

Note: EPA no longer updates this information,
but it may be useful as a reference or resource.

**INTRODUCTION TO
AIR POLLUTANT EMISSION ESTIMATION TECHNIQUES
FOR INDUSTRY**

FINAL REPORT

**U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Technical Support Division
Emission Inventory Branch
Research Triangle Park, NC 27711**

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1.0 INTRODUCTION

The Clean Air Act, as amended in 1990 (hereafter referred to as "the Clean Air Act"), 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 Clean Air Act is the requirement that the EPA improve the quality of emission estimates of air pollutants released from industry.

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

This introductory document is intended to familiarize the private sector with the basic concepts and procedures involved in estimating air pollutant emissions from industrial processes. This document provides an introduction to air pollutant emission assessment, the basic procedures involved in estimating emissions, industry-specific techniques for estimating emissions, and control devices and their applications to various industries. This document is intended to introduce the basic concepts of emission estimation and to identify applicable information and tools available from government agencies, rather than be a comprehensive manual.

Section 2 identifies several purposes for industry making emissions estimates including federal and state regulations and plant initiatives. Section 3 describes and defines some of the terminology used in air pollutant emission estimates. Section 4 describes the basic techniques employed to estimate emissions, including emission factors, source tests, and material balances. This section also describes data resources available for locating information as well as specific emission factors. Section 5 presents several different estimation scenarios and provides example calculations to aid in actual emission estimation. Section 6 describes some typical industrial processes and emissions. Section 7 describes the control devices commonly used for removing or destroying pollutants emitted from industrial processes. Control devices are described for volatile organic compounds (VOCs), particulates, oxides of nitrogen (NO_x), and hazardous air pollutants (HAPs).

Additional reference information is provided in the Appendices. Appendix A includes a glossary of terms. Appendix B contains a list of the 189 pollutants identified in Section 112(b)

of the Clean Air Act which are to be regulated as HAPs. Appendix C includes the table of contents from *AP-42*, Supplement E. Appendix D provides useful conversion factors from *AP-42*, Supplement E. Appendix E includes various contact and resource information. Appendix F includes the Aerometric Information Retrieval System (AIRS) Control Device Codes and Typical Efficiencies. Appendix G lists source categories for which maximum achievable control technology (MACT) standards will be promulgated. Appendix H lists new source performance standard (NSPS) subparts subject to specific emissions recordkeeping and reporting requirements. Finally, Appendix I lists pollutants regulated under the existing NESHAPs program.

2.0 PURPOSES FOR ASSESSING EMISSIONS

Sources often initiate an emissions estimation effort in order to comply with various federal and state regulations. In addition, they may voluntarily initiate such an effort in order to gain information on improving the efficiency of their processes. This section focuses on the federal requirements for various kinds of industry emissions estimates. Typical state requirements and industry initiatives will also be briefly discussed. Figure 2-1 provides an overview of some of the key emissions estimation relationships among industry, and state and federal agencies.

2.1 FEDERAL REQUIREMENTS

Various federal requirements are linked to emissions estimation requirements. Some of these federal requirements fall on individual sources, but many others fall on the states. In these cases, the individual state must decide what to require of industry. This subsection discusses 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. 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 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. This document does not identify which specific data elements are necessary under each requirement. A good source for these data is EPA's November 1992 document entitled *Integrated Reporting Issues: Preliminary Findings*.¹ Table 2-1 of this document provides an overview of the key federal emissions estimation requirements. In addition, Table 2-2, taken from the Integrated Reporting Issues document, provides an overview of the data elements contained in the four major emissions reporting programs described in this section.

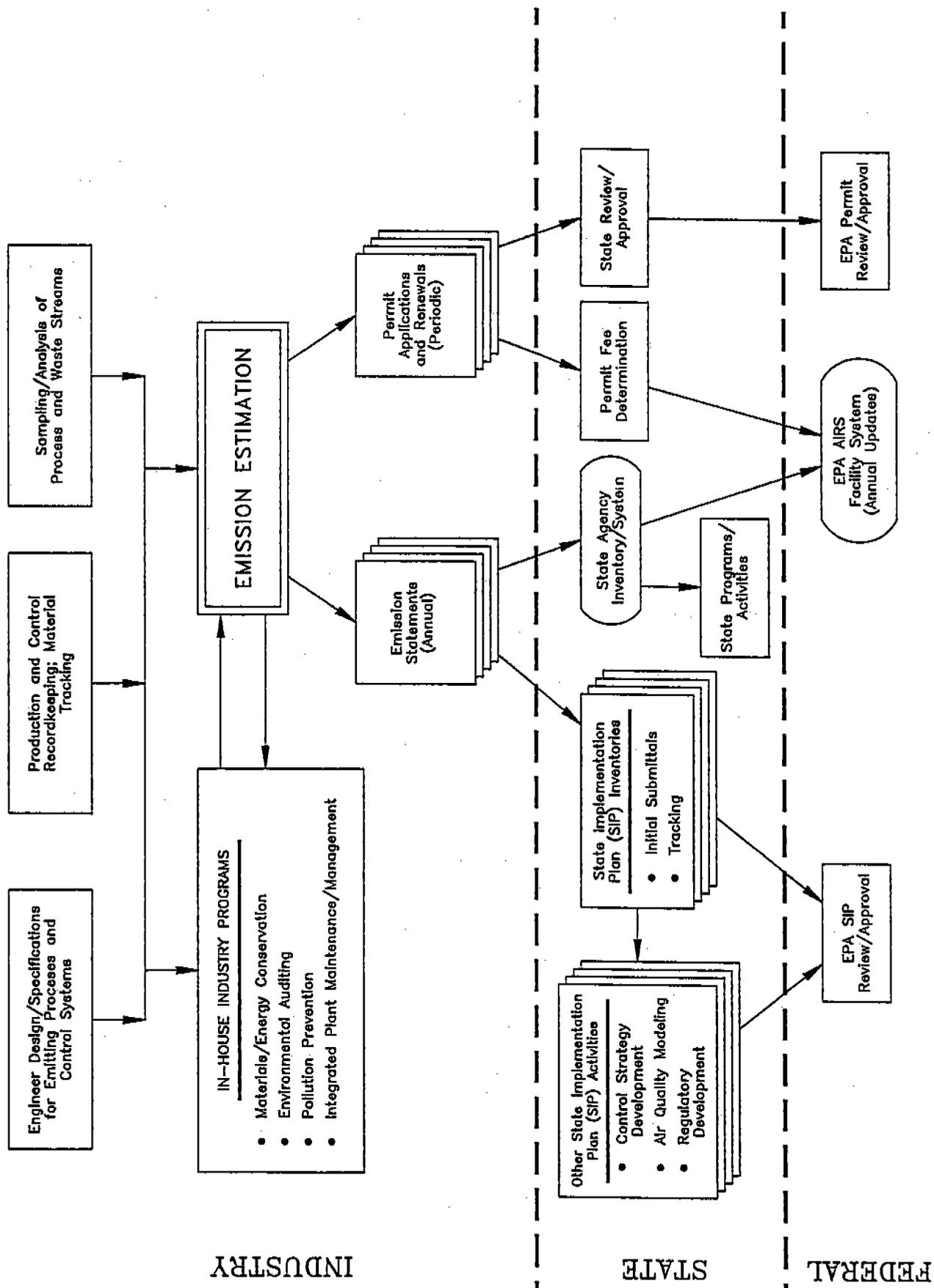


Figure 2-1. Key relationships for industry air pollutant - emission estimation.

TABLE 2-1. OVERVIEW OF KEY FEDERAL EMISSION ESTIMATION REQUIREMENTS

Statutory Requirement	Agency	Pollutant	Due Date	Size Cutoff	Data Requirements	Data System
Annual AIRS Update						
40 CFR 51.321	State to EPA	PM-10, sulfur oxides, VOC, NO _x , CO, and lead	July 1, annually	facility-100 tpy PM-10, sulfur oxides, VOC, and NO _x ; 1000 tpy CO; 5 tpy lead point-25 tpy PM-10, sulfur oxides, VOC, and NO _x ; 250 tpy CO; and 5 tpy lead	general plant information, year of inventory, general operating parameters, emissions data, and control equipment data	AIRS
Emission Inventory (baseyear and periodic)						
Clean Air Act Section 172(c)(3) Section 182(a)(1) ^a Section 182(a)(3)(A) ^a Section 187(a)(1) ^b	State to EPA	all criteria pollutants	November 15, 1992 and every 3 years thereafter	point sources-10 tpy VOC; 100 tpy NO _x and CO; 100 tpy PM-10 moderate; 70 tpy PM-10 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)	AIRS
Emission Statements						
Clean Air Act Section 182(a)(3)(B) ^c	Source to State	VOC, NO _x	April 15, annually	25 tpy VOC or NO _x in nonattainment area; 50 tpy VOC or 100 tpy NO _x 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	State designated System
Title V Operating Permits						
Clean Air Act Title V	Source to State	all criteria pollutants, all HAPs, CFCs, HCFCs	1 year after approval of State permit program; 12 months after operation of a major stationary source	"major" ^{d,e} all NSPS, NESHAP sources	general company information, plant description, emissions information, regulatory requirements and compliance information	AIRS
New Source Review						
Clean Air Act Section 172(c)(5)	Source to State	all criteria pollutants	prior to construction or operation of a new or modified major source	"major" ^d	legal authority, technical specifications, potential emissions, emission compliance demonstration, definition of excess emissions, administrative and other conditions	AIRS

(continued)

TABLE 2-1. OVERVIEW OF KEY FEDERAL EMISSIONS ESTIMATION REQUIREMENTS (Continued)

Statutory Requirement	Agency	Pollutant	Due Date	Size Cutoff	Data Requirements	Data System
Economic Incentive Programs (EIP)						
40 CFR Part 51 (some required, some optional)	Source to State	all criteria pollutants	specific to individual EIP	"major" nd	specific to individual EIP. Emissions must be "quantifiable."	AIRS where applicable
Early Reductions Program						
Clean Air Act Section 112(i)(5)	Source to State	all hazardous pollutants as defined in Section 112(b)	reduction must be achieved before 1/1/94, therefore demonstration must come before then	any stationary source	same as permit with the early reduction demonstration	AIRS, MACT database
Urban Air Toxics Program						
Clean Air Act Section 112(k)	EPA to Congress	all hazardous pollutants as defined in Section 112(b)	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	AIRS, MACT database
Great Lakes and Coastal Waters Program						
Clean Air Act Section 112(m)	EPA to Congress	all hazardous pollutants 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	AIRS, MACT database
Accidental Release Program						
Clean Air Act Section 112(r)	Source to EPA	all hazardous pollutants as defined in Section 112(b)	as specified in 112(r) regulations to be published	Sources emitting amounts above threshold quantities as specified in 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	AIRS, MACT database

(continued)

TABLE 2-1. OVERVIEW OF KEY FEDERAL EMISSIONS ESTIMATION REQUIREMENTS (Continued)

Statutory Requirement	Agency	Pollutant	Due Date	Size Cutoff	Data Requirements	Data System
New Source Performance Standards						
40 CFR Part 60	Source to EPA	SO ₂ , NO _x , total reduced sulfur, hydrogen sulfide, CO, opacity, VOC	30 days after reporting period ends	as specified in standard	pollutant, reporting period, general company information, emission limitation, monitor manufacturer and model number, date of last CMS certification or audit, process units description, total source operating time, emissions data, CMS performance data	AIRS (CMS data)
Acid Rain Allowance Trading (Title IV)						
Title IV Clean Air Act	Source to EPA	SO ₂ , NO _x	30 days after end of quarter (beginning Jan. 30, 1994 for Phase I and Apr. 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)	general plant information, emissions data, fuel use data	National Allowance Database (NADB), Acid Rain Data System (ARDS), Tracking Responses to Acid Rain Compliance (TRAC)
Section 114 General Requirements (i.e., "Section 114 letter")						
Clean Air Act Section 114	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	AIRS
Section 114 Compliance Certification						
Clean Air Act Section 114(a)(3)	Source to EPA	all criteria pollutants and all hazardous air pollutants as defined in Section 112(a)(1)	30 days after quarter ends, on a quarterly or annual basis	"major" nd	general company information, pollutant, emission information, description of enhanced monitoring system, summary of compliance demonstration, deviation description, violation information, and operation data	AIRS

(continued)

TABLE 2-1. OVERVIEW OF KEY FEDERAL EMISSIONS ESTIMATION REQUIREMENTS (Continued)

Statutory Requirement	Agency	Pollutant	Due Date	Size Cutoff	Data Requirements	Data System
National Air Toxics Information Clearinghouse (NATICH)						
Clean Air Act Section 112(j)(3)	State/local agency to EPA	any toxic 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 (see Appendix A for detailed requirements)	NATICH
RACT/BACT/LAER Clearinghouse						
N.A.	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	RACT/BACT/LAER Clearinghouse
NEPA						
PL 91-190	EPA	Anything which may result in a "significant environmental impact"	Prior to implementation of any federal agency action	N.A.	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	N.A.
CERCLA						
PL 96-510, amended SARA 42 U.S.C. Section 9601	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	any release to environment	report on release of the toxic substance, including substance and quantity released. (See SARA Section 304.)	N.A.

(continued)

TABLE 2-1. OVERVIEW OF KEY FEDERAL EMISSIONS ESTIMATION REQUIREMENTS (Continued)

Statutory Requirement	Agency	Pollutant	Due Date	Size Cutoff	Data Requirements	Data System
SARA SARA Section 313 ("right to know")	Source to EPA and States	EPA designated "toxic chemicals" (329 on original list)	July 1, annually	chemicals used $\geq 10,000$ lbs/yr, chemical manufactured or processed $\geq 25,000$ lbs/yr	chemical identity, name, location and principle business identity, certification by senior officials of business, use of each listed chemical, maximum on-site quantity at any time, amount (lbs/yr) released to the environment of each chemical, amount (lbs/yr) transferred off-site, method of waste treatment and disposal including treatment efficiency, release data (fugitive air emissions in lbs/yr, stack/point air emissions in lbs/hr, wastewater discharges, releases to land, transfers to off-site locations, underground injection)	Toxic Release Inventory System (TRIS)
SARA SARA Section 304 (hazardous releases)	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	none
RCRA 40 CFR Subtitle C	Source to EPA	hazardous waste as defined by 40 CFR 261.31, acutely hazardous waste as 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	Biennial Reporting System (BRS)

(continued)

TABLE 2-1. OVERVIEW OF KEY FEDERAL EMISSIONS ESTIMATION REQUIREMENTS (Continued)

Statutory Requirement	Agency	Pollutant	Due Date	Size Cutoff	Data Requirements	Data System
Pollution Prevention Act PL 101-508 Section 6607	Source to EPA	EPA designated "toxic chemicals"	annually	chemicals used \geq 10,000 lbs/yr, chemical manufactured or processed \geq 25,000 lbs/yr	toxic chemical source reduction and recycling report	Pollution Prevention Information Clearinghouse (PPIC) Pollution Prevention Information Exchange System (PIES)

Source: Reference 1.

*for ozone

*for CO

*the periodic inventory requirement is only for ozone nonattainment areas

*definition of major depends on pollutant (e.g., for ozone it depends on an area's classification)

*additional nonmajor sources may be added by EPA rule expected in late 1990's

RACT = Reasonably available control technology

BACT = Best available control technology

LAER = Lowest achievable emissions rate

AIRS = Aerometric Information Retrieval System

NADB = National Allowance Database

ARDS = Acid Rain Data System

TRAC = Tracking Responses to Acid Rain Compliance

TABLE 2-2. COMPARISON OF EMISSIONS REPORTING PROGRAM DATA ELEMENTS

Data Element	Triennial Inventory (State to EPA)	AIRS Annual Update (State to EPA)	Permit Program ^a (Source to State)	Emission Statement (Source to State)
Plant - General Level				
FIPS State Code	✓	✓	✓	✓
FIPS County Code	✓	✓	✓	✓
Year of Record	✓	✓	✓	✓
Plant AFS/NEDS ID	✓	✓	✓	✓
Plant Name	✓	✓		✓
Plant Address	✓	✓	✓	✓
FIPS 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)			✓	
Point - General Level				
FIPS State Code	✓	✓		✓
FIPS County Code	✓	✓		✓
Plant AFS ID	✓	✓		✓
Point AFS ID	✓	✓		✓
Operating hours/day	✓	✓		✓
Operating days/week	✓	✓		✓
Operating hours/year	✓	✓		✓
percent throughput: Dec-Feb	✓	✓		✓
percent throughput: Mar-May	✓	✓		✓

(continued)

TABLE 2-2. COMPARISON OF EMISSIONS REPORTING PROGRAM DATA ELEMENTS (continued)

Data Element	Triennial Inventory (State to EPA)	AIRS Annual Update (State to EPA)	Permit Program^a (Source to State)	Emission Statement (Source to State)
percent throughput: Jun-Aug	✓	✓		✓
percent throughput: Sep-Nov	✓	✓		✓
Stack Level				
FIPS State Code	✓	✓		
FIPS County Code	✓	✓		
Plant AFS ID	✓	✓		
Stack AFS ID	✓	✓		
Stack Height	✓	✓		
Stack Diameter	✓	✓		
Plume Height	✓	✓		
Segment - General Level				
FIPS State Code	✓	✓		✓
FIPS County code	✓	✓		✓
Plant AFS ID	✓	✓		✓
Point AFS ID	✓	✓		✓
Segment AFS ID	✓	✓		✓
SCC Number	✓	✓		✓
Process Rate Units	✓			✓
Actual Annual Process Rate	✓			✓
Ozone Season Daily Process Rate	✓			✓
CO Season Daily Process Rate	✓			
Stack ID for Segment	✓			

(continued)

TABLE 2-2. COMPARISON OF EMISSIONS REPORTING PROGRAM DATA ELEMENTS (continued)

Data Element	Triennial Inventory (State to EPA)	AIRS Annual Update (State to EPA)	Permit Program ^a (Source to State)	Emission Statement (Source to State)
Segment - Pollutant Level				
FIPS State Code	✓	✓	✓	✓
FIPS County Code	✓	✓	✓	✓
Plant AFS ID	✓	✓	✓	✓
Point AFS ID	✓	✓		✓
Segment AFS ID	✓	✓		✓
Pollutant/CAS Code	✓	✓	✓	✓
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	✓	✓		✓
Emission Factor	✓	✓		✓
Annual Nonbanked Emissions (Estimated Actual)	✓	✓		✓
Rule Effectiveness	✓			✓
Ozone Season Daily Emissions	✓			✓
CO Season Daily Emissions	✓			

^aProposed AFS permit enhancements

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). NAAQS set nationwide minimum air quality goals. Each state must assess all areas' air quality relative to the NAAQS. For those areas meeting the standard, the state is required to submit plans showing prevention of significant deterioration (PSD) of the air quality. 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. These legally binding plans are called state implementation plans (SIPs). 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. 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 HAPs, emission and fuel standards for motor vehicles, provisions for control of acid deposition, requirements for operating permit programs, and stratospheric ozone protection.

The proper execution of air quality management principles relies on state and federal access to complete and accurate air pollutant emission data. These data needs form a primary motivation for requiring industry to report emission-related data. Information obtained from point source inventories is used in the development of SIPs for attaining NAAQS and in the design, testing and application of mathematical models for the correlation of air pollutant emissions with ambient air quality. The reporting information typically required for each of these categories is described below. To assure specific data needs are met, the Clean Air Act specifies data collection and reporting requirements, which are also described below.

Annual Point Source Update Section 110 of Title I of the Clean Air Act describes specific requirements of SIPs. Plans must include several specific provisions, including the requirement in Section 110(a)(2)(f)(ii) that, "The plan require, as may be prescribed by the [EPA] Administrator, periodic reports on the nature and amounts of emissions and emissions-related data from such sources." Under this authority, EPA has issued, at Title 40 Part 51.321 of the *Code of Federal Regulations*, a requirement that states report source emissions for the following pollutants: particulate matter less than 10 microns in size (PM-10), VOCs, sulfur oxides (SO_x), NO_x, carbon monoxide (CO), and lead. States must report data for facilities which emit the following amounts of the specified pollutants: 100 tons per year (tpy) or more of PM-10, SO_x, VOC, or NO_x; 1000 tpy or more for CO; and 5 tpy or more for lead. In addition, even if the facility is below one of these cutoffs, states must report data for any individual emissions point at the facility if the point emits the following amounts of the specified pollutants: 25 tpy or more of PM-10, SO_x, VOC, and NO_x; 250 tpy for CO; and 5 tpy for lead. These emissions data are maintained in a national air database called the Aerometric Information Retrieval System (AIRS), which is discussed in more detail in Section 4 of this document.

It should be noted that although AIRS submittals are a reporting requirement for states, this requirement is also likely to lead to mandatory reporting by sources of their individual emissions to the state. Facilities below the emission limits may be considered area sources in most states. States address area source emissions as a group; therefore, detailed data may not be required as for point sources. However, individual states may require a lower cutoff for point sources, and may set other more stringent reporting requirements as well. Specific requirements and reporting formats will vary among states. Information on specific additional emissions inventory requirements is available from the applicable state or local agency.

SIP Base Year and Periodic Emission Inventory (nonattainment areas) Under Section 172(c)(3) of the Clean Air Act, as part of the SIP submitted for any nonattainment area, states are required to include a "comprehensive, accurate, and current" inventory of emissions for any pollutant for which the area is designated as nonattainment. This inventory is called the base year inventory. This same provision also requires states to submit periodic revisions to the inventory as the EPA Administrator determines to be necessary. The EPA has published

guidance on emission inventory requirements for ozone and CO nonattainment areas.^{2,3} Guidance for other pollutants will be published at a later date.

For ozone nonattainment areas, in addition to the general inventory provisions in Section 172(c)(3) of the Clean Air Act, there are some specific inventory provisions contained in Section 182. Section 182(a)(1) requires the state to submit the inventory required in Section 172(c)(3) in accordance with guidance provided by the Administrator. This guidance, entitled *Emission Inventory Requirements for Ozone State Implementation Plans*, specifically requires this inventory to include all sources of VOC, NO_x, and CO.² It also specifies that the estimates should be based on 1990 emissions for these pollutants, and is thus referred to as the 1990 base year inventory. This inventory was due November 15, 1992. The EPA reports that 93 percent of agencies submitted the required SIP inventories by January 15, 1993.⁴

Further specific ozone inventory requirements are found in Section 182(a)(3). This section requires the state to submit a revised inventory for VOC, NO_x, and CO in all ozone nonattainment areas. This inventory is called the periodic inventory, and must be submitted every three years until the area is designated as attainment. The first periodic inventory is due November 15, 1995. Among other things, the periodic inventories are used to monitor reasonable further progress (RFP), which is a regulatory requirement regarding a nonattainment area's progress toward achieving attainment by the applicable date.

For CO nonattainment areas, the general inventory requirements of Section 172(c)(3) apply. A base year inventory for the year 1990 must be developed by November 15, 1992 and periodic inventories are due September 30, 1995 and each three years thereafter. States having moderate CO nonattainment areas with CO concentrations above 12.7 ppm and States having serious CO nonattainment areas will have to develop modeling inventories to demonstrate attainment plans. These requirements are discussed in detail in the guidance document entitled, *Emission Inventory Requirements for Carbon Monoxide State Implementation Plans*.³

Emission Statements (ozone nonattainment areas) Section 182(a)(3)(B) of the Clean Air Act requires states with ozone nonattainment areas to submit SIP revisions requiring emissions statements. These emissions statements require sources to annually report their VOC and NO_x emissions beginning no later than November 1993. Emissions statements are required from sources within the ozone nonattainment area which emit 25 tpy or more of either VOC or NO_x.

Emissions statements are also required from sources which emit more than 50 tpy of VOC or 100 tpy of NO_x and are located in attainment portions of an area designated as an ozone transport region under Section 184 of the Clean Air Act. States may choose not to require emissions statements of sources emitting below the 25 tpy cutoff if they can otherwise account for emissions from these sources.⁵ Requirements for these smaller sources will vary on a state-by-state basis.

The emission statement is a standardized emission report designed to simplify industry reporting requirements for VOC and NO_x emissions. Sources submitting the emissions statement must still meet any other relevant reporting requirements. Data contained in the emissions statement will be used by states to update their required annual point source update and to prepare their SIP periodic emission inventories.^{1,6} Source owners or operators required to submit the annual emissions statement must certify that the information contained in the statement is accurate to the best knowledge of the individual signing the statement. Guidance on the form and content of such a certifying statement is issued by EPA.¹

Operating Permits Program 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 Act. 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 EPA.
- 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 2-3.
- Any source subject to the new source performance standards (NSPS) under Section 111.
- Sources subject to the preconstruction permits requirements of the 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.

**TABLE 2-3. EMISSION CUTOFFS FOR DETERMINING
APPLICABILITY OF TITLE V OPERATING
PERMITS PROGRAM IN NONATTAINMENT AREAS**

	Pollutant	TPY
(i)	ozone (VOC and NO _x)	
	serious nonattainment area	≥50
	transport region not severe or extreme in nonattainment	≥50
	severe nonattainment area	≥25
	extreme nonattainment area	≥10
(ii)	carbon monoxide - serious nonattainment area	≥50
(iii)	particulate matter (PM-10) serious nonattainment area	≥70

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 schedules, as necessary 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. AIRS will have the capabilities to store much of the information contained in applications and permits, as well as information required to be submitted by the permit.

New Source Review Section 172(c)(5) of the Clean Air Act 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 Clean Air Act 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.¹ Once the source begins operation it will be necessary to determine source emissions under design operating conditions in order to demonstrate compliance or non-compliance with the allowable levels of emissions. Sources obtaining permits for new sources often use trading transactions, discussed in the next paragraph, which also require emissions estimations.

Economic Incentive Programs (Including Emissions Trading) The Clean Air Act broadly encourages the use of incentive-based approaches to control air pollution. The Title IV acid rain program (discussed in a later section) and the Title I NAAQS attainment general provisions are two of the areas where incentive-based approaches are used. The Title I provisions encourage, and in certain cases mandate, the use of economic incentive programs (EIP's). These EIP's may be adopted by state agencies (or other appropriate governing bodies) in their SIP's. An EIP is mandated when a state fails to demonstrate mandated progress toward attainment in extreme ozone nonattainment areas. An EIP is also one of three options mandated if a state fails to demonstrate such progress in serious and severe ozone nonattainment areas. In addition, and EIP

is mandated if a state fails to meet specific required emissions reductions milestones, or fails to attain the NAAQS in a serious CO nonattainment area. Finally, discretionary EIP's may be adopted for any criteria pollutant in both nonattainment and attainment areas. The federal requirements for State Economic Incentive Programs were proposed in the *Federal Register* on February 23, 1993.¹

Economic incentive programs may vary widely, and thus, the emissions quantification requirements which result from them may also vary widely. EIP's may include emission fees and marketable permit programs, including emissions trading strategies. These strategies allow for flexibility in meeting several of the Clean Air Act requirements discussed elsewhere in this section. Emission trading strategies may include, but are not limited to, those discussed in EPA's 1986 Emissions Trading Policy Statement.² Examples of emissions trading strategies include emissions rate averaging, plant wide mass emission caps, netting, offsets, and emissions reduction banking. Some kinds of trading are required (e.g., offsets for New Sources) while others are optional (e.g., emission averaging to meet RACT control technology requirements). A detailed discussion of each of these strategies is beyond the scope of this report.

Monitoring, recordkeeping, and reporting requirements play a major role in all economic incentive programs. Any program that is developed by a State as part of their reasonable further progress or attainment demonstration must require that emissions be quantifiable. In addition, transactions under any program must be tracked through a federally enforceable mechanism (e.g., Title V operating permit program. Sources should stay apprised of specific emissions quantification requirements which are developed as EIP's are adopted by states.

Hazardous Air Pollutants Section 112 of the Clean Air Act 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. This list is included in Appendix B of this report. Section 112(c) requires EPA to list the categories of major and area sources of any of these 189 HAPs. This list was published on July 16, 1992 (57 FR 31576) and is included in Appendix G. Section

¹*Federal Register*, Vol. 58, p. 11110. "Economic Incentive Program Rules (Proposed)." February 23, 1993.

²*Federal Register*, Vol. 51, p. 43814. "Emissions Trading Policy Statement; General Principles for Creation, Banking and Use of Emission Reduction Credits." December 4, 1986.

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). These 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). These emissions standards are called MACT standards. For area sources, technology standards may be based on generally available control technology (GACT); such standards are referred to as GACT 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. First, 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).

First, 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.

Second, 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.

Third, 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 sources of the deposited chemicals and their precursors. This investigation will likely lead to emissions estimation requirements for sources which emit HAPs that could be deposited into these waters.

Fourth, 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.

Finally, 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" currently under development. Information and guidance on this database will be available in future rulemakings pertaining to Section 112.

New Source Performance Standards Section 111 of Title I of the Clean Air Act requires EPA to publish and update a list of source categories which contribute significantly to air pollution. For each category on the list, EPA must establish standards of performance for new sources within that category. These standards are called New Source Performance Standards (NSPS). The current NSPS are established at 40 CFR Part 60. This regulation contains NSPS for over 60 source categories. The regulation also establishes specific reporting requirements for certain source categories. These reporting requirements usually consist excess emissions reports based

on continuous emission monitoring (CEM) test data. Other miscellaneous requirements may exist for certain source categories. The list of source categories covered by NSPS is included in Appendix H. It should also be noted that sources subject to NSPS are also subject to the Title V requirements.

Title IV Allowance Trading In order to control sources of acid deposition, Title IV of the Clean Air Act establishes the allowance trading program. This program seeks to reduce emissions of SO₂ by 10 million tons, relative to 1980 levels. Three databases, NADB, ARDS and TRAC, are set up under this program in order to track emissions, allowance trading, and compliance, respectively. Sources affected by Title IV (*i.e.*, those listed in Table A of Title IV of the Clean Air Act), 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.

Section 114 Reporting Requirements, Compliance Certifications and Enhanced Monitoring Section 114 of the Clean Air Act 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 this section, EPA can require sources to establish recordkeeping; make reports; sample emissions; keep production, control technology, or other operations data; submit Section 114(a)(3) compliance certifications (as described below); or provide other necessary information. The EPA may include emissions estimates as part of these information requirements. Information collected under this section is made available to the public, except that non-emissions-related data may be kept confidential if the source can show EPA that trade secrets would be divulged.

Section 114(a)(3) allows EPA to require Enhanced Monitoring and compliance certifications from major sources. Each source subject to the Enhanced Monitoring rule would be required to submit an annual compliance certification and monitoring reports each quarter detailing any deviations from applicable requirements in the source's operating permit. The data received may be used for direct enforcement purposes. The EPA will propose the rule (40 CFR

Part 64) in the fall of 1993, and it will be promulgated in the fall of 1994. The 114(a)(3) compliance certification will likely, in some cases, require some form of emissions estimation."

NATICH and BLIS As part of EPA's air quality management effort, EPA maintains, in addition to AIRS, two databases which contain emissions information: the National Air Toxics Information Clearinghouse (NATICH), and the RACT/BACT/LAER Clearinghouse. (Note: The RACT/BACT/LAER Clearinghouse was formerly named the BACT/LAER Information System and is still referred to as BLIS.)⁸ NATICH contains data on air toxics activities from state/local air pollution control agencies and EPA, and also includes a database of information on permitting and source testing for various facilities. BLIS contains control technology and permit information for criteria pollutants. States submit data to these databases on a voluntary basis. It is expected that states will acquire the data they need from sources for NATICH and BLIS submittals through other programs such as the programs described elsewhere in this section. No additional requirements for sources are expected to arise from these databases.

2.1.2 Requirements under Other Federal Legislation

A number of other EPA requirements which are not directly related to the Clean Air Act 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 The National Environmental Policy Act (1969) 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.

An EIS is not intended to justify a proposed EPA action; it is an objective evaluation of actions and their alternatives in light of all environmental considerations.⁹ In general, an EIS should contain the following information:

- A description of the proposed action and its purpose and needs
- Alternatives to the proposed action
- The environmental, social, and economic impacts of the proposed alternatives

The environmental impact of a proposed action should include cumulative direct and indirect impacts which are both beneficial and adverse as a result of the implementation of the action. Direct impacts are direct changes brought about by the action. Indirect impacts are foreseeable impacts that occur as a result of the action, but at a later time and in a different location. In addition, an EIS should contain additional information pertaining to (1) unavoidable adverse impacts caused by implementing the proposal; (2) the extent to which short-term environmental gains will outweigh long-term losses or vice-versa; (3) any irreversible and irretrievable damage to resources as a result of the implementation of the proposed action; and (4) a summary of comments from reviewing federal, state and local agencies and involved individuals.⁹

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 the 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.)¹⁰

Superfund Amendments and Reauthorization Act 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 available to the public. A database has been established, known as the Toxic Release Inventory System (TRIS), which contains information from the SARA toxic chemical release reports.

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.

Resource Conservation and Recovery Act 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 creation 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 annually file a 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.

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.¹ 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 discussed above.

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. This document does not attempt to identify or list the various state requirements which have been or will be developed in response to these requirements. It is expected that requirements will vary significantly among states.

It should also be noted that, 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.

2.3 INDUSTRY INITIATIVES

There are at least four main areas where activities often pursued by industries can interface with the air emission estimation process: materials/energy conservation processes;

environmental auditing; pollution prevention activities; and integrated plant maintenance/management.

2.3.1 Materials and Energy Conservation

Industrial material/energy conservation programs seek to use conservation to better utilize material and energy inputs. Information generated for material and energy conservation programs, including emissions estimates, can be used to develop strategies to reduce emissions. A three-step method is often used to accomplish such a program. First, a plant should determine its material and energy use requirements. Once the basic requirements are known, operational quality assurance steps can be taken to limit material or energy waste. Next, the plant can establish a minimum/maximum material inventory [*e.g.*, Just-in-Time (JIT) or Material Resource Planning (MRP) methods] which stresses avoidance of wasted operations and resources. Finally, a facility can investigate the use of techniques to track materials from entry into the facility to their use and ultimate disposal. With these steps, a plant can determine its material/energy needs, control the planning of those needs, and track these materials through production operations. This helps in determining the operating rates (throughput) associated with the production of products which are critical parameters in emission estimation.

2.3.2 Environmental Auditing

Environmental auditing is an objective review of a facility's operations and practices to determine if the facility is meeting its environmental requirements. Audits can be designed to internally verify compliance with environmental requirements, evaluate the effectiveness of environmental management systems already in place, or assess risks from regulated and unregulated materials and practices. In addition, the audit can be used by management to plan environmental activities for the future. Typically, environmental audits are designed to account for air emissions.

2.3.3 Pollution Prevention

Pollution prevention seeks to prevent pollution at its source, whether through changes in production or by reducing reliance on environmentally harmful materials. Pollution prevention can be the most effective way to reduce risks by reducing or eliminating pollution at its source. The Pollution Prevention Act of 1990 requires EPA to establish a matching grants program to states for the purpose of offering technical assistance and training to businesses in pollution prevention techniques. In 1991, EPA published its pollution prevention strategy which included the use of state grants to help with the exchange of information about source reduction techniques, to disseminate pollution prevention information to businesses, and to provide technical assistance.¹¹ Pollution prevention is often the most cost-effective option because it reduces raw material losses, the need for expensive "end-of-pipe" technologies, and long-term liability. Pollution prevention offers plant personnel the unique advantage of harmonizing environmental protection with economic efficiency.

The EPA's Office of Pollution Prevention (OPP) has established a Pollution Prevention Information Clearinghouse (PPIC) to help states and businesses to identify pollution reduction options, identify grant and project funding opportunities and identify upcoming events, conferences, training sessions, seminars and workshops related to pollution prevention technologies. The PPIC has established a hotline to help disseminate such information (see Appendix E for contact information).

2.3.4 Integrated Plant Maintenance and Management

Integrated plant maintenance and management can be used to reduce emissions through continuous assessment of operational practices and general integration of all aspects of plant management. Regularly scheduled maintenance inspections, cleaning of equipment, and damage/repair procedures can coincide with emissions and control equipment tests to streamline labor efforts. The plant maintenance function can be used to promote awareness of the importance of identifying, reducing, and managing emission sources through emission control programs, and to routinely develop information which can be used to assess and track emission-related variables. Management can establish emission control programs, perform environmental

audits, and identify areas for pollution reduction. The tracking of relevant operational parameters and estimation of emissions can provide useful information to the management and maintenance of a facility by concentrating activities in areas that need improvement and reviewing areas where emissions have been controlled. Establishing a program that quantifies emissions from a facility may help the facility prevent the loss of valuable product that the plant was unknowingly releasing to the atmosphere, wastewater, or solid waste. Through plant recycling efforts, such material inputs may be used more efficiently.

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3.0 TERMS AND CONCEPTS USED IN EMISSIONS ESTIMATION

This section briefly introduces the key terms and concepts in making emissions estimates and defines and explains basic terminology. A list of frequently used terms and acronyms is also provided in Appendix A.

3.1 POLLUTANTS

The Clean Air Act groups air pollutants into three categories: criteria pollutants, HAPs, and stratospheric ozone-depleting compounds. The following section provides some basic information pertaining to these three categories of pollutants.

The 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 six common air pollutants. These pollutants, commonly referred to as **criteria pollutants**, are as follows.

Ozone (O₃) is a colorless gas which damages lungs and can damage materials and vegetation. It is the primary constituent of smog, and is formed primarily when nitrogen oxides and VOCs react in the presence of sunlight. It is also emitted from motor vehicles, industrial boilers, and other minor sources.

Nitrogen Oxides are a class of compounds which are respiratory irritants, and which react with VOCs to form ozone. They are also precursors to acid rain. Motor vehicles, power plants and other stationary combustion facilities emit large quantities of nitrogen oxides.

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

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

Particulate Matter of aerodynamic diameter less than 10 microns (PM-10) is a measure of small solid matter suspended in the atmosphere. Small particles can penetrate deeply into the lung, where they cause respiratory problems. Emissions of PM-10 are significant from

fugitive dust, power plants, commercial boilers, metallurgical industries, mineral industries, forest and residential fires, and motor vehicles.

Lead (Pb) is an element which 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.

In addition to the six criteria pollutants, EPA regulates emissions of **Volatile Organic Compounds**. VOCs react with nitrogen oxides in the atmosphere to form ozone. 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 VOC, 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.

In addition to the criteria pollutants described above, the 1990 Clean Air Act also regulates **hazardous air pollutants** listed in Section 112(b). These pollutants are 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 Clean Air Act 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. The complete initial list of HAPs is provided in Appendix B.

HAPs are emitted from a wide variety of industrial sources. In many instances, emissions of the criteria pollutants VOC or PM-10 may include some HAPs. For example, evaporative emissions from gasoline manufacture or handling would be categorized as a VOC emission and would therefore be regulated as a criteria pollutant. In addition, because gasoline contains HAPs such as xylene and benzene, these emissions must be counted as HAP emissions in addition to their inclusion in any inventory of VOC emissions. Similarly, some fraction of PM-10 emissions

from a variety of sources may contain HAPs such as polycyclic organic matter, phosphorous, or cobalt. Section 112(c) of the Clean Air Act requires EPA to maintain a list of categories of major or area sources which emit any of the listed HAPs. The list currently contains approximately 200 potential source categories that emit HAPs in significant quantities.¹

Finally, in addition to criteria pollutants and HAPs, the Clean Air Act, in Title VI, regulates Class I and Class II ozone-depleting substances, which may destroy stratospheric ozone. **Class I substances** include chlorofluorocarbons (CFCs), halons, carbon tetrachloride and methyl chloroform. According to the Clean Air Act, 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 which allow for acceleration of this phase-out. **Class II substances** include hydrochlorofluorocarbons (HCFCs). These substances must be phased out of production by the year 2015. Methods to estimate emissions of ozone-depleting compounds are not discussed in this document. Title VI is primarily designed to limit manufacture, not use. For additional information on emissions of ozone-depleting compounds, contact EPA's Office of Atmospheric and Indoor Air Programs, Global Climate Change Division, located at EPA Headquarters in Washington, DC.

3.2 TYPES OF STANDARDS

Air quality management is usually accomplished by setting legal limits on source operations which restrict the amount of emissions from sources. These legal limits, or **standards**, come in many different types. This section discusses the various types of standards. In addition, the main federal standards under current regulations are introduced.

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.

Emission standards are a general type of standard which limit the mass of a pollutant which 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). However, in addition to time, emission standards may be based on other mass relationships.

Emission concentration standards limit the mass emissions of a pollutant per volume of air. Emission concentration standards are expressed in grams per dry standard cubic meter (g/dscm) or some similar units.

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).

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, within a specified time, reduce its emissions to 50 percent of the present value.

Opacity standards limit the opacity (in units of percent opacity) of the pollutant discharge rather than the mass of pollutant, as in the prior examples.

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.

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.

Work practice standards require some action during the routine operation of the unit. For example, 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 feasible.

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.

The types of standards previously defined comprise most of the standards used in state and federal regulations. Several types of federal standards are mentioned in this report, and each can be classified according to one of the above types. The following text describes the major federal standards:

National Ambient Air Quality Standards are the main ambient standards for six criteria pollutants.

New Source Performance Standards are promulgated for criteria, hazardous, and other pollutant emissions from new, modified or reconstructed sources which EPA determines contribute significantly to air pollution. These are typically emission standards, but may be expressed in many forms, such as concentration, opacity, and others. The current NSPS are established at 40 CFR Part 60. This regulation contains NSPS for over 60 source categories. The list of NSPS source categories is included in Appendix G.

National Emissions Standards for Hazardous Air Pollutants are a class of standards limiting emissions of the HAPs. The common use of NESHAP actually refers two different sets of standards. First, there are 22 emissions standards promulgated prior to the 1990 Clean Air Act Amendments. 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), while still others are both pollutant- and source-category specific (*e.g.*, the NESHAP for inorganic arsenic emissions from glass manufacturing plants). The list of NESHAPs promulgated prior to the 1990 Amendments is included in Appendix I.

The second use of NESHAP commonly refers to the new **maximum achievable control technology standards** which will be promulgated under Section 112 of the Clean Air Act, although technically NESHAP and MACT standards are separate programs. MACT standards differ from older NESHAPs because they are mandated by law to require the maximum achievable control technology. To distinguish these from the old NESHAPs, these new technology based standards should be referred to as MACT standards rather than NESHAPs. These MACT standards will all be source category-specific and each standard will cover all the pollutants listed in the new Section 112 that are emitted by that source category. The term NESHAP has probably remained in use to refer to MACT standards because the Act language refers to MACT standards only as "emission standards," and because the first MACT standard proposed (for the Synthetic Organic Chemical Manufacturing Industries) was originally developed as a NESHAP and is still referred to as the Hazardous Organic NESHAP (HON). The list of source categories requiring MACT standards is included in Appendix G.

3.3 SOURCE CHARACTERIZATION

The EPA categorizes emissions sources into three basic groups: point sources, area sources, and mobile sources. Further categorization is often used to acquire more detailed information about emissions from a given source.

3.3.1 Classification by Source Type

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 definitions vary among state and local agencies. 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.

Area sources are smaller sources which do not qualify as point sources under the relevant emissions cutoffs. Area sources encompass more widespread sources which may be abundant, but which, 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, consumer solvent use, and others. As mentioned in Section 2, area sources are generally not required to submit individual emissions estimates.

Mobile sources include all non-stationary 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.

Because the audience for this document is primarily industry, this document is specifically targeted to calculating point source emissions. Guidance for area source emissions estimation is available in the EPA document, *Procedures for Preparation of Emission Inventories for Carbon Monoxide and Precursors of Ozone, Volume I: General Guidance for Stationary Sources*.⁴ Guidance for mobile source emissions estimation is available in *Procedures for Preparation of Emission Inventories for Carbon Monoxide and Precursors of Ozone, Volume IV: Mobile Sources*.⁵

3.3.2 Detailed Source Characterization for Emissions Reporting

Within a given point source, there may be several **emission points** which 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 several 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 pollution control agencies groups emission sources into one of three categories and maintains emission-related data in a different format for each. The **plant level** category is used to consolidate data for an entire plant or facility. A plant may contain one or many pollutant-emitting sources. The **point level** category is used to maintain emission-related information for single stacks or vents individually large enough to be considered point sources under the cutoffs described above. The **process or segment level** category typically contains data for a single process or unit of operation. These different reporting categories are defined below.

If total emissions from a plant (which may be composed of numerous individual emission points) meet the point source cutoff, the plant is generally required to report operating data that 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 which apply data 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 denoting the principal economic activity of the facility.² For the purpose of clearly identifying and tracking emission 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 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.³ In some cases, plantwide emissions may be reported at the plant level.

Regulatory agencies generally maintain individual emission-related records at the point level. **Point level reporting** occurs with specific data for emissions points (typically stacks) which require more detailed information than can be done at the plant level. Such data include

emission-related and modeling information such as stack height of the emission point, diameter of the stack, emission rate, method of determination, gas exit velocity from the stack, gas temperature, and operating schedule. For fugitive sources (see discussion in Section 3.3.3), stack parameters are not relevant, but basic parameters such as dimensions, height, concentration, and most other items apply. 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.

For **process or segment level reporting**, each process within a plant is identified by an EPA source classification code (SCC). For point sources, reporting guidelines may require that a plant identify, for each process or operation (designated by SCC code), the periods of process operation (daily, weekly, monthly, annually); operating rate data, including actual, maximum and design operating rate or capacity; fuel use and properties data (ash, sulfur, trace elements, heat content, etc.); identification of all 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 emission data for a single plant are clearly identified.³

3.3.3 Classification by Means of Release to Atmosphere

When preparing an emission estimate, it is useful to classify not only the type of pollutant emitted but also the means of release to the atmosphere. Environmental agencies usually classify release mechanisms into three categories: process emissions, fugitive emissions, and process fugitive emissions. **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. **Fugitive emissions** are emissions from other sources that are technically infeasible to collect and control (e.g., storage piles, waste water retention ponds, etc.). **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. These three emission types are illustrated in Figure 3-1. These definitions are important because emission factors and other estimation methods are often specific to the type of release.

3.4 EMISSION ESTIMATION PROCEDURES

This section introduces terms used to refer to the most common methods for estimating emissions. Detailed descriptions of these methods are given in Section 4 of this document, and examples are provided in Section 5. Emission estimation methods include the following.

Continuous emissions monitoring (CEM) is any monitoring effort which "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.

Source tests are short-term tests used to collect emissions data which 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 which differ from those under which the test was performed.

Material balance or mass balance is a method for estimating emissions which 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.

Emission factors are ratios which 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, but the primary source is *A Compilation of Air Pollutant Emission Factors (AP-42)*, which is discussed in detail in the next section.

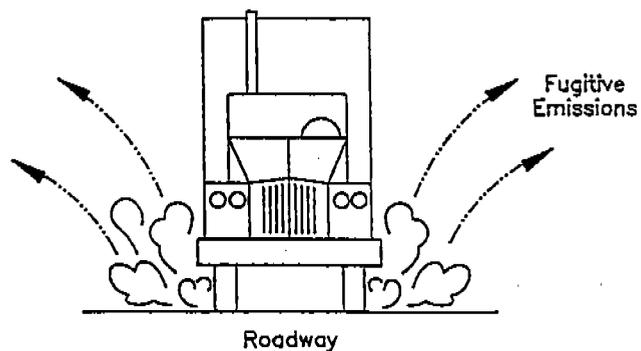
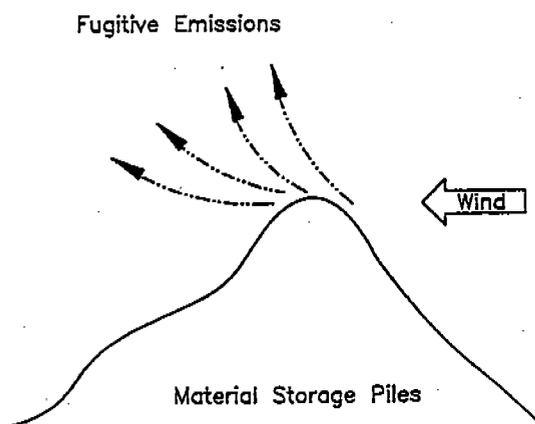
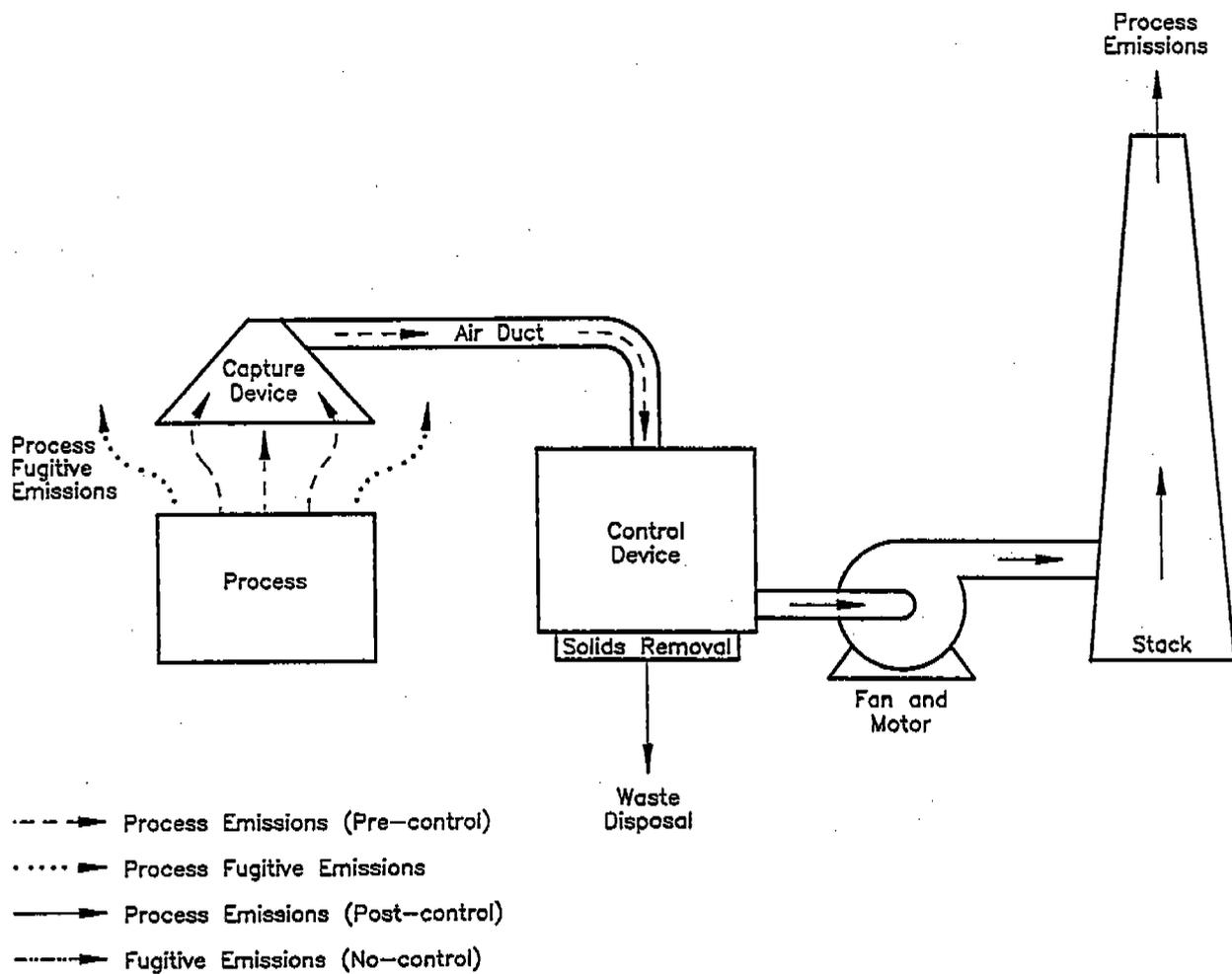


Figure 3-1. Emission release categories.

Process-specific empirical relationships are similar to emission factors, in that they relate emissions to easily identifiable process parameters. However, these relationships are more detailed equations which relate emissions to several variables at once, rather than a simple ratio. An example is the estimate for VOC emissions from storage tanks, which is based on tank size, air temperature, and vapor pressure. *AP-42* contains several of these empirical relationships.

Engineering estimate is a term commonly applied to the best approximation which can be made when the methods described above 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.

REFERENCES FOR SECTION 3.0

1. *Federal Register*, Vol. 57, No. 137, p. 31576. "Initial List of Categories of Sources Under Section 112(c)(1) of the Clean Air Act Amendments of 1990," July 16, 1992.
2. *Standard Industrial Classification Manual, 1987*. Office of Management and Budget. Washington, DC.
3. U.S. Environmental Protection Agency. *AIRS Facility Subsystem Source Classification Codes and Emission Factor Listing for Criteria Air Pollutants*. EPA 450/4-90-003. Research Triangle Park, NC, March 1990.
4. U.S. Environmental Protection Agency. *Procedures for Preparation of Emission Inventories for Carbon Monoxide and Precursors of Ozone, Volume I: General Guidance for Stationary Sources*. EPA-450/4-91-016. Research Triangle Park, NC, May 1991.
5. U.S. Environmental Protection Agency. *Procedures for Preparation of Emission Inventories for Carbon Monoxide and Precursors of Ozone, Volume IV: Mobile Sources*. EPA-450/4-81-026D (Revised). Research Triangle Park, NC, May 1981.

4.0 BASIC EMISSION ESTIMATION PROCEDURES AND TOOLS

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 information provided in this section focuses on point sources and identifies available tools to estimate emissions from many industrial processes, and also provides guidance for making estimates if specific tools are not available.

4.1 ESTIMATION PROCEDURES

Ideally, plants needing emissions estimates would use continuous emissions monitoring to make actual emissions measurements at very short time intervals. Some plants currently do this. The CEM concentration data can be easily converted to mass emission rate estimates provided the air volume through the monitor is also known. In cases where CEM data are unavailable, however, another method must be used to estimate emissions. The three principal methods for estimating emissions are source tests, material balances, and emission factors. The most reliable estimation of emissions is determined using source test data. Because of the time and expense involved in source testing, however, material balances and/or the use of emission factors to estimate process emissions are most often employed. The EIB assigns emission factor ratings based on the criteria for determining data quality and emission factor ratings as required in the document, *Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections*.¹ If none of these methods can be employed for a specific process, an approximation or engineering estimate based on available process, physical, chemical, and emission knowledge may be used. This section describes each of these approaches.

4.1.1 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. A source test program can range from five thousand to hundreds of thousands of dollars, depending on the scope and complexity of the test and source. Typically, a source test uses two instruments: one to collect the pollutant in the emission stream and one to measure emission stream airflow rate. The essential difference between a source test and CEM is the duration of time that measurements are conducted. A source test is conducted over a discrete, finite period of time, while a CEM is actually continuous.

Source tests typically provide better emission estimates than emission factors or material balances, if correctly applied.² 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. Emission data from a one-time source test can be extrapolated to estimate annual emissions if the process stream does not vary and if the process is operated uniformly. If variability exists, multiple tests must be conducted, with knowledge of the process variation, for the source tests to be useful in generating an emission estimate for extended periods that are longer than the test period. Multiple source tests under well-maintained conditions begin to approximate a continuous emission measurement rather than an emission estimate. If facility operation and test methods employed during the source test cannot be adequately characterized, the source test data should not be used. Example 8 in Section 5 of this document shows an example emissions estimate using a source test.

If a source test is used to estimate emissions for a process, using test data gathered on-site for that process is 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, SO₂, NO_x, CO, and VOC. The reference methods, given in the 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.³ Reference methods for estimating HAPs emissions are given in the Title 40, *Code of Federal Regulations*, Part 61, Appendix B; *Test Methods for Evaluating Solid Waste*; and the *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air*.^{4,5,6} 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.⁷ 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 E contains EMTIC contact information.

4.1.2 Material Balances

The material balance (also known as a mass balance) is a method commonly used for estimating emissions from many source categories. The material balance method can be used where source test data, emission factors, or other developed methods are not available. 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.

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. Example 7 in Section 5 of this document illustrates a typical material balance calculation.

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.⁸ 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 paint mixing process, for example, would be calculated as follows (according to ASTM Method D 2369):

$$\text{VOC}_{\text{in}} \text{ (lb/gal)} - \text{VOC}_{\text{mixed paint}} \text{ (lb/gal)} = \text{VOC}_{\text{emitted}} \text{ (lb/gal)}$$

4.1.3 Emission Factors

An emission factor is a ratio that relates quantity of pollutant emissions to the activity level of a specific source. Examples of activity levels include tons of coal burned, tons of chemical produced, and square feet of material plated. If the emission factor and the corresponding activity level for a process are known, an estimate of the emissions can be produced.⁹ The primary reference for criteria pollutant emission factors for industrial sources is *A Compilation of Air Pollutant Emission Factors (AP-42)*.⁹ Some example emission factors from *AP-42* are shown in Table 4-1. Emission factors are developed from source test data, material balance studies, and engineering estimates. In general, the use of emission factors to determine plant emissions is the most common and cost-effective approach.

The use of emission factors is straightforward when the relationship between process data and emissions is direct and relatively uncomplicated. Many emission factors in the metallurgical industry or food and agriculture industries are simply related to readily available process throughputs. An entirely different situation exists, for example, in the case of estimating the emissions of nitrogen oxides (NO_x) from an industrial boiler. The emission factor for NO_x , as given in *AP-42*, varies with both the type and size of the boiler, from 6 to 55 pounds of NO_x per ton of coal.⁹ In this case, the wide variation in emissions factors occurs because NO_x production during combustion is affected by furnace design, combustion temperature, residence time of the gases in the combustion zone, rate of cooling, the amount of excess air, and the amount of nitrogenous compounds in the fuel. Thus, the emission factor of 18 pounds per ton, which is applicable to a pulverized coal boiler burning 100 tons per hour, is an average value. Actual emission values for specific boilers may differ significantly from the quantities estimated using this average value.

In addition to presenting emission factors, *AP-42* gives a quality indicator for each emission factor. 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

TABLE 4-1. EXAMPLE AP-42 EMISSION FACTORS FOR VARIOUS PROCESSES⁹

Process and Control Method	AP-42 Emission Factor
Gypsum Processing Emission Factors:	
Gypsum Processing Flash Calciner (uncontrolled)	19 kg particulate/Mg gypsum processed
Gypsum Processing Flash Calciner (uncontrolled)	7.2 kg PM-10/Mg gypsum processed
Petroleum Refining Emission Factor:	
Petroleum Refinery Moving-bed Catalytic Cracking Unit (uncontrolled)	10.8 kg CO/10 ³ liters fresh feed
Sulfite Pulping Emission Factor:	
Sulfite Pulping Recovery Boiler and Direct Contact Evaporator (uncontrolled)	2.5 kg SO ₂ /Mg air-dried unbleached pulp
Coke Manufacturing Emission Factors:	
Coke Manufacturing Coke Pushing (uncontrolled)	0.25 kg PM-10/Mg coal processed
Coke Manufacturing Coke Pushing (controlled by venturi scrubber)	0.08 kg PM-10/Mg coal processed
Adipic Acid Manufacturing Emission Factors:	
Adipic Acid Manufacture Cyclohexane Oxidation (uncontrolled)	20 kg VOC/Mg adipic acid produced
Adipic Acid Manufacture Cyclohexane Oxidation (controlled by flares)	4 kg VOC/Mg adipic acid produced
Adipic Acid Manufacture Cyclohexane Oxidation (controlled by carbon adsorber)	2 kg VOC/Mg adipic acid produced

Note: Since AP-42 is continually updated, users should refer to the latest information available.

reasonably adequate emission estimates, stack testing may represent an ineffective use of time and resources.

4.1.3.1 Calculation of Emissions Using Emission Factors

In order to calculate emissions from emission factors, various inputs to the estimation algorithm are required:

1. Activity information for the process as specified by the relevant emission factor.
2. Emission factors to translate activity information into uncontrolled or controlled emission estimates.
3. 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 factors is:

$$E = R \times EF \times (1 - C/100)$$

where

E	=	emission estimate for source (at the process level)
R	=	activity level (such as throughput)
EF	=	"uncontrolled" emission factor (such as lb emitted/throughput)
C	=	control effectiveness, equal to the capture device efficiency multiplied by the control device efficiency. Expressed in percent.

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

$$E = R \times EF$$

where

E	=	emission estimate for source (at the process level)
R	=	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. Section 5 of this document contains examples using emission factors.

4.1.3.2 *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., lb, ton, gal or bbl per hour). Similarly, for fuel-burning equipment, activity data are reported as fuel consumption rates (e.g., tons, 10^3 gallons, or 10^6 ft³, 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.

It is important that the numerical values used for throughput are accurate. If an emission factor is used, estimated emissions will vary linearly with the throughput figure. Therefore, any errors in throughput will proportionally affect the emission estimate. Hourly emissions must be correctly converted to weekly or annual emission estimates by using appropriate conversions for hours worked per week, or weeks worked per year.

In many instances, conversion factors must be applied to convert reported consumption or production values to units that correspond to the emission factor throughput units (e.g., tons, barrels, etc.). Useful conversion factors are given in Appendix D. For example, fuel consumption over the desired time interval must be converted to the desired emission factor activity units (tons burned for coal), using the heating value of the fuel. A correction factor representing the fractional efficiency of the fuel burning equipment must be applied for conversion of heat input to power output (electrical) or steam production (thermal). These conversions occasionally require additional process data 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 the AP-42 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.

4.1.3.3 *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.

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 with process, 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* supplies efficiencies for control devices which are commonly encountered in industrial applications. 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 in addition to the estimate.

A third method of obtaining a control device collection efficiency is to employ the manufacturer's design specification or guaranteed performance specification subject to field verification. However, the design collection 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 these source 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. However, it should be noted that regulations and permitting conditions often preclude the operation of the emitting processes when control equipment is inoperative or malfunctioning.

4.1.3.4 *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. These equations, like emissions factors, are based on throughput and control efficiency. However, they are more complex than the simple ratio used for emissions 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. Example 4 in Section 5 of this document illustrates this kind of relationship using the *AP-42* procedure for VOC losses from an internal floating roof tank.

4.1.4 Best Approximation or Engineering Judgement

If one of the methods described above is not applicable to estimating emissions for a process, a best approximation or engineering judgement is a final option, although 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. Emission factors from *AP-42* (or another emission factor reference) may be used to place order-of-magnitude boundaries on possible emissions from the process in question.

4.2 AVAILABLE EMISSION ESTIMATION TOOLS

The emission estimating tools should be used with discretion. Actual emissions from individual sources may vary considerably from values estimated using emission and speciation

factors. This section identifies some of the principal technical resources for obtaining emission factors, calculating emissions, and evaluating plant processes.

4.2.1 Locating and Estimating Emissions of . . . Documents

In addition to *AP-42*, EPA has published more than 24 reports, each with the generic title, *Locating and Estimating Air (Toxic) Emissions From (or of) (Source Category or Substance)*. Approximately 10 additional reports in this series are under review, under development, or in the planning stages now. 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 4-2 lists the available L&E documents, which may be ordered through NTIS (see Appendix E for additional information).

4.2.2 Available Emission Factor Database Management Systems

4.2.2.1 Access to the Systems

Most of the EPA materials described in this section are available through the EPA Clearinghouse for Inventories and Emission Factors Bulletin Board System (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, XATEF, SPECIATE, 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). Industry personnel can access the CHIEF BBS by calling the contacts listed in Appendix E. Access to the CHIEF BBS requires a personal computer with communications software and hardware to connect to the EPA IBM system (see Appendix E for hardware and software requirements, and contacts).

Industry personnel can also use the Air CHIEF CD-ROM to access many of EPA's documents and databases. Users need an IBM™ compatible personal computer with an EGA or VGA monitor, MS-DOS version 3.0 or later, 640 KB of free RAM, 2 MB of expanded memory, a CD-ROM drive, an interface card, and MS-DOS CD-ROM extensions. The 1992 version of

TABLE 4-2. LOCATING AND ESTIMATING DOCUMENT SERIES

Substance or Source Category	EPA Publication Number	Publication Date
Acrylonitrile	EPA-450/4-84-007a	1984
Carbon Tetrachloride	EPA-450/4-84-007b	1984
Chloroform	EPA-450/4-84-007c	1984
Ethylene Dichloride	EPA-450/4-84-007d	1984
Formaldehyde, revised	EPA-450/2-91-012	1991
Nickel	EPA-450/4-84-007f	1984
Chromium	EPA-450/4-84-007g	1984
Manganese	EPA-450/4-84-007h	1984
Phosgene	EPA-450/4-84-007i	1984
Epichlorohydrin	EPA-450/4-84-007j	1984
Vinylidene Chloride	EPA-450/4-84-007k	1984
Ethylene Oxide	EPA-450/4-84-007l	1984
Chlorobenzenes	EPA-450/4-84-007m	1984
Polychlorinated Biphenyls (PCBs)	EPA-450/4-84-007n	1984
Polycyclic Organic Matter (POM)	EPA-450/4-84-007p	1984
Benzene	EPA-450/4-84-007q	1984
Organic Liquid Storage Tanks	EPA-450/4-88-004	1988
Coal and Oil Combustion Sources	EPA-45/2-89-001	1989
Municipal Waste Combustors	EPA-450/2-89-001	1989
Perchloroethylene and Trichloroethylene	EPA-450/2-89-013	1989
1,3-Butadiene	EPA-450/2-89-021	1989
Sewage Sludge Incinerators	EPA-450/2-90-009	1990
Styrene	EPA-450/4-91-029	1991
Medical Waste Incineration	Pending	1992
Mercury	Pending	1993
Methylene Chloride	EPA-454/R-93-006	1993
Cyanides	In Production	1993
Methyl Chloroform	In External Review	1993
Cadmium	Pending	1993
Methyl Ethyl Ketone	In External Review	1993
Methyl Isobutyl Ketone	In External Review	1993
Toluene	In External Review	1993
Xylenes	In External Review	1993
Dioxins/Furans	In Production	1993
Chlorobenzenes, revised	In External Review	1993

Air CHIEF CD-ROM includes Volume I of AP-42 with Supplements A through D (criteria pollutant emission factors for point and area sources, not including mobile sources), XATEF, SPECIATE, and 24 documents in the *Locating and Estimating Emissions of...* series. The Air CHIEF CD-ROM is updated annually.

4.2.2.2 Databases and Systems

The most comprehensive compilation of emission factors for HAPs is available in the Crosswalk/Air Toxic Emission Factor (XATEF) Database Management System. The XATEF system (XATEF Version 1.2), which is available from EPA on one 5.25" high density diskette [via request from the Emission Inventory Branch (EIB) (see Appendix E) or by downloading from the CHIEF BBS], contains more than 7,600 emission factors for more than 410 toxic pollutants and more than 400 source categories. The user's manual [*Crosswalk/Air Toxic Emission Factor Data Base Management System (XATEF), Version 1.2, User's Manual*] is also available from EPA.¹⁰ XATEF is a user-friendly, menu-driven system that relates the quantity of a pollutant released to some activity level for a specific source category (SIC) or process (SCC). Emission factors for the air toxics are identified by pollutant names, Chemical Abstract Services (CAS) registry numbers, process descriptions, emission source descriptions, SIC codes, and SCCs. XATEF also provides the user with brief descriptions of control measures associated with emission factors, and references to sources of further information.

The Factor Information Retrieval (FIRE) System replaces XATEF in October 1993 and will be distributed on one 5.25" high density diskette or will be available for downloading from the CHIEF BBS. An accompanying User's Guide will also be available.

The VOC/PM Speciation Database Management System (SPECIATE) is a clearinghouse for speciation factors for both VOCs and PM.¹¹ Speciation factors are used to derive emission estimates of air species from factors or estimates of total VOC or PM. Each profile, as defined by SCC, 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 VOC or PM emissions. Each individual pollutant speciation factor within a profile can be multiplied by a VOC or PM emission factor (or emission rate) to produce an estimated compound-specific emission factor. However, the lists of compounds attributed to a source category provided in SPECIATE will not necessarily be complete. 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.

SPECIATE is designed to search for speciation factors based on a user-provided SCC, pollutant name, or a source category description. The SPECIATE PM profiles include three particle size range distributions and total measured PM data for each species. The SPECIATE database is updated annually, and is accompanied by a user's manual.⁹ The SPECIATE database is not published in paper form due to the size of the database, but is available on a 5.25" high density diskette.

The Air CHIEF CD, a compact disc-read only memory (CD-ROM) tool, offers on one disc thousands of pages contained in some of EPA's most widely used and requested documents. Air CHIEF CD-ROM includes the XATEF and SPECIATE Database Management Systems, and 25 EPA reports to assist in finding and estimating pollutant emissions. Air CHIEF CD-ROM is updated annually and was last updated in March 1992. That version of the CD-ROM is available from the Government Printing Office (GPO) for \$15. A third version, which will include an additional 12 to 15 recently published EPA reports, is tentatively scheduled for release in August 1993.

EIB's emission estimation tool, the TANKS Program, is also available for download from the CHIEF BBS. TANKS contains the newly revised storage tank equations contained in the new AP-42. The system calculates monthly and annual VOC and toxic air emissions for horizontal and vertical fixed roof tanks, internal and external floating roof tanks, and underground storage tanks, incorporating the latest American Petroleum Institute (API) equations. The TANKS User's Manual is also available on the CHIEF BBS.

AIRS is the EPA database of air pollution information in the United States. AIRS is a computer-based repository of air pollution-related data for the United States. AIRS is presently composed of three subsystems: (1) the AIRS Facility Subsystem (AFS); (2) the Air Quality Subsystem (AQS); and (3) the Geo-Common Subsystem (GCS). The AFS contains emission and compliance information for individual facilities as well as emission factors for individual processes. This database of information is used to establish area levels of emissions and to determine if an established limit of emissions is being obtained. Data from a source's emission statements will be used to update the AFS data for that plant. Data such as plant location, type of industry, plant operating rates, types of pollutants emitted, emissions rates (*e.g.*, precipitators,

baghouses) and other types of information used to describe plant emissions and control will be included in AFS. The AQS and GCS pertain to ambient air monitoring data for criteria pollutants and reference and control information for validation of data submitted to the AFS and AQS, respectively. The Area/Mobile Source Subsystem (AMS) is currently under development. AMS will provide the capability of estimating emissions from area sources of air pollution and from motor vehicles. In addition to providing a uniform format for state submittal of emission inventories, AIRS functions as a national data repository and resource, providing facilities and emissions data for EPA, regulatory development efforts, and a wide range of environmental research programs. Under 40 CFR Part 51, AIRS is required to be updated on an annual basis.

4.2.3 Emission Estimation Software

Several software packages are available that calculate an emission estimate from process inputs provided by the user. For VOC emissions from wastewater treatment, the Surface Impoundment Modeling System (SIMS) is available. The SIMS system is based on treatment, storage and disposal facilities (TSDFs) models and VOC emission models, and uses the CHEMDAT7 database for calculations. CHEMDAT7 is a spreadsheet program with a 700-compound database, and can be run independently from SIMS. CHEMDAT7 has models for disposal impoundments, closed landfills, land treatment facilities, and aeration and non-aeration impoundment processes. LANDFILL estimates air emissions of criteria pollutants and HAPs from landfills. With a menu-driven database and worksheet, it can calculate emissions up to 50 years beyond landfill closure. Models for estimating VOC emissions from storage tanks and PM-10 fugitive dust emissions are also available and may be accessed via the CHIEF BBS.

4.2.4 Other Software

Several other useful software packages have been developed by independent software companies. Many packages are available: a few are discussed here to demonstrate the variety of software that may be available.

The ChemCheck® software system, designed by Gaia Systems of Menlo Park, CA, allows industry to quickly determine which environmental laws apply to the chemicals used at a plant.

ChemCheck® allows the users to compare chemicals in their inventories to more than 8,000 chemicals covered by over 30 federal and state regulations. Regular updates will also be available for the program. The software can be customized by the user to include lists of locally regulated chemicals or lists of chemicals that the user wishes to track. Numerous data output formats are available to help the user summarize relevant data for analysis or environmental reporting. ChemCheck® can be run on virtually any IBM-compatible PC.¹²

The Micro-MAX MRP® system is a popular manufacturing resource planning program designed to assist in inventory control and production planning. Traditionally, this system is designed to reduce inventory overages, high storage costs, and similar issues. With these capacities, the system can be used to quantify production of hazardous wastes and releases of toxic air pollutants. Material lists and production records input into the system allow the system to calculate manufacturing production and materials use. The Micro-MAX MRP® system can produce historical records that can be very valuable for quantifying information necessary for emission estimates, environmental permitting, and Right-to-Know reporting. Production software such as Micro-MAX® typically have the ability to transfer data into standard formats and to provide user-specified custom reports.¹³

4.2.5 Trade Associations

Trade associations may provide the best information 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. Trade associations may also be the best avenue for locating assistance for environmental consulting companies. Many relevant associations are listed in the *National Trade and Professional Associations of the United States* directory.¹⁴

4.3 PLANT EMISSION ESTIMATES

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 formulating a plant-wide emission estimate a complex task, with significant opportunity for error. It is beyond the scope of this document to detail the measures involved in conducting a complete plant estimate, but a few general guidelines are included in this section.

The process of conducting a plant emission estimate can be divided into three general steps:

- Identify and catalog the emission sources
- Identify and quantify the emissions
- Assemble the emission source and emission release data into a coherent format.¹⁵

The difficulty of these steps varies with the size and complexity of the plant and the availability of data (*e.g.*, appropriate emission factors). To maximize efficiency and minimize error, the following general guidelines may be useful.

- *Assemble preliminary information.* Before embarking on measurements or calculations, prepare all necessary process flow charts and site maps. By preparing flowcharts, a thorough understanding of the data needs for each potential emission point is ensured. Site maps will aid in determining the coordinates of the emission points and in locating the source with respect to the site boundary. This latter information will be required for any dispersion modeling. Understanding all the reporting recordkeeping formats and procedures to be used will minimize the duplicate efforts necessary if incomplete data are collected during the initial emission estimate.
- *Understand the final goals and requirements.* Know what information is required by federal, state, and local regulations. A program such as SARA Section 313 has different goals and reporting requirements than a state emission inventory. Plant management needs should also be known. In addition to other objectives, plant management may also wish to integrate the emission estimate effort with other maintenance or manufacturing management needs.
- *Allocate sufficient time and resources to complete the job.* The successful management of any industrial effort depends on proper allocation of time, money, and human

resources. Allocate an appropriate amount of resources to complete the estimate with minimum disruption to other activities at the plant.

- *Design and use a quality assurance plan.* A quality assurance plan helps secure a complete, accurate, and consistent emission estimate. An inaccurate emission estimate is of little use to a regulatory agency or a plant management team. Timeliness is also a consideration when working with regulatory agencies, especially when the emission estimate is tied to compliance or permitting.
- *Seek appropriate assistance.* EPA, state, and local agencies have staff responsible for assisting industry personnel in estimating and controlling air pollutant emissions. Private consultants are also available to assist industry with the details of conducting an estimate. These consultants can often be contracted to conduct the entire estimate for industry. In many cases, the use of contracted help may be the most economical and productive approach for industry to meet the environmental requirements imposed by the government agencies and plant management.

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5.0 EMISSION ESTIMATION EXAMPLES

This section provides detailed examples, complete with sample calculations, for a representative set of emissions estimation methods. Information from *AP-42* and the XATEF database management system is applied, where applicable.

5.1 EXAMPLE 1: COAL-FIRED INDUSTRIAL BOILER EMISSIONS

This example illustrates the procedures to calculate emissions from an industrial boiler firing anthracite coal. This example assumes the boiler to be a travelling grate stoker.

5.1.1 Assumed Operating Parameters

Coal type: Anthracite
Annual coal consumption: 928,000 tons per year (tpy)
Ash content of coal: 7 percent
Sulfur content of coal: 1.87 percent
Particulate emissions are controlled with a 75 percent efficient cyclone
Sulfur oxides emissions are controlled with a 93 percent efficient limestone injection system

5.1.2 *AP-42* Emission Factors

Section 1.2 of *AP-42* provides emission factors for pollutants from anthracite coal combustion in stoker fired boilers:

Total organic compounds (TOC): 0.2 lb/ton (Table 1.2-2)
Particulate matter (PM): 0.9A lb/ton for PM-filterable and 0.08A lb/ton for PM-condensable where A is the ash content of coal in weight percent (Table 1.2-5)
Lead (Pb): 8.9E-03 lb/ton (Table 1.2-5)
Nitrogen oxides (NO_x): 9.2 lb/ton (Table 1.2-6)
Sulfur dioxide (SO₂): 39S lb/ton where S is the weight percent of sulfur in the coal (Table 1.2-6)
Carbon monoxide (CO): 0.6 lb/ton (Table 1.2-7)
Selenium: 1.26E-03 lb/ton (Table 1.2-1)

5.1.3 Estimating Uncontrolled Emissions

The general equation for estimating uncontrolled emissions of TOC, Pb, NO_x, CO, and CO₂ from anthracite coal combustion in boilers is as follows:

$$\text{Boiler Emissions} = \text{Annual Coal Consumption} \times \text{Emission Factor}$$

TOC	=	928,000 tons/year x 0.2 lb/ton = 185,600 lb/year = 92.8 tpy
Pb	=	928,000 tons/year x 8.9E-03 lb/ton = 8,259 lb/year = 4.1 tpy
NO _x	=	928,000 tons/year x 9.2 lb/ton = 8,537,600 lb/year = 4,269 tpy
CO	=	928,000 tons/year x 0.6 lb/ton = 556,800 lb/year = 278 tpy

The general equation for estimating uncontrolled emissions of PM from anthracite coal combustion in boilers is as follows:

$$\text{PM Emissions} = \text{Annual Coal Consumption} \times (\text{Emission Factor} \times \text{Coal Ash Content})$$

PM-Filterable	=	928,000 tons/year x (0.9 lb/ton x 7 percent) = 5,846,000 lb/year
	=	2,923 tpy
PM-Condensable	=	928,000 tons/year x (0.08 lb/ton x 7 percent) = 519,680 lb/year
	=	260 tpy
Total PM	=	2,923 tpy + 260 tpy = 3,183 tpy

The general equation for estimating uncontrolled emissions of SO₂ from anthracite coal combustion in boilers is as follows:

$$\text{SO}_2 \text{ Emissions} = \text{Annual Coal Consumption} \times (\text{Emission Factor} \times \text{Coal Sulfur Content})$$

SO ₂	=	928,000 tons/year x (39 lb/ton x 1.87 percent) = 67,679,040 lb/year
	=	33,840 tpy

Tables 1.2-1 and 1.2-2 of *AP-42* contain emission factors for speciated metals and speciated organic compounds, respectively, from anthracite coal combustion in stoker fired boilers. For illustration purposes, the required computational procedures for estimating selenium emissions are presented below. The general equation for estimating uncontrolled emissions of selenium is as follows:

$$\text{Selenium Emissions} = \text{Annual Coal Consumption} \times \text{Selenium Emission Factor}$$

$$928,000 \text{ lb/year} \times 1.26\text{E-}03 \text{ lb/ton} = 1,169.3 \text{ lb/year} = 0.6 \text{ tpy}$$

5.1.4 Estimating Controlled Emissions

Particulate emissions are controlled with a 75 percent efficient cyclone and SO₂ emissions are controlled with a 93 percent efficient limestone injection system. The general equation for estimating controlled emissions of PM and SO₂ is as follows:

$$\text{Controlled Emissions} = \text{Uncontrolled Emissions} \times \left(1 - \frac{\text{Efficiency}}{100} \right)$$

$$\begin{aligned} \text{Total PM} &= 3,183 \text{ tpy} \times (1-75/100) = 3,183 \text{ tpy} \times (0.25) = 796 \text{ tpy} \\ \text{SO}_2 &= 33,840 \text{ tpy} \times (1-93/100) = 33,840 \text{ tpy} \times (0.07) = 2,369 \text{ tpy} \end{aligned}$$

5.2 EXAMPLE 2: NATURAL GAS AND NUMBER 6 FUEL OIL FIRED INDUSTRIAL BOILER EMISSIONS

This example illustrates the use of *AP-42* to estimate emissions from a small industrial boiler firing natural gas and Number 6 fuel oil. The boiler fires natural gas 81 percent of the time and Number 6 fuel oil 19 percent of the time.

5.2.1 Assumed Operating Parameters

Natural Gas

Annual Consumption: 99,885 MMBtu/year
Heating Value: 1,032 Btu/scf

#6 Oil

Annual Consumption: 147,983 gal/year
Heating Value: 150,000 Btu/gal
Sulfur Content: 1 percent
Nitrogen Content: 0.4 percent

5.2.2 AP-42 Emission Factors

Sections 1.3 and 1.4 of AP-42 provide emission factors for pollutants from industrial boilers firing Number 6 fuel oil and natural gas, respectively.

Natural Gas

PM-Filterable: 6.2 lb/10⁶ scf (Table 1.4-1)
PM-Condensable: 7.5 lb/10⁶ scf (Table 1.4-1)
SO_x: 0.6 lb/10⁶ scf as SO₂ (Table 1.4-2)
NO_x: 140 lb/10⁶ scf as NO₂ (Table 1.4-2)
CO: 35 lb/10⁶ scf (Table 1.4-2)
CO₂: 1.2E05 lb/10⁶ scf (Table 1.4-3)
TOC: 5.8 lb/10⁶ scf (Table 1.4-3)

Number 6 Fuel Oil

All emission factors for Number 6 fuel oil are obtained from Table 1.3-1 in AP-42:

CO:	5 lb/10 ³ gal
Nonmethane Volatile Organics:	0.28 lb/10 ³ gal
Methane Volatile Organics:	1 lb/10 ³ gal
Nitrogen Oxides (NO _x):	[22 + 400 x N ²] lb/10 ³ as NO ₂ where N is the percent of nitrogen in the oil NO ₂ emission factor = 22 + 400 x (0.4) ² = 86 lb/10 ³ gal
Particulate Matter (PM):	[10 x S + 3] lb/10 ³ gal where S is the weight percent of the sulfur in the oil PM emission factor = 10 x 1 + 3 = 13 lb/10 ³ gal
Sulfur Oxides (SO _x):	[157 x S] lb/10 ³ gal as SO ₂ and [2 x S] lb/10 ³ gal as SO ₃ SO ₂ emission factor = 157 x 1 = 157 lb/10 ³ gal SO ₃ emission factor = 2 x 1 = 2 lb/10 ³ gal

5.2.3 Estimating Uncontrolled Emissions by Fuel Type

Natural Gas

The general equation for estimating natural gas consumption in scf/year is as follows:

$$\text{Annual Consumption} = \frac{\text{Annual Heat Input}}{\text{Natural Gas Heating Value}} = \frac{99,885 \times 10^6 \text{ Btu/year}}{1,032 \text{ Btu/scf}} = 96.8 \times 10^6 \text{ scf/year}$$

The general equation for estimating uncontrolled emissions from natural gas combustion is as follows:

$$\text{Natural Gas Emissions} = \text{Annual Gas Consumption} \times \text{Emission Factor}$$

PM-Filterable =	96.8x10 ⁶ scf/year x 6.2 lb/10 ⁶ scf = 600 lb/year = 0.3 tpy
PM-Condensable =	96.8x10 ⁶ scf/year x 7.5 lb/10 ⁶ scf = 726 lb/year = 0.36 tpy
SO _x =	96.8x10 ⁶ scf/year x 0.6 lb/10 ⁶ scf = 58 lb/year = 0.03 tpy
NO _x =	96.8x10 ⁶ scf/year x 140 lb/10 ⁶ scf = 13,600 lb/year = 6.8 tpy
CO =	96.8x10 ⁶ scf/year x 35 lb/10 ⁶ scf = 3,390 lb/year = 1.7 tpy

$$\begin{aligned} \text{CO}_2 &= 96.8 \times 10^6 \text{ scf/year} \times 1.2 \times 10^5 \text{ lb}/10^6 \text{ scf} = 11.6 \times 10^6 \text{ lb/year} = 5,808 \text{ tpy} \\ \text{TOC} &= 96.8 \times 10^6 \text{ scf/year} \times 5.8 \text{ lb}/10^6 \text{ scf} = 561.4 \text{ lb/year} = 0.28 \text{ tpy} \end{aligned}$$

Total PM emissions from the combustion of natural gas is given by the following equation:

$$\begin{aligned} \text{Total PM Emissions} &= \text{PM-Filterable} + \text{PM-Condensable} \\ &= 0.3 \text{ tpy} + 0.36 \text{ tpy} = 0.66 \text{ tpy} \end{aligned}$$

Number 6 Fuel Oil

The general equation for estimating uncontrolled emissions from Number 6 fuel oil combustion in an industrial boiler is as follows:

$$\text{Number 6 Fuel Oil Emissions} = \text{Annual Fuel Oil Consumption} \times \text{Emission Factor}$$

$$\begin{aligned} \text{PM} &= 147,983 \text{ gal/year} \times 13 \text{ lb}/10^3 \text{ gal} = 1,924 \text{ lb/year} = 0.96 \text{ tpy} \\ \text{SO}_x \text{ as SO}_2 &= 147,983 \text{ gal/year} \times 157 \text{ lb}/10^3 \text{ gal} = 23,200 \text{ lb/year} = 11.6 \text{ tpy} \\ \text{SO}_x \text{ as SO}_3 &= 147,983 \text{ gal/year} \times 2 \text{ lb}/10^3 \text{ gal} = 296 \text{ lb/year} = 0.15 \text{ tpy} \\ \text{NO}_x \text{ as NO}_2 &= 147,983 \text{ gal/year} \times 86 \text{ lb}/10^3 \text{ gal} = 12,700 \text{ lb/year} = 6.4 \text{ tpy} \\ \text{CO} &= 147,983 \text{ gal/year} \times 5 \text{ lb}/10^3 \text{ gal} = 740 \text{ lb/year} = 0.37 \text{ tpy} \\ \text{Nonmethane Volatile Organics} &= 147,983 \text{ gal/year} \times 0.28 \text{ lb}/10^3 \text{ gal} = 41.41 \text{ lb/year} = 0.021 \text{ tpy} \\ \text{Methane Volatile Organics} &= 147,983 \text{ gal/year} \times 1 \text{ lb}/10^3 \text{ gal} = 148 \text{ lb/year} = 0.074 \text{ tpy} \end{aligned}$$

Total SO_x emissions from the combustion of Number 6 fuel oil is given by the following equation:

$$\text{SO}_x \text{ Emissions} = \text{SO}_2 \text{ emissions} + \text{SO}_3 \text{ emissions} = 11.6 + 0.15 = 11.75 \text{ tpy}$$

Total Volatile Organic emissions from the combustion of Number 6 fuel oil is given by the following equation:

$$\begin{aligned} \text{Total Organic Emissions} &= \text{Nonmethane Volatile Organics} + \text{Methane Volatile Organics} \\ &= 0.021 \text{ tpy} + 0.074 \text{ tpy} = 0.095 \text{ tpy} \end{aligned}$$

5.2.4 Estimating Total Uncontrolled Emissions

$$\text{Total Emissions} = \text{Natural Gas Emissions} + \text{Number 6 Fuel Oil Emissions}$$

$$\begin{aligned} \text{Total PM} &= 0.66 \text{ tpy} + 0.96 \text{ tpy} = 1.62 \text{ tpy} \\ \text{Total SO}_x &= 0.03 \text{ tpy} + 11.75 \text{ tpy} = 11.78 \text{ tpy} \\ \text{Total NO}_x &= 6.8 \text{ tpy} + 6.4 \text{ tpy} = 13.2 \text{ tpy} \\ \text{Total CO} &= 1.7 \text{ tpy} + 0.37 \text{ tpy} = 2.1 \text{ tpy} \\ \text{Total CO}_2 &= 5,808 \text{ tpy} \\ \text{Total TOC} &= 0.28 \text{ tpy} + 0.095 \text{ tpy} = 0.38 \text{ tpy} \end{aligned}$$

5.3 EXAMPLE 3: FURNITURE SURFACE COATING EMISSIONS

The purpose of this example is to illustrate the procedures to estimate emissions from furniture surface coating. The example coating represents coating office furniture products with polyurethane topcoat, sealer, and stain. The coating line is assumed to be enclosed, and the captured emissions are directed to a 95 percent efficient carbon adsorption system. The enclosure's capture efficiency is assumed to be 85 percent.

5.3.1 Assumed Operating Parameters

Total coating material usage: 78,000 gal/year divided as follows:

Stain: 15,600 gal/year
 Sealer: 39,000 gal/year
 Polyurethane: 23,400 gal/year

Percent solids by volume in stain: 2.7 percent
 Percent solids by volume in sealer: 56 percent
 Percent solids by volume in polyurethane: 60.2 percent

5.3.2 AP-42 Emission Factors

Table 4.2.2.1-2 in AP-42 provides typical densities of coatings:

Stain: 7.3 lb/gal
Sealer: 7.0 lb/gal
Polyurethane: 9.2 lb/gal

VOC content in lb/gal in each of the coatings can be calculated using Table 4.2.2.1-1 in AP-42:

$$\text{VOC Content (lb/gal)} = \frac{(100 - \% \text{Solids by Volume}) \times \text{Density (lb/gal)}}{100}$$

$$\text{Stain VOC Content} = \frac{(100 - 2.7) \times 7.3 \text{ (lb/gal)}}{100} = 7.1 \text{ lb/gal}$$

$$\text{Sealer VOC Content} = \frac{(100 - 56) \times 7.0 \text{ (lb/gal)}}{100} = 3.1 \text{ lb/gal}$$

$$\text{Polyurethane VOC Content} = \frac{(100 - 60.2) \times 9.2 \text{ (lb/gal)}}{100} = 3.7 \text{ lb/gal}$$

5.3.3 Estimating Uncontrolled Emissions

The general equation for estimating uncontrolled emissions from furniture surface coating is as follows:

Uncontrolled Emissions = VOC Content of Coating x Annual Quantity of Coating Used

Stain = 7.1 lb/gal x 15,600 gal/year = 110,760 lb/yr = 55 tpy
Sealer = 3.1 lb/gal x 39,000 gal/year = 120,900 lb/yr = 60 tpy
Polyurethane = 3.7 lb/gal x 23,400 gal/year = 86,600 lb/yr = 43 tpy

Thus, the total estimated uncontrolled emissions = 55 + 60 + 43 = 158 tpy

5.4. EXAMPLE 4: STORAGE TANK

The following example illustrates the AP-42 procedures to develop air emissions for an internal floating roof tank storing acrylic acid. The procedures allow for estimation of standing and withdrawal losses. These procedures are only applicable to the storage of organic liquids. (This can also be accomplished using the electronic TANKS program.)

5.4.1. Assumed Operating Parameters

Tank Specifications

Liquid Stored:	100 percent acrylic acid
Tank Diameter:	14.7 feet
Tank Height:	27 feet
Tank Volume:	39,600 gallons
Annual Quantity Stored:	25,500,000 pounds per year
Tank Color:	Light gray
Primary Seal:	Vapor-mounted
Secondary Seal Construction:	Rim-mounted
Daily Average Ambient Temperature:	70°F
Atmospheric Pressure at Tank Location:	14.7 psia
Floating Roof (Deck) Construction:	Column supported with welded-seams
Deck Equipment Configurations:	

- Access hatch with an unbolted, ungasketed cover
- Automatic gauge float well with an unbolted, ungasketed cover
- Ungasketed buildup column well with sliding cover
- Ladder well with ungasketed sliding cover

- Sample well-slit fabric seal with a 10 percent open area
- Weighted, gasketed, mechanically activated vacuum breaker

Acrylic Acid Physical Properties

Molecular Weight:	60.05 pounds/pound-mole
Density of Acrylic Acid:	8.76 pounds/gallon (368 pounds per barrel)
Antoine's Constant A:	5.652
Antoine's Constant B:	648.629
Antoine's Constant C:	154.683

5.4.2. Estimating Emissions

Section 12 of Supplement E of *AP-42* provides the procedures to estimate the air emissions for VOCs from product/raw material storage tanks. The general formula to estimate storage losses for an internal floating roof tank is:

$$\text{Total losses } (L_T) = \text{rim seal losses } (L_R) + \text{deck fitting losses } (L_F) + \text{deck seam losses } (L_D) + \text{withdrawal losses } (L_{WD})$$

Emissions from any atmospheric storage tank include standing losses and withdrawal losses. Standing losses represent emissions generated due to the atmospheric temperature and pressure changes that cause organic liquids to evaporate. For an internal floating roof tank, the standing losses include rim seal losses, deck fitting losses, and deck seam losses. Rim seal losses represent the quantity of stored material that escapes around the edges (rim) of the floating roof (deck). Deck fitting losses are the emissions of the stored material that escapes through the various deck fittings (i.e., access hatch, etc.). Deck seam losses are the emissions that occur through the seams connecting the panels used to construct the floating roof. Withdrawal losses are the emissions that occur due to the vapor displacement in the tank vapor space when loading/unloading the tank.

Rim Seal Losses (L_R)

From Equation 3-2 in Section 12 of *AP-42*, Supplement E, rim seal losses are estimated using the following relationship:

$$L_R = K_R \times P^* \times D \times M_v \times K_c$$

where:

- L_R = ream seal loss (lb/year)
- K_R = seal factor (Table 12.3-14)
- D = tank diameter (feet)
- M_v = average vapor molecular weight (lbs/lb-mole)
- K_c = product factor
- P^* = vapor pressure function (Equation 3-3)

From Table 12.3-14, the rim seal factor for an internal floating roof tank equipped with a vapor-mounted primary seal and a rim-mounted secondary seal is 2.5. The tank diameter (D) is 14.7 feet and the average molecular weight of the vapor for acrylic acid is 60.06 lbs/lb-mole. *AP-42* identifies that the value of the product factor (K_c) is given a value of 1 for all organic materials excluding crude oil.

The vapor pressure function (P^*) is calculated using the physical properties of the stored organic liquid as shown on Equation 3-3

$$P^* = \frac{\frac{P_{VA}}{P_A}}{\left[1 + \left(1 - \frac{P_{VA}}{P_A} \right)^{0.5} \right]}$$

- where:
- P_{VA} = the true vapor pressure at daily average liquid storage temperature (psia)
 - P_A = the average atmospheric pressure at tank location (psia).

The vapor pressure for acrylic acid can be estimated using Antoine's equation and the constants provided above for the physical properties of acrylic acid.

$$\text{Log}P_{VA} = A - \frac{B}{T_{LA} + C}$$

where: A, B, and C are the applicable Antoine constants
 T_{LA} = the daily average liquid surface temperature (°C)
 P_{VA} = the vapor pressure at average liquid storage temperature (mm Hg)

The acrylic acid vapor pressure must be estimated at the temperature representing the daily average liquid storage temperature. T_{LA} is calculated using Equation 1-13 in AP-42, as follows:

$$T_{LA} = (0.44 \times T_{AA}) + (0.56 \times T_B) + (0.0079 \times \alpha \times I)$$

where: T_{LA} = daily average liquid surface temperature (°R)
 T_{AA} = daily average ambient temperature (°R)
 T_B = liquid bulk temperature (°R)
 I = daily total insulation factor (Btu/ft²-day)
 α = tank paint solar absorptance factor

For the daily average ambient temperature of 70°F, the value of T_{AA} is estimated as 530°R. The rim seal losses are a function of the actual liquid temperature inside the storage tank accounting for the tank color. The liquid bulk temperature is estimated by:

$$T_B = T_{AA} + 6 \times \alpha - 1$$

The daily total insulation factor (I) is obtained from Table 12.3-6 and the value for the paint solar absorptance factor (α) is obtained from Table 12.3-7 in AP-42. From Table 12.3-6, the insulation factor is 1,373 Btu/ft²-day. The solar absorptance factor for a light gray tank from Table 12.3-7 is 0.54, respectively.

$$T_B = T_{AA} + (6 \times \alpha) - 1 = 530 + (6 \times 0.54) - 1 = 532.2^\circ\text{R}$$

Thus, $T_{LA} = (0.44 \times 530) + (0.56 \times 532.24) + (0.0079 \times 0.54 \times 1,373) = 537^\circ\text{R}$
 $= (537 - 492)/1.8^\circ\text{C}$
 $= 25^\circ\text{C}$

Now using the Antoine equation, the acrylic acid vapor pressure (P_{VA}) can then be calculated as follows:

$$\text{Log}P_{VA} = 5.652 - \frac{648.629}{25 + 154.683} = 2.04$$

$$P_{VA} = 10^{2.04}$$

$$P_{VA} = 110 \text{ mm Hg} = 2.1 \text{ psia}$$

Using the atmospheric pressure of 14.7 psia and the acrylic acid vapor pressure, the vapor pressure function is:

$$P^* = \frac{2.1}{14.7} \left[1 + \left(1 - \frac{2.1}{14.7} \right)^{0.5} \right] = 0.039$$

The rim seal losses can now be estimated as:

$$L_R = K_R \times P^* \times D \times M_v \times K_c$$

$$= 2.5 \times 0.039 \times 14.7 \times 60.05 \times 1$$

$$= 86 \text{ lbs/year}$$

Deck Fitting Losses (L_F)

Equation 3-5 in Section 12 of AP-42 provides the following formula to estimate deck fitting losses as:

$$L_F = F_F \times P^* \times M_v \times K_c$$

where:

- L_F = deck fitting losses (lbs/yr)
- F_F = total deck fitting loss factor (lb-mole/year)
- P^* = vapor pressure function (calculated above)
- M_v = average vapor molecular weight (lb/lb-mole)
- K_c = product factor (identified above)

The total deck fitting loss factor is calculated based upon the types of fittings used in the construction of the floating deck. Each individual fitting loss factor represents the contribution of the total fitting loss based on the leakage associated with the various deck fittings. The total deck fitting loss factor (F_F) is estimated using the following relationship:

$$F_F = \sum (K_{Fi} \times N_{Fi})$$

where: N_{Fi} = number of deck fittings by type

K_{Fi} = fitting loss factor for each fitting type (Table 12.13-16)

The deck is equipped with the following: (1) one access hatch with an unbolted, ungasketed cover; (2) one automatic gauge float well with an unbolted, ungasketed cover; (3) one ungasketed buildup column well with sliding cover; (4) one ladder well with ungasketed sliding cover; (5) one sample well-slit fabric seal with a 10 percent open area; and (6) one weighted, gasketed, mechanically-activated vacuum breaker. Based on this information, the values for K_{Fi} can be obtained from Table 12.3-16 and F_F can be computed as follows:

$$\begin{aligned} F_F &= (25 \times 1) + (28 \times 1) + (47 \times 1) + 76 \times 1 + 0 + (12 \times 1) + (0.7 \times 1) \\ &= 189 \text{ lbs-mole/year} \end{aligned}$$

The other parameters required for estimating the deck fitting losses include the vapor pressure function (P^*) with a value of 0.039, the average vapors molecular weight (M_v) of 60.05 lb/lb-mole, the value of the product factor (K_c) is 1.0 as defined above.

Thus,

$$L_F = F_F \times P^* \times M_v \times K_c$$

$$L_F = 189 \times 0.039 \times 60.05 \times 1 = 440 \text{ lbs/year}$$

Deck Seam Losses (L_D)

The procedures to estimate the emissions that escape through the deck seams are also included in the total losses from an internal floating roof storage tank. Equation (3-6) in Section 12 of *AP-42* estimates deck seam losses as follows:

$$L_D = K_D \times S_D \times D^2 \times P^* \times M_v \times K_c$$

where:

- K_D = deck seam loss per unit seam length factor (lb-mole/ft-year)
- S_D = deck seam length (feet)
- D = tank diameter (feet)
- P^* = vapor pressure function (identified above)
- M_v = average vapor molecular weight (lbs/lb-mole)
- K_c = product factor (identified above)

Since the deck is equipped with welded seams, the value of K_D is zero. Thus no emissions occur through the deck seams. Therefore,

$$L_D = 0 \text{ lbs/year}$$

Withdrawal Losses

Equation 3-4 in Section 12 of Supplement E of *AP-42* estimates withdrawal losses as follows:

$$L_{WD} = \frac{0.943 Q \times C \times W_L}{D} \left[1 + \frac{N_c \times F_c}{D} \right]$$

where:

- Q = annual throughput (bbl/year)
- C = shell clingage factor obtained from (Table 12.3-10)
- W_L = average liquid density (lbs/gal)
- D = tank diameter (feet)
- N_c = number of columns obtained (Table 12.3-5)
- F_c = effective column diameter (feet)

The annual volumetric throughput (Q) is estimated using the annual mass throughput and the acrylic acid density provided above. The calculation for the volumetric throughput is:

$$Q = \text{annual mass throughput} / \text{acrylic acid density}$$

$$Q = 25,500,000 \text{ lbs/year} / 368 \text{ lbs/bbl}$$

$$Q = 69,300 \text{ bbl/year}$$

The shell clingage factor (C) is obtained from Table 12.3-10 in Supplement E. Using the specifications on the acrylic acid tank, the value for the clingage factor is 0.0015 bbl/10³ ft².

The acrylic acid density provided for this calculation is 8.76 lbs/gal and the tank diameter also provided is 14.7 feet.

Since no specific data was provided in this example on the column construction, Table 12.3-5 in AP-42 recommends using a value of 1 for the number of columns (N_c) for tanks with a diameter less than 85 feet. An effective column diameter (F_c) of 1 is selected for this parameter as suggested in Note 2 to Equation 3-4 in AP-42.

The calculation for the withdrawal losses is then:

$$\begin{aligned} L_{WD} &= \frac{0.943 Q \times C \times W_L}{D} \left[1 + \frac{N_c \times F_c}{D} \right] \\ &= \frac{0.943 \times 69,300 \times 0.0015 \times 8.76}{14.7} \times \left[1 + \frac{1 \times 1}{14.7} \right] \\ &= 62 \text{ lbs/year} \end{aligned}$$

Total Storage Tank Losses

The total emissions from an internal floating roof storage tank is the sum of the rim seal losses, the deck fittings losses, the deck seam losses, and the withdrawal losses. The total losses are:

$$\begin{aligned}
L_T &= L_R + L_F + L_D + L_{WD} \\
&= 86 + 440 + 0 + 62 \\
&= 588 \text{ lbs/year} \\
&= 0.3 \text{ tpy}
\end{aligned}$$

5.5 EXAMPLE 5: EMISSIONS FROM BENZENE LOADING OPERATIONS

This example illustrates the *AP-42* calculation procedures, at a benzene manufacturing facility, for estimating emissions from transfer of benzene using dedicated, submerged loading transfer trucks equipped with condensers for product recovery.

5.5.1 Assumed Operating Parameters

Transfer truck volume:	9,200 gals
Benzene loading temperature:	80°F
Vapor recovery efficiency:	95 percent
Annual benzene loaded:	820,000 gals

5.5.2 *AP-42* Emission Factors

Emissions from uncontrolled loading operations can be estimated using the following *AP-42* equation obtained from Section 4.4.2 of *AP-42*:

$$L_L = 12.46 \times \frac{S \times P \times M}{T}$$

where

- L_L = loading loss, in lb/10³ gal of liquid loaded
- M = molecular weight of vapors, in lb/lb-mole, obtained from Table 4.3-2
- P = true vapor pressure of liquid loaded, in psia, obtained from Table 4.3-2
- T = temperature of bulk liquid loaded, in °R
- S = saturation factor, obtained from Table 4.4-1 and function of cargo carrier and mode of operation

From Table 4.3-2, M = 78 lbs/lb-mole

From Table 4.3-2, P = 2 psia

T = 80°F = 80°F + 460 = 540°R

From Table 4.4-1, for a submerged loading, dedicated, normal service operation, S = 0.6

Based on the above, the emission factor for benzene loading operations is

$$L_L \text{ (lb/10}^3 \text{ gal)} = 12.46 \times \frac{0.6 \times 2 \text{ psia} \times 78 \frac{\text{lb}}{\text{lb-mole}}}{540^\circ\text{R}} = 2.16 \text{ lb benzene/1,000 gal}$$

5.5.3 Estimating Uncontrolled Emissions

The general equation for estimating uncontrolled emissions from benzene loading operations is as follows:

$$\text{Uncontrolled Emissions} = \text{Quantity of Benzene Loaded} \times \text{Emission Factor}$$

$$\text{Uncontrolled Emissions} = 820,000 \text{ gal/year} \times 2.16 \text{ lb/1,000 gal} = 1,771 \text{ lb/year} = 0.9 \text{ tpy}$$

5.5.4 Estimating Emissions After Control

Emissions from controlled loading operations can be calculated by multiplying the uncontrolled emission rate by the control efficiency:

$$\text{Emissions After Control} = \text{Uncontrolled Emissions} \times \left(1 - \frac{\text{eff}}{100}\right)$$

$$\text{Emissions After Control} = 0.9 \text{ tpy} \times (1 - 95/100) = 0.045 \text{ tpy} = 90 \text{ lb/year}$$

5.6 EXAMPLE 6: EMISSIONS FROM SOLVENT DEGREASING

This example illustrates the calculation procedures required to estimate emissions from a solvent degreasing process using cold cleaners. Uncontrolled emissions from cold cleaners occur through waste solvent evaporation, solvent carryout, solvent bath, and spray evaporation.

5.6.1 Assumed Operating Parameters

Number of degreasing units: 5 units
Volume of virgin solvent used: 120 tpy

5.6.2 AP-42 Emission Factors

From AP-42 Table 4.6-2, VOC emissions are calculated using the following emission factors:

Waste solvent loss = 0.18 tpy/unit
Solvent carryout = 0.08 tpy/unit
Bath and spray evaporation = 0.07 tpy/unit

From XATEF, the emission factor for 1,1,1-trichloroethane (TCA) is 1,920 lb/ton of virgin solvent used.

5.6.3 Estimating Emissions

The general equation for estimating VOC emissions from a solvent degreasing process is as follows:

$$\text{VOC Emissions} = \text{Waste Solvent Losses} + \text{Solvent Carryout} + \text{Bath and Spray Evaporation}$$

Waste solvent losses	=	solvent losses factor x number of units in operation
	=	$0.18 \times 5 = 0.9$ tpy
Solvent carryout	=	solvent carryout factor x number of units in operation
	=	$0.08 \times 5 = 0.4$ tpy
Bath and spray evaporation	=	bath and spray evaporation factor x number of units
	=	$0.07 \times 5 = 0.4$ tpy
VOC emissions	=	$0.9 \text{ ton/year} + 0.4 \text{ ton/year} + 0.35 \text{ ton/year} = 1.65$ tpy

The general equation for estimating TCA emissions from the solvent degreasing process is as follows:

$$\text{TCA Emissions} = \text{TCA Factor} \times \text{Volume of Solvent Used}$$

$$\begin{aligned} \text{TCA Emissions} &= 1,920 \text{ lb/ton} \times 120 \text{ tpy} \\ &= 230,400 \text{ lb/year} \\ &= 115 \text{ tpy} \end{aligned}$$

5.7 EXAMPLE 7: PLANT EMISSIONS USING MASS BALANCE

The purpose of this example is to illustrate the use of material (mass) balances as a method for estimating plant emissions. The example scenario is a metal rolling unit that processes copper coil. Prior to a rolling step, copper coil is sprayed with oil for lubrication and heat dispersion. After rolling, the copper coil is sent to an annealer which has been shown to destroy 85 percent of the oil during the heat treatment of the copper coil. Negligible amounts of oil remain on the copper coil after annealing. The oil is assumed to be 100 percent VOC. The VOC emissions associated with this process occur from volatilization of lubricating oil during its application prior to rolling as well as the undestructed oil exhausted from the annealer.

5.7.1 Assumed Operating Parameters

Mass of copper coil processed:	5,000 kg
Mass of copper coil and oil sent to annealer:	5,075 kg
Mass of lubricating oil sprayed onto the copper:	3,000 kg
Mass of lubricating oil recovered:	2,800 kg

5.7.2 Estimating Emissions

The general formula to complete a material balance is represented by:

$$\text{Input} + \text{Generation} - \text{Output} - \text{Consumption} = \text{Accumulation}$$

where:	Input:	mass entering the process
	Generation:	mass produced in the process
	Output:	mass exiting the process
	Consumption:	mass consumed in the process
	Accumulation:	mass that builds up within the process

For this example, the parameters listed above are described as:

Input:	mass of lubricating oil applied (3,000 kg)
Generation:	not applicable/no material generation (0 kg)
Output:	mass of oil lost as an emission
Consumption:	mass of oil destroyed in the annealer
Accumulation:	mass of lubricating oil recovered (2,800 kg)

The estimate for the Consumption parameter is calculated from the mass of copper coil processed, the mass of copper coil and oil sent to the annealer, and the oil destruction efficiency as it is exposed to high temperatures in the annealer.

$$\begin{aligned}\text{Consumption} &= (\text{mass of coil/oil to annealer} - \text{mass of coil processed}) \times 85 \text{ percent} \\ &= (5,075 \text{ kg} - 5,000 \text{ kg}) \times 0.85 \\ &= 64 \text{ kg oil destroyed in the annealer}\end{aligned}$$

After simplifying the material balance formula, the estimate of the Output (emissions) from this process is:

$$\text{Input} - \text{Output} - \text{Consumption} = \text{Accumulation}$$

Or:

$$\text{Output} = \text{Input} - \text{Consumption} - \text{Accumulation}$$

$$\text{Output} = 3,000 \text{ kg} - 64 \text{ kg} - 2,800 \text{ kg}$$

$$\text{Output} = 136 \text{ kg}$$

The VOC emissions associated with this process are thus 136 kg oil per 5,000 kg of copper coil processed, or 0.027 kg oil per kg of copper coil processed.

5.8 EXAMPLE 8: PROCESS EMISSIONS USING SOURCE TEST DATA

The purpose of this example is to illustrate the use of source test data as a means to estimate process emissions. During a source test, the flowrate of the stack is measured and multiple samples of the pollutant concentration in the stack are taken. This example is for a paint manufacturing facility, where the source test was conducted on a stack for a process spray booth. The materials emitted from the spray booth stack are assumed to be 100 percent VOC.

5.8.1 Assumed Operating Parameters

Stack flowrate:	50,000 scm/hr
Average measured VOC concentration from stack:	0.005 kg VOC/scm
Spray booth annual operation:	2,080 hrs/year

5.8.2 Estimating Emissions

Since the source testing provided a VOC concentration and the average stack exhaust flowrate, the concentration can be converted to a mass flowrate:

$$\begin{aligned}\text{Mass Flowrate} &= \text{volumetric flowrate} \times \text{concentration} \\ &= 50,000 \text{ scm/hr} \times 0.005 \text{ kg VOC/scm} \\ &= 250 \text{ kg VOC/hr}\end{aligned}$$

The annual VOC emissions can then be estimated using the mass flowrate and the annual hours of operation for the paint spray booth:

$$\begin{aligned}\text{Emissions} &= \text{mass flowrate} \times \text{annual hours operation} \\ &= 250 \text{ kg VOC/hr} \times 2,080 \text{ hrs/yr} \\ &= 520,000 \text{ kg VOC/yr or 520 metric tons}\end{aligned}$$

REFERENCES FOR SECTION 5.0

1. U.S. Environmental Protection Agency. *A Compilation of Air Pollutant Emission Factors AP-42 Fourth Edition, Supplements A through E*. Office of Air Quality Planning and Standards, Research Triangle Park, NC, September 1992.
2. U.S. Environmental Protection Agency. Crosswalk/Air Toxic Emission Factor (XATEF) Database Management System, Version 1.2. Office of Air Quality Planning and Standards, Research Triangle Park, NC, September 1992.

6.0 INDUSTRY DESCRIPTIONS

This chapter provides basic descriptions of some of the air pollutant emitting processes associated with most of the major industry categories identified in *AP-42*. These are intended as examples of the variety of existing source types and related emission estimation methods. *AP-42* groups industries into 12 general categories:

Group 1	External combustion
Group 2	Solid waste disposal
Group 3	Stationary internal combustion
Group 4	Evaporation losses
Group 5	Chemical process industry
Group 6	Food and agriculture industry
Group 7	Metallurgical industry
Group 8	Mineral products industry
Group 9	Petroleum industry
Group 10	Wood products industry
Group 11	Miscellaneous sources
Group 12	Storage tanks

6.1 COMMON OPERATIONS AND SOURCE TYPES

Of the many air pollutant emitting processes present in industrial operations, there are a number of basic categories that are common to many industries and applications. Table 6-1 provides a general overview of those common process types/emission sources occurring in the major *AP-42* industry groups. Table 6-2 lists the primary air pollutant emissions associated with each process.

TABLE 6-1. BASIC PROCESS TYPES/EMISSION SOURCES IN MAJOR INDUSTRY GROUPS

Process Types/Emission Sources	Major AP-42 Industry Groups											
	1	2	3	4	5	6	7	8	9	10	11	12
External combustion (all fuels)		
Solid waste incineration			
Internal combustion			.									
Surface coating				.						.		
Organic liquid storage
Organic liquid transportation and handling
Organic chemical manufacturing processes					.							
Organic separation processes					.							
Inorganic chemical manufacturing processes					.		.					
Organic solvent cleaning				.			.					
Waste water collection, treatment and storage					
Metallurgical smelting/melting in furnaces							.					
Metallurgical chemical processes							.					
Sintering processes							.					
Coking processes							.	.				
Metal finishing							.					
Solid material handling/conveying		
Crushing/screening				
Cement kilns								.				
Petroleum manufacturing processes									.			.
Asphalt production									.			
Pulp and paper processes										.		

MAJOR AP-42 INDUSTRY GROUPS

- | | |
|------------------------------------|-------------------------------------|
| 1 - External combustion | 7 - Metallurgical industry |
| 2 - Solid waste disposal | 8 - Mineral products |
| 3 - Stationary internal combustion | 9 - Petroleum production/processing |
| 4 - Evaporation losses | 10 - Wood products |
| 5 - Chemical process industry | 11 - Miscellaneous |
| 6 - Food and agriculture | 12 - Storage tanks |

TABLE 6-2. POLLUTANTS FROM BASIC PROCESSES/EMISSION SOURCES

Process Types/Emission Sources	Pollutants						
	PM-10	SO _x	NO _x	CO	TOC/ VOC*	Pb	HAPs
External combustion (all fuels)	•	•	•	•			•
Solid waste incineration	•	•	•	•			•
Internal combustion	•	•	•	•		•	•
Surface coating					•		•
Organic liquid storage					•		•
Organic liquid transportation and handling					•		•
Organic chemical manufacturing processes	•	•	•	•	•		•
Organic separation processes					•		
Inorganic chemical manufacturing processes	•	•	•	•	•		•
Organic solvent cleaning					•		•
Waste water collection, treatment and storage					•		•
Metallurgical smelting/melting in furnaces	•			•		•	•
Metallurgical chemical processes	•	•		•			•
Sintering processes	•			•			•
Coking processes	•	•		•	•		•
Metal finishing	•					•	
Solid material handling/conveying	•						
Crushing/screening	•						
Cement kilns	•	•	•	•			
Petroleum manufacturing processes	•	•	•	•	•		
Asphalt production					•		•
Pulp and paper processes		•	•	•			•

Pollutants:

- PM-10 - particulate matter less than 10 microns in aerodynamic diameter
- SO_x - sulfur oxides
- NO_x - nitrogen oxides
- CO - carbon monoxide
- VOC - volatile organic compounds
- Pb - lead
- HAPs - hazardous air pollutants (air toxics)
- TOC - Total organic compounds

*TOC/VOCs are emitted from combustion sources but at relatively smaller mass rates, usually in the form of POMs which are HAPs, but also technically TOC and are generally photochemically reactive.

Each process listed in Table 6-1 is described separately in *AP-42*, including discussions of the common process types and emission sources. Each subsection describes the process, the principal sources of emissions within the process, factors affecting emissions, and typical methods of control, where available. The text in this chapter is summarized from more detailed descriptions given in *AP-42*, with some additional material from other sources where cited.¹ For more detailed information, the reader should consult the full descriptions (with emission factors) given in *AP-42*, and, if necessary, the references listed in *AP-42*.

6.2 EXTERNAL COMBUSTION

In the external combustion process, solid, liquid or gaseous fuels (primarily coal, fuel oil and natural gas), are burned to yield energy in steam/electric generating plants, industrial boilers, and commercial and domestic combustion units. Other fuels used in relatively small quantities are liquefied petroleum gas, wood, coke, refinery gas, blast furnace gas and other waste or byproduct fuels. Coal, oil and natural gas currently supply more than 90 percent of the total thermal energy consumed in the United States. Power generation, process heating and space heating are some of the largest fuel combustion sources of SO_x, NO_x and particulate emissions.

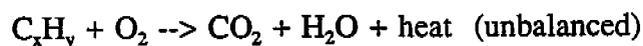
This discussion will provide general information related to emission estimation techniques for all types of external combustion. The range of source types and more specific details are discussed further in *AP-42*. The following are major industrial divisions within the External Combustion source category as listed in *AP-42*:

- bituminous and subbituminous coal combustion
- anthracite coal combustion
- lignite combustion
- fuel oil combustion
- waste oil combustion
- natural gas combustion
- liquefied petroleum gas combustion
- wood waste combustion in boilers

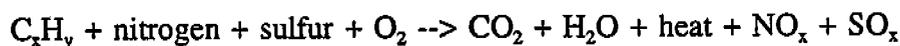
Typical processes associated with the external combustion category include fuel preparation, combustion and waste product disposal. Most of the external combustion emission factor data contained within *AP-42* are associated with the individual types of combustion processes and fuels. Fuel preparation and waste product disposal involve solid material

processing and handling operations; liquid and gaseous fuel storage are also addressed under organic liquid storage (see Section 6.6).

Combustion is a chemical process in which organic material is oxidized in an exothermic reaction. The main reactants are hydrocarbons and oxygen, and the main combustion products are CO₂, water, and heat, as shown in the following reaction:



The reaction shown above is the principal reaction of interest during the combustion process. In addition, because organic materials (such as oil or gas) contain nitrogen and sulfur in addition to hydrocarbons, other combustion products are typically generated:



The NO_x generated during combustion is composed mainly of NO₂, with some amounts of NO, NO₃, N₂O; HNO₃ is also produced as a byproduct regardless of fuel used. Nitrogen for the reaction is provided by the fuel being combusted and from NO₂ in the combustion air. The SO_x generated during combustion is primarily SO₂, with some SO₃ (about 2 percent) and sulfates. Nearly all of the sulfur for the reaction is derived from the fuel being burned.

Products of incomplete combustion and noncombustible products may be released in addition to the combustion products and byproducts listed above. Incomplete combustion and noncombustible products include:

- CO
- VOCs or TOCs
- PM
- PAHs
- POM
- heavy metals

Particulate emissions from solid fuel external combustion can be significant, especially if combustion is not properly controlled. The magnitude of emissions of CO and VOC from combustion processes is relatively insignificant in comparison to other pollutants. Combustion is considered a minor source of VOC and CO in comparison to other sources of these pollutants. Emissions of products of incomplete combustion (PICs) and heavy metals from combustion may occur in relatively low mass and concentrations, but are important because they may be toxic. The following critical factors affect emissions from external combustion:

- configuration of the combustion chamber and fuel-delivery systems
- boiler operation (particularly temperature, air supply, fuel feed, startup and upset conditions)
- fuel type and composition

The technology-specific sections of *AP-42* address how the first two of these items affect emissions from different types of boilers. Table 6-3 provides an overview of the range of fuels used in external combustion, including typical analyses of the carbon, hydrogen, sulfur and ash contents of fuels as well as their heating values.

It should be noted that emissions of different pollutants are affected by the above factors in different ways. Particulate emissions are more likely to be influenced by the firing configuration and changes in operation. Fuel ash content is also important in particulate development. Sulfur oxide emissions are less affected by operation, but are highly dependent on the level of sulfur in the fuel, since almost all of the fuel sulfur is typically converted to SO₂, SO₃ or sulfates. This phenomenon of near-complete conversion is often referred to as a "stoichiometric" reaction, as indicated by the following equation which accounts for conversion of over 95 percent of fuel sulfur to SO₂.



The minor amount of sulfur not converted is typically bound in the ash; the amount of binding is dependent on other fuel characteristics (for example, high alkali coals tend to bind more SO_x in ash).

TABLE 6-3. TYPICAL ANALYSIS AND HEATING VALUES OF VARIOUS FUELS

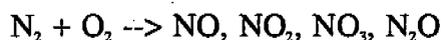
Fuel Type	Analysis, % by weight						Heating Value		
	C	H	S	N	Ash	BTU/lb	BTU/gal	BTU/ft ³	
Natural Gas	75	25				19,695		950-1,150	
Propane	82	18				19,854			
Butane	83	17				19,620			
Naphtha	85	15	0.03			19,152			
Kerosene	86	13.7	0.07			18,558			
Heating Oil	86	13.2	0.3			18,378			
No. 1 Fuel Oil	86.4	13.6	0.09	0.003	<0.01		137,400		
No. 2 Fuel Oil	87.3	12.6	0.22	0.006	<0.01		139,600		
No. 4 Fuel Oil	87	11.7	1.35	0.24	0.02		145,100		
No. 5 Fuel Oil	^a	-	-	-	0.10-1.10		148,800		
No. 6 Fuel Oil	84.7-87.3	10.5-12	0.8-4.0	0.18-0.28	0.02-0.04		152,400		
Anthracite	83.9	2.9	0.7		8.0	13,720			
Bituminous Coal	80.7	4.5	1.8		6.2	11,500-14,000			
Sub-Bituminous Coal	54.6	3.8	0.4		3.8	9,500-11,500			
Lignite, Brown Coal	42.4	2.8	0.7		6.2	6,300-8,300			
Coke	85	0.8	1.0		10.7	12,690			

^a dash indicates no data

Source: References 2 - 5.

NO_x emissions are formed by two mechanisms, oxidation of fuelbound nitrogen and thermal fixation of the nitrogen in combustion air. Fuel NO_x formation is primarily a function of the nitrogen content of the fuel and available oxygen. Thermal NO_x is largely a function of temperature and available oxygen, factors which depend on boiler size, firing configuration and operating practices. Figure 6-1 demonstrates the effect of temperature on NO_x formation in coal boilers. Note that NO_x is formed in appreciable amounts only at temperatures above 1400–1500°C. ("Prompt" NO is produced in small amounts at all combustion temperatures due to the reaction of oxygen with hydrogen cyanide formed from nitrogen and hydrocarbons.) Each of these variables can influence the amount of NO_x formed by these two mechanisms. For example, fuel NO_x is the more important mechanism in residual oil boilers, while thermal NO_x is dominant in units firing distillate oils, which have negligible nitrogen content.

The specific reaction involved in NO_x formation is:



(of which NO₂ is the major net product) and the further formation of nitric acid:



Normally, only minor amounts of VOCs and CO will be emitted from the combustion of fuel oil. The rate at which VOCs are emitted depends on combustion efficiency. Emissions of trace elements (including possible air toxics) from external combustion boilers are related to the trace element concentrations in the fuel.

Emission estimates for small boilers tend to be more uncertain, since they typically involve more unknown variables, less maintenance, and fewer regulatory and economic incentives to adjust boiler performance. Considering these same aspects, utility boilers would typically have the more reliable emission estimates and small boilers burning wood, wastes or other less-uniform biomass fuels would usually have less certain estimates.

AP-42 provides emission factors for a wide range of external combustion technologies and fuels. Table 6-4 is an example of the variety and level of specificity of these factors, including

TABLE 6-4. EXTERNAL COMBUSTION FACTORS FOR BITUMINOUS AND SUBBITUMINOUS COAL^a

FIRING CONFIGURATION	PARTICULATE		SO _x ^b		NO _x		CO		VOC		METHANE	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Pulverized Coal												
Dry Bottom	5A ^c	10A	19.5S ^d (17.5S)	39S (35S)	10.5 (7.5)	21 (15)	0.3	0.6	0.04	0.07	0.015	0.03
Wet Bottom	3.5A	7A			17	34						
Cyclone Furnace	1A	2A	19.5S (17.5S)	39S (35S)	18.5	37	0.3	0.6	0.04	0.07	0.015	0.03
Spreader Stoker Uncontrolled	30	60	19.5S (17.5S)	39S (35S)	7	14	2.5	5	0.04	0.07	0.015	0.03
Multiclone/reinjection	8.5	17										
MC/No reinjection	6	12										
Overfeed Stoker Uncontrolled	8	16	19.5S (17.5S)	39S (35S)	3.25	7.5	3	6	0.04	0.07	0.015	0.03
Multiclone	4.5	9										
Overfeed Stoker Uncontrolled	7.5	15	15.5S	31S	4.75	9.5	5.5	11	0.65	1.3	0.4	0.8
Multiclone	5.5	11										
Handfired	7.5	15	15.5S	31S	1.5	3	45	90	5	10	4	8

^a Refer to complete Table 1.1-1 in AP-42

^b Factors in parentheses are for subbituminous coal

^c "A" = Fuel ash content

Example: The particulate emission factor for dry bottom firing of pulverized coal with an ash content of 5 percent would be:
 6A kg/Mg = 6*5 kg/Mg
 = 30 kg/Mg

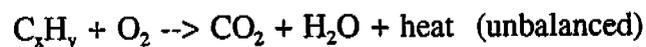
^d "S" = Fuel sulfur content

the dependence of certain rates on fuel content ("S" and "A" indicate factors to be multiplied by the fuel sulfur or ash content).

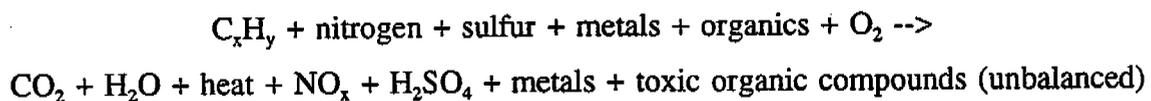
Emission reduction techniques for external combustion include: use of low sulfur fuel; processing of fuel to remove sulfur; manipulation of particulate and NO_x formation mechanics (including boiler geometry, firing mechanisms and flyash reinjection); and application of control devices such as cyclones, precipitators, baghouses or scrubbers. The main factors that influence choice of control types are the fuel, levels of emissions of specific pollutants, and the type of boiler technology in use.

6.3 SOLID WASTE DISPOSAL

Solid waste disposal through incineration involves the combustion of solid wastes, producing ash and gases. In addition to reducing the physical volume of the solid waste, the incineration process can also be exploited to recover energy from the combustion process for heating water, steam or other processes. The reaction that characterizes solid waste incineration is the combustion reaction:



Due to the presence of a variety of chemicals and materials in the incineration process, additional byproducts are produced in the combustion process:



Maintaining high combustion efficiency can be difficult with waste materials, due to moisture, the size and composition of materials burned, level of incombustibles, intermittent operation and potential hazards involved.

The following are various types of solid waste incineration:

- Refuse-derived fuel combustion generally involving municipal solid waste (MSW)
- Automobile body incineration
- Conical burners (a specialized burner for wood and MSW)
- Open burning
- Sewage sludge incineration

These types of incineration are performed in several different types of units which involve a variety of methods of fuel/waste processing and delivery, combustion and air control, and heat recovery. In some cases, multiple wastes and/or fuels can be used in one unit, such as a combination of refuse and sewage sludge. Due to the varied nature of incinerated refuse and differences in incinerator design, there are several potentially significant air emissions associated with refuse combustion. The following major pollutants are emitted:

- PM
- metals (in solid form as particulates, except for mercury)
- acid gases [primarily hydrogen chloride (HCl) and sulfur dioxide (SO₂)]
- CO
- NO_x
- TOCs

AP-42 includes emission factors (in pounds emitted per ton of waste burned) for each of these pollutants for mass burn incinerators, and for all but toxic organics for other municipal waste combustors; for industrial/commercial combustors ranging from trench-type to domestic and pathological waste incinerators; and for sewage sludge incinerators. Additional factors for aldehydes and acetic acid are available for automobile body incinerators.

Mechanisms involved in pollutant formation are as follows. Combustion gas turbulence entrains particulate matter, which can also be produced by condensation of metals and other components of the exhaust stream. Acid gases are produced in direct relation to the levels of chlorine and sulfur in the wastes, which are evolved from rubber, plastic, paper and other components. CO is formed due to low oxygen availability or low temperatures, while NO_x

formation is mostly dependent on nitrogen content of wastes burned and due to the relatively low combustion temperatures, and is less dependent on combustion conditions.

Many emission reduction techniques are used for the different types of solid waste combustion, generally using techniques similar to those mentioned for external combustion. Emission reduction can be achieved by altering the design of the incinerator, using emission control devices (*e.g.*, scrubbers), and modifying the waste mix input to the incinerator.

6.4 STATIONARY INTERNAL COMBUSTION

In internal combustion, fossil fuels (primarily fuel oil and natural gas), are burned to yield energy for electrical power generation, to pump gas or other fluids, or to compress air for pneumatic machinery. *AP-42* includes material on the following industry-related internal combustion sources:

- Stationary gas turbines - using natural gas, distillate (No. 2) or residual oil; for electric power generation (continuous, peaking or standby), gas pipeline pumping or compression, and in some process industries.
- Reciprocating engines - natural gas engines for compression in natural gas extraction, processing and transportation; a wide variety of gasoline and diesel engines for industrial machinery and equipment; large-bore diesel or diesel/natural gas engines for oil and gas production, base or standby electric generation, irrigation and other uses

The following emission factors for these engines are included in *AP-42*:

- NO₂
- CO
- hydrocarbons
- SO₂
- particulates

These emission factors are expressed in multiple time, power or fuel-related units, such as grams per hour, grams per kilowatt-hour or kilograms per liter. They are also specific to the type of fuel used.

For natural gas-fired units, NO_x is the main pollutant of concern. Emission levels are affected by air/fuel ratio, engine load, air temperature and humidity. NO_x control for these units

can be based on manipulation of these variables or may employ exhaust gas recirculation, water injection or steam injection.

6.5 SURFACE COATING EVAPORATION LOSSES

Evaporative losses include the organic solvents emitted from dry cleaning plants and surface coating operations, and the volatile matter in petroleum products. Surface coating includes the application of solvent-based paints, varnishes and lacquers, water-thinned paints, powders or other protective or decorative coatings to the surface of many varied products or materials. Coating processes may involve brushing, rolling, spraying, flow coating, or dipping a surface to coat it with a VOC-containing liquid. VOCs volatilize from the coating during the drying process and enter the surrounding air, leaving the solid components which compose the desired coating. The drying process can be accelerated by air circulation or by heating, typically performed in an enclosed drying oven.

Coating formulations can contain a wide range of VOCs, from sealers and stains that may contain 80 to 90 percent VOC through typical varnishes, enamels and lacquers in the 50 to 80 percent VOC range to low-VOC coatings, waterborne coatings and powder coatings which can range from marginal reduction of the VOC contents listed above to complete elimination of solvents from their formulations.

A coated material may also be cured, either by chemical or physical processes, to fix or preserve the coating. Baking, heating or radiation (such as ultraviolet light) are typically used to effect the curing process. The actual components of VOC emissions may be altered by the heat or radiation or if chemicals are used in the curing process.

The following are major components of VOC emissions from coating operations:

- aliphatic and aromatic hydrocarbons
- alcohols
- ketones
- esters
- alkyl and aryl hydrocarbon solvents
- mineral spirits

Several interrelated factors influence VOC emissions from coating operations. These include the amount of VOC in the coating, application method, the type and size of material being coated, temperature, drying techniques, and control systems or other emission reduction measures used. Additional factors that are more specific to a given coating process include air circulation and turbulence, the sequence and speed of successive operations (such as multiple coats and intervening processes) and the physical arrangement of these operations in the facility.

AP-42 includes characterizations of emissions from the following specific types of coating operations:

- can coating
- magnet wire coating
- large appliance coating
- metal furniture coating
- miscellaneous metal parts and products coating
- flat wood products coating
- paper coating
- polymeric coating of supporting (non-paper) substrates
- automobile and light-duty truck coating
- pressure-sensitive tapes and labels coating
- metal coil surface coating
- magnetic tape coating
- coating of plastic parts for business machines
- nonindustrial surface coating

All of these processes involve multiple steps which may be repeated or sequenced in different ways depending on the item being coated and the type of coating desired. These are described in detail in *AP-42*. Typical processes involve preliminary cleaning or treatment of the item as well as multiple applications of coatings with intervening drying/curing steps. Each of these steps can affect the total emissions from a process as well as the distribution of emissions among the steps.

The shape of the item to be coated is an important consideration, since this is the determining factor in selecting the application method, coating type and solvent content. Products consisting of a continuous wire, roll or number of flat sections can be coated using methods such as dip, roller or flow coating which allow lower solvent content in the coating and better enclosure of the application and drying areas. Other products such as vehicle parts,

appliances and furniture must be sprayed, requiring thinner coatings and allowing much higher solvent evaporation potential from the spray droplets. The shape and/or size of these parts can also make enclosure and capture of volatilizing solvent more difficult.

Most solvents are emitted during application and drying, although the distribution of emissions between these processes can vary. Roller or dip coating results in fewer emissions during application (as little as 19 percent of the total VOC content), while spray application can result in up to 100 percent of the VOC being emitted in the spray area. For the low-emission application methods, emissions from drying ovens can be substantial (estimated at 80 to 95 percent for paper coating), while spray application for large appliances is estimated to leave only 20 percent to be emitted from the oven.

Table 6-5 lists the types of emission factors that have been developed for a number of operations in the various industries that use surface coating. These values are typically expressed in terms of emissions per hour, per area of surface coated or per item coated. These emission factors are often based on mass balances of solvent used in typical operations, and thus should produce reasonable first estimates of emissions if the technology and coatings are similar to the process of concern. For some coating operations, the only suggested emission estimation method is performing a site-specific materials balance. In most other cases as well, this is the most reliable method for developing an emission estimate for a specific operation, although the effort involved is much greater than the method applying available emission factors.

Table 6-5 also shows available emission controls for the different types of surface coating operations. In addition to the add-on controls indicated, the following three options would be applicable in essentially any context, because they can reduce the net amount of solvent needed for an operation:

- Covers and containment for solvent storage and coating preparation equipment
- Substitution of low-solvent, solvent-free or water-borne coatings
- Improvement of transfer efficiencies

Use of incinerators, adsorbers or condensers depends on the ability to capture the emissions at high concentrations. These have been used successfully in a number of surface coating operations, with the typical application capturing the majority of process emissions in a drying

TABLE 6-5. AP-42 EMISSION FACTORS AND CONTROL OPTIONS FOR SURFACE COATING

Coating Category	Types of Emission Factors in AP-42	Emission Control Options					
		Incineration	Carbon Adsorber or Condenser	Low-Solvent	Water or No Solvent	UV-Curable	Transfer Efficiency
Cans	Per hour	*	•	•	•	•	•
Wire	Per hour	•					
Flatwood	Per ft ²	Rare	Feasible		•	•	
Misc. metal part/products	Per year	•	•	•	•		•
Paper	Mat. bal. ^b	•	•	•	•		
Polymeric coating	Mat. bal.	•	•				
Automobiles, light trucks	Per hour, per unit	•	•	•	•		•
Tapes and labels	Mat. bal.	•	•				
Metal coils	Per hour or ft ²	•		•			
Large appliances	Mat. bal.				•		•
Metal furniture	Per hour or ft ²			•	•		•
Magnetic tape	Mat. bal.	•	•				
Business machines	Per ft ² , Mat. bal.						•

*. = indicates a control type demonstrated and in use. See text.

^bMat. bal. = Materials balance is a recommended or optional method.

oven enclosure which is ducted to an incinerator. In some cases, heat from the incinerator is recycled back into the drying oven for energy recovery. Carbon adsorption and condensation can be used in a number of cases, but are less likely to be used where more than one solvent is involved, due to the need to further process the recovered solvents.

6.6 STORAGE, TRANSPORTATION, AND HANDLING OF ORGANIC LIQUIDS

Storage vessels containing organic liquids can be found in many industries, including petroleum producing and refining, petrochemical and chemical manufacturing, bulk storage and transfer operations, and other industries consuming or producing organic liquids. Organic liquids include petroleum liquids, which are usually mixtures comprised of a variety of hydrocarbons (*e.g.*, gasoline and crude oil), and volatile organic liquids, which are pure chemicals or mixtures of highly-similar chemicals (*e.g.*, benzene and mixed alcohols).

The following basic tank designs are used for organic liquid storage vessels.

- fixed roof - considered the minimum acceptable level of quality; static flat, cone or dome roofs with a pressure/vacuum vent; constant volume
- floating roof (internal or external) - floating roof is buoyed by the liquid in the tank, either directly or on pontoons; internal roofs have an additional fixed roof over the floating roof, while external floating roof tanks do not; variable volume
- variable vapor space - equipped with an expandable vapor reservoir (usually telescoping "lifter" roof or flexible diaphragm); normally connected to fixed roof tanks in order to handle internal vapor pressure changes
- pressure tanks - designed to handle solvents with high vapor pressures; many shapes and sizes; high pressure tanks (over 15 psig) prevent evaporative or working losses, low pressure tanks (2.5 to 15 psig) have working losses

Tank sizes can range from 500 gallons to more than 1 million gallons. Solvent and other organic chemical storage tanks are usually fixed roof, pressure or variable vapor space tanks at the lower end of this capacity range, and petroleum liquids are typically stored in larger floating roof or fixed roof tanks.

VOC emissions from storage tanks depend on tank type, design and dimensions, usage patterns, organic liquid volatility, temperature and pressure, and the quality of installation and maintenance. The primary types of storage tank emissions are described below.

- Working loss - caused by moving fluid either into or out of the tank; proportional to the volume of the fluid coming in (filling losses, caused by vapor displacement by entering fluid) or leaving (emptying losses, due to evaporation of liquid left on exposed inner walls of floating roof tanks or expansion of fresh air drawn into the vapor space of fixed roof tanks as it becomes saturated)
- Breathing (or storage) loss - caused by the expansion and contraction of the vapors above the stored liquid due to changing temperatures; emitted almost continuously by fixed roof tanks only

Table 6-6 provides an overview of tank-specific emission types and critical variables relevant to each tank type. As indicated in the footnote to Table 6-6, the variables listed in the table are in addition to basic variables previously noted which are relevant to almost all emission types.

Each emission type for each tank type has characteristically different emissions estimation equations based on empirical relationships. *AP-42* includes equations, supplementary relationships, many data sources, and complete guidance for the estimation of all emission types listed in Table 6-6. The *AP-42* algorithms for calculating emissions from storage tanks are very large, and are therefore not reproduced here. The 1992 version of *AP-42* contains a new Chapter 12 that presents this algorithm.

AP-42 includes a methodology for the estimation of emissions of HAPs from storage tanks, based on the assumption that the mixture in a tank behaves as an ideal liquid. The partial pressures of mixture constituents are calculated from their vapor pressures and liquid mole fractions. This process is based on calculation of the vapor pressure, density and molecular weight of the mixture; use of these values to estimate total emissions with the appropriate storage tank equations; and calculation of constituent weight fractions in the vapor phase to allocate total emissions to the constituents.

TABLE 6-6. STORAGE TANK EMISSION SOURCES AND CRITICAL VARIABLES

Tank Type	Types of Emission Sources		Critical Emissions Variables ^a
	Working Losses	Storage Losses	
Fixed Roof	Filling (vapor expulsion) Emptying (vapor expansion)	Breathing (vapor expansion)	Tank capacity and diameter Vapor space volume Factors for paint, type of product and small tanks
External Floating Roof	Withdrawal losses (interior surfaces)	Rim seal and roof fitting losses	Tank Characteristics (diameter, rim seal type, roof fittings) Wind (rim seals) Liquid-to-shell clingage
Internal Floating Roof	Withdrawal losses (interior surfaces)	Rim seal, deck fitting and deck seam losses	Tank Characteristics (diameter, rim seal type, roof supports, deck fittings and seams) Wind (rim seals) Liquid-to-shell clingage
Pressure	Withdrawal/filling (low pressure only)	Fugitive (if undermaintained)	Maintenance
Variable Vapor Space	Vapor displacement during filling	None	Expansion capacity

^aTank use (throughput and turnovers), liquid/vapor characteristics (molecular weight, density, vapor pressure and temperature), local atmospheric conditions (ambient temperature and pressure) and maintenance are important factors relevant to all tank types.

A personal computer-based program called "TANKS" has been developed to automate the current AP-42 algorithms for fixed and floating roof tanks and HAP speciation. Additional information is also available for a number of special cases such as high turnover rates, nitrogen blanketing, cleaning and degassing, limited time intervals, underground and vapor-balanced tanks and emission estimates with control devices. Further information is available from the EPA CHIEF BBS, access to which is described in Appendix E.

Emission controls vary depending on the type of tank. Fixed roof tanks can be controlled by the addition of an internal floating roof and seals, vapor recovery using vapor/liquid absorption, vapor compression, vapor cooling and/or vapor/solid adsorption, or thermal oxidation. Emission controls for floating roof tanks consist of maintenance, improvement of seals and other components and addition of a fixed roof to external floating roof tanks where possible. Proper maintenance is the only emission control applicable to variable vapor space and pressure tanks.

The transportation and marketing of organic liquids (including petroleum liquids and other volatile organic liquids) involves many distinct operations, each of which represents a potential opportunity for evaporative losses of the VOC being transported or handled. These sources are separated into three categories with the following types of emissions:

- Rail tank cars, tank trucks and marine vessels: loading, transit and ballasting losses
- Service stations: bulk fuel drop losses and underground tank breathing losses
- Motor vehicle tanks: refueling losses

Loading losses occur as organic vapors are released when displaced from "empty" tanks as they are refilled with an organic liquid. The vapors are a composite of the previous cargo and the present cargo, so vapor characteristics will be a combination of the previous and new loads. Accounting for different vapor characteristics is not difficult if a carrier is in "dedicated" service (transporting only one type of product), which occurs in many petroleum transport operations. Other important considerations are the method of unloading and loading, as well as any operations involved in transporting empty carriers from the unloading location to the loading location. The three principal methods of loading are splash loading, submerged loading and bottom loading. Splash loading results in high levels of vapor generation and loss, while submerged loading and bottom loading result in much lower vapor generation. AP-42 provides

an equation for loading petroleum liquids into trucks, tankers and vessels which is based on the molecular weight, vapor pressure and temperature of the liquid as well as a saturation factor related to the type of loading and the previous load. Emission factors are also provided for gasoline and crude oil loading at marine terminals, based on the type of service and previous cargo.

Transit losses occur as vapor expansion in tanks causes venting of pressure during transit, similar to breathing losses in storage tanks. *AP-42* provides a simple relationship for calculation of transit losses from ships and barges (in pounds per week per gallon transported), based on liquid vapor pressure and vapor density, and also gives emission factors for common liquids. For tank trucks and tank cars, emissions depend on a number of factors related to the extent of venting of the tank in transit, such as tightness of the tank and pressure settings on the relief valve. *AP-42* provides truck and rail tank car emission factors only for gasoline transit losses.

Ballasting losses occur when marine tankers vent cargo compartments of organic liquid vapor as those compartments are filled with ocean water to serve as ballast. The vapor released in ballasting losses are characteristic of the last cargo that the compartment contained. *AP-42* provides an equation to calculate ballasting emission factors based on amount of ballast water used, which considers the vapor pressure of the discharged crude oil and the distance between the cargo and the deck above prior to unloading.

Bulk fuel drop losses occur as underground storage tanks (USTs) are filled, and vapor is allowed to escape the tank into the atmosphere. Breathing losses from USTs occur continuously due to gasoline evaporation and barometric pressure changes. The frequency of gas withdrawal affects breathing losses, as fresh air is allowed in when gas is withdrawn, thus increasing the amount of vapor which can form.

Refueling losses occur during motor vehicle tank filling. As the tank is refueled, vapors are produced and emitted to the atmosphere. Vapor buildup in the motor vehicle tank is also vented. Spillage loss from spilled fuel also commonly occurs during refueling.

AP-42 provides emission factors for UST filling, breathing and emptying losses as well as vehicle refueling operations, based on throughput in gallons of gasoline. It should be noted that, in most cases, vehicle refueling emissions can be simulated using the EPA MOBILE mobile source emission factor model, which incorporates vapor pressure and vehicle technology into its calculations.⁷

Vapor emissions during transfer operations can be reduced using a vapor recovery system in which vapors otherwise lost to the air are transferred back to the original storage unit or to a vapor recovery unit using refrigeration, absorption, adsorption or compression to liquefy vapors and return them to the storage tank. Vapor recovery systems are most common to rail tank cars and tank trucks, although some marine vessels have systems for use when performing ballasting operations. Use of "Stage I" vapor balancing allows return of vapors from service station tank filling to a recovery system at the truck loading facility. "Stage II" controls are available for the capture and recycling of vehicle refueling emissions.

6.7 CHEMICAL PROCESS INDUSTRY

Numerous organic chemical manufacturing processes are employed to produce specific desired organic chemicals from raw materials or intermediates. The range of products is very broad and some chemicals are produced by multiple processes or variations. Processes related to 16 categories of organic chemicals or products are addressed in *AP-42*:

- adipic acid
- carbon black
- charcoal
- explosives
- paint and varnish
- phthalic anhydride
- polyvinyl chloride and polypropylene
- poly(ethylene terephthalate)
- polystyrene
- printing ink
- soap and detergents
- synthetic fibers
- synthetic rubber
- terephthalic acid
- pharmaceutical production
- maleic anhydride

Although this section does not address each of these processes, some of the general features of organic chemical manufacturing processes are described. Organic chemical separation processes are addressed in Section 6.7.1.

A multitude of processes used in chemical manufacturing and manipulation, usually referred to by either a proprietary or personal name (often the name of the company or person responsible for developing the process) or by a chemical name. For instance, adipic acid production can be performed using the Farben process, in which cyclohexanone is oxidized to cyclohexanol and cyclohexanone; then cyclohexanol and cyclohexanone are oxidized to adipic acid with a mixed manganese/barium acetate used as a catalyst.

Nearly every chemical process has some potential for emissions. Organic chemical reaction processes typically involve VOC emissions, accompanied by other emissions which depend on the process, reactants and conditions. For example, the Farben process leads to NO_x , VOC, and CO emissions; carbon black manufacture emits all these pollutants as well as carbon disulfide, carbonyl disulfide, particulate matter, polycyclic organic matter and trace elements such as beryllium, lead and mercury. There are some processes in which organic chemicals are produced with few VOC emissions, such as explosives manufacturing, which uses toluene as a feedstock but has emission factors in AP-42 only for particulates, SO_x , NO_x , nitric acid mist, and sulfuric acid mist. Many common organics are also toxic air pollutants and are addressed in the *Locating and Estimating Emissions From...* document series (see Table 4-2).

There are numerous other potential emissions from organic chemical production. Organic chemical processes often use extremes in both temperature and pressure, strong acids and bases, and organic and inorganic chemicals. VOC emissions are usually controlled by incineration, adsorption or absorption. Particulates may also be emitted. SO_2 can be produced, notably when natural gas or other fuels containing sulfur are used in a process. Methane, ammonia and CO_2 are often byproducts of chemical manufacture.

While the potential for emissions from many organic chemical manufacturing processes can be high, emissions are usually stringently controlled and recovered due to economic necessity. In some cases, the manufacturing operation is run as a closed system, allowing little or no emissions to escape to the atmosphere. However, small amounts of emissions will occur from a closed system due to leaks during transfer of chemicals, and due to deficiencies in complex chemical containment vessels and transfer and storage systems (such as pumps, compressors, valves and flanges). The range of equipment types is broad, including furnaces and kilns, reactor vessels (for polymerization, impregnation or other reaction processes), fuel-fired

heating equipment, filters, strippers, separation equipment such as condensers and stills, and raw material or product-processing equipment such as washers, dryers and pelletizers.

6.7.1 Organic Chemical Separation

Organic chemical separation processes are employed to produce finished organic chemicals from a mixture of organic materials. These processes generally use solvents, increased heat, and/or increased atmospheric pressure to isolate specific organics from a mixture. Organic chemical separation is one specific operation used in many organic chemical manufacturing processes and includes a number of different processes such as distillation, condensation, vacuum devolatilization, settling and stripping. Some organic chemical separation processes also cause changes to the physical or chemical state to allow desired components of a mixture to be isolated. One example of such a process is coagulation, in which a substance, either a salt or an acid, is used to precipitate polymer solids out of emulsions or latexes. The precipitated solids can then be separated and polymerized to make fibers. Another example of separation is drying a product to remove unwanted volatile components. Different separation processes may be used in series to permit isolation of specific materials for reuse.

There are numerous potential emissions from organic chemical separation. Most involve volatile components (raw materials or solvents) which are condensed, absorbed or adsorbed for recovery and further use. Vents from each of these recovery processes can be a source of emissions. In distillation, the bottoms may also contain some volatile components which can be released during waste handling, further processing or disposal. In most cases, the pressure in the separation vessel and the volatility of the components of the mixture are the determinants of emission levels. *AP-42* includes process-specific emission factors for the separation phase of many organic chemical operations.

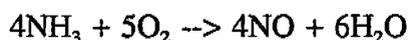
6.7.2 Inorganic Chemical Manufacturing Processes

Inorganic chemical manufacturing processes are employed to produce finished inorganic chemicals from raw materials. Similar to organic chemical manufacturing, these processes often involve extremes in both temperatures and pressures, strong acids and bases, and organic as well

as inorganic chemicals. *AP-42* information on inorganic chemicals includes mostly production of strong acids and bases:

- synthetic ammonia
- chlor-alkali
- hydrochloric acid
- hydrofluoric acid
- nitric acid
- phosphoric acid
- sodium carbonate
- sulfuric acid
- sulfur recovery
- alkyl lead

The variety of inorganic chemical processes documented in *AP-42* is not as great as for organic chemicals, and the inorganic processes tend to be simpler. One typical example is nitric acid production, which can be performed using either the weak acid process or the high-strength acid process. Eighty percent of nitric acid production in the United States is performed using the weak acid process. The weak acid process uses ammonia in a reaction with water to produce nitric oxide and water:



The nitric oxide is then reacted with oxygen and water in sequence to produce nitric acid.

In many cases, the principal or only emission from inorganic chemical processes is the gas or water-borne form (mist) of the feedstock or product. For example, the only emission factors for nitric acid production in *AP-42* are for emissions of NO_2 from weak and high-strength acid plants (including some variations for emission reduction using extended absorption or catalytic reduction). Other cases may involve particulates generated from solid feedstocks or products and/or common combustion-related pollutants from fuel-fired processes.

Typical emission reduction measures for inorganic chemical production involve increasing the efficiency of the product collection or reactant control systems that are already part of the production equipment; adding another unit of this type; or including another emission control device such as a final scrubber, mist eliminator or electrostatic precipitator. For example,

potential controls for nitric acid plants include extended absorption (by increasing the number of trays, using higher pressure, or cooling the absorbent) or catalytic reduction (in which tail gases are heated to ignition temperature and passed over a catalyst to reduce NO_x to N_2).

6.8 ORGANIC SOLVENT CLEANING EVAPORATION LOSSES

Organic solvent cleaning (or solvent degreasing) is the physical process of using organic solvents to remove grease, fats, oils, wax, or soil from various metal, glass or plastic items. These operations are performed in a wide variety of manufacturing and service industries, especially metalworking operations in automotive, electronics, plumbing, aircraft and other production and assembly operations. Solvents used are generally petroleum distillates, chlorinated hydrocarbons, ketones, and alcohols. Emissions from solvent degreasing are entirely VOCs, which are emitted due to evaporation of the solvent to the atmosphere.

Three types of equipment and degreasers are used in solvent cleaning: cold cleaners, open top vapor degreasers, and conveyorized degreasers. Cold cleaners are batch loaded, nonboiling solvent degreasers, and are the simplest and least expensive method of solvent cleaning. Open top vapor degreasers are also batch loaded, but use the vapor layer over a container of boiling solvent, which condenses on soiled parts to saturate and remove surface contaminants. These may use controlled airflow and condensers over the boiling solvent to minimize vapor losses to the surrounding air. Conveyorized degreasers may operate with boiling or nonboiling solvents. They operate with a continuous loading system, and are almost always hooded or enclosed, unlike cold or open top vapor degreasers.

The greatest emissions from cold cleaning are due to evaporation of waste solvent. Emissions from this source can be reduced by distillation or off-site reprocessing of waste solvent. Other emission sources are from solvent carried out on degreased parts, evaporation from solvent baths, and evaporation from sprayed solvent used to degrease parts. Agitation of the solvent bath increases emissions from the bath. Characteristics of the solvent (vapor pressure and any non-VOC co-solvents), exposed solvent surface area, and working practices are the most significant factors affecting emissions.

For open-top vapor degreasing, the most significant factors affecting emissions are convection and diffusion of solvent vapors from the working area of the degreaser. Other

emission sources include solvent carried out on degreased parts, emissions from exhaust systems, and waste solvent evaporation. Solvent characteristics primarily determine the amount of emissions. However, the condition of the equipment is also a significant factor.

Because they are enclosed, conveyORIZED degreasers usually emit less solvent per unit of cleaning than the other type of degreasers. The main source of emissions from conveyORIZED degreasers is vapor and liquid solvent carried out of the enclosure by cleaned parts and associated air turbulence. Design and operating rates are the most important factors affecting the level of emissions.

AP-42 provides two basic approaches to estimating emissions from organic solvent cleaning. The first is a materials balance approach which is based on the assumption that all solvent consumed (input minus recovered solvent) is emitted to the ambient air. The second is a series of emission factors for each type of cleaner/degreaser described above. The emission factor units are either in tons-per-year per unit or in pounds-per-year per square foot of solvent or vapor surface area. Due to the wide variety of cleaning operations and loads encountered, the per-unit or surface area-based emission factors will typically not be as accurate as an operation-specific materials balance based on regular recordkeeping of solvent usage (and, if appropriate, solvent content of sludges removed).

AP-42 also includes estimates of potential emission reductions for cold cleaners, vapor degreasers and conveyORIZED units which include control devices ranging from covers or enclosed designs to freeboard chillers and venting to carbon adsorbers; as well as operating practices such as control of ventilation and slowing entry and exit of parts to reduce turbulence and solvent carry-out.

6.9 WASTEWATER COLLECTION TREATMENT AND STORAGE EVAPORATION LOSSES

Many different industries generate VOC-containing wastewater streams, most of which are collected, treated and/or stored prior to release to a body of water or municipal sewage system. The types of equipment and degree of treatment can vary from pretreatment prior to release to a publicly-owned treatment works (POTWs), to full-scale treatment in which the final effluent must meet Federal and/or State water quality standards. Treatment may involve

equalization, neutralization, biotreatment and/or chlorination, often followed by storage for release at times of adequate water flow in the receiving body. The design and operation of these systems are highly site-specific.

Emissions of VOCs from wastewater occur at all locations involved in collection, treatment and storage. The following specific components of wastewater treatment systems may allow wastewater to contact the atmosphere:

- manholes
- trenches
- junction boxes
- sumps
- lift stations
- weirs
- treatment and/or storage systems

VOC emissions can occur from diffusion, particularly when waterborne VOC concentrations are much higher than airborne concentrations. Emissions can also occur from convection. The amount of emissions related to convection will be directly related to the wind speed over the water. The amount of VOC emissions from a wastewater treatment plant is dependent upon the concentration of VOC in the wastewater, the amount of time the wastewater is allowed to be in contact with ambient air, and the effectiveness of wastewater VOC treatment operations. Many other factors such as wastewater surface area, temperature, turbulence, retention time, biodegradation and other wastewater constituents can effect the rate of volatilization.

AP-42 includes a detailed description of alternative emission models which are available for estimating emissions from wastewater collection, treatment and storage systems, including a flow diagram for determining the appropriate components to model and the equations that can be used in calculating mass transfer coefficients for those components. These methods are contained in the Surface Impoundment Modeling System (SIMS), a personal computer-based set of models which includes sufficient default data for determining basic estimates by supplying only the wastewater flow rate and the component surface area. The SIMS program, user's manual and background technical documentation are available through State air pollution control agencies or through the EPA Control Technology Center. The program and user's manual are

also available through the EPA CHIEF BBS. Appendix E lists several contacts for obtaining this information.

Emission controls available for reducing VOC emissions from wastewater include steam or air stripping, liquid phase carbon adsorption, chemical oxidation, membrane separation, liquid-liquid extraction and biotreatment. The feasibility and effectiveness of each of these technologies depends on the concentration and other characteristics of the VOC (*e.g.*, volatility and solubility) in the wastewater as well as other factors specific to the removal mechanism used in the control. For example, air or steam stripping may remove up to 99 percent of highly volatile compounds but as little as 50 percent of low volatility compounds.

6.10 METALLURGICAL INDUSTRY

Many widely varied processes in the metal producing and processing industry emit air pollutants. The predominant emissions in the metallurgical industry are dust and fumes, some of which may include toxic components. Emissions are the result of processes involving very high heat (temperatures in the range of 2000° to 3000°F) and/or physical modification or transfer of materials. Fugitive emissions can be the major component for most processes and traditional combustion products are also often involved. The following descriptions address some of the typical operations involved in this industry. Many of the material handling and modification operations in metallurgical operations are similar to those used in other types of mineral processing.

AP-42 includes sections on the following metallurgical operations:

- coke production
- primary and/or secondary aluminum, copper, lead, zinc and magnesium processing
- ferroalloy, iron and steel production
- steel and gray iron foundries
- secondary magnesium smelting
- storage battery production
- lead oxide and pigment production
- miscellaneous lead products
- leadbearing ore crushing and grinding

6.10.1 Metallurgical Smelting and Melting

Smelting is the process by which ores and unfinished metals are separated and refined. It involves melting the material, generally with additives, and physically and/or chemically separating the constituents. Smelting can occur in primary metal production operations in which metal is produced from ore, and in secondary metal production operations, in which alloys are produced from ingots and from the recovery of metal from scrap and salvage.

The most significant emissions from smelting are sulfur oxides and particulates. Air currents due to high temperatures in the smelters cause particulate discharge as well as ash and dust formation. Sulfur oxides are generated due to the presence of sulfur in the fuels used to heat the furnaces.

Other potential emissions from smelting include:

- fluoride
- VOCs
- CO
- NO_x
- heavy metals, including lead
- products of incomplete combustion

Electrostatic precipitators (ESPs) are often used to reduce particulate emissions from smelting operations. These may be combined with a spray chamber in order to decrease the temperature of the emissions and increase the efficiency of the ESP. Control of SO₂ emissions is most commonly performed using a single or double contact sulfuric acid plant. Actual emissions from a particular smelter unit depend upon the configuration of equipment in that smelting plant and its operating parameters.

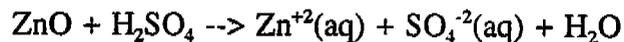
6.10.2 Metallurgical Chemical Processes

The most prominent chemical processes used in metallurgical processes are reduction reactions. These reactions are used to remove oxygen from ores and to dope metals with other elements to produce a product with more desirable qualities. An example is the reduction

reaction used in ferroalloy production. In this reaction, ferrous oxide, silicon oxide and carbon are combined to yield ferrosilicon and CO:



Electrolysis is used to achieve a similar result in zinc production. The first step in this process is leaching, illustrated in the following reaction:



The aqueous zinc is then further reduced to elemental zinc using electrolysis. In addition to reduction reactions, chemical processes are also employed to desulfurize metals. Various reagents are used to remove sulfur, which generally reacts with the reagents to form a liquid which can be easily separated from the desired metallic components.

The most common emissions from metallurgical reactions are particulates (usually metal oxides), CO, and sulfur compounds (including SO₂). Particulates are generated by movement of the raw materials. Both CO and sulfur compound production are reaction based. The amount of emission produced in metallurgical reactions is dependent primarily upon the emission control techniques employed at the plant.

6.10.3 Sintering Processes

Sintering is one of the major operations performed at an integrated iron and steel plant. The process of sintering converts fine sized raw materials, including iron ore, coke breeze, limestone, mill scale, and flue dust, into an agglomerated product ("sinter") of suitable size for charging into the blast furnace. The raw material may be mixed with water to provide a cohesive matrix, and then is placed on a continuous, travelling grate called the sinter strand. A burner hood at the beginning of the sinter strand ignites the coke in the mixture, after which the combustion is self supporting and hot enough to cause melting and agglomeration of the mix. The sinter is crushed, screened, and cooled, and then crushed and screened a second time.

Undersize sinter is recycled into the furnace. The product is then sent to the blast furnaces for iron production.

Emissions are generated from raw material handling, from windboxes used to draw air through the sinter to aid in the combustion process, from sinter as it is discharged from the furnace, and during screening. The windbox is the primary source of particulate emissions, which are mainly iron oxides, sulfur oxides, carbonaceous compounds, aliphatic hydrocarbons, and chlorides. Particulates produced at discharge are primarily iron and calcium oxides. Emissions are related to the type and efficiency of emission control devices employed. CO can also be generated from the windbox during the combustion process. The level of CO emitted is dependent upon the utilization and efficiency of control techniques.

6.10.4 Coking Processes

Metallurgical coke is manufactured by destructive distillation of coal in a byproduct coke oven battery. This "coking" process is accomplished in a series of ovens with an absence of oxygen. Volatile compounds are driven from the coal and collected from each oven for processing.

Particulates, VOCs, CO, SO_x, and other emissions originate from several byproduct coking operations:

- coal preparation
- coal preheating
- charging into heated ovens
- oven leakage
- pushing the coke out of the oven
- quenching the hot coke
- underfire combustion stacks (for heating)

Particulates are emitted primarily from coal preheating, coal charging, oven leakage, coke pushing, and coke quenching. Emissions are related to operating practices; if the process equipment is kept clean, emissions will be reduced. VOCs are released during coal preheating, coke charging, and oven leakage. VOCs can also be released during coke pushing and coke quenching if the coal is not fully coked due to process operating deficiencies. The quality of the

sealing of the brickwork in the plant is the most important factor effecting emissions. Emissions of SO_x from the underfire combustion stacks are possible if the fuel used is not desulfurized. Emissions are related to the effectiveness of the scrubbers on the combustion stacks.

6.10.5 Metal Finishing

Metal finishing consists of the physical processes used to shape a metal block, usually in an ingot or other casted shape, into a desired final shape. After metal has been cast, sand clinging to the casting is removed in an agitation device called a "shakeout." The metal casting will generally have burrs and other casting deformities that must be removed before use. This operation is accomplished by breaking and/or grinding off deformities. After grinding has taken place, the metal is usually shot blasted as a final cleaning process. This process, which uses small particles to bombard the metal, strips off remaining mold residue.

Particulate matter is the only significant emission generated by the metal finishing process. The grinding action produces metal dust. Particulates are also generated during shakeout and shot blasting of the cast. Emissions are made up primarily of relatively large-sized particles of the metal which is being finished. Emissions from metal finishing are generally controlled effectively by cyclones.

6.11 MINERAL PRODUCTS INDUSTRY PROCESSES

The mineral products industry includes crushing, grinding, screening, transfer, drying and other operations conducted on many different types of raw and processed materials. Processes and products covered in AP-42 include:

- asphaltic concrete
- asphalt roofing
- bricks and related clay products
- calcium carbide
- castable refractories
- portland cement
- ceramic clay
- clay and fly ash sintering
- coal cleaning
- concrete batching
- glass and glass fiber
- frit
- glass gypsum
- lime
- mineral wool
- perlite

- phosphate rock processing
- construction aggregate processing
- coal conversion
- taconite ore processing
- metallic minerals processing
- Western surface coal mining

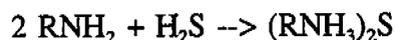
Emissions from these processes are principally particulates entrained into the air by mechanical activities, and particulates and combustion-related pollutants generated by kilns and other heat-intensive processes. The particulates generated by mechanical activities tend to have larger size ranges than combustion-related particulates. Fugitive particulate emissions tend to dominate this sector. Discussions on three operations characteristic of mineral products material handling, crushing/screening and cement production are discussed in detail in *AP-42*.

6.12 PETROLEUM INDUSTRY PROCESSES

Varied processes in the petroleum producing and processing industry emit air pollutants. The following descriptions address some of the typical operations involved in this industry (petroleum sweetening, petroleum cracking and asphalt production). Predominant emissions in the petroleum industry include VOC from product and raw material losses as well as CO and NO_x from combustion operations. The VOC emissions from petroleum processes include many toxic compounds.

6.12.1 Petroleum Sweetening

Sweetening is performed to reduce the amount of sulfur-containing material in a product. For natural gas, hydrogen sulfide (H₂S) is removed by sweetening using the Girdler process, in which the gas is exposed to various amine solutions which absorb H₂S. The process is summarized by the general amine reaction, where R is a general symbol used to represent any hydrocarbon group:



Emissions of SO_x occur in the process when the acid waste gas is incinerated or combusted in a smokeless flare. Only small amounts of particulate, VOC, NO_x, or PICs are emitted from gas sweetening due to the combustion temperature (1200°F). Emissions may be affected by equipment usage (*i.e.*, frequency of startup and shutdown) and combustion characteristics (*i.e.*, temperature, airflow, amount of waste gas).

For petroleum products other than natural gas, sweetening involves converting mercaptans to alkyl disulfides in the presence of a catalyst. This process involves adding sulfur to the sour distillate with caustic and air. The mixture is then passed upward through a fixed bed catalyst counter to a flow of caustic entering at the top of the vessel. In the conversion and extraction process, the sour distillate is washed with caustic and then is contacted in the extractor with a solution of catalyst and caustic. The extracted distillate is then contacted with air to convert mercaptans to disulfides. The distillate is then treated and sent to storage. The conversion process may be followed by an alkyl disulfide extraction step.¹

Emissions occur during the conversion process when the distillate product is exposed to air in the "air blowing" step where hydrocarbons evaporate into the air. These emissions are related to equipment types and configuration, as well as to operating conditions and maintenance practices.

6.12.2 Petroleum Cracking

Thermal cracking processes are used to break heavy oil molecules into smaller fractions by exposing them to high temperatures. There are two types of cracking: visbreaking and coking. Visbreaking is used to convert topped crude or other residuals from vacuum distillation (a petroleum refinery operation) by heating the substance to between 850 and 900°F. The cracked products are then flashed into a fractionator, which separates the products into light and heavy distillate products. Coking is used to convert low value residual fuel oil to higher value gas oil and petroleum coke. The process involves exposing the heavy petroleum products to high temperature and low pressure.

Emissions from cracking are difficult to characterize and estimate. Air emissions include coke dust from decoking operations, combustion gases from the visbreaking and coking process

heaters, and fugitive emissions from leaking equipment, spills, and transfers. Potential emissions include:

- particulate matter
- VOC
- SO_x
- NO_x
- PICs
- CO

Variables effecting emission levels include the condition of the cracking equipment and control technologies employed.

6.12.3 Asphalt Manufacturing

Asphalt is manufactured from residual oils produced in various petroleum refinery operations. Asphaltic residual oils are polymerized by oxidation. This is accomplished by blowing heated air through a heated batch mixture or, in a continuous process, by passing hot air countercurrent to the oil flow. The reaction is exothermic and quench steam is sometimes needed for temperature control. Catalysts and dopers may be added to speed the asphalting process and to impart special characteristics to the asphalt.

Air pollutant emissions from asphalt blowing are primarily hydrocarbon vapors vented with the blowing air. The quantities of emissions are small because of the prior removal of volatile hydrocarbons in the distillation units of the petroleum refinery. However, the emissions may contain hazardous polynuclear organics. The uncontrolled emission factor for VOC is 60 pounds per ton of asphalt unless controlled by vapor scrubbing, incineration, or both. With controls, emission levels are negligible.

6.13 WOOD PRODUCTS

Wood pulp is derived from wood by four pulping processes: kraft, acid sulfite, neutral sulfite semichemical (NSSC), and soda. Of these four processes, the first three are the most significant in terms of air emissions.

Kraft pulping involves digesting wood chips at elevated temperature and pressure in a water solution of sodium sulfide and sodium hydroxide ("white liquor"). The remainder of the kraft process is involved in recovering the spent liquor. Particulate emissions originate in the recovery furnace for the spent white liquor, the lime kiln (used in recovery), and the smelt dissolving tank (for inorganics). The emissions are mainly sodium salts, with some calcium salts from the lime kiln caused mostly by carryover of solids and by sublimation and condensation of the inorganic chemicals. Sulfur compounds, including SO_2 , are emitted as well, mainly through the recovery furnace exhaust. Emissions are dependent upon process operating conditions. Other emissions include CO, formed when the kiln is operated above rated capacities; and NO_x , from the lime kiln and recovery furnace.

Acid sulfite pulping employs the same process as kraft pulping, except sulfurous acid replaces the caustic solution used to dissolve the wood. This increases the likelihood of SO_2 emissions, most notably from gas streams given off during the pulping process. The amount emitted is dependent upon the pH of the cooking liquor, the pressure at which the digester contents are discharged, and the effectiveness of the absorption systems used for SO_2 recovery.

NSSC pulping uses a neutral sodium sulfite and sodium carbonate solution to dissolve wood chips. The sulfur compounds of SO_2 and hydrogen sulfide are the primary emissions. They originate in the recovery furnace, absorbing towers, and the wood chip digester system. Emissions are dependent upon the capability of the scrubbing devices installed for control and recovery.

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7.0 EMISSION CONTROL TECHNIQUES

This chapter provides a basic description of the techniques typically used by industry to control PM-10, VOCs, SO₂, NO_x, and HAPs; briefly describes the control-device efficiencies commonly achieved by major types of control devices in current use; and describes the way control-system efficiencies are factored into the emission estimation process. This chapter is intended to provide the background information necessary to apply the emission estimation calculation techniques introduced in Section 4. In addition to the discussion of add-on emission controls, control techniques for non-process fugitive PM-10 emissions are briefly described.

7.1 CONTROL SYSTEMS

7.1.1 Control System Elements

Emission control systems are designed to minimize the air pollutant emissions released to the atmosphere from pollutant-emitting processes. An emission control system typically operates by using a fan-driven system to capture the air surrounding the emission-generating process. This pollutant-laden air is subsequently passed through a control device that "removes" or "cleans" the pollutant from the air. Typically, pollutants in gaseous form are removed from the air by physically or chemically removing the gas from the air stream. Alternately, many gaseous pollutants (and some particulate matter) can be destroyed by combustion. Particulate matter (including PM-10) may be removed from the airstream by a number of mechanisms making use of inertia, gravity, and the physical or electrostatic nature of the particles.

Local exhaust systems are used to capture emissions at their sources before they enter the workroom air. Components of local exhaust systems generally include the hood, duct, control device, fan, and a vent or outlet arranged in series. Figure 3-1 (in Section 3) illustrates a common arrangement of these devices. The hood is the initial opening through which contaminated air enters the control system. The term "hood," also referred to as a "capture device," is used generically to identify any control-system opening, whether it has a specific design or simply consists of the open end of a round or rectangular duct section. Many hoods

are specifically designed and located to meet the requirements of the operation and the contaminant being generated.

The second control system component is the duct system through which the pollutant-laden air is transported from the hood to the control device. The duct system may have branches that connect separate local hoods and ducts into a single exhaust system. The hood and duct, taken together, may be referred to as the capture system.

The control device is the third component of the control system. Pollutants are removed from the airstream to prevent excessive emissions of criteria or hazardous air pollutants. Air cleaning devices are frequently referred to as collection, cleaning, control, or removal devices; these terms are used interchangeably here. Various types of control devices are commonly used. Cyclones, fabric filters, scrubbers and precipitators are used for PM-10 control; adsorbers and incinerators are used for VOC control; selective nitrogen reduction systems and other systems are used for NO_x control. The characteristics of the contaminant and airstream dictate the type of control device used.

The next component of a control system is the air mover or fan. The fan induces airflow into and through the control system. Control-system fans may be placed in the ductwork in front of or behind the control device, depending on the application.

The outlet, stack, or vent is the final component of a local exhaust system. Often, the outlet or vent is placed on the facility roof or the control-system exhaust may be vented through stacks placed exterior to the plant. Monitoring devices are sometimes placed at the outlet or vent to alert the plant if emission concentrations indicate that the control system is not operating properly.

7.1.2 Design Considerations

Control systems may be designed with individual local hoods placed in the immediate location of the emission-generating process, or they may be designed with centrally-located hoods that capture emissions from throughout the facility. Local hoods are necessary where highly toxic pollutants are generated. Although a general dilution ventilation can be used to reduce the work area concentration of air pollutants, the rate of flow that would be required is often too high to be practical as a method of work-area control, and this method does nothing to reduce

pollutant emissions to the exterior of the plant. In these cases, local exhaust ventilation systems are usually most appropriate.

For maximum efficiency at minimum cost (a function of airflow), the local hood must be placed close to the source. In addition, the hood must be designed to maximize capture efficiency. This involves enclosing as much of the emission source as possible without affecting the process operation. When designing and installing a control system, it is important to consider any air currents near the process that might cause the contaminant to be moved away from the hood. Potential sources of external air motion that can result in inadequate emission capture in a local exhaust system include the following.

- Currents caused by motion in the plant
- Currents caused by general ventilation systems
- Thermal draft
- Motion imparted to the emission stream by the process
- Entrainment of emissions by motion of large particles that are also generated by the process
- Motion of the air caused by indirect mechanical action of the processing equipment

Gases and, to a degree, particulates, follow the air currents and tend not to settle out or have projected motion. Thus, to remove these pollutants, control of the airflow is necessary.

7.1.3 Capture and Control Device Efficiencies

As introduced in Section 4, the following basic emission factor algorithm is for estimating emissions from a process controlled by "add-on" or "end-of-pipe" control devices.

$$E = R \times EF \times (1 - C/100)$$

where E = emission estimate for source (at the process level)
 R = activity level (such as throughput)

EF = uncontrolled emission factor (such as lb emitted/throughput)
C = control effectiveness, equal to the capture system efficiency multiplied by the control device efficiency. Expressed in percent.

In the above equation, the term "C/100," referred to as the control effectiveness, represents the fraction of the emissions generated by the process that are removed from the atmosphere and collected as solid waste or sludge, or destroyed. The term $(1 - C/100)$ represents the fraction of the emissions generated by the process that escapes to the atmosphere.

Control effectiveness is a function of how completely the capture system pulls the emission-laden air into the control system and how completely the control device removes the pollutant from the airstream. Although control systems are designed for optimum effectiveness, because they are subject to practical constraints (such as engineering design, physical wear, and cost considerations), control systems do not perform at 100-percent efficiency. The emission factor estimation technique requires providing estimated efficiencies for both the capture system (capture device and ducts) and the control system. The following sections are designed to help determine estimates of the capture-system efficiencies and control-system efficiencies that are used in the emission factor estimation equation. A detailed discussion of the methods used to estimate these efficiencies is beyond the scope of this document, but the basic approaches are briefly described.

The discussion above applies to the use of uncontrolled emission factor calculations. Uncontrolled emission factors describe typically expected emissions from processes without controls; the inclusion of control effectiveness in the equation enables the user to estimate controlled emissions for processes using add-on controls such as fabric filters, incinerators, or catalytic reduction units. A variation from the previously described method is required if a plant achieves reductions from baseline emissions by changing work practices or process equipment type rather than by addition of a control device. In these cases, a different emission factor should be developed for the new equipment or practice employed rather than attempting to incorporate these changes into the control effectiveness figure. Section 6 includes discussions of several work practice changes and modifications for processes such as combustion and solvent storage.

In some cases, an available controlled emission factor may be used. A controlled emission factor emission estimate, as shown in Section 4, does not require knowledge of the system control effectiveness.

Controlled emission factors represent typical emissions from processes using a specific type of control device. For example, a controlled emission factor may be given as "x pound PM-10 emitted/ton throughput for metal melting controlled by fabric filter." A controlled emission factor for a specific process and device type is developed through source applicable tests. Estimates using controlled emission factors may be less precise than estimates using uncontrolled emission factors because the estimate is made from data that incorporate control-effectiveness from various facilities throughout the industry rather than using control-effectiveness figures for the site actually being considered.

7.1.3.1 *Capture System Efficiencies*

In general, capture devices are designed to operate at close to 100-percent efficiency. Hood design and placement, as well as capture system airflows, are incorporated into the control-system design in a way that yields high-efficiency capture without excessive cost. In practice, capture efficiencies near 100 percent are often attained; to ensure worker safety, this is particularly true for capture devices for processes emitting HAPs. However, where capture-system design is less thoroughly implemented, efficiencies can be much less than 100 percent.

If 100-percent capture cannot be assumed, reasonable estimates of the capture system efficiencies must be made. Several methods exist for estimating capture system efficiencies. The most thorough method is to conduct source tests of emission releases and emission capture within the control system. This method can be expensive but may be required to prove compliance with air pollutant emission regulations. A second method is to conduct material balance analyses that measure the mass emissions from the process, mass emissions from the control device, and mass collected by the control device. These values are then used to calculate an estimated capture efficiency. As a last alternative, an engineering estimate of capture system efficiency, based on visible observations, comparison to similar systems with known capture efficiencies, or with other methods, must be made. In general, the first two methods are preferred to engineering estimate if emission estimates are for state or Federal reporting.

7.1.3.2 Control Device Efficiencies

Control-device efficiencies can be easier to measure or estimate than capture-system efficiencies. Control-device efficiencies can usually be measured by source tests at lower cost than tests of capture-system efficiencies. If source tests are not conducted, design efficiencies provided by control-device vendors generally provide a good baseline for estimating actual efficiencies. The accuracy of this estimate depends on the proper application and operation of controls.

The two tables in Appendix F are intended to provide a broad overview of the types of control devices in use and the general range of efficiencies expected for each control device and the applicable pollutant. Table F-1 lists control devices (and other emission reduction techniques) currently listed in the AIRS system. The devices in Table F-1 are listed by AIRS codes; the AIRS codes in Table F-1 are used in Table F-2 to cross-reference the devices with their typical efficiencies.

Control-device efficiencies are necessary for any emission estimation calculation using uncontrolled emission factors, as introduced in Section 4. The ranges in Appendix F are not absolute values, but should provide efficiencies inconsistent with reasonably expectable values.

7.2 GENERAL CATEGORIES OF CAPTURE DEVICES¹

The major categories of local exhaust system hoods are enclosing hoods, partial enclosing hoods, and exterior hoods. Emissions that escape the local exhaust system may be captured by indirect emission systems that typically capture emissions rising to the shop ceiling. Numerous specialty hoods have been designed for specific processes in some industries, but these are not discussed here.

7.2.1 Hoods

Enclosing Hoods--Total Enclosures. Enclosing hoods have been applied in many situations such as abrasive blasting, crucible melting furnaces, paint mixing, and numerous processes generating emissions with high toxicity. Wherever possible, the enclosing hood (total

or partial) is the most appropriate type of exhaust hood to apply because of its inherent efficiency in capturing generated pollutants.

A total enclosing hood, as implied by the name, encloses the emission-generating process on all sides. Openings in this enclosure are minimized by using doors to limit access to the emission generation area. Airflow through the enclosing hood should create a negative pressure that creates inflow of air from the workroom atmosphere into the process area through any existing openings. The capture velocity at the emission source must be sufficient to overcome any air movement that exists or is generated within the enclosure itself. The effect of external air movement is usually minimal in a total enclosure.

Partial Enclosing Hoods - Booths and Tunnels. Booth or tunnel-type enclosing hoods are the most desirable design when access to one or two sides of a process is necessary. A booth hood encloses the process on all but one side, thus allowing worker or machinery access to the interior of the hood. Tunnel-types enclose the process on all but two sides, and are often appropriate where materials are being passed on a conveyer or other material-moving system through the area in which emissions are released.

The appropriate face velocity (the linear air velocity at the face of the hood) used with these enclosures is determined by the emission characteristics of the process contained and the dimensions of the hood openings. The face velocity must be sufficient to eliminate the escape of air from the enclosure and to eliminate effects of external movement on the process within the enclosure.

A booth or tunnel will require higher airflows than those required for a total enclosure, making the booth or tunnel less cost-efficient. However, certain applications such as laboratory hoods, abrasive cut-off saws, continuous buffing in a tunnel, etc, require the use of these types of hoods.

Exterior Hoods. An exterior hood can be applied when it is not possible to use a total enclosure or partial enclosure such as a booth or tunnel. Exterior hoods are hoods that are adjacent to (rather than enclosing) the emissions sources. These types of hoods require that the capture velocity present at the source be sufficient to overcome any movement and successfully capture the containment.

Exterior hoods are less efficient than enclosure-type hoods because air enters the hood from all directions, and the area between the source and hood is subject to the effects of external

air movement. The hood itself may be located in a direction of emission generation or projection (such as in the pathway of thermally rising emissions or in the pathway of projected emissions from processes such as grinders or millers) in order to improve emission capture.

The round or rectangular duct opening is one of the most simple and inefficient types of exterior hoods. The operation generating the emissions must be close to the hood face in order to provide adequate capture velocity. The hood can be attached to a flexible duct to allow varied placement to capture emissions from different locations in the work area. The round or rectangular duct opening hood can be used in many applications. Examples of its use include welding benches, surface grinding, and band saws. In addition, it can be applied to various portable and hand tools when a flexible duct or rubber hose is used.

Another type of exterior hood is the canopy hood. Canopy hoods are overhead openings that are generally used for hot processes where thermal draft occurs. Canopy hoods can also be used for cold processes where, for example, it is necessary to control evaporation from an open tank. Sides or baffles can improve the operation of a canopy hood by approximating the design of an enclosed hood or booth. Applications of the canopy hood include die casting melting furnaces and the open tanks.

Finally, the receiving hood is also a type of exterior hood. The receiving hood is actually one of the above types of hoods placed near the emitting process such that the hood opening is the path of the emissions stream. A hood placed in front of a grinder that propels particulate or above a heated bath that releases VOC emissions that rise on a thermal draft would be considered a receiving hood. The receiving hood takes advantage of any directional inertia of the emission, lowering the necessary capture velocity that must be applied. Examples of receiving hoods include hoods used for grinding or polishing wheels, and hoods used for various types of table saws or band saws.

7.2.2 Capture of Indirect Process Emissions

Indirect emission capture systems are used where local hoods are not used or where additional emission capture is needed in plant areas not ventilated by local exhaust hoods. Canopy hoods used to capture emissions from more than one process are considered indirect

emission capture systems. Scavenger ducts connected to canopy hoods or other overhead systems are also considered indirect capture systems.

As emissions regulations have become more stringent, building evacuation has become more frequently employed for indirect emissions capture. Building evacuation involves exhausting all emissions that accumulate under the shop roof. This method is normally employed when there is no room for a canopy hood and/or when circumstances require emissions capture from numerous processes within one building. Building evacuation has been accomplished in existing facilities by closing roof openings and installing a large induced draft evacuation system with a fabric filter. In these facilities, the air pollution control system is the only means of heat removal from high-temperature processes (such as in metallurgical operations). This requires a considerably larger air pollution control system than would otherwise be needed, because of the need to control the large volumes of warm air. Building evacuation tends to be an expensive form of emission capture and is employed when individual capture systems become prohibitively expensive or do not fit into the facility, or when strict emission limits cannot otherwise be met.

7.3 ADD-ON CONTROL DEVICES

The control device is typically the most complex element of an air pollutant control system. The control device must efficiently, economically and safely remove the contaminant of concern (any of the criteria or hazardous pollutants) from the airstream before the air is released to the atmosphere. The choice of control device is primarily a function of pollutant type but is also a function of parameters such as pollutant concentration, emission stream thermodynamic parameters, efficiency, and cost. The following sections discuss some of the basic control devices used to remove PM-10, VOC, SO₂ and NO_x from process emission streams. Table 7-1 lists the air pollution control technologies used for the control of particulates, organic vapors, and inorganic vapors.

7.3.1 Particulate Control Devices

Particulate devices function by removing particulate from the airstream and concentrating the pollutant in a dust or sludge form for later disposal. The cyclone, fabric filter, wet scrubber,

TABLE 7-1. AIR POLLUTION CONTROL TECHNOLOGIES

Method	Pollutant Type		
	Organic Vapors	Inorganic Vapors	Particulates
Cyclones			X
Fabric Filter			X
Wet Scrubbers	X ^a	X	X
Electrostatic Precipitators			X
Carbon Adsorption	X ^b		
Fluidized-bed Systems	X ^c		
Absorption	X ^d		
Condensation	X	X ^e	
Incineration	X		

^aDepends on material, should be miscible in water.

^bCarbon adsorption or fired-bed systems.

^cNot widely used.

^dMaterial must be readily soluble in water or other solvents.

^eDepends on vaporization point of material.

and electrostatic precipitator (ESP) are four of the most common collection devices used for the control of particulate emissions.

7.3.1.1 Cyclones²

The cyclone is a particulate control device that falls into the general category of mechanical collectors that also includes settling chambers and momentum separators. Mechanical collectors use gravity, inertia, and impaction to remove particulates from the air stream before exhausting the air to the atmosphere. The cyclone is the most common type of mechanical collector in industrial use. In general, the cyclone is not as effective as the fabric filter, wet scrubber, or ESP, but it is the least expensive control device of the four.

The cyclone collector, essentially a cylinder with inlet and outlet ducts for the airstream, uses a combination of gravity and particle inertia to settle particles out of the air stream. A

vortex is created within the cylindrical section of the cyclone by either injecting the airstream tangentially or by passing the gas stream through a set of angled vanes. The particles migrate across the vortex gas streamlines and concentrate near the cyclone walls. Although the airstream reverses direction within the cylinder, the inertia force of the particulates causes the particulates to fall out of the airstream rather than changing direction with the air. The particulate is discharged through the bottom of the cyclone into hoppers for removal. The cleaned airstream passes upward and out of the cyclone.

The *simple cyclone* consists of an inlet, cylindrical section, conical section, gas outlet tube, and dust outlet tube. A typical simple cyclone is shown in Figure 7-1. Particle separation is a function of the gas throughput and the cyclone cylindrical diameter. Partial removal efficiency increases with higher airstream velocities and decreases with smaller cylinder diameter. There is an upper limit, however, at which the increased turbulence caused by increased airstream velocities can reduce particulate removal efficiencies. Medium-efficiency single cyclones are usually less than 4 meters in diameter and operate at static pressure drops of 0.50 to 1.50 kPa.

A *multiple cyclone* or multiclone consists of numerous small-diameter cyclones operating in parallel. The multiple cyclone uses the high-efficiency advantage of small-diameter tubes without sacrificing the ability to treat large exhaust volumes. Properly designed units can be constructed and operated with a control efficiency of 90 percent for particles in the 5 to 10 micron range.

Factors affecting the performance of simple cyclones include abrasion (eventually resulting in leaks) and plugging of the dust outlet tube. Leaks and rough areas within the cylinder can cause local turbulence, reducing the effectiveness of the vortex in removing particulate. Performance of multiple cyclones is affected by the same factors listed for simple cyclones, and hopper recirculation. Hopper recirculation occurs when uneven pressure drops within the system lead to reversed flow of the exhaust stream in some areas of the multiple cyclone. Hopper recirculation can substantially reduce the multiple cyclone efficiency.

7.3.1.2 *Fabric Filters*

Fabric filters achieve the highest particulate collection efficiencies of all particulate control devices. The fabric filter is a versatile type of equipment used for the removal of solid particulate from an air stream. For PM-10 emissions, a control efficiency of virtually 100 percent

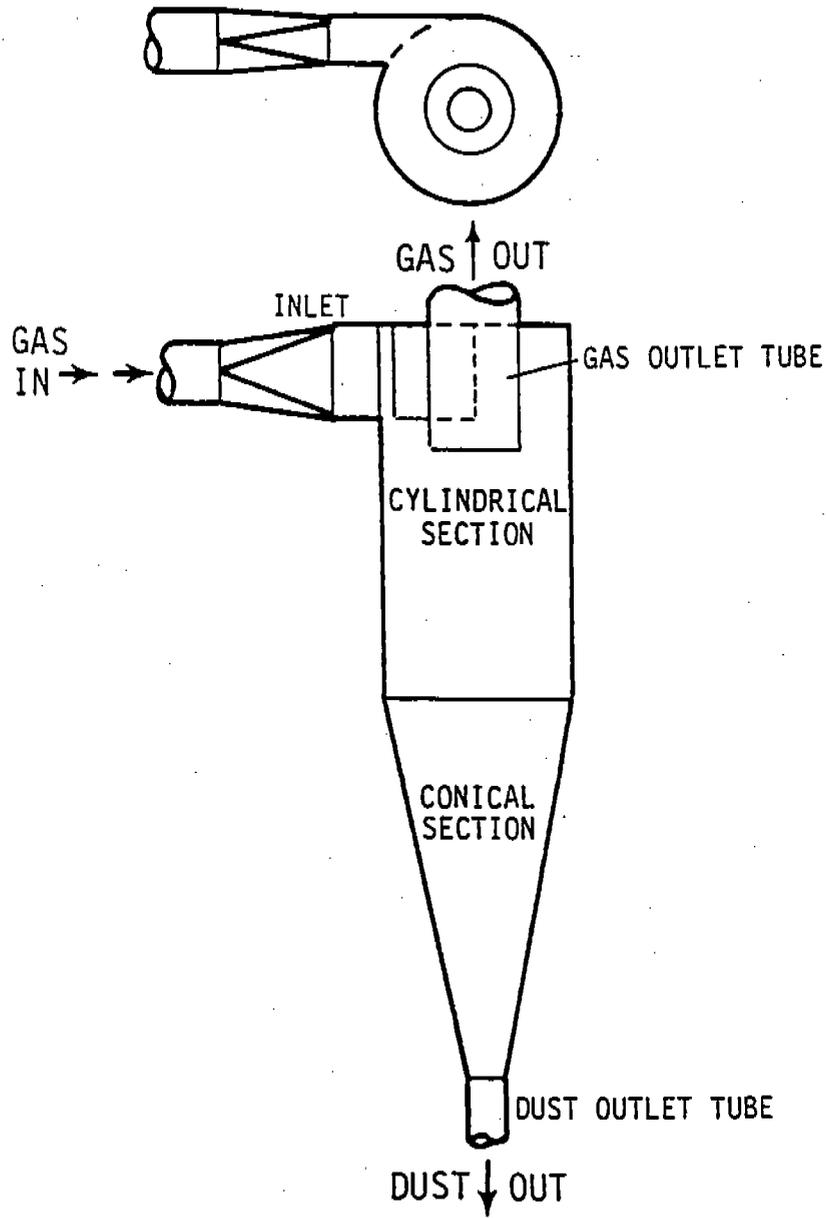


Figure 7-1. Typical cyclone.⁴

can be expected.² As the filter medium becomes caked with particulate, the control efficiency increases and the proportion of smaller particles collected increases.³

A fabric filter system (baghouse) consists of several filtering elements (bags) and a bag cleaning system, all contained in the main shell structure with dust hoppers (see Figure 7-2).⁴ Particulate-laden gases are passed through the bags so that particles are retained on the fabric. This creates a filtering dust layer that enhances the fabric filter's performance. The major fabrics used for bags are woven and felted fiberglass and Teflon® fluorocarbon materials, depending on the application.⁵ Typically, a baghouse is divided into compartments or sections, each containing several bags. In larger installations, an extra section is often provided to allow one compartment to be out of service for cleaning at any given time without affecting the overall efficiency of the fabric filter.⁶

The basic mechanisms used for cleaning particulate-laden gases in a fabric filter are inertial impaction, diffusion, direct interception, and sieving. The first three mechanisms prevail only briefly during the first few minutes of operation with new or recently cleaned bags. However, the sieving action of the dust layer accumulating on the fabric surface soon predominates. This sieving mechanism leads to high-efficiency control of particulate, unless defects such as pinhole leaks in the bags or cracks in the filter cake appear.⁷

In fabric filtration, both the control efficiency and the pressure drop across the bag surface increase as the dust layer on the bag builds up. Because the system cannot continue to operate economically with an increasing pressure drop, the bags are cleaned periodically by reverse airflow, pulse-jet, or a shaker mechanism. The dust is collected below the filters in hoppers and is either recycled or sent to a landfill.

The fabric filter capacity rate can be varied widely with little effect on efficiency. This inherent flexibility permits an increase in capacity within reasonable limits by increasing system fan horsepower. An oversized unit is more desirable than an undersized unit, since the dust loading and gas volume may surge during many particulate-emitting operations. This sudden increase in dust loading and possible air volume increase will increase the outlet dust loading on other types of collection devices, but a fabric filter can absorb the surge without loss of performance.⁶

The control efficiency of a fabric filter exceeds that of any other applicable collection device. Fabric filters also have many other advantages that make them suitable for control of

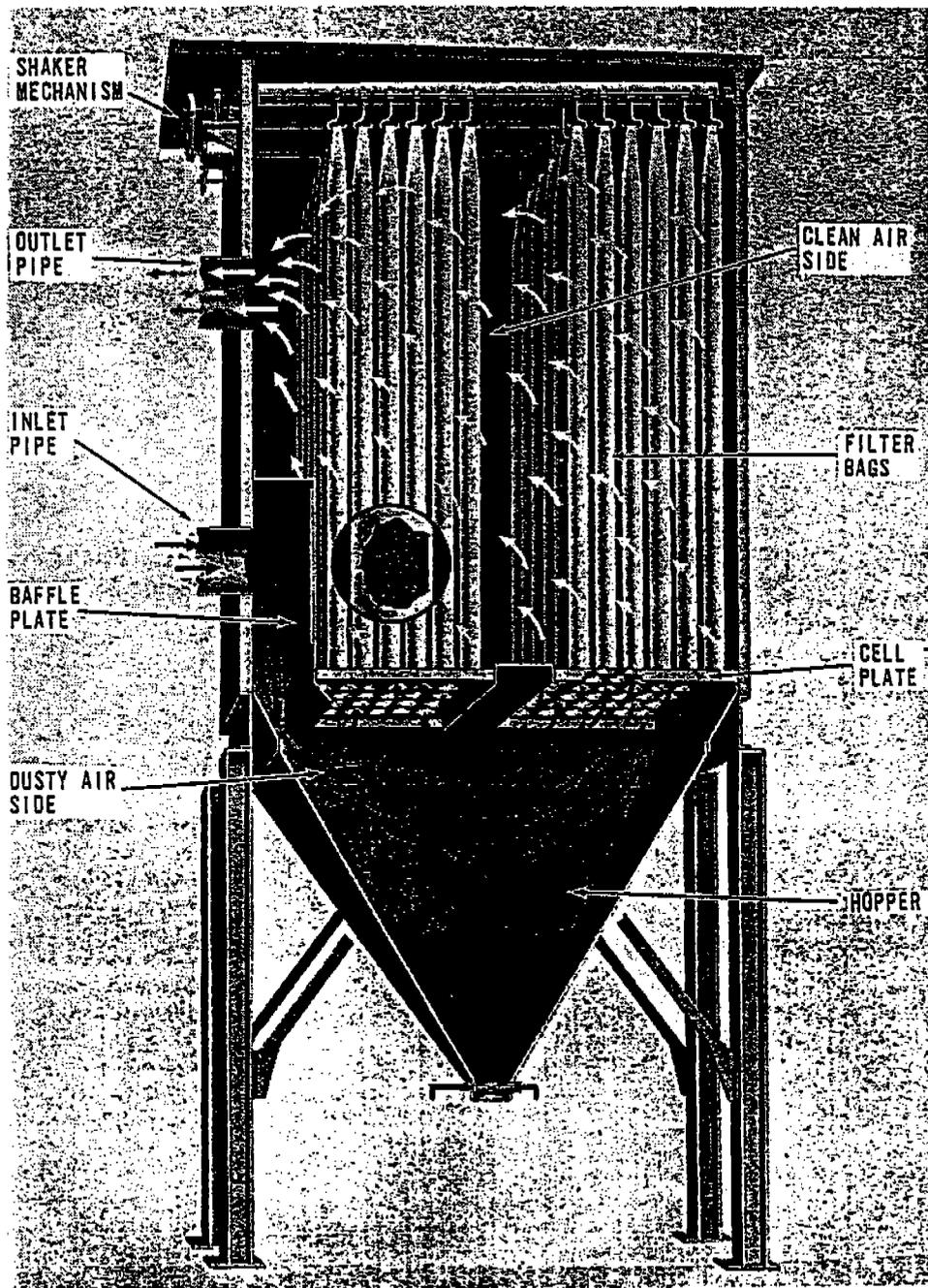


Figure 7-2. Typical fabric filter.⁴

particulate emissions from many types of processes. Fabric filters use less energy than either scrubbers or ESPs for equivalent outlet particulate concentrations. They are efficient collectors of very fine particulate and are tolerant of fluctuations in the inlet particle size distribution (which affects ESPs). Finally, fabric filters collect particulate emissions as a dry dust, which is easier to handle or recycle than the wastewater and sludge collected from scrubbers. If desired, the dust from a fabric filter can be wetted in a pug mill or pelletized before it is recycled or landfilled (decreasing handling problems associated with the fine dust): the fabric filter allows a facility the option of dealing with either dry or wet particulate removal, while other systems yield only wet waste.

Two types of fabric filter systems used in industry are the positive-pressure type and the negative-pressure type. They are distinguished by how the exhaust air stream is pulled through the baghouse. Positive-pressure fabric filter systems are those in which the effluent gases are forced through the fabric filter by a fan placed between the emissions removal system and the fabric filter. The compartments in the positive-pressure fabric filter do not need to be airtight since only the unfiltered air side of the collector needs to be sealed. Bag inspections and maintenance are easier to perform than on negative-pressure fabric filters. The compartments can be entered while the positive-pressure fabric filter is in operation if the temperature is low enough for worker safety. Uncleaned air entering the fabric filter is filtered through the cloth and then vented to the atmosphere through louvers, stub stacks, or a ridge vent (monitor) on the top of the positive-pressure fabric filter.⁶

The alternative to the positive-pressure system is a negative-pressure or suction-type fabric filter. In this system, the fan is placed on the clean air side of the fabric filter and effluent gas is drawn through the fabric. This system requires the bags to be kept in an airtight compartment and thus, each compartment must be taken off-line for bag maintenance and replacement. These negative-pressure filters usually require less fan maintenance and fewer operating horsepower than the positive-pressure type. However, there are disadvantages; they require more ductwork due to the need for a stack, they must be able to withstand the suction created by the fans, and good sealing is necessary to prevent the introduction of dilution air.⁷ Large-size particulate can quickly destroy fan blades if not filtered before entering the fan.⁴

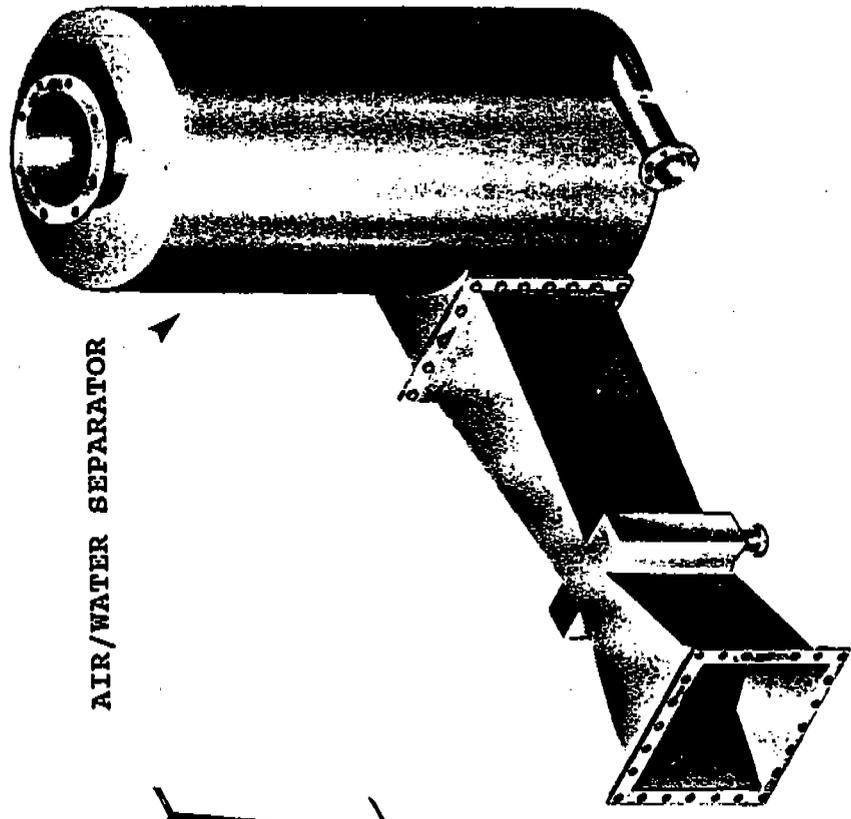
7.3.1.3 Wet Scrubbers

The wet scrubber is another frequently used particulate control device. Mechanically generated dust can normally be handled with medium or low energy wet scrubbers, but fine particulate (*i.e.*, PM-10) can only be removed effectively with higher energy wet scrubbers. However, high energy wet scrubbers consume a large amount of energy and therefore have high operating costs.

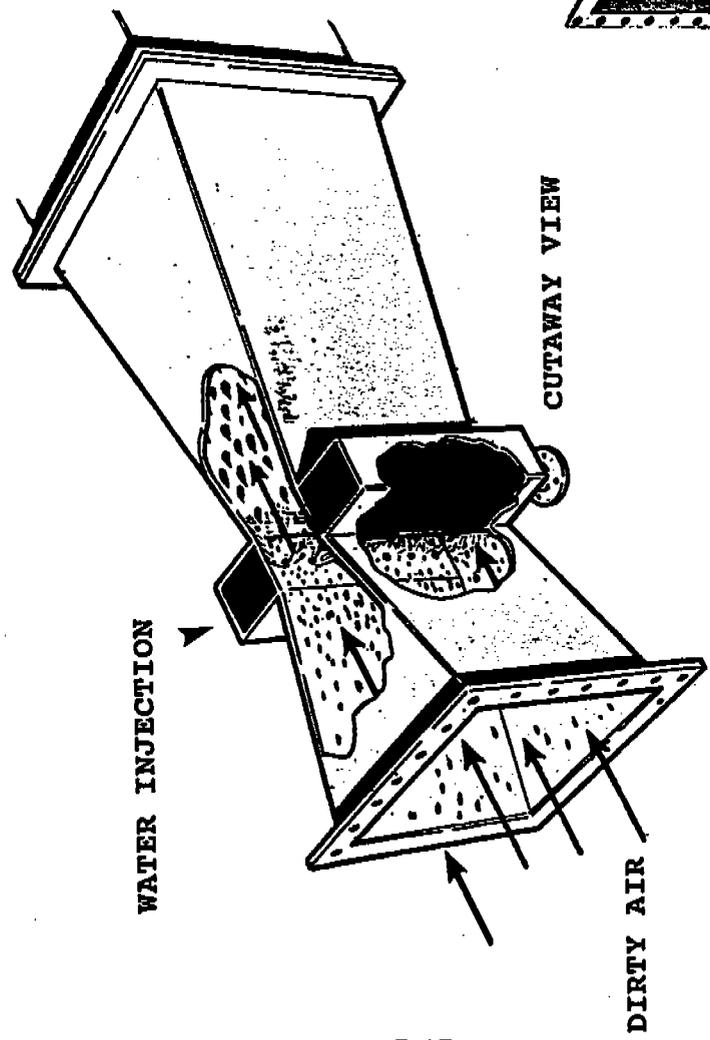
Many wet scrubber designs exist, but as shown by the control efficiency data in Table F-2, only a few are highly effective. High-energy wet venturi scrubbers remove 90 percent or more of the material in the zero to ten micrometer range encompassed by PM-10. Low- and medium-energy scrubber designs fail to meet this standard and therefore do not perform as well as high-energy wet scrubbers for particulate control. In the wet venturi scrubber shown in Figure 7-3, the gases are passed through a venturi tube to which low-pressure water is added at the throat. In spite of the relatively short residence time, the extreme turbulence in the venturi promotes very intimate contact with the water. The wetted particles and droplets are collected in a cyclone spray separator.² This venturi scrubber design has shown the best performance of wet removal devices.⁷

Properly designed, plant-size, high-energy venturi scrubbers are capable of a maximum efficiency of 97 percent for one-micrometer particles, 99.6 percent for five-micrometer particles, and over 99.7 percent for ten-micrometer particles. These results were determined in a controlled test with standard silica dust and a pressure drop in excess of 50 inches of water.²

Finally, many scrubbers require settling ponds of appreciable size in which the solids can separate from the water, and a recirculating system to reuse the water because raw overflow from the scrubber system cannot be discharged into streams or sewers. Scrubber wastes from some processes may include substances considered hazardous to the environment; these waste must be treated before disposal, or disposed of in approved landfills or other facilities. Improved wet scrubbing technologies are addressing the wet waste problem. Recovering some reusable material from the waste stream can reduce material and energy costs.



AIR/WATER SEPARATOR



CUTAWAY VIEW

WATER INJECTION

DIRTY AIR

Figure 7-3. Wet venturi scrubber.³

7.3.1.4 *Electrostatic Precipitators*

A third type of particulate control device is the ESP. Figure 7-4 shows an ESP, which is essentially a large box with rows of electrically grounded plates set at specified intervals.⁸ Particulate-laden air streams flow through the box, where high-voltage current is applied by electrodes which ionize the gas molecules. The charged ions collide with particles suspended in the gas and attach themselves to those particles. The charged particles are then drawn to oppositely charged plates, where they collect in a layer that must be removed periodically. This is done by diverting the flow of uncleaned air from a section of the collector plates, grounding plates to remove the charge, and cleaning the plates. The plates can be cleaned either by vibrating them or washing them with a water spray. If water is used, it must be cleaned before it can be recirculated or discharged.⁶

ESPs are used less frequently than fabric filters or wet scrubbers, in part because ESPs are much more expensive to install and maintain than high-energy wet venturi scrubbers or baghouses of similar capacity.⁷ However, recent enhancements to precipitators have increased their efficiency while reducing capital and operating costs. Pulse energization and intermittent energization apply high-voltage currents to the base voltage, allowing the base voltage to be reduced. The high voltage bursts result in better control efficiency while the base voltage reductions provide energy cost savings. Also, wider plate spacing and the reduction in the number of discharge electrodes has resulted in capital cost savings of ten to twenty percent.⁵

7.3.2 *VOC Control Devices*

VOC control devices typically employ one of two means to remove VOCs from the airstream--recovery or combustion. VOC recovery units (*e.g.*, adsorbers, condensers, or absorbers) remove the VOC from the airstream without destroying the chemical structure. The recovered VOC is often then reused as a process material in the original process or in a different application. An example of this is the removal of perchloroethylene from a dry cleaning stack by means of a carbon adsorption unit, with the later reuse of the perchloroethylene in another batch of dry cleaning. In contrast to the VOC recovery units, VOC combustion units (*e.g.*, incinerators, flares, or industrial boilers) remove the VOC from the airstream by combustion. In a VOC-destruction control device, the VOC is converted primarily into CO₂ and

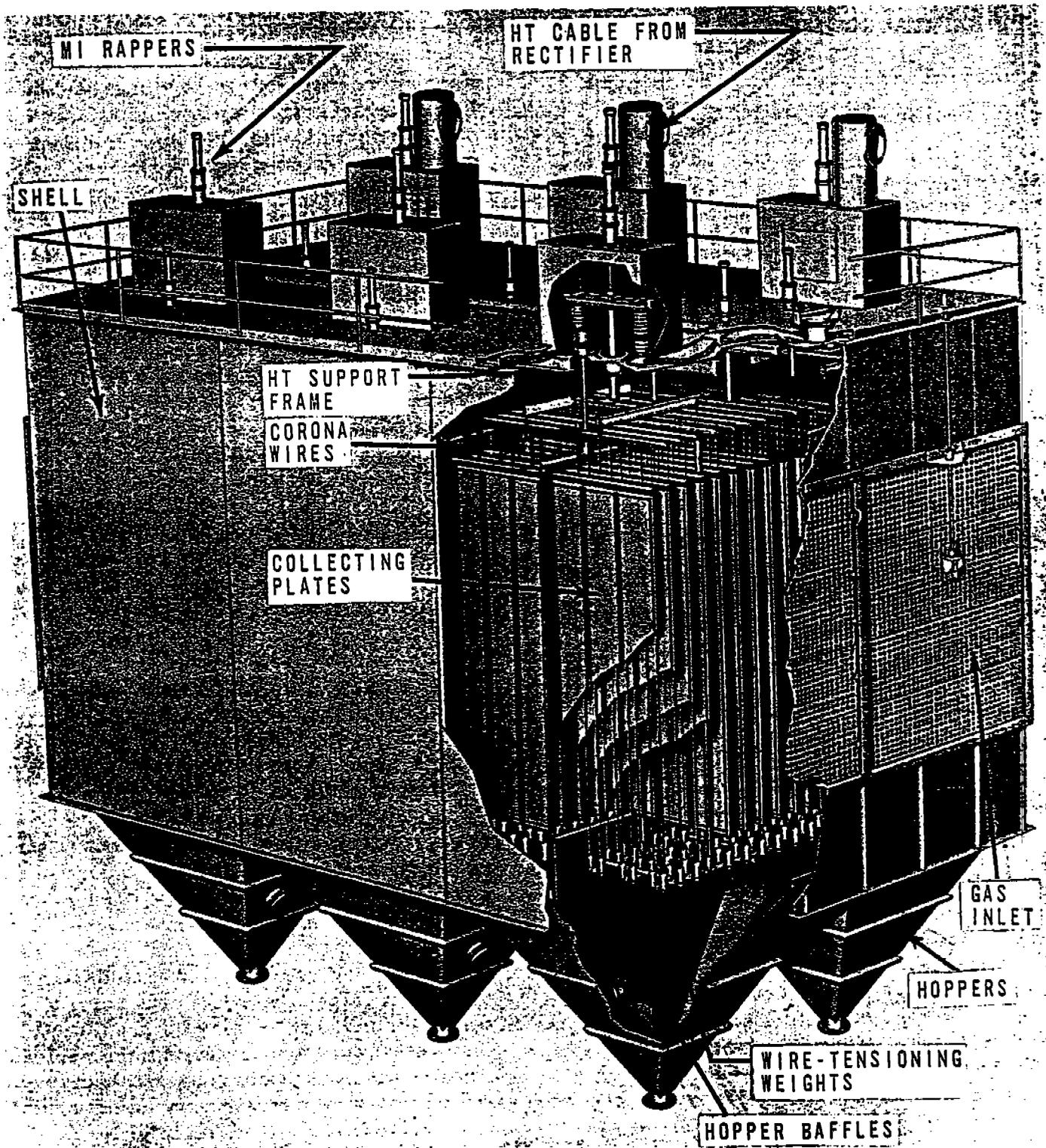


Figure 7-4. Typical electrostatic precipitator.⁴

water vapor. This section discusses three kinds of VOC-recovery devices: adsorbers, condensers, and absorbers; and two types of VOC-combustion devices: incinerators and boilers.

Many removal devices (such as adsorbers or incinerators) have removal efficiencies well above 90 percent. Capture devices, in comparison, have a much larger range of capture efficiencies.

7.3.2.1 VOC-recovery Control Devices

Carbon adsorption. In the carbon adsorption process, VOC emission streams are passed through a bed of activated carbon in which the VOC molecules are captured on the porous carbon surfaces by non-chemical Van der Waals forces. The adsorptive capacity of the carbon bed tends to increase with the gas phase VOC concentration, molecular weight, diffusivity, polarity, and boiling point of the VOC.⁹ After the working VOC capacity of the carbon is reached, the VOC can be desorbed from the carbon and collected for reuse.

Desorption of the solvent VOC from the used carbon bed is typically achieved by passing low-pressure steam through the bed.¹⁰ In the regeneration cycle, heat from the steam forces the VOC to desorb from the carbon, where it is entrained in the steam. After the carbon bed has been sufficiently cleared of VOC, it is cooled and replaced on-line with the emission stream. Meanwhile, the VOC-laden steam is condensed, and the VOC is separated from the water by decanting or, if necessary, by distillation; if the VOC is not recovered for reuse or reprocessing, it may be incinerated.¹¹

Carbon adsorbers are commonly used for air pollution control and/or solvent recovery from dilute (less than 10,000 ppmv) streams of VOC in air. Adsorption provides a very low outlet concentration as well as the opportunity to recover the VOC. Removal efficiencies range from 95 to 99 percent for well-operated systems, and outlet concentrations of 50 to 100 ppmv can be routinely achieved. Packaged systems are available with flow rate capacities beyond 100,000 scfm.⁴

The principal advantage of carbon adsorption is that it is very cost effective with low concentrations of VOCs. VOC recovery may offset operation costs. Operation of the adsorber is relatively simple for both continuous and intermittent use. However, at concentrations below 2,500 ppm, adsorption may become uneconomical.¹²

Certain types of VOCs, such as those which are difficult to strip from carbon or those which are miscible with water, can be difficult to collect. If the VOC involved is miscible with water, additional distillation measures are necessary to recover the VOC. If steam-stripping is conducted with chlorinated hydrocarbons, corrosion and wastewater treatment problems may occur.¹¹ Also, carbon adsorption is relatively sensitive to emission stream humidity and temperature. Dehumidification is necessary if the emission stream has a high humidity (relative humidity > 50 percent) and cooling may be required if the emission stream temperature exceeds 40° to 113°F.⁴

Two carbon adsorption systems currently in use are the fixed-bed system and the fluidized-bed system. In the fixed-bed system, non-moving beds of carbon are alternately placed on-line and regenerated. When a continuous emission stream is being treated, at least one bed is on-line and one bed is regenerating at any given time. In the fluidized-bed system, loose, clean carbon is constantly metered into the bed while loose, VOC-laden carbon is removed for regeneration.⁴

Fixed-bed systems. In a continually operating fixed-bed system, the VOC emission stream is passed through two or more non-mobile carbon beds. In a two-bed system, one bed is on-line with the emission stream while the other bed is being regenerated or on standby. When the first bed reaches its working VOC capacity, the emission stream is redirected to the second bed, and the first bed is regenerated. While two beds are common, three or more beds can be used in a variety of configurations, with more than one bed on-line at a time.¹⁰ Figure 7-5 shows the schematic arrangement of a two-bed carbon adsorber system.

Fluidized-bed systems. The fluidized-bed adsorber system contains one or more beds of loose, beaded activated carbon. The VOC emission stream is directed upward through the bed where the VOCs are adsorbed onto the carbon. The flow of the emission stream stirs the carbon beads, causing them to fluidize and flow within the adsorber. The VOC-cleaned air exiting the adsorber is passed through a dust collector, then released into the atmosphere.¹⁰ Fresh carbon is continually metered into the bed while VOC-laden carbon is removed for regeneration.

Fluidized-bed adsorbers can capture more VOC with a given quantity of carbon because the fluidized bed mixes newly regenerated carbon and VOC more thoroughly, and because the

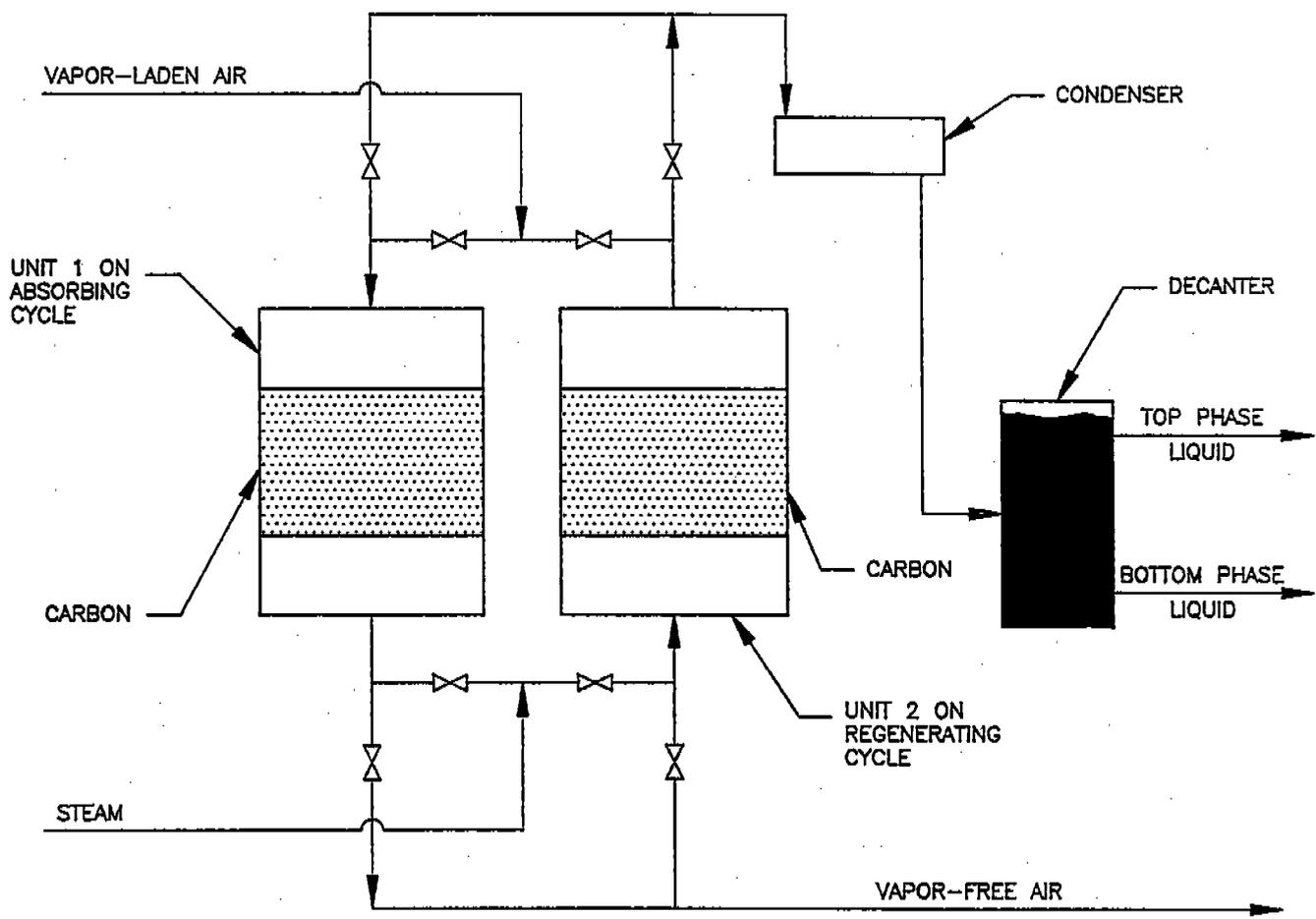


Figure 7-5. Schematic of two-bed carbon adsorber.⁴

system continually replaces used carbon with regenerated carbon. This increased VOC-capacity reduces costs for steam regeneration. Fluidized-bed adsorbers are less common than fixed-bed adsorbers because fluidized-bed adsorption technology has been commercially feasible only since the early 1970s.¹³

Absorption (Scrubbing). In the physical absorption process, VOCs are removed from the emission stream by absorption in a liquid solvent such as a high molecular weight oil. Packed towers, spray towers, venturi scrubbers, or other methods are used to bring the absorbent into contact with the emission stream. A packed tower scrubber is shown in Figure 7-6. After the VOCs dissolve into the solvent, the cleaned gas is released from the absorber.⁴ After the VOCs have been captured in the absorbent, fractional distillation or some other method can be used to recover the VOC from the absorbent.¹⁴

Absorption is most efficient when the VOC is soluble in the absorbent, and when the absorbent's boiling point is significantly higher than the VOC to be absorbed. Absorbers have been shown to remove from 86 to greater than 99 percent of the waste stream VOC for various species.^{12,15}

Absorbers can be used with a wide variety of organic compounds without many of the problems associated with other VOC removal devices such as the carbon adsorber, incinerator, or condenser. A closed-loop system has been developed that demonstrates no deterioration with use and does not generate steam or wastewater, or cause corrosion.¹⁶

Despite its advantages, the closed-loop adsorption system is not cost effective with very low inlet concentrations of VOCs or with airflows less than 1,000 cfm.¹⁶ These restrictions make the absorber a less-frequently used option for VOC control. For most industrial processes, the waste stream VOC concentrations are generally low, making absorption less desirable than adsorption or incineration unless the absorbent is easily regenerated or the solution can be used as a process make-up stream.¹⁰

Condensation. Condensers remove VOCs from the emission stream by causing the VOC to condense and separate from the gas. The VOC can be condensed by decreasing or increasing the pressure at a given temperature. Surface condensers and contact condensers are two common systems that condense VOCs by cooling the emission stream at atmospheric pressure. The

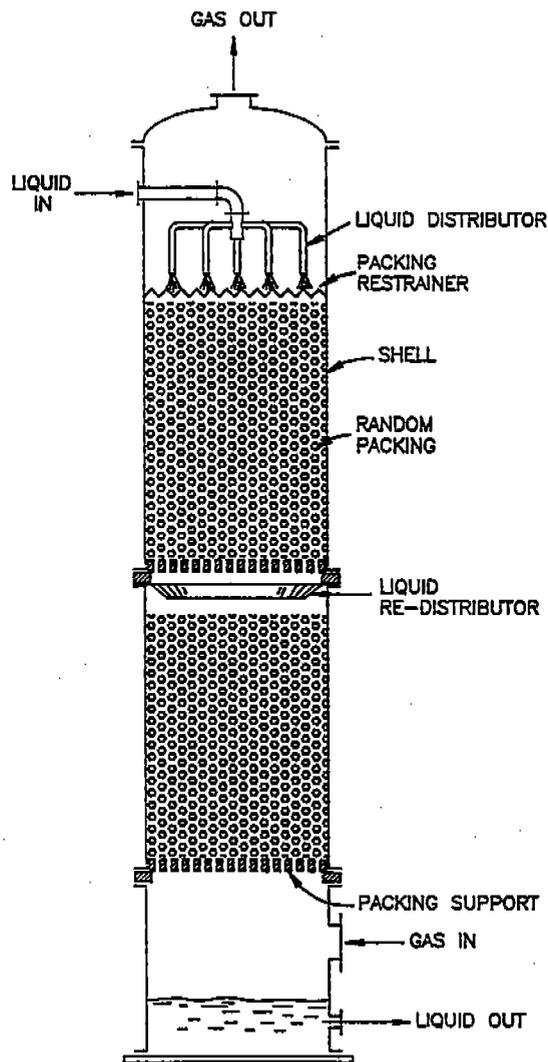


Figure 7-6. Packed-bed absorber.⁴

removal efficiency of a condenser is dependent on the VOC characteristics, concentration, and airflow design.⁴

In the surface condenser, the emission stream is passed by a tube or manifold containing a chilled liquid. When the emission stream contacts the chilled surface, the VOCs condense, then drain to storage or disposal.¹⁰ No contact occurs between the coolant and the emission stream, thus the condensate is strictly composed of the species condensing on its surface.

Contact condensers typically condense the VOC by spraying a liquid (such as water) that ambient temperature or slightly chilled directly into the gas stream in a simple spray chamber or similar device.¹⁰ In contrast to the surface condenser, the contact condenser intimately mixes the cooling agent with the VOC to be removed. The VOC and coolant mixture is collected for reprocessing or disposal.

Condensers are widely used as raw material and/or product recovery devices.⁴ Often, condensers are not used alone but are used in conjunction with other VOC removal devices. Condensers may be placed upstream of absorbers, adsorbers, or incinerators to reduce the material load entering these more expensive or sensitive devices. Used in this way, the condenser can remove components harmful to the other devices (such as chlorine or sulfur) or remove valuable components that would otherwise be destroyed.

Condensers can be used alone for controlling waste streams containing high VOC concentrations (>5,000 ppmv). In these cases, condenser VOC removal efficiencies usually range between 50 and 95 percent.⁴ Flow rates up to about 2,000 scfm are typical for condensers used as emission control devices. At larger flowrates, prohibitively large heat transfer areas are required.⁴

Surface and contact condensers each have merits relative to the other. Surface condensers may more easily recover marketable condensate while minimizing waste disposal problems. However, surface condensers are more expensive to operate than contact condensers.¹⁰ Contact condensers are generally less expensive, more flexible, and more efficient in removing VOC than are surface condensers. Condensate from contact condensers cannot be reused and may require wastewater treatment prior to disposal.¹⁰ Schematic drawings of surface and contact condensers are shown in Figure 7-7.

The condenser does not remove VOCs as efficiently as other VOC control devices such as the incinerator, adsorber, or absorber. As the sole method of VOC control, the condenser may

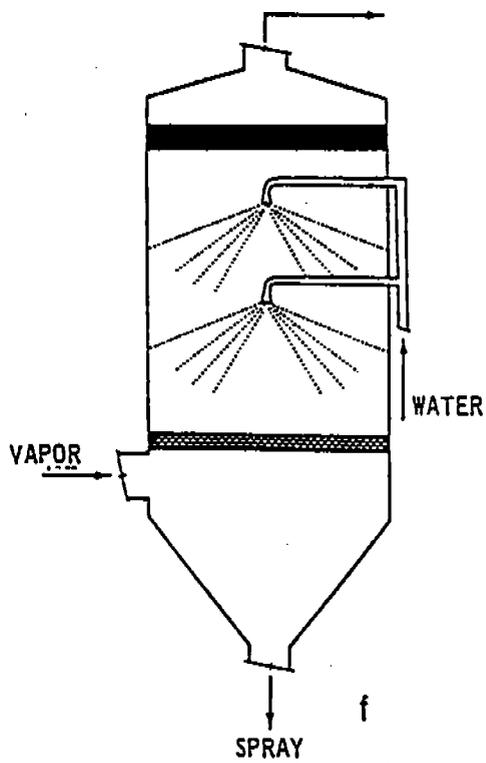
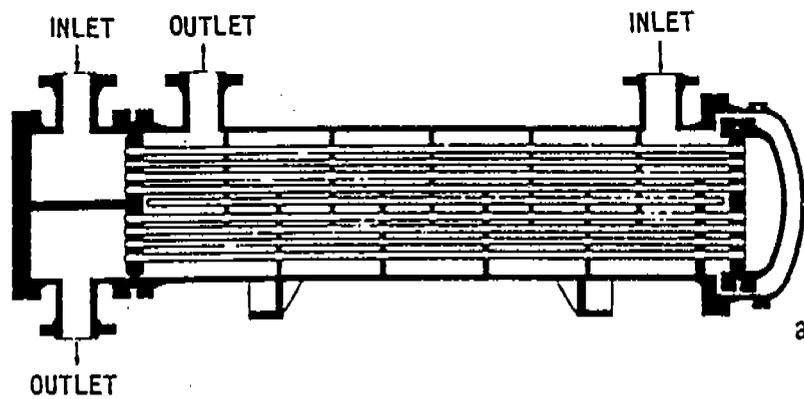


Figure 7-7. Shell-and-tube contact condensers.⁴

not be sufficient for removing VOCs from the waste stream, particularly at high airflows. The condenser may be best applied as an auxiliary VOC removal device placed upstream from other removal devices and used to remove moisture, substances (such as chlorine or sulfur) harmful to other devices, or to recover easily captured materials that would be destroyed if an incinerator were used downstream.

A disadvantage of the condenser is that VOC outlet concentrations below 10,000 to 20,000 ppmv are difficult to achieve due to saturation conditions. If extremely low outlet concentrations are necessary, condensation will usually be economically infeasible.⁴ The condenser is not a feasible control device where a wide range of VOC concentrations and components are anticipated in the emission stream.¹²

7.3.2.2 Combustion Techniques

The most common combustion technique is incineration. Incinerators remove VOCs from the emission stream by combustion, converting the VOCs into CO₂, water vapor, and small amounts of other compounds. The VOC-laden emission stream enters the incinerator chamber where the VOCs are burned, sometimes with the assistance of a catalyst. Incinerator performance is a function of the waste gas heating value, inert content, waste gas water content, and the amount of excess combustion air.¹⁰ Other design variables include degree of mixing, residence time, and the type of auxiliary burning used.

In contrast to adsorbers, absorbers, or condensers, incinerators do not recover the VOC for reuse; however, heat is generated during the combustion reaction, and this heat may be recovered for use elsewhere in the plant. The two most common means of incineration are thermal incineration and catalytic incineration, in which the emission streams are ducted to a combustion device primarily designated for control of organic emissions. The thermal incinerator and catalytic incinerator are illustrated in Figures 7-8 and 7-9. In a third means of incineration, the emission stream can be vented to the combustion chamber of an industrial boiler or process heater. The destruction method efficiency of a boiler or process heater is similar to that of the thermal incinerator. The distinction between the two devices is that the boiler or process heater is designated primarily as a heat source, and secondarily as a control device.

Both thermal and catalytic incinerators are often appropriate control devices for removal of VOCs from emission streams. Heat recovery is readily attained with both thermal and

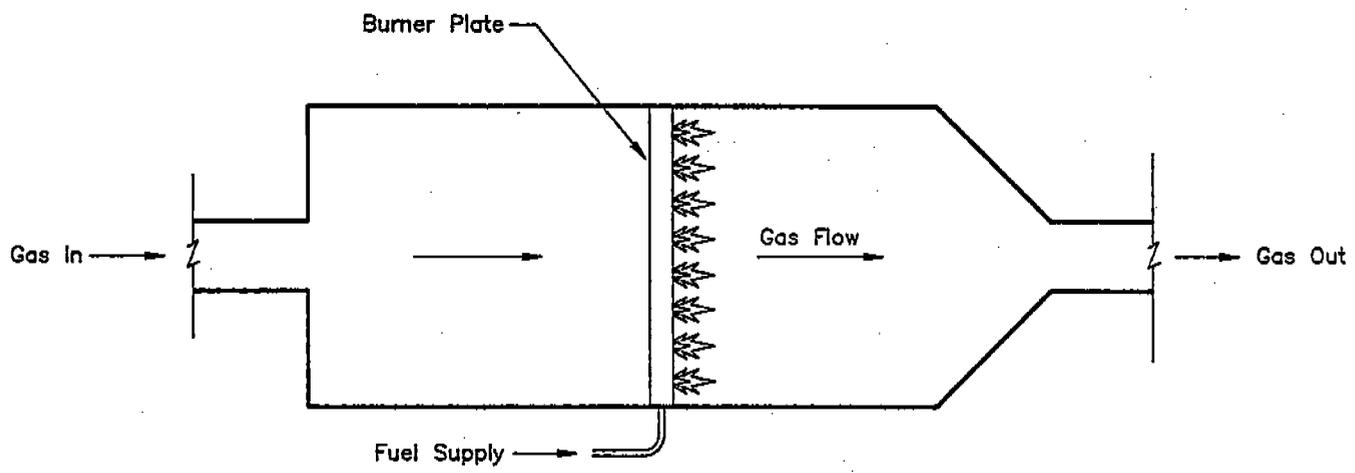


Figure 7-8. Thermal incinerator.

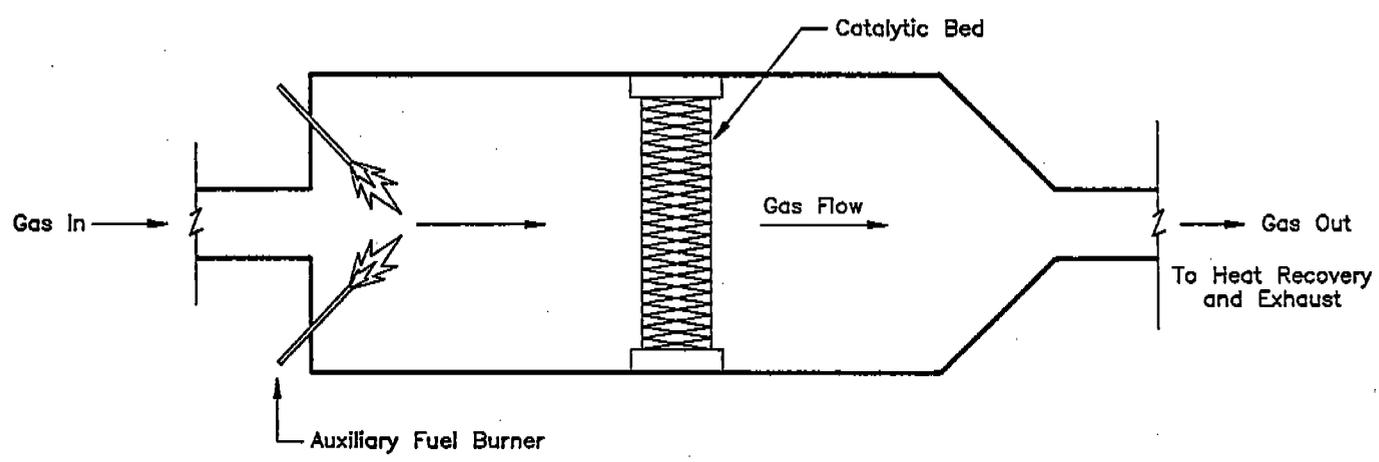


Figure 7-9. Catalytic incinerator.

catalytic incinerators, and this feature enhances the economy of using an incinerator rather than another VOC removal device.¹²

There are some disadvantages to using incinerators. Incinerators destroy the VOCs rather than recovering them; in some cases, the energy benefit may not be as great as the lost value of the VOC. Incinerators may not be practical choices for VOC removal if certain types of VOCs or other materials are burned. Incineration of VOCs that contain halogens or sulfur will produce acidic compounds such as HCl or H₂SO₄. These streams are likely to require removal of the acid components by a scrubber unit, greatly adding to the cost of the VOC control system.⁹ Catalytic incinerators are very sensitive to materials that can reduce the effectiveness of the catalyst. Phosphorous, lead, sulfur, and halogens can poison typical catalysts and severely affect their performance.⁴ If it is necessary to use catalytic incineration to control waste streams containing these materials, special catalysts or other measures must be employed. Liquid or solid particles that deposit on the catalyst and form a coating also reduce the catalyst's usefulness by preventing contact between the catalyst and the VOC.^{4,11}

Thermal incinerators. Thermal incinerators pass the emission stream through a combustion chamber where the VOCs are burned at temperatures typically ranging from 700° to 1,130°C (1,130° to 2,190°F).¹⁰ Initially, burning is started with the assistance of a natural gas flame or similar heat source. If the VOC in the emission stream has a sufficient heating value and concentration, ignition temperatures can be sustained by the combustion of the VOC, and the auxiliary heat can be turned off. If the ignition temperature cannot be maintained by combustion only, the auxiliary heat must be left on. Auxiliary heat can be provided by fuels such as natural gas, and from recovery of heat released during combustion. The waste gases from the thermal incinerator are usually vented to the atmosphere.

Thermal incineration is widely used to control continuous, dilute VOC emission streams with constituents from a number of compounds. Thermal incinerators can achieve VOC removal efficiencies of 98 percent or greater depending on the design of the equipment. These efficiencies may not be possible in cases where the inlet VOC concentration is less than approximately 2,000 ppm. For inlet concentrations lower than 2,000 ppm, the performance of an incinerator is more appropriately indicated as a maximum exit concentration of 20 ppmv.¹⁰ For safety considerations, VOC concentrations are usually limited to 25 percent of the lower

explosive limit (LEL) for the VOC. If the VOC concentration is higher in the waste gas, dilution may be required. Packaged, single-unit thermal incinerators are available to control emission streams with flow rates up to about 100,000 scfm.⁴ Thermal incinerators, via combustion, remove particulate and other organics in addition to VOCs, thus enhancing their utility.¹¹

A regenerative thermal incineration system can be used to control odors and VOC emissions.¹⁵ The contaminated gases enter the system through an upper ring-shaped manifold. The air from this manifold is directed into inlet stoneware (*i.e.*, ceramic) beds which act as energy recovery chambers. As the gases pass through the ceramic beds towards the incineration chamber, they are heated to a temperature nearing that of incineration. The VOC present in the fumes will autoignite in the beds. Oxidation is completed in the central incineration chamber where a gas or oil burner maintains a preset temperature. The purified air then passes through a second set of ceramic beds which absorb much of the gas's internal heat. The flow is periodically reversed to continually feed the inlet stream to the hot bed. The energy which is stored in the stoneware bed during the outlet mode is subsequently used to preheat inlet gases. Thermal efficiencies can exceed 95 percent. Although capital costs are high, they are generally offset by a decreased need for auxiliary fuels.^{17,18} For safety reasons, both thermal and catalytic incinerators may require large amounts of dilution air to reduce the VOC concentration in the emission stream below the explosive limit. Heating the dilution air to the ignition point of the VOC may be prohibitively expensive, particularly if a waste gas contains entrained water droplets which must be vaporized and raised to combustion chamber temperatures.

Catalytic incinerators. Catalytic incinerators are similar to thermal incinerators in that they eliminate VOCs from the waste stream via combustion. The distinguishing feature of a catalytic incinerator is the presence of a catalyst (such as platinum or copper oxide) that allows the VOC combustion reaction to take place at a temperature lower than the normal ignition temperature exhibited by the VOC in air.^{4,10} By allowing the combustion reaction to take place at lower temperatures than required for a thermal incinerator, less preheating of the emission stream from auxiliary heat is necessary, and significant fuel savings are achieved.

In the catalytic incinerator, the emission stream is preheated to approximately 150°C (600°F) by recovered incinerator heat or by auxiliary burners.¹⁰ The preheated emission stream is passed through the catalyst bed where combustion takes place on the activated catalytic

surface. The incinerators are operated from 150° to 650°C (600° to 1,200°F), significantly lower than operating temperatures for thermal incinerators. Higher temperatures can shorten the life of the catalytic bed. Properly operated catalytic converters can be satisfactorily operated for three to five years before replacement of the catalyst is necessary.⁴

Catalytic incinerators have been applied to emission streams in many industries. Packaged, single-unit catalytic incinerators are available to control emission streams with flow rates up to about 100,000 standard cubic feet per minute (scfm) at efficiencies greater than 98 percent.¹¹

Low energy costs make the catalytic incinerator an important option for removal of VOC from emission streams; however, the catalytic incinerator cannot be used in as many applications as the thermal incinerator. Catalytic materials can be quickly degraded by many elements or compounds present in industrial emissions such as sulfur or particulate. Many of these materials are burned without difficulty in thermal incinerators.

Some of the issues which must be addressed when applying catalytic incineration techniques are the incinerator's ability to handle the variety of vapor phase organics that would be emitted from the facility, the variety of organic concentrations in process waste streams, and the changing speciation of organic emissions that may occur with adjustment in the process material feed.¹² In many cases, one catalyst cannot handle all of the waste stream variations generated by an VOC-emitting process.

Industrial boilers and process heaters. In industrial boilers and process heaters, hot combustion gases (typically from natural gas or fuel oils) are placed into contact with heat transfer tubes that contain water or process liquids. Heat from the combustion gases is transferred across the tube to the liquids to produce steam or to heat the process material. In addition to their function as steam generators and heaters, industrial boilers and process heaters are currently used in industry to control organic emissions from manufacturing operations. Both devices are most applicable where high heat recovery potential exists.¹⁰

Because the combustion of organic emissions can affect the performance of a boiler, the emission characteristics must be considered. Such factors as variable flow rates, variable heat contents, pressure, and the presence of corrosive compounds may require changes in the operation of the boiler or heater. Boilers currently operating in a facility may not be able to control all of

the emissions from the plant, and an additional incineration device may be required. When a new boiler or other incineration device is to be purchased, the operating and design parameters can be calculated to fit specific facility needs.^{10,17}

If a boiler or process heater is applicable and available for use as a control device, it may provide excellent control efficiencies comparable to a thermal incinerator, while reducing capital and operating costs. The only capital investments involved are those associated with capture system ductwork, fans, and boiler or process heater modifications required to direct emissions to the boiler/process heater. One difficulty associated with boilers and process heaters is that they must operate continuously and concurrently with the emission source unless other control devices or strategies are available.^{10,17}

7.3.3 NO_x Control Devices

Currently, the most developed and widely applied add-on NO_x control technique is selective catalytic reduction (SCR). Selective noncatalytic reduction (SNCR) using ammonia- or urea-based compounds is used in some industries, but is not currently in widespread use. In the SCR process, ammonia is injected into the NO_x-laden emission stream. The NO_x reacts with the ammonia and is reduced to molecular nitrogen in a separate reactor vessel containing a catalyst, which is usually a mixture of titanium dioxide, vanadium pentoxide, and tungsten trioxide.¹⁸

Because NO_x is generally the byproduct of a combustion reaction that also produces particulate emissions, any SCR devices are usually placed in line with a particulate control device such as a baghouse or an ESP. An SCR device may be placed on line either before or after the particulate control device. If the SCR system is located in front of the control device, the mesh size of the catalyst has to be kept higher to avoid dust buildup and catalyst fouling. However, increasing the catalyst mesh size results in a lower catalyst-specific surface area. If the SCR is located after the particulate control device, finer mesh catalysts can be used.¹⁸

Catalyst deactivation and residual NH₃ in the flue gas are the two key operating considerations in an SCR system. Catalyst performance degrades over time due to fouling. Unreacted NH₃ passing through the reactor forms ammonium sulfate and causes clogging in any downstream equipment.

NO_x emission reductions of 60-90 percent have been reported in full-scale SCR systems internationally. One issue that remains to be resolved before SCR can be extensively used in the United States is whether the data obtained from Japanese and European boiler applications can be directed extrapolated to the United States, where higher-sulfur coals are used.¹⁸

7.3.4 SO₂ Control Devices

SO₂ is an inevitable byproduct of the combustion of any materials that contain sulfur. Coal-burning power plants are the primary industrial emitters of SO₂ in the United States. Several "scrubbing" systems are designed to remove SO₂ from combustion emissions. Scrubbing systems use alkaline solutions, slurries, or aggregates to scrub SO₂ from the air stream. Scrubbing systems have achieved SO₂ removal rates of up to 95 percent for various coals, including those containing up to 4 percent sulfur.¹⁹

In wet-scrubbing systems, an alkaline liquid solution is introduced into the flue gas. Wet-scrubbing is generally accompanied by the generation of wet waste, which typically must be treated and disposed of in accordance with landfill and wastewater regulations. A new system, however, is producing salable gypsum through the use of an in situ oxidation system and a dewatering system. Semi-dry scrubbing systems use an alkaline slurry or caustic solution that is atomized by a spray dryer. Flue gas is passed through the mist, allowing the reagent to react with the acid gases and water. Dry scrubbing systems inject dry alkaline materials into the flue gas, where the alkaline powder reacts with the acid gases to create a solid material that is then captured by a particulate collection system.¹⁹

7.3.5 Secondary Control of HAPs

Section 3 introduced the distinction between the regulatory bases for controlling emissions of criteria pollutants and hazardous air pollutants (HAPs). Because HAPs are often emitted as VOCs or particulate matter, control devices that remove VOC or particulate matter from the emission stream may also effectively remove some HAPs from the atmosphere.

The EPA handbook *Control Technologies for Hazardous Air Pollutants* is an excellent reference for information on the process of selecting emission control equipment for HAPs and

for estimating emission reductions using these devices.⁴ 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 size, volatility, or combustibility. Control Techniques Guidelines (CTGs) Documents have been written for numerous VOC-emitting source categories: some of these documents contain information relevant to the control of HAPs. Information on available CTG documents can be obtained via the Emission Factor Assistance line (see Appendix E).

7.3.6 Control of Non-process Particulate Fugitive Emissions

Control techniques for non-process particulate fugitive emissions are not achieved by the use of control devices as discussed in the earlier paragraphs, but a discussion of the methods used to control fugitive emissions is included here for reference. Several non-process emissions are generated by activities such as vehicular travel on paved and unpaved roads, wind erosion from storage piles, and materials transfer to or from vehicles or storage piles. This section discusses control methods designed to reduce particulate emissions from these sources.

7.3.6.1 Paved roads

Particulate emissions occur whenever a vehicle travels over a paved surface, such as public and industrial roads and parking lots. These emissions can originate from material previously deposited on the travel surface or a re-suspension of material from tires and undercarriages. In general, emissions are from the surface material loading which is composed of such things as pavement wear, deposition of material from vehicles, and deposition from other nearby sources, etc. Because of the importance of surface loading, available control techniques either attempt to prevent material from being deposited on the surface or to remove any material that has been deposited.²⁰ Two types of measures are used to control PM-10 emissions from paved roads, preventative and mitigative. Preventative measures are techniques for controlling fugitive particulate emissions which prevent the creation and/or release of PM-10.²¹ Mitigative measures involve the periodic removal of dust-producing material.²⁰ Preventative measures are preferred by EPA, although mitigative measures may be more practical for industrial plant roads

because these roads are more subject to spillage, carryout from unpaved areas, etc. Both types of control methods for paved roads are discussed in the following sections.

Preventative measures for paved roads. One preventative measure involves replacing usual snow/ice control materials with other harder and/or coarser materials. The use of anti-skid materials with either a lower initial silt content or greater resistance to forming silt-size particles will result in lower road surface silt loadings. A second preventative measure involves eliminating mud and dirt carryout from unpaved areas such as parking lots, construction sites, etc. The elimination of this carryout can significantly reduce paved road emissions. Other preventative measures for paved roads include covering trucks, wet suppression of material being hauled, and paving/stabilizing portions of unpaved areas nearest to paved road.²⁰

Mitigative measures for paved roads. The best mitigative method for controlling particulate is street flushing. Street flushers remove surface materials from roads and parking lots using high pressure water sprays. Some systems supplement the cleaning with broom sweeping after flushing. Although flushing presents some obvious drawbacks in terms of water usage, potential water pollution, and the frequent need to return to the water source, it is generally the most effective in controlling particulate emissions from paved roads.²⁰ The next best mitigative method is the vacuum sweeping of roads. Vacuum sweepers remove material from paved surfaces by entraining particles in a moving air stream. In addition to the vacuum pickup heads, a sweeper may also be equipped with gutter and other brooms to enhance collection. A hopper collects filtered material and air exhausts through the filter system in an open loop. The least effective mitigative measure employs street cleaners to mechanically broom sweep paved roads. Street cleaners use rotary brooms to remove surface materials from roads and parking lots. Much of the effect is cosmetic, however, because a substantial fraction of the original loading is emitted during the sweeping. Thus, this measure can be as much a source as a control of particulate emissions.

7.3.6.2 Unpaved roads

Particulate emissions occur whenever a vehicle travels over an unpaved surface. Unlike paved roads, however, the unpaved road itself is the source of the emissions rather than any surface loading. Within the various categories of open dust sources in industrial settings, unpaved travel surfaces have historically accounted for the greatest share of particulate emissions in industrial settings. Control methods for unpaved roads are usually subdivided into three categories, source extent reductions, surface treatments, and surface improvements. Each of these is discussed in the following sections.

Source extent reductions for unpaved roads. Source extent reductions either limit the amount of traffic on a road or lower speed limits to reduce the emissions rate. The reduction may be obtained by restricting roads to certain vehicle types or by strict enforcement of reduced speed limits. This method is attractive in that the initial and operating costs may be very low; however, speed reduction measures could require additional trucks and drivers to maintain production levels. The effective control efficiencies for speed reduction increase as the speed is reduced.²⁰

Surface treatment techniques for unpaved roads. Surface treatment refers to those control techniques, such as watering or chemical stabilization, which require periodic re-applications. Necessary reapplication frequencies range from several minutes for plain water under hot, summertime conditions to several months for some chemicals. A variety of chemical stabilizers are used to suppress dust from unpaved surfaces. The chemicals bind the loose roadway material into a fairly impervious surface or form a surface which attracts and retains moisture. The degree of control achieved is a direct function of the application intensity (volume of solution per area), dilution ratio, and application frequency (number of applications per unit time). Another surface treatment method is watering. This method, although considered less expensive than chemical treatment, has many drawbacks including the need for continuous application, decreased efficiency during dry weather, increased potential to add mud carry-on to nearby paved surfaces, and limited applicability during cold winter periods.⁹

Surface improvements for unpaved roads. Surface improvements alter the road surface by covering it with a low silt aggregate material (aggregation) or by paving. This option is

expensive and is probably most applicable to roads that are not subject to very heavy vehicles or spillage of material in transport. Initial costs are high; however, maintenance costs are lower than for aggregation.²⁰ Covering an unpaved road with an aggregate that has a lower silt content than the dirt roadbed reduces the amount of fines available for entrainment. This type of improvement is initially much less expensive than paving; however, continuous road maintenance is required.

7.3.6.3 Storage Piles

Maintenance of outdoor storage piles is inherently necessary in many operations that use minerals in aggregate form. Storage piles are usually left uncovered, partially because of the need for frequent material transfer. Dust emissions occur at several points in the storage cycle: during material loading onto the pile, during disturbances by strong wind currents, and during loadout from the pile. The movement of trucks and loading equipment in the storage pile area is also a substantial source of dust. Preventative methods for control of windblown emissions from raw material storage piles include enclosures, wetting, and chemical stabilization. These methods are discussed in the following sections.²⁰

Enclosures for storage piles. Enclosures are an effective way to control fugitive particulate emissions from open dust sources. Enclosures can either fully or partially enclose the storage pile and transfer mechanisms to and from the plant or trucks. Types of passive enclosures traditionally used for open dust control include three-sided bunkers for the storage of bulk materials, storage silos for various types of aggregate material (in lieu of open piles), and open-ended buildings. Partial enclosures used for reducing windblown dust from large exposed areas and storage piles include porous wind screens and similar types of barriers (e.g., trees). The principle of the wind fence/barrier is to provide an area of reduced wind velocity which allows settling of the large particles (which cause saltation) and reduces the particle flux from the exposed surface on the leeward side of the fence/barrier.²⁰

Wet suppression systems for storage piles. Fugitive emissions from aggregate materials handling systems are frequently controlled by wet suppression systems. These systems use liquid sprays or foam to suppress the formation of airborne dust. The primary control mechanisms are those

that prevent emissions through agglomerate formation by combining small dust particles with larger aggregate or with liquid droplets. Key factors affecting the degree of agglomeration and the performance of the system are the degree of material coverage by the liquid and the ability of the liquid to "wet" small particles. Two types of wet suppression systems are often suitable: liquid sprays, which use water or water/surfactant mixtures as the wetting agent; and systems which supply foams as the wetting agent.²⁰

Liquid spray wet suppression systems can be used to control dust emissions from materials handling at conveyor transfer points. The wetting agent can be water or a combination of water and a chemical surfactant. This surfactant (surface active agent) reduces the surface tension of the water. As a result, the quantity of liquid needed to achieve good control is reduced. For systems using water only, adding surfactant can reduce the quantity of water necessary to achieve good control.²⁰

Application of micron-sized foam is an alternative to water spray systems. The primary advantage of foam systems is that they provide equivalent control at lower moisture-addition rates than spray systems. However, the foam system is more costly and requires using extra materials and equipment. The foam system also achieves good control primarily through wetting and agglomerating fine particles.²⁰

Chemical stabilization for storage piles. Chemical stabilization involves using chemical dust suppressants to control fugitive particulate emissions from material storage piles. Control efficiencies have been determined in portable wind tunnel tests on various types of materials and show that chemical stabilization is a viable option to control fugitive dust emissions from storage piles.²⁰

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APPENDIX A - GLOSSARY OF TERMS



GLOSSARY OF TERMS

Absorption: The taking up of gases by liquids or solids.

Activity level: Any variable parameter associated with the operation of a source (e.g., production rate, fuel consumption, etc.) that may be correlated with the air pollutant emissions from that source.

Adsorption: A physico-chemical phenomenon in which a gas is concentrated on the surface of a solid or liquid.

Aerometric Information Retrieval System (AIRS): A computer-based repository of information about airborne pollution in the United States. The system is administered by EPA's National Air Data Branch (NADB) in the Office of Air Quality Planning and Standards (OAQPS). Point source emissions data will be stored on AIRS Facility Subsystem (AFS). Area and mobile source emissions data will be stored on AIRS Area and Mobile Sources Subsystem (AMS).

AP-42: EPA Document Number *AP-42, Compilation of Air Pollutant Emission Factors*, Environmental Protection Agency, Research Triangle Park, North Carolina. Supplements are published regularly. This document includes process descriptions and emission factors for a broad range of criteria pollutant emission sources.

Area source: Normally, an aggregation of all sources not defined as point sources in a specific geographic area. Area sources usually include all mobile sources and any stationary sources too small, difficult, or numerous to classify as point sources. The area source emissions are assumed to be spread over a broad area.

Attainment area: An area considered to have air quality as good as or better than the National Ambient Air Quality Standards as defined in the Clean Air Act. An area may be an attainment area for one pollutant and a nonattainment area for others.

Baseline projection: Estimate of emissions expected in future years, based on a growth and emission control scenario. Baseline emission controls for a given projection year include only those controls that have been legally mandated at the time of preparing the projection.

Best Available Control Measure (BACM): A term used in the House Clean Air Act Amendments of 1990 bill referring to the "best" measures (according to EPA guidance) for controlling small or dispersed sources of particulate matter.

Breathing loss: Loss of vapors from storage tanks due to diurnal warming and cooling.

Clean Air Act Amendments of 1990 (CAAA): The CAAA were passed by Congress in October 1990 and signed into law by President Bush on November 15, 1990. November 15, 1990 is considered the date of enactment of the CAAA.

Control strategy projection inventory: An inventory of emissions, for a future year, which differs from the baseline inventory in that it takes into account the expected impact of a proposed control strategy.

Control Techniques Guidelines (CTG): Guidance documents issued by EPA which define Reasonably Available Control Technology (RACT) to be applied to existing facilities that emit certain threshold quantities of air pollutants; they contain information both on the economic and technological feasibility of available techniques.

Correction factors: Special multipliers employed in emission calculations to adjust the resulting emission estimates more accurately by taking into account special parameters such as temperature, pressure, operating load, etc. Appropriate correction factors are particularly important in accurately calculating organic emissions from mobile sources and petroleum product storage and handling operations.

Degreasing: Any operation in which impurities such as greases and oils are removed from a surface using an organic solvent.

Diffusion modeling: A mathematical technique for calculating the atmospheric distribution of air pollutants based on emissions data and meteorological data for an area. Also referred to as dispersion modeling.

Documentation (inventory): A compilation of the methods, assumptions, calculations, references, etc., that are employed in the development of an inventory.

Emission factor: An estimate of the amount of a pollutant released per rate of activity (e.g., production rate or throughput).

Emission inventory: A compilation of information relating to sources of pollutant emissions, including location, quantity of emissions, number and type of control devices, stack dimensions and gas flow rates, and additional pertinent details. Can be a large-scale, statewide or area-wide collection of point, area, and mobile source emissions or be small, plant-specific.

Empirical Kinetic Modeling Approach (EKMA): A source/receptor relationship developed by EPA for estimating the overall reduction of volatile organic compound levels needed in an urban area based on existing oxidant levels and VOC/NO_x ratios.

Evaporative losses: Emissions caused by the vaporization of materials (generally solvents) at normal atmospheric temperature and pressure conditions.

Exhaust gas: Any gas, along with any particulate matter and uncombined water contained therein, emitted from a source to the atmosphere.

Fugitive organics: Organic compounds that are not emitted through stacks, vents, or other confined air streams, but are emitted from equipment leaks, valves, etc.

Fugitive source: A source where any gaseous or particulate contaminant enters the atmosphere without passing through a vent designed to direct or control its flow.

Gasoline marketing operations: The operations and systems associated with the transportation of gasoline from refineries to bulk terminals, to bulk storage, to dispensing outlets, and to vehicle gas tanks.

Gridding and subcounty allocation: The practice of distributing emissions or any other parameter from a larger geographical area (usually a county) to a smaller geographic area (i.e., a grid) using data presumed to be proportional to the parameter being distributed.

Hydrocarbons: Any compounds containing only carbon and hydrogen. The term "hydrocarbon" is often used synonymously and erroneously with "volatile organic compound," although the latter also includes hydrocarbon derivatives, as well.

Imprecision (emission inventory): That error in an emission inventory due to the variability (or random error) in the data used in determining the inventory.

Inaccuracy (emission inventory): That error in an emission inventory due to omissions, errors, and biases in the data used in determining the inventory.

Material balance: Technique used to estimate emissions from a source by accounting for the weights of one or more substances in all incoming and outgoing process streams.

Maximum Achievable Control Technology (MACT): Emissions limitations based on the best demonstrated control technology or practices in similar sources to be applied to major sources emitting one or more of the listed toxic pollutants.

Methane: The simplest hydrocarbon species; often excluded from VOC measurements or inventories because it is essentially photochemically unreactive.

Mobile source: Any moving source of air pollutants, such as automobiles, vessels, locomotives, aircraft, etc.

Motor vehicles: Motor powered vehicles such as automobiles, trucks, motorcycles, and buses, operated primarily on streets and highways.

Nitric oxide (or nitrogen oxide): One of the two oxides of nitrogen which are collectively referred to as NO_x . The amount of nitric oxide (NO) in NO_x is often reported in terms of the equivalent weight of nitrogen dioxide (NO_2), in which case its true weight is only 30/46 of the reported weight.

Nitrogen dioxide: One of the two oxides of nitrogen which are collectively referred to as NO_x . The total weight of NO_x is often reported "as nitrogen dioxide (NO_2)," which is not the true weight of the mixture but the weight which would be attained if all the nitric oxide (NO) were converted to NO_2 .

Nonmethane hydrocarbon: All hydrocarbons, except methane.

Office of Business Economics, Research Service (OBERS): Acronym used in reference to projections prepared jointly by the U.S. Department of Commerce, Bureau of Economic Affairs, Office of Business Economics, and the U.S. Department of Agriculture, Economic Research Service, for the U.S. Water Resources Council.

Oxides of nitrogen: In air pollution usage, this comprises nitric oxide (NO) and nitrogen dioxide (NO₂); usually expressed in terms of the equivalent amount of NO₂.

Ozone: Three atoms of oxygen (O₃) combined through complex photochemical reactions involving volatile organic compounds and oxides of nitrogen.

Ozone control strategy: A plan developed by an agency to control ambient ozone levels within its jurisdiction.

Ozone precursors: Volatile organic compounds and oxides of nitrogen, as air pollutant emissions and as air contaminants which undergo a series of reactions under the influence of ultraviolet light from the sun, to form photochemical oxidants, including ozone.

Ozone season: That period of the year during which conditions for photochemical ozone formation are most favorable. Generally, sustained periods of direct sunlight (i.e., long days, small cloud cover) and warm temperatures.

Paraffins: Saturated, nonaromatic hydrocarbons, also known as long straight-chain alkanes.

Photochemistry: The chemistry of reactions which involve light as the source of activation energy.

Photochemical model (air quality): A detailed computer model that estimates ozone concentrations both as a function of space and time by directly simulating all of the physical and chemical processes that occur during the photochemical process.

Point source: Generally, any stationary source for which individual records are collected and maintained. Point sources are usually defined as any facility which releases more than a specified amount of a pollutant.

Process variable: Any condition associated with the operation of a process, including the quantities and properties of any materials entering or leaving any point in the process, which is, or may readily be, monitored, measured, etc., during the normal course of process operation.

Process weight rate: The process weight charged per unit of time. The term is loosely used interchangeably with operating rate. However, operating rate may cover either input to or output from a process, whereas strictly speaking, process weight rate should cover only material input to a process.

Reactivity: A measure of the rate and extent to which a volatile organic compound will react, in the presence of sunlight and nitrogen oxides, to form photochemical ozone.

Reasonably Available Control Technology (RACT): Reasonably available control technology is defined as the lowest emission limit that a particular source is capable of meeting by the application of control technology that is reasonably available considering technical and economic feasibility.

Rule Effectiveness (RE): A measure of the ability of the regulatory program to achieve all the emission reductions that could be achieved by full compliance with the applicable regulations at all sources at all times. It reflects the assumption that regulations typically are not 100 percent effective due to limitations of control techniques or shortcomings in the enforcement process. EPA allows the use of an 80 percent default value, but gives States the option to derive local, category-specific RE factors.

Standard Industrial Classification (SIC) Codes: A series of codes devised by the Office of Management and Budget to classify establishments according to the type of economic activity in which they are engaged.

State Implementation Plan (SIP) inventories: Emission inventories required as part of the overall State Implementation Plan for achieving the National Ambient Air Quality Standards. States are required under the Clean Air Act to submit these plans to the U.S. Environmental Protection Agency.

Solvent: A liquid that is used to dissolve another compound or group of compounds.

Source: Any device or facility that contributes to air pollution.

Source category: Any group of similar sources. For instance, all residential dwelling units would constitute a source category.

Source (process) information: Information collected on each point source in an inventory that describes that source, such as location, fuel use and fuel characteristics, operational data, stack data, or other identifiers. Source information, together with emissions and control device data, comprise the basic elements of an emission inventory. For area sources, this information is usually limited to activity levels.

Source/receptor model: A model or relationship that predicts ambient ozone levels based on precursor emission strengths (of NO_x and VOC) and various meteorological parameters. Source/receptor models may range in complexity from simple empirical or statistical relationships [such as rollback or the Empirical Kinetic Modeling Approach (EKMA)] to detailed photochemical atmospheric simulation models.

Source test: Direct measurement of pollutants of a facility.

Spatial resolution: The degree to which the location of a source can be pinpointed geographically within an inventory area.

Species class: Any grouping of VOC compounds, combined in accordance with regulatory policy or rules specified by input instructions for a photochemical simulation model. Also called "reactive class" or "reactivity class."

Stationary source: A source which remains at a fixed location.

Surrogate indicator: (1) For spatial resolution, a quantity for which distribution over an area is known or accurately estimated and which may be assumed similar to the emissions distribution from some source category for which spatial allocation is unknown. (2) For growth, a quantity for which official growth projections are available which may be assumed similar to that of activity in some source category for which projections are needed.

Volatile organic compounds (VOC): Organic compounds include all compounds of carbon except carbonates, metallic carbides, carbon monoxide, carbon dioxide, and carbonic acid. A volatile organic compound (VOC) is any organic compound that, when released to the atmosphere, can remain long enough to participate in photochemical reactions.

Volume percent: The number of volumes of a given component in 100 volumes of a mixture. In gaseous mixtures, equivalent to mole percent.

Weight percent: The number of weight or mass units of a given component in 100 units of a mixture.

Zone: A subdivision of a study area, constituting the smallest geographic area for which data are aggregated and basic analyses made.

APPENDIX B - LIST OF 189 HAZARDOUS AIR POLLUTANTS



189 LIST OF HAZARDOUS AIR POLLUTANTS

<u>Chemical Name</u>	<u>CAS Number</u>
Acetaldehyde	75-07-0
Acetamide	60-35-5
Acetonitrile	75-05-8
Acetophenone	98-86-2
2-Acetylaminofluorene	53-96-3
Acrolein	107-02-8
Acrylamide	79-06-1
Acrylic acid	79-10-7
Acrylonitrile	107-13-1
Allyl chloride	107-05-1
4-Aminobiphenyl	92-67-1
Aniline	62-53-3
o-Anisidine	90-04-0
Asbestos	1332-21-4
Benzene	71-43-2
Benzidine	92-87-5
Benzotrichloride	98-07-7
Benzyl chloride	100-44-7
Biphenyl	92-52-4
Bis(2-ethylhexyl)phthalate	117-81-7
Bis(chloromethyl)ether	542-88-1
Bromoform	75-25-2
1,3-Butadiene	106-99-0
Calcium cyanamide	156-62-7
Caprolactam	105-60-2
Captan	133-06-2
Carbaryl	63-25-2
Carbon disulfide	75-15-0
Carbon tetrachloride	56-23-5
Carbonyl sulfide	463-58-1
Catechol	120-80-9
Chloramben	133-90-4
Chlordane	57-74-9
Chlorine	7782-50-5
Chloroacetic acid	79-11-8
2-Chloroacetophenone	532-27-4
Chlorobenzene	108-90-7
Chlorobenzilate	510-15-6
Chloroform	67-66-3
Chloromethyl methyl ether	107-30-2
Chloroprene	126-99-8

<u>Chemical Name</u>	<u>CAS Number</u>
Cresols/Cresylic acid (isomers and mixture)	1319-77-3
m-Cresol	108-39-4
o-Cresol	95-48-7
p-Cresol	106-44-5
Cumene	98-82-8
2,4-D, Salts and esters	94-75-7
DDE	3547-04-4
Diazomethane	334-88-3
Dibenzofuran	132-64-9
1,2-Dibromo-3-chloropropane	96-12-8
Dibutyl phthalate	84-74-2
1,4-Dichlorobenzene	106-46-7
3,3-Dichlorobenzidine	91-94-1
Dichloroethyl ether (Bis(2-chloroethyl)ether)	111-44-4
1,3-Dichloropropene	542-75-6
Dichlorvos	62-73-7
Diethanolamine	111-42-2
N,N-Diethyl aniline (N,N-Dimethylaniline)	121-69-7
Diethyl sulfate	64-67-5
3,3-Dimethoxybenzidine	119-90-4
Dimethylaminoazobenzene	60-11-7
3,3'-Dimethyl benzidine	119-93-7
Dimethyl carbamoyl chloride	79-44-7
Dimethyl formamide	68-12-2
1,1-Dimethyl hydrazine	57-14-7
Dimethyl phthalate	131-11-3
Dimethyl sulfate	77-78-1
4,6-Dinitro-o-cresol, and salts	534-52-1
2,4-Dinitrophenol	51-28-5
2,4-Dinitrotoluene	121-14-2
1,4-Dioxane (1,4-Diethyleneoxide)	123-91-1
1,2-Diphenylhydrazine	122-66-7
Epichlorohydrin (1-Chloro-2,3-epoxypropane)	106-89-8
1,2-Epoxybutane	106-88-7
Ethyl acrylate	140-88-5
Ethyl benzene	100-41-4
Ethyl carbamate (Urethane)	51-79-6
Ethyl chloride (Chloroethane)	75-00-3
Ethylene dibromide (1,2-Dibromoethane)	106-93-4
Ethylene dichloride (1,2-Dichloroethane)	107-06-2
Ethylene glycol	107-21-1
Ethylene imine (Aziridine)	151-56-4
Ethylene oxide	75-21-8
Ethylene thiourea	96-45-7

<u>Chemical Name</u>	<u>CAS Number</u>
Ethylidene dichloride (1,1-Dichloroethane)	75-34-3
Formaldehyde	50-00-0
Heptachlor	76-44-8
Hexachlorobenzene	118-74-1
Hexachlorobutadiene	87-68-3
Hexachlorocyclopentadiene	77-47-4
Hexachloroethane	67-72-1
Hexamethylene-1,6-diisocyanate	822-06-0
Hexamethylphosphoramide	680-31-9
Hexane	110-54-3
Hydrazine	302-01-2
Hydrochloric acid	7647-01-0
Hydrogen fluoride (Hydrofluoric acid)	7664-39-3
Hydrogen sulfide	7783-06-4
Hydroquinone	123-31-9
Isophorone	78-59-1
Lindane (all isomers)	58-89-9
Maleic anhydride	108-31-6
Methanol	67-56-1
Methoxychlor	72-43-5
Methyl bromide (Bromomethane)	74-83-9
Methyl chloride (Chloromethane)	74-87-3
Methyl chloroform (1,1,1-Trichloroethane)	71-55-6
Methyl ethyl ketone (2-Butanone)	78-93-3
Methyl hydrazine	60-34-4
Methyl iodide (Iodomethane)	74-88-4
Methyl isobutyl ketone (Hexone)	108-10-1
Methyl isocyanate	624-83-9
Methyl methacrylate	80-62-6
Methyl tert-butyl ether	1634-04-4
4,4-Methylene bis(2-chloroaniline)	101-14-4
Methylene chloride (Dichloromethane)	75-09-2
Methylene diphenyl diisocyanate (MDI)	101-68-8
4,4'-Methylenedianiline	101-77-9
Naphthalene	91-20-3
Nitrobenzene	98-95-3
4-Nitrobiphenyl	92-93-3
4-Nitrophenol	100-02-7
2-Nitropropane	79-46-9
N-Nitrosodimethylamine	62-75-9
N-Nitrosomorpholine	59-89-2
N-Nitroso-N-methylurea	684-93-5
Parathion	56-38-2
Pentachloronitrobenzene (Quintobenzene)	82-68-8

<u>Chemical Name</u>	<u>CAS Number</u>
Pentachlorophenol	87-86-5
Phenol	108-95-2
p-Phenylenediamine	106-50-3
Phosgene	75-44-5
Phosphine	7803-51-2
Phosphorous	7723-14-0
Phthalic anhydride	85-44-9
Polychlorinated biphenyls (Arochlors)	1336-36-3
1,3-Propane sultone	1120-71-4
beta-Propiolactone	57-57-8
Propionaldehyde	123-38-6
Propoxur (Baygon)	114-26-1
Propylene dichloride (1,2-Dichloropropane)	78-87-5
Propylene oxide	75-56-9
1,2-Propylenimine (2-Methyl aziridine)	75-55-8
Quinoline	91-22-5
Quinone	106-51-4
Styrene	100-42-5
Styrene oxide	96-09-3
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746-01-6
1,1,2,2-Tetrachloroethane	79-34-5
Tetrachloroethylene (Perchloroethylene)	127-18-4
Titanium tetrachloride	7550-45-0
Toluene	108-88-3
2,4-Toluene diamine	95-80-7
2,4-Toluene diisocyanate	584-84-9
o-Toluidene	95-53-4
Toxaphene (chlorinated camphene)	8001-35-2
1,2,4-Trichlorobenzene	120-82-1
1,1,2-Trichloroethane	79-00-5
Trichloroethylene	79-01-6
2,4,5-Trichlorophenol	95-95-4
2,4,6-Trichlorophenol	88-06-2
Triethylamine	121-44-8
Trifluralin	1582-09-8
2,2,4-Trimethylpentane	540-84-1
Vinyl acetate	108-05-4
Vinyl bromide	593-60-2
Vinyl chloride	75-01-4
Vinylidene chloride (1,1-Dichloroethylene)	75-35-4
Xylene (mixed isomers)	1330-20-7
m-Xylene	108-38-3
o-Xylene	95-47-6

<u>Chemical Name</u>	<u>CAS Number</u>
p-Xylene	106-42-3
Antimony Compounds Antimony	7440-36-0
Arsenic Compounds (inorganic including arsine) Arsenic Arsine	7440-38-2
Beryllium Compounds Beryllium	7440-41-7
Cadmium Compounds Cadmium	7440-43-9
Chromium Compounds Chromium	7440-47-3
Cobalt Compounds Cobalt	7440-48-4
Coke Oven Emissions	
Cyanide Compounds (XCN where X=H or any other group where a formal dissociation may occur) Hydrogen Cyanide	74-90-8
Glycol ethers	[includes moni- and di- ethers of ethylene glycol, diethylene glycol, and triethylene glycol R-(OCH ₂ CH ₂) _n -OR' where n = 1, 2, or 3 R = alkyl or aryl groups R' = R, H, or groups which, when removed, yield glycol ethers with the structure: R-(OCH ₂ CH) _n -OH Polymers are excluded from the glycol category.]
Lead Compounds Lead	7439-92-1
Manganese Compounds Manganese	7439-96-5

Chemical Name

CAS Number

Mercury Compounds

Mercury

7439-97-6

Mineral fibers

[includes mineral fiber emissions from facilities manufacturing or processing glass, rock, or slag fibers (or other minerals derived fibers) of average diameter 1 micrometer or less.]

Nickel Compounds

Nickel

7440-02-0

Polycyclic Organic

Matter (POM)

(includes organic compounds with more than one benzene ring, and which have a boiling point greater than or equal to 100°C)

Radionuclides

(including radon)

(a type of atom which spontaneously undergoes radioactive decay)

Selenium Compounds

Selenium

7782-49-2

APPENDIX C - *AP-42*, SUPPLEMENT E TABLE OF CONTENTS

Note: The pages in the following Appendix are taken directly from *AP-42*.



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APPENDIX D - CONVERSION FACTORS FROM *AP-42*, SUPPLEMENT E

Note: The pages in the following Appendix are photocopied directly from *AP-42*.



SOME USEFUL WEIGHTS AND MEASURES

grain	0.002	ounces	pound (troy)	12 ounces
gram	0.04	ounces	ton (short)	2000 pounds
ounce	28.35	grams	ton (long)	2240 pounds
kilogram	2.21	pounds	ton (metric)	2200 pounds
pound	0.45	kilograms	ton (shipping)	40 feet ³

acre	43,560	ft ² *
centimeter	0.39	inches
inch	2.54	centimeters
foot	30.48	centimeters
meter	1.09	yards
yard	0.91	meters
mile	1.61	kilometers

centimeter ²	0.16	inches ²	centimeter ³	0.061	inches ³
inch ²	6.45	centimeters ²	inch ³	16.39	centimeters ³
foot ²	0.09	meters ²	foot ³	283.17	centimeters ³
meter ²	1.2	yards ²	foot ³	1728	inches ³
yard ²	0.84	meters ²	meter ³	1.31	yards ³
mile ²	2.59	kilometers ²	yard ³	0.77	meters ³

cord	128	feet ³	gallon (U.S.)	231	inches ³
cord	4	meters ³	barrel	31.5	gallons
peck	8	quarts	hogshead	2	barrels
bushel (dry)	4	pecks	township	36	miles ²
bushel	2150.4	inches ³	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 lbs. 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 lbs. 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 column of water, multiply the height of the column in feet by 0.434.

*not included in AP-42.

TYPICAL PARAMETERS OF VARIOUS FUELS^a

Type of Fuel	Heating Value		Sulfur % (by weight)	Ash % (by weight)
	kcal	BTU		
Solid Fuels				
Bituminous Coal	7,200/kg	13,000/lb	0.6-5.4	4-20
Anthracite Coal	6,810/kg	12,300/lb	0.5-1.0	7.0-16.0
Lignite (@ 35% moisture)	3,990/kg	7,200/lb	0.7	6.2
Wood (@ 40% moisture)	2,880/kg	5,200/lb	N	1-3
Bagasse (@ 50% moisture)	2,220/kg	4,000/lb	N	1-2
Bark (@ 50% moisture)	2,492/kg	4,500/lb	N	1-3b
Coke, Byproduct	7,380/kg	13,300/lb	0.5-1.0	0.5-5.0
Liquid Fuels				
Residual Oil	9.98 x 10 ⁶ /m ³	150,000/gal	0.5-4.0	0.05-0.1
Distillate Oil	9.30 x 10 ⁶ /m ³	140,000/gal	0.2-1.0	N
Diesel	9.12 x 10 ⁶ /m ³	137,000/gal	0.4	N
Gasoline	8.62 x 10 ⁶ /m ³	130,000/gal	0.03-0.04	N
Kerosene	8.32 x 10 ⁶ /m ³	135,000/gal	0.02-0.05	N
Liquid Petroleum Gas	6.25 x 10 ⁶ /m ³	94,000/gal	N	N
Gaseous Fuels				
Natural Gas	9,341/nm ³	1,050/SCF	N	N
Coke Oven Gas	5,249/nm ³	590/SCF	0.5-2.0	N
Blast Furnace Gas	890/nm ³	100/SCF	N	N

^aN = negligible.
^bAsh content may be considerably higher when sand, dirt, etc. are present.

THERMAL EQUIVALENTS FOR VARIOUS FUELS

Type of fuel	Btu (gross)	kcal
Solid fuels		
Bituminous coal	(21.0 to 28.0) x 10 ⁶ /ton	(5.8 to 7.8) x 10 ⁶ /MT
Anthracite coal	25.3 x 10 ⁶ /ton	7.03 x 10 ⁶ /MT
Lignite	16.0 x 10 ⁶ /ton	4.45 x 10 ⁶ /MT
Wood	21.0 x 10 ⁶ /cord	1.47 x 10 ⁶ /m ³
Liquid fuels		
Residual fuel oil	6.3 x 10 ⁶ /bbl	10 x 10 ³ /liter
Distillate fuel oil	5.9 x 10 ⁶ /bbl	9.35 x 10 ³ /liter
Gaseous fuels		
Natural gas	1,050/ft ³	9,350/m ³
Liquefied petroleum gas		
Butane	97,400/gal	6,480/liter
Propane	90,500/gal	6,030/liter

WEIGHTS OF SELECTED SUBSTANCES

Type of substance	lb/gal	g/liter
Asphalt	8.57	1030
Butane, liquid at 60° F	4.84	579
Crude oil	7.08	850
Distillate oil	7.05	845
Gasoline	6.17	739
Propane, liquid at 60° F	4.24	507
Residual oil	7.88	944
Water	8.4	1000

DENSITIES OF SELECTED SUBSTANCES

Substance	Density	
Fuels		
Crude Oil	874 kg/m ³	7.3 lb/gal
Residual Oil	944 kg/m ³	7.88 lb/gal
Distillate Oil	845 kg/m ³	7.05 lb/gal
Gasoline	739 kg/m ³	6.17 lb/gal
Natural Gas	673 kg/m ³	1 lb/23.8 ft ³
Butane	579 kg/m ³	4.84 lb/gal (liquid)
Propane	507 kg/m ³	4.24 lb/gal (liquid)
Wood (Air dried)		
Elm	561 kg/m ³	35 lb/ft ³
Fir, Douglas	513 kg/m ³	32 lb/ft ³
Fir, Balsam	400 kg/m ³	25 lb/ft ³
Hemlock	465 kg/m ³	29 lb/ft ³
Hickory	769 kg/m ³	48 lb/ft ³
Maple, Sugar	689 kg/m ³	43 lb/ft ³
Maple, White	529 kg/m ³	33 lb/ft ³
Oak, Red	673 kg/m ³	42 lb/ft ³
Oak, White	769 kg/m ³	48 lb/ft ³
Pine, Southern	641 kg/m ³	40 lb/ft ³
Agricultural Products		
Corn	25.4 kg/bu	56 lb/bu
Milo	25.4 kg/bu	56 lb/bu
Oats	14.5 kg/bu	32 lb/bu
Barley	21.8 kg/bu	48 lb/bu
Wheat	27.2 kg/bu	60 lb/bu
Cotton	226 kg/bale	500 lb/bale
Mineral Products		
Brick	2.95 kg/brick	6.5 lb/brick
Cement	170 kg/bbl	375 lb/bbl
Cement	1483 kg/m ³	2500 lb/yd ³
Concrete	2373 kg/m ³	4000 lb/yd ³
Glass, Common	2595 kg/m ³	162 lb/ft ³
Gravel, Dry Packed	1600-1920 kg/m ³	100-120 lb/ft ³
Gravel, Wet	2020 kg/m ³	126 lb/ft ³
Gypsum, Calcined	880-960 kg/m ³	55-60 lb/ft ³
Lime, Pebble	850-1025 kg/m ³	53-64 lb/ft ³
Sand, Gravel (Dry, loose)	1440-1680 kg/m ³	90-105 lb/ft ³

CONVERSION FACTORS

The table of conversion factors on the following pages contains factors for converting English to metric units and metric to English units as well as factors to manipulate units within the same system. The factors are arranged alphabetically by unit within the following property groups.

- o Area
- o Density
- o Energy
- o Force
- o Length
- o Mass
- o Pressure
- o Velocity
- o Volume
- o Volumetric Rate

To convert a number from one unit to another:

- 1) Locate the unit in which the number is currently expressed in the left hand column of the table,
- 2) Find the desired unit in the center column, and
- 3) Multiply the number by the corresponding conversion factor in the right hand column.

CONVERSION FACTORS^a

To convert from	to	multiply by
<u>Area</u>		
Acres.....	Sq feet.....	4.356×10^4
Acres.....	Sq kilometers.....	4.0469×10^{-3}
Acres.....	Sq meters.....	4.0469×10^3
Acres.....	Sq miles(statute).....	1.5625×10^{-3}
Acres.....	Sq yards.....	4.84×10^3
Sq feet.....	Acres.....	2.2957×10^{-5}
Sq feet.....	Sq cm.....	929.03
Sq feet.....	Sq inches.....	144.0
Sq feet.....	Sq meters.....	0.092903
Sq feet.....	Sq miles.....	3.587×10^{-8}
Sq feet.....	Sq yards.....	0.111111
Sq inches.....	Sq feet.....	6.9444×10^{-3}
Sq inches.....	Sq meters.....	6.4516×10^{-4}
Sq inches.....	Sq mm.....	645.16
Sq kilometers.....	Acres.....	247.1
Sq kilometers.....	Sq feet.....	1.0764×10^7
Sq kilometers.....	Sq meters.....	1.0×10^6
Sq kilometers.....	Sq miles.....	0.386102
Sq kilometers.....	Sq yards.....	1.196×10^6
Sq meters.....	Sq cm.....	1.0×10^4
Sq meters.....	Sq feet.....	10.764
Sq meters.....	Sq inches.....	1.55×10^3
Sq meters.....	Sq kilometers.....	1.0×10^{-6}
Sq meters.....	Sq miles.....	3.861×10^{-7}
Sq meters.....	Sq mm.....	1.0×10^6
Sq meters.....	Sq yards.....	1.196
Sq miles.....	Acres.....	640.0
Sq miles.....	Sq feet.....	2.7878×10^7
Sq miles.....	Sq kilometers.....	2.590
Sq miles.....	Sq meters.....	2.59×10^6
Sq miles.....	Sq yards.....	3.0976×10^6
Sq yards.....	Acres.....	2.0661×10^{-4}
Sq yards.....	Sq cm.....	8.3613×10^3
Sq yards.....	Sq ft.....	9.0
Sq yards.....	Sq inches.....	1.296×10^3
Sq yards.....	Sq meters.....	0.83613
Sq yards.....	Sq miles.....	3.2283×10^{-7}

^aWhere 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 Contd.

To convert from	to	multiply by
<u>Density</u>		
Dynes/cu cm.....	Grams/cu cm.....	1.0197 x 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 x 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 x 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 x 10 ⁴
Pounds/gal (U.S., liq).	Grams/cu cm.....	0.1198
Pounds/gal (U.S., liq).	Pounds/cu ft.....	7.4805
<u>Energy</u>		
Btu.....	Cal., <u>gm</u> (IST.).....	251.83
Btu.....	Ergs.....	1.05435 x 10 ¹⁰
Btu.....	Foot-pounds.....	777.65
Btu.....	Hp-hours.....	3.9275 x 10 ⁻⁴
Btu.....	Joules(Int.).....	1054.2
Btu.....	Kg-meters.....	107.51
Btu.....	Kw-hours(Int.).....	2.9283 x 10 ⁻⁴
Btu/hr.....	Cal., <u>kg</u> /hr.....	0.252
Btu/hr.....	Ergs/sec.....	2.929 x 10 ⁶
Btu/hr.....	Foot-pounds/hr.....	777.65
Btu/hr.....	Horsepower (mechanical).....	3.9275 x 10 ⁻⁴
Btu/hr.....	Horsepower (boiler).....	2.9856 x 10 ⁻⁵
Btu/hr.....	Horsepower (electric).....	3.926 x 10 ⁻⁴
Btu/hr.....	Horsepower (metric).....	3.982 x 10 ⁻⁴
Btu/hr.....	Kilowatts.....	2.929 x 10 ⁻⁴
Btu/lb.....	Foot-pounds/lb.....	777.65
Btu/lb.....	Hp-hr/lb.....	3.9275 x 10 ⁻⁴
Btu/lb.....	Joules/gram.....	2.3244
Calories, <u>kg</u> (mean).....	Btu(IST.).....	3.9714
Calories, <u>kg</u> (mean).....	Ergs.....	4.190 x 10 ¹⁰

CONVERSION FACTORS Contd.

To convert from	to	multiply by
Calories, <u>kg</u> (mean).....	Foot-pounds.....	3.0904×10^3
Calories, <u>kg</u> (mean).....	Hp-hours.....	1.561×10^{-3}
Calories, <u>kg</u> (mean).....	Joules.....	4.190×10^3
Calories, <u>kg</u> (mean).....	Kg-meters.....	427.26
Calories, <u>kg</u> (mean).....	Kw-hours(Int.).....	1.1637×10^{-3}
Ergs.....	Btu.....	9.4845×10^{-11}
Ergs.....	Foot-poundals.....	2.373×10^{-6}
Ergs.....	Foot-pounds.....	7.3756×10^{-8}
Ergs.....	Joules (Int.).....	9.99835×10^{-8}
Ergs.....	Kw-hours.....	2.7778×10^{-14}
Ergs.....	Kg-meters.....	1.0197×10^{-8}
Foot-pounds.....	Btu(IST.).....	1.2851×10^{-3}
Foot-pounds.....	Cal., <u>kg</u> (IST.).....	3.2384×10^{-4}
Foot-pounds.....	Ergs.....	1.3558×10^7
Foot-pounds.....	Foot-poundals.....	32.174
Foot-pounds.....	Hp-hours.....	5.0505×10^{-7}
Foot-pounds.....	Joules.....	1.3558
Foot-pounds.....	Kg-meters.....	0.138255
Foot-pounds.....	Kw-hours(Int.).....	3.76554×10^{-7}
Foot-pounds.....	Newton-meters.....	1.3558
Foot-pounds/hr.....	Btu/min.....	2.1432×10^{-5}
Foot-pounds/hr.....	Ergs/min.....	2.2597×10^5
Foot-pounds/hr.....	Horsepower (mechanical)....	5.0505×10^{-7}
Foot-pounds/hr.....	Horsepower (metric).....	5.121×10^{-7}
Foot-pounds/hr.....	Kilowatts.....	3.766×10^{-7}
Horsepower (mechanical)	Btu(mean)/hr.....	2.5425×10^3
Horsepower (mechanical)	Ergs/sec.....	7.457×10^9
Horsepower (mechanical)	Foot-pounds/hr.....	1.980×10^6
Horsepower (mechanical)	Horsepower (boiler).....	0.07602
Horsepower (mechanical)	Horsepower (electric).....	0.9996
Horsepower (mechanical)	Horsepower (metric).....	1.0139
Horsepower (mechanical)	Joules/sec.....	745.70
Horsepower (mechanical)	Kilowatts(Int.).....	0.74558
Horsepower (boiler)....	Btu(mean)/hr.....	3.3446×10^4
Horsepower (boiler)....	Ergs/sec.....	9.8095×10^{10}
Horsepower (boiler)....	Foot-pounds/min.....	4.341×10^5
Horsepower (boiler)....	Horsepower (mechanical)....	13.155
Horsepower (boiler)....	Horsepower (electric).....	13.15
Horsepower (boiler)....	Horsepower (metric).....	13.337
Horsepower (boiler)....	Joules/sec.....	9.8095×10^3
Horsepower (boiler)....	Kilowatts.....	9.8095
Horsepower (electric)..	Btu(mean)/hr.....	2.5435×10^3
Horsepower (electric)..	Cal., <u>kg</u> /hr.....	641.87
Horsepower (electric)..	Ergs/sec.....	7.46×10^9
Horsepower (electric)..	Foot-pounds/min	3.3013×10^4
Horsepower (electric)..	Horsepower (boiler).....	0.07605
Horsepower (electric)..	Horsepower (metric).....	1.0143
Horsepower (electric)..	Joules/sec.....	746.0

CONVERSION FACTORS Contd.

To convert from	to	multiply by
Horsepower (electric)..	Kilowatts.....	0.746
Horsepower (metric)....	Btu(mean)/hr.....	2.5077×10^3
Horsepower (metric)....	Ergs/sec.....	7.355×10^9
Horsepower (metric)....	Foot-pounds/min.....	3.255×10^4
Horsepower (metric)....	Horsepower (mechanical)....	0.98632
Horsepower (metric)....	Horsepower(boiler).....	0.07498
Horsepower (metric)....	Horsepower (electric).....	0.9859
Horsepower (metric)....	Kg-meters/sec.....	75.0
Horsepower (metric)....	Kilowatts.....	0.7355
Horsepower-hours.....	Btu(mean).....	2.5425×10^3
Horsepower-hours.....	Foot-pounds.....	1.98×10^6
Horsepower-hours.....	Joules.....	2.6845×10^6
Horsepower-hours.....	Kg-meters.....	2.73745×10^5
Horsepower-hours.....	Kw-hours.....	0.7457
Joules (Int.).....	Btu (IST.).....	9.4799×10^{-4}
Joules (Int.).....	Ergs.....	1.0002×10^7
Joules (Int.).....	Foot-poundals.....	12.734
Joules (Int.).....	Foot-pounds.....	0.73768
Joules (Int.).....	Kw-hours.....	2.778×10^{-7}
Joules (Int.)/sec.....	Btu(mean)/min.....	0.05683
Joules (Int.)/sec.....	Cal.,kg/min.....	0.01434
Joules (Int.)/sec.....	Horsepower.....	1.341×10^{-3}
Kilogram-meters.....	Btu (mean).....	9.2878×10^{-3}
Kilogram-meters.....	Cal.,kg (mean).....	2.3405×10^{-3}
Kilogram-meters.....	Ergs.....	9.80665×10^7
Kilogram-meters.....	Foot-poundals.....	232.715
Kilogram-meters.....	Foot-pounds.....	7.233
Kilogram-meters.....	Hp-hours.....	3.653×10^{-6}
Kilogram-meters.....	Joules (Int.).....	9.805
Kilogram-meters.....	Kw-hours.....	2.724×10^{-6}
Kilogram-meters/sec....	Watts.....	9.80665
Kilowatts (Int.).....	Btu (IST.)/hr.....	3.413×10^3
Kilowatts (Int.).....	Cal,kg (IST.)/hr.....	860.0
Kilowatts (Int.).....	Ergs/sec.....	1.0002×10^{10}
Kilowatts (Int.).....	Foot-poundals/min.....	1.424×10^6
Kilowatts (Int.).....	Foot-pounds/min.....	4.4261×10^4
Kilowatts (Int.).....	Horsepower (mechanical)....	1.341
Kilowatts (Int.).....	Horsepower (boiler).....	0.10196
Kilowatts (Int.).....	Horsepower (electric).....	1.3407
Kilowatts (Int.).....	Horsepower (metric).....	1.3599
Kilowatts (Int.).....	Joules (Int.)/hr.....	3.6×10^6
Kilowatts (Int.).....	Kg-meters/hr.....	3.6716×10^5
Kilowatt-hours (Int.)..	Btu (mean).....	3.41×10^3
Kilowatt-hours (Int.)..	Foot-pounds.....	2.6557×10^6
Kilowatt-hours (Int.)..	Hp-hours.....	1.341
Kilowatt-hours (Int.)..	Joules (Int.).....	3.6×10^6
Kilowatt-hours (Int.)..	Kg-meters.....	3.6716×10^5

CONVERSION FACTORS Contd.

To convert from	to	multiply by
Newton-meters.....	Gram-cm.....	1.01972 x 10 ⁴
Newton-meters.....	Kg-meters.....	0.101972
Newton-meters.....	Pound-feet.....	0.73756

Force

Dynes.....	Newtons.....	1.0 x 10 ⁻⁵
Dynes.....	Poundals.....	7.233 x 10 ⁻⁵
Dynes.....	Pounds.....	2.248 x 10 ⁻⁶
Newtons.....	Dynes.....	1.0 x 10 ⁻⁵
Newtons.....	Pounds (avdp.).....	0.22481
Poundals.....	Dynes.....	1.383 x 10 ⁴
Poundals.....	Newtons.....	0.1383
Poundals.....	Pounds (avdp.).....	0.03108
Pounds (avdp.).....	Dynes.....	4.448 x 10 ⁵
Pounds (avdp.).....	Newtons.....	4.448
Pounds (avdp.).....	Poundals.....	32.174

Length

Feet.....	Centimeters.....	30.48
Feet.....	Inches.....	12
Feet.....	Kilometers.....	3.048 x 10 ⁻⁴
Feet.....	Meters.....	0.3048
Feet.....	Miles (statute).....	1.894 x 10 ⁻⁴
Inches.....	Centimeters.....	2.540
Inches.....	Feet.....	0.08333
Inches.....	Kilometers.....	2.54 x 10 ⁻⁵
Inches.....	Meters.....	0.0254
Kilometers.....	Feet.....	3.2808 x 10 ³
Kilometers.....	Meters.....	1000
Kilometers.....	Miles (statute).....	0.62137
Kilometers.....	Yards.....	1.0936 x 10 ³
Meters.....	Feet.....	3.2808
Meters.....	Inches.....	39.370
Micrometers.....	Angstrom units.....	1.0 x 10 ⁴
Micrometers.....	Centimeters.....	1.0 x 10 ⁻³
Micrometers.....	Feet.....	3.2808 x 10 ⁻⁶
Micrometers.....	Inches.....	3.9370 x 10 ⁻⁵
Micrometers.....	Meters.....	1.0 x 10 ⁻⁶
Micrometers.....	Millimeters.....	0.001
Micrometers.....	Nanometers.....	1000
Miles (statute).....	Feet.....	5280
Miles (statute).....	Kilometers.....	1.6093
Miles (statute).....	Meters.....	1.6093 x 10 ³
Miles (statute).....	Yards.....	1760
Millimeters.....	Angstrom units.....	1.0 x 10 ⁷
Millimeters.....	Centimeters.....	0.1
Millimeters.....	Inches.....	0.03937
Millimeters.....	Meters.....	0.001

CONVERSION FACTORS Contd.

To convert from	to	multiply by
Millimeters.....	Micrometers.....	1000
Millimeters.....	Mils.....	39.37
Nanometers.....	Angstrom units.....	10
Nanometers.....	Centimeters.....	1.0×10^{-7}
Nanometers.....	Inches.....	3.937×10^{-8}
Nanometers.....	Micrometers.....	0.001
Nanometers.....	Millimeters.....	1.0×10^{-6}
Yards.....	Centimeters.....	91.44
Yards.....	Meters.....	0.9144

Mass

Grains.....	Grams.....	0.064799
Grains.....	Milligrams.....	64.799
Grains.....	Pounds (apoth. or troy)....	1.7361×10^{-4}
Grains.....	Pounds (avdp.).....	1.4286×10^{-4}
Grains.....	Tons (metric).....	6.4799×10^{-8}
Grams.....	Dynes.....	980.67
Grams.....	Grains.....	15.432
Grams.....	Kilograms.....	0.001
Grams.....	Micrograms.....	1×10^6
Grams.....	Pounds (avdp.).....	2.205×10^{-3}
Grams.....	Tons, metric (megagrams)...	1×10^{-6}
Kilograms.....	Grains.....	1.5432×10^4
Kilograms.....	Poundals.....	70.932
Kilograms.....	Pounds (apoth. or troy)....	2.679
Kilograms.....	Pounds, (avdp.).....	2.2046
Kilograms.....	Tons (long).....	9.842×10^{-4}
Kilograms.....	Tons (metric).....	0.001
Kilograms.....	Tons (short).....	1.1023×10^{-3}
Megagrams.....	Tons (metric).....	1.0
Milligrams.....	Grains.....	0.01543
Milligrams.....	Grams.....	1.0×10^{-3}
Milligrams.....	Ounces (apoth. or troy)....	3.215×10^{-5}
Milligrams.....	Ounces (avdp.).....	3.527×10^{-5}
Milligrams.....	Pounds (apoth. or troy)....	2.679×10^{-6}
Milligrams.....	Pounds (avdp.).....	2.2046×10^{-6}
Ounces (apoth. or troy)	Grains.....	480
Ounces (apoth. or troy)	Grams.....	31.103
Ounces (apoth. or troy)	Ounces (avdp.).....	1.097
Ounces (avdp.).....	Grains.....	437.5
Ounces (avdp.).....	Grams.....	28.350
Ounces (avdp.).....	Ounces (apoth. or troy)....	0.9115
Ounces (avdp.).....	Pounds (apoth. or troy)....	0.075955
Ounces (avdp.).....	Pounds (avdp.).....	0.0625
Pounds (avdp.).....	Poundals.....	32.174
Pounds (avdp.).....	Pounds (apoth. or troy)....	1.2153

CONVERSION FACTORS Contd.

To convert from	to	multiply by
Pounds (avdp.).....	Tons (long).....	4.4643×10^{-4}
Pounds (avdp.).....	Tons (metric).....	4.5359×10^{-4}
Pounds (avdp.).....	Tons (short).....	5.0×10^{-4}
Pounds (avdp.).....	Grains.....	7000
Pounds (avdp.).....	Grams.....	453.59
Pounds (avdp.).....	Ounces (apoth. or troy)....	14.583
Pounds (avdp.).....	Ounces (avdp.).....	16
Tons (long).....	Kilograms.....	1.016×10^3
Tons (long).....	Pounds (apoth. or troy)....	2.722×10^3
Tons (long).....	Pounds (avdp.).....	2.240×10^3
Tons (long).....	Tons (metric).....	1.016
Tons (long).....	Tons (short).....	1.12
Tons (metric).....	Grams.....	1.0×10^6
Tons (metric).....	Megagrams.....	1.0
Tons (metric).....	Pounds (apoth. or troy)....	2.6792×10^3
Tons (metric).....	Pounds (avdp.).....	2.2046×10^3
Tons (metric).....	Tons (long).....	0.9842
Tons (metric).....	Tons (short).....	1.1023
Tons (short).....	Kilograms.....	907.18
Tons (short).....	Pounds (apoth. or troy)....	2.4301×10^3
Tons (short).....	Pounds (avdp.).....	2000
Tons (short).....	Tons (long).....	0.8929
Tons (short).....	Tons (metric).....	0.9072

Pressure

Atmospheres.....	Cm of H ₂ O (4°C).....	1.033×10^3
Atmospheres.....	Ft of H ₂ 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
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 ₂ O (4°C)....	Atmospheres.....	2.458×10^{-3}
Inches of H ₂ O (4°C)....	In of Hg (32°F).....	0.07355
Inches of H ₂ O (4°C)....	Kg/sq meter.....	25.399
Inches of H ₂ O (4°C)....	Pounds/sq ft.....	5.2022
Inches of H ₂ 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 ₂ 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.....	1.3158×10^{-3}
Millimeters of Hg (0°C)	Grams/sq cm.....	1.3595

CONVERSION FACTORS Contd.

To convert from	to	multiply by
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 ₂ O (4°C).....	70.309
Pounds/sq inch.....	In of Hg (32°F).....	2.036
Pounds/sq inch.....	In of H ₂ 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
Feet/minute.....	Cm/sec.....	0.508
Feet/minute.....	Kilometers/hr.....	0.01829
Feet/minute.....	Meters/min.....	0.3048
Feet/minute.....	Meters/sec.....	5.08 x 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 x 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,US).	Cu feet.....	5.6146
Barrels (petroleum,US).	Gallons (US).....	42
Barrels (petroleum,US).	Liters.....	158.98
Barrels (US, liq.).....	Cu feet.....	4.2109
Barrels (US, liq.).....	Cu inches.....	7.2765 x 10 ³

CONVERSION FACTORS Contd.

To convert from	to	multiply by
Barrels (US, liq.).....	Cu meters.....	0.1192
Barrels (US, liq.).....	Gallons (US, liq.).....	31.5
Barrels (US, liq.).....	Liters.....	119.24
Cubic centimeters.....	Cu feet.....	3.5315×10^{-5}
Cubic centimeters.....	Cu inches.....	0.06102
Cubic centimeters.....	Cu meters.....	1.0×10^{-6}
Cubic centimeters.....	Cu yards.....	1.308×10^{-6}
Cubic centimeters.....	Gallons (US, liq.).....	2.642×10^{-4}
Cubic centimeters.....	Quarts (US, liq.).....	1.0567×10^{-3}
Cubic feet.....	Cu centimeters.....	2.8317×10^4
Cubic feet.....	Cu meters.....	0.028317
Cubic feet.....	Gallons (US, liq.).....	7.4805
Cubic feet.....	Liters.....	28.317
Cubic inches.....	Cu cm.....	16.387
Cubic inches.....	Cu feet.....	5.787×10^{-4}
Cubic inches.....	Cu meters.....	1.6387×10^{-5}
Cubic inches.....	Cu yards.....	2.1433×10^{-5}
Cubic inches.....	Gallons (US, liq.).....	4.329×10^{-3}
Cubic inches.....	Liters.....	0.01639
Cubic inches.....	Quarts (US, liq.).....	0.01732
Cubic meters.....	Barrels (US, liq.).....	8.3864
Cubic meters.....	Cu cm.....	1.0×10^6
Cubic meters.....	Cu feet.....	35.315
Cubic meters.....	Cu inches.....	6.1024×10^4
Cubic meters.....	Cu yards.....	1.308
Cubic meters.....	Gallons (US, liq.).....	264.17
Cubic meters.....	Liters.....	1000
Cubic yards.....	Bushels (Brit.).....	21.022
Cubic yards.....	Bushels (US).....	21.696
Cubic yards.....	Cu cm.....	7.6455×10^5
Cubic yards.....	Cu feet.....	27
Cubic yards.....	Cu inches.....	4.6656×10^4
Cubic yards.....	Cu meters.....	0.76455
Cubic yards.....	Gallons.....	168.18
Cubic yards.....	Gallons.....	173.57
Cubic yards.....	Gallons.....	201.97
Cubic yards.....	Liters.....	764.55
Cubic yards.....	Quarts.....	672.71
Cubic yards.....	Quarts.....	694.28
Cubic yards.....	Quarts.....	807.90
Gallons (US, liq.).....	Barrels (US, liq.).....	0.03175
Gallons (US, liq.).....	Barrels (petroleum, US).....	0.02381
Gallons (US, liq.).....	Bushels (US).....	0.10742
Gallons (US, liq.).....	Cu centimeters.....	3.7854×10^3
Gallons (US, liq.).....	Cu feet.....	0.13368
Gallons (US, liq.).....	Cu inches.....	231
Gallons (US, liq.).....	Cu meters.....	3.7854×10^{-3}
Gallons (US, liq.).....	Cu yards.....	4.951×10^{-3}

CONVERSION FACTORS Contd.

To convert from	to	multiply by
Gallons (US, liq.).....	Gallons (wine).....	1.0
Gallons (US, liq.).....	Liters.....	3.7854
Gallons (US, liq.).....	Ounces (US, fluid).....	128.0
Gallons (US, liq.).....	Pints (US, liq.).....	8.0
Gallons (US, liq.).....	Quarts (US, liq.).....	4.0
Liters.....	Cu centimeters.....	1000
Liters.....	Cu feet.....	0.035315
Liters.....	Cu inches.....	61.024
Liters.....	Cu meters.....	0.001
Liters.....	Gallons (US, liq.).....	0.2642
Liters.....	Ounces (US, fluid).....	33.814

Volumetric Rate

Cu ft/min.....	Cu cm/sec.....	471.95
Cu ft/min.....	Cu ft/hr.....	60.0
Cu ft/min.....	Gal (US)/min.....	7.4805
Cu ft/min.....	Liters/sec.....	0.47193
Cu meters/min.....	Gal (US)/min.....	264.17
Cu meters/min.....	Liters/min.....	999.97
Gallons (US)/hr.....	Cu ft/hr.....	0.13368
Gallons (US)/hr.....	Cu meters/min.....	6.309×10^{-5}
Gallons (US)/hr.....	Cu yd/min.....	8.2519×10^{-5}
Gallons (US)/hr.....	Liters/hr.....	3.7854
Liters/min.....	Cu ft/min.....	0.0353
Liters/min.....	Gal (US, liq.)/min.....	0.2642

CONVERSION FACTORS FOR COMMON AIR POLLUTION MEASUREMENTS

AIRBORNE PARTICULATE MATTER

To convert from	To	Multiply by
Milligrams/cu m	Grams/cu ft	283.2×10^{-6}
	Grams/cu m	0.001
	Micrograms/cu m	1000.0
	Micrograms/cu ft	28.32
	Pounds/1000 cu ft	62.43×10^{-6}
Grams/cu ft	Milligrams/cu m	35.3145×10^3
	Grams/cu m	35.314
	Micrograms/cu m	35.314×10^6
	Micrograms/cu ft	1.0×10^6
	Pounds/1000 cu ft	2.2046
Grams/cu m	Milligrams/cu m	1000.0
	Grams/cu ft	0.02832
	Micrograms/cu m	1.0×10^6
	Micrograms/cu ft	28.317×10^3
	Pounds/1000 cu ft	0.06243
Micrograms/cu m	Milligrams/cu m	0.001
	Grams/cu ft	28.317×10^{-9}
	Grams/cu m	1.0×10^{-6}
	Micrograms/cu ft	0.02832
	Pounds/1000 cu ft	62.43×10^{-9}
Micrograms/cu ft	Milligrams/cu m	35.314×10^{-3}
	Grams/cu ft	1.0×10^{-6}
	Grams/cu m	35.314×10^{-6}
	Micrograms/cu m	35.314
	Pounds/1000 cu ft	2.2046×10^{-6}
Pounds/1000 cu ft	Milligrams/cu m	16.018×10^3
	Grams/cu ft	0.35314
	Micrograms/cu m	16.018×10^6
	Grams/cu m	16.018
	Micrograms/cu ft	353.14×10^3

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
Inches of water (60°F)	Millimeters of mercury (0°C)	1.8663
	Inches of mercury (0°C)	73.48×10^{-3}

CONVERSION FACTORS FOR COMMON AIR POLLUTION MEASUREMENTS

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)	$\frac{24.04}{M}$
	Ppm by weight	0.8347
	Pounds/cu ft	62.43×10^{-9}
Micrograms/cu m	Milligrams/cu m	0.001
	Micrograms/liter	0.001
	Ppm by volume (20°C)	$\frac{0.02404}{M}$
	Ppm by weight	834.7×10^{-6}
	Pounds/cu ft	62.43×10^{-12}
Micrograms/liter	Milligrams/cu m	1.0
	Micrograms/cu m	1000.0
	Ppm by volume (20°C)	$\frac{24.04}{M}$
	Ppm by weight	0.8347
	Pounds/cu ft	62.43×10^{-9}
Ppm by volume (20°C)	Milligrams/cu m	$\frac{M}{24.04}$
	Micrograms/cu m	$\frac{M}{0.02404}$
	Micrograms/liter	$\frac{M}{24.04}$
	Ppm by weight	$\frac{M}{28.8}$
	Pounds/cu ft	$\frac{M}{385.1 \times 10^6}$
	Milligrams/cu m	1.198
	Micrograms/cu m	1.198×10^{-3}
Ppm by weight	Micrograms/liter	1.198
	Ppm by volume (20°C)	$\frac{28.8}{M}$
	Pounds/cu ft	7.48×10^{-6}
Pounds/cu ft	Milligrams/cu m	16.018×10^6
	Micrograms/cu m	16.018×10^9
	Micrograms/liter	16.018×10^6
	Ppm by volume (20°C)	$\frac{385.1 \times 10^6}{M}$
	Ppm by weight	133.7×10^3

M = Molecular weight of gas.

CONVERSION FACTORS FOR COMMON AIR POLLUTION MEASUREMENTS

VELOCITY

To convert from	To	Multiply by
Meters/sec	Kilometers/hr	3.6
	Feet/sec	3.281
	Miles/hr	2.237
Kilometers/hr	Meters/sec	0.2778
	Feet/sec	0.9113
	Miles/hr	0.6214
Feet/sec	Meters/sec	0.3048
	Kilometers/hr	1.09728
	Miles/hr	0.6818
Miles/hr	Meters/sec	0.4470
	Kilometers/hr	1.6093
	Feet/sec	1.4667

ATMOSPHERIC PRESSURE

To convert from	To	Multiply by
Atmospheres	Millimeters of mercury	760.0
	Inches of mercury	29.92
	Millibars	1013.2
Millimeters of mercury	Atmospheres	1.316×10^{-3}
	Inches of mercury	39.37×10^{-3}
	Millibars	1.333
Inches of mercury	Atmospheres	0.03333
	Millimeters of mercury	25.4005
	Millibars	33.35
Millibars	Atmospheres	0.00987
	Millimeters of mercury	0.75
	Inches of mercury	0.30

VOLUME EMISSIONS

To convert from	To	Multiply by
Cubic m/min	Cubic ft/min	35.314
Cubic ft/min	Cubic m/min	0.0283

BOILER CONVERSION FACTORS

- 1 Megawatt = 10.5×10^6 BTU/hr
(8 to 14×10^6 BTU/hr)
- 1 Megawatt = 8×10^3 lb steam/hr
(6 to 11×10^3 lb steam/hr)
- 1 BHP = 34.5 lb steam/hr
- 1 BHP = 45×10^3 BTU/hr
(40 to 50×10^3 BTU/hr)
- 1 lb steam/hr = 1.4×10^3 BTU/hr
(1.2 to 1.7×10^3 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	0.5541	4.3290×10^{-3}	1.37429×10^{-4}	5.78704×10^{-4}
Milliliters	0.061024	.....	0.001	0.03381	2.6418×10^{-4}	8.387×10^{-6}	3.5316×10^{-5}
Liters	61.024	1000	.....	33.8147	0.26418	8.387×10^{-3}	0.035316
Ounces (U. S. fl.)	1.80469	29.5729	0.029573	.....	7.8125×10^{-3}	2.48×10^{-4}	1.0443×10^{-3}
Gallons (U. S.) ^a ..	231	3785.3	3.7853	128	.....	0.031746	0.13368
Barrels (U. S.)...	7276.5	1.1924×10^5	119.2369	4032.0	31.5	.....	4.2109
Cubic feet	1728	2.8316×10^4	28.316	957.568	7.481	0.23743	.....

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

^aMass of 27.692 cubic inches water weighed in air at 4.0°C, 760 mm mercury pressure.

WORK AND ENERGY	R. cal.	kg. cal.	ergs	Joules	BTU	ft. lb.	kg. meters	L-Atm	HP Hours	ft. pound ² /s ²	kWh	MJ
Gram Calories (mean)	1000	0.601	4.186x10 ⁷	4.186	3.968x10 ⁻³	3.0874	0.42685	0.041311	1.5593x10 ⁻⁶	99.334	3.1628x10 ⁻⁶	1.1628x10 ⁻³
Kilogram Calories	1000	0.601	4.186x10 ¹⁰	4186	3.968	3087.4	426.85	41.311	1.5593x10 ⁻³	9933.4	3.1628x10 ⁻³	1.1628x10 ⁻³
ergs	2.3889x10 ⁻⁸	2.3889x10 ⁻¹¹	.....	1x10 ⁻⁷	9.4805x10 ⁻¹¹	7.3756x10 ⁻⁸	1.0197x10 ⁻⁶	9.8689x10 ⁻¹⁰	3.7251x10 ⁻¹⁴	2.3730x10 ⁻⁶	2.7778x10 ⁻¹⁴	2.7778x10 ⁻¹¹
Joules	0.23889	2.3889x10 ⁻⁴	1x10 ⁷	.....	9.4805x10 ⁻⁴	0.73756	0.10197	9.8689x10 ⁻³	3.7251x10 ⁻⁷	23.730	2.7778x10 ⁻⁷	2.7778x10 ⁻⁴
BTU (mean)	251.99	0.25199	1.0548x10 ¹⁰	1054.8	.....	777.98	107.56	10.409	3.9292x10 ⁻⁴	2.5070x10 ⁴	2.930x10 ⁻⁴	0.2930
Foot Pounds	0.32389	3.2389x10 ⁻⁴	1.35582x10 ⁷	1.3558	1.2854x10 ⁻³	.....	0.13835	0.013381	5.0505x10 ⁻⁷	32.174	3.7662x10 ⁻⁷	3.7662x10 ⁻⁴
Kilogram meters	2.3427	2.3427x10 ⁻³	9.8066x10 ⁷	9.8066	9.2967x10 ⁻³	7.2730	.....	0.096781	3.6529x10 ⁻⁶	232.71	2.7241x10 ⁻⁶	2.7241x10 ⁻³
liters Atmospheres (normal)	74.706	2.4206x10 ⁻²	1.0133x10 ⁹	101.328	0.09406	74.735	10.333	.....	3.7745x10 ⁻³	2406.5	2.8164x10 ⁻³	2.8164x10 ⁻²
Horsepower Hours	6.4130x10 ³	641.30	2.6845x10 ¹³	2.6845x10 ⁶	2454.0	1.9800x10 ⁶	2.7374x10 ⁵	26494	.....	6.3705x10 ⁷	0.2457	745.7
Foot pound ² /s ²	0.0140067	10.067x10 ⁻⁶	4.21407x10 ⁵	0.04214	3.9952x10 ⁻⁵	0.031081	4.2972x10 ⁻³	4.1558x10 ⁻⁴	1.5697x10 ⁻⁸	.....	1.17055x10 ⁻⁸	1.17055x10 ⁻⁵
Kilowatt Hours	8.6001x10 ³	860.01	3.6000x10 ¹³	3.6000x10 ⁶	3413.0	2.6552x10 ⁶	3.6709x10 ⁻³	3.5529x10 ⁶	1.3440	.....	.....	1000
Watt Hours	860.01	0.86001	3.6000x10 ¹⁰	3600	3.4130	2655.2	367.09	3.5529x10 ³	1.3410x10 ³	8.5430x10 ¹	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	1000	0.001	0.73756	1x10 ⁷	0.056884	1.0197x10 ⁴	0.01433	1.341x10 ⁻³	668	1	3.41304
Kilowatts	1000	0.001	737.56	1x10 ¹⁰	36.884	1.0197x10 ⁷	14.3334	1.3410	6.68x10 ⁵	1000	3413.04
Foot pounds per second	1.35582	1.3558x10 ⁻³	.....	1.3558x10 ⁷	0.077174	1.3826x10 ⁴	0.019433	1.8182x10 ⁻³	906.28	1.3558	4.8274
Ergs per second	1x10 ⁻⁷	1x10 ⁻¹⁰	7.3756x10 ⁻⁸	.....	5.688x10 ⁻⁹	1.0197x10 ⁻³	1.4333x10 ⁻⁹	1.3410x10 ⁻¹⁰	6.6885x10 ⁻⁵	1x10 ⁻⁷	3.4130x10 ⁻⁷
BTU* per minute ..	17.360	0.017360	12.9600	1.7580x10 ⁸	.....	1.7926x10 ⁵	0.2520	0.023375	11751	17.580	60
Gram Centimeters per second	9.8067x10 ⁻⁵	9.8067x10 ⁻⁸	7.2330x10 ⁻⁵	980.665	5.3783x10 ⁻⁶	.....	1.4056x10 ⁻⁶	1.3151x10 ⁻⁷	0.065552	9.8067x10 ⁻⁵	3.3470x10 ⁻⁴
Xilogram calories per minute	69.767	0.069767	51.457	6.9770x10 ⁸	3.9685	7.1146x10 ⁵	.....	0.093557	46676	69.769	238.11
Horsepower (U. S.)	745.7	0.7457	550	7.457x10 ⁹	42.4176	7.6042x10 ⁶	10.588	.....	498129	745.7	2545.1
Lumens	1.496x10 ⁻³	1.496x10 ⁻⁶	1.0034x10 ⁻³	1.496x10 ⁴	8.5096x10 ⁻⁵	15.254	2.1437x10 ⁻⁵	2.0061x10 ⁻⁶	.....	1.496x10 ⁻³	5.1069x10 ⁻³
Joules per second	1	0.001	0.73756	1x10 ⁷	0.056884	1.0197x10 ⁴	0.01433	1.341x10 ⁻³	668	.....	3.41304
BTU* per hour	0.29299	2.9299x10 ⁻⁴	0.21610	2.9299x10 ⁶	0.01667	2.9878x10 ³	4.1997x10 ⁻³	3.9291x10 ⁻⁴	195.80	0.29299	.....

* British Thermal Units (Mean)

CONVERSION FACTORS FOR VARIOUS SUBSTANCES (a)

Type of substance	Conversion factors
Fuel	
Oil	1 bbl = 159 liters (42 gal)
Natural gas	1 therm = 100,000 Btu (approx. 25000 kcal)
Gaseous Pollutants	
O ₃	1 ppm, volume = 1960 ug/m ³
NO ₂	1 ppm, volume = 1880 ug/m ³
SO ₂	1 ppm, volume = 2610 ug/m ³
H ₂ S	1 ppm, volume = 1390 ug/m ³
CO	1 ppm, volume = 1.14 mg/m ³
HC (as methane)	1 ppm, volume = 0.654 mg/m ³
Agricultural products	
Corn	1 bu = 25.4 kg = 56 lb
Milo	1 bu = 25.4 kg = 56 lb
Oats	1 bu = 14.5 kg = 32 lb
Barley	1 bu = 21.8 kg = 48 lb
Wheat	1 bu = 27.2 kg = 60 lb
Cotton	1 bale = 226 kg = 500 lb
Mineral products	
Brick	1 brick = 2.95 kg = 6.5 lb
Cement	1 bbl = 170 kg = 375 lb
Cement	1 yd ³ = 1130 kg = 2500 lb
Concrete	1 yd ³ = 1820 kg = 4000 lb
Mobile sources, fuel efficiency	
Motor vehicles	1.0 mi/gal = 0.426 km/liter
Water born vessels	1.0 gal/naut mi = 2.05 liters/km
Miscellaneous liquids	
Beer	1 bbl = 31.5 gal
Paint	1 gal = 4.5 to 6.82 kg = 10 to 15 lb
Varnish	1 gal = 3.18 kg = 7 lb
Whiskey	1 bbl = 190 liters = 50.2 gal
Water	1 gal = 3.81 kg = 8.3 lb

(a) Many of the conversion factors in this table represent average values and approximations and some of the values vary with temperature and pressure. These conversion factors should however, be sufficiently accurate for general field use.

APPENDIX E - CONTACTS AND INFORMATION RESOURCES



**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)

Hardware & Software Requirements:

Computer
Communications software package
Modem
Communications software parameters:
 8 data bits
 1 stop bit
 no parity
 full duplex

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 XATEF, SPECIATE, FIRE, Air CHIEF CD-ROM, L&E documents, or AP-42

Address:

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

Contact:

Angela W. Andrews (Martin Marietta on-site contractor)

Telephone:

(919) 541-5285

3. 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

4. Government Printing Office (GPO)

Address:

Government Printing Office
Superintendent of Documents
P.O. Box 371954
Washington, DC 20402

Telephone:

202-783-3238
202-512-2250 (Fax)

5. 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.

6. Pollution Prevention Information Clearinghouse

Telephone:

(703) 821-4800

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

7. Control Technology Center

Address:

U.S. Environmental Protection Agency

AEERL/GECD/OCB

MD-61

Research Triangle Park, NC 27711

Telephone:

(919) 541-0800

8. Emergency Planning and Community Right-to-Know Act Hotline

(703) 412-9877

(800) 553-7672

(800) 535-0202



**APPENDIX F - AEROMETRIC INFORMATION RETRIEVAL SYSTEM CONTROL
DEVICE CODES AND TYPICAL EFFICIENCIES**

Source: U.S. Environmental Protection Agency. *AEROS Manual Series Volume III: AEROS User's Manual*. EPA-450/2-76-029b. 3rd Edition. Office of Air Quality Planning and Standards, Research Triangle Park, NC, July 1984.



TABLE F-1. AIRS CONTROL EQUIPMENT CODES

Identification Number	Control Device/Method
000	No Equipment
001	Wet Scrubber - High Efficiency
002	Wet Scrubber - Medium Efficiency
003	Wet Scrubber - Low Efficiency
004	Gravity Collector - High Efficiency
005	Gravity Collector - Medium Efficiency
006	Gravity Collector - Low Efficiency
007	Centrifugal Collector - High Efficiency
008	Centrifugal Collector - Medium Efficiency
009	Centrifugal Collector - Low Efficiency
010	Electrostatic Precipitator - High Efficiency
011	Electrostatic Precipitator - Medium Efficiency
012	Electrostatic Precipitator - Low Efficiency
013	Gas Scrubber (general, not classified)
014	Mist Eliminator - High Velocity (i.e., $v > 250$ ft/min)
015	Mist Eliminator - Low Velocity (i.e., $v < 250$ ft/min)
016	Fabric Filter - High Temperature (i.e., $T > 250^\circ\text{F}$)
017	Fabric Filter - Medium Temperature (i.e., $180^\circ\text{F} < T < 250^\circ$)
018	Fabric Filter - Low Temperature (i.e., $T < 180^\circ\text{F}$)
019	Catalytic Afterburner
020	Catalytic Afterburner with Heat Exchanger
021	Direct Flame Afterburner
022	Direct Flame Afterburner with Heat Exchanger
023	Flaring
024	Modified Furnace or Burner Design
025	Staged Combustion
026	Flue Gas Recirculation
027	Reduced Combustion - Air Preheating
028	Steam or Water Injection
029	Low-Excess - Air Firing
030	Use of Fuel with Low Nitrogen Content
031	Air Injection
032	Ammonia Injection

(continued)

TABLE F-1. AIRS CONTROL EQUIPMENT CODES (Continued)

Identification Number	Control Device/Method
033	Control of % O ₂ in Combustion Air (Off-Stoichiometric Firing) for NO _x
034	Wellman-Lord/Sodium Sulfite Scrubbing
035	Magnesium Oxide Scrubbing
036	Dual Alkali Scrubbing
037	Citrate Process Scrubbing
038	Ammonia Scrubbing
039	Catalytic Oxidation - Flue Gas Desulfurization
040	Alkalized Alumina
041	Dry Limestone Injection
042	Wet Limestone Injection
043	Sulfuric Acid Plant - Contact Process
044	Sulfuric Acid Plant - Double Contact Process
045	Sulfur Plant
046	Process Change
047	Vapor Recovery System (including condensers, hooding, and other enclosures)
048	Activated Carbon Adsorption
049	Liquid Filtration System
050	Packed-Gas Adsorption Column
051	Tray-Type Gas Adsorption Column Bubble Caps
052	Spray Tower
053	Venturi Scrubber
054	Process Enclosed
055	Impingement Plate Scrubber
056	Dynamic Separator (Dry)
057	Dynamic Separator (Wet)
058	Mat or Panel Filter
059	Metal Fabric Filter Screen (Cotton Gins)
060	Process Gas Recovery
061	Dust Suppression by Water Sprays
062	Dust Suppression by Chemical Stabilizers or Wetting Agency
063	Gravel Bed Filter
064	Annular Ring Filter
065	Catalytic Reduction
066	Molecular Sieve
067	Wet Lime Slurry Scrubbing
068	Alkaline Fly Ash Scrubbing

(continued)

TABLE F-1. AIRS CONTROL EQUIPMENT CODES (Continued)

Identification Number	Control Device/Method
069	Sodium Carbonate Scrubbing
070	Sodium-Alkali Scrubbing
071	Fluid Bed Dry Scrubber
072	Tube and Shell Condenser
073	Refrigerated Condenser
074	Barometric Condenser
075	Single Cyclone
076	Multiple Cyclone without Fly Ash Reinjection
077	Multiple Cyclone with Fly Ash Reinjection
080	Chemical Oxidation
081	Chemical Reduction
082	Ozonation
083	Chemical Neutralization
084	Activated Clay Adsorption
085	Wet Cyclonic Separator
086	Water Curtain
087	Nitrogen Blanket
088	Conservation Vent
089	Bottom Filling
090	Conversion to Variable Vapor Space Tank
091	Conversion to Floating Roof Tank
092	Conversion to Pressurized Tank
093	Submerged Filling
094	Underground Tank
095	White Paint
099	Miscellaneous Control Devices

TABLE F-2. PERCENT EFFICIENCY RANGE BY EMISSION BY CONTROL EQUIPMENT CODE

Control Equipment No.	Part	Percent Efficiency Range											
		SO ₂		NO _x		VOC		CO					
		Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.				
000	Not validated												
001	95	99.9	75	97.0									
002	80	95.0	60	75.0									
003	70	80.0	30	60.0									
004	95	99.9											
005	80	95.0											
006	20	80.0											
007	95	99.9											
008	80	95.0											
009	20	80.0											
010	95	99.9											
011	90	95.0											
012	60	80.0											
013			70	99.0	70	99.0	70	99.0	70.0	99.0	70.0	99.0	99.0
014	70	99.9	70	99.0									
015	50	99.9	50	99.0									
016	75	99.9	20	80.0									
017	80	99.9	20	80.0									
018	80	99.9	20	80.0									

(continued)

TABLE F-2. PERCENT EFFICIENCY RANGE BY EMISSION BY CONTROL EQUIPMENT CODE (Continued)

Control Equipment No.	Percent Efficiency Range											
	Part		SO ₂		NO _x		VOC		CO			
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
019	80	95.0					90	99.0	90.0	99.9		
020	80	95.0					90	99.0	90.0	99.9		
021	25	70.0					94	99.9	99.0	99.9		
022	25	70.0					94	99.9	99.0	99.9		
023	25	98.0					90	99.9	95.0	99.9		
024					20	80.0						
025					20	60.0						
026					20	70.0						
027					20	60.0						
028					20	70.0						
029					10	60.0						
030					10	70.0						
031					10	80.0						
032					10	80.0						
033					10	80.0						
034			50	95.0								
035			50	95.0								
036			50	95.0								

(continued)

TABLE F-2. PERCENT EFFICIENCY RANGE BY EMISSION BY CONTROL EQUIPMENT CODE (Continued)

Control Equipment No.	Percent Efficiency Range											
	Part		SO ₂		NO _x		VOC		CO			
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
037			50	95.0								
038			50	95.0								
039			75	90.0								
040			75	90.0								
041			40	60.0								
042			80	90.0								
043			50	98.0								
044			95	99.9								
045			85	99.9								
046	10	90.0	10	90.0	10	90.0	10	90.0	10.0	90.0	10.0	90.0
047												
048												
049	50	99.9										
050	70	99.0	70	99.0	70	99.0	70	99.0	70.0	99.0	70.0	99.0
051	70	99.0	70	99.0	70	99.0	70	99.0	70.0	99.0	70.0	99.0
052	90	99.9	70	99.0	70	99.0	70	99.0	70.0	99.0	70.0	99.0
053	90	99.9	70	99.0	70	99.0	70	99.0	70.0	99.0	70.0	99.0
054	50	99.9										

(continued)

TABLE F-2. PERCENT EFFICIENCY RANGE BY EMISSION BY CONTROL EQUIPMENT CODE (Continued)

Control Equipment No.	Part		SO ₂		NO _x		VOC		CO	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
055	20	99.0	20	99.0	20	99.0	20	99.0	20.0	99.0
056	20	99.9								
057	20	99.9								
058	10	95.0								
059	50	99.0								
060					95	99.9	99.0	99.9	99.0	99.9
061	00	99.9								
062	00	99.9								
063	90	99.9								
064	90	99.9								
065					75	99.9				
066					95	99.9				
067			50	95.0						
068			50	95.0						
069			50	95.0						
070			50	95.0						
071	90	99.9								
072					20	99.9				

(continued)

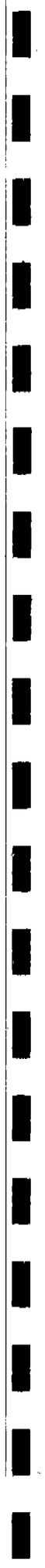
TABLE F-2. PERCENT EFFICIENCY RANGE BY EMISSION BY CONTROL EQUIPMENT CODE (Continued)

Control Equipment No.	Percent Efficiency Range											
	Part		SO ₂		NO _x		VOC		CO			
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.		
073					20	99.9						
074					20	99.9						
075	25	99.0										
076	50	99.9										
077	50	99.9										
080	20	99.9			20	99.9	20.0	99.9		99.9		
081					20	99.9						
082					10	99.9						
083	10	99.9	10	99.9	10	99.9	10.0	99.9	10.0	99.9		
084					20	99.9						
085	20	99.9										
086	10	95.0			10	95.0						
087					10	99.9						
088					10	99.9						
089					10	99.9						
090					10	99.9						
091					10	99.9						
092					10	99.9						

(continued)

TABLE F-2. PERCENT EFFICIENCY RANGE BY EMISSION BY CONTROL EQUIPMENT CODE (Continued)

Control Equipment No.	Percent Efficiency Range											
	Part		SO ₂		NO _x		VOC		CO			
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.		
093			10	99.9			10	99.9				
094			10	99.9			10	99.9				
095			10	99.9			10	99.9				
099	Not Validated											



**APPENDIX G - LIST OF SOURCE CATEGORIES FOR WHICH MACT
STANDARDS WILL BE PROMULGATED**



**LIST OF SOURCE CATEGORIES FOR WHICH
MACT STANDARDS WILL BE PROMULGATED**

Fuel Combustion

Engine Test Facilities

Industrial Boilers**

Institutional/Commercial Boilers**

Process Heaters

Stationary Internal Combustion Engines**

Stationary Turbines**

Non-Ferrous Metals Processing

Primary Aluminum Production

Secondary Aluminum Production

Primary Copper Smelting

Primary Lead Smelting

Secondary Lead Smelting

Lead Acid Battery Manufacturing

Primary Magnesium Refining

Ferrous Metals Processing

Coke By-Product Plants

Coke Ovens: Charging, Top Side, and Door Leaks

Coke Ovens: Pushing, Quenching, and Battery Stacks

Ferroalloys Production

Integrated Iron and Steel Manufacturing

Non-Stainless Steel Manufacturing—Electric Arc Furnace (EAF) Operation

Stainless Steel Manufacturing—Electric Arc Furnace (EAF) Operation

* Revised to reflect EPA's initial list of source categories under CAAA Section 112(c)(1) that are subject to national emissions standards for hazardous air pollutants (57 FR 31576, July 16, 1992), 8/92.

** Sources defined as electric utility steam generating units under Section 112(a)(8) shall not be subject to emission standards pending the findings of the study required under Section 112(n)(1) and subsequent listing and regulation thereof.

Food and Agriculture Processes

Baker's Yeast Manufacturing

Cellulose Food Casing Manufacturing

Vegetable Oil Production

Pharmaceutical Production Processes

Pharmaceuticals Production

Polymers and Resins Production

Acetal Resins Production

Acrylonitrile-Butadiene-Styrene Production

Alkyd Resins Production

Amino Resins Production

Boat Manufacturing

Butadiene-Furfural Copolymer (R-11)

Butyl Rubber Production

Carboxymethylcellulose Production

Cellophane Production

Cellulose Ethers Production

Epichlorohydrin Elastomers Production

Epoxy Resins Production

Ethylene-Propylene Elastomers Production

Flexible Polyurethane Foam Production

Hypalon (tm) Production

Maleic Anhydride Copolymers Production

Methylcellulose Production

Methyl Methacrylate-Acrylonitrile-Butadiene-Styrene Production

Methyl Methacrylate-Butadiene-Styrene Terpolymers Production

Neoprene Production

Nitrile Butadiene Rubber Production

Non-Nylon Polyamides Production

Nylon 6 Production

Phenolic Resins Production

Polybutadiene Rubber Production

Polycarbonates Production
Polyester Resins Production
Polyethylene Teraphthalate Production
Polymerized Vinylidene Chloride Production
Polymethyl Methacrylate Resins Production
Polystyrene Production
Polysulfide Rubber Production
Polyvinyl Acetate Emulsions Production
Polyvinyl Alcohol Production
Polyvinyl Butyral Production
Polyvinyl Chloride and Copolymers Production
Reinforced Plastic Composites Production
Styrene-Acrylonitrile Production
Styrene-Butadiene Rubber and Latex Production

Production of Inorganic Chemicals

Ammonium Sulfate Production—Caprolactam By-Product Plants
Antimony Oxides Manufacturing
Chlorine Production
Chromium Chemicals Manufacturing
Cyanuric Chloride Production
Fume Silica Production
Hydrochloric Acid Production
Hydrogen Cyanide Production
Hydrogen Fluoride Production
Phosphate Fertilizers Production
Phosphoric Acid Manufacturing
Quaternary Ammonium Compounds Production
Sodium Cyanide Production
Uranium Hexafluoride Production

Production of Organic Chemicals

Synthetic Organic Chemical Manufacturing

Miscellaneous Processes

Aerosol Can-Filling Facilities
Benzyltrimethylammonium Chloride Production
Butadiene Dimers Production
Carbonyl Sulfide Production
Chelating Agents Production
Chlorinated Paraffins Production
Chromic Acid Anodizing
Commercial Dry Cleaning (Perchloroethylene)—Transfer Machines
Commercial Sterilization Facilities
Decorative Chromium Electroplating
Dodencanedioic Acid Production
Dry Cleaning (Petroleum Solvent)
Ethylidene Norbornene Production
Explosives Production
Halogenated Solvent Cleaners
Hard Chromium Electroplating
Hydrazine Production
Industrial Dry Cleaning (Perchloroethylene)—Transfer Machines
Industrial Dry Cleaning (Perchloroethylene)—Dry-to-Dry Machines
Industrial Process Cooling Towers
OBPA/1,3-Diisocyanate Production
Paint Stripper Users
Photographic Chemicals Production
Phthalate Plasticizers Production
Plywood/Particle Board Manufacturing
Polyether Polyols Production
Pulp and Paper Production
Rocket Engine Test Firing
Rubber Chemicals Manufacturing
Semiconductor Manufacturing
Symmetrical Tetrachloropyridine Production
Tire Production
Wood Treatment

*Categories of Area Sources**

Asbestos Processing

Chromic Acid Anodizing

Commercial Dry Cleaning (Perchloroethylene)—Transfer Machines

Commercial Dry Cleaning (Perchloroethylene)—Dry-to-Dry Machines

Commercial Sterilization Facilities

Decorative Chromium Electroplating

Halogenated Solvent Cleaners

Hard Chromium Electroplating

* These eight categories of area sources are subject to forthcoming national emissions standards for hazardous air pollutants, based on EPA's finding that they pose a threat of adverse effects to human health or the environment warranting regulation under Section 112.



**APPENDIX H - NSPS SUBPARTS SUBJECT TO SPECIFIC EMISSIONS
RECORDKEEPING AND REPORTING REQUIREMENTS**



**NSPS SUBPARTS SUBJECT TO SPECIFIC EMISSIONS
RECORDKEEPING AND REPORTING REQUIREMENTS**

Subpart Ca	Municipal Waste Combustors
Subpart D	Fossil Fuel Fired Steam Generators
Subpart Da	Electric Utility Steam Generating Units
Subpart Db	Industrial Commercial Institutional Steam Generating Units
Subpart Dc	Small Industrial Commercial Institutional Steam Generating Units
Subpart E	Incinerators
Subpart Ea	Municipal Waste Combustors
Subpart F	Portland Cement Plants
Subpart G	Nitric Acid Plants
Subpart H	Sulfuric Acid Plants
Subpart J	Petroleum Refineries
Subpart K	Storage Vessels for Petroleum Liquids, June 11, 1973-May 19, 1978
Subpart Ka	Storage Vessels for Petroleum Liquids, May 18, 1978-July 23, 1984
Subpart Kb	Volatile Organic Liquid Storage Vessels (including Petroleum Liquids) after July 23, 1984
Subpart N	Primary Emissions from Basic Oxygen Process Furnaces, Construction Commenced after June 11, 1973
Subpart Na	Secondary Emissions from Basic Oxygen Process Steel Making Facilities, Construction Commenced after Jan. 20, 1983
Subpart O	Sewage Treatment Plants
Subpart P	Primary Copper Smelters
Subpart Q	Primary Zinc Smelters

Reporting and Recordkeeping

Subpart R	Primary Lead Smelters
Subpart S	Primary Limited Reduction Plants
Subpart T	Phosphate Fertilizer Industry: Wet Process Phosphoric Acid Plants
Subpart U	Phosphate Fertilizer Industry: Super Phosphoric Acid Plants
Subpart V	Phosphate Fertilizer Industry: Diammonium Phosphate Plants
Subpart W	Phosphate Fertilizer Industry: Triple Super Phosphate Plants
Subpart X	Phosphate Fertilizer Industry: Granular Triple Superphosphate Storage Facilities
Subpart Y	Coal Preparation Plants
Subpart Z	Ferroalloy Production Facilities
Subpart AA	Steel Plants: Electric Arc Furnaces Constructed after Oct. 21, 1974, and on or before Aug. 17, 1983
Subpart AAa	Steel Plants: Electric Arc Furnaces in Argon Oxygen Decarbonization Vessels Constructed after Aug. 7, 1983
Subpart BB	Performance for Kraft Pulp Mills
Subpart CC	Glass Manufacturing Plants
Subpart EE	Surface Coating of Metal Furniture
Subpart GG	Stationary Gas Turbines
Subpart HH	Lime Manufacturing Plants
Subpart KK	Lead-Acid Battery Manufacturing Plants
Subpart LL	Metallic Mineral Processing Plants
Subpart MM	Automobile Light Duty Trucks Surface Coating Operations
Subpart NN	Phosphate Rock Plants
Subpart PP	Ammonium Sulfate Manufacture
Subpart QQ	Graphics Arts Industry: Publication Rotogravure Printing

Reporting and Recordkeeping

Subpart RR	Pressure Sensitive Tape and Label Surface Coating Operations
Subpart SS	Industrial Surface Coating: Large Appliances
Subpart TT	Metal Coil Surface Coating
Subpart UU	Asphalt Processing and Asphalt Roofing Manufacture
Subpart VV	Equipment Leaks of VOC in the Synthetic Organic Chemical Manufacturing Industry
Subpart WW	Beverage Can Surface Coating Industry
Subpart XX	Bulk Gasoline Terminals
Subpart AAA	New Residential Wood Heaters (Manufacturers)
Subpart BBB	Rubber Tire Manufacturing Industry
Subpart DDD	VOC Emissions from Polymer Manufacturing Industry
Subpart FFF	Flexible Vinyl and Urethane Coating and Printing
Subpart GGG	Equipment Leaks of VOC in Petroleum Refineries
Subpart HHH	Synthetic Fiber Production Facilities
Subpart III	VOC Emissions from SOCOMI Air Oxidation Unit Processes
Subpart JJJ	Petroleum Dry Cleaners
Subpart KKK	Equipment Leaks of VOC from Onshore Natural Gas Processing Plants
Subpart LLL	Onshore Natural Gas Processing: SO ₂ Emission
Subpart NNN	VOC Emissions from SOCOMI Distillation Operations
Subpart OOO	Non-Metallic Mineral Processing Plants
Subpart PPP	Wool Fiberglass Insulation Manufacturing Plants
Subpart QQQ	Petroleum Refinery Wastewater Systems
Subpart SSS	Magnetic Tape Coating Facilities
Subpart TTT	Industrial Surface Coating of Plastic Parts for Business Machines
Subpart VVV	Polymeric Coating of Supporting Substrates Facilities



**APPENDIX I - POLLUTANTS REGULATED UNDER EXISTING
NESHAPS PROGRAM**



POLLUTANTS REGULATED UNDER EXISTING NESHAPS PROGRAM

Asbestos—Subpart M

Production of asbestos

Manufacturing of asbestos-containing products

Asbestos removal and disposal

Benzene—Subpart J

Petroleum refining

Fugitive emissions

Beryllium

Manufacturing of beryllium-containing products

Coke Oven Emissions

Coke ovens

Inorganic Arsenic—Subparts N and O

Glass manufacturing

Primary copper smelters

Mercury

Mercury processing

Chloralkali plants

Alkali metal hydroxide plants

Sewage sludge incineration

Radionuclides

Radon 222 from underground uranium mines

Department of Energy facilities

Uranium mill tailings

Metal phosphorus plants—Subpart K

Vinyl Chloride

Vinyl chloride manufacture

