AP-42
Supplement 8

SUPPLEMENT NO. 8

FOR

COMPILATION OF AIR POLLUTANT EMISSION FACTORS THIRD EDITION (INCLUDING SUPPLEMENTS 1-7)

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
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INSTRUCTIONS
FOR INSERTING SUPPLEMENT NO. 8
INTO
COMPILATION OF AIR POLLUTANT EMISSION FACTORS

Replace pages v through xxii with new pages v through xxii.

Add pages 1 and 2 following page xxiii.

Replace pages 1.1-3 and 1.1-4 dated 4/76 with new pages 1.1-3 and 1.1-4 dated 12/77.

Add pages 1.10-1 and 1.10-2 following page 1.9-2.

Replace pages 2.1-1 through 2.1-6 dated 4/73 with new pages 2-1 and 2.1-1 through 2.1-5 dated 12/77.

Replace pages 2.4-1 through 2.4-5 dated 4/77 with new pages 2.4-1 through 2.4-6 dated 12/77.

Add page 3.0-1 preceeding page 3.1.1-1.

Replace pages 3.3.1-1 through 3.3.1-3 dated 1/75 with new pages 3.3.1-1 through 3.3.1-4 dated 12/77.

Replace page 6.3-1 dated 2/72 with new pages 6.3-1 through 6.3-6 dated 12/77.

Replace pages 6.8-1 and 6.8-2 dated 2/72 with new pages 6.8-1 through 6.8-4 dated 12/77.

Replace pages 7.3-1 and 7.3-2 dated 2/72 with new pages 7.3-1 through 7.3-6 dated 12/77.

Replace pages 7.9-1 and 7.9-2 dated 2/72 with new pages 7.9-1 through 7.9-6 dated 12/77.

Replace pages 8.1-1 through 8.1-5 dated 4/73 with new pages 8.1-1 through 8.1-8 dated 12/77.

Replace pages 8.2-1 and 8.2-2 dated 2/72 with new pages 8.2-1 through 8.2-6 dated 12/77.

Replace pages 8.13-1 and 8.13-2 dated 2/72 with new pages 8.13-1 through 8.13-6 dated 12/77.

Replace pages 9.1-1 through 9.1-8 dated 4/73 and 4/76 with new pages 9.1-1 through 9.1-13 dated 12/77.

Replace pages 11.2-1 through 11.2-4 dated 12/75 with new pages 11.2.1-1 through 11.2.1-5 dated 12/77.

Add pages 11.2.5-1 through 11.2.5-4 following page 11.2.4-1.

Replace page C-1 undated with new page C-1 dated 12/77.

Replace Form 2220-1 (Technical Report Data) with new pages E-1 and F-1.

PREFACE

This document reports data available on those atmospheric emissions for which sufficient information exists to establish realistic emission factors. The information contained herein is based on Public Health Service Publication 999-AP-42, *Compilation of Air Pollutant Emission Factors*, by R.L. Duprey, and on three revised and expanded editions of *Compilation of Air Pollutant Emission Factors* that were published by the Environmental Protection Agency in February 1972, April 1973, and February 1976. This document is the third edition and includes the supplements issued in July 1973, September 1973, July 1974, January 1975, December 1975, April 1976, and April 1977 (see page iv). It contains no new information not already presented in the previous issuances.

Chapters and sections of this document have been arranged in a format that permits easy and convenient replacement of material as information reflecting more accurate and refined emission factors is published and distributed. To speed dissemination of emission information, chapters or sections that contain new data will be issued—separate from the parent report—whenever they are revised.

To facilitate the addition of future materials, the punched, loose-leaf format was selected. This approach permits the document to be placed in a three-ring binder or to be secured by rings, rivets, or other fasteners; future supplements or revisions can then be easily inserted. The lower left- or right-hand corner of each page of the document bears a notation that indicates the date the information was issued.

Information on the availability of future supplements to *Compilation of Air Pollutant Emission Factors* can be obtained from the Environmental Protection Agency, Library Services, MD-35, Research Triangle Park, N.C. 27711 (Comm. Telephone: 919-541-2777, FTS: 629-2777).

Comments and suggestions regarding this document should be directed to the attention of Director, Monitoring and Data Analysis Division, Office of Air Quality Planning and Standards, Environmental Protection Agency, Research Triangle Park, N.C. 27711.

ACKNOWLEDGMENTS

Because this document is a product of the efforts of many individuals, it is impossible to acknowledge each person who has contributed. Special recognition is given to Environmental Protection Agency employees in the Requests and Information Section, National Air Data Branch, Monitoring and Data Analysis Division, for their efforts in the production of this work. Bylines identify the contributions of individual authors who revised specific sections and chapters.

PUBLICATIONS IN SERIES

Issuance		Release Date
Compilation of Air Pollutant Emission Factors, Third Edition (Including Supplements 1-7)		**8/77**
Supplement No. 8		**12/77**
	Introduction	
Section 1.10	**Wood Stoves**	
Section 2.1	**Refuse Incineration**	
Section 2.4	**Open Burning**	
Section 3.0	**Internal Combustion Engine Sources; Notice**	
Section 3.3	**Off-Highway Stationary Sources**	
Section 6.3	**Cotton Ginning**	
Section 6.8	**Ammonium Nitrate Fertilizers**	
Section 7.3	**Primary Copper Smelting**	
Section 7.9	**Secondary Copper Smelting and Alloying**	
Section 8.1	**Asphaltic Concrete Plants**	
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INTRODUCTION

In the assessment of community air pollution, there is a critical need for accurate data on the quantity and characteristics of emissions from the numerous sources that contribute to the problem. The large number of individual sources and the diversity of source types make conducting field measurements of emissions on a source-by-source basis at the point of release impractical. The only feasible method of determining pollutant emissions for a given community is to make generalized estimates of typical emissions from each of the source types.

One of the most useful (and logical) tools for estimating typical emissions is the "emission factor," which is an estimate of the rate at which a pollutant is released to the atmosphere as a result of some activity, such as combustion or industrial production, *divided by* the level of that activity (also expressed in terms of a temporal rate). In other words, the emission factor relates the quantity of pollutants emitted to some indicator (activity level) such as production capacity, quantity of fuel burned, or vehicle miles traveled. In most cases, these factors are simply given as statistical or estimated averages; that is, no empirical information on the various process parameters (temperature, reactant concentrations, etc.) is considered in their calculation. However, for a few cases, such as in the estimation of hydrocarbon emissions from petroleum storage tanks, precise empirical formulas relating emissions to such variables as tank diameter, liquid storage temperature, and wind velocity have been developed. Because of their superior precision, emission factors based on empirical formulas are more desirable to obtain and can usually be given the highest accuracy rating. Factors derived from statistical averages, however, if based on an adequate number of field measurements ("source tests"), can also be both precise and accurate within practical and useful limits.

An example should illustrate how the factors are to be used:

Suppose a sulfuric acid plant, with a production rate of 200 tons/day of 100 percent acid, operates at an overall SO_2 to SO_3 conversion efficiency of 97 percent. Using the formula given as a footnote to Table 5.17-1 of this publication, the *uncontrolled* sulfur dioxide emissions can be calculated:

$$\begin{aligned} SO_2 \text{ emissions} &= [-13.65\ (\%\text{conversion efficiency}) + 1365] \times \text{production rate} \\ &= [-13.65\ (97\%) + 1365]\ \text{lb/ton acid} \times 200\ \text{tons acid/day} \\ &= 40\ \text{lb/ton acid} \times 200\ \text{tons acid/day} \\ &= 8000\ \text{lb/day}\ (3632\ \text{kg/day}) \end{aligned}$$

The emission factors presented in this report have been estimated using a wide spectrum of techniques available for their determination. The preparation/revision of each factor section involves, first of all, locating and obtaining all the known written information on that source category from such sources as available literature, Environmental Protection Agency technical reports (including emission test reports), and the National Emissions Data System point source file. After these data are reviewed, organized, and analyzed, the process descriptions, process flowsheets, and other background portions of the section are prepared. Then, using the compiled information, representative emission factors are developed for each pollutant emitted by each point source of the process category. As stated above, these factors are usually obtained by simply averaging the respective numerical data obtained. When feasible, the ranges in the factors are presented for further clarity. Occasionally, enough data exist to permit the development of either empirical or theoretical formulas (or graphs) relating emissions factors to various process parameters such as stream temperature, sulfur content, or catalyst. In these cases, *representative* values of these process parameters are selected and substituted into the formulas or graphs to obtain representative emission factors, which are then tabulated. The pertinent formulas and graphical data are also included in the section to allow the estimation of emission factors when the process conditions differ from those selected as representative.

After the draft of a section is completed, it is circulated for technical review to various personnel routinely familiar with the emission aspects of the particular activity. After these review comments are obtained and evaluated, the final draft is written and submitted for editing and publication.

The limitations and applicability of emission factors must be understood. To give some notion of the accuracy of the factors for a specific process, each set of factors has been ranked according to the available data upon which it was based. Each rank was based on the weighting of the various information categories used to obtain the factor(s). These categories and associated numerical values were:

Measured emission data: 20 points; maximum.
Process data: 10 points; maximum.
Engineering analysis: 10 points; maximum.

The emission data category rated the amount of measured (source test) data available for the development of the factor. The process data category involved such considerations as the variability of the process and its resultant effect on emissions, as well as the amount of data available on these variables. Finally, the engineering analysis category was concerned with the data available upon which a material balance or related calculation could be made.

Depending on which information categories were employed to develop it, each set of factors was assigned a numerical score, ranging from 5 to 40. For example, if the factors developed for a certain process were based on a large number of source tests, a moderate amount of process data, and no engineering analysis work, the assigned score would be 20 + 5 = 25.

Each numerical score was, in turn, converted to a letter rank as follows:

Numerical Rank	*Letter Rank*
5 or less	E(Poor)
6 to 15	D(Below average)
16 to 25	C(Average)
26 to 35	B(Above average)
36 to 40	A(Excellent)

These rankings are presented below the table titles throughout this publication.

The reader must be cautioned not to used these emission factors indiscriminately. That is, the factors generally will not permit the calculation of accurate emissions measurements from an individual installation. Only an on-site source test can provide data sufficiently accurate and precise to use in such undertakings as design and purchase of control equipment or initiation of a legal action. Factors are more valid when applied to a large number of processes, as, for example, when emission inventories are conducted as part of community or nationwide air pollution studies.

Table 1.1-2. EMISSION FACTORS FOR BITUMINOUS COAL COMBUSTION WITHOUT CONTROL EQUIPMENT
EMISSION FACTOR RATING: A

Furnace size, 10^6 Btu/hr heat input[a]	Particulates[b]		Sulfur oxides[c]		Carbon monoxide		Organics[d]		Nitrogen oxides		Aldehydes	
	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned
Greater than 100[e] (Utility and large industrial boilers)												
Pulverized												
General	16A	8A	38S	19S	1	0.5	0.3	0.15	18	9	0.005	0.0025
Wet bottom	13A[f]	6.5A	38S	19S	1	0.5	0.3	0.15	30	15	0.005	0.0025
Dry bottom	17A	8.5A	38S	19S	1	0.5	0.3	0.15	18	9	0.005	0.0025
Cyclone	2A	1A	38S	19S	1	0.5	0.3	0.15	55	27.5	0.005	0.0025
10 to 100[g] (large commercial and general industrial boilers)												
Spreader stoker[h]	13A[i]	6.5A	38S	19S	2	1	1	0.5	15	7.5	0.005	0.0025
Less than 10[j] (commercial and domestic furnaces)												
Underfeed stoker	2A	1A	38S	19S	10	5	3	1.5	6	3	0.005	0.0025
Hand-fired units	20	10	38S	19S	90	45	20	10	3	1.5	0.005	0.0025

[a] 1 Btu/hr = 0.252 kcal/hr.

[b] The letter A on all units other than hand-fired equipment indicates that the weight percentage of ash in the coal should be multiplied by the value given. Example: If the factor is 16 and the ash content is 10 percent, the particulate emissions before the control equipment would be 10 times 16, or 160 pounds of particulate per ton of coal (10 times 8, or 80 kg of particulates per MT of coal).

[c] S equals the sulfur content (see footnote b above).

[d] Expressed as methane.

[e] References 1 and 3 through 7.

[f] Without fly-ash reinjection.

[g] References 1, 4, and 7 through 9.

[h] For all other stokers use 5A for particulate emission factor.

[i] Without fly-ash reinjection. With fly-ash reinjection use 20A. This value is not an emission factor but represents loading reaching the control equipment.[1]

[j] References 7, 9, and 10.

References for Section 1.1

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4. Heller, A. W. and D. F. Walters. Impact of Changing Patterns of Energy Use on Community Air Quality. J. Air Pol. Control Assoc. *15*:426, September 1965.

5. Cuffe, S. T. and R. W. Gerstle. Emissions from Coal-Fired Power Plants: A Comprehensive Summary. U.S. DHEW, PHS, National Air Pollution Control Administration. Raleigh, N. C. PHS Publication Number 999-AP-35. 1967. p. 15.

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10. Communication with National Coal Association. Washington, D. C. September 1969.

11. Private communication with R.D. Stern, Control Systems Division, Environmental Protection Agency. Research Triangle Park, N.C. June 21, 1972.

12. Control Techniques for Sulfur Oxide Air Pollutants. U.S. DHEW, PHS, EHS, National Air Pollution Control Administration. Washington, D.C. Publication Number AP-52. January 1969. p. xviii and xxii.

13. Air Pollution Aspects of Emission Sources: Electric Power Production. Environmental Protection Agency, Office of Air Programs. Research Triangle Park, N.C. Publication Number AP-96. May 1971.

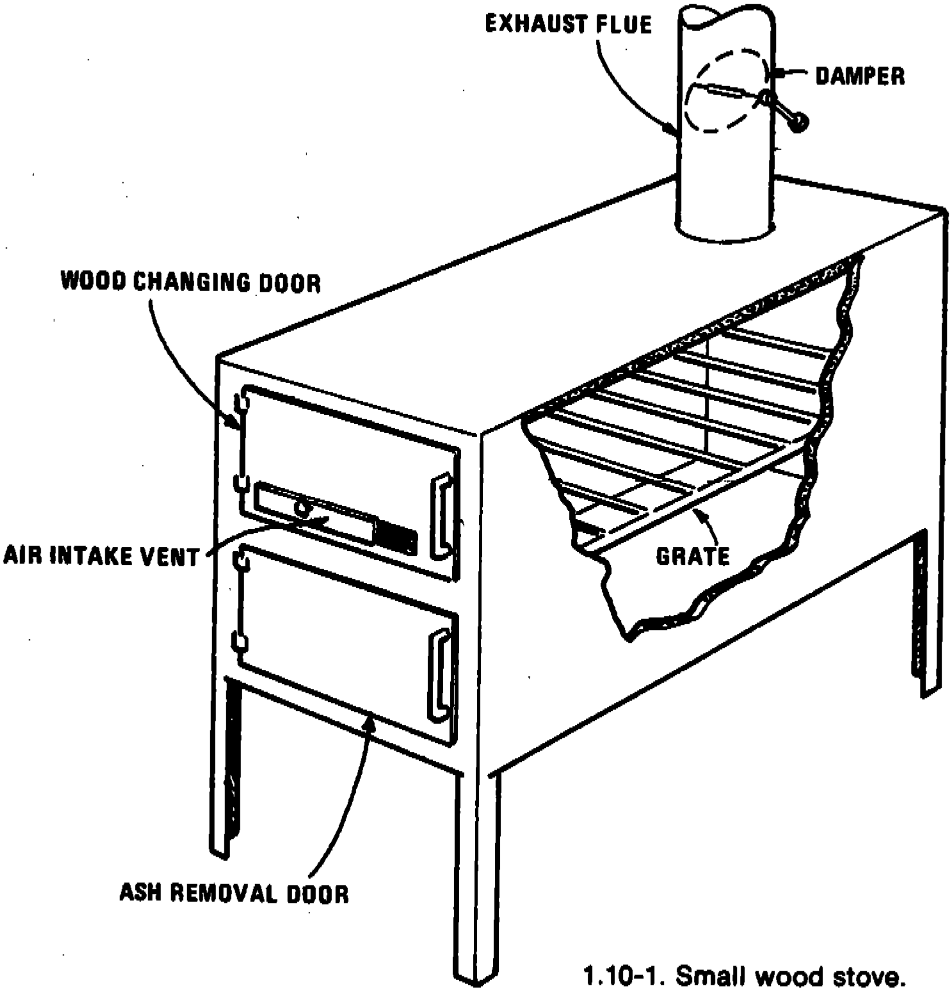
1.10 WOOD STOVES

1.10.1 General[1]

Small wood stoves are used primarily as domestic space heaters to supplement conventional heating systems, particularly in the Northeastern United States. The common availability of wood and the increased cost of conventional heating fuels has led to wider use of this type of residential heating unit. Wood combustion produces significant emissions of particulates and carbon monoxide and an array of chemicals, aerosols, and tar, depending upon the type of wood burned.

1.10.2 Process Description

Small wood stoves are usually box-shaped, made of cast iron, and have a flue that carries smoke from th room. An adjustable intake vent controls the quantity of air available for combustion. Exhaust gases are removed via the exhaust flue, which contains an adjustable damper. The rate of combustion is controlled by both the damper and the intake vent. Wood is supported on grates, and ashes collect below for easy removal. Figure 1.10-1 illustrates a typical small wood stove.



1.10-1. Small wood stove.

1.10.3 Emissions

Particulate emissions from wood are very sensitive to the amount of fuel added at one time, draft setting, fuel moisture, and type of stove. Emission factors for wood stoves are presented in Table 1.10-1.

Table 1.10-1. EMISSION FACTORS FOR SMALL WOOD STOVES[a]
EMISSION FACTOR RATING: D

Pollutant	Emission factors[b]	
	lb/ton	kg/MT
Particulate[c]	4-30	2-15
Carbon monoxide[d]	260	130

[a] Small wood stoves burning oak, pine, and birch wood.

[b] Emission factors expressed as pounds (kilograms) of pollutant per ton [metric ton (MT)] of wood burned. Wood tested ranged from 8 to 48% moisture content.

[c] Figures at the low end of this range are appropriate for small loads of dry wood with abundant air. Figures at the upper end of the range represent common firing practices. Based on References 1 and 3.

[d] Based on References 2 and 4.

References for Section 1.10

1. Butcher, S. S. and D. I. Buckley. A. Preliminary Study of Particulate Emissions from Small Wood Stoves. J. Air Pollut. Contr. Ass. *27*: 346-348, April 1977.

2. Shelton, J. W., T. Black, M. Chaffee, and M. Schwartz. Williams College, Williamstown, Ma. Wood Stove Testing Methods and Some Preliminary Experimental Results. (Presented at American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) Symposium, Atlanta, Ga. January 1978.)

3. Butcher, S. S. Bowdoin College, Brunswick, Me. Private communication to Pacific Environmental Services, Santa Monica, Ca. December 9, 1977.

4. Shelton, J. W. Williams College, Williamstown, Ma. Private communication to Pacific Environmental Services, Santa Monica, Ca. December 8, 1977.

2. SOLID WASTE DISPOSAL

As defined in the Solid Waste Disposal Act of 1965, the term "solid waste" means garbage, refuse, and other discarded solid materials, including solid-waste materials resulting from industrial, commercial, and agricultural operations, and from community activities. It includes both combustibles and noncombustibles.

Solid wastes may be classified into four general categories: urban, industrial, mineral, and agricultural. Although urban wastes represent only a relatively small part of the total solid wastes produced, this category has a large potential for air pollution since in heavily populated areas solid waste is often burned to reduce the bulk of material requiring final disposal[1] The following discussion will be limited to the urban and industrial waste categories.

An average of 5.5 pounds (2.5 kilograms) of urban refuse and garbage is collected per capita per day in the United States.[2] This figure does not include uncollected urban and industrial wastes that are disposed of by other means. Together, uncollected urban and industrial wastes contribute at least 4.5 pounds (2.0 kilograms) per capita per day. The total gives a conservative per capita generation rate of 10 pounds (4.5 kilograms) per day of urban and industrial wastes. Approximately 50 percent of all the urban and industrial waste generated in the United States is burned, using a wide variety of combustion methods with both enclosed and open burning[3]. Atmospheric emissions, both gaseous and particulate, result from refuse disposal operations that use combustion to reduce the quantity of refuse. Emissions from these combustion processes cover a wide range because of their dependence upon the refuse burned, the method of combustion or incineration, and other factors. Because of the large number of variables involved, it is not possible, in general, to delineate when a higher or lower emission factor, or an intermediate value should be used. For this reason, an average emission factor has been presented.

References

1. Solid Waste - It Will Not Go Away. League of Women Voters of the United States. Publication Number 675. April 1971.
2. Black, R.J., H.L. Hickman, Jr., A.J. Klee, A.J. Muchick, and R.D. Vaughan. The National Solid Waste Survey: An Interim Report. Public Health Service, Environmental Control Administration. Rockville, Md. 1968.
3. Nationwide Inventory of Air Pollutant Emissions, 1968. U.S. DHEW, PHS, EHS, National Air Pollution Control Administration. Raleigh, N.C. Publication Number AP-73. August 1970.

2.1 REFUSE INCINERATION

2.1.1 Process Description[1-4]

The most common types of incinerators consist of a refractory-lined chamber with a grate upon which refuse is burned. In some newer incinerators water-walled furnaces are used. Combustion products are formed by heating and burning of refuse on the grate. In most cases, since insufficient underfire (undergrate) air is provided to enable complete combustion, additional over-fire air is admitted above the burning waste to promote complete gas-phase combustion. In multiple-chamber incinerators, gases from the primary chamber flow to a small secondary mixing chamber where more air is admitted, and more complete oxidation occurs. As much as 300 percent excess air may be supplied in order to promote oxidation of combustibles. Auxiliary burners are sometimes installed in the mixing chamber to increase the combustion temperature. Many small-size incinerators are single-chamber units in which gases are vented from the primary combustion chamber directly into the exhaust stack. Single-chamber incinerators of this type do not meet modern air pollution codes.

2.1.2 Definitions of Incinerator Categories[1]

No exact definitions of incinerator size categories exist, but for this report the following general categories and descriptions have been selected:

1. *Municipal incinerators* — Multiple-chamber units often have capacities greater than 50 tons (45.3 MT) per day and are usually equipped with automatic charging mechanisms, temperature controls, and movable grate systems. Municipal incinerators are also usually equipped with some type of particulate control device, such as a spray chamber or electrostatic precipitator.

2. *Industrial/commercial incinerators* — The capacities of these units cover a wide range, generally between 50 and 4,000 pounds (22.7 and 1,800 kilograms) per hour. Of either single- or multiple-chamber design, these units are often manually charged and intermittently operated. Some industrial incinerators are similar to municipal incinerators in size and design. Better designed emission control systems include gas-fired afterburners or scrubbing, or both.

3. *Trench incinerators* — A trench incinerator is designed for the combustion of wastes having relatively high heat content and low ash content. The design of the unit is simple: a U-shaped combustion chamber is formed by the sides and bottom of the pit and air is supplied from nozzles along the top of the pit. The nozzles are directed at an angle below the horizontal to provide a curtain of air across the top of the pit and to provide air for combustion in the pit. The trench incinerator is not as efficient for burning wastes as the municipal multiple-chamber unit, except where careful precautions are taken to use it for disposal of low-ash, high-heat-content refuse, and where special attention is paid to proper operation. Low construction and operating costs have resulted in the use of this incinerator to dispose of materials other than those for which it was originally designed. Emission factors for trench incinerators used to burn three such materials[7] are included in Table 2.1-1.

4. *Domestic incinerators* — This category includes incinerators marketed for residential use. Fairly simple in design, they may have single or multiple chambers and usually are equipped with an auxiliary burner to aid combustion.

5. *Flue-fed incinerators* — These units, commonly found in large apartment houses, are characterized by the charging method of dropping refuse down the incinerator flue and into the combustion chamber. Modified flue-fed incinerators utilize afterburners and draft controls to improve combustion efficiency and reduce emissions.

Table 2.1-1. EMISSION FACTORS FOR REFUSE INCINERATORS WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: A

Incinerator type	Particulates		Sulfur oxides[b]		Carbon monoxide		Organics[c]		Nitrogen oxides[d]	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Municipal[e]										
Multiple chamber, uncontrolled	30	15	2.5	1.25	35	17.5	1.5	0.75	3	1.5
With settling chamber and water spray system[f]	14	7	2.5	1.25	35	17.5	1.5	0.75	3	1.5
Industrial/commercial										
Multiple chamber[g]	7	3.5	2.5[h]	1.25	10	5	3	1.5	3	1.5
Single chamber[i]	15	7.5	2.5[h]	1.25	20	10	15	7.5	2	1
Trench[j]										
Wood	13	6.5	0.1[k]	0.05	NA[l]	NA	NA	NA	4	2
Rubber tires	138	69	NA	NA	NA	NA	NA	NA	NA	NA
Municipal refuse	37	18.5	2.5[h]	1.25	NA	NA	NA	NA	NA	NA
Controlled air[m]	1.4	0.7	1.5	0.75	Neg	Neg	Neg	Neg	10	5
Flue-fed single chamber[n]	30	15	0.5	0.25	20	10	15	7.5	3	1.5
Flue-fed (modified)[o,p]	6	3	0.5	0.25	10	5	3	1.5	10	5
Domestic single chamber										
Without primary burner[q]	35	17.5	0.5	0.25	300	150	100	50	1	0.5
With primary burner[r]	7	3.5	0.5	0.25	Neg	Neg	2	1	2	1
Pathological[s]	8	4	Neg	Neg	Neg	Neg	Neg	Neg	3	1.5

[a] Average factors given based on EPA procedures for incinerator stack testing.

[b] Expressed as sulfur dioxide.

[c] Expressed as methane.

[d] Expressed as nitrogen dioxide.

[e] References 5 and 8 through 14.

[f] Most municipal incinerators are equipped with at least this much control: see Table 2.1-2 for appropriate efficiencies for other controls.

[g] References 3, 5, 10, 13, and 15.

[h] Based on municipal incinerator data.

[i] References 3, 5, 10, and 15.

[j] Reference 7.

[k] Based on data for wood combustion in conical burners.

[l] Not available.

[m] Reference 9.

[n] References 3, 10, 11, 13, 15, and 16.

[o] With afterburners and draft controls.

[p] References 3, 11, and 15.

[q] References 5 and 10.

[r] Reference 5.

[s] References 3 and 9.

6. *Pathological incinerators* — These are incinerators used to dispose of animal remains and other organic material of high moisture content. Generally, these units are in a size range of 50 to 100 pounds (22.7 to 45.4 kilograms) per hour. Wastes are burned on the hearth in the combustion chamber. The units are equipped with combustion controls and afterburners to ensure good combustion and minimal emissions.

7. *Controlled air incinerators* — These units operate on a controlled combustion principle in which the waste is burned in the absence of sufficient oxygen for complete combustion in the main chamber. This process generates a highly combustible gas mixture that is then burned with excess air in a secondary chamber, resulting in efficient combustion. These units are usually equipped with automatic charging mechanisms and are characterized by the high effluent temperatures reached at the exit of the incinerators.

2.1.3 Emissions and Controls[1]

Operating conditions, refuse composition, and basic incinerator design have a pronounced effect on emissions. The manner in which air is supplied to the combustion chamber or chambers has, among all the parameters, the greatest effect on the quantity of particulate emissions. Air may be introduced from beneath the chamber, from the side, or from the top of the combustion area. As underfire air is increased, and increase in fly-ash emissions occurs. Erratic refuse charging causes a disruption of the combustion bed and a subsequent release of large quantities of particulates. Large quantities of uncombusted particulate matter and carbon monoxide are also emitted for an extended period after charging of batch-fed units because of interruptions in the combustion process. In continuously fed units, furnace particulate emissions are strongly dependent upon grate type. The use of rotary kiln and reciprocating grates results in higher particulate emissions than the use of rocking or traveling grates.[14] Emissions of oxides of sulfur are dependent on the sulfur content of the refuse. Carbon monoxide and unburned hydrocarbon emissions may be significant and are caused by poor combustion resulting from improper incinerator design or operating conditions. Nitrogen oxide emissions increase with an increase in the temperature of the combustion zone, an increase in the residence time in the combustion zone before quenching, and an increase in the excess air rates to the point where dilution cooling overcomes the effect of increased oxygen concentration.[14]

Hydrochloric acid emissions were found to approximate 1.0 lb/ton of feed in early work[14] and 1.8 lb/ton in more recent work.[23] The level can be sharply increased in areas where large quantities of plastics are consumed. Methane levels found in recent work[22] range from 0.04 to 0.4 lb/ton of feed.

Table 2.1-2 lists the relative collection efficiencies of particulate control equipment used for municipal incinerators. This control equipment has little effect on gaseous emissions. Table 2.1-1 summarizes the uncontrolled emission factors for the various types of incinerators previously discussed.

Table 2.1-2. COLLECTION EFFICIENCIES FOR VARIOUS TYPES OF MUNICIPAL INCINERATION PARTICULATE CONTROL SYSTEMS[a]

Type of system	Efficiency, %
Settling chamber	0 to 30
Settling chamber and water spray	30 to 60
Wetted baffles	60
Mechanical collector	30 to 80
Scrubber	80 to 95
Electrostatic precipitator	90 to 96
Fabric filter	97 to 99

[a] References 3, 5, 6, and 17 through 21.

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2.4 OPEN BURNING

Revised by Tom Lahre
and Pam Canova

2.4.1 General[1]

Open burning can be done in open drums or baskets, in fields and yards, and in large open dumps or pits. Materials commonly disposed of in this manner are municipal waste, auto body components, landscape refuse, agricultural field refuse, wood refuse, bulky industrial refuse, and leaves.

2.4.2 Emissions[1-10]

Ground-level open burning is affected by many variables including wind, ambient temperature, composition and moisture content of the debris burned, and compactness of the pile. In general, the relatively low temperatures associated with open burning increase the emission of particulates, carbon monoxide, and hydrocarbons and suppress the emission of nitrogen oxides. Sulfur oxide emissions are a direct function of the sulfur content of the refuse. Emission factors are presented in Table 2.4-1 for the open burning of municipal refuse and automobile components.

Table 2.4-1. EMISSION FACTORS FOR OPEN BURNING OF NONAGRICULTURAL MATERIAL
EMISSION FACTOR RATING: B

	Particulates	Sulfur oxides	Carbon monoxide	Organics (CH_4)	Nitrogen oxides
Municipal refuse[a]					
lb/ton	16	1	85	30	6
kg/MT	8	0.5	42	15	3
Automobile components[b,c]					
lb/ton	100	Neg.	125	30	4
kg/MT	50	Neg.	62	15	2

[a] References 2 through 6.
[b] Upholstery, belts, hoses, and tires burned in common.
[c] Reference 2.

Emissions from agricultural refuse burning are dependent mainly on the moisture content of the refuse and, in the case of the field crops, on whether the refuse is burned in a headfire or a backfire. (Headfires are started at the upwind side of a field and allowed to progress in the direction of the wind, whereas backfires are started at the downwind edge and forced to progress in a direction opposing the wind.) Other variables such as fuel loading (how much refuse material is burned per unit of land area) and how the refuse is arranged (that is, in piles, rows, or spread out) are also important in certain instances. Emission factors for open agricultural burning are presented in Table 2.4-2 as a function of refuse type and also, in certain instances, as a function of burning techniques and/or moisture content when these variables are known to significantly affect emissions. Table 2.4-2 also presents typical fuel loading values associated with each type of refuse. These values can be used, along with the corresponding emission factors, to estimate emissions from certain categories of agricultural burning when the specific fuel loadings for a given area are not known.

Emissions from leaf burning are dependent upon the moisture content, density, and ignition location of the leaf piles. Increasing the moisture content of the leaves generally increases the amount of carbon monoxide,

Table 2.4-2. EMISSION FACTORS AND FUEL LOADING FACTORS FOR OPEN BURNING OF AGRICULTURAL MATERIALS[a]

EMISSION FACTOR RATING: B

	Emissions factors							
	Particulate[b]		Carbon monoxide		Organics (as C_6H_{14})		Fuel loading factors (waste production)	
Refuse category	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	ton/acre	MT/hectare
Field crops[c]								
Unspecified	21	11	117	58	23	12	2.0	4.5
Burning technique not significant[d]								
Asparagus[e]	40	20	150	75	85	42	1.5	3.4
Barley	22	11	157	78	19	10	1.7	3.8
Corn	14	7	108	54	16	8	4.2	9.4
Cotton	8	4	176	88	6	3	1.7	3.8
Grasses	16	8	101	50	19	10		
Pineapple[f]	8	4	112	56	8	4		
Rice[g]	9	4	83	41	10	5	3.0	6.7
Safflower	18	9	144	72	26	13	1.3	2.9
Sorghum	18	9	77	38	9	4	2.9	6.5
Sugar cane[h]	6-8.4	2.5-3.5	60-81	25-33	5-16	2-6.6	3-17	8-46
Headfire burning[i]								
Alfalfa	45	23	106	53	36	18	0.8	1.8
Bean (red)	43	22	186	93	46	23	2.5	5.6
Hay (wild)	32	16	139	70	22	11	1.0	2.2
Oats	44	22	137	68	33	16	1.6	3.6
Pea	31	16	147	74	38	19	2.5	5.6
Wheat	22	11	128	64	17	9	1.9	4.3
Backfire burning[j]								
Alfalfa	29	14	119	60	37	18	0.8	1.8
Bean (red), pea	14	7	148	72	25	12	2.5	5.6
Hay (wild)	17	8	150	75	17	8	1.0	2.2
Oats	21	11	136	68	18	9	1.6	3.6
Wheat	13	6	108	54	11	6	1.9	4.3
Vine crops	5	3	51	26	7	4	2.5	5.6
Weeds								
Unspecified	15	8	85	42	12	6	3.2	7.2
Russian thistle (tumbleweed)	22	11	309	154	2	1	0.1	0.2
Tules (wild reeds)	5	3	34	17	27	14		
Orchard crops[c,k,l]								
Unspecified	6	3	52	26	10	5	1.6	3.6
Almond	6	3	46	23	8	4	1.6	3.6
Apple	4	2	42	21	4	2	2.3	5.2
Apricot	6	3	49	24	8	4	1.8	4.0
Avocado	21	10	116	58	32	16	1.5	3.4
Cherry	8	4	44	22	10	5	1.0	2.2
Citrus (orange lemon)	6	3	81	40	12	6	1.0	2.2

Table 2.4-2 (continued). EMISSION FACTORS AND FUEL LOADING FACTORS FOR OPEN BURNING OF AGRICULTURAL MATERIALS[a]
EMISSION FACTOR RATING: B

Refuse category	Emission factors						Fuel loading factors (waste production)	
	Particulate[b]		Carbon monoxide		Organics (as C_6H_{14})			
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	ton/acre	MT/hectare
Orchard crops[c,k,l] (continued)								
Date palm	10	5	56	28	7	4	1.0	2.2
Fig	7	4	57	28	10	5	2.2	4.9
Nectarine	4	2	33	16	4	2	2.0	4.5
Olive	12	6	114	57	18	9	1.2	2.7
Peach	6	3	42	21	5	2	2.5	5.6
Pear	9	4	57	28	9	4	2.6	5.8
Prune	3	2	42	21	3	2	1.2	2.7
Walnut	6	3	47	24	8	4	1.2	2.7
Forest residues								
Unspecified[m]	17	8	140	70	24	12	70	157
Hemlock, Douglas fir, cedar[n]	4	2	90	45	5	2		
Ponderosa pine[o]	12	6	195	98	14	7		

[a] Factors expressed as weight of pollutant emitted per weight of refuse material burned.

[b] Particulate matter from most agricultural refuse burning has been found to be in the submicrometer size range.[12]

[c] References 12 and 13 for emission factors; Reference 14 for fuel loading factors.

[d] For these refuse materials, no significant difference exists between emissions resulting from headfiring or backfiring.

[e] These factors represent emissions under typical high moisture conditions. If ferns are dried to less than 15 percent moisture, particulate emissions will be reduced by 30 percent, CO emission by 23 percent, and HC by 74 percent.

[f] When pineapple is allowed to dry to less than 20 percent moisture, as it usually is, the firing technique is not important. When headfired above 20 percent moisture, particulate emission will increase to 23 lb/ton (11.5 kg/MT) and HC will increase to 12 lb/ton (6 kg/MT). See Reference 11.

[g] This factor is for dry (<15 percent moisture) rice straw. If rice straw is burned at higher moisture levels, particulate emission will increase to 29 lb/ton (14.5 kg/MT), CO emission to 161 lb/ton (80.5 kg/MT), and HC emission to 21 lb/ton (10.5 kg/MT).

[h] See Section 6.12 for discussion of sugar cane burning. The following fuel loading factors are to be used in the corresponding states: Louisiana, 3-5 ton/acre (8-13.6 MT/hectare); Florida, 4-7 ton/acre (11-19 MT/hectare); Hawaii, 11-17 ton/acre (30-46 MT/hectare). For other areas, values generally increase with length of growing season. Use the larger end of the emission factor range for lower loading factors.[20]

[i] See accompanying text for definition of headfiring.

[j] See accompanying text for definition of backfiring. This category, for emission estimation purposes, includes another technique used occasionally for limiting emissions, called into-the-wind striplighting, which involves lighting fields in strips into the wind at 100-200 m (300-600 ft) intervals.

[k] Orchard prunings are usually burned in piles. No significant difference in emission results from burning a "cold pile" as opposed to using a roll-on technique, where prunings are bulldozed onto a bed of embers from a preceding fire.

[l] If orchard removal is the purpose of a burn, 30 ton/acre (66 MT/hectare) of waste will be produced.

[m] Reference 10. Nitrogen oxide emissions estimated at 4 lb/ton (2 kg/MT).

[n] Reference 15.

[o] Reference 16.

hydrocarbon, and particulate emissions. Increasing the density of the piles increases the amount of hydrocarbon and particulate emissions, but has a variable effect on carbon monoxide emissions. Arranging the leaves in conical piles and igniting around the periphery of the bottom proves to the least desirable method of burning. Igniting a single spot on the top of the pile decreases the hydrocarbon and particulate emissions. Carbon monoxide emissions with top ignition decreases if moisture content is high but increases if moisture content is low. Particulate, hydrocarbon, and carbon monoxide emissions from windrow ignition (piling the leaves into a long row and igniting one end, allowing it to burn toward the other end) are intermediate between top and bottom ignition. Emission factors for leaf burning are presented in Table 2.4-3.

For more detailed information on this subject, the reader should consult the references cited at the end of this section.

Table 2.4-3. EMISSION FACTORS FOR LEAF BURNING[18,19]
EMISSION FACTOR RATING: B

Leaf species	Particulate[a,b]		Carbon monoxide[a]		Organics[a,c]	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Black Ash	36	18	127	63.5	41	20.5
Modesto Ash	32	16	163	81.5	25	12.5
White Ash	43	21.5	113	57	21	10.5
Catalpa	17	8.5	89	44.5	15	7.5
Horse Chestnut	54	27	147	73.5	39	19.5
Cottonwood	38	19	90	45	32	16
American Elm	26	13	119	59.5	29	14.5
Eucalyptus	36	18	90	45	26	13
Sweet Gum	33	16.5	140	70	27	13.5
Black Locust	70	35	130	65	62	31
Magnolia	13	6.5	55	27.5	10	5
Silver Maple	66	33	102	51	25	12.5
American Sycamore	15	7.5	115	57.5	8	4
California Sycamore	10	5	104	52	5	2.5
Tulip	20	10	77	38.5	16	8
Red Oak	92	46	137	68.5	34	17
Sugar Maple	53	26.5	108	54	27	13.5
Unspecified	38	19	112	56	26	13

[a] These factors are an arithmetic average of the results obtained by burning high- and low-moisture content conical piles ignited either at the top or around the periphery of the bottom. The windrow arrangement was only tested on Modesto Ash, Catalpa, American Elm, Sweet Gum, Silver Maple, and Tulip, and the results are included in the averages for these species.

[b] The majority of particulates are submicron in size.

[c] Tests indicate organics consist, on the average, of 42% olefins, 32% methane, 8% acetylene, and 13% other saturates.

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3.0 INTERNAL COMBUSTION ENGINE SOURCES

NOTICE

Emission factors for hydrocarbons, carbon monoxides, and oxides of nitrogen presented in Sections 3.1.1, 3.1.2, 3.1.4, 3.1.5, and 3.1.7, and in Appendix D have been superseded by factors in "Mobile Source Emission Factors," Final Document, January 1978. Factors appearing in these sections for sulfur oxides and particulates have not been superseded and are still applicable.

AP-42 will be revised to reflect the factors in the above document at some future date. In the interim, copies of "Mobile Source Emission Factors" and related computer programs may be obtained from the Office of Transportation and Land Use Policy, U.S. Environmental Protection Agency, Mail Code AW 445, 401 M Street SW, Washington, D.C. 20460.

3.3 OFF-HIGHWAY STATIONARY SOURCES

In general, engines included in this category are internal combustion engines used in applications similar to those associated with external combustion sources (see Chapter 1). The major engines within this category are gas turbines and large, heavy-duty, general utility reciprocating engines. Emission data currently available for these engines are limited to gas turbines and natural-gas-fired, heavy-duty, general utility engines. Most stationary internal combustion engines are used to generate electric power, to pump gas or other fluids, or to compress air for pneumatic machinery.

3.3.1 Stationary Gas Turbines for Electric Utility Power Plants

3.3.1.1 General — Stationary gas turbines find application in electric power generators, in gas pipeline pump and compressor drives, and in various process industries. The majority of these engines are used in electrical generation for continuous, peaking, or standby power.[1] The primary fuels used are natural gas and No. 2 (distillate) fuel oil, although residual oil is used in a few applications.

3.3.1.2 Emissions — Data on gas turbines were gathered and summarized under an EPA contract.[2] The contractor found that several investigators had reported data on emissions from gas turbines used in electrical generation but that little agreement existed among the investigators regarding the terms in which the emissions were expressed. The efforts represented by this section include acquisition of the data and their conversion to uniform terms. Because many sets of measurements reported by the contractor were not complete, this conversion often involved assumptions on engine air flow or fuel flow rates (based on manufacturers' data). Another shortcoming of the available information was that relatively few data were obtained at loads below maximum rated (or base) load.

Available data on the population and usage of gas turbines in electric utility power plants are fairly extensive, and information from the various sources appears to be in substantial agreement. The source providing the most complete information is the Federal Power Commission, which requres major utilities (electric revenues of $1 million or more) to submit operating and financial data on an annual basis. Sawyer and Farmer[3] employed these data to develop statistics on the use of gas turbines for electric generation in 1971. Although their report involved only the major, publicly owned utilities (not the private or investor-owned companies), the statistics do appear to include about 87 percent of the gas turbine power used for electric generation in 1971.

Of the 253 generating stations listed by Sawyer and Farmer, 137 have more than one turbine-generator unit. From the available data, it is not possible to know how many hours *each* turbine was operated during 1971 for these multiple-turbine plants. The remaining 116 (single-turbine) units, however, were operated an average of 1196 hours during 1971 (or 13.7 percent of the time), and their average load factor (percent of rated load) during operation was 86.8 percent. This information alone is not adequate for determining a representative operating pattern for electric utility turbines, but it should help prevent serious errors.

Using 1196 hours of operation per year and 250 starts per year as normal, the resulting average operating day is about 4.8 hours long. One hour of no-load time per day would represent about 21 percent of operating time, which is considered somewhat excessive. For economy considerations, turbines are not run at off-design conditions any longer than necessary, so time spent at intermediate power points is probably minimal. The bulk of turbine operation must be at base or peak load to achieve the high load factor already mentioned.

If it is assumed that time spent at off-design conditions includes 15 percent at zero load and 2 percent each at 25 percent, 50 percent, and 75 percent load, then the percentages of operating time at rated load (100 percent) and peak load (assumed to be 125 percent of rated) can be calculated to produce an 86.8 percent load factor. These percentages turn out to be 19 percent at peak load and 60 percent at rated load; the postulated cycle based on this line of reasoning is summarized in Table 3.3.1-1.

Table 3.3.1-1. TYPICAL OPERATING CYCLE FOR ELECTRIC UTILITY TURBINES

Condition, % of rated power	Percent operating time spent at condition	Time at condition based on 4.8-hr day		Contribution to load factor at condition
		hours	minutes	
0	15	0.72	43	0.00 x 0.15 = 0.0
25	2	0.10	6	0.25 x 0.02 = 0.005
50	2	0.10	6	0.50 x 0.02 = 0.010
75	2	0.10	6	0.75 x 0.02 = 0.015
100 (base)	60	2.88	173	1.0 x 0.60 = 0.60
125 (peak)	19	0.91	55	1.25 x 0.19 = 0.238
		4.81	289	Load factor = 0.868

The operating cycle in Table 3.3.1-1 is used to compute emission factors, although it is only an estimate of actual operating patterns.

The operating cycle in Table 3.3.1-1 is used to compute emission factors, although it is only an estimate of actual operating patterns. Table 3.3.1-2 is the resultant composite emission factors based on the operating cycle of Table 3.3.1-1 and the 1971 population of electric utility turbines.

Different values for time at base and peak loads are obtained by changing the total time at lower loads (0 through 75 percent) or by changing the distribution of time spent at lower loads. The cycle given in Table 3.3.1-1 seems reasonable, however, considering the fixed load factor and the economies of turbine operation. Note that the cycle determines *only* the importance of each load condition in computing composite emission factors for each type of turbine, *not* overall operating hours.

The top portion of Table 3.3.1-2 gives separate factors for gas-fired and oil-fired units, and the bottom portion gives fuel-based factors that can be used to estimate emission rates when overall fuel consumption data are available. Fuel-based emission factors on a mode basis would also be useful, but present fuel consumption data are not adequate for this purpose.

3.3.1.3 Nitrogen Oxide Control[4,5]–Nitrogen oxide emissions from gas turbines are reduced by injecting water or steam into the primary flame zone of the combustion system. Moisture is added to the fuel or combustion air, or is injected directly into the combustion chamber. The addition of water limits the combustion temperature and thereby controls the formation of nitrogen oxide.

Water and steam injection rates, commonly expressed as a water-to-fuel ratio (by weight), have an effect on turbine efficiency. Injection of water and fuel with a ratio of 1 *reduces* gas turbine efficiency by approximately 1 percent. Injection of steam at the same ratio *increases* efficiency by 1 percent. For a combined-cycle turbine using steam from the waste-heat boiler, there is an overall reduction in efficiency of 1 percent at a steam/fuel injection ratio of 1. The incremental effectiveness of injecting either steam or water is sharply reduced at water/fuel ratios above 1. Table 3.3.1-3 gives average percentages of nitrogen oxide emission reduction for various water-to-fuel ratios.

Another possible means of controlling nitrogen oxide emissions is the modification of operations and system designs to include catalysts in the combustion and catalytic cleaning in the exhaust stream. These improvements, still in the experimental stage, would be used in addition to the water-injection methods.

Table 3.3.1-2. COMPOSITE EMISSION FACTORS FOR 1971 POPULATION OF ELECTRIC UTILITY TURBINES

EMISSION FACTOR RATING: B

Time basis	Nitrogen oxides	Organics (CH^4)	Carbon Monoxide	Particulate	Sulfur oxides
Entire population					
lb/hr rated load[a]	8.84	0.79	2.18	0.52	0.33
kg/hr rated load	4.01	0.36	0.99	0.24	0.15
Gas-fired only					
lb/hr rated load	7.81	0.79	2.18	0.27	0.098
kg/hr rated load	3.54	0.36	0.99	0.12	0.044
Oil-fired only					
lb/hr rated load	9.60	0.79	2.18	0.71	0.50
kg/hr rated load	4.35	0.36	0.99	0.32	0.23
Fuel basis					
Gas-fired only					
lb/10^6 ft^3 gas	413.	42.	115.	14.	940S[b]
kg/10^6 m^3 gas	6615.	673.	1842.	224.	15,000S
Oil-fired only					
lb/10^3 gal oil	67.8	5.57	15.4	5.0	140S
kg/10^3 liter oil	8.13	0.668	1.85	0.60	16.8S

[a] Rated load expressed in megawatts.

[b] S is the percentage sulfur. Example: If the factor is 940 and the sulfur content is 0.01 percent, the sulfur oxides emitted would be 940 times 0.01, or 9.4 lb/10^6 ft^3 gas.

Table 3.3.1-3. PERCENT REDUCTION OF NO_x EMISSIONS FROM WATER OR STEAM INJECTION[a]

EMISSION FACTOR RATING: B

Water-to-fuel ratio	Percent reduction of NO_x emissions
0.2	28
0.4	48
0.6	63
0.8	73
1.0	79
1.2	84
1.4	88
1.6	90
1.8	92
2.0	92

[a] Not corrected for efficiency variations.

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6.3 COTTON GINNING

6.3.1 General[1]

The primary function of a cotton gin is to separate seed from the lint of raw seed cotton. Approximately one 500-pound bale of cotton can be produced from 1 ton of seed cotton. During ginning, lint dust, fine leaves, and other trash are emitted into the air. The degree of pollution depends on the seed cotton trash content, which depends on the method used to harvest the cotton. Handpicked cotton has a lower trash content than machine-stripped cotton.

6.3.2 Process Description[2]

Figure 6.3-1 is a flow diagram of the typical cotton ginning process. Each of the five ginning steps and associated equipment is described in the following sections.

6.3.2.1 Unloading System — Trucks and trailers transport seed cotton from the field to the gin. Pneumatic systems convey the seed cotton from the vehicles or storage houses to a separator and feed control unit. (Some gins utilize a stone and green boll trap for preliminary trash removal.) The screen assembly in the separator collects the seed cotton and allows it to fall into the feed control unit. The conveying air flows from the separator to a cyclone system where it is cleaned and discharged to the atmosphere.

6.3.2.2 Seed Cotton Cleaning System — Seed cotton is subjected to three basic conditioning processes — drying, cleaning, and extracting — before it enters the gin stand for separation of lint from seed. To ensure adequate conditioning, cotton gins typically use two conditioning systems in series (see Figure 6.3-1).

Cotton dryers are designed to reduce the moisture content of the seed cotton to an optimum level of 6.5 to 8.0 percent. A push-pull high-pressure fan system conveys seed cotton through the tower dryer to the cleaner, which loosens the cotton and removes fine particles of foreign matter such as leaf trash, sand, and dirt. Large pieces of foreign matter (e.g., sticks, stems, and burrs) are removed from the seed cotton by a different process, referred to as "extracting." Several types of extractors are used at cotton gins: burr machines, stick machines, stick and burr machines, stick and green leaf extractors, and extractor-feeders. The burr machine removes burrs and pneumatically conveys them to the trash storage area. The seed cotton then enters a stick (or a stick and green leaf) machine, which removes sticks, leaves, and stems. Afterwards, the seed cotton is pneumatically conveyed to the next processing step.

6.3.2.3 Overflow System — From the final conditioning unit, the seed cotton enters a screw conveyor distributor, which apportions the seed cotton to the extractor-feeders at a controlled rate. When the flow of seed cotton exceeds the limit of the extractor-feeders, the excess seed cotton flows into the overflow hopper. A pneumatic system transfers seed cotton from the overflow hopper back to the extractor-feeder as required.

6.3.2.4 Lint Cotton Handling System — Cotton enters the gin stand through a "huller front," which performs some cleaning. A saw grasps the locks of cotton and draws them through a widely spaced set of "huller ribs," which strip off hulls and sticks. The cotton locks are then drawn into the roll box, where seeds are separated from the fibers. As the seeds are removed, they slide down the face of the ginning ribs and fall to the bottom of the gin stand for subsequent removal to storage. Cotton lint is removed from the saw by a brush or a blast of air and conveyed pneumatically to the lint cleaning system for final cleaning and combing. The lint cotton is separated from the conveying air stream by a separator that forms the lint into a batt. This batt is fed into the first set of lint cleaners, where saws comb the lint cotton and remove leaf particles, grass, and motes.

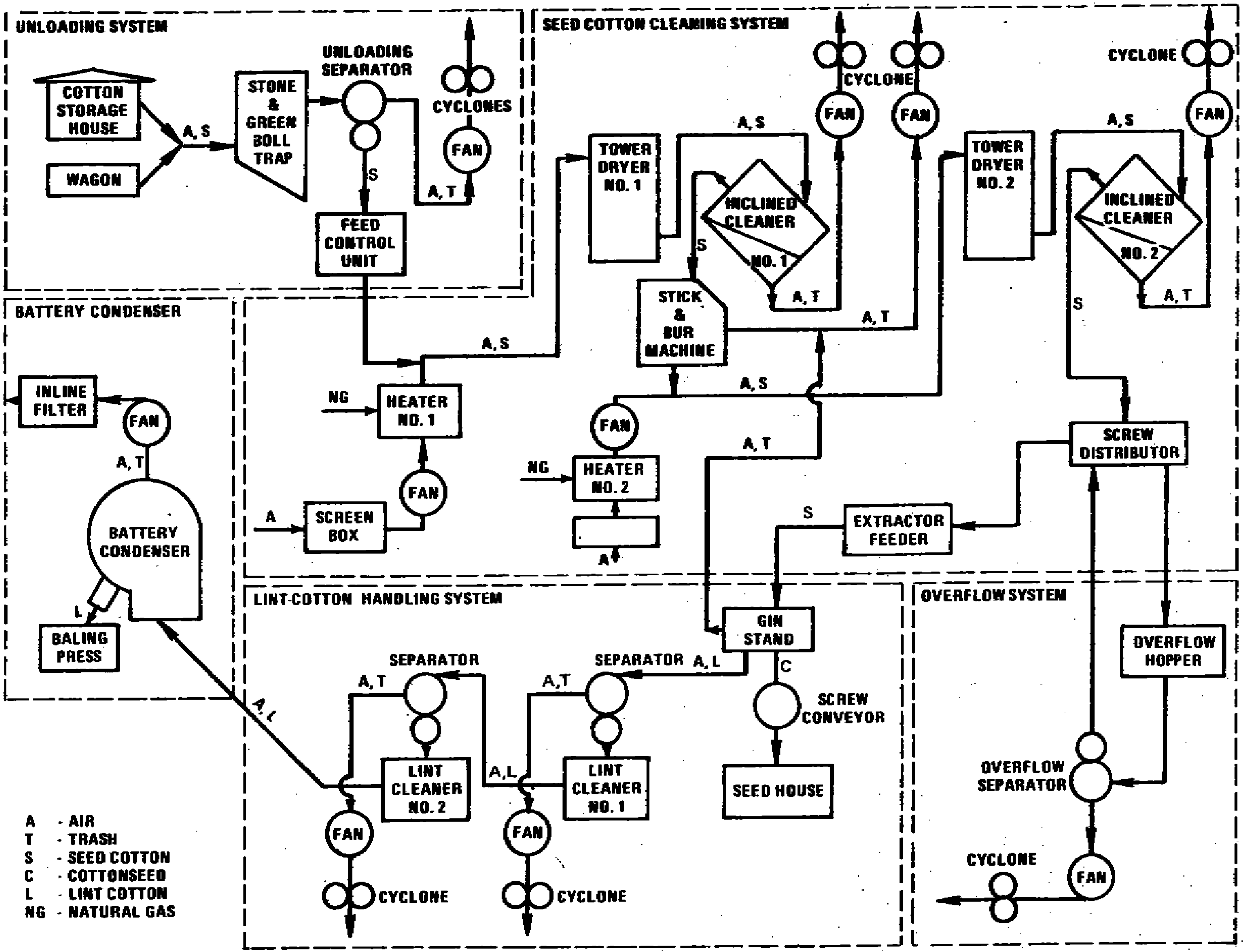

Figure 6.3-1. Flow diagram of cotton ginning process.[2]

6.3.2.5 Battery Condenser and Baling System — Lint cotton is pneumatically transported from the lint cleaning system to a battery condenser, which consists of drums equipped with screens that separate the lint cotton from the conveying air. The conveying air is then discharged through an in-line filter or cyclones before being exhausted to the atmosphere. The batt of lint cotton is then fed into the baling press, which packs it into uniform bales of cotton.

6.3.3 Emissions and Controls

The major sources of particulates from cotton ginning can be arranged into 10 emission source categories based on specific ginning operations (Figure 6.3-2). Three primary methods of particulate control are in use: (1) high efficiency cyclones on the high-pressure fan discharges with collection efficiencies greater than 99 percent,[2] (2) in-line filters on low-pressure fan exhaust vents with efficiencies of approximately 80 percent, and (3) fine screen coverings on condenser drums in the low-pressure systems with efficiencies of approximately 50 percent.[3,4] The unifilter is a new concept for collecting all wastes from cotton gins. It is designed to replace all cyclones, in-line filters, and covered condenser drums, and has a collection efficiency of up to 99 percent.[5]

Table 6.3-1 presents emission factors from uncontrolled cotton ginning operations.[1]

Table 6.3-2 presents emission factors for a typical cotton gin equipped with available control devices; the data base involved cotton gins with a variety of different control devices, including cyclones, in-line filters, screen coverings, and unifilters.[2,6-9] The total emission factor can be expected to vary by roughly a factor of two, depending on the type of seed cotton, the trash content of the seed cotton, the maintenance of control devices, and the plant operation procedures.

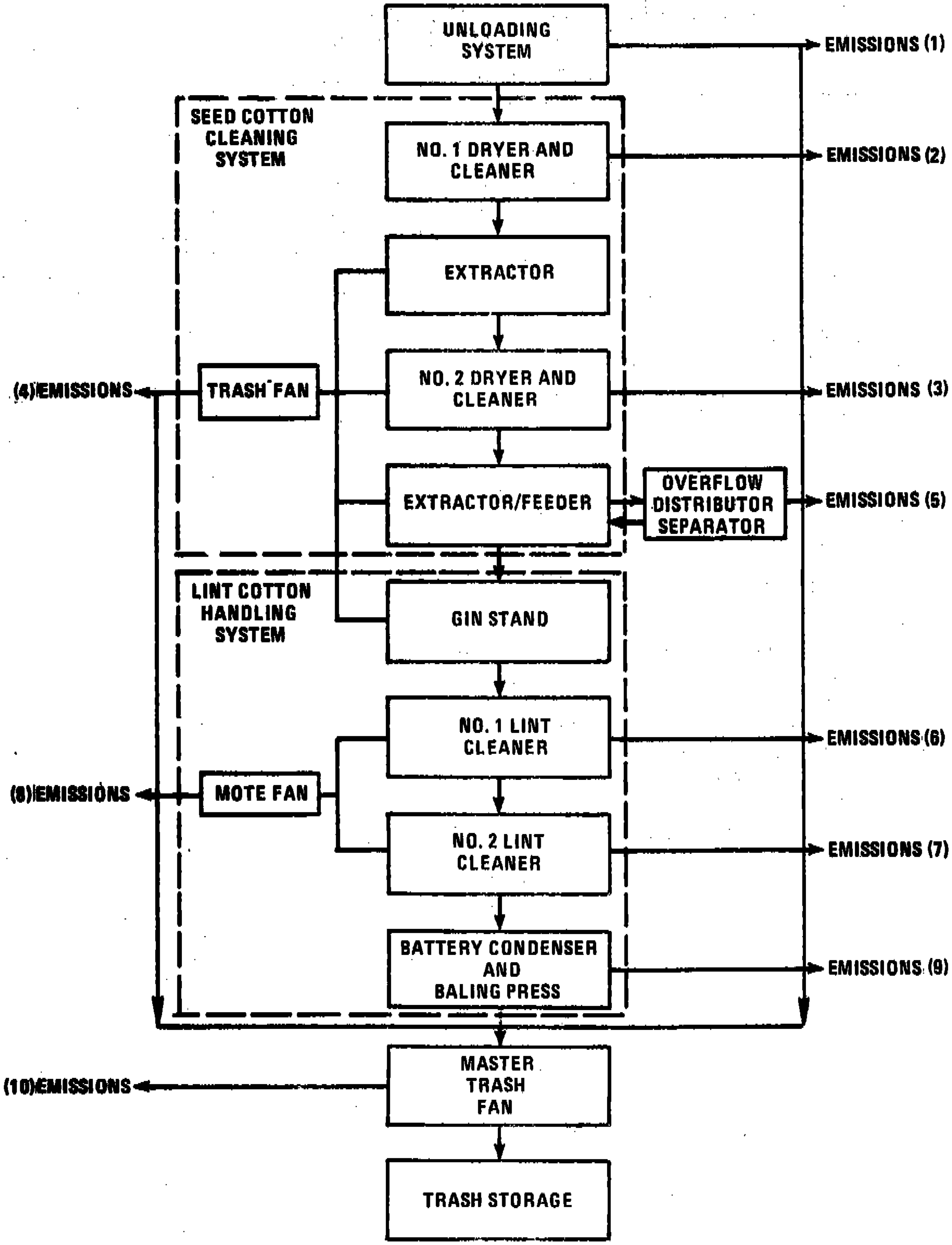

Figure 6.3-2. Emissions from a typical ginning operation.

Table 6.3-1. EMISSION FACTORS FOR COTTON GINNING OPERATIONS WITHOUT CONTROL[a,b]
EMISSION FACTOR RATING: C

Process	Estimated total particulate		Particulates >100 μm settled out, %[c]	Estimated emission factor (released to atmosphere)	
	lb/bale	kg/bale		lb/bale	kg/bale
Unloading fan	5	2.27	0	5.0	2.27
Seed cotton cleaning system					
Cleaners and dryers[d]	1	0.45	70	0.3	0.14
Stick and burr machine	3	1.36	95	0.2	0.09
Miscellaneous[e]	3	1.36	50	1.5	0.68
Total	12	5.44	---	7.0	3.2

[a] Reference 1.

[b] One bale weighs 500 pounds (226 kilograms).

[c] Percentage of the particles that settle out in the plant.

[d] Corresponds to items 1 and 2 in Table 6.3-2.

[e] Corresponds to items 4 through 9 in Table 6.3-2.

Table 6.3-2. PARTICULATE EMISSION FACTORS FOR COTTON GINS WITH CONTROLS[a]
EMISSION FACTOR RATING: C

Emission source[b]	Emission factor	
	lb/bale[c]	g/kg
1. Unloading fan	0.32	0.64
2. No. 1 dryer and cleaner	0.18	0.36
3. No. 2 dryer and cleaner	0.10	0.20
4. Trash fan	0.04	0.08
5. Overflow fan	0.08	0.16
6. No. 1 lint cleaner condenser	0.81	1.62
7. No. 2 lint cleaner condenser	0.15	0.30
8. Mote fan	0.20	0.40
9. Battery condenser	0.19	0.38
10. Master trash fan	0.17	0.34
Total	2.24	4.48

[a] References 2,6-9.

[b] Numbers correspond to those in Figure 6.3-2.

[c] A bale of cotton weighs 500 pounds (227 Kilograms).

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6.8 AMMONIUM NITRATE FERTILIZERS

6.8.1 General [1,3]

Ammonium nitrate fertilizers are produced by reacting nitric acid and ammonia to form the ammonium nitrate solutions or solids. Essentially four steps are involved in producing solid ammonium nitrate: neutralization, evaporation/concentration, solidification, and final particle characterization and finishing (Figure 6.8-1).

Anhydrous ammonia and 55 percent nitric acid are combined in a neutralizer to produce a 61 percent ammonium nitrate solution, with the heat of reaction concentrating that solution to approximately 83 percent ammonium nitrate before it leaves the neutralizer. The solution is then further concentrated in the evaporator/concentrator before the solid formation step. If a liquid ammonium nitrate product is desired, it is obtained at this point in the process.

Solidification can be achieved by means of prilling, granulation, crystallization, or graining. Prilling, the most common method used, accounts for over 90 percent of the solid product formed. High-density or low-density prills can be produced, depending on the feed solution concentration. High-density prills are preferred in fertilizers because of their excellent blending and spreading characteristics and their long storage life. Low-density prills, while used for fertilizer, are primarily good for blasting agents because of their high porosity. Solid fertilizer production by granulation uses ordinary granulator processes instead of a prilling tower in order to achieve the desired solid product.

An adjusting tank is used in conjunction with the neutralizer to store the 83 percent ammonium nitrate solution from the neutralizer, receive the overflow from a head tank at the top of the prilling tower, and supply the evaporator/concentrator on a demand basis. A lump-dissolving tank is used to recycle substandard material (undersize or oversize). The oversize and/or fine materials enter the tank, dissolve, and are sent to the neutralizer as a weak (~60 percent) recycle liquor.

Final particle characterization and finishing may include sizing, cooling, drying, coating, and preparation for shipment. The actual operations used at a particular plant depend on the product manufactured and the solidification process employed.

6.8.2 Emissions[3]

Emissions from the manufacture of ammonium nitrate consist of particulates and of either ammonia or nitric acid from the neutralizer, depending upon which reactant is added in excess to the process. Normally, ammonia is added in excess because it reduces the particulate loading and opacity of the exhaust stream.

Table 6.8-1 presents emission factors for the different emission points in the prilling process. Except for the dryer and cooler, uncontrolled emission factors are given because most plants operate without controls on the neutralizer, evaporator/concentrator, and prill tower. Coolers and dryers are normally equipped with high-efficiency scrubbers to recover valuable products and recycle them in the process.

In addition to the emissions indicated in Table 6.8-1, particulate matter may escape from coating/bulk loading operations. Emissions from coating operations are estimated to be <6 g/kg under the assumption that a maximum of 10 percent of the coating material used is lost to the atmosphere. Particulates from bulk loading operations are estimated to have an emission factor of <0.01 g/kg of material loaded.

Solid fertilizer produced by granulation or graining amounts to less than 9 percent of the solid fertilizer produced and emissions are only fugitive losses.[3] Table 6.8-2 presents emissions from the granulation process.

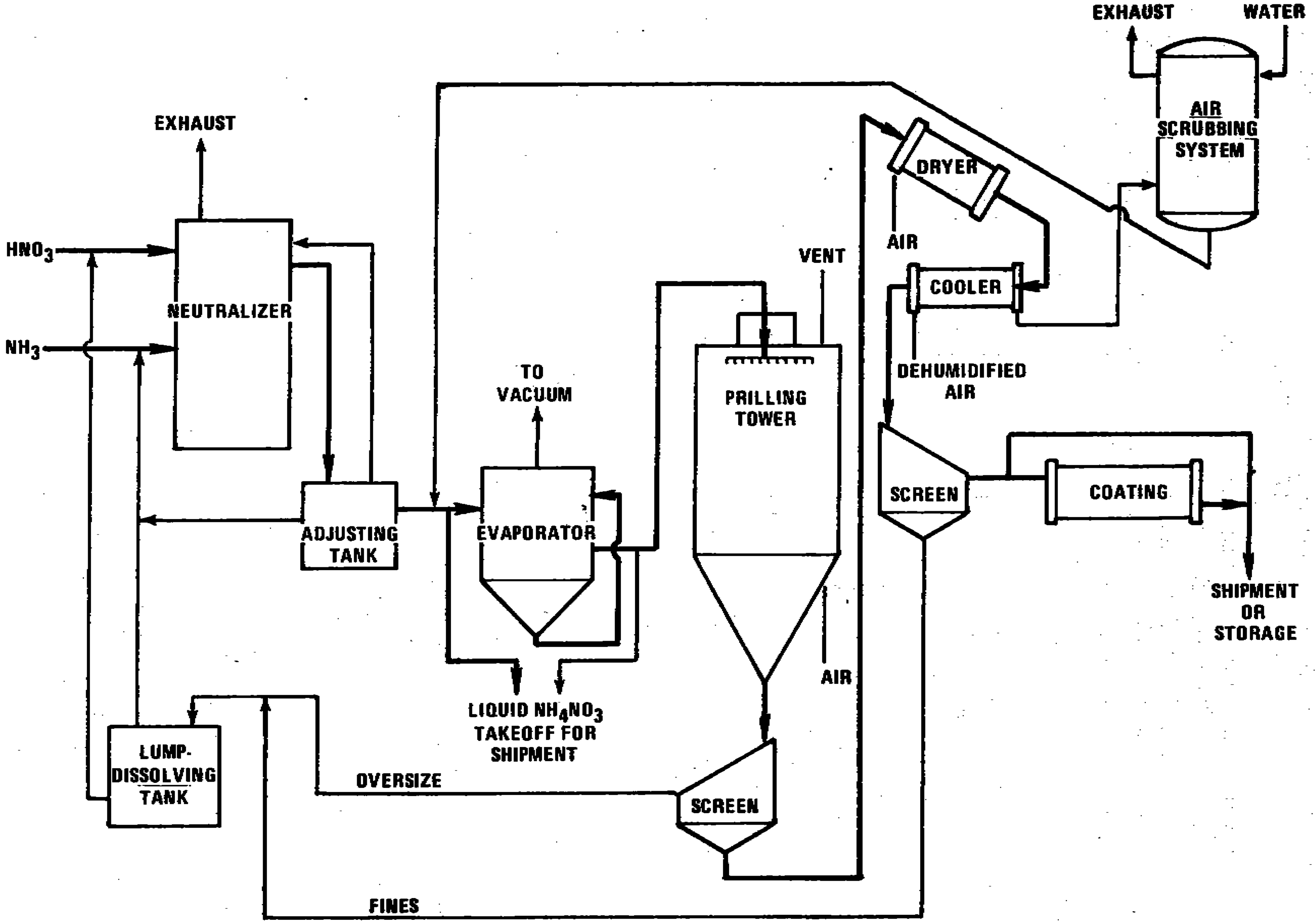

Figure 6.8-1. Prilling process flow diagram.

Table 6.8-1. EMISSION FACTORS FOR AMMONIUM NITRATE FERTILIZER MANUFACTURING[a]
EMISSION FACTOR RATING: A

	High-density prilling						Low-density prilling					
	Particulate		Ammonia		Nitric acid		Particulate		Ammonia		Nitric acid	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/Mt	lb/ton	kg/Mt	lb/ton	kg/Mt
Neutralizer[b]	3.3[c]	1.6[c]	0.86[d]	0.43[d]	≤0.52	≤0.26	0.08[c]	0.04[c]	0.86[d]	0.43[d]	≤0.52	≤0.26
Evaporator/ concentrator	0.94[c]	0.47[c]					0.18[c]	0.09[c]				
Prilling tower	2.7[c]	1.4[c]					1.00[c]	0.50[c]				
Dryer and cooler[e,f]	0.10	0.05					0.08	0.04				
Coating[g,h]	≤ 4.0	≤2.0					≤6.0	≤3.0				
Bulk loading[g]	≤0.02	≤0.01					≤0.02	≤0.01				

[a] Emission factor expressed as lb (kg) per ton [metric ton (MT)] of ammonium nitrate fertilizer produced.

[b] Ammonia or nitric acid released during production is assumed to come from the neutralizer. Available data are insufficient to provide further breakdown of the emissions.

[c] Data are for uncontrolled operations.

[d] Emission ranges of 0.052 to 6.3 lb/ton (0.26 to 3.1 kg/MT) result from variations in plant operation.

[e] Data are for controlled operations using a wet scrubber with an efficiency of 95 percent.

[f] Dryer is not used in high-density prilling.

[g] Fugitive particulate emissions escape from coating and bulk loading operations.

[h] Coating increases the particle emission level of low-density prills. Coatings are not normally applied to high density prills (~3 percent are coated).

Table 6.8-2. EMISSION FACTORS FOR GRANULAR NITRATE FERTILIZER MANUFACTURING WITHOUT CONTROLS[a,b]

EMISSION FACTOR RATING: B

	Particulate		Nitrogen oxides (NO_x)		Ammonia	
Emission point[c]	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Neutralizer [d,e]	-	-	-	-	2	1
Grandulator [f]	0.4	0.2	0.9	0.45	0.5	0.25
Dryers & coolers [f,g]	7	3.5	3	1.5	1.3	0.65

[a] Emission factor expressed as lb (kg) per ton [metric ton (MT)] of fertilizer produced.

[b] Solid formulation by granulation accounts for less than 9 percent of fertilizer production (Reference 3).

[c] Reference 1.

[d] Reference 2.

[e] Controlled factor based on 95 percent recovery in recycle scrubber.

[f] Use of wet cyclones can reduce emissions by 70 percent.

[g] Use of wet-screen scrubber following cyclone can reduce emissions by 95 percent.

6.8.3 Controls[3]

Several systems have been developed for the control of emissions from the prilling tower and the neutralizer. A system using a modified neutralizer may have a 10- to 20-fold reduction in emissions. Wet scrubbing systems for prill towers have been shown to achieve a 90 percent reduction (by weight) in prill tower emissions. Another system, using a special cone in the prill tower and a mist eliminator, has achieved 98.6 percent removal efficiencies on combined exhausts from the prill tower, neutralizer, and evaporator/concentrator.

High-efficiency wet scrubbers are used on cooler and dryer exhausts to recover entrained particulates. The weak ammonium nitrate scrubbing liquor is recycled to the lump-dissolving tank and ultimately back to the system. Removal efficiencies of 95 to 97 percent are standard for these scrubbers due to the large (10 to 1000 μm) size of the particulate. Controlled emission factors are given for dryers and coolers in Table 6.8-1 since the use of controls is standard industry practice.

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7.3 PRIMARY COPPER SMELTING

7.3.1 Process Description[1,3,7]

Pyrometallurgical smelting methods are utilized extensively in the United States to produce copper from sulfide ores. These ores usually contain less than 1 percent copper and therefore must be concentrated before being transported to the smelter. Concentration to 15 to 35 percent copper is accomplished by crushing, grinding, and flotation at the mine site. Sulfur content of the concentrate is generally 25 to 35 percent. Most of the remaining concentrate is iron (25 percent) and water (10 percent). Some concentrates also contain significant quantities of arsenic, cadmium, lead, boron, antimony, and other heavy metals.

The most common configuration of operations for pyrometallurgical smelters in the United States includes roasting, reverberatory or electric furnace smelting, and converting to produce blister copper (99+ percent pure copper) from concentrate. The remaining impurities are usually removed by fire refining and electrolytic refining. Figure 7.3-1 is a generalized flowsheet for this combination of operations. About half of the smelters in the United States do not use the roasting step and instead feed wet or "green" charge directly to the smelting furnace.

In roasting, concentrate is heated in air, eliminating 20 to 50 percent of the sulfur as sulfur dioxide (SO_2). Relatively volatile impurities such as antimony, arsenic, and bismuth are also driven off, and some of the iron is converted to oxides, which combine with slag in ensuing processes. Concentrate is mixed with a siliceous flux (often a low-grade ore) to produce the roaster charge material. The roasted product, called calcine, serves as a dried and preheated charge for the smelting furnace. Either multiple-hearth or fluidized-bed roaster furnaces are used for roasting copper concentrate. Because there is less air dilution, higher SO_2 concentrations are present in fluidized-bed roaster gases than in multiple-hearth roaster gases.

The second step is smelting. In this process, hot calcines from the roaster or raw unroasted concentrate are fused with limestone and siliceous flux in reverberatory or electric-arc furnaces to produce copper matte. Copper matte is primarily miscible liquid sulfides and some heavy metals. In reverberatory furnace operation, heat is supplied by combustion of oil, gas, or pulverized coal, and is reflected from the roof of the furnace onto the charge. As the charge is melted, copper, iron, and sulfur form cuprous sulfide (Cu_2S) and ferrous sulfide (FeS). Other minerals combine with fluxes, forming slag. Slag floats on top of the molten bath and is removed continuously. Copper matte remains in the furnace until poured. Normal smelting furnace operations produce a matte that contains 40 to 45 percent copper.

For smelting in electric-arc furnaces, heat is generated by an electric current passing through carbon electrodes that are lowered into the slag layer of the molten bath. Electric furnaces do not produce fuel combustion gases; therefore, gas flow rates are lower and SO_2 concentrations are higher in electric furnace effluent streams than in reverberatory furnace gases.

The final step in the production of blister copper is converting. Converting is normally performed in Peirce-Smith converters, which consist of a cylindrical steel shell mounted on trunnions at either end and rotated about its major axis. An opening in one side of the converter functions as a mouth through which molten matte, siliceous flux, and scrap copper are charged to the converter and gaseous products are vented. Air or oxygen-enriched air is blown through the metal; FeS is oxidized and combined with the flux to form a slag, which floats on the surface. Relatively pure Cu_2S (called "white metal") is collected in the bottom of the converter. After removal of slag, a renewed air blast oxidizes the sulfide sulfur to SO_2 leaving blister copper in the converter.

Hoboken converters have recently been installed at one U.S. smelter to replace the standard Peirce-Smith converters. The metallurgical operations of the Hoboken unit are the same as those of the Peirce-Smith unit; however, to prevent dilution air from entering the exhaust gas stream, the Hoboken converter is fitted with a stationary side flue instead of a movable hood.

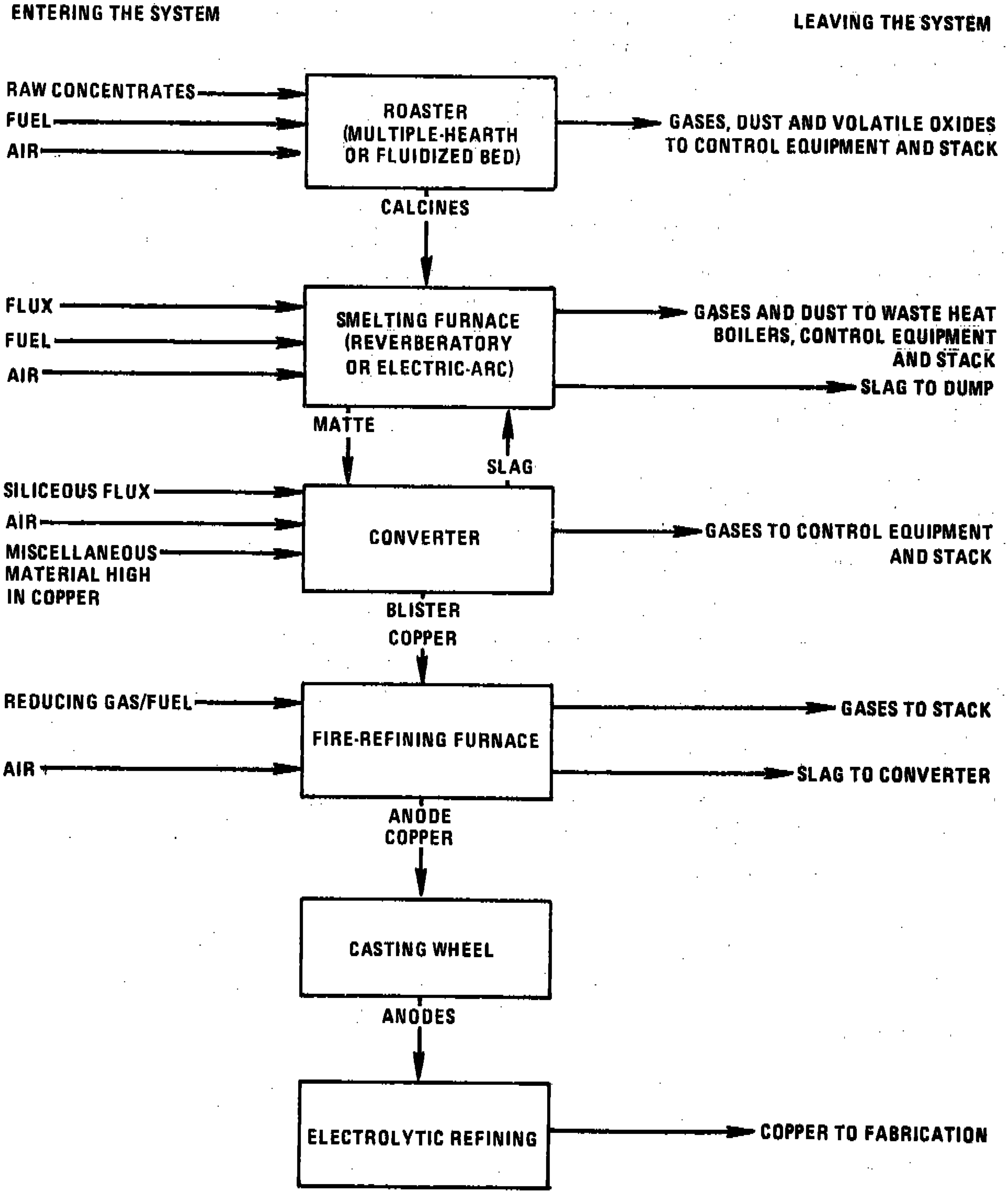


Figure 7.3-1. Typical primary copper smelter flowsheet.

In a newer process, roasting and smelting are combined in one operation to produce a high-grade copper matte from concentrates and fluxes using a flash furnace. Fuel is supplied to sustain combustion reactions, but most of the heat necessary for smelting is generated autogenously by the oxidation of the sulfides in the concentrate. The flash smelting operation has also been applied to the oxidation of matte to blister copper in the continuous smelting process. Continuous smelting systems that have been operated at foreign smelters include the Noranda, WORCRA, Mitsubishi, and TBRC (top-blown rotary converter) processes.

Blister copper usually contains from 98.5 to 99.5 percent pure copper. Impurities may include gold, silver, antimony, arsenic, bismuth, iron, lead, nickel, selenium, sulfur, tellurium, and zinc. To further purify the blister copper, fire refining and electrolytic refining are used. In fire refining, air is blown through the metal to oxidize remaining impurities; these are removed as a slag, and the remaining metal bath is subjected to a reducing atmosphere to reconvert cuprous oxide to copper. The fire-refined copper is cast into anodes and further refined electrolytically.

Electrolytic refining involves separation of copper from impurities by electrolysis in a solution containing copper sulfate and sulfuric acid. Metallic impurities precipitate from the solution and form a sludge that is removed and treated for recovery of precious metals. The copper produced is 99.95 to 99.97 percent pure.

Hydrometallurgical processes are usually applied to recovery of copper from oxide ores, but their application in U.S. plants is limited.

7.3.2 Emissions and Controls

Particulates and sulfur dioxide are the principal air contaminants emitted at primary smelters. In some cases, these emissions are generated directly as a result of the processes involved, as in the liberation of SO_2 from the ore or the volatilization of trace elements to oxide fumes. Significant quantities of fugitive emissions are generated during material handling operations and charging and tapping of furnaces.

Mutiple-hearth and fluidized-bed roasters are sources of both particulates and sulfur oxides. Particulates consist of oxides of the metals that are found in the concentrate. Copper and iron oxides are the primary constituents, but other oxides such as those of arsenic, antimony, cadmium, lead, mercury, and zinc may also be present with metallic sulfates and sulfuric acid. Combustion products from fuel burning also contribute to the particulate emissions from multiple-hearth roasters. Control of particulates from roaster gases is standard practice because of the value of the recovered copper in the dust and because of the presence of toxic particulates such as arsenic. Cyclones and scrubbers may be used for coarse particulate removal and are usually followed by electrostatic precipitators (ESPs) or fabric filters for collection of fines.

Smelting furnaces also emit significant quantities of oxidized metal particulates and SO_2. Particulate collection systems for smelting furnaces are similar to those used for roasters. Reverberatory furnace offgases are usually routed through low-velocity balloon flues and waste heat boilers to recover large particles and heat, then routed through electrostatic precipitators. Overall collection efficiencies of 95 to 99 percent for ESP systems are normal for these applications. Efficiencies as high as 99.7 percent have been reported.

Converter flue gases also contain particulates and SO_2. In the standard Peirce-Smith converter, flue gases are captured during the blowing phase by movable hooding covering the converter mouth opening. To prevent the hood freezing to the converter due to splashing of molten metal, there is a gap between the hood and the vessel. Sophisticated draft control devices that maintain a negative pressure at the gap to draw air in for cooling and to prevent fugitive emissions have been developed. During charging and pouring operations, significant fugitive emissions may occur when the hooding is removed to allow crane access.

Remaining smelter processes handle material that contains very little sulfur; hence SO_2 emissions from these processes are relatively insignificant. Particulate emissions from fire-refining operations, however, may still be of concern. Electrolytic refining does not produce emissions unless the associated sulfuric acid tanks are open to the atmosphere. Crushing and grinding systems used in ore, flux, and slag processing also contribute to fugitive dust problems.

Control of SO_2 emissions from smelter sources is most commonly performed in a single- or double-contact sulfuric acid manufacturing plant. Use of a sulfuric acid plant on copper smelter effluent gas streams requires that gas be free from particulate matter and that a certain minimum SO_2 concentration be maintained. Table 7.3-1 shows typical average SO_2 concentrations for the various smelter unit offgases. These offgas streams may be treated individually, or weak and strong concentration streams may be blended. Typically, single-contact acid plants achieve 96.5 to 97 percent conversion of SO_2 to acid with approximately 2000 ppm SO_2 remaining in the acid plant effluent gas. Double-contact acid plants collect 98 percent of the SO_2 and emit about 500 ppm SO_2 Absorption of the SO_2 in dimethylaniline (DMA) solution has also been used in U.S. smelters for production of liquid SO_2.

Table 7.3-1. AVERAGE SULFUR DIOXIDE CONCENTRATIONS IN OFFGASES FROM PRIMARY COPPER SMELTING SOURCES

Unit	Sulfur dioxide concentration, percent
Multiple-hearth roaster	1.5-3
Fluidized-bed roaster	10-12
Reverberatory furnace	0.5-1.5
Electric-arc furnace	4-8
Flash-smelting furnace	10-20
Continuous smelting furnace	5-15
Peirce-Smith converter	4-7
Hoboken converter	8
Single-contact H_2SO_4 plant	0.2
Double-contact H_2SO_4 plant	0.05

Emissions from hydrometallurgical smelting plants are generally small in quantity and easily controlled. In the Arbiter process, ammonia gas escapes from the leach reactors, mixer-settlers, thickeners, and tanks. For control, all of these units are covered and vented to a packed-tower scrubber, which recovers the ammonia and recycles it.

No control practices tor nitrogen oxides, carbon monoxide, or hydrocarbon emissions, which are found in the offgas streams from units requiring fuel combustion are currently utilized in U.S. smelters. Multiple-hearth roasters, reverberatory furnaces, converters, and refining furnaces are sources of these contaminants. Data are available for assigning emission factors for NO_x emissions from reverberatory furnaces and converters in only one smelter configuration (Table 7.3-2). Data for assigning emission factors for CO and hydrocarbons are unavailable.

Actual emissions from a particular smelter unit depend upon the configuration of equipment in the smelting plant and the operating parameters employed. Table 7.3-2 summarizes the emission factors for the major units for various smelter configurations. Other potential emission sources, which have not been quantified, include ore crushing and preparation, flux crushing, ore storage, concentrate drying, slag dumping, fire refining, and copper casting.

Table 7.3-2. EMISSION FACTORS FOR PRIMARY COPPER SMELTERS[a,b]
EMISSION FACTOR RATING: B

Smelter configuration	Unit	Control[c]	Particulates[d]		SO_2[d]		SO (as H_2SO_4)[d]		NO_x(as NO_2)[d]	
			lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Reverberatory furnace followed by converters	Reverb.	None	36	18	390	195	0.81	0.41	0.09	0.045
		ESP	22	11						
	Converter	None	42	21	860	430			0.05	0.025
		ESP	2.5	1.3						
		ESP + SCAP	0.28	0.14	27	14	0.06	0.03		
Multiple-hearth roaster followed by reverberatory furnace and converters	Roaster	None	45	22.5	410	205				
		Baghouse	0.2	0.1						
	Roaster and reverb.[e]	None			460	230	1.5	0.75		
		ESP	4.8	2.4						
		Spray Chamber + ESP	1.4	0.7						
	Converter	None	42	21	540	270				
		ESP	2.9	1.5						
		ESP + SCAP	0.38	0.19	61	31	0.14	0.07		
		ESP + DCAP	0.38	0.19	0.62	0.31				
Fluidized-bed roaster followed by reverberatory furnace and converters	Roaster	None	55	28	540	270				
		Baghouse + SCAP	0.1	0.05	2	1				
	Reverb.	ESP	2.4	1.2	66	33	0.22	0.11		
	Converter	ESP + SCAP	1.1	0.55						
Fluidized-bed roaster followed by electric furnace and converters	Roaster	None	55	28	540	270				
		Baghouse + SCAP	0.1	0.05	2	1				
	Furnace	None			131	66				
	Converter	None			444	222				
Total uncontrolled smelter		None	135	66.5	1,254	627				

[a] Emission factors are expressed as units per unit weight of concentrated ore processed by the smelter. Approximately 4 unit weights of concentrate are required to produce 1 unit weight of copper metal.

[b] Other potential emission sources include (1) ore storage, crushing, and handling, (2) flux crushing and handling, (3) concentrate drying and handling, (4) slag dumping, (5) fire refining, and (6) copper casting, but emission rates have not been quantified.

[c] ESP = electrostatic precipitator
SCAP = single-contact acid plant
DCAP = double-contact acid plant

[d] References 2, 4, 5, 6, 7, and 8. Additional information was furnished by the following agencies.
Arizona Department of Health Services, Phoenix, Arizona
Montana State Department of Health and Environmental Sciences, Helena, Montana
Puget Sound Air Pollution Control District, Seattle, Washington
New Mexico Environmental Improvement Agency, Santa Fe, New Mexico

[e] Roaster and reverberatory furnace emissions are combined and therefore a single set of emission factors is provided.

References for Section 7.3

1. Air Pollution Engineering Manual (2nd Ed.). John A. Danielson, Air Pollution Control District, County of Los Angeles (ed.). U.S. Environmental Protection Agency, Research Triangle Park, N.C. Publication No. AP-40. May 1973.

2. Weisenberg, I. J. and G. E. Umlauf. Evaluation of the Controllability of SO_2 Emissions from Copper Smelters in the State of Arizona. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, N.C. under Contract No. 68-02-1354, Task Order No. 8 June 1975.

3. Field Surveillance and Enforcement Guide for Primary Metallurgical Industries. U.S. Environmental Protection Agency, Research Triangle Park, N.C. Publication No. EPA-450/3-73-002. December 1973.

4. Background Information for New Source Performance Standards: Primary Copper, Zinc and Lead Smelters, Volume 1: Proposed Standards. U.S. Environmental Protection Agency, Research Triangle Park, N.C. Publication No. EPA-450/2-74-002a. October 1974.

5. Billings, Carl H. First Annual Report on Arizona Copper Smelter Pollution Control Technology. Arizona Department of Health Services, Phoenix, Az. April 1977.

6. Control of Sulfur Dioxide Emissions in Copper, Lead, and Zinc Smelting. U.S. Bureau of Mines, Washington, D. C. Information Circular 8527. 1971.

7. Extraction Metallurgy of Copper, Volume I: Pyrometallurgy and Electrolytic Refining, and Volume II: Hydrometallurgy and Electrowinning. The Metallurgical Society of AIME, New York, N. Y. 1976.

8. Atmospheric Emissions from Sulfuric Acid Manufacturing Processes. U.S. Department of Health, Education and Welfare, National Air Pollution Control Administration, Cincinnati, Oh. NAPCA Publication No. 999-13. 1966.

9. Emission Factors and Emission Source Information for Primary and Secondary Copper Smelters. U.S. Environmental Protection Agency, Research Triangle Park, N.C. Publication No. EPA-450/3-77-051. December 1977.

7.9 SECONDARY COPPER SMELTING AND ALLOYING

7.9.1 Process Description[1,2]

The secondary copper industry processes scrap metals for the recovery of copper. Products include refined copper or copper alloys in forms such as ingots, wirebar, anodes, and shot. Copper alloys are combinations of copper with other materials, notably, tin, zinc, and lead. Also, for special applications, combinations include such metals as cobalt, manganese, iron, nickel, cadmium, and beryllium and nonmetals such as arsenic and silicon.

The principal processess involved in copper recovery are scrap metal pretreatment and smelting. Pretreatment includes cleaning and concentration to prepare the material for the smelting furnace. Smelting involves heating and treating the scrap to achieve separation and purification of specific metals.

The feed material used in the recovery process can be any metallic scrap containing a useful amount of copper, bronze (copper and tin), or brass (copper and zinc). Traditional forms are punchings, turnings and borings, defective or surplus goods, metallurgical residues such as slags, skimmings, and drosses, and obsolete, worn out, or damaged articles including automobile radiators, pipe, wire, bushings, and bearings.

The type and quality of the feed material determines the processes the smelter will use. Due to the large variety of possible feed materials available, the method of operation varies greatly between plants. Generally, a secondary copper facility deals with less pure raw materials and produces a more refined product, whereas brass and bronze alloy processors take cleaner scrap and do less purification and refining. Figure 7.9-1 is a flowsheet depicting the major processes that can be expected in a secondary copper smelting operation. A brass and bronze alloying operation is shown in Figure 7.9-2.

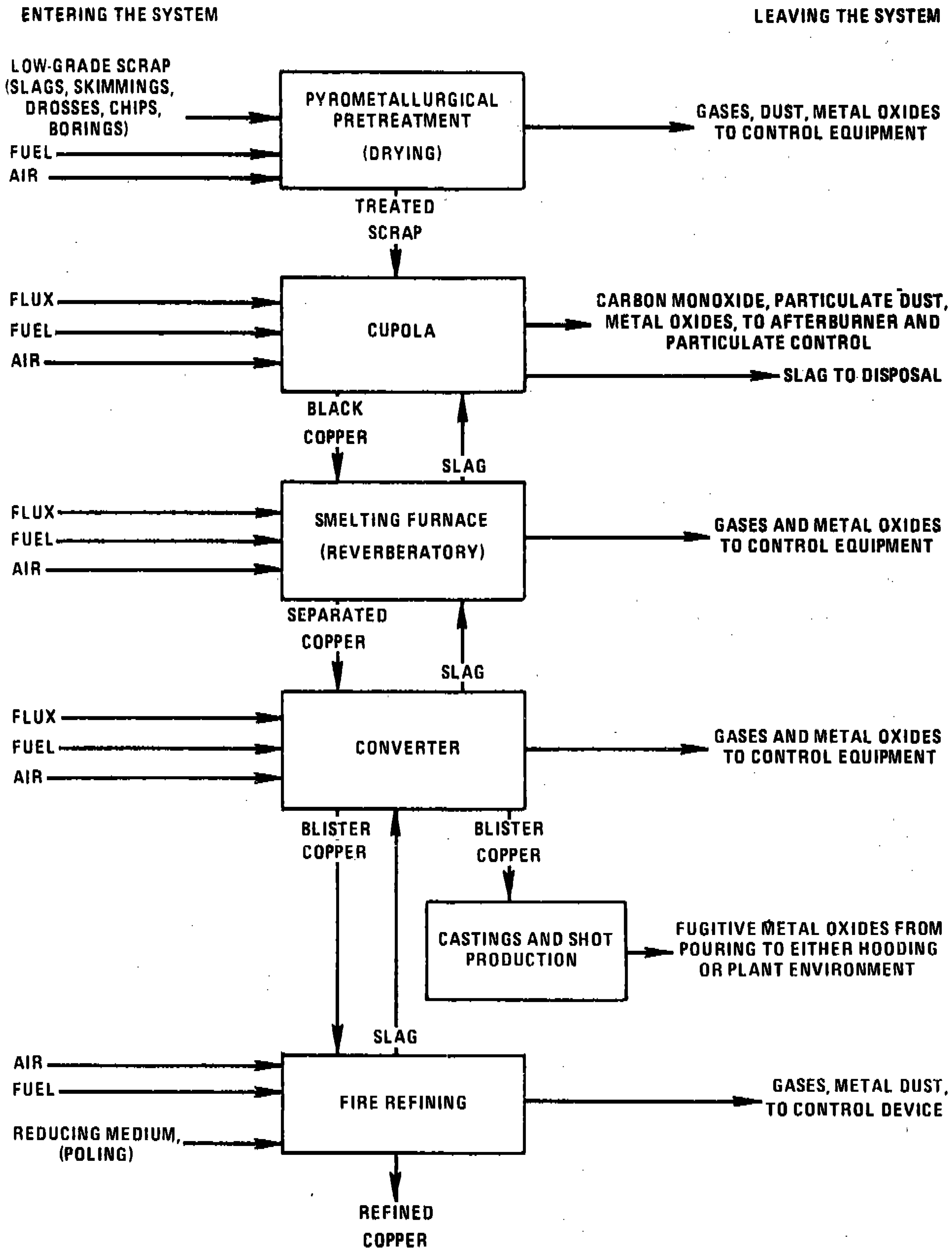
Pretreatment of the feed material can be accomplished using several different procedures, either separately or in combination. Feed scrap is concentrated by manual and mechanical methods such as sorting, stripping, shredding, and magnetic separation. Feed scrap is sometimes briquetted in a hydraulic press. Pyrometallurgical pretreatment may include sweating, burning of insulation (especially from wire scrap), and drying (burning off oil and volatiles) in rotary kilns. Hydrometallurgical methods include flotation and leaching, with chemical recovery.

In smelting, low-grade scrap is melted in a cupola furnace, producing "black copper" (70 to 80 percent Cu) and slag; these are often separated in a reverberatory furnace, from which the melt is transferred to a converter or electric furnace to produce "blister" copper, which is 90 to 99 percent Cu.

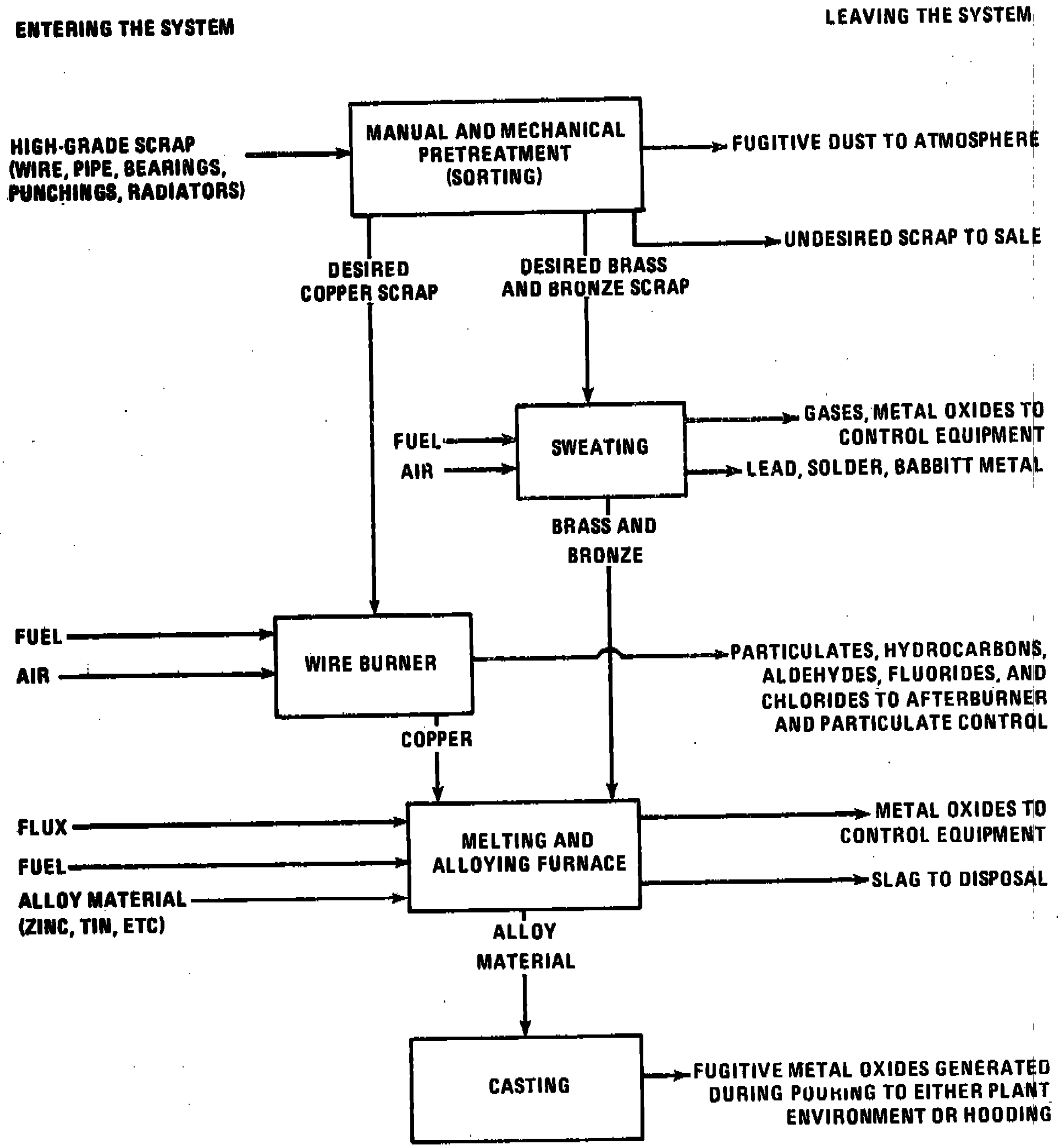
Blister copper may be poured to produce shot or castings, but is often further refined electrolytically or by fire refining. The fire-refining process is essentially the same as that described for the primary copper smelting industry (Section 7.3.1). The sequence of events in fire-refining is (1) charging, (2) melting in an oxidizing atmosphere, (3) skimming the slag, (4) blowing with air or oxygen, (5) adding fluxes, (6) "poling" or otherwise providing a reducing atmosphere, (7) reskimming, and (8) pouring.

To produce bronze or brass rather than copper, an alloying operation is required. Clean, selected bronze and brass scrap is charged to a melting furnace with alloys to bring the resulting mixture to the desired final composition. Fluxes are added to remove impurities and to protect the melt against oxidation by air. Air or oxygen may be blown through the melt to adjust the composition by oxidizing excess zinc.

With zinc-rich feed such as brass, the zinc oxide concentration in the exhaust gas is sometimes high enough to make recovery for its metal value desirable. This process is accomplished by vaporizing the zinc from the melt at high temperature and capturing the oxide downstream in a process baghouse.



7.9-1. Low-grade copper recovery.



7.9-2. High-grade brass and bronze alloying.

The final step is always casting of the suitably alloyed or refined metal into a desired form, i.e, shot, wirebar, anodes, cathodes, ingots, or other cast shapes. The metal from the melt is usually poured into a ladle or a small pot, which serves the functions of a surge hopper and a flow regulator, then into a mold.

7.9.2 Emissions and Controls

The principal pollutants emitted from secondary copper smelting activities are particulate matter in various forms. Removal of insulation from wire by burning causes particulate emissions of metal oxides and unburned insulation. Drying of chips and borings to remove excess oils and cutting fluids can cause discharges of large amounts of dense smoke consisting of soot and unburned hydrocarbons. Particulate emissions from the top of a cupola furnace consist of metal oxide fumes, dirt, and dust from limestone and coke.

The smelting process utilizes large volumes of air to oxidize sulfides, zinc, and other undesirable constituents of the feed. This procedure generates much particulate matter in the exit gas stream. The wide variation among furnace types, charge types, quality, extent of pretreatment, and size of charge is reflected in a broad spectrum of particle sizes and variable grain loadings in the escaping gases. One major factor contributing to differences in emission rates is the amount of zinc present in scrap feed materials; the low-boiling zinc evaporates and combines with air oxygen to give copious fumes of zinc oxide.

Metal oxide fumes from furnaces used in secondary smelters have been controlled by baghouses, electrostatic precipitators, or wet scrubbers. Efficiency of control by baghouses may be better than 99 percent, but cooling systems are needed to prevent the hot exhaust gases from damaging or destroying the bag filters. A two-stage system employing both water jacketing and radiant cooling is common. Electrostatic precipitators are not as well suited to this application, having a low collection efficiency for dense particulates such as oxides of lead and zinc. Wet scrubber installations are also relatively ineffective in the secondary copper industry. Scrubbers are useful mainly for particles larger than 1 micron, (μm) but the metal oxide fumes generated are generally submicron in size.

Particulate emissions associated with drying kilns can be similarly controlled. Drying temperatures up to 150° C (300° F) produce relatively cool exhaust gases, requiring no precooling for control by baghouses.

Wire burning generates much particulate matter, largely unburned combustibles. These emissions can be effectively controlled by direct-flame afterburners, with an efficiency of 90 percent or better if the afterburner combustion temperature is maintained above 1000° C (1800° F). If the insulation contains chlorinated organics such as polyvinyl chloride, hydrogen chloride gas will be generated and will not be controlled by the afterburner.

One source of fugitive emissions in secondary smelter operations is charging of scrap into furnaces containing molten metals. This often occurs when the scrap being processed is not sufficiently compact to allow a full charge to fit into the furnace prior to heating. The introduction of additional material onto the liquid metal surface produces significant amounts of volatile and combustible materials and smoke, which can escape through the charging door. Briquetting the charge offers a possible means of avoiding the necessity of such fractional charges. When fractional charging cannot be eliminated, fugitive emissions are reduced by turning off the furnace burners during charging. This reduces the flow of exhaust gases and enhances the ability of the exhaust control system to handle the emissions.

Metal oxide fumes are generated not only during melting, but also during pouring of the molten metal into the molds. Other dusts may be generated by the charcoal, or other lining, used in association with the mold. Covering the metal surface with ground charcoal is a method used to make "smooth-top" ingots. This process creates a shower or sparks, releasing emissions into the plant environment at the vicinity of the furnace top and the molds being filled.

Emission factor averages and ranges for six different types of furnaces are presented in Table 7.9-1.

Table 7.9-1. PARTICULATE EMISSION FACTORS FOR FURNACES USED IN SECONDARY COPPER SMELTING AND ALLOYING PROCESSES[a,b]

EMISSION FACTOR RATING: B

Furnace and charge type	Control equipment[c]	Emissions			
		Avg kg/MT	Range kg/MT	Avg lb/ton	Range lb/ton
Cupola					
Scrap copper	0	0.002	-	0.003	-
Insulated copper wire	0	120	-	230	-
	1	5	-	10	-
Scrap copper and brass	0	35	30-40	70	60-80
	1	1.2	1.0-1.4	2.4	2.0-2.8
Reverberatory					
Copper	0	2.6	0.4-15	5.1	0.8-30
	2	0.2	0.1-0.3	0.4	0.3-0.6
Brass and bronze	0	18	0.3-35	36	0.6-70
	2	1.3	0.3-2.5	2.6	0.05-5
Rotary					
Brass and bronze	0	150	50-250	300	100-500
	1	7	3-10	13	6-19
Crucible and pot					
Brass and bronze	0	11	1-20	21	2-40
	1	0.5	0.1-1	1	0.1-2
Electric arc					
Copper	0	2.5	1-4	5	2-8
	2	0.5	0.02-1.0	1	0.04-2
Brass and bronze	0	5.5	2-9	11	4-18
	2	3	-	6	-
Electric induction					
Copper	0	3.5	-	7	-
	2	0.25	-	0.5	-
Brass and bronze	0	10	0.3-20	20	0.5-40
	2	0.35	0.01-0.65	0.7	0.01-1.3

[a] All factors given in terms of raw materials charged to unit.

[b] The information for Table 7.9-1 was based on unpublished data furnished by the following:

Philadelphia Air Management Services, Philadelphia, Pennsylvania.
New Jersey Department of Environmental Protection, Trenton, New Jersey.
New Jersey Department of Environmental Protection, Metro Field Office, Springfield, New Jersey.
New Jersey Department of Environmental Protection, Newark Field Office, Newark, New Jersey.
New York State Department of Environmental Conservation, New York, New York.
The City of New York Department of Air Resources, New York, New York.
Cook County Department of Environmental Control, Maywood, Illinois.
Wayne County Department of Health, Air Pollution Control Division, Detroit, Michigan.
City of Cleveland Department of Public Health and Welfare, Division of Air Pollution Control, Cleveland, Ohio.
State of Ohio Environmental Protection Agency, Columbus, Ohio.
City of Chicago Department of Environmental Control, Chicago, Illinois.
South Coast Air Quality Management District, Los Angeles, California.

[c] Control equipment:
0 signifies none operated
1 indicates electrostatic precipitator
2 indicates baghouse filter system

References for Section 7.9

1. Air Pollution Aspects of Brass and Bronze Smelting and Refining Industry. U.S. Department of Health, Education and Welfare, National Air Pollution Control Administration, Raleigh, N. C. Publication No. AP-58. November 1969.

2. Air Pollution Engineering Manual (2nd Ed.). John A. Danielson, Air Pollution Control District, County of Los Angeles (ed.). U.S. Environmental Protection Agency, Research Triangle Park, N.C. Publication No. AP-40. May 1973.

3. Emission Factors and Emission Source Information for Primary and Secondary Copper Smelters. U.S. Environmental Protection Agency, Research Triangle Park, N.C. Publication No. EPA-450/3-77-051. December 1977.

8. MINERAL PRODUCTS INDUSTRY

This section involves the processing and production of various minerals. Mineral processing is characterized by particulate emissions in the form of dust. Frequently, as in the case of crushing and screening, this dust is identical to the material being handled. Emissions also occur through handling and storing the finished product because this material is often dry and fine. Particulate emissions from some of the processes such as quarrying, yard storage, and dust from transport are difficult to control. Most of the emissions from the manufacturing processes discussed in this section, however, can be reduced by conventional particulate control equipment such as cyclones, scrubbers, and fabric filters. Because of the wide variety in processing equipment and final product, emissions cover a wide range; however, average emission factors have been presented for general use.

8.1 ASPHALTIC CONCRETE PLANTS

8.1.1 General

Asphaltic concrete is a paving material consisting of a combination of aggregate that has been dried, heated, and then evenly coated with hot asphalt.

8.1.2 Process Description

Selecting and handling the raw material is the first step in the production of asphaltic concrete. Different applications of asphaltic concrete require different aggregate size distributions and the raw aggregates are crushed and screened at the quarries. The coarse aggregate usually consists of crushed stone and gravel, but waste materials, such as slag from steel mills or crushed glass, can be used as raw material. Asphaltic concrete is produced by one of three major processes: batch, continuous, and drum-mix.

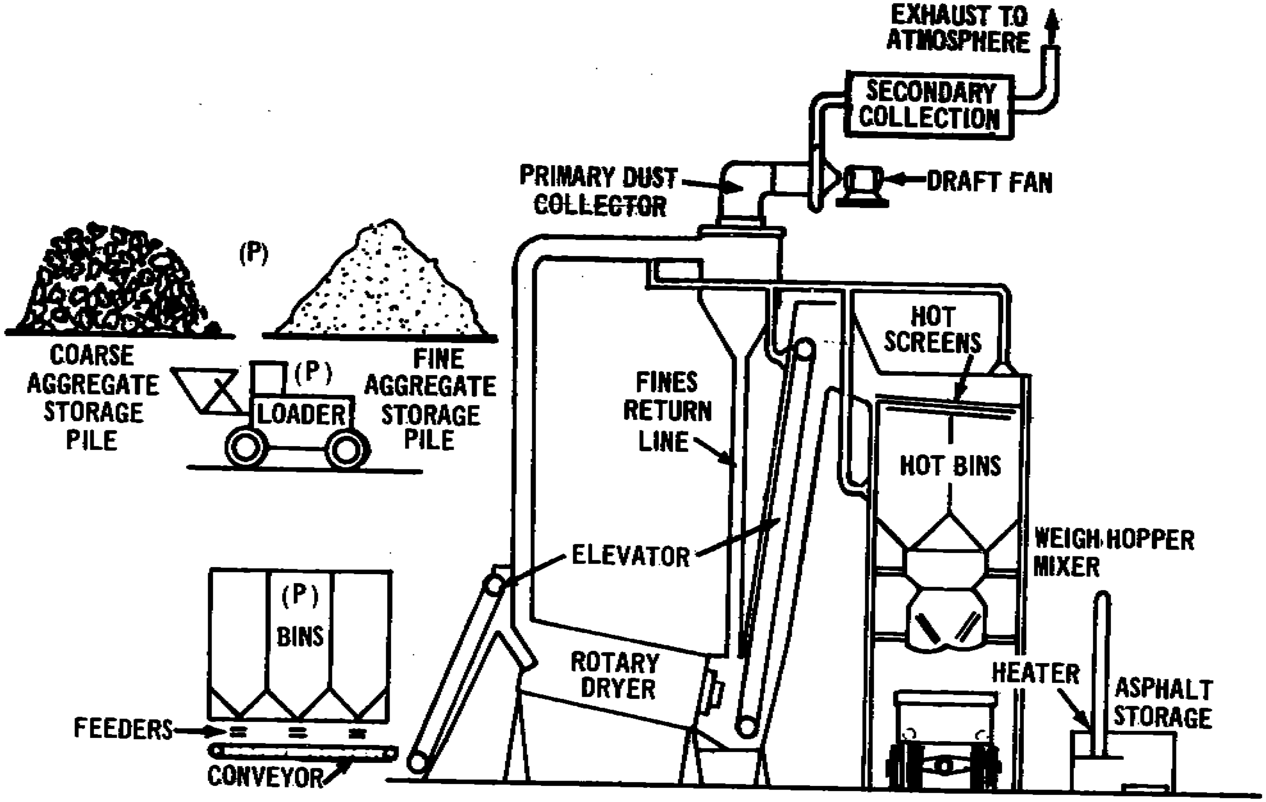
8.1.2.1 Conventional Plants [1,2]—Conventional plants produce finished asphaltic concrete through either batch (Figure 8.1-1) or continuous (Figure 8.1-2) aggregate mixing operations. The raw aggregate is normally stockpiled near the plant at a location where the moisture content will stabilize between 3 and 5 percent by weight.

As processing for either type of operation begins, the aggregate is hauled from the storage piles and placed in the appropriate hoppers of the cold-feed unit. The material is metered from the hoppers onto a conveyor belt and is transported into a gas- or oil-fired rotary dryer. Because a substantial portion of the heat is transferred by radiation, dryers are equipped with flights that are designed to tumble the aggregate and promote drying.

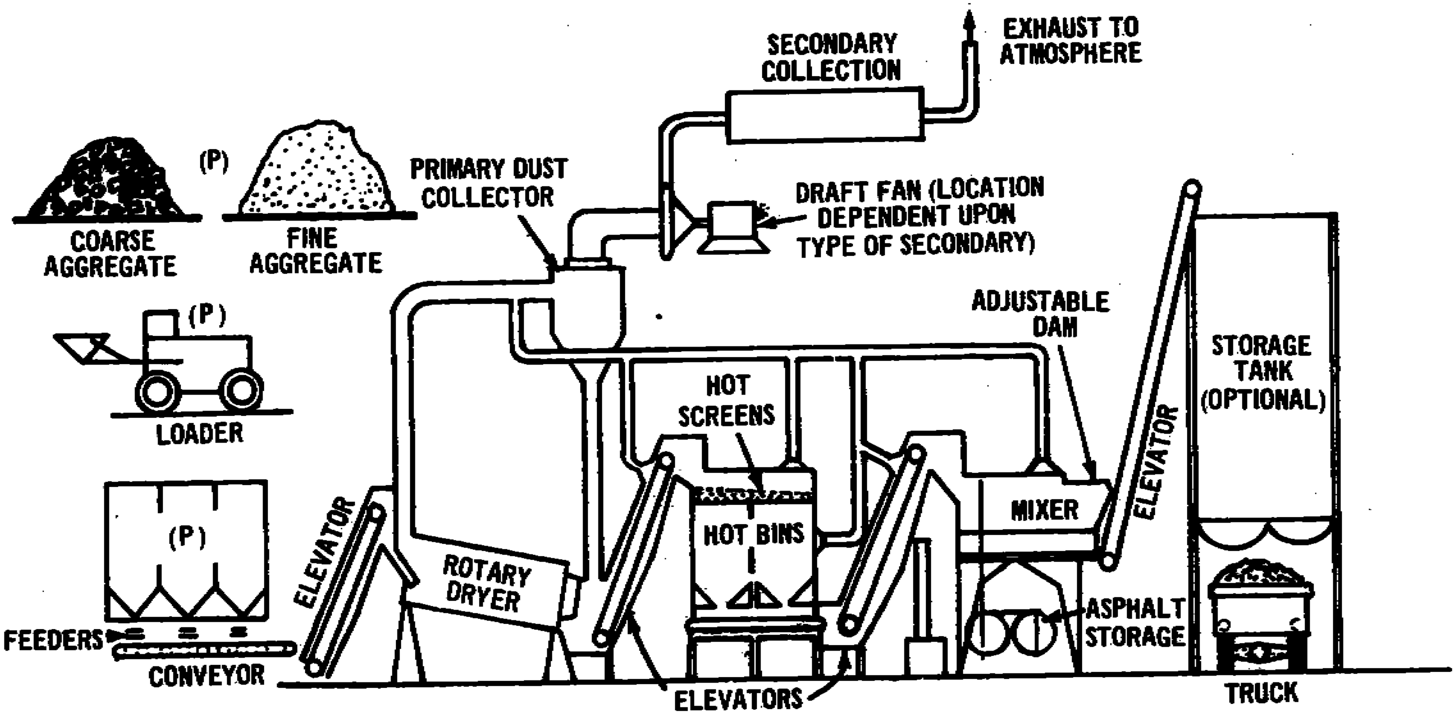
As it leaves the dryer, the hot material drops into a bucket elevator and is transferred to a set of vibrating screens where it is classified by size into as many as four different grades. The classified hot materials then enter the mixing operation.

In a batch plant, the classified aggregate drops into one of four large bins. The operator controls the aggregate size distribution by opening individual bins and allowing the classified aggregate to drop into a weigh hopper until the desired weight is obtained. After all the material is weighed, the sized aggregates are dropped into a mixer and mixed dry for about 30 seconds. The asphalt, which is a solid at ambient temperatures, is pumped from heated storage tanks, weighed, and then injected into the mixer. The hot mixed batch is then dropped into a truck and hauled to the job site.

In a continous plant, the classified aggregate drops into a set of small bins that collect and meter the classified aggregate to the mixer. From the hot bins, the aggregate is metered through a set of feeder conveyors to another bucket elevator and into the mixer. Asphalt is metered into the inlet end of the mixer and retention time in the mixer is controlled by an adjustable dam at the end of the mixer. The mix flows out of the mixer into a hopper from which the trucks are loaded.



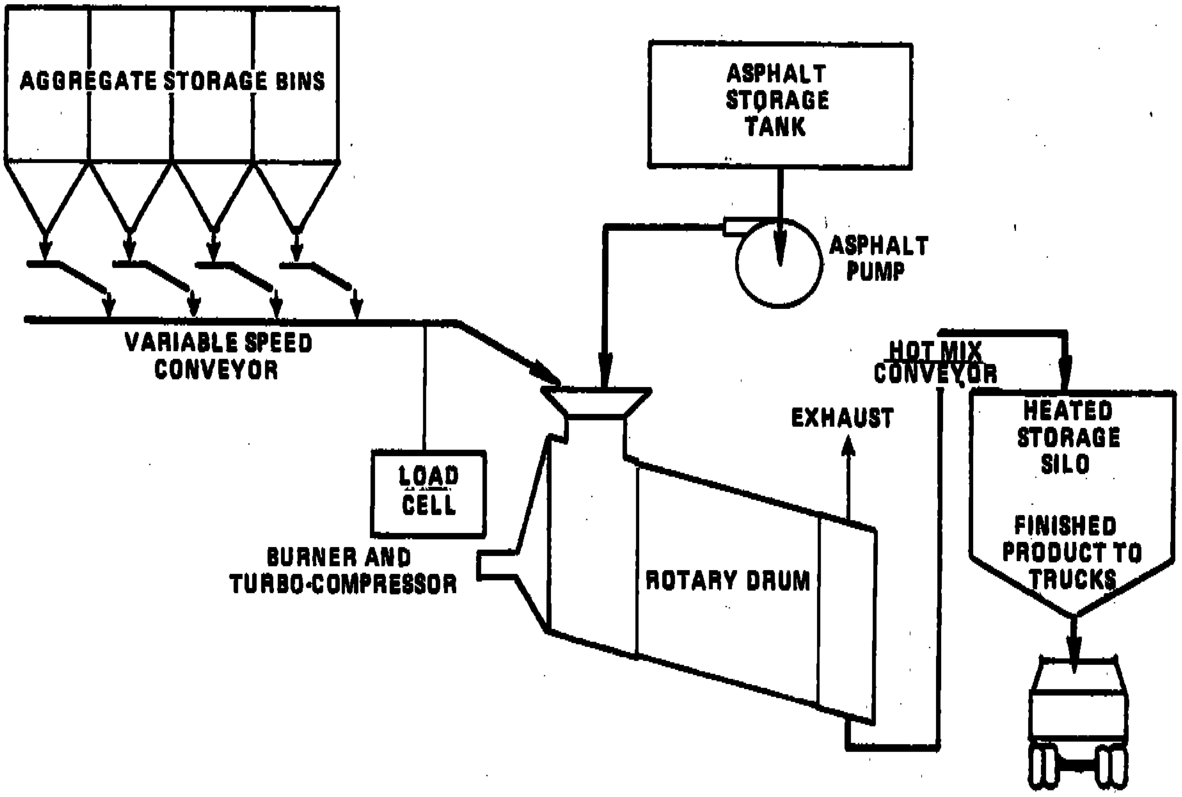
8.1-1. Batch hot-mix asphalt plant. "P" denotes particulate emission points.[1]



8.1-2. Continuous hot-mix asphalt plant. "P" denotes particulate emission points.[1]

8.1.2.2 Dryer-drum Hot Asphalt Plants [11,12,16]—Dryer-drum plants produce asphaltic concrete through a drum-mix process. In this process, the aggregate is dried, heated, and mixed with asphalt in the same vessel—a specially designed rotary drum dryer. This eliminates the need for a separate mixing tower with screens, weigh hoppers, and mixers as in a "conventional" plant, thereby reducing plant capital costs and improving portability.

The typical dryer-drum plant shown in Figure 8.1-3 consists of conventional cold-feed equipment, a continous belt weighing device, a rotary drum dryer that combines the drying and mixing functions, a product storage silo, and an asphalt storage tank.



8.1-3. Shearer type dryer-drum hot asphalt plant.

The sized-aggregate is fed from three to four storage bins by means of a variable speed conveyer into a main conveyer where the aggregate weight is monitored. The belt weigh unit conveys the proper amount into the rotary drum dryer. The required amount of liquid asphalt is then injected into the drum-dryer and mixed with the dry aggregate. As the coated aggregate passes through the dryer, the flight design causes the mixing action to take place in an atmosphere of hot gases. The drying, coating, and mixing continues as the material is conveyed through the drum. The residence time of the mix in the dryer is 5 to 7 minutes. The finished mix is discharged at the end of the drum dryer onto a conveyer where it is transferred into a heated storage silo for delivery onto a truck.

The different versions of the drum-mix process can be classified in two ways: (1) the manner in which the material flows in the dryer-drum with respect to the flow of gases and (2) the point at which the asphalt is introduced into the drum-dryer.

The majority (90 percent) of the drum-mix systems, currently marketed utilize a parallel-flow rotary dryer-drum in which the flow of material and hot gases is in the same direction. The alternative is the counter-flow dryer. In parallel-flow, the hot-test flame and gases exist at the charging end of the drum where the aggregate is at the lowest temperature. In the parallel-flow method, the asphalt is protected from oxidation by moisture being vaporized from the aggregate.

Parallel-flow rotary dryer-drum mixing can be divided into two general types based on the point of introduction of the asphalt. One is the Shearer process illustrated in Figure 8.1-3, where the aggregate and hot asphalt are added to the dryer-drum at the same time. The other process introduces the aggregate into the dryer-drum first, where the bulk of the moisture is driven off. The aggregate is then released to the next section of the drum, where adjustable spray bars coat the aggregate with hot asphalt. This reduces the direct contact between the liquid asphalt and the burner flame and tends to reduce hydrocarbon emissions.

8.1.3 Emissions and Controls

8.1.3.1 Conventional Plants[3,4] Dust sources from the conventional plants are: rotary dryers, hot aggregate elevators, vibrating screens, hot aggregate storage bins, weigh hoppers, mixers, and transfer points. The largest dust emission source is the rotary dryer. In some plants, the dust from the dryer is handled separately. More commonly, the dryer, its vent lines, and other fugitive sources are treated in combination by a single collector and fan system.

The choice of applicable control equipment ranges from dry mechanical collectors to scrubbers and fabric collectors. Attempts to apply electrostatic precipitators have met with little success. Practically all plants use primary dust collection equipment, such as large diameter cyclones, skimmers, or settling chambers. These chambers are often used as classifiers where the collected material is returned to the hot aggregate elevator and is combined with the dryer aggregate load. The air discharge from the primary collector is seldom vented to the atmosphere because high emission levels would result. The primary collector effluent is therefore ducted to a secondary collection device.

Particulate emission factors for conventional asphaltic concrete plants are presented in Table 8.1-1. Particle size information has not been included because the particle size distribution varies with the aggregate being used, the mix being made, and the type of plant operation.

8.1.3.2 Dryer-drum Hot Asphalt Plants [11,14,15,16]—Sources of air pollution from dryer-drum hot asphalt plants include both fugitive and stack emissions. In both instances, the source, nature, and magnitude of the emissions are considerably different from their counterparts in the conventional process. This difference is attributable to the difference in the processing techniques.

Stack emissions represent the major air pollution source from the drum-mix process. Both particulate and gaseous contaminants are present in the stack emissions. The particulate emissions generally include mineral, hydrocarbon, and carbonaceous matter. Mineral particulates consist mainly of aggregate dust entrained during the drying-mixing action in the drum, while the hydrocarbon and carbonaceous matter result primarily from the exposure of asphalt to various degrees of oxidation in the drum. Lower molecular weight asphalt oxidation products and fuel combustion contaminants account for the gaseous emissions in the stack.

Asphalt-related emissions from the drum-mix process are generally found to be greater than those from conventional plants. In dryer-drum plants, the asphalt is exposed to the total exhaust in a turbulent fashion, which tends to increase the entrainment of asphaltic products. In conventional plants, this type of emission is vented into the exhaust from an enclosed mixer at low airflow rates.

Table 8.1-1. PARTICULATE EMISSION FACTORS FOR CONVENTIONAL ASPHALTIC CONCRETE PLANTS[a]

EMISSION FACTOR RATING: A

Type of control	Emissions	
	lb/ton[b]	kg/MT[b]
Uncontrolled[c]	45.0	22.5
Precleaner	15.0	7.5
High-efficiency cyclone	1.7	0.85
Spray tower	0.4	0.20
Multiple centrifugal scrubber[d]	0.07	0.04
Baffle spray tower	0.3	0.15
Orifice-type scrubber	0.04	0.02
Venturi scrubber[e]	0.04	0.02
Baghouse[f]	0.02	0.01

[a] References 1, 2, and 5 through 10.

[b] Factors expressed in terms of emissions per unit weight of asphalt concrete produced.

[c] Almost all plants have at least a precleaner following the rotary dryer.

[d] The average emission from a properly designed, installed, operated, and maintained scrubber based on a study to develop new source performance standards. Reference 15.

[e] References 14 and 15.

[f] Emissions from a properly designed, installed, operated, and maintained baghouse based on a study to develop new source performance standards. References 14 and 15.

The uncontrolled mineral dust is generally less in a dryer-drum plant compared with a conventional plant. The emission quantities from a dryer-drum plant are a function of process design and operating parameters. This results in a significant variation in emissions from different dryer-drum plants.

The following factors have a direct relation to the amount of emissions from a dryer-drum plant:

1. Mix temperature.
2. Asphalt injection point.
3. Coarseness of the mix.
4. Air velocity in the rotary drum.
5. Flight arrangement.
6. Aggregate moisture content.
7. Drum rotation speed.
8. Rate of production.
9. Type of asphalt.

The dust from the rotary drum dryer is generally exhausted to a primary collector and then to a secondary collector. The choice of applicable control equipment is similar to those of conventional plants, with two exceptions:

1. A baghouse presents a problem with respect to sticking and binding of the filter medium because of asphaltic emissions and mineral particles coated with asphalt. However, some manufacturers claim that this problem has been solved.

2. Electrostatic precipitators are not practical because the power required is not usually available for portable operations and the plates become coated with oily particulates that significantly reduce

2. Electrostatic precipitators are not practical because the power required is not usually available for portable operations and the plates become coated with oily particulates that significantly reduce collection efficiency.

The venturi scrubber shows the best degree of control of particulate material while also partially controlling hydrocarbon emissions. This type of scrubber is generally capable of reducing emission concentrations below the Federal New Source Performance Standard of 0.04 g/dscf.

Emission factors for dryer-drum plants are presented in Table 8.1-2. Particle size information has not been included for the reasons cited for conventional plants (8.1.3.1). Emission factors for particulates in an uncontrolled plant can vary by a factor of 10 depending upon the percent of fine particles in the aggregate.

Table 8.1-2. PARTICULATE EMISSION FACTORS FOR DRYER-DRUM HOT ASPHALT PLANTS[a]

EMISSION FACTOR RATING: B

Type of control	Emission	
	lb/ton[b]	kg/MT[b]
Uncontrolled	4.9	2.45
Cyclone or multicyclone	0.67	0.34
Low-energy wet scrubber[c]	0.07	0.04
Venturi scrubber	0.04	0.02

[a] Reference 11.

[b] Factors expressed in terms of emissions per unit weight of asphalt concrete produced.

[c] Either stack sprays where water droplets are injected into the exit stack or a dynamic scrubber that incorporates a wet fan.

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8.2 ASPHALT ROOFING

8.2.1 General[1]

The asphalt roofing industry manufactures asphalt-saturated felt rolls, shingles, rolls with mineral granules on the surface, and smooth rolls that may contain a small amount of mineral dust or mica on the surface. While most of these products are used in the construction of roofs, a relatively small quantity is used in walls and in other building applications.

8.2.2 Process Description

The manufacturing of asphalt felt, roofing, and shingles involves saturation of felt (fiber media) with heated asphalt (asphalt saturant) by means of dipping and/or spraying.[2] The entire process can be divided as (1) asphalt blowing, (2) felt saturation, and (3) mineral surfacing.

Although the processes are not always done at the same site, preparation of the asphalt saturant is an integral part of asphalt roofing. This preparation is called "blowing" and oxidizes the asphalt by bubbling air through liquid asphalt at 220° to 260° C for 1 to 4 hours depending on the desired melting point.[3] Blowing may be done either in vertical tanks or in horizontal chambers. Figure 8.2-1 illustrates an asphalt blowing operation.

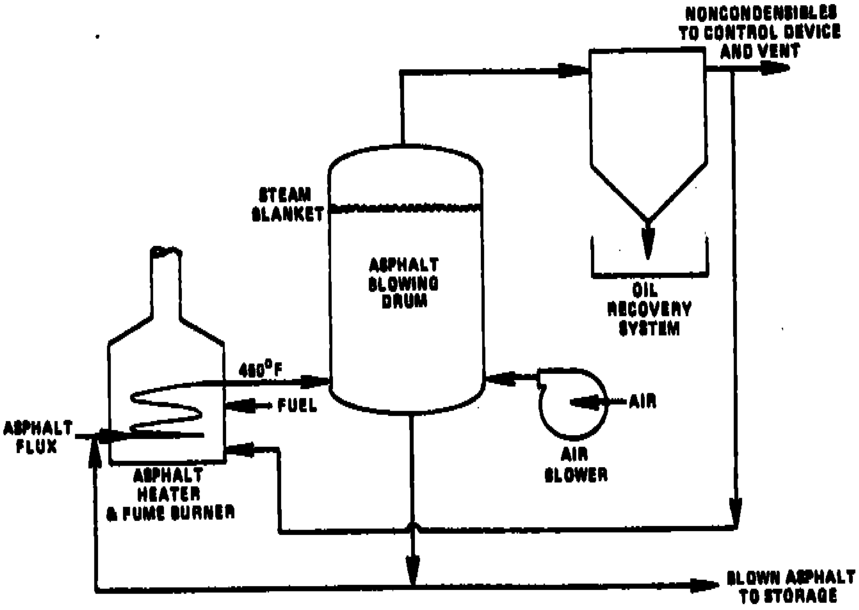
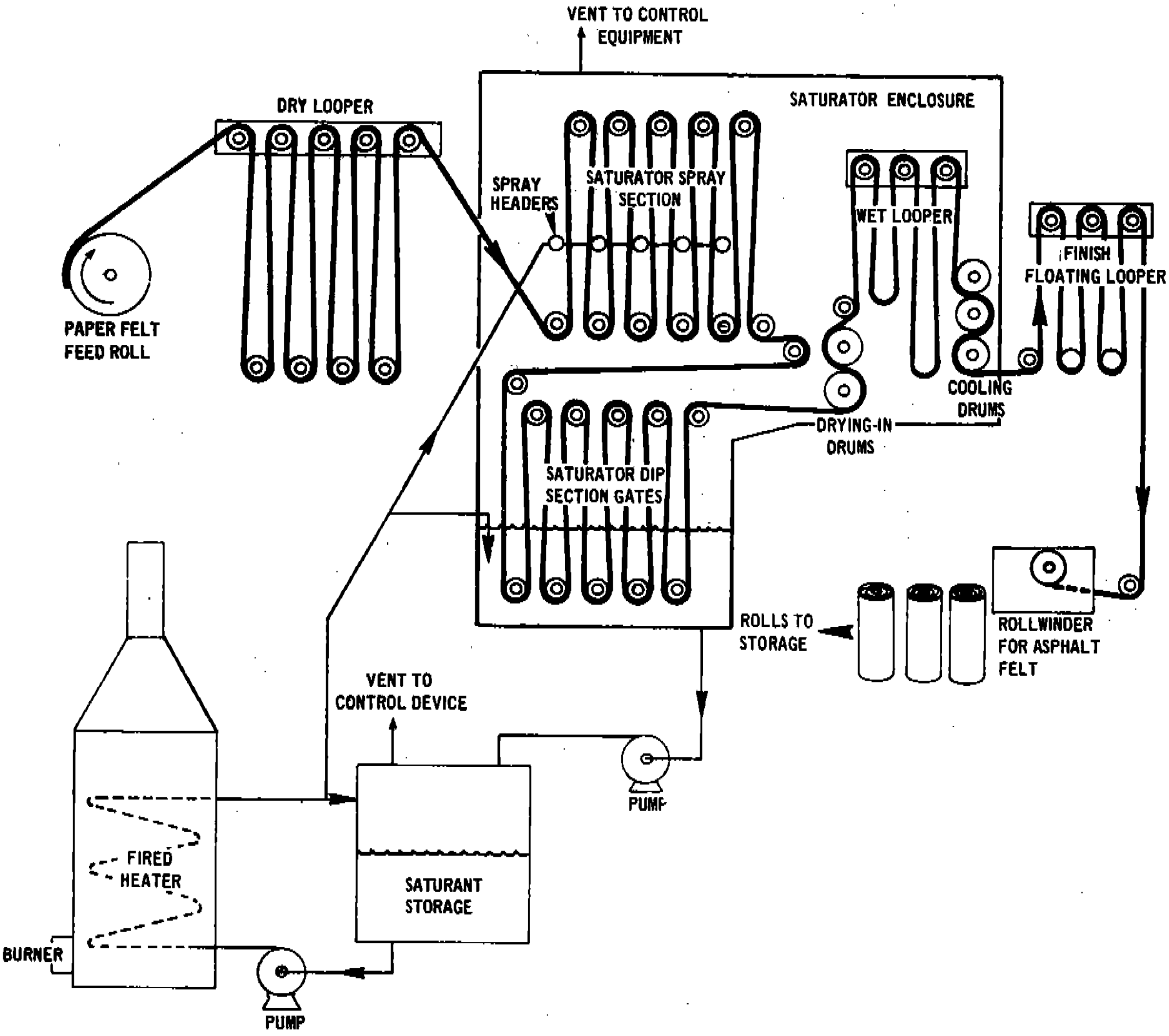
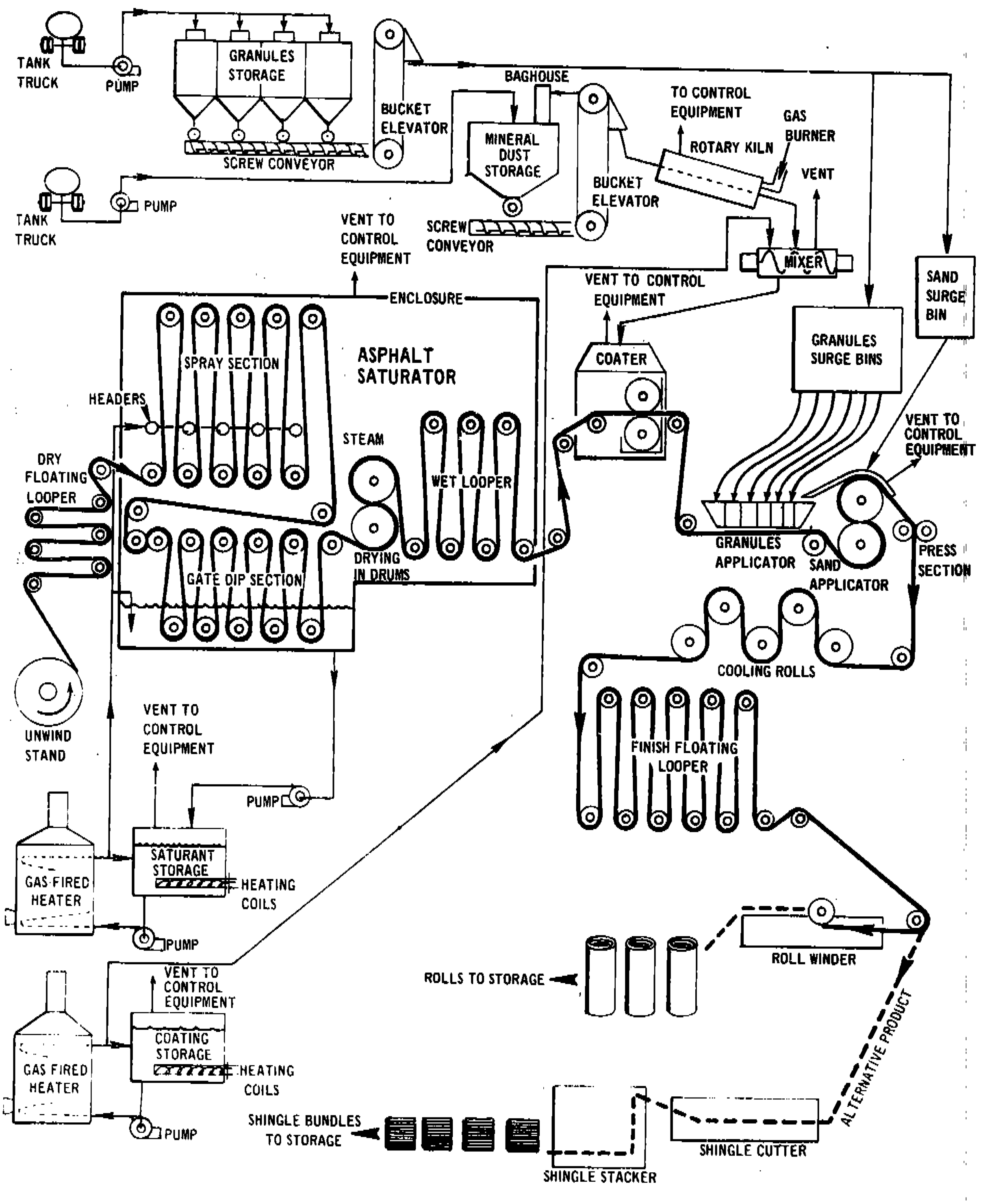


Figure 8.2-1. Air blowing of asphalt.[3]

Figure 8.2-2 shows a typical line for the manufacture of asphalt-saturated felt, which consists of a paper feed roll, a dry looper section, a saturator spray section (if used), a saturator dipping section, steam-heated drying-in drums, a wet looper, water-cooled rolls, a finish floating looper, and a roll winder. A typical line for manufacturing asphalt shingles, mineral-surfaced rolls, and smooth rolls is illustrated in Figure 8.2-3. This includes, after the wet looper: a coater, a granule applicator, a press section, water-cooled rolls, a finish floating looper, and either a roll winder or a shingle cutter and stacker, depending upon the product being made.



8.2-2. Schematic of line for manufacturing asphalt-saturated felt.[1]



8.2-3. Schematic of line for manufacturing asphalt shingles, mineral-surfaced rolls, and smooth rolls.[1]

The felt, usually made of heavy paper, may weigh from 15 to 75 pounds per 480 square feet (a common unit in paper industry). The felt is unrolled from the unwind stand into the dry looper, which maintains a constant tension on the material. From the dry looper, the felt passes into the spray section of the saturator where asphalt at 200° to 230° C is sprayed onto one side of the felt through several nozzles. In the saturator dip section, the felt is drawn over a series of rollers, with the bottom rollers completely submerged in hot asphalt at 200° to 230° C. At the next step, steam-heated drying-in drums and the wet looper provide heat and time, respectively, for the asphalt to penetrate the felt web. The web then passes through water-cooled rolls and onto the finish floating looper and then is rolled and cut on the roll winder to product size. Two common weights of asphalt felt are 15 and 30 pounds per 108 square feet (108 square feet of felt covers exactly 100 square feet of roof, which is a roofer's square).

After leaving the wet looper, a web to be made into shingles, mineral-surfaced rolls, or smooth rolls passes through the coater (see Figure 8.2-3). Filled asphalt coating at 180° to 205° C is released through a valve onto the web just as it passes into the coater.[1] Heated squeeze rolls in the coater distribute the coating evenly upon the web surface to form a thick base coating to which rock granules, sand, talc, or mica can adhere. Filled asphalt is prepared by mixing coating asphalt at 205° C with a mineral stabilizer (filler) in approximately equal proportion to form the filled asphalt coating that is piped to the coater. Sometimes the mineral stabilizer is preheated to about 120° C in a rotary kiln (filler dryer) before mixing, to lower its moisture content and produce a higher temperature coating asphalt. After leaving the coater, a web to be made into shingles or mineral-surfaced rolls passes through the granules applicator where granules are fed onto the hot, coated surface. The granules are pressed into the coating by passing the coated web through squeeze rolls. Sand, talc, or mica is applied to the back or opposite side of the web and is also pressed into the web surface. Following the application of the granules, the web is cooled rapidly and is transferred through the finish floating looper to a roll winder or shingle cutter (see Figure 8.2-3).

8.2.3 Emission and Controls

Atmospheric emissions from asphalt roofing manufacturing can be divided into two categories:

1. Gaseous and particulate organic compounds from the blowing and saturating processes, which include small amounts of particulate polycyclic organic matter (PPOM).

2. Particulate emissions from filler drying and application of mineral coating agents.

Emission factors for particulate, PPOM, carbon monoxide, hydrocarbons, and aldehydes from an uncontrolled blowing and saturating process are summarized in Table 8.2-1. In addition, emissions of hydrogen sulfide also occur during an uncontrolled blowing operation.

A common method of emissions control at asphalt saturating plants is to completely enclose the saturator, wet looper, and coater and vent the emissions to one or more collection devices (see Figures 8.2-2 and 8.2-3). These devices include afterburners, high-energy air filters, or low-voltage electrostatic precipitators. Wet scrubbers have also been used at some plants. Blowing operations are controlled by afterburners. Table 8.2-2 presents emission factors for a controlled blowing and saturating process.

Particulate emissions associated with filler drying and application of mineral coating agents are captured by enclosures, hoods, or pickup pipes and controlled by using fabric filters with removal efficiency better than 99 percent.

Table 8.2-1. EMISSION FACTORS FOR ASPHALT ROOFING MANUFACTURING WITHOUT CONTROLS[a]

EMISSION FACTOR RATING: D

Operation	Particulates		PPOM[b]	Carbon monoxide (CO)		Organics (as CH_4)		Aldehydes (as CHOH)	
	lb/ton	kg/MT	% of particulate x 10^{-3}	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton x 10^{-3}	kg/MT x 10^{-3}
Asphalt blowing[c]	7.3[e]	3.65[e]	0.26[e]	0.27[f]	0.14[f]	1.19[f]	0.60[f]	2.9[f]	1.45[f]
Felt saturation[d]	6.3	3.15	0.3	2.9	1.45	0.48	0.24	25.0	12.5

[a] Reference 2.

[b] Particulate polycyclic organic matter.

[c] Emission factors expressed as pounds (kilograms) per ton (metric ton) of asphalt processed.

[d] Emission factors expressed as pounds (kilograms) per ton (metric ton) of saturated felt produced. Approximately 0.62 ton of asphalt is required to produce 1 ton of saturated felt.

[e] Based on blowing required for high-melt-point (220° F) asphalt saturant.

[f] Based on 2.2 hours blowing time.

Table 8.2-2. EMISSION FACTORS FOR CONTROLLED ASPHALT ROOFING MANUFACTURING[a]

EMISSION FACTOR RATING: D

Operation	Particulates		PPOM[b]	Carbon monoxide (CO)		Organics (as CH_4)		Aldehydes (as CHOH)	
	lb/ton	kg/MT	% of particulate x 10^{-3}	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton x 10^{-3}	kg/MT x 10^{-3}
Asphalt blowing[c]	0.58	0.29	2.3	3.66[e]	1.83[e]	0.65[e]	0.33[e]	0.02[e]	0.01[e]
Felt saturation[d]	2.7	1.35	0.3	3.3[e]	1.65[e]	0.36[e]	0.18[e]	0.02[e]	0.01[e]

[a] Reference 2.

Particulate polycyclic organic matter.

[c] Emission factors expressed as pounds (kilograms) per ton (metric ton) of asphalt processed.

[d] Emission factors expressed as pounds (kilograms) per ton (metric ton) of saturated felt produced. Approximately 0.62 ton of asphalt is required to produce 1 ton of saturated felt.

[e] Afterburner is used as control device.

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8.13 GLASS MANUFACTURING

Revised by Pam Canova

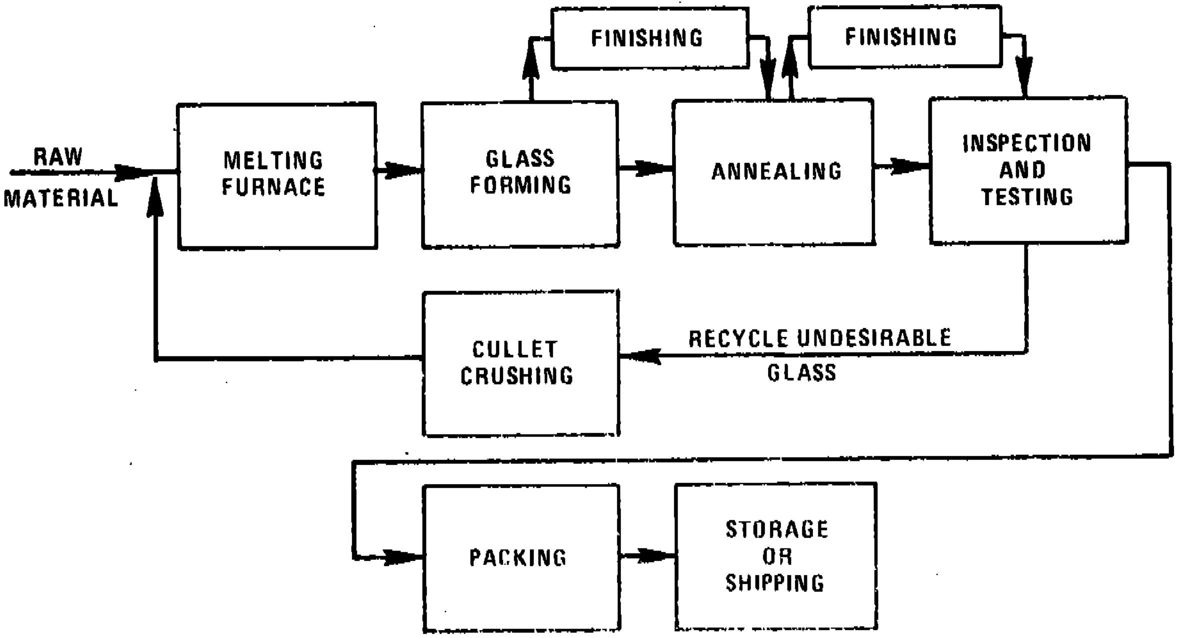
8.13.1 General [1-5]

Commercially produced glass can be classified as either soda-lime, lead, fused silica, borosilicate, or 96 percent silica. Soda-lime glass, which constitutes 77 percent of total glass production, will be discussed in this section. Soda-lime glass consists of sand, limestone, soda ash, and cullet (broken glass). The manufacture of glass can be broken down into four phases: (1) preparation of raw material, (2) melting in a furnace, (3) forming, and (4) finishing. Figure 8.13-1 shows an overall flow diagram for glass manufacturing.

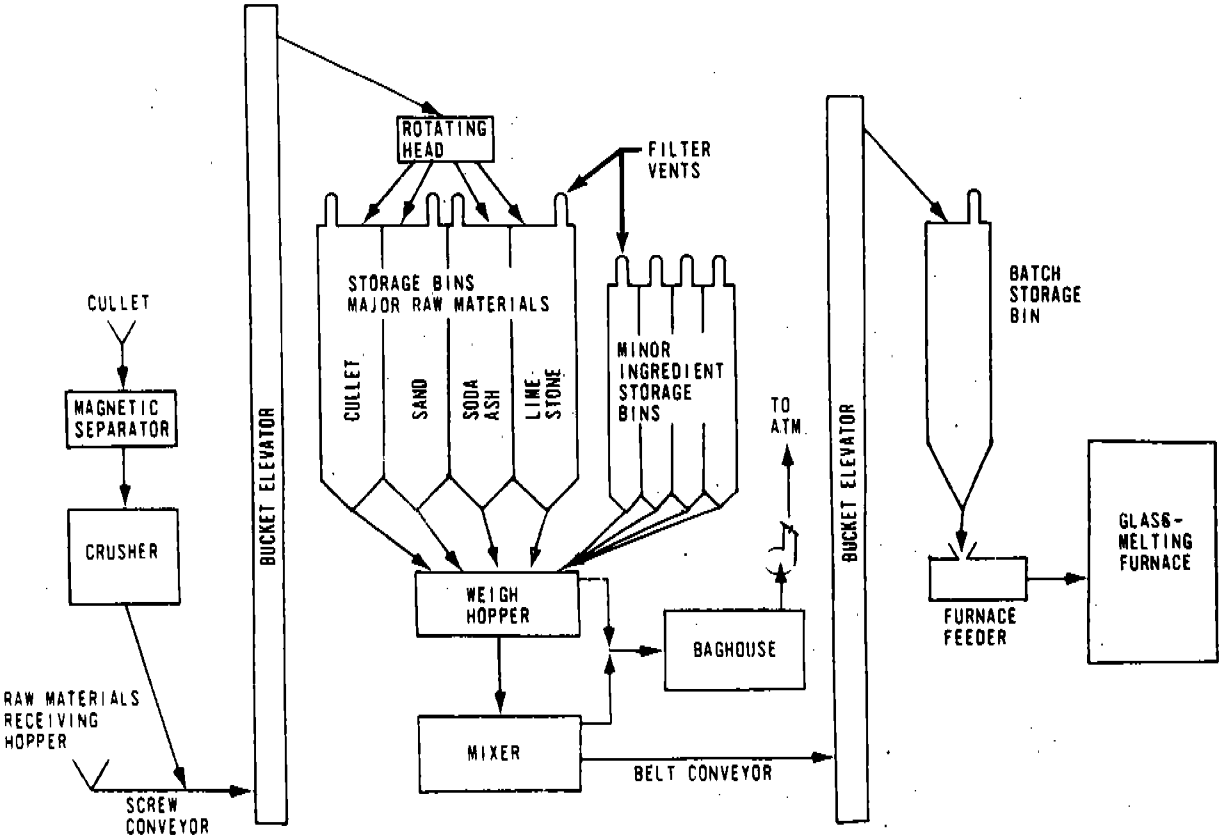
The products of the glass manufacturing industry are flat glass, container glass, or pressed and blown glass. The procedure for manufacturing glass is the same for all three categories except for forming and finishing. Flat glass, which comprises 24 percent of total glass production, is formed by either the float, drawing, or rolling process. Container glass and pressed and blown glass, which comprise 51 and 25 percent, respectively, of total glass production, utilize either pressing, blowing, or pressing and blowing to form the desired product.

As raw materials are received, they are crushed and stored in separate elevated bins. The raw materials are transferred through a gravity feed system to the weigher and mixer, where the material and cullet are mixed to ensure homogeneous melting. The mixture is then transferred by conveyor to the batch storage bin where it remains until being dropped into the furnace feeder, which supplies the raw material to the melting furnace. All equipment used in handling and preparing the raw material is housed separately from the furnace and is usually referred to as the batch plant. Figure 8.13-2 shows a flow diagram of a batch plant.

The furnace most commonly utilized is a continuous regenerative furnace capable of producing between 50 and 300 tons (45 and 272 metric tons) of glass per day. A furnace may have either side or end ports connecting brick checkers to the inside of the melter. The purpose of the checkers is to conserve fuel by utilizing the heat of the combustion products in one side of the furnace to preheat combustion air in the other side. As material enters the melting furnace through the feeder, it floats on the top of the molten glass already in the furnace. As it melts, it passes to the front of the melter and eventually flows through a throat connecting the melter and the refiner. In the refiner, the molten glass is heat conditioned for delivery to the forming process. Figures 8.13-3 and 8.13-4 show side-port and end-port regenerative furnaces.



8.13-1. Flow diagram for glass manufacturing.



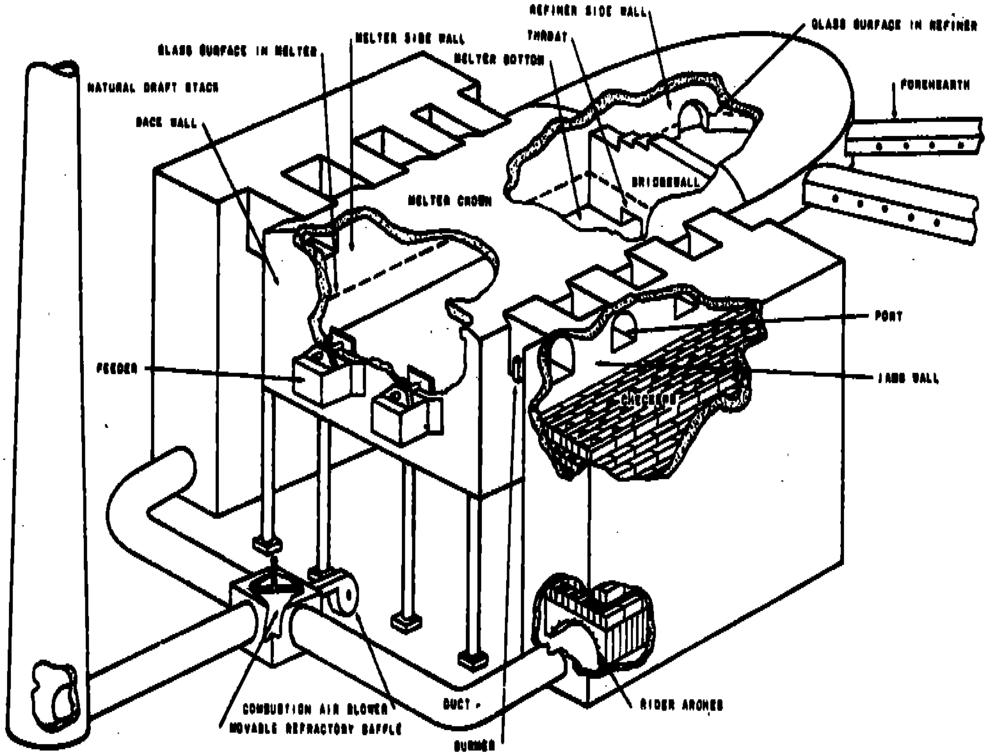
8.13-2. Flow diagram of a batch plant.[1]

After refining, the molten glass leaves the furnace through forehearths (except for the float process in which molten glass goes directly to the tin bath) and goes to be shaped by either pressing, blowing, pressing and blowing, drawing, rolling, or floating, depending upon the desired product. Pressing and blowing are preformed mechanically using blank molds and glass cut into sections (gobs) by a set of shears. In the drawing process, molten glass is drawn upward through rollers that guide the sheet glass. The thickness of the sheet is determined by the speed of the draw and the configuration of the draw bar. The rolling process is similar to the drawing process except that the glass is drawn horizontally by plain or patterned rollers and, for plate glass, requires grinding and polishing. The float process utilizes a molten tin bath over which the glass is drawn and formed into a finely finished surface requiring no grinding or polishing. The product undergoes finishing (decorating or coating) and annealing (removing unwanted stress areas in the glass), and is then inspected and prepared for shipment to market. Any damaged or undersirable glass is transferred back to the batch plant to be used as cullet.

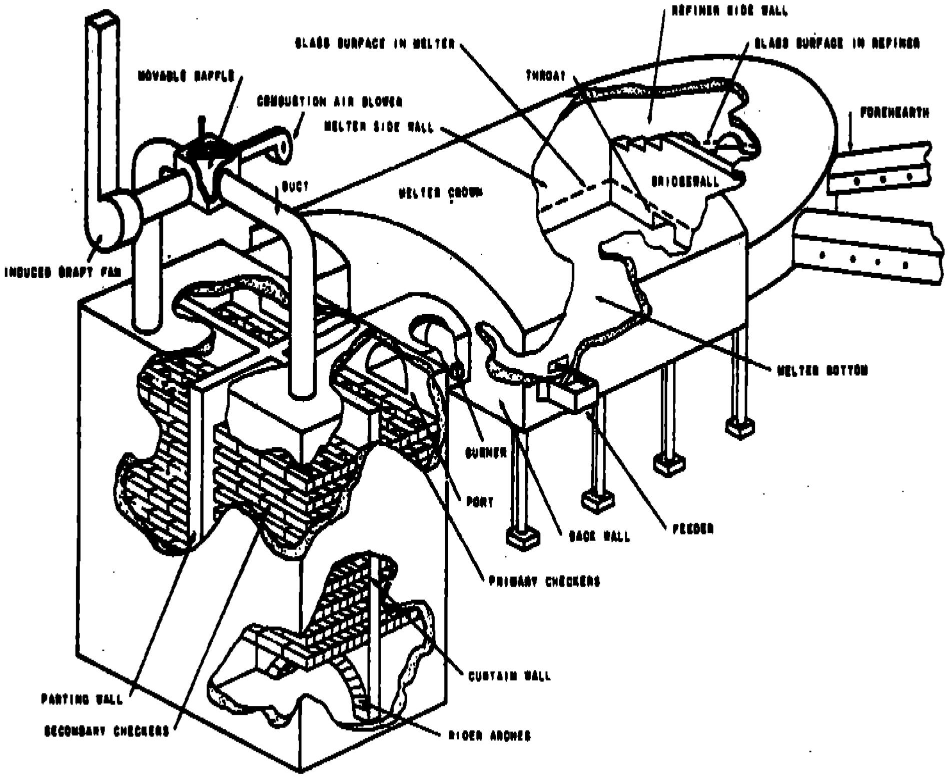
8.13.2 Emissions and Controls[1-5]

Table 8.13-1 lists controlled and uncontrolled emission factors for glass manufacturing.

The main pollutant emitted by the batch plant is particulates in the form of dust. This can be controlled, with 99 to 100 percent efficiency, by enclosing all possible dust sources and using baghouses or cloth filters. Another way to control dust emissions, also with an efficiency approaching 100 percent, is to treat the batch to reduce the amount of fine particles present. Forms of preparation are presintering, briquetting, pelletizing, or liquid alkali treatment.



8.13-3. Side-port continuous regenerative furnace.[1]



8.13-4. End-port continuous regenerative furnace.[1]

Table 8.13-1. EMISSION FACTORS FOR GLASS MANUFACTURING [2,3,5,a,b]

EMISSION FACTOR RATING: B

Procedure	Particulate[c]		Sulfur oxides		Nitrogen oxides		Organics		Carbon monoxide	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Raw materials handling[d] (all types of glass)	Negl[e]	Negl	0	0	0	0	0	0	0	0
Melting furnace[f]										
Container										
Uncontrolled	1.4(0.9-1.9)	0.7(0.4-0.9)	3.4(2.0-4.8)	1.7(1.0-2.4)	6.2(3.3-9.1)	3.1(1.6-4.5)	0.2(0-0.4)	0.1(0-0.2)	0.2(0-0.5)	0.1(0-0.2)
W/low-energy scrubber[g]	0.7	0.4	1.7	0.9	6.2	3.1	0.2	0.1	0.2	0.1
W/venturi scrubber[h]	0.1	< 0.1	0.2	0.1	6.2	3.1	0.2	0.1	0.2	0.1
W/baghouse[i]	Negl	Negl	3.4	1.7	6.2	3.1	0.2	0.1	0.2	0.1
W/electrostatic precipitator[i]	Negl	Nelg	3.4	1.7	6.2	3.1	0.2	0.1	0.2	0.1
Flat										
Uncontrolled	2(0.8-3.2)	1(0.4-1.6)	3(2.2-3.8)	1.5(1.1-1.9)	8(5.6-10.4)	4(2.8-5.2)	< 0.1	< 0.1	< 0.1	< 0.1
W/low-energy scrubber[g]	1.0	0.5	1.5	0.8	8.0	4.0	< 0.1	< 0.1	< 0.1	< 0.1
W/venturi scrubber[h]	Negl	Negl	0.2	0.1	8.0	4.0	< 0.1	< 0.1	< 0.1	< 0.1
W/baghouse[i]	Negl	Negl	3.0	1.5	8.0	4.0	< 0.1	< 0.1	< 0.1	< 0.1
W/electrostatic percipitator[i]	Negl	Negl	3.0	1.5	8.0	4.0	< 0.1	< 0.1	< 0.1	< 0.1
Pressed and blown[j]										
Uncontrolled	17.4(1.0-25.1)	8.7(0.5-12.6)	5.6(1.1-10.9)	2.8(0.5-5.4)	8.5(0.8-20.0)	4.3(0.4-10.0)	0.3(0.1-1.0)	0.2(<0.1-0.3)	0.2(0.1-0.3)	0.1(0.1-0.2)
W/low-energy scrubber[g]	8.4	4.2	2.7	1.3	8.5	2.2	0.3	0.2	0.2	0.1
W/venturi scrubber[h]	0.9	0.5	0.3	0.1	8.5	2.2	0.3	0.2	0.2	0.1
W/baghouse[i]	0.2	0.1	5.6	2.8	8.5	2.2	0.3	0.2	0.2	0.1
W/electrostatic precipitator[i]	0.2	0.1	5.6	2.8	8.5	2.2	0.3	0.2	0.2	0.1

Table 8.13-1. EMISSION FACTORS FOR GLASS MANUFACTURING [2,3,5,a,b]

EMISSION FACTOR RATING: B

Process	Particulate[c]		Sulfur oxides		Nitrogen oxides		Organics		Carbon monoxide	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Forming and finishing										
Container[k,l]	Negl	Negl	Negl	Negl	Negl	Negl	8.7	4.4	Negl	Negl
Flat	Negl	Negl	Negl	Negl	Negl	Negl	Negl	Negl	Negl	Negl
Pressed and blown[k,l]	Negl	Negl	Negl	Negl	Negl	Negl	9.0	4.5	Negl	Negl

[a] Emission factors are expressed as pounds of pollutant per ton and kilograms of pollutant per metric ton of glass produced.

[b] When literature references reported ranges in emission rates, these ranges are shown in parentheses along with the average emission factor. Single emission factors are averages of literature data for which no ranges were reported.

[c] Particulates are submicron in size.

[d] Emission factors for raw materials handling are not separated into types of glass produced since batch preparation is the same for all types. Particulate emissions are negligible because almost all plants utilize some form of control (i.e. baghouses, scrubbers, or centrifugal collectors).

[e] Negligible.

[f] Control efficiencies for the various devices are applied only to the average emission factor.

[g] Approximately 52 percent efficient in reducing particulate and sulfur oxides emissions. Effect on nitrogen oxides is unknown.

[h] Approximately 95 percent efficient in reducing particulate and sulfur oxides emissions. Effect on nitrogen oxides is unknown.

[i] Approximately 99 percent efficient in reducing particulate emissions.

[j] Particulate emission factors were calculated using data for furnaces melting soda lime and lead glasses. No data were available for borosilicate or opal glasses.

[k] Hydrocarbon emission factors for container and pressed and blown glass are from the decorating process. Emissions can be controlled by incineration, absorption, or condensation; however, efficiencies are not known.

[l] For container and pressed and blown glass, tin chloride, hydrated tin chloride, and hydrogen chloride are also emitted during the surface treatment process at a rate of less than 0.1 lb/ton (<0.1 kg/MT) each.

The melting furnace contributes over 99 percent of the total emissions from the glass plant. In the furnace, both particulates and gaseous pollutants are emitted. Particulates result from volatilization of materials in the melt that combine with gases to form condensates. These are either collected in the checker-work and gas passages or escape to the atmosphere. Serious problems arise when the checkers are not properly cleaned in that slag can form, clogging the passages and eventually deteriorating the condition and efficiency of the furnace. Nitrogen oxides form when nitrogen and oxygen react in the high temperatures of the furnace. Sulfur oxides result from the decomposition of the sulfates in the batch and the fuel. Proper maintenance and firing of the furnace can control emissions and also add to the efficiency of the furnace and reduce operational costs. Low-pressure wet centrifugal scrubbers have been used to control particulates and sulfur oxides, but their low efficiency (approximately 50 percent) indicates their inability to collect particulates of submicron size. High-energy venturi scrubbers are approximately 95 percent effective in reducing particulate and sulfur oxide emissions; their effect on nitrogen oxide emissions is unknown. Baghouses, which have up to 99 percent particulate collection efficiency, have been used on small regenerative furnaces, but, due to fabric corrosion, require careful temperature control. Electrostatic precipitators have an efficiency of up to 99 percent in the collection of particulates.

Emissions from the forming and finishing phase depend upon the type of glass being manufactured. For container, press, and blow machines, the majority of emissions result from the gob coming into contact with the machine lubricant. Emissions in the form of a dense white cloud, which can exceed 40 percent opacity, are generated by flash vaporization of hydrocarbon greases and oils. Grease and oil lubricants are being replaced by silicone emulsions and water-soluble oils, which may virtually eliminate the smoke. For flat glass, the only contributor to air pollutant emissions is gas combustion in the annealing lehr, which is totally enclosed except for entry and exit openings. Since emissions are small and operational procedures are efficient, no controls are utilized.

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PETROLEUM INDUSTRY

9.1 PETROLEUM REFINING[1]

Revised by Charles C. Masser

9.1.1 General Description

The petroleum refining industry converts crude oil into more than 2500 refined products, including liquefied petroleum gas, gasoline, kerosene, aviation fuel, diesel fuel, fuel oils, lubricating oils, and feedstocks for the petrochemical industry. Petroleum refinery activities start with receipt of crude for storage at the refinery, include all petroleum handling and refining operations, and terminate with storage preparatory to shipping the refined products from the refinery.

The petroleum refining industry employs a wide variety of processes. A refinery's processing flow scheme is largely determined by the composition of the crude oil feedstock and the chosen slate of petroleum products. The example refinery flow scheme presented in Figure 9.1-1 shows the general processing arrangement used by refineries in the United States for major refinery processes. The arrangement of these processes will vary among refineries, and few, if any, employ all of these processes. Petroleum refining processes having direct emission sources are presented in bold-line boxes on the figure.

Listed below are five categories of general refinery processes and associated operations:

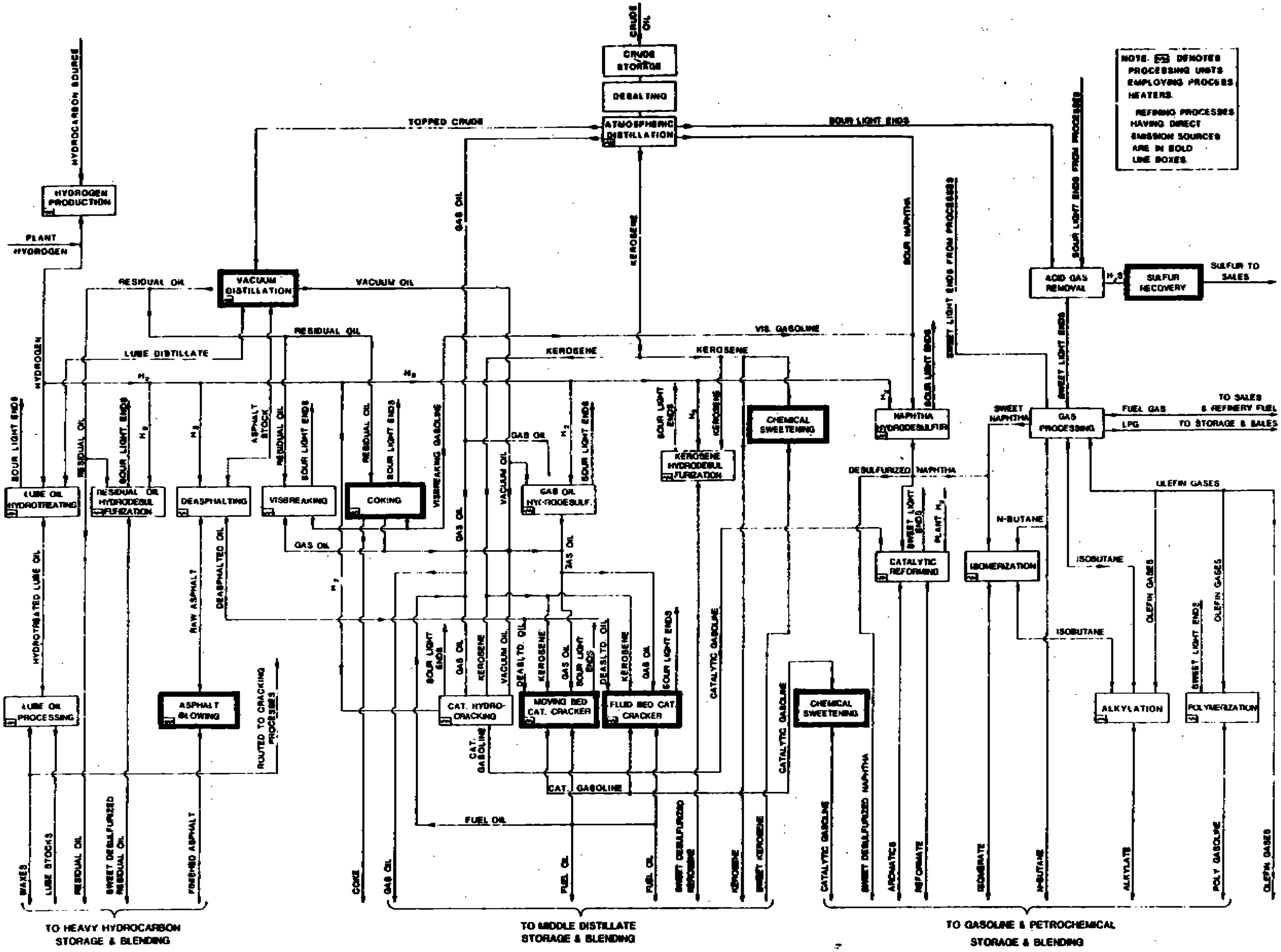
1. Separation processes
    a. atmospheric distillation
    b. vacuum distillation
    c. light ends recovery (gas processing)

2. Petroleum conversion processes
    a. cracking (thermal and catalytic)
    b. reforming
    c. alkylation
    d. polymerization
    e. isomerization
    f. coking
    g. visbreaking

3. Petroleum treating processes
    a. hydrodesulfurization
    b. hydrotreating
    c. chemical sweetening
    d. acid gas removal
    e. deasphalting

4. Feedstock and product handling
    a. storage
    b. blending
    c. loading
    d. unloading

5. Auxiliary facilities
    a. boilers
    b. wastewater treatment
    c. hydrogen production



9.1-1. Schematic of an example integrated petroleum refinery.

d. sulfur recovery plant
e. cooling towers
f. blowdown system
g. compressor engines

These refinery processes are defined in the following section and their emission characteristics and applicable emission control technology are discussed.

9.1.1.1. Separation Processes — The first phase in petroleum refining operations is the separation of crude oil into its major constituents using three petroleum separation processes: atmospheric distillation, vacuum distillation, and light ends recovery (gas processing). Crude oil consists of a mixture of hydrocarbon compounds including paraffinic, naphthenic, and aromatic hydrocarbons plus small amounts of impurities including sulfur, nitrogen, oxygen, and metals. Refinery separation processes separate these crude oil constituents into common-boiling-point fractions.

9.1.1.2. Conversion Processes—To meet the demands for high-octane gasoline, jet fuel, and diesel fuel, components such as residual oils, fuel oils, and light ends are converted to gasolines and other light fractions. Cracking, coking, and visbreaking processes are used to break large petroleum molecules into smaller petroleum molecules. Polymerization and alkylation processes are used to combine small petroleum molecules into larger ones. Isomerization and reforming processes are applied to rearrange the structure of petroleum molecules to produce higher-value molecules of a similar molecular size.

9.1.1.3. Treating Processes—Petroleum treating processes stabilize and upgrade petroleum products by separating them from less desirable products and by removing objectionable elements. Undesirable elements such as sulfur, nitrogen, and oxygen are removed by hydrodesulfurization, hydrotreating, chemical sweetening and acid gas removal. Treating processes employed primarily for the separation of petroleum products include such processes as deasphalting. Desalting is used to remove salt, minerals, grit, and water from crude oil feed stocks prior to refining. Asphalt blowing is used for polymerizing and stabilizing asphalt to improve its weathering characteristics.

9.1.1.4. Feedstock and Product Handling—The refinery feedstock and product handling operations consist of unloading, storage, blending, and loading activities.

9.1.1.5. Auxiliary Facilities—A wide assortment of processes and equipment not directly involved in the refining of crude oil are used in functions vital to the operation of the refinery. Examples are boilers, wastewater treatment facilities, hydrogen plants, cooling towers, and sulfur recovery units. Products from auxiliary facilities (clean water, steam, and process heat) are required by most refinery process units throughout the refinery.

9.1.2 Process Emission Sources and Control Technology

This section presents descriptions of those refining processes that are significant air pollutant contributors. Process flow schemes, emission characteristics, and emission control technology are discussed for each process. Table 9.1-1 lists the emission factors for direct-process emissions in petroleum refineries. The following process emission sources are discussed in this section on petroleum refining emissions:

1. Vacuum distillation.
2. Catalytic cracking.
3. Thermal cracking processes.
4. Utility boilers.
5. Heaters.

6. Compressor engines.
7. Blowdown systems.
8. Sulfur recovery.

9.1.2.1. Vacuum Distillation—Topped crude withdrawn from the bottom of the atmospheric distillation column is composed of high-boiling-point hydrocarbons. When distilled at atmospheric pressures, the crude oil decomposes and polymerizes to foul equipment. To separate topped crude into components, it must be distilled in a vacuum column at a very low pressure and in a steam atmosphere.

In the vacuum distillation unit, topped crude is heated with a process heater to temperatures ranging from 700 to 800° F (370 to 425° C). The heated topped crude is flashed into a multi-tray vacuum distillation column operating at vacuums ranging from 0.5 to 2 psia (350 to 1400 kg/m^2). In the vacuum column, the topped crude is separated into common-boiling-point fractions by vaporization and condensation. Stripping steam is normally injected into the bottom of the vacuum distillation column to assist in the separation by lowering the effective partial pressures of the components. Standard petroleum fractions withdrawn from the vacuum distillation column include lube distillates, vacuum oil, asphalt stocks, and residual oils. The vacuum in the vacuum distillation column is normally maintained by the use of steam ejectors but may be maintained by the use of vacuum pumps.

The major sources of atmospheric emissions from the vacuum distillation column are associated with the steam ejectors or vacuum pumps. A major portion of the vapors withdrawn from the column by the ejectors or pumps are recovered in condensers. Historically, the noncondensable portion of the vapors has been vented to the atmosphere from the condensers. There are approximately 50 pounds (23 kg) of noncondensable hydrocarbons per 1000 barrels of topped crude processed in the vacuum distillation column.[2,12,13] A second source of atmospheric emissions from vacuum distillation columns is combustion products from the process heater. Process heater requirements for the vacuum distillation column are approximately 37,000 Btu per barrel (245 Joules/cm^3) of topped crude processed in the vacuum column. Process heater emissions and their control are discussed later in this section. Fugitive hydrocarbon emissions from leaking seals and fittings are also associated with the vacuum distillation unit, but these are minimized by the low operating pressures and low vapor pressures in the unit. Fugitive emission sources are also discussed later in this section.

Control technology applicable to the noncondensable emissions vented from the vacuum ejectors or pumps include venting into blowdown systems or fuel gas systems, and incineration in furnaces or waste heat boilers.[2,12,13] These control techniques are generally greater than 99 percent efficient in the control of hydrocarbon emissions, but they also contribute to the emission of combustion products.

9.1.2.2. Catalytic Cracking—Catalytic cracking, using heat, pressure, and catalysts, converts heavy oils into lighter products with product distributions favoring the more valuable gasoline and distillate blending components. Feedstocks are usually gas oils from atmospheric distillation, vacuum distillation, coking, and deasphalting processes. These feedstocks typically have a boiling range of 650 to 1000° F (340 to 540° C). All of the catalytic cracking processes in use today can be classified as either fluidized-bed or moving-bed units.

Fluidized-bed Catalytic Cracking (FCC) — The FCC process uses a catalyst in the form of very fine particles that act as a fluid when aerated with a vapor. Fresh feed is preheated in a process heater and introduced into the bottom of a vertical transfer line or riser with hot regenerated catalyst. The hot catalyst vaporizes the feed bringing both to the desired reaction temperature, 880 to 980° F (470 to 525° C). The high activity of modern catalysts causes most of the cracking reactions to take place in the riser as the catalyst and oil mixture flows upward into the reactor. The hydrocarbon vapors are separated from the catalyst particles by cyclones in the reactor. The reaction products are sent to a fractionator for separation.

The spent catalyst falls to the bottom of the reactor and is steam stripped as it exists the reactor bottom to remove absorbed hydrocarbons. The spent catalyst is then conveyed to a regenerator. In the regenerator, coke deposited on the catalyst as a result of the cracking reactions is burned off in a controlled combustion process with preheated air. Regenerator temperature is usually 1100 to 1250° F (590 to 675° C). The catalyst is then recycled to be mixed with fresh hydrocarbon feed.

Moving-bed Catalytic Cracking (TCC)— In the TCC process, catalyst beads ($\sim$0.5 cm) flow by gravity into the top of the reactor where they contact a mixed-phase hydrocarbon feed. Cracking reactions take place as the catalyst and hydrocarbons move concurrently downward through the reactor to a zone where the catalyst is separated from the vapors. The gaseous reaction products flow out of the reactor to the fractionation section of the unit. The catalyst is steam stripped to remove any adsorbed hydrocarbons. It then falls into the regenerator where coke is burned from the catalyst with air. The regenerated catalyst is separated from the flue gases and recycled to be mixed with fresh hydrocarbon feed. The operating temperatures of the reactor and regenerator in the TCC process are comparable to those in the FCC process.

Air emissions from catalytic cracking processes are (1) combustion products from process heaters and (2) flue gas from catalyst regeneration. Emissions from process heaters are discussed later in this section. Emissions from the catalyst regenerator include hydrocarbons, oxides of sulfur, ammonia, aldehydes, oxides of nitrogen, cyanides, carbon monoxide, and particulates (Table 9.1-1). The particulate emissions from FCC units are much greater than those from TCC units because of the higher catalyst circulation rates used.[2,3,5]

FCC particulate emissions are controlled by cyclones and/or electrostatic precipitators. Particulate control efficiencies are as high as 80 to 85 percent.[3,5] Carbon monoxide wasteheat boilers reduce the carbon monoxide and hydrocarbon emissions from FCC units to negligible levels.[3] TCC catalyst regeneration produces similar pollutants to FCC units but in much smaller quantities (Table 9.1-1). The particulate emissions from a TCC unit are normally controlled by high-efficiency cyclones. Carbon monoxide and hydrocarbon emissions from a TCC unit are incinerated to negligible levels by passing the flue gases through a process heater fire-box or smoke plume burner. In some installations, sulfur oxides are removed by passing the regenerator flue gases through a water or caustic scrubber.[2,3,5]

9.1.2.3 Thermal Cracking — Thermal cracking processes include visbreaking and coking, which break heavy oil molecules by exposing them to high temperatures.

Visbreaking — Topped crude or vacuum residuals are heated and thermally cracked (850 to 900° F, 50 to 250 psig) (455 to 480° C, 3.5 to 17.6 kg/cm^2) in the visbreaker furnace to reduce the viscosity or pour point of the charge. The cracked products are quenched with gas oil and flashed into a fractionator. The vapor overhead from the fractionator is separated into light distillate products. A heavy distillate recovered from the fractionator liquid can be used as a fuel oil blending component or used as catalytic cracking feed.

Coking — Coking is a thermal cracking process used to convert low value residual fuel oil to higher value gas oil and petroleum coke. Vacuum residuals and thermal tars are cracked in the coking process at high temperature and low pressure. Products are petroleum coke, gas oils, and lighter petroleum stocks. Delayed coking is the most widely used process today, but fluid coking is expected to become an important process in the future.

In the delayed coking process, heated charge stock is fed into the bottom section of a fractionator where light ends are stripped from the feed. The stripped feed is then combined with recycle products from the coke drum and rapidly heated in the coking heater to a temperature of 900 to 1100° F (480 to 590° C). Steam injection is used to control the residence time in the heater. The vapor-liquid feed leaves the heater, passing to a coke drum where, with controlled residence time, pressure (25 to 30 psig) (1.8 to 2.1 kg/cm^2), and temperature (750° F) (400° C), it is cracked to form coke and vapors. Vapors from the drum return to the fractionator where the thermal cracking products are recovered.

Table 9.1-1. EMISSION FACTORS FOR PETROLEUM REFINERIES

Process	Particulates	Sulfur oxides (as SO_2)	Carbon monoxide	Total hydro-carbons[a]	Nitrogen oxides (as NO_2)	Aldehydes	Ammonia	Emission factor rating
Boilers and process heaters,								
Fuel Oil	See Section 1.3 - Fuel Oil Combustion							
Natural Gas	See Section 1.4 - Natural Gas Combustion							
Fluid catalytic cracking units,[b]								
Uncontrolled								
lb/10^3bbl fresh feed	242 (93 to 340)[c]	493 (100 to 525)	13,700	220	71.0 (37.1 to 145.0)	19	54	B
kg/10^3 liters fresh feed	0.695 (0.267 to 0.976)	1.413 (0.286 to 1.505)	39.2	0.630	0.204 (0.107 to 0.416)	0.054	0.155	B
Electrostatic precipitator and CO boiler								
lb/10^3 bbl fresh fed	45[d] (7 to 150)	493 (100 to 525)	Neg[e]	Neg	71.0[f] (37.1 to 145.0)	Neg	Neg	B
kg/10^3 liters fresh feed	0.128 (0.020 to 0.428)	1.413 (0.288 to 1.505)	Neg	Neg	0.204[j] (0.107 to 0.416)	Neg	Neg	B
Moving-bed catalytic cracking units[g]								
lb/10^3 bbl fresh feed	17	60	3,600	87	5	12	6	B
kg/10^3 liters fresh feed	0.049	0.171	10.8	0.250	0.014	0.034	0.017	B
Fluid coking units[h]								
Uncontrolled								
lb/10^3 bbl fresh feed	523	NA[i]	NA	NA	NA	NA	NA	C
kg/10^3 liters fresh feed	1.50	NA	NA	NA	NA	NA	NA	C
Electrostatic precipitator and CO boiler								
lb/10^3 bbl fresh feed	6.85	NA	Neg	Neg	NA	Neg	Neg	C
kg/10^3 liters fresh feed	0.0196	NA	Neg	Neg	NA	Neg	Neo	C
Delayed coking units	NA	NA	NA	NA	NA	NA	NA	
Compressor engines[j]								
Reciprocating engines								
lb/10^3 ft³ gas burned	Neg	2s[k]	0.43	1.4	3.4	0.1	0.2	B
kg/10^3 m³ gas burned	Neg	32s	7.02	21.8	55.4	1.61	3.2	B
Gas turbines								
lb/10^3 ft³ gas burned	Neg	2s	0.12	0.02	0.3	NA	NA	B
kg/10^3 m³ gas burned	Neg	32s	1.94	0.28	4.7	NA	NA	B

Table 9.1-1. (Continued) EMISSION FACTORS FOR PETROLEUM REFINERIES

Process	Particulates	Sulfur oxides (as SO_2)	Carbon monoxide	Total hydrocarbons	Nitrogen oxides (as NO_2)	Aldehydes	Ammonia	Emission factor rating
Blowdown systems[j]								
Uncontrolled								
lb/10^3 bbl refinery feed	Neg	Neg	Neg	580	Neg	Neg	Neg	C
kg/10^3 liters refinery feed	Neg	Neg	Neg	1.662	Neg	Neg	Neg	C
Vapor recovery system and flaring								
lb/10^3 bbl refinery feed	Neg	26.9	4.3	0.8	16.9	Neg	Neg	C
kg/10^3 liters refinery feed	Neg	0.077	0.012	0.002	0.054	Neg	Neg	C
Vacuum distillation[m] column condensers								
Uncontrolled								
lb/10^3 bbl refinery feed	Neg	Neg	Neg	18	Neg	Neg	Neg	C
kg/10^3 liters refinery feed	Neg	Neg	Neg	0.052	Neg	Neg	Neg	C
lb/10^3 bbl vacuum feed	Neg	Neg	Neg	50 (0-130)	Neg	Neg	Neg	C
kg/10^3 liters vacuum feed	Neg	Neg	Neg	0.144	Neg	Neg	Neg	C
Controlled	Neg	Neg	Neg	Neg	Neg	Neg	Neg	C
Claus plant and tail gas treatment		See section 5.18						

[a] Overall, less than 1 percent by weight of the total hydrocarbon emissions are methane.

[b] References 2 through 8.

[c] Numbers in parenthesis indicate range of values observed.

[d] Under the New Source Performance Standards, controlled FCC regenerators will have particulate emissions lower than 19 lb/10^3 bbl fresh feed.

[e] Negligible emission.

[f] May be higher due to the combustion of ammonia.

[g] Reference 2.

[h] Reference 5.

[i] NA, Not Available.

[j] References 9, 10.

[k] s = Refinery gas sulfur content (lb/1000 ft³): Factors based on 100 percent combustion of sulfur to SO_2.

[l] References 2, 11.

[m] References 2, 12, 13.

In the fluid coking process, typified by Flexicoking, residual oil feeds are injected into the reactor where they are thermally cracked, yielding coke and a wide range of vapor products. Vapors leave the reactor and are quenched in a scrubber where entrained coke fines are removed. The vapors are then fractionated. Coke from the reactor enters a heater and is devolatilized. The volatiles from the heater are treated for fines and sulfur removal to yield a particulate free, low-sulfur fuel gas. The devolatilized coke is circulated from the heater to a gasifier where 95 percent of the reactor coke is gasified at high temperature with steam and air or oxygen. The gaseous products and coke from the gasifier are returned to the heater to supply heat for the devolatilization. These gases exit the heater with the heater volatiles through the same fines and sulfur removal processes.

From available literature, it is unclear what emissions are released and where they are released. Air emissions from thermal cracking processes include coke dust from decoking operations, combustion gases from the visbreaking and coking process heaters, and fugitive emissions. Emissions from the process heaters are discussed later in this section. Fugitive emissions from miscellaneous leaks are significant because of the high temperatures involved, and are dependent upon equipment type and configuration, operating conditions, and general maintenance practices. Fugitive emissions are also discussed later in this section. Particulate emissions from delayed coking operations are potentially very significant. These emissions are associated with removing the coke from the coke drum and subsequent handling and storage operations. Hydrocarbon emissions are also associated with cooling and venting the coke drum prior to coke removal. However, comprehensive data for delayed coking emissions have not been included in available literature. [4,5]

Particulate emission control is accomplished in the decoking operation by wetting down the coke.[5] Generally, there is no control of hydrocarbon emissions from delayed coking. However, some facilities are now collecting coke drum emissions in an enclosed system and routing them to a refinery flare.[4,5]

9.1.2.4 Utilities Plant — The utilities plant supplies the steam necessary for the refinery. Although the steam can be used to produce electricity by throttling through a turbine, it is primarily used for heating and separating hydrocarbon streams. When used for heating, the steam usually heats the petroleum indirectly in heat exchangers and returns to the boiler. In direct contact operations, the steam can serve as a stripping medium or a process fluid. Steam may also be used in vacuum ejectors to produce a vacuum. Emissions from boilers and applicable emission control technology are discussed in much greater detail in Chapter 1.0.

9.1.2.5 Sulfur Recovery Plant — Sulfur recovery plants are used in petroleum refineries to convert hydrogen sulfide (H_2S) separated from refinery gas streams into the more disposable by-product, elemental sulfur. Emissions from sulfur recovery plants and their control are discussed in Section 5.18.

9.1.2.6 Blowdown System — The blowdown system provides for the safe disposal of hydrocarbons (vapor and liquid) discharged from pressure relief devices.

Most refining processing units and equipment subject to planned or unplanned hydrocarbon discharges are manifolded into a collection unit, called the blowdown system. By using a series of flash drums and condensers arranged in decreasing pressure, the blowdown is separated into vapor and liquid cuts. The separated liquid is recycled into the refinery. The gaseous cuts can either be smokelessly flared or recycled.

Uncontrolled blowdown emissions primarily consist of hydrocarbons, but can also include any of the other criteria pollutants. The emission rate in a blowdown system is a function of the amount of equipment manifolded into the system, the frequency of equipment discharges, and the blowdown system controls.

Emissions from the blowdown system can be effectively controlled by combustion of the noncondensables in a flare. To obtain complete combustion or smokeless burning (as required by most states), steam is injected in the combustion zone of the flare to provide turbulence and to inspirate air. Steam injection also reduces emissions of nitrogen oxides by lowering the flame temperature. Controlled emissions are listed in Table 9.1-1.[2,11]

9.1.2.7 Process Heaters — Process heaters (furnaces) are used extensively in refineries to supply the heat necessary to raise the temperature of feed materials to reaction or distillation temperature. They are designed to raise petroleum fluid temperatures to a maximum of about 950° F (510° C). The fuel burned may be refinery gas, natural gas, residual fuel oils, or combinations, depending on economics, operating conditions, and pollution requirements. The process heaters may also use carbon monoxide-rich regenerator flue gas as fuel.

All the criteria pollutants are emitted from process heaters. The quantity of these emissions is a function of the type of fuel burned, the nature of the contaminants in the fuel, and the heat duty of the furnace. Emission of sulfur oxide can be controlled by fuel desulfurization or flue gas treatment. Carbon monoxide and hydrocarbons can be limited by better combustion efficiency. Currently, four general techniques or modifications for the control of nitrogen oxides are being investigated: combustion modification, fuel modification, alternate furnace design, and flue gas treatment. Several of these techniques are presently being applied to large utility boilers, but their applicability to process heaters has not been established.[2,14]

9.1.2.8 Compressor Engines — Many older refineries use reciprocating and gas turbine engines fired with natural gas to run high-pressure compressors. Natural gas has traditionally been a cheap, abundant source of energy. Examples of refining units operating at high pressure include hydrodesulfurization, isomerization, reforming, and hydrocracking units. Internal combustion engines are less reliable and harder to maintain than steam engines or electric motors. For this reason and because of increasing natural gas costs, very few such units have been installed in the last few years.

The major source of emissions from compressor engines is combustion products in the exhaust gas. These emissions include carbon monoxide, hydrocarbons, nitrogen oxides, aldehydes, and ammonia. Sulfur oxides may also be present depending on the sulfur content of the natural gas. All of these emissions are significantly higher in exhaust from reciprocating engines than from turbine engines.

The major emission control technique applied to compressor engines is carburetion adjustment similar to that applied on automobiles. Catalyst systems similar to those applied to automobiles may also be effective in reducing emissions, but their use has not been reported.

9.1.3 Fugitive Emission Sources and Control Equipment

This section presents descriptions of refinery processes and operations that are significant sources of fugitive emissions. Process flow schemes, emission characteristics, and emission control technology are discussed for each process. Emission factors for both uncontrolled and controlled fugitive emission sources are listed in Table 9.1-2. The following fugitive emission sources are discussed in this section on petroleum refining emissions:

1. Wastewater systems.
2. Cooling towers.
3. Pipeline fittings.
4. Relief valves.
5. Pump and compressor seals.
6. Asphalt blowing.
7. Blind changing.
8. Sweetening.
9. Storage.
10. Transfer operations.

9.1.3.1 Sweetening — Sweetening of distillates is accomplished by the conversion of mercaptans to alkyl-disulfides in the presence of a catalyst. The conversion process may be followed by an extraction step for the removal of the alkyl-disulfides.

In the *conversion* process, sulfur is added to the sour distillate with a small amount of caustic and air. This mixture is then passed upward through a fixed-bed catalyst counter-current to a flow of caustic entering at the top of the vessel.

In the *conversion and extraction* process the sour distillate is prewashed with caustic and then is contacted with a solution of catalyst and caustic in the extractor. The extracted distillate is then contacted with air to convert mercaptans to disulfides. After oxidation, the distillate is settled, inhibitors are added, and the distillate is sent to storage. Regeneration is accomplished by mixing caustic from the bottom of the extractor with air and separating the disulfides and excess air.

The major source of air emissions are fugitive hydrocarbon emissions generated when the distillate product is contacted with air in the "air blowing" step. These emissions are dependent upon equipment type and configuration as well as on operating conditions and maintenance practices.[4]

9.1.3.2 Asphalt Blowing — The asphalt blowing process polymerizes asphaltic residual oils by oxidation, increasing their melting temperature and hardness to achieve an increased resistance to weathering. The oils, containing a large quantity of polycyclic aromatic compounds (asphaltic oils), are oxidized by blowing heated air through a preheated batch mixture or, in the continuous process, by passing hot air countercurrent to the oil flow. The reaction is exothermic, and quench steam is sometimes needed for temperature control. In some cases ferric chloride or phosphorus pentoxide is used as a catalyst to increase the reaction rate and impart special characteristics to the asphalt.

Air emissions from asphalt blowing are primarily fugitive 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, but the emissions may contain hazardous polynuclear organics. [2,4,13,15] Emissions from asphalt blowing can be controlled to negligible levels by vapor scrubbing, incineration, or both.[4,13]

9.1.3.3 Storage — All refineries have a feedstock and product storage area, termed a "tank farm," which provides surge storage capacity to ensure smooth, uninterrupted refinery operations. Individual storage tank capacities range from less than 1000 barrels to more than 500,000 barrels, and total tank farm storage capacities commonly range from several days to several weeks. Storage tank designs, emissions, and emission control technologies are discussed in detail in Section 4.3.

9.1.3.4 Transfer Operations — Although most refinery feedstocks and products are transported by pipeline, some are transported by trucks, rail cars, and marine vessels. They are transferred to and from these transport vehicles in the refinery tank farm area using specialized pumps and piping systems. The emissions from transfer operations and applicable emission control technology are discussed in much greater detail in Section 4.4.

9.1.3.5 Wastewater Treatment Plant — All refineries employ some form of wastewater treatment to upgrade the quality of water effluents such that they can be safely returned to the environment or reused within the refinery. The design of wastewater treatment plants is complicated by the diversity of refinery pollutants, including oil, phenols, sulfides, dissolved solids, suspended solids, and toxic chemcials. Although the wastewater treatment processes employed by refineries vary greatly, they generally include neutralizers, oil-water separators, settling chambers, clarifiers, dissolved air flotation systems, coagulators, aerated lagoons, and activated sludge ponds. Refinery water effluents are collected from various processing units and conveyed through sewers and ditches to the wastewater treatment plant. Most of the wastewater treatment processing occurs in open ponds and tanks.

The main components of atmospheric emissions from wastewater treatment plants are fugitive hydrocarbons and dissolved gases that evaporate from the surfaces of wastewaters residing in open process

Table 9.1-2. FUGITIVE HYDROCARBON EMISSION FACTORS FOR PETROLEUM REFINERIES[a,b]

EMISSION FACTOR RATING: D

Emission source	Emission factor units	Uncontrolled emissions	Controlled emissions	Applicable control technology
Process drains and waste water separators	lb/10^3 gal. wastewater	5	0.2	Vapor recovery systems and/or separator covers
	kg/10^3 liters wastewater	0.6	0.024	
	lb/10^3 bbl refinery feed[c]	200	10	
	kg/10^3 liters refinery feed	0.6	0.03	
Cooling towers	lb/10^6 gal. cooling water	6	NA[d]	Minimization of oil leaks into cooling water system through good housekeeping and maintenance
	kg/10^6 liters cooling water	0.7	NA	
	lb/10^3 bbl refinery feed	10	NA	
	kg/10^3 liters refinery feed	0.03	NA	
Pipeline valves and flanges	lb/day-valve	0.15	NA	Good housekeeping and maintenance
	kg/day-valve	0.07	NA	
	lb/10^3 bbl refinery feed	28	NA	
	kg/10^3 liters refinery feed	0.08	NA	
Vessel relief valves	lb/day-valve	2.4	Neg	Rupture discs up stream of relief valves and/or vent to blowdown system
	kg/day-valve	1.1	Neg	
	lb/10^3 bbl refinery feed	11	Neg	
	kg/10^3 liters refinery feed	0.03	Neg	
Pump seals	lb/day-seal	5	3	Mechanical seals, dual seals, purged seals
	kg/day-seal	2.3	1.4	
	lb/10^3 bbl refinery feed	17	10	
	kg/10^3 liters refinery feed	0.05	0.03	
Compressor seals	lb/day-seal	9	NA	Mechanical seals, dual seals, purged seals
	kg/day-seal	4	NA	
Asphalt blowing	lb/10^3 bbl refinery feed	5	NA	Scrubber, incinerator
	kg/10^3 liters refinery feed	0.014	NA	
Blind.changing	lb/ton of asphalt	60	Neg	Line flushing, use of "line" blinds, blind insulation with gate valves
	kg/metric ton of asphalt	30	Neg	
	lb/10^3 bbl refinery feed	0.3	Neg	
	kg/10^3 liters refinery feed	0.001	Neg	
Miscellaneous: sampling, non-asphalt blowing, (sweetening), purging, etc.	lb/10^3 bbl refinery feed	10	NA	Good housekeeping and maintenance
	kg/10^3 liters refinery feed	0.03	NA	
Storage	See Section 4.3			
Loading	See Section 4.4			

[a] References 2, 4, 12, 13.

[b] Overall, less than 1 percent by weight of total hydrocarbon emissions are methane.

[c] Refinery feed is defined as the crude oil feed rate to the atmospheric distillation column.

[d] NA - These factors are not available.

drains, wastewater separators, and wastewater ponds (Table 9.1-2). Treatment processes that involve extensive contact of wastewater with air, such as aeration ponds and dissolved air flotation, create an even greater potential for atmospheric emissions.

The control of wastewater treatment plant emissions involves covering wastewater systems where emission generation is greatest (such as covering American Petroleum Institute separators and settling basins) and removing dissolved gases from wastewater streams with sour water strippers and phenol recovery units prior to their contact with the atmosphere. These control techniques can potentially achieve greater than 90 percent reduction of wastewater system emissions.[13]

9.1.3.6 Cooling Towers — Cooling towers are used extensively in refinery cooling water systems to transfer waste heat from the cooling water to the atmosphere. The only refineries not employing cooling towers are those with once-through cooling. The increasing scarcity of large water supplies required by once-through cooling is contributing to the disappearance of that form of refinery cooling. In the cooling tower, warm cooling water returning from refinery processes is contacted with air by cascading through packing. Cooling water circulation rates for refineries commonly range from 0.3 to 3.0 gal./min per barrel per day of refinery capacity.[2,16]

Atmospheric emissions from the cooling tower consist of fugitive hydrocarbons and gases stripped from the cooling water as the air and water come into contact. These contaminants enter the cooling water system from leaking heat exchangers and condensers. Although the predominant contaminant in cooling water is hydrocarbons, dissolved gases such as hydrogen sulfide and ammonia may also be found (Table 9.1-2).[2,4]

Control of cooling tower emissions is accomplished by reducing contamination of cooling water through the proper maintenance of heat exchangers and condensers. The effectiveness of cooling tower controls is highly variable, depending on refinery configuration and existing maintenance practices.[4]

9.1.3.7 Miscellaneous Fugitive — Miscellaneous fugitive emission sources are generally defined as hydrocarbon emission sources that are not associated with a particular refining process but are scattered throughout the refinery. Fugitive emission sources include valves, flanges, pipe fittings, pump and compressor seals, blind changing, and sample line purging. Hydrocarbon emissions from fugitive emission sources are attributable to the evaporation of leaked or spilled petroleum liquids and gases. Normally the control of fugitive emissions involves the minimization of leaks and spills through equipment changes, procedural changes, and improved housekeeping and maintenance practices. Localized fugitive emissions can often be controlled by incineration or vapor recovery systems.

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11.2 FUGITIVE DUST SOURCES

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Significant sources of atmospheric dust arise from the mechanical disturbance of granular material exposed to the air. Dust generated from these open sources is termed "fugitive" because it is not discharged to the atmosphere in a confined flow stream. Common sources of fugitive dust include: (1) unpaved roads, (2) agricultural tilling operations, (3) aggregate storage piles, and (4) heavy construction operations.

For the above categories of fugitive dust sources, the dust generation process is caused by two basic physical phenomena:

1. Pulverization and abrasion of surface materials by application of mechanical force through implements (wheels, blades, etc.).

2. Entrainment of dust particles by the action of turbulent air currents. Airborne dust may also be generated independently by wind erosion of an exposed surface if the wind speed exceeds about 12 mi/hr (19 km/hr).

The air pollution impact of a fugitive dust source depends on the quantity and drift potential of the dust particles injected into the atmosphere. In addition to large dust particles that settle out near the source (often creating a localized nuisance problem), considerable amounts of fine particles are also emitted and dispersed over much greater distances from the source.

Control techniques for fugitive dust sources generally involve watering, chemical stabilization, or reduction of surface wind speed using windbreaks or source enclosures. Watering, the most common and generally least expensive method, provides only temporary dust control. The use of chemicals to treat exposed surfaces provides longer term dust suppression but may be costly, have adverse impacts on plant and animal life, or contaminate the treated material. Windbreaks and source enclosures are often impractical because of the size of fugitive dust sources. At present, too few data are available to permit estimation of the control efficiencies of these methods.

11.2.1 Unpaved Roads (Dirt and Gravel)

11.2.1.1 General—Dust plumes trailing behind vehicles traveling on unpaved roads are a familiar sight in rural areas of the United States. When a vehicle travels over an unpaved road, the force of the wheels on the road surface causes pulverization of surface material. Particles are lifted and dropped from the rolling wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface. The turbulent wake behind the vehicle continues to act on the road surface after the vehicle has passed.

11.2.1.2 Emissions and Correction Parameters — The quantity of dust emissions from a given segment of unpaved road varies linearly with the volume of traffic. In addition, emissions depend on correction parameters (average vehicle speed, vehicle mix, surface texture, and surface moisture) that characterize the condition of a particular road and the associated vehicular traffic.

In the typical speed range on unpaved roads, that is, 30 to 50 mi/hr (48 to 80 km/hr), field measurements indicate that emissions are directly proportional to vehicle speed.[1-3] Limited field measurements further indicate that vehicles produce dust from an unpaved road in proportion to the number of wheels.[1] For roads with a significant volume of vehicles with six or more wheels, the traffic volume should be adjusted to the equivalent volume of four-wheeled vehicles.

Dust emissions from unpaved roads have been found to vary in direct proportion to the fraction of silt (that is, particles smaller than 75 µm in diameter—as defined by American Association of State Highway Officials) in the road surface material.[1] The silt fraction is determined by measuring the proportion of loose, dry, surface dust that passes a 200-mesh screen using the ASTM-C-136 method. The silt content of gravel roads averages about 12 percent.[1] The silt content of a dirt road will vary with location and should be measured. As a conservative approximation, the silt content of the parent soil in the area can be used; however, tests show the road silt content is lower than the surrounding parent soil. This is due to the fines being continually removed by the vehicle traffic, leaving a higher percentage of course particles.

Unpaved roads have a hard, nonporous surface that dries quickly after a rainfall. The temporary reduction in emissions because of rainfall may be accounted for by neglecting emissions on "wet" days, that is, days with more than 0.01 in. (0.254 mm) of rainfall.

11.2.1.3 Corrected Emission Factor – The quantity of fugitive dust emissions from an unpaved road, per vehicle-mile of travel, may be estimated (within ± 20 percent) using the following empirical expression:[1]

$$E = \left(0.81s\right)\left(\frac{S}{30}\right)\left(\frac{365 - w}{365}\right) \qquad (1)$$

where: E = Emission factor, pounds per vehicle-mile

s = Silt content of road surface material, percent

S = Average vehicle speed, miles per hour

w = Mean annual number of days with 0.01 in. (0.254 mm) or more of rainfall (see Figure 11.2-1)

The equation is valid for vehicle speeds in the range of 30 to 50 mi/hr (48 to 80 km/hr).

On the average, dust emissions from unpaved roads, as given by Equation 1, have the following particle size characteristics:[6]

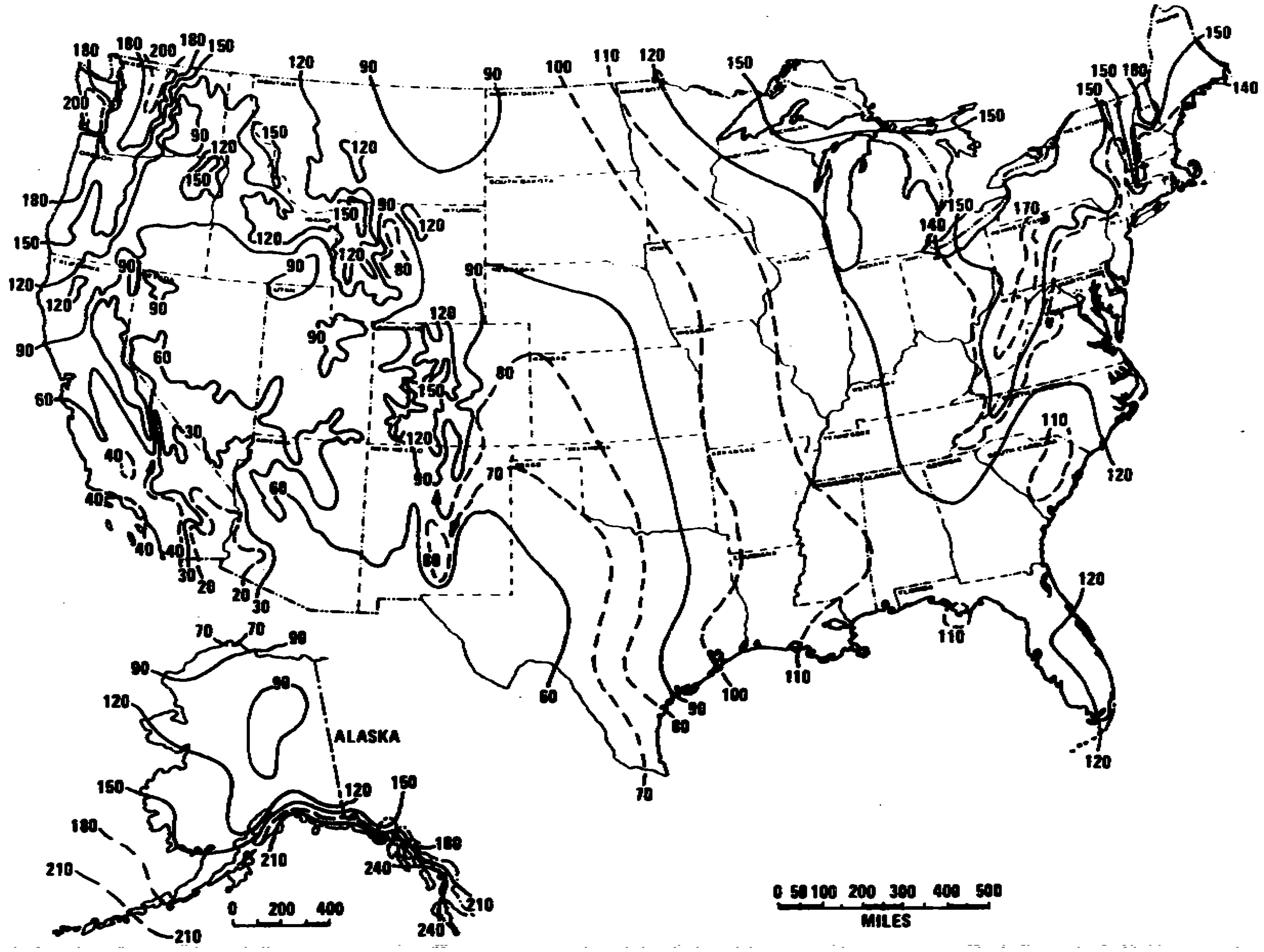
Gravel roads

Particle size, µm	Weight percent
<5	23
5 - 30	39
30 - 100	38

Dirt roads

Particle size, µm	Weight percent
<5	8
5 - 30	24
30 - 100	68

The effective aerodynamic cutoff diameter for the capture of road dust by a standard high-volume filtration sampler, based on a particle density of 2.0 to 2.5 g/cm^3 is 30 µm. On this basis, road dust emissions of particles larger than 30 to 40 µm in diameter are not likely to be captured by high-volume samplers remote from unpaved roads. Furthermore, the potential drift distance of particles is governed by the initial injection height of the particle, the particle's terminal settling velocity, and the degree of atmospheric turbulence. Theoretical drift distances, as a function of particle diameter and mean wind speed, have been computed for unpaved road emissions.[1] These results indicate that, for a typical mean wind speed of 10 mi/hr (16 km/hr), particles larger than about 100 m are likely to settle out within 20 to 30 feet (6 to 9 m) from the edge of the road. Dust that settles within this distance is not included in Equation 1. Particles that are 30 to 100 µm in diameter are likely to undergo impeded settling. These particles, depending upon the extent of atmospheric turbulence, are likely to settle within a few hundred feet from the road. Smaller particles, particularly those less than 10 to 15 µm in diameter, have much slower gravitational settling velocities and are much more likely to have their settling rate



11.2-1. Mean number of days with 0.01 inch or more of precipitation in United States.[4]

retarded by atmospheric turbulence. Thus, based on the presently available data, it appears appropriate to report only those particles smaller than 30 μm (62 percent of the emissions predicted by Equation 1 for gravel roads and 32 percent for dirt roads) as emissions that may remain indefinitely suspended.

11.2.1.4 Control Methods — Common control techniques for unpaved roads are paving, surface treating with penetration chemicals, working of soil stabilization chemicals into the roadbed, watering, and traffic control regulations. Paving as a control technique is often not practical because of its high cost. Surface chemical treatments and watering can be accomplished with moderate to low costs, but frequent retreatments are required for such techniques to be effective. Traffic controls, such as speed limits and traffic volume restrictions, provide moderate emission reductions, but such regulations may be difficult to enforce. Table 11.2.1-1 shows approximate control efficiencies achievable for each method. Watering, because of the frequency of treatments required, is generally not feasible for public roads and is effectively used only where watering equipment is readily available and roads are confined to a single site, such as a construction location.

Table 11.2.1-1 CONTROL METHODS FOR UNPAVED ROADS

Control method	Approximate control efficiency, %
Paving	85
Treating surface with penetrating chemicals	50
Working soil stabilizing chemicals into roadbed	50
Speed control[a]	
30 mi/hr	25
20 mi/hr	65
15 mi/hr	80

[a] Based on the assumption that "uncontrolled" speed is typically 40 mi/hr. Between 30 and 50 mi/hr, emissions are linearly proportional to vehicle speed. Below 30 mi/hr, however, emissions appear to be proportional to the square of the vehicle speed.[1]

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11.2.5 Paved Roads

11.2.5.1 General—Various field studies indicated that dust emissions from paved streets are a major component of the material collected by high-volume samplers.[1] Reentrained traffic dust has been found to consist primarily of mineral matter similar to common sand and soil, mostly tracked or deposited onto the roadway by vehicular traffic itself. Other particulate matter is emitted directly by the vehicles, for example, from engine exhaust, from wear of bearings and brake linings, and from abrasion of tires against the road surface. Some of these direct emissions may settle to the street surface and become subsequently reentrained. Although emissions from paved streets are generated primarily by vehicle traffic, appreciable emissions are added by wind erosion when the wind velocity exceeds a threshold value of about 20 km/hr (13 mi/hr).[2] Figure 11.2-3 illustrates particulate transfer processes occurring on urban streets.

11.2.5.2 Emission Factors and Correction Parameters — Table 11.2.5-1 presents measured emission factors resulting from two studies of reentrained street dust in the Kansas City area. Despite differences in sampling procedures, the results given in Table 11.2.5-1 seem to be fairly consistent. An average emission factor resulting from the two studies is shown. This appears to be the most representative emission factor for dust emissions from paved roadways.

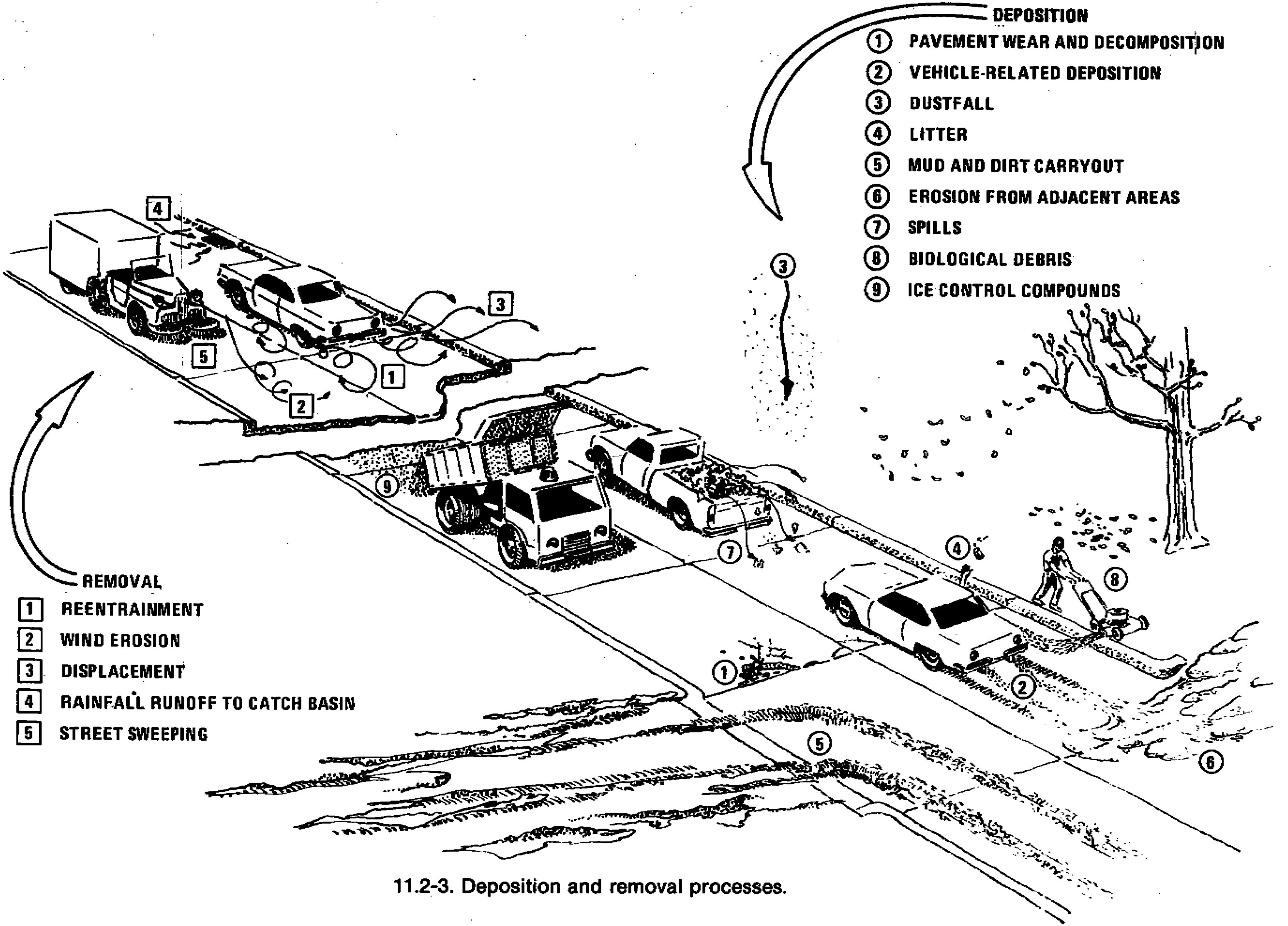
Dust emission rates may vary according to a number of factors. The most important are thought to be traffic volume and speed, quantity and particle size of loose surface material on the street, and wind speed. As shown in Figure 11.2-5, various activities take place that add or remove street surface material. On a normal paved street, an equilibrium condition is reached whereby the accumulated street deposits are maintained at a relatively constant level. On the average, vehicular carry-out from unpaved areas may be the largest source of street deposit. Accidental spills, street cleaning, and rainfall are activities that disrupt the normal equilibrium street loading for a relatively short duration in most circumstances.

Mathematical relationships for estimating the effects of these variables on emissions would be desirable. Research conducted to date has not produced conclusive results, however. References 3 and 4 describe details of investigations made to date.

11.2.5.3 Particle Size Data — From Reference 3, measured average particle size data for entrained street dust were found to be:

Particle size, μm	Weight percent
>30	10
<30	90
< 5	50

The 30-μm value has been determined[5] to be the effective aerodynamic cutoff diameter for capture of airborne dust by a standard high-volume sampler, based on a particle density of 2.0 to 2.5 g/cm^3. It is probable that the above data are biased toward small particle sizes since the particle size measurements taken downwind from the street edge contain a significant urban background concentration that would be predominantly particles smaller than 30 μm. Therefore, a true particle size distribution for entrained street dust may have smaller fractions of particles less than 30 μm and 5 μm than shown. Particle size measurements taken both upwind and downwind of the street would be needed to resolve this problem. Microscopic analysis indicated the origin of material collected on high-volume sampler filters to be about 40 percent by weight from combustion products and 59 percent mineral matter with traces of biological matter and rubber tire particles.[4] The small particulate was identified as mainly combustion products, while most of the large material was of mineral origin.



11.2-3. Deposition and removal processes.

Table 11.2.5-1. MEASURED EMISSION FACTORS FOR DUST ENTRAINMENT FROM PAVED ROADWAYS

	Emission factors[a,b] (range and average)	
Study	g/vehicle-km	lb/vehicle-mile
Reference 3[c]	(2.8-5.6)4.3	(0.01-0.02)0.015
Reference 4[d]	(0.26-10.4)2.6	(0.0009-0.037)0.009
Average[e]	3.5	0.012

[a] Table 3.1.4-7 indicates 0.33 g/km of particulate emissions from exhaust and tire wear, which have not been excluded from the measured results given in Table 11.2.5-1. Average emissions of entrained dust, excluding exhaust and tire wear, would therefore be approximately 3.2 g/km.

[b] Emission factors reflect average "dry day" conditions. During periods of rainfall, reentrainment of dust should be negligible. However, after rain ends emissions may be temporarily increased as a result of deposition of mud on street surfaces. When this material dries, it may become entrained by vehicle action.

[c] These measurements relate to the amount of material passing through a vertical plane located approximately 5 meters downwind from the nearest edge of the street. Thus, these measured results exclude any particles that settle within 5 meters from the edge of the street. In Reference 3, measured emission factors were also obtained for a case where streets were artificially loaded with very high (10,000 kg/km) amounts of dirt and gravel. Very high emissions were observed for a short period of time (up to 9.8 kg/vehicle-km), but emission factors decreased rapidly as street loadings were decreased by vehicle traffic.

[d] These measurements were based on high-volume sampler data taken 10 meters downwind from the street. Thus, particles settling within 10 meters of the edge of the street are excluded from the emission factor. Measurements were also taken 20 and 30 meters downwind. These measurements show that apparent emission rates decrease with increasing distance from the source, presumably due to particle settling. On the average, the emission rate calculated 20 meters downwind was 86 percent of the 10-meter value, and the emission rate 30 meters downwind was 77 percent of the 10-meter value.

[e] Average determined from average results of References 3 and 4, with each study weighted equally.

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