**

The types of control technologies generally used in reducing VOC emissions from wastewater include: steam stripping or air stripping (when followed by a collection device such as a carbon adsorber or a control device such as a flare), carbon adsorption (vapor or liquid phase), chemical oxidation, biotreatment (aerobic or anaerobic), and process modifications. Several of the control techniques (steam/air stripping and carbon adsorption) do not destroy the VOCs, they capture them. VOCs captured by these methods should be recovered or destroyed to prevent air emission releases to the environment.

For efficient control, all control elements should be placed as close as possible to the point of wastewater generation, with all collection, treatment, and storage systems ahead of the control technology being covered to suppress emissions. Tightly covered, well-maintained collection systems can suppress emissions by 95 to 99 percent. However, if there is explosion potential, it can be reduced by a low-volume flow of inert gas into the collection component, followed by venting to a device such as an incinerator or carbon adsorber.

The following are brief descriptions of the control technologies listed above and of any secondary controls that may need to be considered for fugitive air emissions.

### ***Air and Steam Stripping***

Steam stripping and air stripping off gases most often are vented to a secondary control or collection device, such as a combustion device or gas-phase carbon adsorber, in order to prevent air emissions. Combustion devices may include incinerators, boilers, and flares. Vent gases of high fuel value can be used as an alternative fuel and may be combined with other fuels such as natural gas and fuel oil. If the fuel value of the vent gas stream is very low, vent gases may be preheated and combined with combustion air.

### ***Liquid-phase Carbon Adsorption***

Liquid-phase carbon adsorption takes advantage of compound affinities for activated carbon. Activated carbon is an excellent adsorbent because of its large surface area and because it is usually in granular or powdered form for easy handling. Two types of liquid-phase carbon adsorption are the fixed-bed and moving-bed systems. The fixed-bed system is used primarily for low-flow wastewater streams with contact times around 15 minutes, and it is a batch operation (i.e., once the carbon is spent, the system is taken off line). Moving-bed carbon adsorption systems operate continuously with wastewater typically being introduced from the bottom of the column and regenerated carbon from the top (countercurrent flow). Spent carbon is continuously removed from the bottom of the bed. Liquid-phase carbon adsorption is usually used to recover compounds present in low concentrations or for high concentrations of nondegradable compounds. Removal efficiencies depend on the compound's affinity for activated carbon. Average removal efficiency ranges from 90 to 99 percent, but is dependent on compound concentrations (EPA, 1995).

### ***Chemical Oxidation***

Chemical oxidation involves a chemical reaction between the organic compound and an oxidant such as ozone, hydrogen peroxide, permanganate, or chlorine dioxide. Ozone is usually added to the wastewater through an ultraviolet-ozone reactor. Permanganate and chlorine dioxide are added directly into the wastewater. It is important to note that adding chlorine dioxide can form chlorinated hydrocarbons in a side reaction. The applicability of this technique depends on the reactivity of the individual organic compound.

### ***Biotreatment***

Biotreatment is the aerobic or anaerobic chemical breakdown of organic chemicals by microorganisms. Removal of organics by biodegradation is highly dependent on the compound's biodegradability, volatility, and ability to be adsorbed onto solids. Removal

efficiencies range from almost 0 to 100 percent. In an acclimated biotreatment system, the microorganisms easily convert available organics into biological cells or biomass, or  $\text{CO}_2$ . This often requires a mixed culture of organisms, where each organism utilizes the food source most suitable to its metabolism. The organisms will starve and the organics will not be biodegraded if a system is not acclimated (i.e., the organisms cannot metabolize the available food source).

### ***Process Modifications***

Emissions from wastewater collection or treatment units may also be reduced by process modifications such as the use of level control gates, closed piping, or covered process units. These techniques reduce emissions by minimizing weir drops, turbulence, and contact with air.



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## OVERVIEW OF AVAILABLE METHODS

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### 3.1 EMISSION ESTIMATION METHODOLOGIES

Several methodologies are available for calculating fugitive emissions from industrial and municipal wastewater treatment systems. The method used is dependent upon available data, available resources, and the degree of accuracy required in the estimate.

This section discusses the methods available for calculating emissions from WWCT and identifies the preferred method of calculation. The discussion focuses on estimating emissions that occur from stripping mechanisms and the volatilization of pollutants present in wastewater streams.

#### 3.1.1 MANUAL CALCULATIONS

Several EPA documents are available that provide theoretical equations that may be used to calculate emissions from WWCT. These include *Industrial Wastewater Volatile Organic Compound Emissions - Background Information for BACT/LAER Determinations* (EPA-450/3-90-004), *AP-42*, and *Air Emissions Models for Waste and Wastewater* (EPA-453/R-94-080A). The equations are based on mass transfer and liquid-gas equilibrium theory and use individual gas-phase and liquid-phase mass transfer coefficients to estimate overall mass transfer coefficients. Calculating air emissions using these equations is a complex procedure, especially if several systems are present, because the physical properties of the numerous contaminants must be individually determined. Because of the great deal of complexity involved, computer programs are available that incorporate these equations to estimate emissions from WWCT.

#### 3.1.2 EMISSION MODELS

Some emission models currently available are based on measured or empirical values. The computer model may be based on theoretical equations that have been calibrated using actual data. Or, the models may be purely empirical, in which case the equations are usually based on statistical correlations with independent variables. Emissions estimated using models are a function of the WWCT system configuration, the properties of the specific compounds present in the wastewater streams, and the emission estimation approaches used in the model algorithms.

### 3.1.3 GAS-PHASE MEASUREMENT

Measuring air emissions from large open surfaces common at industrial and municipal wastewater treatment facilities is extremely difficult and perhaps one of the most challenging air quantification problems. Several techniques have been developed for this purpose, including surface emission isolation flux chambers, and transect and fenceline methods. If the industrial process is enclosed and vented, it is possible to directly measure emissions using standard measurement techniques. (Refer to Chapter 1 of this volume for a discussion of available methods.) In particular, POTWs may be covered or enclosed to reduce odor and/or prevent freezing in which case gas-phase measurement may be appropriate.

### 3.1.4 EMISSION FACTORS

Emission factors have been or are being developed for WWCT for several source categories. These factors have been developed as part of regulatory development projects such as the National Emissions Standards for Hazardous Air Pollutants (NESHAP) for the pulp and paper industry and for petroleum refineries. In some cases, emission factors are based on emissions estimates obtained using models, but have been reduced to a more simplistic form (mass of pollutant per process rate).

In addition, emission factors were developed by a consortium of California POTW operators as part of the Pooled Emissions Estimation Program (PEEP). These factors are not publicly available but may be obtained through Jim Bewley of the South Bayside System Authority at (415) 594-8411.

The PEEP emission factors were developed from field samples at 20 POTWs and cover 18 compounds and 18 processes. Liquid- and gas-phase samples were collected to complete mass balances at plants with similar processes. The emission factors are medians of the measured offgas mass emissions divided by the influent mass. When no data were available, because of "nondetects" or other causes, emission factors were extrapolated by averaging the known emission factors of either chlorinated or nonchlorinated compounds. PEEP factors usually predict significantly lower emissions than BAAT or fate models.

### 3.1.5 MATERIAL BALANCE

The simplest estimation method, material balance, relies on wastewater flow rate and influent and effluent liquid-phase pollutant concentrations. Compound mass that cannot be accounted for in the effluent is assumed to be volatilized. However, it needs to be noted that this method does not account for biodegradation or sorption onto solids or other removal mechanisms.

## 3.2 COMPARISON OF AVAILABLE EMISSION ESTIMATION METHODOLOGIES

### 3.2.1 MANUAL CALCULATIONS

Estimating emissions from WWCT by hand (or by spreadsheets) using the equations presented in the various literature is a very labor-intensive process and increases the potential for manual calculation error. For this reason, the use of manual calculations is not a preferred method, and should only be used in cases where access to models is prohibitive. It should be noted that the equations presented in the EPA document *Air Emissions Model for Waste and Wastewater* (EPA, 1994) have been incorporated into EPA's WATER8 model (discussed in Section 4) to alleviate the burden of performing the calculations by hand.

### 3.2.2 EMISSIONS MODELS

The use of emissions software models to calculate emissions from WWCT provides a widely accepted method of calculation. Most models are based on the theoretical equations presented in various literature and provide an automated means of performing the calculations. It should be noted that models estimate average emissions over a period of time. Peak or maximum emission rates over a short term may be more accurately assessed using gas-phase measurement or material balance approaches. Also, an in-depth knowledge of the WWCT schemes including pollutant concentrations and flow rate information are needed in order to obtain an accurate emission estimate.

### 3.2.3 GAS-PHASE MEASUREMENT

Direct and indirect gas-phase measurements are alternative methods of calculating emissions from WWCT. Once pollutant concentrations are known at a specific point, atmospheric dispersion modeling equations may be used to estimate an emission rate. Two potential sources of uncertainty, pollutant measurement error and the representativeness of the statistical dispersion equations for this type of application, are present in this method. In addition, the monitoring equipment needed to perform this method may be cost-prohibitive unless already in place.

If the treatment plant is enclosed and vented through a limited number of vents, traditional stack testing may be used to estimate emissions and would be considered a preferred method.

### **3.2.4 EMISSION FACTORS**

Emission factors may be used to calculate emissions where approximate figures are acceptable. However, due to the variability of emissions based on site-specific operational, physical, and chemical parameters, emission factors should be carefully chosen that are based on similar-type sources.

### **3.2.5 MATERIAL BALANCE**

Material balance calculations are a simple method of estimating emissions where inlet and outlet pollutant concentrations are known.

Other variables also may affect an estimate. Effluent data can be used to account for compounds passing through the plant, but if chlorine is added during treatment, chlorinated compounds that form can result in higher emissions than predicted by a material balance approach. To compensate, intermediate samples must be taken to quantify chlorinated compound emissions.

As mentioned before, material balance does not account for fate mechanisms other than volatilization. For example, it can overestimate emissions if the compound is biodegradable or adsorbs onto sludge.

## PREFERRED METHOD FOR ESTIMATING EMISSIONS

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The preferred method for estimating emissions from WWCT is the use of computer-based emissions models. There are numerous emissions estimation models available to calculate emissions from WWCT. These include publicly available models as well as proprietary models. Differences in the models include applicability to the types of collection and treatment systems, the level of site-specific data accepted, the level of default data provided, and whether or not the models account for the full spectrum of pollutant pathways (volatilization, biodegradation, and sorption). Models may also contain different default data (e.g., Henry's Law constants, biodegradation rate constants).

Many of these models allow for user input of data. The use of site-specific data is always preferred over the use of default data. Typically, the types of data needed are the chemical and physical properties of the wastewater stream, as well as collection and treatment device parameters. At a minimum, wastewater stream characteristics are needed at the inlet to the treatment plant or collection device. However, if data are available for various points within the treatment plant, a more accurate emissions estimate may be obtained.

In order to obtain a reliable emissions estimate using a software model, the modeler needs to understand both the configuration and wastewater stream characteristics of the collection and/or treatment units, as well as the emissions estimation algorithm used by the model. Not all models can handle all collection/treatment devices and results are likely to vary between models. A more accurate emissions estimate will result if the user has confidence in the input data and understands the emission estimation approach used by the model.

**NOTE:** A brief summary of some currently available models is provided below. Work is ongoing to improve some of the current models and to develop new ones. The discussion presented in this document is not to be interpreted as an endorsement of one model over another, but is provided for informational purposes only. The reader should consult with their state regulatory agency for guidance on the selection and use of an appropriate model. Also, Appendix C contains a reference list of technical articles providing qualitative as well as quantitative comparisons between models and emission estimation techniques.

## 4.1 WATER8/CHEMDAT8 (TREATMENT AND COLLECTION)

WATER8 is a publicly available computer program model developed by EPA that models the fate of organic compounds in various wastewater treatment units, including collection systems, aerated basins, and other units. WATER8 contains useful features such as the ability to link treatment units to form a treatment system, the ability to recycle among units, and the ability to generate and save site-specific compound properties. WATER8 has a database with compound-specific data for over 950 chemicals. The mathematical equations used to calculate emissions in this model are based on the approaches described in *Air Emissions Models for Waste and Wastewater* (EPA, 1994). The WATER8 model is publicly available on the Clearinghouse for Inventories and Emission Factors (CHIEF) bulletin board system (BBS), (919) 541-5742. Many of the emissions models contained in WATER8 are also presented in spreadsheet form in CHEMDAT8.

## 4.2 BASTE (TREATMENT ONLY)

This model was developed to estimate sewage treatment emissions from treatment plants in the Bay Area of California. BASTE is a computer-based model with menu-driven input and is structured to allow significant flexibility in simulating a wide range of treatment processes. It can simulate the fate of organic compounds in well-mixed to plug-flow reactors, diffused bubble and surface aeration, and emissions from weirs and drops. BASTE is available through the CH<sub>2</sub>M Hill Company.

## 4.3 CORAL + (COLLECTION ONLY)

CORAL+ is a model that predicts emissions from sewer reaches based on actual data from field experiments. CORAL+ allows for continuous or slug discharges to sewers, variations in depth of flow and temperature, sewer physical conditions, and retardation of mass transfer by gas accumulation in the sewer headspace. Emissions are based on inputs of ventilation rates and patterns. CORAL+ also estimates losses at sewer drop structures and is available through the Enviromega Ltd. Company.

## 4.4 PAVE (TREATMENT ONLY)

This model was developed for the Chemical Manufacturers Association. It simulates the fate of contaminants in both surface-aerated and diffused-air activated sludge systems. The PAVE model offers a selection of different biological kinetic models. It is based on traditional kinetic process modelling for biological reactors and performs the traditional calculations of dissolved oxygen concentration and waste-activated sludge flow. The PAVE model works with compounds that have low volatilities and, therefore, may be

gas-phase mass transfer limited. Most other models use oxygen as a mass transfer surrogate so that only liquid-phase mass transfer resistance is considered. PAVE is available through the Chemical Manufacturers Association.

#### **4.5 CINCI (EPA - CINCINNATI MODEL) - *INTEGRATED MODEL FOR PREDICTING THE FATE OF ORGANICS IN WASTEWATER TREATMENT PLANTS (TREATMENT ONLY)***

This model was developed with support from the EPA Risk Reduction Engineering Laboratory. The physical properties database of the model includes 196 chemicals and metals, Henry's Law constants, sorption coefficients, biodegradation rate constants, and diffusivities. Removal mechanisms included are stripping/volatilization, stripping, surface volatilization, sorption, and biodegradation. Unit operations included are primary treatment followed by secondary treatment with sludge recycle, secondary treatment with sludge recycle, and secondary treatment without sludge recycle. The model is written in FORTRAN and has three built-in default cases. CINCI is available at no charge through the U.S. EPA Risk Reduction Engineering Laboratory.

#### **4.6 NOCEPM - *NCASI ORGANIC COMPOUND ELIMINATION PATHWAY MODEL (TREATMENT ONLY)***

This model was developed by the National Council of the Paper Industry for Air and Stream Improvement, Inc. (NCASI); components were chosen from published literature. This model is also in the public domain. The physical properties database includes 11 chemicals, Henry's Law constants, sorption coefficients, biodegradation rate constants, and diffusion coefficients for 9 chemicals. Conceptual removal mechanisms are stripping, surface aeration, subsurface aeration, surface volatilization, sorption, and biodegradation. NOCEPM simulates only the secondary treatment step, but can represent activated sludge or aerated stabilization. It is written in QuickBasic™ and has no built-in default cases. The model was validated with chloroform for activated sludge and aerated stabilization processes and is available through NCASI.

#### **4.7 TORONTO - *A MODEL OF ORGANIC CHEMICAL FATE IN A BIOLOGICAL WASTEWATER TREATMENT PLANT (TREATMENT ONLY)***

This model was developed with the support of the Ontario Ministry of the Environment, from which copies are available. There are 18 chemicals, Henry's Law constants, sorption coefficients, and biodegradation rate constants in the physical properties



database. Removal mechanisms include stripping, surface volatilization, sorption, and biodegradation. TORONTO simulates primary sedimentation and secondary (biological) treatment. According to the report, this is a relatively simple model that uses a "fugacity" approach that "takes advantage of the linear relationship of fugacity to concentration to derive a relatively simple set of linear material balance expressions." Fugacity capacities and rate parameters are calculated for the air, water, and biomass phases. TORONTO is available through the Ontario Ministry of the Environment.

#### **4.8 TOXCHEM+ - TOXIC CHEMICAL MODELING PROGRAM FOR WATER POLLUTION CONTROL PLANTS (TREATMENT AND COLLECTION)**

This model was developed by Enviromega Ltd. Company (Campbellville, Ontario), in cooperation with the Environment Canada Wastewater Technology Centre. The database includes 204 chemicals (including metals) and detailed information on physical properties. The model also includes Henry's Law constants, sorption coefficients, and biodegradation rate constants. The model simulates volatilization, stripping, sorption, and biodegradation removal mechanisms from weirs, surface volatilization, surface aeration, and subsurface aeration. A wide variety of wastewater unit operations can be represented including grit chambers, primary clarifiers, collection reaches, sludge digestion, aeration basins, and secondary clarifiers. Both steady-state and dynamic results can be obtained. TOXCHEM+ is available through the Enviromega Ltd. Company.

# 5

## ALTERNATIVE METHODS FOR ESTIMATING EMISSIONS

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### 5.1 EMISSION FACTORS

Emission factors for WWCT are presented in the literature in two forms: traditional emission factors that relate emissions of a particular pollutant to a process rate, and fraction emitted (Fe) emission factors that relate emissions of a particular pollutant to the total amount of that pollutant present in the wastewater stream.

Examples 5.5-1 and 5.5-2 show how process rate emission factors and Fe emission factors may be used to calculate emissions from WWCT.

#### Example 5.5-1

This example shows how toluene emissions can be calculated using Fe and the wastewater stream characteristics provided:

Wastewater flow into collection system	=	4,575,000 gal/day
Toluene concentration	=	4 $\mu\text{g/L}$
Fe	=	0.35 (for the collection system)
Toluene mass flow rate	=	$4,575,000 \text{ gal/day} * 3.785 \text{ L/gal} * 4 \mu\text{g/L} * 10^{-6} \text{ g}/\mu\text{g} * \text{lb}/453.6 \text{ g}$
	=	0.153 lb/day
Toluene emissions	=	$0.35 * 0.153 \text{ lb/day}$
	=	0.054 lb/day

**Example 5.5-2**

This example shows how VOC emissions can be calculated using process rate-based emission factors (EFs) and the process parameters provided:

$$EF_{\text{voc}} = 0.17 \text{ kg VOC/Mg pulp}$$

$$\text{Process rate} = 27 \text{ Mg pulp/hr}$$

$$\begin{aligned} \text{VOC emissions} &= 27 \text{ Mg pulp/hr} * 0.17 \text{ kg VOC/Mg pulp} * 1,000 \text{ g/1 kg} \\ &\quad * \text{lb/453.6 g} \\ &= 10.1 \text{ lb VOC/hr} \end{aligned}$$

## 5.2 MATERIAL BALANCE

Using a material balance approach to calculate emissions from WWCT is straightforward if the data are available and if the emissions estimate does not require extreme accuracy. In most cases, a material balance calculation will provide an emission estimate that is biased toward overestimating emissions due to the fact that the other (nonair) pollutant removal mechanisms (sorption and biodegradation) are not considered. This approach may be a viable option for collection systems and nonbiologically activated treatment where inlet and outlet pollutant concentrations are known. Example 5.5-3 shows how a material balance approach may be used to calculate emissions from WWCT.

## 5.3 MANUAL CALCULATIONS

Appendix B provides example calculations using the mass transfer equations presented in AP-42. The equations, along with guidance on how to use them, are included. (Please note that while the AP-42 section still refers to the SIMS model, this has been superseded by the WATER8 model, which is available on the CHIEF BBS. Therefore, as of the writing of this document, AP-42 is not consistent with EPA's method of choice for estimating emissions from wastewater treatment.)

**Example 5.5-3**

This example shows how toluene emissions can be calculated using a material balance approach. The wastewater stream is the same as that considered in Example 5.5-1. However, in this example, it is known that the wastewater stream exiting the collection system has a toluene concentration of 2 µg/L:

Wastewater flow	=	4,575,000 gal/day
Toluene concentration at inlet	=	4 µg/L
Toluene concentration at outlet	=	2 µg/L
Toluene lost through system	=	4 µg/L - 2 µg/L = 2 µg/L
Toluene emissions	=	4,575,000 gal/day * 3.785 L/gal * 2 µg/L * 10 <sup>-6</sup> g/µg * lb/453.6 g
	=	0.0764 lb/day

**5.4 GAS-PHASE MEASUREMENT****5.4.1 DIRECT MEASUREMENT**

The surface isolation flux chamber is the only commonly accepted direct measurement technique available for open wastewater surfaces. When properly placed and operated, the flux chamber accurately measures surface emissions. Total surface emissions are calculated by multiplying the values from the individual flux chamber measurements by the surface area each measurement represents. This can be quite challenging for processes that are not completely mixed and may have unique emissions at every point on the surface. For these cases, modeling can be used to interpolate surface emission values between flux chamber measurement points. This method is not suitable for estimating emissions of compounds with low volatility.

Treatment processes that are enclosed or covered may lend themselves to traditional stack testing methods for emission estimation purposes. If a collection system or treatment plant is well covered and vented through a limited number of openings, direct measurement (such as the use of EPA Method 25) may be considered a preferred, rather than an alternative, method of emission estimation.

### **5.4.2 INDIRECT MEASUREMENT**

Indirect measurement techniques, including transect and fenceline sensing, primarily are used for estimating fugitive emissions from area sources.

Transect and fenceline methods are both indirect measurement techniques that rely on dispersion modeling to predict the emission rate based on measurements of the ambient pollutant concentrations in the emission plume.

The transect method typically uses both vertically and horizontally dispersed measurement points positioned close to the source.

# QUALITY ASSURANCE/QUALITY CONTROL

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The consistent use of standardized methods and procedures is essential in the compilation of reliable emission inventories. Quality assurance (QA) and quality control (QC) of an inventory are accomplished through a set of procedures that ensure the quality and reliability of data collection and analysis. These procedures include the use of appropriate emission estimation techniques, applicable and reasonable assumptions, accuracy/logic checks of computer models, checks of calculations, and data reliability checks. Depending upon the technical approach used to estimate emissions, a checklist with all of the particular data needs should be prepared to verify that each piece of information is used accurately and appropriately.

This section discusses QA/QC procedures for specific emission estimation methods presented in Sections 4 and 5 of this chapter. Volume VI, *Quality Assurance Procedures*, of this series describes additional QA/QC methods and tools for performing these procedures. Also, Volume II, Chapter 1, *Introduction to Stationary Point Source Emission Inventory Development*, presents recommended standard procedures to follow to ensure that the reported inventory data are complete and accurate.

## 6.1 GENERAL FACTORS INVOLVED IN EMISSION ESTIMATION TECHNIQUES

All calculations, whether done manually or electronically, should be verified by repeating at least one complete set of calculations. If a computer model is being used, verification that the calculations are done correctly need only be done once (until the model is updated or modified). The model verification process should be documented carefully (see Volume VI, Chapter 3, Section 4). Although this level of checking for a program can require a significant amount of time, it is necessary. Furthermore, given that these programs are generally used many times over, the effort required to check the algorithms is relatively small.

Manual calculations should be checked even more carefully, although completely replicating the set of equations is overly burdensome. Because manual calculations introduce more possibility for errors, are difficult to quality assure, and are harder to revise or update later, use of a spreadsheet or other electronic tool is strongly advised.

Often, emissions inventories are developed and/or compiled in computerized emissions databases or models. Presumably, the methods, assumptions, and any data included with the software are documented in a user's or a technical manual. If not, the user should conduct extensive and careful QA of the model or find a better documented system.

Even if the validation of the system is well-documented, the user will need to provide information about the input data. Comment fields, if available and sufficiently large, can be used to record assumptions, data references, and any other pertinent information. Alternatively, this information can be recorded in a separate document, electronically or otherwise. If at all possible, the electronic database should record a cross-reference to the document. This cross-reference could be a file name (and directory or disk number), a notebook identification number, or other document.

### **6.1.1 EMISSIONS MODELS**

Use of emission models and equations generally involves more effort than use of emission factors. The level of effort is related to the complexity of the equation, the types of data that must be collected, and the diversity of products manufactured at a facility. Typically, the use of emission models involves making one or more conservative assumptions if a complete set of site-specific data is unavailable. As a result, the use of models may result in an overestimation of emissions. However, the accuracy and reliability of models can be improved by ensuring that data collected for emission calculations (e.g., material speciation data) are of the highest possible quality.

The EIIP recommends that sensitivity analyses be used as part of the QA program for emissions models. A sensitivity analysis is a process for identifying the magnitude, direction, and form of the effect of an individual parameter on the model's result. It is usually done by repeatedly running the model and changing the value of one variable while holding the others constant. Sensitivity analyses may be used to select the most appropriate model for a given situation. For example, one model may be particularly sensitive to errors in a variable that is not reliably measured. An alternative model may be found that is better suited to the available data. Sensitivity analyses also aid QC by identifying the key variables to be checked.

### **6.1.2 GAS-PHASE MEASUREMENT**

When applying this technique for estimating emissions, sampling and analytical procedures, use of data, preparation and use of a QA plan, and report preparation should be described and understood by the team conducting the test. A systems audit should be conducted on-site as a qualitative review of the various aspects of a total sampling and analytical system to assess its overall effectiveness. For detailed information pertaining to specific test methods, procedures described in the published reference methods should be reviewed, as well as, Chapter 1 of this volume.

### 6.1.3 EMISSION FACTORS

The use of emission factors is straightforward when the relationship between process data and emissions is direct and relatively uncomplicated. When using emission factors, the user should be aware of the quality indicator associated with the value. Emission factors published within EPA documents and electronic tools have a quality rating applied to them. The lower the quality indicator, the more likely that a given emission factor may not be representative of the source type. The reliability and uncertainty of using emission factors as an emission estimation technique are discussed in detail in the QA/QC section of Chapter 1 of this volume.

### 6.1.4 MATERIAL BALANCE

As stated in Section 5, the accuracy and reliability of emission values calculated using the material balance approach are biased toward overestimation. Uncertainty of emissions using the material balance approach is also related to the quality of material speciation data, which is typically extracted from Material Safety Data Sheets (MSDSs). To assess the level of uncertainty of such data, the user should verify if a standard analytical test method (e.g., one using a gas chromatograph) has been used to measure the concentrations of the constituents.

## 6.2 DATA ATTRIBUTE RATING SYSTEM (DARS) SCORES

One measure of emission inventory data quality is the DARS score. Four examples are given here to illustrate DARS scoring using the preferred and alternative methods presented in this document. The DARS provides a numerical ranking on a scale of 0.1 to 1.0 for individual attributes of the emission factor and the activity data. Each score is based on what is known about the factor and activity data, such as the specificity to the source category and the measurement technique employed. The composite attribute score for the emissions estimate can be viewed as a statement of the confidence that can be placed in the data. For a complete discussion of DARS and other rating systems, see the *Quality Assurance Procedures* (Volume VI, Chapter 4) and *Introduction to Stationary Point Sources Emission Inventory Development* (Volume II, Chapter 1).

Each of the examples below is hypothetical. A range is given where appropriate to cover different situations. Table 5.6-1 shows scores developed from the use of emission models. Table 5.6-2 demonstrates scores determined for gas-phase measurement. Table 5.6-3 gives a set of scores for an estimate made with an emission factor. Table 5.6-4 demonstrates scores developed from a material balance approach. The activity data are assumed to be measured directly or indirectly. These examples are given as an illustration of the relative quality of each method. If the same analysis were done for an actual site, the scores could be different but the relative ranking of methods should stay the same.



TABLE 5.6-1

## DARS SCORES: EMISSION MODELS

Attribute	Scores		
	Factor <sup>a</sup>	Activity <sup>b</sup>	Emissions
Measurement	0.3 - 0.9	1.0	0.3 - 0.9
Specificity	0.5 - 0.9	0.9	0.45 - 0.81
Spatial	1.0	1.0	1.0
Temporal	1.0	0.5 - 0.9	0.5 - 0.9
Composite Scores	0.75 - 0.95	0.85 - 0.95	0.56 - 0.90

<sup>a</sup> Lower scores apply to purely theoretical models and/or use of defaults rather than site-specific input values.

<sup>b</sup> Scores assume activity is volume of wastewater processed and that it is measured.

TABLE 5.6-2

## DARS SCORES: GAS-PHASE MEASUREMENT

Attribute	Scores		
	Factor <sup>a</sup>	Activity <sup>b</sup>	Emissions
Measurement	0.5 - 1.0	1.0	0.5 - 1.0
Specificity	0.7 - 1.0	0.9	0.63 - 0.9
Spatial	0.5 - 1.0	1.0	0.5 - 1.0
Temporal	0.5 - 1.0	0.7 - 1.0	0.35 - 1.0
Composite Scores	0.55 - 1.0	0.9 - 0.98	0.50 - 0.98

<sup>a</sup> Exact score will depend on sample size, method used, and whether scales are appropriate to inventory.

<sup>b</sup> Assumes activity is wastewater processed and measured.

TABLE 5.6-3

## DARS SCORES: EMISSION FACTORS

Attribute	Scores		
	Factor	Activity <sup>a</sup>	Emissions
Measurement	0.3 - 0.5	1.0	0.3 - 0.5
Specificity	0.3 - 0.7	0.9	0.21 - 0.63
Spatial	1.0	1.0	1.0
Temporal	0.8	0.8	0.5 - 0.9
Composite Scores	0.45 - 0.85	0.78 - 0.98	0.40 - 0.76

<sup>a</sup> Scores assume activity is volume of wastewater processed and that it is measured.

TABLE 5.6-4

## DARS SCORES: MATERIAL BALANCE

Attribute	Scores		
	Factor	Activity	Emissions
Measurement <sup>a</sup>	0.5 - 0.7	1.0	0.5 - 0.7
Specificity	1.0	1.0	1.0
Spatial	1.0	1.0	1.0
Temporal <sup>b</sup>	0.5 - 1.0	0.5 - 1.0	0.25 - 1.0
Composite Scores	0.75 - 0.93	0.88 - 1.0	0.69 - 0.93

<sup>a</sup> Score increases as sample sizes (influent and effluent) increase.

<sup>b</sup> If influent/effluent concentrations are scaled up or down, lower DARS scores.

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## REFERENCES

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## **APPENDIX A**

# **EXAMPLE DATA COLLECTION FORMS- WASTEWATER TREATMENT UNITS**

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## **EXAMPLE DATA COLLECTION FORMS INSTRUCTIONS**

1. These forms may be used as work sheets to aid the plant engineer in collecting the information necessary to calculate emissions from wastewater treatment units. The information requested on the forms relates to the methods (described in Sections 3 through 5) for quantifying emissions. These forms may also be used by regulatory agency personnel 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, write "NA" in the blank.
4. If you want to modify the form to better serve your needs, an electronic copy of the form may be obtained through the EIIP on the Clearinghouse for Inventories and Emission Factors bulletin board system (CHIEF BBS).
5. Table A-1 can be used as a reference for typical dimensions associated with each unit design parameter.
6. Use the comments field on the form to record all useful information that will allow your work to be reviewed and reconstructed.



TABLE A-1

DIMENSIONS FOR WASTE STREAM COLLECTION AND TREATMENT UNITS<sup>a</sup>

Component	Design Parameter	Typical Dimensions
Drain	riser height (m)	0.6
	riser diameter (m)	0.2
	process drain pipe diameter (m)	0.1
	effective diameter of riser (m)	0.1
	riser cap thickness (cm)	0.6
	sewer diameter (m)	0.9
Manhole	diameter (m)	1.2
	height (m)	1.2
	cover diameter (m)	0.6
	diameter of holes in cover (cm)	2.5
	cover thickness (cm)	0.6
	sewer diameter (m <sup>2</sup> )	0.9
Junction Box	effective diameter (m)	0.9
	grade height (m)	1.5
	water depth (m)	0.9
	surface area (m <sup>2</sup> )	0.7
Lift Station	effective diameter (m)	1.5
	width (m)	1.8
	grade height (m)	2.1
	water depth (m)	1.5
	surface area (m <sup>2</sup> )	1.8
Trench	length (m)	15.2
	water depth (m)	0.6
	depth (m)	0.8
	width (m)	0.6
Weir	height (m)	1.8
Oil/Water Separator	length (m)	13.7
	width (m)	7.6
	retention time (hr)	0.8

**TABLE A-1**  
**(CONTINUED)**

Component	Design Parameter	Typical Dimensions
Clarifier	diameter (m)	18.3
	depth (m)	3.5
	retention time (hr)	4.0
Sump	effective diameter (m)	1.5
	water depth (m)	1.5
	surface area (m <sup>2</sup> )	1.8
Equalization Basin	effective diameter (m)	109
	water depth (m)	2.9
	surface area (m <sup>2</sup> )	9,290
	retention time (days)	5
Aeration Basin	effective diameter (m)	150
	water depth (m)	2.0
	surface area (m <sup>2</sup> )	17,652
	retention time (days)	6.5
Treatment Tank	effective diameter (m)	11
	water depth (m)	4.9
	surface area (m <sup>2</sup> )	93
	retention time (hr)	2

<sup>a</sup> EPA. 1990. *Industrial Wastewater Volatile Organic Compound Emissions-Background Information for BACT/LAER Determinations*. U.S. Environmental Protection Agency, EPA-450/3-90-004. Research Triangle Park, North Carolina.

## EXAMPLE DATA COLLECTION FORM - WASTEWATER UNITS

GENERAL INFORMATION		
Facility/Plant Name:		
SIC Code:		
SCC:		
SCC Description:		
Location:		
County:	City:	State:
Plant Geographical Coordinates:		
Latitude:		
Longitude:		
UTM Zone:		
UTM Easting:		
UTM Northing:		
Contact Name:		
Title:		
Telephone Number:	Facsimile Number:	
Source ID Number:	Unit ID Number:	
Permit Number:		
Permitted Hours of Operation (per year):		
Actual Hours of Operation:		
Hours/Day:	Days/Weeks:	Weeks/Year:

## EXAMPLE DATA COLLECTION FORM - WASTEWATER UNITS

UNIT DESCRIPTION<sup>a</sup>

UNIT NUMBER \_\_\_ of \_\_\_

Junction box:

Reach:

Drain:

Drain type:

Lift station:

Sump:

Weir:

Other:

## CONFIGURATION

Flowthrough:

Disposal:

## MECHANICAL AERATION

Diffused air:

Biodegradation:

Oil film layer:

## DESIGN PARAMETERS

Volume flow rate (units):

Surface area (units):

Liquid depth (units):

Width (units):

Fetch length (units):

Retention time (turnover/yr):

Pollutant of interest:

Concentration before treatment:

Refer to Table A-1 for typical dimensions associated with design parameters.

## INPUT DATA FOR MODELING WASTEWATER TREATMENT SYSTEMS

COLLECTION SYSTEM			
Please fill out the following information for each unit. Attach additional sheets as needed.			
TRUNK/REACH	UNIT NUMBER	UNIT NUMBER	UNIT NUMBER
Wastewater flow:			
Open or closed channel:			
Reach (channel) diameter:			
Reach surface roughness: (e.g., smooth, concrete, tile, pipe)			
Reach slope:			
Reach length:			
Wastewater temperature:			
Water concentration of known organics:			
Manholes and drop structures:			
Manhole gas volume:			
Tailwater depth in manhole:			
Air concentration of VOCs (if available):			
Water drop height in drop structure (height of splashing flow):			
Wind speed or ventilation rate in sewer:			

## INPUT DATA FOR MODELING WASTEWATER TREATMENT SYSTEMS (CONTINUED)

BASINS & TANKS	COMMENTS
Flow rates and composition:	
Influent flow rate to unit (gal/hr):	
Recycle flow rate from clarifier (gal/hr):	
Feed influent organics:	
Major components (mg/L):	
Total organics (mg/L):	
Microorganism level in recycle (mg/L MLVSS <sup>a</sup> ):	
Microorganism level in basin (mg/L MLVSS):	
Microorganism level in feed (mg/L MLVSS):	
Microorganism level in clarifier effluent (mg/L MLVSS):	
Oxygen concentration in feed (ppm):	
Oxygen concentration in basin (ppm):	
Basin geometry and characteristics:	
Volume (gal):	
Depth (ft):	
Surface area (ft <sup>2</sup> ):	
Temperature of liquid in basin (°C):	
Number of turbines:	
Turbine speed (rpm):	
Delivered power of turbine (hp/turbine):	
Oxygen transfer rating of turbine (lb of O <sub>2</sub> /hp-hr):	
Diameter of turbine blade (ft):	
or subsurface aeration:	
Air flow to basin (ft <sup>3</sup> /min):	
Liquid injection rate (ft <sup>3</sup> /hr):	
Biodegradation rates:	
Overall removal efficiency (%):	
Compound-specific biorates (if known):	

MLVSS = mixed liquor volatile suspended solids.

## EMISSION ESTIMATION RESULTS

Pollutant	Emission Estimation Method <sup>a</sup>	Annual Emissions	Emissions Units	Emission Factor <sup>b</sup>	Emission Factor Units	Comments
VOC						
Hazardous Air Pollutants (list individually)						

<sup>a</sup> Use the following codes to indicate which emission estimation method is used for each pollutant:

Emission Factor = EF; Other (indicate) = O; Model (indicate which model was used) = M.

<sup>b</sup> Where applicable, enter the emission factor and provide the full citation of the reference or source of information from where the emission factor came. Include edition, version, table, and page numbers if AP-42 is used.

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## APPENDIX B

# AP-42 EMISSION ESTIMATION ALGORITHM AND EXAMPLE CALCULATIONS

Source: EPA. January 1995. "Waste Water Collection, Treatment and Storage" (Section 4.3.2). In: *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources, Fifth Edition, AP-42*. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park, North Carolina.

Note: AP-42 refers to the SIMS model although it has been superseded by the WATER8 model, which is available on the CHIEF BBS.



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## EMISSIONS

Volatile organic compounds (VOCs) are emitted from wastewater collection, treatment, and storage systems through volatilization of organic compounds at the liquid surface. Emissions can occur by diffusive or convective mechanisms, or both. Diffusion occurs when organic concentrations at the water surface are much higher than ambient concentrations. The organics volatilize or diffuse into the air, in an attempt to reach equilibrium between aqueous and vapor phases. Convection occurs when air flows over the water surface, sweeping organic vapors from the water surface into the air. The rate of volatilization relates directly to the speed of the air flow over the water surface.

Other factors that can affect the rate of volatilization include wastewater surface area, temperature, and turbulence; wastewater retention time in the system(s); the depth of the wastewater in the system(s); the concentration of organic compounds in the wastewater and their physical properties, such as volatility and diffusivity in water; the presence of a mechanism that inhibits volatilization, such as an oil film; or a competing mechanism, such as biodegradation.

The rate of volatilization can be determined by using mass transfer theory. Individual gas phase and liquid phase mass transfer coefficients ( $k_g$  and  $k_L$ , respectively) are used to estimate overall mass transfer coefficients ( $K$ ,  $K_{oil}$ , and  $K_D$ ) for each VOC.<sup>1,2</sup>

Figure 5.B-1 presents a flow diagram to assist in determining the appropriate emissions model for estimating VOC emissions from various types of wastewater treatment, storage, and collection systems. Tables 5.B-1 and 5.B-2, respectively, present the emission model equations and definitions.

VOCs vary in their degree of volatility. The emission models presented in this section can be used for high-, medium-, and low-volatility organic compounds. The Henry's Law constant (HLC) is often used as a measure of a compound's volatility, or the diffusion of organics into the air relative to diffusion through liquids. High-volatility VOCs are  $HLC > 10^{-3} \text{ atm-m}^3/\text{gmol}$ ; medium-volatility VOCs are  $10^{-3} < HLC < 10^{-5} \text{ atm-m}^3/\text{gmol}$ ; and low-volatility VOCs are  $HLC < 10^{-5} \text{ atm-m}^3/\text{gmol}$ .<sup>1</sup>

The design and arrangement of collection, treatment, and storage systems are facility-specific; therefore the most accurate wastewater emissions estimate will come from actual tests of a facility (i.e., tracer studies or direct measurement of emissions from openings). If actual data are unavailable, the emission models provided in this section can be used.

Emission models should be given site-specific information whenever it is available. The most extensive characterization of an actual system will produce the most accurate

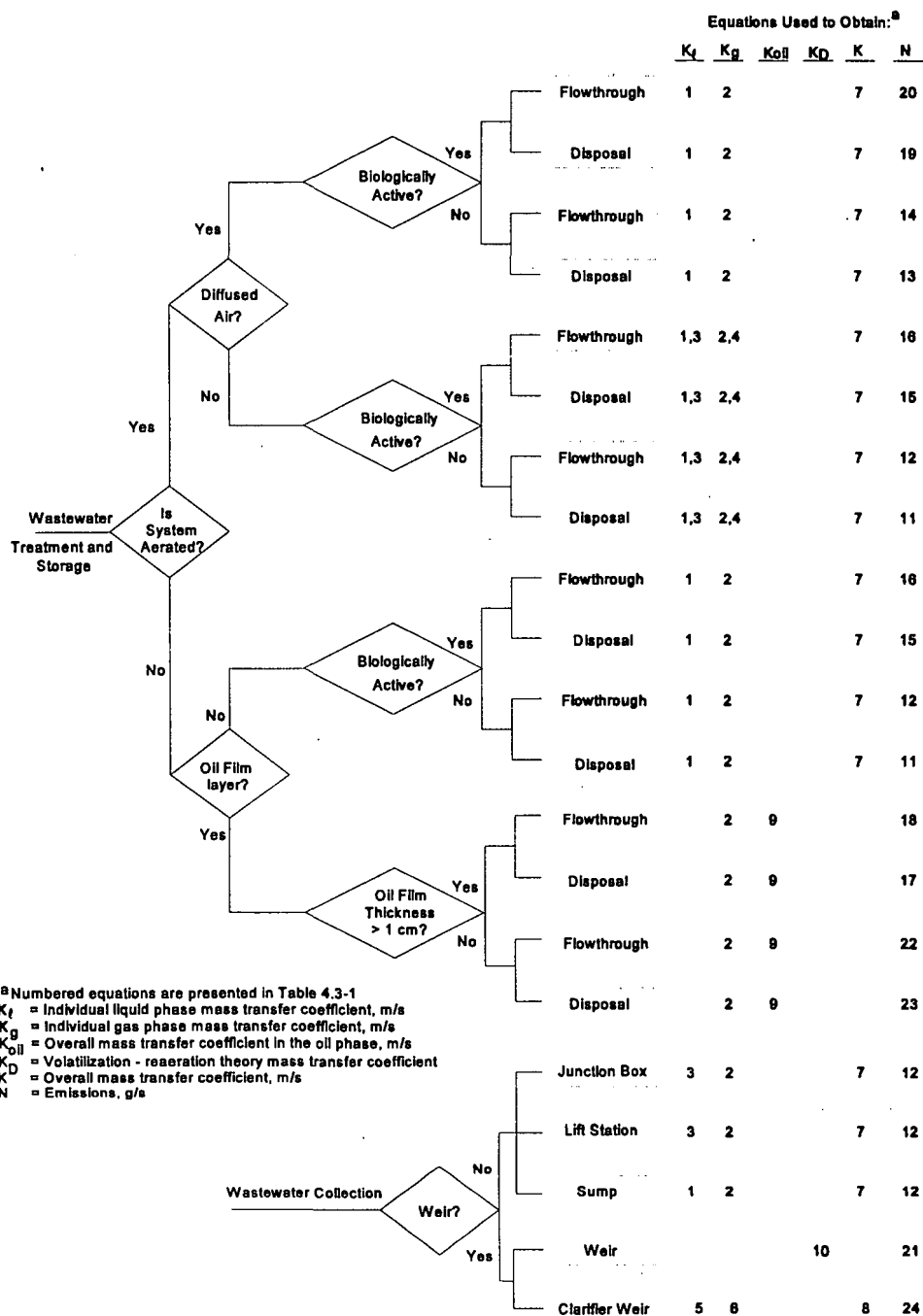


Figure 5.B-1. Flow diagram for estimating VOC emissions from wastewater collection, treatment, and storage systems.

<sup>a</sup> Citation refers to table assignment number in AP-42.

TABLE 5.B-1  
MASS TRANSFER CORRELATIONS AND EMISSIONS EQUATIONS<sup>a</sup>

Equation No.	Equation
<u>Individual liquid (<math>k_L</math>) and gas (<math>k_g</math>) phase mass transfer coefficients</u>	
1	$k_L \text{ (m/s)} = (2.78 \times 10^{-6})(D_w/D_{\text{ether}})^{2/3}$ <p>For: <math>0 &lt; U_{10} &lt; 3.25 \text{ m/s}</math> and all <math>F/D</math> ratios</p> $k_L \text{ (m/s)} = [(2.605 \times 10^{-9})(F/D) + (1.277 \times 10^{-7})](U_{10})^2(D_w/D_{\text{ether}})^{2/3}$ <p>For: <math>U_{10} &gt; 3.25 \text{ m/s}</math> and <math>14 &lt; F/D &lt; 51.2</math></p> $k_L \text{ (m/s)} = (2.61 \times 10^{-7})(U_{10})^2(D_w/D_{\text{ether}})^{2/3}$ <p>For: <math>U_{10} &gt; 3.25 \text{ m/s}</math> and <math>F/D &gt; 51.2</math></p> $k_L \text{ (m/s)} = 1.0 \times 10^{-6} + 144 \times 10^{-4} (U^*)^{2.2} (Sc_L)^{-0.5}; U^* < 0.3$ $k_L \text{ (m/s)} = 1.0 \times 10^{-6} + 34.1 \times 10^{-4} U^* (Sc_L)^{-0.5}; U^* > 0.3$ <p>For: <math>U_{10} &gt; 3.25 \text{ m/s}</math> and <math>F/D &lt; 14</math></p> <p>where:</p> $U^* \text{ (m/s)} = (0.01)(U_{10})(6.1 + 0.63(U_{10}))^{0.5}$ $Sc_L = \mu_L/(\rho_L D_w)$ $F/D = 2 (A/\pi)^{0.5}$
2	$k_g \text{ (m/s)} = (4.82 \times 10^{-3})(U_{10})^{0.78} (Sc_G)^{-0.67} (d_c)^{-0.11}$ <p>where:</p> $Sc_G = \mu_a/(\rho_a D_a)$ $d_c \text{ (m)} = 2(A/\pi)^{0.5}$
3	$k_L \text{ (m/s)} = [(8.22 \times 10^{-9})(J)(\text{POWR})(1.024)^{(T-20)}(O_i)(10^6) * (MW_L)/(Va_v \rho_L)](D_w/D_{O2,w})^{0.5}$ <p>where:</p> $\text{POWR (hp)} = (\text{total power to aerators})(V)$ $Va_v \text{ (ft}^2\text{)} = (\text{fraction of area agitated})(A)$
4	$k_g \text{ (m/s)} = (1.35 \times 10^{-7})(\text{Re})^{1.42} (P)^{0.4} (Sc_G)^{0.5} (\text{Fr})^{-0.21}(D_a \text{ MW}_a/d)$ <p>where:</p> $\text{Re} = d^2 w \rho_a/\mu_a$ $P = [(0.85)(\text{POWR})(550 \text{ ft-lb}_f/\text{s-hp})/N_I] g_c/(\rho_L (d^*)^5 w^3)$ $Sc_G = \mu_a/(\rho_a D_a)$ $\text{Fr} = (d^*) w^2/g_c$

TABLE 5.B-1

(CONTINUED)

Equation No.	Equation
5	$k_l \text{ (m/s)} = (f_{\text{air},l})(Q)/[3600 \text{ s/min } (h_c)(\pi d_c)]$ <p>where:</p> $f_{\text{air},l} = 1 - 1/r$ $r = \exp [0.77(h_c)^{0.623}(Q/\pi d_c)^{0.66}(D_w/D_{O2,w})^{0.66}]$
6	$k_g \text{ (m/s)} = 0.001 + (0.0462(U^{**})(Sc_G)^{-0.67})$ <p>where:</p> $U^{**} \text{ (m/s)} = [6.1 + (0.63)(U_{10})]^{0.5}(U_{10}/100)$ $Sc_G = \mu_a/(\rho_a D_a)$
<u>Overall mass transfer coefficients for water (K) and oil (K<sub>oil</sub>) phases and for weirs (K<sub>D</sub>)</u>	
7	$K = (k_l \text{ Keq } k_g)/(\text{Keq } k_g + k_l)$ <p>where:</p> $\text{Keq} = H/(RT)$
8	$K \text{ (m/s)} = [[MW_L/(k_{L,L}^*(100 \text{ cm/m})] + [MW_a/(k_g \rho_a H^* 55,555(100 \text{ cm/m}))]]^{-1} MW_L/[(100 \text{ cm/m})\rho_L]$
9	$K_{\text{oil}} = k_g \text{ Keq}_{\text{oil}}$ <p>where:</p> $\text{Keq}_{\text{oil}} = P^* \rho_a MW_{\text{oil}}/(\rho_{\text{oil}} MW_a P_o)$
10	$K_D = 0.16h (D_w/D_{O2,w})^{0.75}$
<u>Air emissions (N)</u>	
11	$N(\text{g/s}) = (1 - Ct/Co) V Co/t$ <p>where:</p> $Ct/Co = \exp[-K A t/V]$

TABLE 5.B-1

(CONTINUED)

Equation No.	Equation
12	$N(g/s) = K C_L A$ <p>where:</p> $C_L(g/m^3) = Q Co / (KA + Q)$
13	$N(g/s) = (1 - Ct/Co) V Co/t$ <p>where:</p> $Ct/Co = \exp[-(KA + KeqQ_a)t/V]$
14	$N(g/s) = (KA + Q_a Keq) C_L$ <p>where:</p> $C_L(g/m^3) = QCo / (KA + Q + Q_a Keq)$
15	$N(g/s) = (1 - Ct/Co) KA / (KA + Kmax b_i V/K_s) V Co/t$ <p>where:</p> $Ct/Co = \exp[-Kmax b_i t/K_s - K A t/V]$
16	$N(g/s) = K C_L A$ <p>where:</p> $C_L(g/m^3) = [-b + (b^2 - 4ac)^{0.5}] / (2a)$ <p>and:</p> $a = KA/Q + 1$ $b = K_s(KA/Q + 1) + Kmax b_i V/Q - Co$ $c = -K_s Co$
17	$N(g/s) = (1 - Ct_{oil}/Co_{oil}) V_{oil} Co_{oil}/t$ <p>where:</p> $Ct_{oil}/Co_{oil} = \exp[-K_{oil} t/D_{oil}]$ <p>and:</p> $Co_{oil} = Kow Co / [1 - FO + FO(Kow)]$ $V_{oil} = (FO)(V)$ $D_{oil} = (FO)(V)/A$

TABLE 5.B-1

(CONTINUED)

Equation No.	Equation
18	$N(g/s) = K_{oil} C_{L,oil} A$ <p>where:</p> $C_{L,oil}(g/m^3) = Q_{oil} Co_{oil} / (K_{oil} A + Q_{oil})$ <p>and:</p> $Co_{oil} = Kow Co / [1 - FO + FO(Kow)]$ $Q_{oil} = (FO)(Q)$
19	$N(g/s) = (1 - Ct/Co)(KA + Q_a Keq) / (KA + Q_a Keq + Kmax b_i V/K_s)$ $V Co/t$ <p>where:</p> $Ct/Co = \exp[-(KA + KeqQ_a)t/V - Kmax b_i t/K_s]$
20	$N(g/s) = (KA + Q_a Keq) C_L$ <p>where:</p> $C_L(g/m^3) = [-b + (b^2 - 4ac)^{0.5}] / (2a)$ <p>and:</p> $a = (KA + Q_a Keq) / Q + 1$ $b = K_s [(KA + Q_a Keq) / Q + 1] + Kmax b_i V/Q - Co$ $c = -K_s Co$
21	$N(g/s) = (1 - \exp[-K_D]) Q Co$
22	$N(g/s) = K_{oil} C_{L,oil} A$ <p>where:</p> $C_{L,oil}(g/m^3) = Q_{oil} (Co_{oil}^*) / (K_{oil} A + Q_{oil})$ <p>and:</p> $Co_{oil}^* = Co / FO$ $Q_{oil} = (FO)(Q)$

TABLE 5.B-1  
(CONTINUED)

Equation No.	Equation
23	$N(g/s) = (1 - C_{t_{oil}}/C_{o_{oil}}^*)(V_{oil})(C_{o_{oil}}^*)/t$ <p>where:</p> $C_{t_{oil}}/C_{o_{oil}}^* = \exp[-K_{oil} t/D_{oil}]$ <p>and:</p> $C_{o_{oil}}^* = C_o/FO$ $V_{oil} = (FO)(V)$ $D_{oil} = (FO)(V)/A$
24	$N(g/s) = (1 - \exp[-K \pi d_c h_c/Q])Q C_o$

\* All parameters in numbered equations are defined in Table 5.B-2.



**TABLE 5.B-2**  
**PARAMETER DEFINITIONS FOR MASS TRANSFER CORRELATIONS**  
**AND EMISSIONS EQUATIONS**

Parameter	Definition	Units	Code <sup>a</sup>
A	Wastewater surface area	m <sup>2</sup> or ft <sup>2</sup>	A
b <sub>i</sub>	Biomass concentration (total biological solids)	g/m <sup>3</sup>	B
C <sub>L</sub>	Concentration of constituent in the liquid phase	g/m <sup>3</sup>	D
C <sub>L,oil</sub>	Concentration of constituent in the oil phase	g/m <sup>3</sup>	D
C <sub>o</sub>	Initial concentration of constituent in the liquid phase	g/m <sup>3</sup>	A
C <sub>o,oil</sub>	Initial concentration of constituent in the oil phase considering mass transfer resistance between water and oil phases	g/m <sup>3</sup>	D
C <sub>o,oil</sub> <sup>*</sup>	Initial concentration of constituent in the oil phase considering no mass transfer resistance between water and oil phases	g/m <sup>3</sup>	D
C <sub>t</sub>	Concentration of constituent in the liquid phase at time = t	g/m <sup>3</sup>	D
C <sub>t,oil</sub>	Concentration of constituent in the oil phase at time = t	g/m <sup>3</sup>	D
d	Impeller diameter	cm	B
D	Wastewater depth	m or ft	A,B
d <sup>*</sup>	Impeller diameter	ft	B
D <sub>a</sub>	Diffusivity of constituent in air	cm <sup>2</sup> /s	C
d <sub>c</sub>	Clarifier diameter	m	B
d <sub>e</sub>	Effective diameter	m	D
D <sub>ether</sub>	Diffusivity of ether in water	cm <sup>2</sup> /s	(8.5x10 <sup>-6</sup> ) <sup>b</sup>
D <sub>O2,w</sub>	Diffusivity of oxygen in water	cm <sup>2</sup> /s	(2.4x10 <sup>-5</sup> ) <sup>b</sup>
D <sub>oil</sub>	Oil film thickness	m	B

TABLE 5.B-2

(CONTINUED)

Parameter	Definition	Units	Code <sup>a</sup>
$D_w$	Diffusivity of constituent in water	$\text{cm}^2/\text{s}$	C
$f_{\text{air},t}$	Fraction of constituent emitted to the air, considering zero gas resistance	dimensionless	D
F/D	Fetch to depth ratio, $d_e/D$	dimensionless	D
FO	Fraction of volume which is oil	dimensionless	B
Fr	Froude number	dimensionless	D
$g_c$	Gravitation constant (a conversion factor)	$\text{lb}_m\text{-ft/s}^2\text{-lb}_f$	32.17
h	Weir height (distance from the wastewater overflow to the receiving body of water)	ft	B
$h_c$	Clarifier weir height	m	B
H	Henry's Law constant of constituent	$\text{atm}\cdot\text{m}^3/\text{gmol}$	C
J	Oxygen transfer rating of surface aerator	$\text{lb O}_2/(\text{hr}\cdot\text{hp})$	B
K	Overall mass transfer coefficient for transfer of constituent from liquid phase to gas phase	m/s	D
$K_D$	Volatilization-re-aeration theory mass transfer coefficient	dimensionless	D
$K_{eq}$	Equilibrium constant or partition coefficient (concentration in gas phase/concentration in liquid phase)	dimensionless	D
$K_{eq,oi}$	Equilibrium constant or partition coefficient (concentration in gas phase/concentration in oil phase)	dimensionless	D
$k_g$	Gas phase mass transfer coefficient	m/s	D
$k_l$	Liquid phase mass transfer coefficient	m/s	D
Kmax	Maximum biorate constant	$\text{g/s}\cdot\text{g biomass}$	A,C
$K_{oi}$	Overall mass transfer coefficient for transfer of constituent from oil phase to gas phase	m/s	D

TABLE 5.B-2

(CONTINUED)

Parameter	Definition	Units	Code <sup>a</sup>
K <sub>ow</sub>	Octanol-water partition coefficient	dimensionless	C
K <sub>s</sub>	Half saturation biorate constant	g/m <sup>3</sup>	A,C
MW <sub>a</sub>	Molecular weight of air	g/gmol	29
MW <sub>oil</sub>	Molecular weight of oil	g/gmol	B
MW <sub>L</sub>	Molecular weight of water	g/gmol	18
N	Emissions	g/s	D
N <sub>i</sub>	Number of aerators	dimensionless	A,B
O <sub>i</sub>	Oxygen transfer correction factor	dimensionless	B
P	Power number	dimensionless	D
P <sup>*</sup>	Vapor pressure of the constituent	atm	C
P <sub>o</sub>	Total pressure	atm	A
POWER	Total power to aerators	hp	B
Q	Volumetric flow rate	m <sup>3</sup> /s	A
Q <sub>a</sub>	Diffused air flow rate	m <sup>3</sup> /s	B
Q <sub>oil</sub>	Volumetric flow rate of oil	m <sup>3</sup> /s	B
r	Deficit ratio (ratio of the difference between the constituent concentration at solubility and actual constituent concentration in the upstream and the downstream)	dimensionless	D
R	Universal gas constant	atm-m <sup>3</sup> /gmol-K	8.21x10 <sup>-5</sup>
Re	Reynolds number	dimensionless	D
Sc <sub>g</sub>	Schmidt number on gas side	dimensionless	D
Sc <sub>L</sub>	Schmidt number on liquid side	dimensionless	D

TABLE 5.B-2

(CONTINUED)

Parameter	Definition	Units	Code <sup>a</sup>
T	Temperature of water	°C or Kelvin (K)	A
t	Residence time of disposal	s	A
U*	Friction velocity	m/s	D
U**	Friction velocity	m/s	D
U <sub>10</sub>	Wind speed at 10 m above the liquid surface	m/s	B
V	Wastewater volume	m <sup>3</sup> or ft <sup>3</sup>	A
V <sub>a_v</sub>	Turbulent surface area	ft <sup>2</sup>	B
V <sub>oil</sub>	Volume of oil	m <sup>3</sup>	B
w	Rotational speed of impeller	rad/s	B
ρ <sub>a</sub>	Density of air	g/cm <sup>3</sup>	(1.2x10 <sup>-3</sup> ) <sup>b</sup>
ρ <sub>L</sub>	Density of water	g/cm <sup>3</sup> or lb/ft <sup>3</sup>	1 <sup>b</sup> or 62.4 <sup>b</sup>
ρ <sub>oil</sub>	Density of oil	g/m <sup>3</sup>	B
μ <sub>a</sub>	Viscosity of air	g/cm-s	(1.81x10 <sup>-4</sup> ) <sup>b</sup>
μ <sub>L</sub>	Viscosity of water	g/cm-s	(8.93x10 <sup>-3</sup> ) <sup>b</sup>

<sup>a</sup> Code:

A = Site-specific parameter.

B = Site-specific parameter. For default values, see Table 5.B-3.

C = Parameter can be obtained from literature. See Table 5.B-4 for a list of ~150 compound chemical properties at T = 25°C (298°K).

D = Calculated value.

<sup>b</sup> Reported values at 25°C (298°K).

estimates from an emissions model. In addition, when addressing systems involving biodegradation, the accuracy of the predicted rate of biodegradation is improved when site-specific compound biorates are input. Reference 3 contains information on a test method for measuring site-specific biorates, and Table 5.B-4 presents estimated biorates for approximately 150 compounds.

To estimate an emissions rate ( $N$ ), the first step is to calculate individual gas phase and liquid phase mass transfer coefficients  $k_g$  and  $k_L$ . These individual coefficients are then used to calculate the overall mass transfer coefficient,  $K$ . Exceptions to this procedure are the calculation of overall mass transfer coefficients in the oil phase,  $K_{oil}$ , and the overall mass transfer coefficient for a weir,  $K_D$ .  $K_{oil}$  requires only  $k_g$  and  $K_D$  does not require any individual mass transfer coefficients. The overall mass transfer coefficient is then used to calculate the emissions rates. The following discussion describes how to use Figure 5.B-1 to determine an emission rate. An example calculation is presented in Part B-1 below.

Figure 5.B-1 is divided into two sections: wastewater treatment and storage systems, and wastewater collection systems. Wastewater treatment and storage systems are further segmented into aerated/nonaerated systems, biologically active systems, oil film layer systems, and surface impoundment flowthrough or disposal. In flowthrough systems, wastewater is treated and discharged to a publicly owned treatment works (POTW) or a receiving body of water, such as a river or stream. All wastewater collection systems are by definition flowthrough. Disposal systems, on the other hand, do not discharge any wastewater.

Figure 5.B-1 includes information needed to estimate air emissions from junction boxes, lift stations, sumps, weirs, and clarifier weirs. Sumps are considered quiescent, but junction boxes, lift stations, and weirs are turbulent in nature. Junction boxes and lift stations are turbulent because incoming flow is normally above the water level in the component, which creates some splashing. Wastewater falls or overflows from weirs and creates splashing in the receiving body of water (both weir and clarifier weir models). Wastewater from weirs can be aerated by directing it to fall over steps, usually only the weir model.

Assessing VOC emissions from drains, manholes, and trenches is also important in determining the total wastewater facility emissions. As these sources can be open to the atmosphere and closest to the point of wastewater generation (i.e., where water temperatures and pollutant concentrations are greatest), emissions can be significant. Currently, there are no well-established emission models for these collection system types. However, work is being performed to address this need.

Preliminary models of VOC emissions from waste collection system units have been developed.<sup>4</sup> The emission equations presented in Reference 4 are used with standard collection system parameters to estimate the fraction of the constituents released as the wastewater flows through each unit. The fractions released from several units are estimated for high-, medium-, and low-volatility compounds. The units used in the estimated fractions included open drains, manhole covers, open trench drains, and covered sumps.

The numbers in Figure 5.B-1 under the columns for  $k_L$ ,  $k_g$ ,  $K_{oil}$ ,  $K_D$ ,  $K$ , and  $N$  refer to the appropriate equations in Table 5.B-1.<sup>a</sup> Definitions for all parameters in these equations are given in Table 5.B-2. Table 5.B-2 also supplies the units that must be used for each parameter, with codes to help locate input values. If the parameter is coded with the letter A, a site-specific value is required. Code B also requires a site-specific parameter, but defaults are available. These defaults are typical or average values and are presented by specific system in Table 5.B-3.

Code C means the parameter can be obtained from literature data. Table 5.B-4 contains a list of approximately 150 chemicals and their physical properties needed to calculate emissions from wastewater, using the correlations presented in Table 5.B-1. All properties are at 25°C (77°F). A more extensive chemical properties data base is contained in Appendix C of Reference 1.) Parameters coded D are calculated values.

Calculating air emissions from wastewater collection, treatment, and storage systems is a complex procedure, especially if several systems are present. Performing the calculations by hand may result in errors and will be time consuming. A personal computer program called the Surface Impoundment Modeling System (SIMS) is now available for estimating air emissions. The program is menu driven and can estimate air emissions from all surface impoundment models presented in Figure 5.B-1, individually or in series. The program requires for each collection, treatment, or storage system component, at a minimum, the wastewater flow rate and component surface area. All other inputs are provided as default values. Any available site-specific information should be entered in place of these defaults, as the most fully characterized system will provide the most accurate emissions estimate.

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<sup>a</sup> All emission model systems presented in Figure 5.B-1 imply a completely mixed or uniform waste water concentration system. Emission models for a plug flow system, or system in which there is no axial, or horizontal mixing, are too extensive to be covered in this document. (An example of plug flow might be a high waste water flow in a narrow channel.) For information on emission models of this type, see Reference 1.

**TABLE 5.B-3**  
**SITE-SPECIFIC DEFAULT PARAMETERS<sup>a</sup>**

Default Parameter <sup>b</sup>	Definition	Default Value
<b>General</b>		
T	Temperature of water	298°K
U <sub>10</sub>	Windspeed	4.47 m/s
<b>Biotreatment Systems</b>		
b <sub>i</sub>	Biomass concentration (for biologically active systems)	
	Quiescent treatment systems	50 g/m <sup>3</sup>
	Aerated treatment systems	300 g/m <sup>3</sup>
	Activated sludge units	4000 g/m <sup>3</sup>
POWR	Total power to aerators (for aerated treatment systems) (for activated sludge)	0.75 hp/1000 ft <sup>3</sup> (V) 2 hp/1000 ft <sup>3</sup> (V)
W	Rotational speed of impeller (for aerated treatment systems)	126 rad/s (1200 rpm)
d(d')	Impeller diameter (for aerated treatment systems)	61 cm (2 ft)
V <sub>a</sub>	Turbulent surface area (for aerated treatment systems) (for activated sludge)	0.24 (A) 0.52 (A)
J	Oxygen transfer rating to surface aerator (for aerated treatment systems)	3 lb O <sub>2</sub> /hp•hr
O <sub>i</sub>	Oxygen transfer correction factor (for aerated treatment systems)	0.83
N <sub>i</sub>	Number of aerators	POWR/75
<b>Diffused Air Systems</b>		
Q <sub>a</sub>	Diffused air volumetric flow rate	0.0004(V) m <sup>3</sup> /s

TABLE 5.B-3

(CONTINUED)

Default Parameter <sup>b</sup>	Definition	Default Value
<b>Oil Film Layers</b>		
MW <sub>oil</sub>	Molecular weight of oil	282 g/gmol
D <sub>oil</sub>	Depth of oil layer	0.001 (V/A) m
V <sub>oil</sub>	Volume of oil	0.001 (V) m <sup>3</sup>
Q <sub>oil</sub>	Volumetric flow rate of oil	0.001 (Q) m <sup>3</sup> /s
$\rho_{oil}$	Density of oil	0.92 g/cm <sup>3</sup>
FO	Fraction of volume which is oil <sup>c</sup>	0.001
<b>Junction Boxes</b>		
D	Depth of Junction Box	0.9 m
N <sub>i</sub>	Number of aerators	1
<b>Lift Station</b>		
D	Depth of Lift Station	1.5 m
N <sub>i</sub>	Number of aerators	1
<b>Sump</b>		
D	Depth of sump	5.9 m
<b>Weirs</b>		
d <sub>c</sub>	Clarifier weir diameter <sup>d</sup>	28.5 m
h	Weir height	1.8 m
h <sub>c</sub>	Clarifier weir height <sup>e</sup>	0.1 m

<sup>a</sup> Reference 1.<sup>b</sup> As defined in Table 5.B-2.<sup>c</sup> Reference 4.<sup>d</sup> Reference 2.<sup>e</sup> Reference 5.



The SIMS program with user's manual and background technical document can be obtained through state air pollution control agencies and through the U.S. Environmental Protection Agency's Control Technology Center in Research Triangle Park, North Carolina, telephone (919) 541-0800. The user's manual and background technical document should be followed to produce meaningful results.

The SIMS program and user's manual also can be downloaded from EPA's Clearinghouse for Inventories and Emission Factors bulletin board system (CHIEF BBS). The CHIEF BBS is open to all persons involved in air emission inventories. To access this BBS, one needs a computer, modem, and communication package capable of communicating at up to 14,400 baud, 8 data bits, 1 stop bit, and no parity (8-N-1). This BBS is part of EPA's Office of Air Quality Planning and Standards (OAQPS) Technology Transfer Network (TTN) system and its telephone number is (919) 541-5742. First-time users must register before access is allowed.

Emissions estimates from SIMS are based on mass transfer models developed by Emissions Standards Division (ESD) during evaluations of treatment, storage, and disposal facilities (TSDFs) and VOC emissions from industrial wastewater. As a part of the TSDF project, a Lotus® spreadsheet program called CHEMDAT7 was developed for estimating VOC emissions from wastewater land treatment systems, open landfills, closed landfills, and waste storage piles, as well as from various types of surface impoundments. For more information about CHEMDAT7, contact the ESD's Chemicals And Petroleum Branch (MD-13), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711.

#### EXAMPLE CALCULATION

An example industrial facility operates a flowthrough, mechanically aerated biological treatment impoundment that receives wastewater contaminated with benzene at a concentration of 10.29 g/m<sup>3</sup>.

The following format is used for calculating benzene emissions from the treatment process:

- I. Determine which emission model to use
- II. User-supplied information
- III. Defaults
- IV. Pollutant physical property data and water, air, and other properties
- V. Calculate individual mass transfer coefficient
- VI. Calculate the overall mass transfer coefficients
- VII. Calculate VOC emissions

- I. Determine Which Emission Model To Use – Following the flow diagram in Figure 5.B-1, the emission model for a treatment system that is aerated, but not by diffused air, is biologically active, and is a flowthrough system, contains the following equations:

Parameter	Definition	Equation Nos. from Table 5.B-1
K	Overall mass transfer coefficient, m/s	7
$k_l$	Individual liquid phase mass transfer coefficient, m/s	1, 3
$k_g$	Individual gas phase mass transfer coefficient, m/s	2, 4
N	VOC emissions, g/s	16

- II. User-supplied Information – Once the correct emission model is determined, some site-specific parameters are required. As a minimum for this model, site-specific flow rate, wastewater surface area and depth, and pollutant concentration should be provided. For this example, these parameters have the following values:

$$\begin{aligned}
 Q &= \text{Volumetric flow rate} = 0.0623 \text{ m}^3/\text{s} \\
 D &= \text{Wastewater depth} = 1.97 \text{ m} \\
 A &= \text{Wastewater surface area} = 17,652 \text{ m}^2 \\
 Co &= \text{Initial benzene concentration in the liquid phase} = 10.29 \text{ g/m}^3
 \end{aligned}$$

- III. Defaults – Defaults for some emission model parameters are presented in Table 5.B-3. Generally, site-specific values should be used when available. For this facility, all available general and biotreatment system defaults from Table 5.B-3 were used:

$$\begin{aligned}
 U_{10} &= \text{Wind speed at 10 m above the liquid surface} = e = 4.47 \text{ m/s} \\
 T &= \text{Temperature of water} = 25^\circ\text{C} (298^\circ\text{K}) \\
 b_i &= \text{Biomass concentration for aerated treatment systems} = 300 \text{ g/m}^3 \\
 J &= \text{Oxygen transfer rating to surface aerator} = 3 \text{ lb O}_2/\text{hp-hr} \\
 \text{POWR} &= \text{Total power to aerators} = 0.75 \text{ hp/1,000 ft}^3 \text{ (V)} \\
 O_t &= \text{Oxygen transfer correction factor} = 0.83 \\
 Va_v &= \text{Turbulent surface area} = 0.24 \text{ (A)} \\
 d &= \text{Impeller diameter} = 61 \text{ cm} \\
 d^* &= \text{Impeller diameter} = 2 \text{ ft} \\
 w &= \text{Rotational speed of impeller} = 126 \text{ rad/s} \\
 N_1 &= \text{Number of aerators} = \text{POWR}/75 \text{ hp}
 \end{aligned}$$

IV. Pollutant Physical Property Data, And Water, Air and Other Properties – For each pollutant, the specific physical properties needed by this model are listed in Table 5.B-4. Water, air, and other property values are given in Table 5.B-2.

A. Benzene (from Table 5.B-4)

$$\begin{aligned} D_{w,\text{benzene}} &= \text{Diffusivity of benzene in water} = 9.8 \times 10^{-6} \text{ cm}^2/\text{s} \\ D_{a,\text{benzene}} &= \text{Diffusivity of benzene in air} = 0.088 \text{ cm}^2/\text{s} \\ H_{\text{benzene}} &= \text{Henry's Law constant for benzene} = 0.0055 \text{ atm} \cdot \text{m}^3/\text{gmol} \\ K_{\text{max},\text{benzene}} &= \text{Maximum biorate constant for benzene} = 5.28 \times 10^{-6} \text{ g/g} \cdot \text{s} \\ K_{s,\text{benzene}} &= \text{Half saturation biorate constant for benzene} = 13.6 \text{ g/m}^3 \end{aligned}$$

B. Water, Air, and Other Properties (from Table 5.B-2)

$$\begin{aligned} \rho_a &= \text{Density of air} = 1.2 \times 10^3 \text{ g/cm}^3 \\ \rho_L &= \text{Density of water} = 1 \text{ g/cm}^3 (62.4 \text{ lb}_m/\text{ft}^3) \\ \mu_a &= \text{Viscosity of air} = 1.81 \times 10^{-4} \text{ g/cm} \cdot \text{s} \\ D_{\text{O}_2,w} &= \text{Diffusivity of oxygen in water} = 2.4 \times 10^{-5} \text{ cm}^2/\text{s} \\ D_{\text{ether}} &= \text{Diffusivity of ether in water} = 8.5 \times 10^{-6} \text{ cm}^2/\text{s} \\ MW_L &= \text{Molecular weight of water} = 18 \text{ g/gmol} \\ MW_a &= \text{Molecular weight of air} = 29 \text{ g/gmol} \\ g_c &= \text{Gravitation constant} = 32.17 \text{ lb}_m \cdot \text{ft}/\text{lb}_f \cdot \text{s}^2 \\ R &= \text{Universal gas constant} = 8.21 \times 10^{-5} \text{ atm} \cdot \text{m}^3/\text{gmol} \end{aligned}$$

V. Calculate Individual Mass Transfer Coefficients – Because part of the impoundment is turbulent and part is quiescent, individual mass transfer coefficients are determined for both turbulent and quiescent areas of the surface impoundment.

Turbulent area of impoundment – Equations 3 and 4 from Table 5.B-1.

A. Calculate the individual liquid mass transfer coefficient,  $k_L$ :

$$k_L (\text{m/s}) = [(8.22 \times 10^{-9})(J)(\text{POWR})(1.024)^{(T-20)} * (O_i)(10^6)MW_L / (V_a \rho_L)](D_w/D_{\text{O}_2,w})^{0.5}$$

The total power to the aerators, POWR, and the turbulent surface area,  $V_a$ , are calculated separately [Note: some conversions are necessary.]:

1. Calculate total power to aerators, POWR (Default presented in III):

$$\begin{aligned} \text{POWR (hp)} &= 0.75 \text{ hp}/1,000 \text{ ft}^3 (V) \\ V &= \text{wastewater volume, m}^3 \\ V (\text{m}^3) &= (A)(D) = (17,652 \text{ m}^2)(1.97 \text{ m}) \\ V &= 34,774 \text{ m}^3 \\ \text{POWR} &= (0.75 \text{ hp}/1,000 \text{ ft}^3)(\text{ft}^3/0.028317 \text{ m}^3)(34,774 \text{ m}^3) \\ &= 921 \text{ hp} \end{aligned}$$

2. Calculate turbulent surface area,  $Va_v$  (default presented in III):

$$\begin{aligned} Va_v \text{ (ft}^2\text{)} &= 0.24 \text{ (A)} \\ &= 0.24(17,652 \text{ m}^2)(10.758 \text{ ft}^2/\text{m}^2) \\ &= 45,576 \text{ ft}^2 \end{aligned}$$

Now, calculate  $k_t$ , using the above calculations and information from II, III, and IV:

$$\begin{aligned} k_t \text{ (m/s)} &= [(8.22 \times 10^{-9})(3 \text{ lb O}_2/\text{hp-hr})(921 \text{ hp}) * \\ &\quad (1.024)^{(25-20)}(0.83)(10^6)(18 \text{ g/gmol})/ \\ &\quad ((45,576 \text{ ft}^2)(1 \text{ g/cm}^3))] * \\ &\quad [(9.8 \times 10^{-6} \text{ cm}^2/\text{s})/(2.4 \times 10^{-5} \text{ cm}^2/\text{s})]^{0.5} \\ &= (0.00838)(0.639) \\ k_t &= 5.35 \times 10^{-3} \text{ m/s} \end{aligned}$$

- B. Calculate the individual gas phase mass transfer coefficient,  $k_g$ :

$$k_g \text{ (m/s)} = (1.35 \times 10^{-7})(\text{Re})^{1.42}(\text{P})^{0.4}(\text{Sc}_G)^{0.5}(\text{Fr})^{-0.21}(\text{D}_a \text{ MW}_a/d)$$

The Reynolds number, Re, power number, P, Schmidt number on the gas side,  $\text{Sc}_G$ , and Froude's number, Fr, are calculated separately:

1. Calculate Reynolds number, Re:

$$\begin{aligned} \text{Re} &= d^2 w \rho_a / \mu_a \\ &= (61 \text{ cm})^2 (126 \text{ rad/s})(1.2 \times 10^{-3} \text{ g/cm}^3) / (1.81 \times 10^{-4} \text{ g/cm-s}) \\ &= 3.1 \times 10^6 \end{aligned}$$

2. Calculate power number, P:

$$\begin{aligned} P &= [(0.85)(\text{POWER})(550 \text{ ft-lb}_f/\text{s-hp})/N_l] g_c / (\rho_L (d^*)^5 w^3) \\ N_l &= \text{POWER}/75 \text{ hp (default presented in III)} \\ P &= (0.85)(75 \text{ hp})(\text{POWER}/\text{POWER})(550 \text{ ft-lb}_f/\text{s-hp}) * \\ &\quad (32.17 \text{ lb}_m\text{-ft/lb}_f\text{-s}^2) / [(62.4 \text{ lb}_m/\text{ft}^3)(2 \text{ ft})^5 (126 \text{ rad/s})^3] \\ &= 2.8 \times 10^{-4} \end{aligned}$$

3. Calculate Schmidt number on the gas side,  $\text{Sc}_G$ :

$$\begin{aligned} \text{Sc}_G &= \mu_a / (\rho_a D_a) \\ &= (1.81 \times 10^{-4} \text{ g/cm-s}) / [(1.2 \times 10^{-3} \text{ g/cm}^3)(0.088 \text{ cm}^2/\text{s})] \\ &= 1.71 \end{aligned}$$

4. Calculate Froude number,  $Fr$ :

$$\begin{aligned} Fr &= (d^*)w^2/g_c \\ &= (2 \text{ ft})(126 \text{ rad/s})^2/(32.17 \text{ lb}_m\text{-ft/lb}_f\text{-s}^2) \\ &= 990 \end{aligned}$$

Now, calculate  $k_g$  using the above calculations and information from II, III, and IV:

$$\begin{aligned} k_g \text{ (m/s)} &= (1.35 \times 10^{-7})(3.1 \times 10^6)^{1.42}(2.8 \times 10^{-4})^{0.4}(1.71)^{0.5} * \\ &\quad (990)^{-0.21}(0.088 \text{ cm}^2/\text{s})(29 \text{ g/gmol})/(61 \text{ cm}) \\ &= 0.109 \text{ m/s} \end{aligned}$$

Quiescent surface area of impoundment – Equations 1 and 2 from Table 5.B-1.

A. Calculate the individual liquid phase mass transfer coefficient,  $k_L$ :

$$\begin{aligned} F/D &= 2(A/\pi)^{0.5}/D \\ &= 2(17,652 \text{ m}^2/\pi)^{0.5}/(1.97 \text{ m}) \\ &= 76.1 \end{aligned}$$

$$U_{10} = 4.47 \text{ m/s}$$

For  $U_{10} > 3.25 \text{ m/s}$  and  $F/D > 51.2$  use the following:

$$\begin{aligned} k_L \text{ (m/s)} &= (2.61 \times 10^{-7})(U_{10})^2(D_w/D_{\text{ether}})^{2/3} \\ &= (2.61 \times 10^{-7})(4.47 \text{ m/s})^2[(9.8 \times 10^{-6} \text{ cm}^2/\text{s})/ \\ &\quad (8.5 \times 10^{-6} \text{ cm}^2/\text{s})]^{2/3} \\ &= 5.74 \times 10^{-6} \text{ m/s} \end{aligned}$$

B. Calculate the individual gas phase mass transfer coefficient,  $k_g$ :

$$k_g = (4.82 \times 10^{-3})(U_{10})^{0.78}(Sc_G)^{-0.67}(d_e)^{-0.11}$$

The Schmidt number on the gas side,  $Sc_G$ , and the effective diameter,  $d_e$ , are calculated separately:

1. Calculate the Schmidt number on the gas side,  $Sc_G$ :

$$Sc_G = \mu_a/(\rho_a D_a) = 1.71 \text{ (same as for turbulent impoundments)}$$

2. Calculate the effective diameter,  $d_e$ :

$$\begin{aligned}
 d_e \text{ (m)} &= 2(A/\pi)^{0.5} \\
 &= 2(17,652 \text{ m}^2/\pi)^{0.5} \\
 &= 149.9 \text{ m} \\
 k_g \text{ (m/s)} &= (4.82 \times 10^{-3})(4.47 \text{ m/s})^{0.78} (1.71)^{-0.67} (149.9 \text{ m})^{-0.11} \\
 &= 6.24 \times 10^{-3} \text{ m/s}
 \end{aligned}$$

- VI. Calculate The Overall Mass Transfer Coefficient – Because part of the impoundment is turbulent and part is quiescent, the overall mass transfer coefficient is determined as an area-weighted average of the turbulent and quiescent overall mass transfer coefficients. (Equation 7 from Table 5.B-1).

Overall mass transfer coefficient for the turbulent surface area of impoundment,  $K_T$

$$\begin{aligned}
 K_T \text{ (m/s)} &= (k_t K_{eq} k_g) / (K_{eq} k_g + k_t) \\
 K_{eq} &= H/RT \\
 &= (0.0055 \text{ atm-m}^3/\text{gmol}) / [(8.21 \times 10^{-5} \text{ atm-m}^3/\text{gmol-}^\circ\text{K})(298^\circ\text{K})] \\
 &= 0.225 \\
 K_T \text{ (m/s)} &= (5.35 \times 10^{-3} \text{ m/s})(0.225)(0.109) / [(0.109 \text{ m/s})(0.225) + (5.35 \times 10^{-6} \text{ m/s})] \\
 K_T &= 4.39 \times 10^{-3} \text{ m/s}
 \end{aligned}$$

Overall mass transfer coefficient for the quiescent surface area of impoundment,  $K_Q$

$$\begin{aligned}
 K_Q \text{ (m/s)} &= (k_t K_{eq} k_g) / (K_{eq} k_g + k_t) \\
 &= (5.74 \times 10^{-6} \text{ m/s})(0.225)(6.24 \times 10^{-3} \text{ m/s}) / \\
 &\quad [(6.24 \times 10^{-3} \text{ m/s})(0.225) + (5.74 \times 10^{-6} \text{ m/s})] \\
 &= 5.72 \times 10^{-6} \text{ m/s}
 \end{aligned}$$

Overall mass transfer coefficient,  $K$ , weighted by turbulent and quiescent surface areas,  $A_T$  and  $A_Q$

$$\begin{aligned}
 K \text{ (m/s)} &= (K_T A_T + K_Q A_Q) / A \\
 A_T &= 0.24(A) \text{ (Default value presented in III: } A_T = V a_v) \\
 A_Q &= (1 - 0.24)A \\
 K \text{ (m/s)} &= [(4.39 \times 10^{-3} \text{ m/s})(0.24 A) + (5.72 \times 10^{-6} \text{ m/s})(1 - 0.24)A] / A \\
 &= 1.06 \times 10^{-3} \text{ m/s}
 \end{aligned}$$

VII. Calculate VOC Emissions For An Aerated Biological Flowthrough Impoundment – Equation 16 from Table 5.B-1:

$$N \text{ (g/s)} = K C_L A$$

where:

$$C_L \text{ (g/m}^3\text{)} = [-b + (b^2 - 4ac)^{0.5}]/(2a)$$

and:

$$a = KA/Q + 1$$

$$b = K_s(KA/Q + 1) + K_{max} b_i V/Q - C_o$$

$$c = -K_s C_o$$

Calculate a, b, c, and the concentration of benzene in the liquid phase,  $C_L$ , separately:

1. Calculate a:

$$\begin{aligned} a &= (KA/Q + 1) = [(1.06 \times 10^{-3} \text{ m/s})(17,652 \text{ m}^2)/(0.0623 \text{ m}^3/\text{s})] + 1 \\ &= 301.3 \end{aligned}$$

2. Calculate b ( $V = 34,774 \text{ m}^3$  from IV):

$$\begin{aligned} b &= K_s (KA/Q + 1) + K_{max} b_i V/Q - C_o \\ &= (13.6 \text{ g/m}^3)[(1.06 \times 10^{-3} \text{ m/s})(17,652 \text{ m}^2)/(0.0623 \text{ m}^3/\text{s})] + \\ &\quad [(5.28 \times 10^{-6} \text{ g/g-s})(300 \text{ g/m}^3)(34,774 \text{ m}^3)/(0.0623 \text{ m}^3/\text{s})] - 10.29 \text{ g/m} \\ &= 4,084.6 + 884.1 - 10.29 \\ &= 4,958.46 \text{ g/m}^3 \end{aligned}$$

3. Calculate c:

$$\begin{aligned} c &= -K_s C_o \\ &= -(13.6 \text{ g/m}^3)(10.29 \text{ g/m}^3) \\ &= -139.94 \end{aligned}$$

4. Calculate the concentration of benzene in the liquid phase,  $C_L$ , from a, b, and c above:

$$\begin{aligned} C_L \text{ (g/m}^3\text{)} &= [-b + (b^2 - 4ac)^{0.5}]/(2a) \\ &= [(4,958.46 \text{ g/m}^3) + [(4,958.46 \text{ g/m}^3)^2 - \\ &\quad [4(301.3)(-139.94)]]^{0.5}]/(2(301.3)) \\ &= 0.0282 \text{ g/m}^3 \end{aligned}$$

Now calculate N with the above calculations and information from II and V:

$$\begin{aligned} N \text{ (g/s)} &= K A C_L \\ &= (1.06 \times 10^{-3} \text{ m/s})(17,652 \text{ m}^2)(0.0282 \text{ g/m}^3) \\ &= 0.52 \text{ g/s} \end{aligned}$$

## GLOSSARY OF TERMS

- Basin** - an earthen or concrete-lined depression used to hold liquid.
- Completely mixed** - having the same characteristics and quality throughout or at all times.
- Disposal** - the act of permanent storage. Flow of liquid into, but not out of a device.
- Drain** - a device used for the collection of liquid. It may be open to the atmosphere or be equipped with a seal to prevent emissions of vapors.
- Flowthrough** - having a continuous flow into and out of a device.
- Plug flow** - having characteristics and quality not uniform throughout. These will change in the direction the fluid flows, but not perpendicular to the direction of flow (i.e., no axial movement).
- Storage** - any device to accept and retain a fluid for the purpose of future discharge. Discontinuity of flow of liquid into and out of a device.
- Treatment** - the act of improving fluid properties by physical means. The removal of undesirable impurities from a fluid.



VOC -

volatile organic compounds, referring to all organic compounds except the following, which have been shown not to be photochemically reactive: methane, ethane, trichlorotrifluoroethane, methylene chloride, 1,1,1-trichloroethane, trichlorofluoromethane, dichlorodifluoromethane, chlorodifluoromethane, trifluoromethane, dichlorotetrafluoroethane, and chloropentafluoroethane.

TABLE 5.B-4  
SIMS CHEMICAL PROPERTY DATA FILE (PART 1)

3/12/97

CHAPTER 5 - WWCT

Chemical Name	CAS Number	Molecular Weight	Vapor Pressure At 25°C (mm Hg)	Henry's Law Constant At 25°C (atm·m <sup>3</sup> /mol)	Diffusivity Of Chemical In Water At 25°C (cm <sup>2</sup> /s)	Diffusivity Of Chemical In Air At 25°C (cm <sup>2</sup> /s)
ACETALDEHYDE	75-07-0	44.00	760	0.000095	0.0000141	0.124
ACETIC ACID	64-19-7	60.05	15.4	0.0627	0.000012	0.113
ACETIC ANHYDRIDE	108-24-7	102.09	5.29	0.00000591	0.00000933	0.235
ACETONE	67-64-1	58.00	266	0.000025	0.0000114	0.124
ACETONITRILE	75-05-8	41.03	90	0.0000058	0.0000166	0.128
ACROLEIN	107-02-8	56.10	244.2	0.0000566	0.0000122	0.105
ACRYLAMIDE	79-06-1	71.09	0.012	0.00000000052	0.0000106	0.097
ACRYLIC ACID	79-10-7	72.10	5.2	0.0000001	0.0000106	0.098
ACRYLONITRILE	107-13-1	53.10	114	0.000088	0.0000134	0.122
ADIPIC ACID	124-04-9	146.14	0.0000225	0.00000000005	0.00000684	0.0659
ALLYL ALCOHOL	107-18-6	58.10	23.3	0.000018	0.0000114	0.114
AMINOPHENOL(-O)	95-55-6	109.12	0.511	0.00000367	0.00000864	0.0774
AMINOPHENOL(-P)	123-30-8	109.12	0.893	0.0000197	0.00000239	0.0774
AMMONIA	7664-41-7	17.03	7470	0.000328	0.0000693	0.259
AMYL ACETATE(-N)	628-37-8	130.18	5.42	0.000464	0.0000012	0.064
ANILINE	62-53-3	93.10	1	0.0000026	0.0000083	0.07
BENZENE	71-43-2	78.10	95.2	0.0055	0.0000098	0.088
BENZO(A)ANTHRACENE	56-55-3	228.30	0.00000015	0.00000000138	0.000009	0.051
BENZO(A)PYRENE	50-32-8	252.30	0.00568	0.00000000138	0.000009	0.043

TABLE 5.B-4 (PART 1)  
(CONTINUED)

Chemical Name	CAS Number	Molecular Weight	Vapor Pressure At 25°C (mm Hg)	Henry's Law Constant At 25°C (atm·m <sup>3</sup> /mol)	Diffusivity Of Chemical In Water At 25°C (cm <sup>2</sup> /s)	Diffusivity Of Chemical In Air At 25°C (cm <sup>2</sup> /s)
CRESYLIC ACID	1319-77-3	108.00	0.3	0.0000017	0.0000083	0.074
CROTONALDEHYDE	4170-30-0	70.09	30	0.00000154	0.0000102	0.0903
CUMENE (ISOPROPYLBENZENE)	98-82-8	120.20	4.6	0.0146	0.0000071	0.065
CYCLOHEXANE	110-82-7	84.20	100	0.0137	0.0000091	0.0839
CYCLOHEXANOL	108-93-0	100.20	1.22	0.00000447	0.00000831	0.214
CYCLOHEXANONE	108-94-1	98.20	4.8	0.00000413	0.00000862	0.0784
DI-N-OCTYL PHTHALATE	117-84-0	390.62	0	0.137	0.0000041	0.0409
DIBUTYLPHTHALATE	84-74-2	278.30	0.00001	0.00000028	0.0000079	0.0438
DICHLORO(-2)BUTENE(1,4)	764-41-0	125.00	2.87	0.000259	0.00000812	0.0725
DICHLOROBENZENE(1,2) (-O)	95-50-1	147.00	1.5	0.00194	0.0000079	0.069
DICHLOROBENZENE(1,3) (-M)	541-73-1	147.00	2.28	0.00361	0.0000079	0.069
DICHLOROBENZENE(1,4) (-P)	106-46-7	147.00	1.2	0.0016	0.0000079	0.069
DICHLORODIFLUOROMETHANE	75-71-8	120.92	5000	0.401	0.00001	0.0001
DICHLOROETHANE(1,1)	75-34-3	99.00	234	0.00554	0.0000105	0.0914
DICHLOROETHANE(1,2)	107-06-2	99.00	80	0.0012	0.0000099	0.104
DICHLOROETHYLENE(1,2)	156-54-2	96.94	200	0.0319	0.000011	0.0935
DICHLOROPHENOL(2,4)	120-83-2	163.01	0.1	0.0000048	0.0000076	0.0709
DICHLOROPHENOXYACETIC ACID(2,4)	94-75-7	221.00	290	0.0621	0.00000649	0.0588
DICHLOROPROPANE(1,2)	78-87-5	112.99	40	0.0023	0.0000087	0.0782

TABLE B-4 (PART 1)  
(CONTINUED)

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Chemical Name	CAS Number	Molecular Weight	Vapor Pressure At 25°C (mm Hg)	Henry's Law Constant At 25°C (atm·m <sup>3</sup> /mol)	Diffusivity Of Chemical In Water At 25°C (cm <sup>2</sup> /s)	Diffusivity Of Chemical In Air At 25°C (cm <sup>2</sup> /s)
DIETHYL (N,N) ANILINE	91-66-7	149.23	0.00283	0.0000000574	0.00000587	0.0513
DIETHYL PHTHALATE	84-66-2	222.00	0.003589	0.0111	0.0000058	0.0542
DIMETHYL FORMAMIDE	68-12-2	73.09	4	0.0000192	0.0000103	0.0939
DIMETHYL HYDRAZINE(1,1)	57-14-7	60.10	157	0.000124	0.0000109	0.106
DIMETHYL PHTHALATE	131-11-3	194.20	0.000187	0.00000215	0.0000063	0.0568
DIMETHYLBENZ(A)ANTHRACENE	57-97-6	256.33	0	0.00000000027	0.00000498	0.0461
DIMETHYLPHENOL(2,4)	105-67-9	122.16	0.0573	0.000921	0.0000084	0.0712
DINITROBENZENE (-M)	99-65-0	168.10	0.05	0.000022	0.00000764	0.279
DINITROTOLUENE(2,4)	121-14-2	182.10	0.0051	0.00000407	0.00000706	0.203
DIOXANE(1,4)	123-91-1	88.20	37	0.0000231	0.0000102	0.229
DIOXIN	NOCAS2	322.00	0	0.0000812	0.0000056	0.104
DIPHENYLAMINE	122-39-4	169.20	0.00375	0.00000278	0.00000631	0.058
EPICHLOROHYDRIN	106-89-8	92.50	17	0.0000323	0.0000098	0.086
ETHANOL	64-17-5	46.10	50	0.0000303	0.000013	0.123
ETHANOLAMINE(MONO-)	141-43-5	61.09	0.4	0.000000322	0.0000114	0.107
ETHYL ACRYLATE	140-88-5	100.00	40	0.00035	0.0000086	0.077
ETHYL CHLORIDE	75-00-3	64.52	1200	0.014	0.0000115	0.271
ETHYL-(2)PROPYL-(3) ACROLEIN	645-62-5	92.50	17	0.0000323	0.0000098	0.086
ETHYLACETATE	141-78-6	88.10	100	0.000128	0.00000966	0.0732

**TABLE 5.B-4 (PART 1)**  
**(CONTINUED)**

Chemical Name	CAS Number	Molecular Weight	Vapor Pressure At 25°C (mm Hg)	Henry's Law Constant At 25°C (atm·m <sup>3</sup> /mol)	Diffusivity Of Chemical In Water At 25°C (cm <sup>2</sup> /s)	Diffusivity Of Chemical In Air At 25°C (cm <sup>2</sup> /s)
ETHYLBENZENE	100-41-4	106.20	10	0.00644	0.0000078	0.075
ETHYLENEOXIDE	75-21-8	44.00	1250	0.000142	0.0000145	0.104
ETHYLETHER	60-29-7	74.10	520	0.00068	0.0000093	0.074
FORMALDEHYDE	50-00-0	30.00	3500	0.0000576	0.0000198	0.178
FORMIC ACID	64-18-6	46.00	42	0.0000007	0.00000137	0.079
FREONS	NOCAS3	120.92	5000	0.401	0.00001	0.104
FURAN	110-00-9	68.08	596	0.00534	0.0000122	0.104
FURFURAL	96-01-1	96.09	2	0.0000811	0.0000104	0.0872
HEPTANE (ISO)	142-82-5	100.21	66	1.836	0.00000711	0.187
HEXACHLOROBENZENE	118-74-1	284.80	1	0.00068	0.00000591	0.0542
HEXACHLOROBUTADIENE	87-68-3	260.80	0.15	0.0256	0.0000062	0.0561
HEXACHLOROCYCLOPENTADIENE	77-47-4	272.80	0.081	0.016	0.00000616	0.0561
HEXACHLOROETHANE	67-72-1	237.00	0.65	0.00000249	0.0000068	0.00249
HEXANE(-N)	100-54-3	86.20	150	0.122	0.00000777	0.2
HEXANOL(-1)	111-27-3	102.18	0.812	0.0000182	0.00000753	0.059
HYDROCYANIC ACID	74-90-8	27.00	726	0.000000465	0.0000182	0.197
HYDROFLUORIC ACID	7664-39-3	20.00	900	0.000237	0.000033	0.388
HYDROGEN SULFIDE	7783-06-4	34.10	15200	0.023	0.0000161	0.176
ISOPHORONE	78-59-1	138.21	0.439	0.00000576	0.00000676	0.0623

TABLE 5.B-4 (PART 1)  
(CONTINUED)

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Chemical Name	CAS Number	Molecular Weight	Vapor Pressure At 25°C (mm Hg)	Henry's Law Constant At 25°C (atm·m <sup>3</sup> /mol)	Diffusivity Of Chemical In Water At 25°C (cm <sup>2</sup> /s)	Diffusivity Of Chemical In Air At 25°C (cm <sup>2</sup> /s)
METHANOL	67-56-1	32.00	114	0.0000027	0.0000164	0.15
METHYL ACETATE	79-20-9	74.10	235	0.000102	0.00001	0.104
METHYL CHLORIDE	74-87-3	50.50	3830	0.00814	0.0000065	0.126
METHYL ETHYL KETONE	78-93-3	72.10	100	0.0000435	0.0000098	0.0808
METHYL ISOBUTYL KETONE	108-10-1	100.20	15.7	0.0000495	0.0000078	0.075
METHYL METHACRYLATE	80-62-6	100.10	39	0.000066	0.0000086	0.077
METHYL STYRENE (ALPHA)	98-83-9	118.00	0.076	0.00591	0.0000114	0.264
METHYLENE CHLORIDE	75-09-2	85.00	438	0.00319	0.0000117	0.101
MORPHOLINE	110-91-8	87.12	10	0.0000573	0.0000096	0.091
NAPHTHALENE	91-20-3	128.20	0.23	0.00118	0.0000075	0.059
NITROANILINE(-O)	88-74-4	138.14	0.003	0.0000005	0.000008	0.073
NITROBENZENE	98-95-3	123.10	0.3	0.0000131	0.0000086	0.076
PENTACHLOROBENZENE	608-93-5	250.34	0.0046	0.0073	0.0000063	0.057
PENTACHLOROETHANE	76-01-7	202.30	4.4	0.021	0.0000073	0.066
PENTACHLOROPHENOL	87-86-5	266.40	0.00099	0.0000028	0.0000061	0.056
PHENOL	108-95-2	94.10	0.34	0.000000454	0.0000091	0.082
PHOSGENE	75-44-5	98.92	1390	0.171	0.00000112	0.108
PHTHALIC ACID	100-21-0	166.14	121	0.0132	0.0000068	0.064
PHTHALIC ANHYDRIDE	85-44-9	148.10	0.0015	0.0000009	0.0000086	0.071

**TABLE 5.B-4 (PART 1)**  
**(CONTINUED)**

Chemical Name	CAS Number	Molecular Weight	Vapor Pressure At 25°C (mm Hg)	Henry's Law Constant At 25°C (atm·m <sup>3</sup> /mol)	Diffusivity Of Chemical In Water At 25°C (cm <sup>2</sup> /s)	Diffusivity Of Chemical In Air At 25°C (cm <sup>2</sup> /s)
PICOLINE(-2)	108-99-6	93.12	10.4	0.000127	0.0000096	0.075
POLYCHLORINATED BIPHENYLS	1336-36-3	290.00	0.00185	0.0004	0.00001	0.104
PROPANOL (ISO)	71-23-8	60.09	42.8	0.00015	0.0000104	0.098
PROPIONALDEHYDE	123-38-6	58.08	300	0.00115	0.0000114	0.102
PROPYLENE GLYCOL	57-55-6	76.11	0.3	0.0000015	0.0000102	0.093
PROPYLENE OXIDE	75-66-9	58.10	525	0.00134	0.00001	0.104
PYRIDINE	110-86-1	79.10	20	0.0000236	0.0000076	0.091
RESORCINOL	108-46-3	110.11	0.00026	0.0000000188	0.0000087	0.078
STYRENE	100-42-5	104.20	7.3	0.00261	0.000008	0.071
TETRACHLOROETHANE(1,1,1,2)	630-20-6	167.85	6.5	0.002	0.0000079	0.071
TETRACHLOROETHANE(1,1,2,2)	79-34-5	167.85	6.5	0.00038	0.0000079	0.071
TETRACHLOROETHYLENE	127-18-4	165.83	19	0.029	0.0000082	0.072
TETRAHYDROFURAN	109-99-9	72.12	72.1	0.000049	0.0000105	0.098
TOLUENE	109-88-3	92.40	30	0.00668	0.0000086	0.087
TOLUENE DIISOCYANATE(2,4)	584-84-9	174.16	0.08	0.0000083	0.0000062	0.061
TRICHLORO(1,1,2)TRIFLUOROETHANE	76-13-1	187.38	300	0.435	0.0000082	0.078
TRICHLOROBENZENE(1,2,4)	120-82-1	181.50	0.18	0.00142	0.0000077	0.0676
TRICHLOROBUTANE(1,2,3)	NOCAS5	161.46	4.39	4.66	0.0000072	0.066
TRICHLOROETHANE(1,1,1)	71-55-6	133.40	123	0.00492	0.0000088	0.078

TABLE 5.B-4 (PART II)  
(CONTINUED)

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Chemical Name	CAS Number	Molecular Weight	Vapor Pressure At 25°C (mm Hg)	Henry's Law Constant At 25°C (atm·m <sup>3</sup> /mol)	Diffusivity Of Chemical In Water At 25°C (cm <sup>2</sup> /s)	Diffusivity Of Chemical In Air At 25°C (cm <sup>2</sup> /s)
TRICHLOROETHANE(1,1,2)	79-00-5	133.40	25	0.000742	0.0000088	0.078
TRICHLOROETHYLENE	79-01-6	131.40	75	0.0091	0.0000091	0.079
TRICHLOROFLUOROMETHANE	75-69-4	137.40	796	0.0583	0.0000097	0.087
TRICHLOROPHENOL(2,4,6)	88-06-2	197.46	0.0073	0.0000177	0.0000075	0.0661
TRICHLOROPROPANE(1,1,1)	NOCAS6	147.43	3.1	0.029	0.0000079	0.071
TRICHLOROPROPANE(1,2,3)	96-18-4	147.43	3	0.028	0.0000079	0.071
UREA	57-13-6	60.06	6.69	0.000264	0.0000137	0.122
VINYL ACETATE	108-05-4	86.09	115	0.00062	0.0000092	0.085
VINYL CHLORIDE	75-01-4	62.50	2660	0.086	0.0000123	0.106
VINYLDENE CHLORIDE	75-35-4	97.00	591	0.015	0.0000104	0.09
XYLENE(-M)	1330-20-7	106.17	8	0.0052	0.0000078	0.07
XYLENE(-O)	95-47-6	106.17	7	0.00527	0.00001	0.087



**TABLE 5.B-4**  
**SIMS CHEMICAL PROPERTY DATA FILE (PART 2)**

Chemical Name	Antoine's Equation Vapor Pressure Coefficient A	Antoine's Equation Vapor Pressure Coefficient B	Antoine's Equation Vapor Pressure Coefficient C	Maximum Biodegradation Rate Constant (g/g Biomass-s)	Half Saturation Constant (g/m <sup>3</sup> )	Octanol-Water Partition Coefficient At 25°C
ACETALDEHYDE	8.005	1600.017	291.809	0.0000228944	419.0542	2.69153
ACETIC ACID	7.387	1533.313	222.309	0.0000038889	14.2857	0.48978
ACETIC ANHYDRIDE	7.149	1444.718	199.817	0.0000026944	1.9323	1
ACETONE	7.117	1210.595	229.664	0.0000003611	1.1304	0.57544
ACETONITRILE	7.119	1314.4	230	0.00000425	152.6014	0.45709
ACROLEIN	2.39	0	0	0.0000021667	22.9412	0.81283
ACRYLAMIDE	11.2932	3939.877	273.16	0.00000425	56.2388	6.32182
ACRYLIC ACID	5.652	648.629	154.683	0.0000026944	54.7819	2.04174
ACRYLONITRILE	7.038	1232.53	222.47	0.000005	24	0.12023
ADIPIC ACID	0	0	0	0.0000026944	66.9943	1.20226
ALLYL ALCOHOL	0	0	0	0.0000048872	3.9241	1.47911
AMINOPHENOL(-O)	0	0	0	0.00000425	68.1356	3.81533
AMINOPHENOL(-P)	-3.357	699.157	-331.343	0.00000425	68.1356	3.81533
AMMONIA	7.5547	1002.711	247.885	0.00000425	15.3	1
AMYL ACETATE(-N)	0	0	0	0.0000026944	16.1142	51.10801
ANILINE	7.32	1731.515	206.049	0.0000019722	0.3381	7.94328
BENZENE	6.905	1211.033	220.79	0.0000052778	13.5714	141.25375
BENZO(A)ANTHRACENE	6.9824	2426.6	156.6	0.0000086389	1.7006	407380.2778

TABLE 5.B-4 (PART 2)  
(CONTINUED)

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Chemical Name	Antoine's Equation Vapor Pressure Coefficient A	Antoine's Equation Vapor Pressure Coefficient B	Antoine's Equation Vapor Pressure Coefficient C	Maximum Biodegradation Rate Constant (g/g Biomass-s)	Half Saturation Constant (g/m <sup>3</sup> )	Octanol-Water Partition Coefficient At 25°C
BENZO(A)PYRENE	9.2455	3724.363	273.16	0.0000086389	1.2303	954992.58602
BENZYL CHLORIDE	0	0	0	0.0000049306	17.5674	199.52623
BIS(2-CHLOROETHYL)ETHER	0	0	0	0.0000029889	20.0021	38.01894
BIS(2-CHLOROISOPROPYL)ETHER	0	0	0	0.0000029889	8.3382	380.1894
BIS(2-ETHYLHEXYL)PHTHALATE	0	0	0	0.0000002139	2.2	199526.2315
BROMOFORM	0	0	0	0.0000029889	10.653	199.52623
BROMOMETHANE	0	0	0	0.0000029889	30.4422	12.58925
BUTADIENE-(1,3)	6.849	930.546	238.854	0.0000042534	15.3	74.32347
BUTANOL (ISO)	7.4743	1314.19	186.55	0.0000021667	70.9091	5.62341
BUTANOL-(1)	7.4768	1362.39	178.77	0.0000021667	70.9091	5.62341
BUTYL BENZYL PHTHALATE	0	0	0	0.0000086389	14.1364	60255.95861
CARBON DISULFIDE	6.942	1169.11	241.59	0.0000042534	5.8175	1
CARBON TETRACHLORIDE	6.934	1242.43	230	0.0000004167	1	524.80746
CHLORO-(P)CRESOL-(M)	0	0	0	0.0000029889	5.2902	1258.92541
CHLOROACETALDEHYDE	0	0	0	0.0000029889	49.838	3.4405
CHLOROBENZENE	6.978	1431.05	217.55	0.0000001083	.039	316.22777
CHLOROFORM	6.493	929.44	196.03	0.0000008167	3.7215	91.20108
CHLORONAPHTHALENE-(2)	0	0	0	0.0000029889	2.167	13182.56739

TABLE 5.B-4 (PART 2)  
(CONTINUED)

Chemical Name	Antoine's Equation Vapor Pressure Coefficient A	Antoine's Equation Vapor Pressure Coefficient B	Antoine's Equation Vapor Pressure Coefficient C	Maximum Biodegradation Rate Constant (g/g Biomass-s)	Half Saturation Constant (g/m <sup>3</sup> )	Octanol-Water Partition Coefficient At 25°C
CHLOROPRENE	6.161	783.45	179.7	0.0000029968	6.3412	1
CRESOL(-M)	7.508	1856.36	199.07	0.0000064472	1.3653	93.32543
CRESOL(-O)	6.911	1435.5	165.16	0.0000063278	1.34	95.49926
CRESOL(-P)	7.035	1511.08	161.85	0.0000064472	1.3653	87.09636
CRESYLIC ACID	0	0	0	0.0000041667	15	1
CROTONALDEHYDE	0	0	0	0.0000026944	27.6285	12.36833
CUMENE (ISOPROPYLBENZENE)	6.963	1460.793	207.78	0.0000086458	16.5426	1
CYCLOHEXANE	6.841	1201.53	222.65	0.0000042534	15.3	338.0687
CYCLOHEXANOL	6.255	912.87	109.13	0.0000026944	18.0816	37.74314
CYCLOHEXANONE	7.8492	2137.192	273.16	0.0000031917	41.8921	6.45654
DI-N-OCTYL PHTHALATE	0	0	0	0.000000083	0.02	141253.7
DIBUTYLPHTHALATE	6.639	1744.2	113.59	0.0000001111	0.4	158489.31925
DICHLORO(-2)BUTENE(1,4)	0	0	0	0.0000029889	9.8973	242.1542
DICHLOROBENZENE(1,2) (-O)	0.176	0	0	0.0000006944	4.3103	2398.83292
DICHLOROBENZENE(1,3) (-M)	0	0	0	0.0000017778	2.7826	2398.83292
DICHLOROBENZENE(1,4) (-P)	0.079	0	0	0.0000017778	2.7826	2454.70892
DICHLORODIFLUOROMETHANE	0	0	0	0.0000029889	12.0413	144.54398
DICHLOROETHANE(1,1)	0	0	0	0.0000029889	4.6783	61.6595
DICHLOROETHANE(1,2)	7.025	1272.3	222.9	0.0000005833	2.1429	61.6595

**TABLE 5 B-4 (PART 2)**  
**(CONTINUED)**

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Chemical Name	Antoine's Equation Vapor Pressure Coefficient A	Antoine's Equation Vapor Pressure Coefficient B	Antoine's Equation Vapor Pressure Coefficient C	Maximum Biodegradation Rate Constant (g/g Biomass-s)	Half Saturation Constant (g/m <sup>3</sup> )	Octanol-Water Partition Coefficient At 25°C
DICHLOROETHYLENE(1,2)	6.965	1141.9	231.9	0.0000029889	6.3294	1
DICHLOROPHENOL(2,4)	0	0	0	0.0000069444	7.5758	562.34133
DICHLOROPHENOXYACETIC ACID(2,4)	0	0	0	0.0000029889	14.8934	82.61445
DICHLOROPROPANE(1,2)	6.98	1380.1	22.8	0.0000047222	12.1429	1
DIETHYL (N,N) ANILINE	7.466	1993.57	218.5	0.00000425	27.0047	43.57596
DIETHYL PHTHALATE	0	0	0	0.000000753	1.28	1412.537
DIMETHYL FORMAMIDE	6.928	1400.87	196.43	0.00000425	15.3	1
DIMETHYL HYDRAZINE(1,1)	7.408	1305.91	225.53	0.00000425	15.3	1
DIMETHYL PHTHALATE	4.522	700.31	51.42	0.0000006111	0.7097	74.13102
DIMETHYLBENZ(A)ANTHRACENE	0	0	0	0.0000086389	0.3377	28680056.33087
DIMETHYLPHENOL(2,4)	0	0	0	0.0000029722	2.2766	263.0268
DINITROBENZENE (-M)	4.337	229.2	-137	0.00000425	29.9146	33.28818
DINITROTOLUENE(2,4)	5.798	1118	61.8	0.00000425	19.5233	102.3293
DIOXANE(1,4)	7.431	1554.68	240.34	0.0000026944	24.7001	16.60956
DIOXIN	12.88	6465.5	273	0.0000029968	6.3412	1
DIPHENYLAMINE	0	0	0	0.0000052778	8.4103	1659.58691
EPICHLOROHYDRIN	8.2294	2086.816	273.16	0.0000029968	6.3412	1.07152
ETHANOL	8.321	1718.21	237.52	0.0000024444	9.7778	0.47863
ETHANOLAMINE(MONO-)	7.456	1577.67	173.37	0.00000425	223.0321	0.16865

**TABLE 5.B-4 (PART 2)**  
**(CONTINUED)**

Chemical Name	Antoine's Equation Vapor Pressure Coefficient A	Antoine's Equation Vapor Pressure Coefficient B	Antoine's Equation Vapor Pressure Coefficient C	Maximum Biodegradation Rate Constant (g/g Biomass-s)	Half Saturation Constant (g/m <sup>3</sup> )	Octanol-Water Partition Coefficient At 25°C
ETHYL ACRYLATE	7.9645	1897.011	273.16	0.0000026944	39.4119	4.85667
ETHYL CHLORIDE	6.986	1030.01	238.61	0.0000029889	22.8074	26.91535
ETHYL-(2)PROPYL-(3) ACROLEIN	0	0	0	0.000004425	15.3	1
ETHYLACETATE	7.101	1244.95	217.88	0.0000048833	17.58	1
ETHYLBENZENE	6.975	1424.255	213.21	0.0000018889	3.2381	1412.53754
ETHYLENEOXIDE	7.128	1054.54	237.76	0.0000011667	4.6154	0.50003
ETHYLETHER	6.92	1064.07	228.8	0.0000026944	17.1206	43.57596
FORMALDEHYDE	7.195	970.6	244.1	0.0000013889	20	87.09636
FORMIC ACID	7.581	1699.2	260.7	0.0000026944	6.3412	0.1191
FREONS	0	0	0	0.0000029968	6.3412	1
FURAN	6.975	1060.87	227.74	0.0000026944	14.1936	71.37186
FURFURAL	6.575	1198.7	162.8	0.0000026944	18.0602	37.86047
HEPTANE (ISO)	6.8994	1331.53	212.41	0.0000042534	15.3	1453.372
HEXACHLOROBENZENE	0	0	0	0.0000029889	0.6651	295120.92267
HEXACHLOROBUTADIENE	- 0.824	0	0	0.000003	6.3412	5495.408
HEXACHLOROCYCLOPENTADIENE	0	0	0	0.0000029968	0.3412	9772.372
HEXACHLOROETHANE	0	0	0	0.0000029889	3.3876	4068.32838
HEXANE(-N)	6.876	1171.17	224.41	0.0000042534	15.3	534.0845
HEXANOL(-1)	7.86	1761.26	196.66	0.0000026944	15.2068	59.52851

TABLE 5.B-4 (PART 2)  
(CONTINUED)

Chemical Name	Antoine's Equation Vapor Pressure Coefficient A	Antoine's Equation Vapor Pressure Coefficient B	Antoine's Equation Vapor Pressure Coefficient C	Maximum Biodegradation Rate Constant (g/g Biomass-s)	Half Saturation Constant (g/m <sup>3</sup> )	Octanol-Water Partition Coefficient At 25°C
HYDROCYANIC ACID	7.528	1329.5	260.4	0.0000026944	1.9323	1
HYDROFLUORIC ACID	7.217	1268.37	273.87	0.0000026944	1.9323	1
HYDROGEN SULFIDE	7.614	885.319	250.25	0.0000029889	6.3294	1
ISOPHORONE	0	0	0	0.00000425	25.6087	50.11872
METHANOL	7.897	1474.08	229.13	0.000005	90	0.19953
METHYL ACETATE	7.065	1157.63	219.73	0.0000055194	159.2466	0.81285
METHYL CHLORIDE	7.093	948.58	249.34	0.0000029889	14.855	83.17638
METHYL ETHYL KETONE	6.9742	1209.6	216	0.0000005556	10	1.90546
METHYL ISOBUTYL KETONE	6.672	1168.4	191.9	0.0000002056	1.6383	23.98833
METHYL METHACRYLATE	8.409	2050.5	274.4	0.0000026944	109.2342	0.33221
METHYL STYRENE (ALPHA)	6.923	1486.88	202.4	0.0000008639	11.12438	2907.589
METHYLENE CHLORIDE	7.409	1325.9	252.6	0.0000061111	54.5762	17.78279
MORPHOLINE	7.7181	1745.8	235	0.00000425	291.9847	0.08318
NAPHTHALENE	7.01	1733.71	201.86	0.0000117972	42.47	1
NITROANILINE(-O)	8.868	336.5	273.16	0.00000425	22.8535	67.6083
NITROBENZENE	7.115	1746.6	201.8	0.0000030556	4.7826	69.1831
PENTACHLOROBENZENE	0	0	0	0.0000029889	0.4307	925887.02902
PENTACHLOROETHANE	6.74	1378	197	0.0000029889	0.4307	925887.02902
PENTACHLOROPHENOL	0	0	0	0.0000361111	38.2353	102329.29923

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TABLE 5.B-4 (PART 2)  
(CONTINUED)

Chemical Name	Antoine's Equation Vapor Pressure Coefficient A	Antoine's Equation Vapor Pressure Coefficient B	Antoine's Equation Vapor Pressure Coefficient C	Maximum Biodegradation Rate Constant (g/g Biomass-s)	Half Saturation Constant (g/m <sup>3</sup> )	Octanol-Water Partition Coefficient At 25°C
PHENOL	7.133	1516.79	174.95	0.0000269444	7.4615	28.84032
PHOSGENE	6.842	941.25	230	0.00000425	70.8664	3.4405
PHTHALIC ACID	0	0	0	0.0000026944	34.983	6.64623
PHTHALIC ANHYDRIDE	8.022	2868.5	273.16	0.0000048872	3.9241	0.23988
PICOLINE(-2)	7.032	1415.73	211.63	0.00000425	44.8286	11.48154
POLYCYLORINATED BIPHENYLS	0	0	0	0.000005278	20	1
PROPANOL (ISO)	8.117	1580.92	219.61	0.0000041667	200	0.69183
PROPIONALDEHYDE	16.2315	2659.02	-44.15	0.0000026944	39.2284	4.91668
PROPYLENE GLYCOL	8.2082	2085.9	203.5396	0.0000026944	109.3574	0.33141
PROPYLENE OXIDE	8.2768	1656.884	273.16	0.0000048872	3.9241	1
PYRIDINE	7.041	1374.8	214.98	0.0000097306	146.9139	4.4684
RESORCINOL	6.9243	1884.547	186.0596	0.0000026944	35.6809	6.30957
STYRENE	7.14	1574.51	224.09	0.0000086389	282.7273	1445.43977
TETRACHLOROETHANE(1,1,2)	6.898	1365.88	209.74	0.0000029889	6.3294	1
TETRACHLOROETHANE(1,1,2,2)	6.631	1228.1	179.9	0.0000017222	9.1176	363.07805
TETRACHLOROETHYLENE	6.98	1386.92	217.53	0.0000017222	9.1176	398.10717
TETRAHYDROFURAN	6.995	1202.29	226.25	0.0000026944	20.3702	27.58221
TOLUENE	6.954	1344.8	219.48	0.0000204111	30.6167	489.77882
TOLUENE DIISOCYANATE(2,4)	0	0	0	0.0000425	15.3	1

**TABLE 5.B-4 (PART 2)**  
**(CONTINUED)**

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Chemical Name	Antoine's Equation Vapor Pressure Coefficient A	Antoine's Equation Vapor Pressure Coefficient B	Antoine's Equation Vapor Pressure Coefficient C	Maximum Biodegradation Rate Constant (g/g Biomass-s)	Half Saturation Constant (g/m <sup>3</sup> )	Octanol-Water Partition Coefficient At 25°C
TRICHLORO(1,1,2)TRIFLUOROETHANE	6.88	1099.9	227.5	0.0000029889	3.3876	4068.32838
TRICHLOROBENZENE(1,2,4)	0	0	0	0.0000029889	2.4495	9549.92586
TRICHLOROBUTANE(1,2,3)	0	0	0	0.0000029968	6.3412	1450901.06626
TRICHLOROETHANE(1,1,1)	8.643	2136.6	302.8	0.0000009722	4.7297	309.02954
TRICHLOROETHANE(1,1,2)	6.951	1314.41	209.2	0.0000009722	4.7297	1
TRICHLOROETHYLENE	6.518	1018.6	192.7	0.0000010833	4.4318	194.98446
TRICHLOROFLUOROMETHANE	6.884	1043.004	236.88	0.000003	6.3412	338.8441
TRICHLOROPHENOL(2,4,6)	0	0	0	0.0000425	58.8462	4897.78819
TRICHLOROPROPANE(1,1,1)	0	0	0	0.0000029889	10.7719	193.7827
TRICHLOROPROPANE(1,2,3)	6.903	788.2	243.23	0.0000029889	10.7719	193.7827
UREA	0	0	0	0.00000425	4.8169	4068.32838
VINYL ACETATE	7.21	1296.13	226.66	0.0000026944	31.8363	8.51722
VINYL CHLORIDE	3.425	0	0	0.000003	6.3412	1.14815
VINYLDENE CHLORIDE	6.972	1099.4	237.2	0.0000029968	6.3412	1
XYLENE(-M)	7.009	1426.266	215.11	0.0000086389	14.0094	1584.89319
XYLENE(-O)	6.998	1474.679	213.69	0.0000113306	22.8569	891.25094



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## **APPENDIX C**

# **BIBLIOGRAPHY OF SELECTED AVAILABLE LITERATURE ON EMISSIONS MODELS**

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**TECHNICAL REPORT DATA**

(PLEASE READ INSTRUCTIONS ON THE REVERSE BEFORE COMPLETING)

<b>REPORT NO.</b> PA-454/R-97-004b	<b>2.</b>	<b>3. RECIPIENT'S ACCESSION NO.</b>
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		<b>6. PERFORMING ORGANIZATION CODE</b>
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<b>PERFORMING ORGANIZATION NAME AND ADDRESS</b> U.S. Environmental Protection Agency Office Of Air Quality Planning And Standards (MD-14) Research Triangle Park, NC 27711		<b>10. PROGRAM ELEMENT NO.</b>
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<b>5. SUPPLEMENTARY NOTES</b>		
<b>6. ABSTRACT</b> <p>The Emission Inventory Improvement Program (EIIP) was established in 1993 to promote the development and use of standard procedures for collecting, calculating, storing, reporting, and sharing air emissions data. The EIIP is designed to promote the development of emission inventories that have targeted quality objectives, are cost-effective, and contain reliable and accessible data for end users. To this end, the EIIP is developing inventory guidance and materials which will be available to states and local agencies, the regulated community, the public and the EPA.</p> <p>Volume II presents preferred and alternatives methods for estimating emissions from point sources.</p>		
<b>7. KEY WORDS AND DOCUMENT ANALYSIS</b>		
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