COMPILATION

OF

AIR POLLUTANT EMISSION FACTORS

(Revised)

Note: This is an early version of the *AP 42, Compilation of Air Pollutant Emission Factors, Volume I Stationary Point and Area Sources.* EPA has made this available for historical reference purposes. The latest emission factors are available on the AP42 webpage.

The most recent updates to AP42 are located on the EPA web site at www.epa.gov/ttn/chief/ap42/

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PREFACE

This document reports available atmospheric emission data for which sufficient information exists to establish realistic emission factors. Although based on Public Health Service Publication 999-AP-42, Compilation of Air Pollutant Emission Factors, by R. L. Duprey, this document has been expanded and revised considerably and supercedes the previous report. The scope of the document has been broadened to reflect expanding knowledge of emissions.

As data are refined and additional information becomes available, this document will be reissued or revised as necessary to reflect more accurate and refined emission factors. New processes will be included in future supplements. The loose-leaf form of this document is designed to facilitate the addition of future materials.

Comments and suggestions regarding this document should be directed to the attention of Director, Applied Technology Division, SSPCP, OAP, EPA, Research Triangle Park, North Carolina 27711.

ACKNOWLEDGMENTS

Because this document is a product of the efforts of many individuals, it is impossible to acknowledge each individual who has contributed. Special recognition is given, however, to Mr. Richard Gerstle and the staff of Resources Research, Inc., who provided a large part of the efforts that went into this document. Their complete effort is documented in their report for contract number CPA-22-69-119.

Environmental Protection Agency employees M. J. McGraw, A. J. Hoffman, J. H. Southerland, and R. L. Duprey are also acknowledged for their efforts in the production of this work.

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ABSTRACT

Emission data obtained from source tests, material balance studies, engineering estimates, etc., have been compiled for use by individuals and groups responsible for conducting air pollution emission inventories. Emission factors given in this document, the result of the expansion and continuation of earlier work, cover most of the common emission categories: fuel combustion by stationary and mobile sources; combustion of solid wastes; evaporation of fuels, solvents, and other volatile substances; various industrial processes; and miscellaneous sources. When no source-test data are available, these factors can be used to estimate the quantities of primary pollutants (particulates, CO, SO_2, NO_x, and hydrocarbons) being released from a source or source group.

Key words: fuel combustion, stationary sources, mobile sources, industrial processes, evaporative losses, emissions, emission data, emission inventories, primary pollutants, emission factors

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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 numbers of these 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.

The emission factor is a statistical average 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. For example, assume that in the production of 260, 000 tons (236, 000 MT*) of ammonia per year, 26, 000 tons (23, 600 MT) of carbon monoxide is emitted to the atmosphere. The emission factor for the production of ammonia would therefore be 200 pounds of CO released per ton (100 kilograms per MT) of ammonia produced. The emission factor thus relates the quantity of pollutants emitted to some indicator such as production capacity, quantity of fuel burned, or vehicle miles traveled by autos.

The emission factors presented in this report were estimated by the whole spectrum of techniques available for determining such factors. These techniques include: detailed source testing that involved many measurements related to a variety of process variables, single measurements not clearly defined as to their relationship to process operating conditions, process material balances, and engineering appraisals of a given process.

The limitations and applicability of emission factors must be understood. To give some idea of the accuracy of the factors presented for a specific process, each process has been ranked as "A," "B," "C," "D," or "E." For a process with an "A" ranking, the emission factor should be considered excellent, i.e., based on field measurements of a large number of sources. A process ranked "B" should be considered above average, i.e., based on a limited number of field measurements. A ranking of "C" is considered average; "D," below average; and

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*MT = metric ton.

"E," poor. These rankings are presented below the table titles throughout the report.

In general, the emission factors presented are not precise indicators of emissions for a single process. They are more valid when applied to a large number of processes. With this limitation in mind, emission factors are extremely useful when intelligently applied in conducting source inventories as part of community or nationwide air pollution studies.

In addition to the specific tables in each section of this report, the Appendix presents general data on particle size distribution from various sources, nationwide emission estimates for 1968, average collection efficiencies for different types of particulate control equipment, and conversion factors for a number of different substances.

1. STATIONARY COMBUSTION SOURCES

Stationary combustion sources include steam-electric generating plants, industrial establishments, commercial and institutional buildings, and domestic combustion units. Coal, fuel oil, and natural gas are the major fossil fuels used by these sources. Other fuels such as liquefied petroleum gas, wood, lignite, coke, refinery gas, blast furnace gas, and other waste or by-product type fuels are also used, but the quantities consumed are relatively small. Coal, oil, and natural gas currently supply about 95 percent of the total heat energy in the United States. In 1968 over 500 million tons (454 million MT) of coal, 580 million barrels (92×10^9 liters) of residual fuel oil, 590 million barrels (94×10^9 liters) of distillate fuel oil, and 20 trillion cubic feet (566 trillion liters) of natural gas were consumed in the United States.[1]

The burning of these fuels for both space heating and process heating is one of the largest sources of sulfur oxides, nitrogen oxides, and particulate emissions. Controls for particulate emissions are presently being used, but for sulfur oxides and nitrogen oxides control techniques are not being practiced. The following sections present detailed emission data for the major fossil fuels—coal, fuel oil, and natural gas—as well as for liquefied petroleum gas and wood waste. Detailed information on the size distribution of the particles emitted from the combustion of each of these fuels is presented in Table A-1 of the Appendix.

BITUMINOUS COAL COMBUSTION

General Information

Coal, the most plentiful fuel in the United States, is burned in a wide variety of furnaces to produce heat and steam. Coal-fired furnaces range in size from small hand-fired units, with capacities of 10 to 20 pounds (4.5 to 9 kilograms) of coal per hour to large pulverized-coal-fired units, which burn 300 to 400 tons (275 to 360 MT) of coal per hour.

Although predominantly carbon, coal contains many compounds in varying amounts. The exact nature and quantity of these compounds are determined by the locale of the mine producing the coal and will usually affect the final use of the coal.

Emissions and Controls

Particulates - Particulates emitted from coal combustion consist primarily of carbon, silica, alumina, and iron oxide in the fly ash. The quantity of particulate emissions is dependent upon the ash content of the coal, the type of combustion unit, and the control equipment used. Table 1-1 gives the range of collection efficiencies for common types of fly-ash control equipment. Particulate emission factors presented in Table 1-2 for the various types of furnaces are based on the quantity of coal burned.

Table 1-1. RANGE OF COLLECTION EFFICIENCIES FOR COMMON TYPES OF EQUIPMENT FOR FLY-ASH CONTROL[a]

Type of furnace	Range of collection efficiencies, %			
	Electrostatic precipitator	High-efficiency cyclone	Low-resistance cyclone	Settling chamber expanded chimney bases
Cyclone furnace	65-99[b]	30-40	20-30	-
Pulverized unit	80-99.9[b]	65-75	40-60	-
Spreader stoker	-	85-90	70-80	20-30
Other stokers	-	90-95	75-85	25-50

[a] Reference 2.

[b] High values attained with high-efficiency cyclones in series with electrostatic precipitators.

Sulfur Oxides - Increased attention has been given to the control of sulfur oxide emissions from the combustion of coal. Low-sulfur coal has been recommended in many areas; where this is not possible, other methods in which the focus is on the removal of sulfur oxide emissions from the flue gas before it enters the atmosphere must be considered. No flue-gas desulfurization process is presently in widespread use, but several methods are presented in Table 1-3 with the expected efficiencies obtainable from the various types of control. Uncontrolled emissions of sulfur oxides are shown in Table 1-2 along with the other gaseous emissions.

Other Gases - Gaseous emissions from coal combustion include sulfur oxides, aldehydes, carbon monoxide, hydrocarbons, and nitrogen oxides. In this section, attention will be focused on hydrocarbons, carbon monoxide, and nitrogen oxides.

The carbon monoxide and hydrocarbon content of the gases emitted from bituminous coal combustion depend mainly on the efficiency of combustion. Successful combustion and a low level of gaseous carbon and organic emissions involve a high degree of turbulence, high temperatures, and sufficient time for the combustion reaction to take place. Thus, careful control of excess air rates, high combustion temperature, and intimate contact of fuel and air will minimize these emissions.

Emissions of oxides of nitrogen result not only from the high-temperature reaction of atmospheric nitrogen and oxygen in the combustion zone, but also from partial combustion of the nitrogenous compounds contained in the fuel. This pollutant is usually emitted at a greater rate from more efficient combustion sources, which have a higher combustion temperature, and greater furnace release rates.

Factors for gaseous emissions are presented in Table 1-2. The size range in Btu (kcal) per hour for the various categories is only shown as a guide in applying these factors and is not meant to clearly distinguish between furnace applications.

Table 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		Hydro-carbons[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[f]	6.5A	38S	19S	2	1	1	0.5	15	7.5	0.005	0.0025
Less than 10[i] (commercial and domestic furnaces)												
Spreader 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 2 through 7, and 11.

[f] Without fly-ash reinjection.

[g] References 2, 4, 5, 8, 9, and 11.

[h] For all other stokers, use 5A (2.5A) for particulate emission factor.

[i] References 9 through 11.

Table 1-3. SULFUR DIOXIDE REMOVAL FROM VARIOUS TYPES OF PROCESSES[a]

Process	SO_2 removal, %
Limestone-dolomite injection, dry process	40 to 60
Limestone-dolomite injection, wet process	80 to 90
Catalytic oxidation	90

[a] Reference 12.

ANTHRACITE COAL COMBUSTION

General[13]

Because of its low volatile content and the nonclinking characteristics of its ash, anthracite coal is used in medium-sized industrial and institutional boilers with stationary or traveling grates. Anthracite coal is not used in spreader stokers because of its low volatile content and relatively high ignition temperature. This fuel may be burned in pulverized-coal-fired units, but this practice is limited to only a few plants in Eastern Pennsylvania because of ignition difficulties. This fuel has also been widely used in hand-fired furnaces.

Emissions and Controls[13]

Particulate emissions from anthracite coal combustion are greatly affected by the rate of firing and by the ash content of the fuel. Smoke emissions from anthracite coal are rarely a problem. High grate loadings result in excessive emissions because of the underfire air required to burn the fuel. Large units equipped with forced-draft fans may also produce high rates of particulate emissions. Hand-fired and some small natural-draft units have fewer particulate emissions because underfire air is not usually supplied by mechanical means.

As is the case with other fuels, sulfur dioxide emissions are directly related to the sulfur content of the coal. Nitrogen oxides and carbon monoxide emissions are similar to those found in bituminous-coal-fired units because excess air rates and combustion temperatures are similar. Because the volatile matter content of anthracite is lower than that of bituminous, hydrocarbon emissions from anthracite are somewhat lower than those from bituminous coal combustion.

The uncontrolled emissions from anthracite coal combustion are presented in Table 1-4.

FUEL OIL COMBUSTION

General Information

Fuel oil is one of the major fossil fuels used in this country for power production, industrial process heating, and space heating. It is classified into two major types, residual and distillate. Distillate fuel oil is primarily a domestic fuel, but it is used in some commercial and industrial applications where a high-quality oil

Table 1-4. EMISSIONS FROM ANTHRACITE COAL COMBUSTION WITHOUT CONTROL EQUIPMENT

EMISSION FACTOR RATING: B

	Particulate[a,b]		SO_2[c]		SO_3[c,d]		HC[e,f]		CO[g]		NO_x[d,h]	
Type of furnace	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Pulverized (dry bottom), no fly-ash reinjection	17A	8.5A	38S	19S	0.5S	0.25S	0.03	0.015	1	0.5	18	9
Overfeed stokers, no fly-ash reinjection[i]	2A	1A	38S	19S	0.5S	0.25S	0.2	0.1	(2 to 10)[j]	1 to 5	(6 to 15)[k]	3 to 7.5
Hand-fired units	10	5	36S	18S	0.8S	0.4S	2.5	1.25	90	45	3	1.5

[a] References 8 and 14 through 18.

[b] A is the ash content expressed as weight percent.

[c] S is the sulfur content expressed as weight percent.

[d] References 16 and 18 through 20.

[e] Based on Reference 8 and bituminous coal combustion.

[f] Expressed as methane.

[g] Based on bituminous coal combustion.

[h] Emitted as NO.

[i] Based on data obtained from traveling-grate stokers in the 12 to 180 Btu/hr (3 to 45 kcal/hr) heat input range. Anthracite is not burned in spreader stokers.

[j] Use high side of range for smaller-sized units [less than 10×10^6 Btu/hr (2.5×10^6 kcal/hr) heat input].

[k] Use low side of range for smaller-sized units [less than 10×10^6 Btu/hr (2.5×10^6 kcal/hr) heat input].

NOTE: Approximate efficiencies of control devices used for anthracite are cyclone, 75 to 85 percent, and electrostatic precipitator, 85 percent.

is required. Fuel oils are classified by grades: grades No. 1 and No. 2 distillate, No. 5 and No. 6 residual, and No. 3 and No. 4 blends. (Grade No. 3 has been practically discontinued.) Residual fuel is used in power plants, commercial establishments, and industries. The primary difference between residual oil and distillate oil is the higher ash and sulfur content of residual oil and the fact that it is harder to burn properly. Residual fuel oils have a heating value of approximately 150,000 Btu/gallon (10,000 kcal/liter), whereas for distillate oils the heating value is about 140,000 Btu/gallon (9,300 kcal/liter).

Emissions

Emissions from oil combustion are dependent on type and size of equipment, method of firing, and maintenance. Table 1-5 presents emission factors for fuel oil combustion. Note that the industrial and commercial category is split into residual and distillate because there is a significant difference in particulate emissions from the same equipment depending on the fuel oil used. It should also be noted that power plants emit less particulate matter per quantity of oil consumed, reportedly because of better design and more precise operation of equipment.

In general, large sources produce more nitrogen oxides than small sources,[2] primarily because of the higher flame and boiler temperatures characteristic of large sources. Large sources, however, emit fewer aldehydes than smaller sources as a result of more complete combustion and higher flame temperatures. It may be expected that small sources would emit relatively larger amounts of hydrocarbons than large sources because of the small flame volume, the large proportion of relatively cool gases near the furnace walls, and frequently improper operating practices. These factors were not reflected in the data, however.

NATURAL GAS COMBUSTION

General Information

Natural gas is rapidly becoming one of the major fuels used throughout the country. It is used mainly in power plants, industrial heating, domestic and commercial space heating, and gas turbines. The primary component of natural gas is methane, but smaller quantities of inorganics, particularly nitrogen and carbon dioxide, are also present. Pennsylvania natural gas has been reported to contain as much as one-third ethane.[34] The heating value of natural gas is approximately 1,050 Btu per standard cubic foot (9,350 kcal/m^3).

Emissions and Controls

Even though natural gas is considered to be a relatively clean fuel, emissions sometimes occur from the combustion reaction. When insufficient air is supplied, large amounts of carbon monoxide and hydrocarbons may be produced.[35] Emissions of sulfur oxides are dependent on the amount of sulfur in the fuel. The sulfur content of natural gas is usually low, around 2,000 grains/10^6 ft^3 (4,600 g/10^6 m^3).

Nitrogen oxide emissions are a function of the temperature in the combustion chamber and the rate of cooling of the combustion products. These values vary

Table 1-5. EMISSION FACTORS FOR FUEL OIL COMBUSTION

EMISSION FACTOR RATING: A

	Type of unit							
	Power plant		Industrial and commercial				Domestic	
			Residual		Distillate			
Pollutant	lb/10^3 gal	kg/10^3 liters	lb/10^3 gal	kg/10^3 liters	lb/10^3 gal	kg/10^3 liters	lb/10^3 gal	kg/10^3 liters
Particulate[a]	8	1	23	2.75	15	1.8	10	1.2
Sulfur dioxide[b,c]	157S	19S	157S	19S	142S	17S	142S	17S
Sulfur trioxide[b,c]	2S	0.25S	2S	0.25S	2S	0.25S	2S	0.25S
Carbon monoxide[d]	0.04	0.005	0.2	0.025	0.2	0.025	5	0.6
Hydrocarbons[e]	2	0.25	3	0.35	3	0.35	3	0.35
Nitrogen oxides (NO_2)[f]	105	12.6	(40 to 80)[g]	4.8 to 9.6[g]	(40 to 80)[g]	4.8 to 9.6[g]	12	1.5
Aldehydes (HCHO)[h]	1	0.12	1	0.12	2	0.25	2	0.25

[a] References 21 through 25.

[b] Reference 21.

[c] S equals percent by weight of sulfur in the oil.

[d] References 21, and 26 through 29.

[e] References 21, 25, and 28 through 30.

[f] References 21 through 25, and 28, 29, and 31.

[g] Use 40 (4.8) for tangentially fired units and 80 (9.6) for horizontally fired units.

[h] References 21, 28, 30, and 31.

considerably with the type and size of unit. Emissions of aldehydes are increased when there is an insufficient amount of combustion air or incomplete mixing of the fuel and the combustion air.

Emission factors for natural-gas combustion are presented in Table 1-6. Control equipment has not been utilized to control emissions from natural-gas combustion equipment.

LIQUEFIED PETROLEUM GAS CONSUMPTION

General Information[13]

Liquefied petroleum gas, commonly referred to as LPG, consists mainly of butane, propane, or a mixture of the two, and of trace amounts of propylene and butylene. This gas, obtained from oil or gas wells or as a by-product of gasoline refining, is sold as a liquid in metal cylinders under pressure and, therefore, is often called bottled gas. LP gases are graded according to maximum vapor pressure, with Grade A being predominantly butane, Grade F being predominantly propane, and Grades B through E consisting of varying mixtures of butane and propane. The heating value of LPG ranges from 97,400 Btu/gallon (6,480 kcal/liter) for Grade A to 90,500 Btu/gallon (6,030 kcal/liter) for Grade F. The largest market for LPG is presently the domestic-commercial heating market, followed by the chemical industry and internal combustion engines.

Emissions[13]

LPG is considered a "clean" fuel because it does not produce visible emissions. Gaseous pollutants such as carbon monoxide, hydrocarbons, and nitrogen oxides, however, do occur. The most significant factors affecting these emissions are the burner design, adjustment, and venting.[45] Improper design, blocking, and clogging of the flue vent and lack of combustion air result in improper combustion that causes the emission of aldehydes, carbon monoxide, hydrocarbons, and other organics. Nitrogen oxide emissions are a function of a number of variables including temperature, excess air, and residence time in the combustion zone. The amount of SO_2 emitted is directly proportional to the amount of sulfur in the fuel.

Emission factors for LPG combustion are presented in Table 1-7.

WOOD WASTE COMBUSTION IN BOILERS

General Information

Wood is no longer a primary source of heat energy; however, in certain industries such as lumber, furniture, and plywood, in which it is a readily available product, wood is a desirable fuel. The wood is used in the form of hogged chips, shavings, and sawdust.

Firing Practices

In general, furnaces designed for the burning of wood waste are of three types: (1) pile, (2) thin-bed, and (3) cyclonic. These furnaces are usually water-cooled and can be modified to burn supplemental fuel with the wood.

Table 1-6. EMISSION FACTORS FOR NATURAL-GAS COMBUSTION

EMISSION FACTOR RATING: B

Pollutant	Power plant		Industrial process boilers		Domestic and commercial heating units		Gas turbines		Gas engines	
	lb/10^6 ft^3	kg/10^6 m^3	lb/10^6 ft^3	kg/10^6 m^3	lb/10^6 ft^3	kg/10^6 m^3	lb/10^6 ft^3	kg/10^6 m^3	lb/10^6 ft^3	kg/10^6 m^3
Particulates[a]	15	240	18	290	19	302	-	-	-	-
Oxides of sulfur[b] (SO_2)	0.6	9.6	0.6	9.6	0.6	9.6	-	-	-	-
Carbon monoxide[c]	0.4	6.4	0.4	6.4	20	320	-	-	-	-
Hydrocarbons[d] (CH_4)	40	640	40	640	8	128	-	-	-	-
Oxides of nitrogen[e] (NO_2)	390	6,250	(120 to 230)[f]	1,920 to 3,700[f]	(50 to 100)[g]	800 to 1,600[g]	200	3,200	770 to 7,300[h]	12,300 to 117,000
Aldehydes[i] (HCHO)	3	48	3	48	10	160	-	-	-	-
Organics[j]	4	64	7	112	1	16	-	-	-	-

[a] Reference 22.

[b] Reference 36 (based on average sulfur content of natural gas of 2,000 grains/10^6 ft^3 (4,600 g/10^6 m^3).

[c] References 37 through 39.

[d] References 23, and 37 through 39.

[e] References 22, 29, 35, and 44.

[f] Use 120 (1,920) for smaller industrial boilers <500 boiler horsepower and 230 (3,700) for larger industrial boilers >7,500 boiler horsepower.

[g] Use 50 (800) for domestic heating units and 100 (1,600) for commercial units.

[h] Use 770 (12,300) for oil and gas production; 4,300 (69,000) for gas plants; 4,400 (71,000) for refineries; and 7,300 (117,000) for pipelines.

[i] References 23, 28, 29, 35, 38, and 40 through 43.

[j] Reference 44.

Table 1-7. EMISSION FACTORS FOR LPG COMBUSTION[a]

EMISSION FACTOR RATING: C

Pollutant	Industrial process furnaces				Domestic and commercial furnaces			
	Butane		Propane		Butane		Propane	
	lb/10^3 gal	kg/10^3 liters	lb/10^3 gal	kg/10^3 liters	lb/10^3 gal	kg/10^3 liters	lb/10^3 gal	kg/10^3 liters
Particulates	1.8	0.22	1.7	0.20	1.9	0.23	1.8	0.22
Sulfur oxides[b]	0.09S	0.005S	0.09S	0.005S	0.09S	0.005S	0.09S	0.005S
Carbon monoxide	0.01	0.001	0.01	0.001	2.0	0.24	1.9	0.23
Hydrocarbons	4.0	0.48	3.8	0.45	0.8	0.096	0.7	0.081
Nitrogen oxides[c]	12.1	1.45	11.2	1.35	6 to 10[d]	0.72 to 1.2	6 to 10[d]	0.72 to 1.2
Aldehydes (HCHO)	1.0	0.12	0.9	0.11	1.0	0.12	0.9	0.11
Other organics	0.7	0.08	0.65	0.08	0.1	0.012	0.1	0.012

[a] Factors based on an analysis of the similarities between LPG combustion and natural gas and fuel oil combustion, and data in Reference 22.

[b] S equals sulfur content expressed in grains per 100 ft^3 gas vapor, e.g., if the sulfur content is 0.16 grain per 100 ft^3 (0.366 g/100 m^3) vapor, the SO_2 emission factor would be 0.09 x 0.16 or 0.014 lb SO_2 per 1,000 gallons (0.005 x 0.366 or 0.0018 kg SO_2/10^3 liters) butane burned.

[c] Expressed as NO_2.

[d] Use 6 (0.72) for domestic units and 10 (1.2) for commercial units.

In pile burning, the wood is fed through the furnace roof and burned in a cone-shaped pile on the grate. Thin-bed burning is accomplished on a moving grate similar to that of a spreader stoker. In a cyclone furnace, wood (especially bark) is usually burned with coal.

Emissions[13]

Excessive smoking results from improper grate maintenance of wood-burning furnaces, especially where coal is burned simultaneously with the wood. Another major factor affecting emissions is the water content of the wood refuse. This is not only a function of the absorptive property of the wood, but also a function of the process that produces the waste. Wet bark generally produces more emissions than kiln-dried lumber. Of minor importance, except as it reflects on the factor noted above, is the composition of the material being burned. For example, bark contains less carbon and nitrogen, but more sulfur than wood. This difference coupled with a high moisture content is thought to account for the more severe dust and smoke problems associated with burning bark. Emission factors for the combustion of wood and bark in boilers are shown in Table 1-8.

Table 1-8. EMISSION FACTORS FOR WOOD AND BARK COMBUSTION IN BOILERS WITH NO REINJECTION[a,b]

EMISSION FACTOR RATING: C

Pollutant	Emissions	
	lb/ton	kg/MT
Particulates[c]	25 to 30	12.5 to 15.0
Sulfur oxides (SO_2)[d]	0 to 3	0.0 to 1.5
Carbon monoxide	2	1
Hydrocarbons[e]	2	1
Nitrogen oxides (NO_2)	10	5
Carbonyls[f]	0.5[g]	0.25[g]

[a] References 46 through 49.

[b] Approximately 50 percent moisture content.

[c] This number is an atmospheric emission factor without fly ash reinjection. For boilers with reinjection, the particulate loadings reaching the control equipment are 30 to 35 lb/ton (15 to 17.5 kg/MT) fuel with 50 percent reinjection and 40 to 45 lb/ton (20 to 22.5 kg/MT) fuel with 100 percent reinjection.

[d] Use 0 for most wood and higher values for bark.

[e] Expressed as methane.

[f] Emitted as formaldehyde.

[g] Based on trench incinerator emission.

REFERENCES FOR CHAPTER 1

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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.

An average of 5.5 pounds (2.5 kilograms) of refuse and garbage is collected per capita per day in the United States.[1] This does not include some of the uncollected waste such as industrial waste, wastes burned in commercial and apartment house incinerators, and wastes disposed of by backyard burning, which contribute at least 4.5 pounds (2 kilograms) per capita per day. Together, this gives a conservative per capita generation rate of 10 pounds (4.5 kilograms) per day. Approximately 50 percent of all the generated waste in the United States is burned by a wide variety of combustion methods including both enclosed and open burning.[2] Atmospheric emissions, both gaseous and particulate, result from refuse-disposal operations that utilize combustion to reduce the quantity of refuse. Emissions from these combustion processes cover a wide range because of their dependence on the refuse burned, the method of combustion or incineration, and many other factors. Because of the large number of variables involved, it was impossible in most cases to establish usable ranges in emission factors and to delineate those conditions when the upper or lower limit should be used. For this reason, in most cases, only a single factor has been presented.

REFUSE INCINERATION

Process Description[3-6]

The most common types of incinerators consist of a refractory-lined chamber with a grate upon which refuse is burned. Combustion products are formed by contact between underfire air and waste on the grates in the primary chamber. Additional air (overfire air) is admitted above the burning waste to promote gas-phase combustion. In the multiple-chamber-type incinerator, gases from the primary chamber flow to a small mixing chamber where more air is admitted, then to a larger, secondary chamber where more complete oxidation occurs. As much as 150 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.

Definitions of Incinerator Categories[3]

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

1. Municipal incinerators - These multiple-chamber units have capacities greater than 50 tons (45.3 MT) per day and are usually equipped with

automatic charging mechanisms and temperature controls. Municipal incinerators are also usually equipped with some type of particulate control device, such as a spray chamber.

2. Industrial/commercial incinerators - These units cover a wide range, generally between 50 and 4,000 pounds per hour (22.7 and 1,800 kilograms). Of either single- or multiple-chamber design, they are frequently manually charged and intermittently operated. Better designed emission control systems include gas-fired afterburners or scrubbing, or both.

3. Domestic incinerators - This category include 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.

4. 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.

5. 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. They are equipped with combustion controls and afterburners to ensure good combustion and minimum emissions.

6. Controlled air incinerators - These units operate on the controlled combustion principle in which a small percentage of the air theoretically required to burn the waste is supplied to the main chamber. These units are usually equipped with automatic charging mechanisms and are characterized by the high effluent temperatures reached at the exit of the incinerators.

Emissions and Controls[3]

Operating conditions, refuse composition, and basic incinerator design determine the composition of the effluent and thus the nature of emissions. The manner in which air is supplied to the combustion chamber or chambers has 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 chamber. As underfire air is increased, fly-ash emissions increase. The way in which refuse is charged also has an effect on the particulate emissions. Improper charging disrupts the combustion bed and precipitates release of large quantities of particulates. Emissions of oxides of sulfur are dependent on the sulfur content of the refuse. Nitrogen oxide emissions depend on the temperature of the combustion zones, their residence time in the combustion zone before quenching, and the excess air rate. Carbon monoxide and hydrocarbon emissions also depend on the quantity of air supplied to the combustion chamber and the efficiency of combustion.

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

Table 2-1. 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 5, 7 through 13.

AUTOMOBILE BODY INCINERATION

Process Description[3]

Auto incinerators consist of a primary combustion chamber in which one or several partially stripped cars are burned. (Tires are removed.) Approximately 30 to 40 minutes is required to burn two bodies simultaneously.[22] Up to 50 cars per day can be burned in this batch-type operation, depending on the capacity of the incinerator. Continuous operations in which cars are placed on a conveyor belt and passed through a tunnel-type incinerator have capacities of more than 50 cars per 8-hour day.

Emissions and Controls[3]

Both the degree of combustion as determined by the incinerator design and the amount of combustible material left on the car greatly affect emissions. Temperatures on the order of 1200° F (650° C) are reached during auto body incineration.[22] This relatively low combustion temperature is a result of the large incinerator volume needed to contain the bodies as compared to the small quantity of combustible material. The use of overfire air jets in the primary combustion chamber increases combustion efficiency by providing air and increased turbulence.

In an attempt to reduce the various air pollutants produced by this burning, some auto incinerators are equipped with emission control devices. Afterburners and low-voltage electrostatic precipitators have been used to reduce particulate emissions; the former also reduces some of the gaseous emissions.[23,24] When afterburners are used to control emissions, the temperature in the secondary combustion chamber should be at least 1500° F (815° C). Lower temperatures result in higher emissions. Emission factors for auto body incinerators are presented in Table 2-3.

Table 2-2. EMISSION FACTORS FOR REFUSE INCINERATORS WITHOUT CONTROLS[a]

EMISSION FACTOR RATING: A

Incinerator type	Particulates		Sulfur oxides[b]		Carbon monoxide		Hydrocarbons[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 (8 to 70)	15	1.5	0.75	35(0 to 233)	17.5	1.5	0.75	2	1
With settling chamber and water spray system[f]	14 (3 to 35)	7	1.5	0.75	35(0 to 233)	17.5	1.5	0.75	2	1
Industrial/commercial										
Multiple chamber[g]	7 (4 to 8)	3.5	1.5[h]	0.75	10(1 to 25)	5	3(0.3 to 20)	1.5	3	1.5
Single chamber[i]	15 (4 to 31)	7.5	1.5[h]	0.75	20(4 to 200)	10	15(0.5 to 50)	7.5	2	1
Controlled air[j]	1.4(0.7 to 2)	0.7	1.5	0.75	Neg	Neg	Neg	Neg	10	5
Flue-fed[k]	30 (7 to 70)	15	0.5	0.25	20	10	15(2 to 40)	7.5	3	1.5
Flue-fed (modified)[l,m]	6 (1 to 10)	3	0.5	0.25	10	5	3(0.3 to 20)	1.5	10	5
Domestic single chamber										
Without primary burner[n]	35	17.5	0.5	0.25	300	150	100	50	1	0.5
With primary burner[o]	7	3.5	0.5	0.25	Neg	Neg	2	1	2	1
Pathological[p]	8 (2 to 10)	4	Neg	Neg	Neg	Neg	Neg	Neg	3	1.5

[a] Average factors given based on EPA procedures for incinerator stack testing. Use high side of particulate, HC, and CO emission ranges when operation is intermittent and combustion conditions are poor.

[b] Expressed as SO_2.

[c] Expressed as methane.

[d] Expressed as NO_2.

[e] References 7, and 14 through 19.

[f] Most municipal incinerators are equipped with at least this much control; see Table 2-1 for appropriate efficiencies for other controls.

[g] References 5,7,16,19, and 20.

[h] Based on municipal incinerator data.

[i] References 5,7,16, and 20.

[j] Reference 15.

[k] References 5, 16, 17, and 19 through 21.

[l] With afterburners and draft controls.

[m] References 5, 17, and 20.

[n] References 7 and 16.

[o] Reference 7.

[p] References 5 and 15.

Table 2-3. EMISSION FACTORS FOR AUTO BODY INCINERATION[a]

EMISSION FACTOR RATING: B

Pollutants	Uncontrolled		With afterburner	
	lb/car	kg/car	lb/car	kg/car
Particulates[b]	2	0.9	1.5	0.68
Carbon monoxide[c]	2.5	1.1	Neg	Neg
Hydrocarbons[c] (CH_4)	0.5	0.23	Neg	Neg
Nitrogen oxides[d] (NO_2)	0.1	0.05	0.02	0.01
Aldehydes[d] (HCOH)	0.2	0.09	0.06	0.03
Organic acids[d] (Acetic)	0.3	0.14	0.4	0.18

[a] Based on 250 lb (112 kg) of combustible material on stripped car body.

[b] References 22 and 24.

[c] Based on data for open burning and References 22 and 25.

[d] Reference 24.

CONICAL BURNERS

Process Description[3]

Conical burners are generally a truncated metal cone with a screened top vent. The charge is placed on a raised grate by either conveyor or bulldozer. Use of a conveyor results in more efficient burning than placing the charge by bulldozer. No supplemental fuel is used, but combustion air is often supplemented by underfire air blown into the chamber below the grate and by overfire air introduced through peripheral openings in the shell.

Emissions and Controls

The quantities and types of pollutants released from conical burners are dependent on the composition and moisture content of the charged material, control of combustion air, type of charging system used, and the condition in which the incinerator is maintained. The most critical of these factors seems to be the lack of maintenance on the incinerators. It is not uncommon for conical burners to have missing doors and numerous holes in the shell—resulting in excessive combustion air, low temperatures, and therefore high emission rates.[26]

Particulate control systems have been adapted to conical burners with some success. These control systems include water curtains (wet caps) and water scrubbers. Emission factors for conical burners are shown in Table 2-4.

OPEN BURNING

General Information[3]

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

Table 2-4. EMISSION FACTORS FOR WASTE INCINERATION IN CONICAL BURNERS WITHOUT CONTROLS[a]

EMISSION FACTOR RATING: B

Type of waste	Particulates		Sulfur oxides		Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Municipal refuse[b]	20(10 to 60)[c,d]	10	2	1	60	30	20	10	5	2.5
Wood[e]	1[f]	0.5	0.1	0.05	130	65	11	5.5	1	0.5
	7[g]	3.5								
	20[h]	10								

[a] Moisture content as fired is approximately 50 percent for wood waste.

[b] Except for particulates, factors are based on comparison with other waste disposal practices.

[c] Use high side of range for intermittent operations charged with a bulldozer.

[d] Based on Reference 27.

[e] References 28 through 33.

[f] Satisfactory operation: properly maintained burner with adjustable underfire air supply and adjustable, tangential overfire air inlets, approximately 500 percent excess air and 700° F (370° C) exit gas temperature.

[g] Unsatisfactory operation: properly maintained burner with radial overfire air supply near bottom of shell, approximately 1,200 percent excess air and 400° F (204° C) exit gas temperature.

[h] Very unsatisfactory operation: improperly maintained burner with radial overfire air supply near bottom of shell and many gaping holes in shell, approximately 1,500 percent excess air and 400° F (204° C) exit gas temperature.

Emissions

Ground-level open burning is affected by many variables including wind, ambient temperature, composition and moisture content of the debris burned, size and shape of the debris burned, and compactness of the pile. In general, the relatively low temperatures associated with open burning increase the emissions of particulates, carbon monoxide, and hydrocarbons and suppress the emissions of nitrogen oxides. Sulfur oxide emissions are also a direct function of the sulfur content of the refuse. Emission factors are presented in Table 2-5 for the open burning of three broad categories of waste: (1) municipal refuse, (2) automobile components, and (3) horticultural refuse.

Table 2-5. EMISSION FACTORS FOR OPEN BURNING

EMISSION FACTOR RATING: B

Type of waste	Particulates		Sulfur oxides		Carbon monoxide		Hydrocarbons (CH_4)		Nitrogen oxides	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Municipal refuse[a]	16	8	1	0.5	85	42.5	30	15	6	3
Automobile components[b,c]	100	50	Neg	Neg	125	62.5	30	15	4	2
Horticultural refuse[d]										
Agricultural field burning	17	8.5	Neg	Neg	100	50	20	10	2	1
Landscape refuse and pruning	17	8.5	Neg	Neg	60	30	20	10	2	1
Wood	17	8.5	Neg	Neg	50	25	4	2	2	1

[a] References 25 and 34 through 37.

[b] Upholstery, belts, hoses, and tires burned in common.

[c] Reference 25.

[d] References 25, 36, and 38 through 40.

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3. MOBILE COMBUSTION SOURCES

Transportation in general is a major source of carbon monoxide, hydrocarbons, and nitrogen oxides. In 1968 estimated emissions from all transportation sources in the United States were 64 million tons (58 million MT) of carbon monoxide, 17 million tons (15.4 million MT) of hydrocarbons, and 8 million tons (7.25 million MT) of nitrogen oxides.[1] The primary mobile source of these emissions is the gasoline-powered motor vehicle. Other significant sources include aircraft, diesel-powered trucks and buses, locomotives, and river vessels. Emission factors for these sources are presented in this section. The effects of controls have been shown whenever possible.

GASOLINE—POWERED MOTOR VEHICLES

General

The gasoline-powered motor vehicle category consists of three major types of vehicles: passenger cars, light-duty trucks, and gasoline-powered heavy-duty vehicles. In order to develop an overall emission factor for all gasoline-powered vehicles, each of these classes had to be weighted according to its "relative travel, allowing for the incorporation of new vehicles and scrappage of older vehicles in the overall vehicle population, allowing for the deterioration of vehicles with age and mileage, and allowing for differential travel as a function of vehicle age."[2] In order to take into consideration the control of motor vehicle emissions, the emission factors are presented on a year-by-year basis and are based on applicable Federal standards in effect as of 1971, including those proposed for 1973 and 1975.[3-5] It is emphasized that the factors given in Table 3-1 are for the vehicle population mix for the calendar year given and not for vehicles of that model year only.

These emission factors are presented in Table 3-1 for two types of vehicle operation conditions. Urban travel was assumed to be at an average speed of 25 miles per hour (40 kilometers per hour), beginning from a "cold start," and all rural travel was assumed to be at an average speed of 45 miles per hour (72.5 kilometers per hour), beginning from a "hot start." Exhaust emissions of carbon monoxide and hydrocarbons vary considerably with speed. If emission factors are needed for speeds other than the assumed average speeds for urban and rural driving, Figures 3-1 and 3-2 should be used. For example, the emission factor for hydrocarbon exhaust emissions under urban driving conditions in 1975 for a speed of 10 miles per hour (16 kilometers per hour) would be 1.79 times the exhaust hydrocarbon emissions for that year.

Because legislation has only been proposed for hydrocarbons, carbon monoxide, particulates, and nitrogen oxides, it was not necessary to present the emissions of other pollutants on a year-by-year basis. For this reason, emission factors for sulfur oxides, aldehydes, and organic acids do not vary by year.

Table 3-1. EMISSION FACTORS FOR GASOLINE-POWERED MOTOR VEHICLES[a]

EMISSION FACTOR RATING: A

Emissions	1960		1965		1970		1971		1972		1973		1974		1975	
	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km
Carbon monoxide[b]																
Urban	120	74.5	120	74.5	95	59.0	90	56.0	85	52.8	80	49.7	75	46.6	60	37.2
Rural	70	43.5	70	43.5	60	37.3	55	34.2	50	31.0	45	28.0	40	24.8	35	21.7
Hydrocarbons[b]																
Evaporation	2.7	1.68	2.7	1.68	2.7	1.61	2.3	1.43	2.3	1.43	1.8	1.12	1.8	1.12	1.4	0.87
Crankcase[c]	4.1	2.54	2.7	1.68	0.9	0.56	0.45	0.28	0.45	0.28	0.32	0.2	0.22	0.14	0.22	0.14
Exhausts																
Urban	16	10.0	16	10.0	12	7.45	11	6.83	9.5	5.9	8.5	5.28	7.2	4.5	6	3.72
Rural	10.5	6.53	10.5	6.53	8	5.0	7	4.35	6.5	4.04	6	3.72	5	3.10	4	2.48
Nitrogen oxides (NO_x as NO_2)[b,i]	6.58	4.1	6.60	4.1	6.63	4.12	6.47	4.02	6.17	3.83	5.75	3.57	5.55	3.45	4.90	3.04
Particulates[d,e]	0.3	0.19	0.3	0.19	0.3	0.19	0.3	0.19	0.3	0.19	0.3	0.19	0.3	0.19	0.1	0.062
Sulfur oxides (SO_2)[f]	0.18	0.11	No legislation is in effect or has been proposed for these pollutants, and thus only one factor is presented.													
Aldehydes (HCHO)[g]	0.36	0.224														
Organic acids (acetic)[h]	0.13	0.081														

[a] To convert emission factors to grams/gallon (kg/10^3 liters), assume the average gasoline-powered engines get 12.5 miles/gallon (5.3 km/liter).

[b] Reference 2.

[c] Crankcase emissions for vehicles after 1962 are neglible. These factors are based on pre-1962 vehicles left in the vehicle population.

[d] Reference 6.

[e] Urban factor = rural factor.

[f] Based on sulfur content of 0.04 percent and a density of 6.17 lb/gallon (0.74 kg/liter).

[g] References 7 through 9.

[h] References 7, and 9 through 11.

[i] Updated to reflect revised test cycle and test procedures current in July 1971.

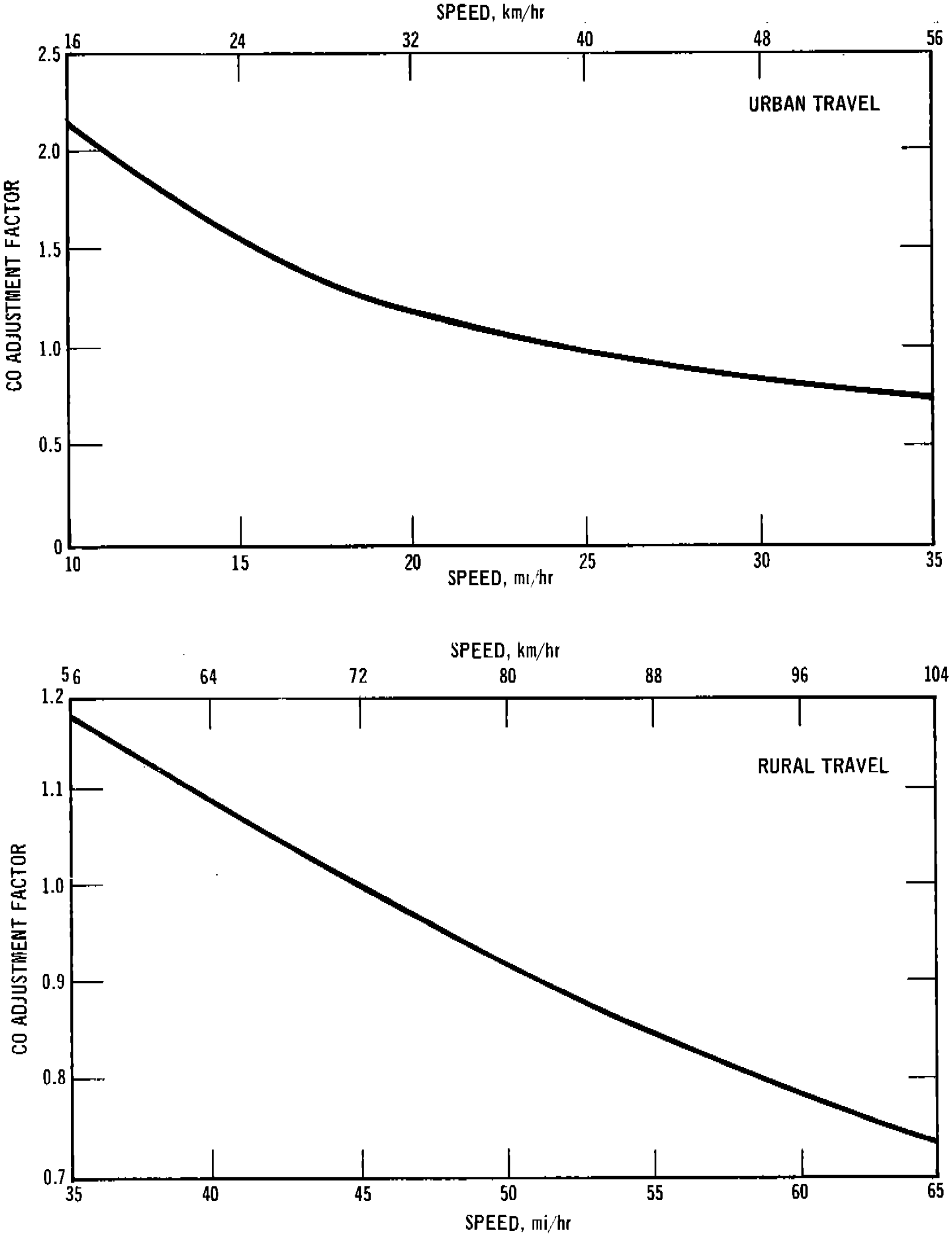

Figure 3-1. Speed adjustment graphs for carbon monoxide emission factors.

Emissions

Air pollutant emissions from motor vehicles come from three principal sources: exhaust, crankcase blow-by, and evaporation from the fuel tank and carburetor. It has been estimated that about 55 percent of the hydrocarbons come from the engine exhaust, 25 percent from the blow-by, and 20 percent from

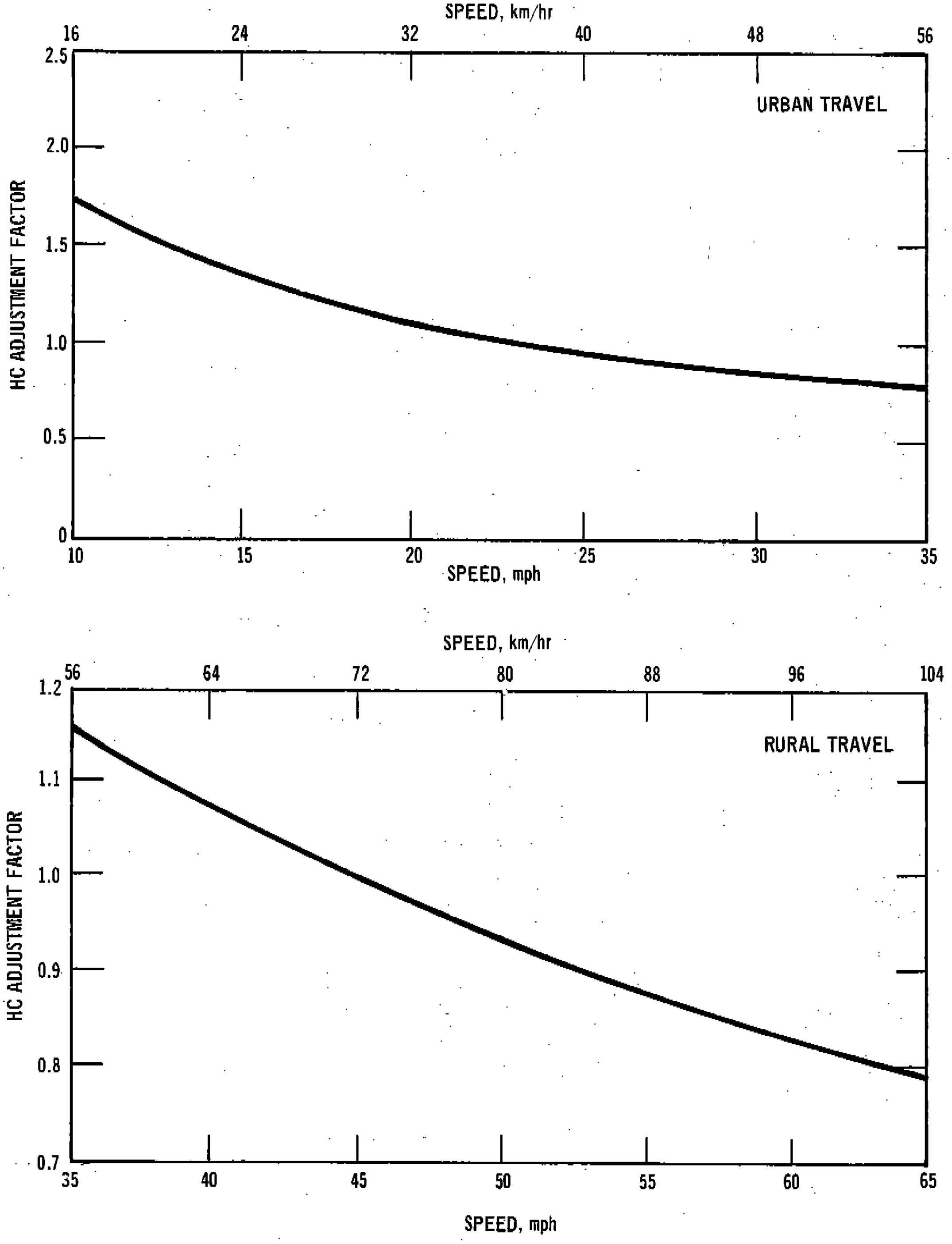

Figure 3-2. Speed adjustment graphs for hydrocarbon exhaust emission factors.

evaporation from the fuel tank and carburetor for an uncontrolled vehicle, whereas essentially all of the carbon monoxide and nitrogen oxides come from the engine exhaust.[12] As a rough approximation, the amount of particulate matter emitted in the blow-by is about one-third to one-half the amount emitted in the exhaust.

Evaporative Emissions - Emissions from the fuel tank result primarily from the evaporation of gasoline in the vehicle tank. These emissions occur under both operating and stationary conditions and are due to the temperature changes in the tank fuel and changes in vapor volume that induce breathing through the tank vent.

Carburetor emissions result under two separate conditions. Running losses occur during vehicle operation as a result of internal carburetor pressures that release hydrocarbon vapors through the external carburetor vents. Hot-soak losses result from evaporation of the fuel in the carburetor float bowl when the vehicle is stationary.

Crankcase Emissions[13] - Gases vented from the engine crankcase through the road draft tube and oil filter tube are, if uncontrolled, the second largest source of hydrocarbon emissions. These emissions consist predominantly of engine blow-by gases, with some crankcase ventilation air and a very limited amount of crankcase lubricant fumes.

Exhaust Emissions[12, 13]

In contrast to the evaporative and crankcase emissions, which are composed predominantly of hydrocarbons, engine exhaust gases additionally contain carbon monoxide, nitrogen oxides, and other combustion products.

The primary factor influencing the formation of carbon monoxide and hydrocarbons is the air/fuel ratio supplied to the engine. The concentrations of these pollutants increase as the air/fuel ratio decreases. Nitrogen oxide formation is influenced by combustion temperature and the amount of oxygen available for reaction with nitrogen. Another major factor in the rate of release of these pollutants is vehicle speed; hydrocarbon and carbon monoxide emissions decrease with an increase in vehicle speed, whereas nitrogen oxides are independent of average vehicle speed.

Particulates, consisting primarily of lead compounds, carbon particles, and motor oil, are also emitted from the engine exhaust. Because of the complex relationships involved, the effects of engine design and other factors on particulate emissions are not well known. Sulfur oxide emissions from engine exhaust are a function of the sulfur content of the gasoline. Because of the low average sulfur content of gasoline (0.035 percent), however, this is not normally a major concern.

DIESEL—POWERED MOTOR VEHICLES

General[14, 15]

Diesel engines have been divided into three primary user categories — heavy-duty trucks, buses, and locomotives. The operating characteristics of a diesel engine are significantly different from the previously discussed gasoline engine.

In a diesel engine, fuel and air are not mixed before they enter the cylinder. The air is drawn through an intake valve and then compressed. The fuel is then injected as a spray into this high-temperature air and ignites without the aid of a spark. Power output of the diesel engines is controlled by the amount of fuel injected for each cycle.

Emissions

Diesel trucks and buses emit pollutants from the same sources as gasoline systems: blow-by, evaporation, and exhaust. Blow-by is practically eliminated in the diesel because only air is in the cylinder during the compression stroke. The low volatility of diesel fuel along with the use of closed injection systems essentially eliminates evaporation losses in diesel systems.

Exhaust emissions from diesel engines have the same general characteristics as auto exhausts. Concentrations of some of the pollutants, however, may vary considerably. Emissions of sulfur dioxide are a direct function of the fuel composition. Thus, because of the higher average sulfur content of diesel fuel (0.35 percent) as compared to gasoline (0.035 percent), sulfur dioxide emissions from diesel exhausts[16, 17] are relatively higher.

Because diesel engines have more complete combustion and use less volatile fuels than spark-ignited engines, their HC and CO emissions are relatively low. Because hydrocarbons in diesel exhaust are largely just unburned diesel fuel, their emissions are related to the volume of fuel sprayed into the combustion chamber. Recently improved needle valve injectors reduce the amount of fuel that can be burned. These valves can reduce hydrocarbon emissions by as much as 50 percent.[18] Both the high temperatures and the large excesses of oxygen involved in diesel combustion are conducive to the high nitrogen oxide emissions.[19]

Particulates from diesel exhaust are in two major forms - black smoke and white smoke. White smoke is emitted when the fuel droplets are kept cool in an environment abundant in oxygen (cold starts). Black smoke, however, is emitted when the fuel droplets are subjected to high temperatures in an environment lacking in oxygen (road conditions).[19]

Emission factors for the three classes of diesel engines, trucks, buses, and locomotives, are presented in Table 3-2.

AIRCRAFT

General[22]

Aircraft engines are of two major categories: reciprocating, or piston, engines and gas turbine engines. There are four basic types of gas turbine engines used for aircraft propulsion: turbofan, turboprop, turbojet, and turboshaft. The gas turbine engine in general consists of a compressor, a combustion chamber, and a turbine. Air entering the forward end of the engine is compressed and then heated by burning fuel. The major portion of the energy in the heated air stream is used for aircraft propulsion. Part of the energy is expended in driving the turbine, which, in turn, drives the compressor.

The basic element in piston engine aircraft is the combustion chamber, or cylinder, in which fuel and air mixtures are burned and from which energy is extracted through a piston and crank mechanism that drives a propeller. Nearly all aircraft piston engines have two or more cylinders and are generally classified according to their cylinder arrangements - either "opposed" or "radial." Opposed engines are installed in most light or utility aircraft. Radial engines are used mainly in large transport aircraft.

Table 3-2. EMISSION FACTORS FOR DIESEL ENGINES[a]

EMISSION FACTOR RATING: B

Pollutant	Heavy-duty truck and bus engines[b]		Locomotives[c]	
	lb/10^3 gal	kg/10^3 liters	lb/10^3 gal	kg/10^3 liters
Particulates	13	1.56	25	3
Oxides of sulfur (SO_x as SO_2)[d]	27	3.24	65	7.8
Carbon monoxide	225	27.0	70	8.4
Hydrocarbons	37	4.44	50	6.0
Oxides of nitrogen (NO_x as NO_2)	370	44.4	75	9.0
Aldehydes (as HCHO)	3	0.36	4	0.48
Organic acids	3	0.36	7	0.84

[a] Data presented in this table are based on weighting factors applied to actual tests conducted at various load and idle conditions with an average gross vehicle weight of 30 tons (27.2 MT) and fuel consumption of 5.0 mi/gal (2.2 km/liter).

[b] Reference 20.

[c] Based on analysis of data from Reference 21.

[d] Data for trucks and buses based on average sulfur content of 0.20 percent, and for locomotives, on average sulfur content of 0.5 percent.

A representative list of various models of aircraft by type is shown in Table 3-3. Both turbofan aircraft and piston engine aircraft have been further subdivided into classes depending on the size of the aircraft. Long-range jets normally have approximately 18,000 pounds maximum thrust, whereas medium-range jets have about 14,000 pounds maximum thrust. For piston engines, this division is more pronounced. The large transport piston engines are in the 500 to 3,000 horsepower range, whereas the smaller piston engines have less than 500 horsepower.

Emissions

Emissions from the various types of aircraft are presented in Table 3-4. Emission factors are presented on the basis of pounds (kilograms) per landing-take-off (LTO) cycle per engine. An LTO cycle includes all normal operational modes performed by an aircraft between the time it descends through an altitude of 3,500 feet (1,100 meters) above the runway on its approach to the time it subsequently reaches the 3,500-foot (1100-meter) altitude after take-off. It should be made clear that the term operation used by the FAA to describe either a landing or a take-off is not the same as the LTO cycle. Two operations are involved in one LTO cycle. The LTO cycle incorporates the ground operations of idle, taxi, landing run, take-off run and the flight operations of take-off and climb-out to 3,500 feet (1,100 meters) and approach from 3,500 feet (1,100 meters) to touchdown.

The rates of emission of air pollutants by aircraft engines, as with other internal combustion engines, are related to the fuel consumption rate. The average amount of fuel used for each phase of an LTO cycle is shown in Table 3-5.

Table 3-3. AIRCRAFT CLASSIFICATION SYSTEM[a]

Aircraft type	Examples of models	Engines most commonly used
Turbofan		
Jumbo jet	Boeing 747, Douglas DC-10, Lockheed L-1011	Pratt & Whitney JT-9D
Long range	Boeing 707, Douglas DC-8	Pratt & Whitney JT-3D
Medium range	Boeing 727, Douglas DC-9	Pratt & Whitney JT-8D
Turbojet	Boeing 707, 720 Douglas DC-8	Pratt & Whitney JT-3C Pratt & Whitney JT-4A General Electric CJ 805-3B
Turboprop	Convair 580, Electra L-188, Fairchild Hiller FH-227	General Motors-Allison 501-D13
Turboshaft	Sikorsky S-61, Vertol 107	General Electric CT58
Piston		
Transport	Douglas DC-6, Lockheed L-1049	Pratt & Whitney R-2800
Light	Cessna 210, Piper 32-300	Continental 10-520-A

[a] References 22 through 24.

These data can be used in conjunction with the emission factors presented in Table 3-4 to determine an emission factor in pounds per gallon (kilograms per liter) per engine.

VESSELS

General[29]

Fuel oil is the primary fuel used in vessels. It powers steamships, motor ships, and gas-turbine-powered ships. Gas turbines presently are not in widespread use and are thus not included in this section. However, within the next few years they will become increasingly common.[30, 31]

Steamships are any ships that have steam turbines driven by an external combustion engine. Motor ships, on the other hand, have internal combustion engines operated on the diesel cycle.

Emissions

The air pollutant emissions resulting from vessel operations may be divided into two groups: emissions that occur as the ship is underway and emissions that occur when the ship is dockside or in-berth.

Underway emissions may vary considerably for vessels that are maneuvering or docking because of the varying fuel consumption. During such a time a vessel is operated under a wide range of power demands for a period of 15 minutes to 1 hour. The high demand may be 15 times the low demand; however, once the vessel has reached and sustained a normal operation speed, the fuel consumed is reasonably constant. Table 3-6 shows that 29 to 65 gallons of fuel oil is consumed per nautical mile (60 to 133 liters per kilometer) for steamships and 7 to 30 gallons of oil, per nautical mile (14 to 62 liters per kilometer) for motorships.

Table 3-4. EMISSION FACTORS FOR AIRCRAFT

(lb/engine - LTO cycle and kg/engine - LTO cycle)

EMISSION FACTOR RATING: A

Type of aircraft	Particulates		Sulfur oxides		Carbon monoxide		Hydrocarbons		Nitrogen oxides		Aldehydes[a]	
	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg
Turbofan												
Jumbo jet[b,c]	10	4.54	2	0.91	28	12.7	3	1.36	6	2.72	0.5	0.23
Long range[d,e]	8	3.63	2	0.91	26	11.8	17	7.7	5	2.27	0.5	0.23
Medium range[d,f]	7	3.18	2	0.91	16	7.3	(0.6 to 86)[g]	0.27 to 39.0[g]	7	3.18	0.5	0.23
Turbojet[d,h]	11	5.0	2	0.91	24	10.9	26	11.8	5	2.27	1.0	0.45
Turboprop[i,j]	6	2.72	1	0.45	2	0.91	3	1.36	5	2.27	0.2	0.09
Turboshaft[k,l]	3	1.36	1	0.45	6	2.72	0.5	0.23	0.6	0.27	0.2	0.09
Piston												
Transport[k,m]	5	2.27	0.13	0.059	303	137.0	40	18.2	0.4	0.18	0.2	0.09
Light[n]	0.2	0.09	0.01	0.0045	12	5.5	0.4	0.18	0.2	0.09	0.1	0.05

[a] Estimates based on old data in Reference 25.

[b] Reference 26.

[c] Based on Pratt & Whitney JT-9D engine.

[d] References 26 and 27.

[e] Based on Pratt & Whitney JT-3D engine.

[f] Based on Pratt & Whitney JT-8D engine.

[g] Use 50 (22.7) for uncontrolled jets and 3 (1.36) for jets equipped with smoke burner cans.

[h] Based on General Electric CJ805-3B, Pratt & Whitney JT-3C-6, and Pratt & Whitney JT-4A engines.

[i] Reference 27.

[j] Based on General Motors-Allison 501-D13 engine.

[k] Reference 22.

[l] Based on General Electric CT 58 engine.

[m] Typical engine used is the Pratt & Whitney R-2800.

[n] References 22 and 28.

Table 3-5. FUEL CONSUMPTION RATES FOR VARIOUS TYPES OF AIRCRAFT DURING LANDING AND TAKE-OFF CYCLE

Type of aircraft	Taxi and idle		Landing and approach		Take-off and climb-out		Total LTO cycle	
	gal/engine	liters/engine	gal/engine	liters/engine	gal/engine	liters/engine	gal/engine	liters/engine
Turbofan								
Jumbo jet[a]	75	284	100	379	150	568	325	1,230
Long range[b]	35	133	30	114	115	435	180	682
Medium range[b]	35	133	40	151	95	360	170	644
Turbojet[b]	50	189	50	189	120	455	220	833
Turboprop[b]	30	114	15	56.8	25	95	70	265
Turboshaft[c]	5	18.9	0	0	20	96	25	94.6
Piston								
Transport[c]	10	37.9	5	18.9	30	114	45	170
Light[c]	1	3.79	0.2	0.76	1	3.79	2.2	8.33

[a] Reference 26.

[b] Reference 27.

[c] Reference 22.

Table 3-6. FUEL CONSUMPTION RATES FOR STEAMSHIPS AND MOTOR SHIPS[a]

Fuel consumption	Steamships		Motor ships	
	Range	Average	Range	Average
Underway				
lb/hp-hr	0.51 to 0.65	0.57	0.28 to 0.44	0.34
kg/hp-hr	0.23 to 0.29	0.26	0.13 to 0.20	0.15
gal/naut mile	29 to 65	44	7 to 30	19
liters/kilometer	59.4 to 133	90	14 to 62	38.8
In-berth				
gal/day	840 to 3,800	1,900	240 to 1,260	660
liters/day	3,192 to 14,400	7,200	910 to 4,800	2,500

[a] Reference 29.

Unless a ship goes immediately into drydock or is otherwise out of operation after arrival in port, she continues her emissions at dockside. Power must be generated for the ship's light, heat, pumps, refrigeration, ventilation, etc. A few steamships use auxiliary engines to supply power, but they generally operate one or two main boilers under reduced draft and lowered fuel rates, a much less efficient process. Motor ships generally use diesel-powered generators to furnish auxiliary power.

As shown in Table 3-6, fuel oil consumption at dockside varies appreciably. Based on the data presented in this table and the emission factors for residual fuel-oil combustion and diesel-oil combustion, emission factors have been determined for vessels and are presented in Table 3-7.

Table 3-7. EMISSION FACTORS FOR VESSELS

EMISSION FACTOR RATING: D

Pollutant	Steamships[a]				Motor ships[b]			
	Underway		In-berth		Underway		In-berth	
	lb/mi	kg/km	lb/day	kg/day	lb/mi	kg/km	lb/day	kg/day
Particulate	0.4	0.098	15	6.8	2	0.49	16.5	7.5
Sulfur dioxide[c]	7S	1.71S	300S	136S	(SO_x) 1.5	0.37	43	19.5
Sulfur trioxide[c]	0.1S	0.02S	4S	1.8S				
Carbon monoxide	0.002	0.0005	0.08	0.036	1.2	0.29	46	20.8
Hydrocarbons	0.2	0.05	9	4.1	0.9	0.22	33	14.9
Nitrogen oxides (NO_2)	4.6	1.13	200	90.7	1.4	0.34	50	22.7
Aldehydes (HCHO)	0.04	0.01	2	0.9	0.07	0.017	2.6	1.2

[a] Based on data in Table 3-6 and emission factors for fuel oil.

[b] Based on data in Table 3-6 and emission factors for diesel fuel.

[c] S = weight percent sulfur in fuel; assumed to be 0.5 percent for diesel.

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4. EVAPORATION LOSS SOURCES

Evaporation losses include the organic solvents emitted from dry-cleaning plants and surface-coating operations as well as the volatile matter in petroleum products. This section presents the hydrocarbon emissions from these sources, including petroleum storage and gasoline marketing. Where possible the effect of controls to reduce the emissions of organic compounds has been shown.

DRY CLEANING

General[1]

Clothing and other textiles may be cleaned by treating them with organic solvents. This treatment process involves agitating the clothing in a solvent bath, rinsing with clean solvent, and drying with warm air.

There are basically two types of dry-cleaning installations: those using petroleum solvents [Stoddard and 140° F (60° C)] and those using chlorinated synthetic solvents (perchloroethylene). The trend in dry-cleaning operations today is toward smaller package operations located in shopping centers and suburban business districts that handle approximately 1500 pounds (675 kg) of clothes per week on the average. These plants almost exclusively use perchloroethylene, whereas the older, larger dry-cleaning plants use petroleum solvents. It has been estimated that perchloroethylene is used on 50 percent of the weight of clothes dry-cleaned in the United States today and that 70 percent of the dry-cleaning plants use perchloroethylene.[2]

Emissions and Controls[1]

The major source of hydrocarbon emissions in dry cleaning is the tumbler through which hot air is circulated to dry the clothes. Drying leads to vaporization of the solvent and consequent emissions to the atmosphere, unless control equipment is used. The primary control element in use in synthetic solvent plants is a water-cooled condenser that is an integral part of the closed cycle in a tumbler or drying system. Up to 95 percent of the solvent that is evaporated from the clothing is recovered here. About half of the remaining solvent is then recovered in an activated-carbon adsorber, giving an overall control efficiency of 97 to 98 percent. There are no commercially available control units for solvent recovery in petroleum-based plants because it is not economical to recover the vapors. Emission factors for dry-cleaning operations are shown in Table 4-1.

It has been estimated that about 18 pounds (8.2 kilograms) per capita per year of clothes are cleaned in moderate climates[3] and about 25 pounds (11.3 kilograms) per capita per year, in colder areas.[4] Based on this information and the facts that 50 percent of all solvents used are petroleum based[2] and 25 percent of the synthetic solvent plants are controlled,[5] emission factors can be determined on a pounds- (kilograms-) per-capita basis. Thus approximately 2 pounds (0.9 kilogram) per capita per year are emitted from dry-cleaning plants in moderate climates and 2.7 pounds (1.23 kilograms) per capita per year in colder areas.

Table 4-1. HYDROCARBON EMISSION FACTORS FOR DRY-CLEANING OPERATIONS

EMISSION FACTOR RATING: C

Control	Petroleum solvents		Synthetic solvents	
	lb/ton	kg/MT	lb/ton	kg/MT
Uncontrolled[a]	305	152.5	210	105
Average control[b]	--	--	95	47.5
Good control[c]	--	--	35	17.5

[a] References 2, 4, 6, and 7.

[b] Reference 6.

[c] Reference 8.

SURFACE COATING

Process Description[9, 10]

Surface-coating operations primarily involve the application of paint, varnish, lacquer, or paint primer for decorative or protective purposes. This is accomplished by brushing, rolling, spraying, flow coating, and dipping. Some of the industries involved in surface-coating operations are automobile assemblies, aircraft companies, container manufacturers, furniture manufacturers, appliance manufacturers, job enamelers, automobile repainters, and plastic products manufacturers.

Emissions and Controls[1]

Emissions of hydrocarbons occur in surface-coating operations because of the evaporation of the paint vehicles, thinners, and solvents used to facilitate the application of the coatings. The major factor affecting these emissions is the amount of volatile matter contained in the coating. The volatile portion of most common surface coatings averages approximately 50 percent, and most, if not all, of this is emitted during the application and drying of the coating. The compounds released include aliphatic and aromatic hydrocarbons, alcohols, ketones, esters, alkyl and aryl hydrocarbon solvents, and mineral spirits. Table 4-2 presents emission factors for surface-coating operations.

Control of the gaseous emissions can be accomplished by the use of adsorbers (activated carbon) or afterburners. The collection efficiency of activated carbon has been reported at 90 percent or greater. Water curtains or filter pads have little or no effect on escaping solvent vapors; they are widely used, however, to stop paint particulate emissions.

PETROLEUM STORAGE

General[11, 12]

In the storage and handling of crude oil and its products, evaporation losses may occur. These losses may be divided into two categories: breathing loss and

Table 4-2. GASEOUS HYDROCARBON EMISSION FACTORS FOR SURFACE-COATING APPLICATIONS[a]

EMISSION FACTOR RATING: B

Type of coating	Emissions[b]	
	lb/ton	kg/MT
Paint	1,120	560
Varnish and shellac	1,000	500
Lacquer	1,540	770
Enamel	840	420
Primer (zinc chromate)	1,320	660

[a] Reference 9.

[b] Reported as undefined hydrocarbons, usually organic solvents both aryl and alkyl. Paints weigh 10 to 15 pounds per gallon (1.2 to 1.9 kilograms per liter); varnishes weigh about 7 pounds per gallon (0.84 kilogram per liter).

working loss. Breathing losses are associated with the thermal expansion and contraction of the vapor space resulting from the daily temperature cycle. Working losses are associated with a change in liquid level in the tank (filling or emptying).

Emissions

There are two major classifications of tanks used to store petroleum products: fixed-roof tanks and floating-roof tanks. The evaporation losses from both of these types of tanks depend on a number of factors, such as type of product stored (gasoline or crude oil), vapor pressure of the stored product, average temperature of the stored product, tank diameter and construction, color of tank paint, and average wind velocity of the area. In order to estimate emissions from a given tank, References 11 and 13 should be used. An average factor can be obtained, however, by making a few assumptions. These average factors for both breathing losses and working losses for fixed-roof and floating-roof tanks are presented in Table 4-3.

GASOLINE MARKETING

General

In the marketing of gasoline from the original storage and distribution to the final use in motor vehicles, there are five major points of emission:

1. Breathing and working losses from storage tanks at refineries and bulk terminals.
2. Filling losses from loading-tank conveyances at refineries and bulk terminals (included under working losses from storage tanks).
3. Filling losses from loading underground storage tanks at service stations.

Table 4-3. HYDROCARBON EMISSION FACTORS FOR EVAPORATION LOSSES FROM THE STORAGE OF PETROLEUM PRODUCTS

EMISSION FACTOR RATING: C

Type of tank[a]	Units	Type of material stored: Gasoline or finished petroleum product	Type of material stored: Crude oil
Fixed roof			
Breathing loss[b]	lb/day-1000 gal storage capacity	0.4	0.3
	kg/day-1000 liters storage capacity	0.05	0.04
Working loss[b,c]	lb/1000 gal throughput	11	8
	kg/1000 liters throughput	1.32	0.96
Floating roof			
Breathing loss[d]	lb/day-tank	140(40 to 210)[e]	100(30 to 160)[f]
	kg/day-tank	63.5	45.4
Working loss[d]	lb/1000 gal throughput	Neg	Neg
	kg/1000 liters throughput	Neg	Neg

[a] For tanks equipped with vapor-recovery systems, emissions are negligible.[14]

[b] Reference 11.

[c] An average turnover rate for petroleum storage is approximately 6.[14] Thus, the throughput is equal to 6 times the capacity.

[d] Reference 13.

[e] 140 (63.5) based on average conditions and tank diameter of 100 ft (30.5 m); use 40 (18.1 kg) for smaller tanks, 50 ft (15.3 m) diameter; use 210 (95 kg) for larger tanks, 150 ft (45.8 m) diameter.

[f] Use 30 (13.6 kg) for smaller tanks, 50 ft (15.3 m) diameter; use 160 (72.5 kg) for larger tanks, 150 ft (45.8 m) diameter.

4. Spillage and filling losses in filling automobile gas tanks at service stations.

5. Evaporative losses from the carburetor and gas tank of motor vehicles.

In this section only points 3 and 4 will be discussed. Points 1 and 2 have been covered in the section on petroleum storage and point 5 is covered under the section on gasoline-powered motor vehicles.

Emissions and Controls

The emissions associated with gasoline marketing are primarily vapors expelled from a tank by displacement as a result of filling. The vapor losses are a function of the method of filling the tank (either splash or submerged fill). Splash and submerged fill have been defined as follows: "In splash fill the gasoline enters the top of the fill pipe and then has a free fall to the liquid surface in the tank. The free falling tends to break up the liquid stream into droplets. As these droplets strike the liquid surface, they carry entrained air into the liquid, and a 'boiling' action results as this air escapes up through the liquid surface. The net effect of these actions is the creation of additional vapors in the tank. In submerged filling, the gasoline flows to the bottom of the tank through the fill pipes and enters below the surface of the liquid. This method of filling creates very little disturbance in the liquid bath and, consequently, less vapor formation than splash filling."[15]

Emission factors for gasoline marketing are shown in Table 4-4. As is shown in footnote "b," if a vapor-return system in which the underground tank vent line is left open is used, losses from filling service station tanks can be greatly reduced. If a displacement type, closed vapor-return system is employed, the losses can be almost completely eliminated.

Table 4-4. EMISSION FACTORS FOR EVAPORATION LOSSES FROM GASOLINE MARKETING

EMISSION FACTOR RATING: B

Point of emission	Emissions	
	$lb/10^3$ gal	$kg/10^3$ liters
Filling service station tanks[a,b]		
Splash fill	12	1.44
Submerged fill	7	0.84
50% splash fill and 50% submerged fill	9	1.08
Filling automobile tanks[c]	12	1.44

[a] Reference 15.

[b] With a vapor return, open-system emissions can be reduced to approximately 0.8 $lb/10^3$ gal (0.096 $kg/10^3$ liters), and closed-system emissions are negligible.

[c] References 16 and 17.

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5. CHEMICAL PROCESS INDUSTRY

This section deals with emissions from the manufacture and/or use of chemicals or chemical products. Potential emissions from many of these processes are high, but because of the nature of the compounds they are usually recovered as an economic necessity. In other cases, the manufacturing operation is run as a closed system allowing little or no escape to the atmosphere.

In general, the emissions that reach the atmosphere from chemical processes are primarily gaseous and are controlled by incineration, adsorption, or absorption. In some cases particulate emissions may also be a problem. The particulates emitted are generally extremely small and require very efficient treatment for removal. Emission data from chemical processes are sparse. It was therefore necessary frequently to form estimates of emission factors based on material balances, yields, or similar processes.

ADIPIC ACID

Process Description[1]

Adipic acid, $COOH \cdot (CH_2)_4 \cdot COOH$, is a dibasic acid used in the manufacture of synthetic fibers. The acid is made in a continuous two-step process. In the first step, cyclohexane is oxidized by air over a catalyst to a mixture of cyclohexanol and cyclohexanone. In the second step, adipic acid is made by the catalytic oxidation of the cyclohexanol-cyclohexanone mixture using 45 to 55 percent nitric acid. The final product is then purified by crystallization.[2]

Emissions

The only significant emissions from the manufacture of adipic acid are nitrogen oxides. In oxidizing the cyclohexanol/cyclohexanone, nitric acid is reduced to unrecoverable N_2O and potentially recoverable NO and NO_2. This NO and NO_2 can be emitted into the atmosphere. Table 5-1 shows typical emissions of NO and NO_2 from an adipic acid plant.

Table 5-1. EMISSION FACTORS FOR AN ADIPIC ACID PLANT
WITHOUT CONTROL EQUIPMENT
EMISSION FACTOR RATING: D

Source	Nitrogen oxides (NO,NO_2) emissions	
	lb/ton	kg/MT
Oxidation of cyclohexanol/cyclohexanone[a]	12	6

[a] Reference 1.

AMMONIA

Process Description[3]

The manufacture of ammonia (NH_3) is accomplished primarily by the catalytic reaction of hydrogen and nitrogen at high temperatures and pressures. In a typical plant a hydrocarbon feed stream (usually natural gas) is desulfurized, mixed with steam, and catalytically reformed to carbon monoxide and hydrogen. Air is introduced into the secondary reformer to supply oxygen and provide a nitrogen to hydrogen ratio of 1 to 3. The gases then enter a two-stage shift converter that allows the carbon monoxide to react with water vapor to form carbon dioxide and hydrogen. The gas stream is next scrubbed to yield a gas containing less than 1 percent CO_2. A methanator may be used to convert quantities of unreacted CO to inert CH_4 before the gases, now largely nitrogen and hydrogen in a ratio of 1 to 3, are compressed and passed to the converter. Alternatively, the gases leaving the CO_2 scrubber may pass through a CO scrubber and then to the converter. The synthesis gases finally react in the converter to form ammonia.

Emissions and Controls[3]

When a carbon monoxide scrubber is used before sending the gas to the converter, the regenerator offgases contain significant amounts of carbon monoxide (73 percent) and ammonia (4 percent). This gas may be scrubbed to recover ammonia and then burned to utilize the CO fuel value.[4]

The converted ammonia gases are partially recycled, and the balance is cooled and compressed to liquefy the ammonia. The non-condensable portion of the gas stream, consisting of unreacted nitrogen, hydrogen, and traces of inerts such as methane, carbon monoxide, and argon, is largely recycled to the converter. However, to prevent the accumulation of these inerts, some of the non-condensable gases must be purged from the system.

The purge or bleed-off gas stream contains about 15 percent ammonia.[4] Another source of ammonia is the gases from the loading and storage operations. These gases may be scrubbed with water to reduce the atmospheric emissions. In addition, emissions of CO and ammonia can occur from plants equipped with CO-scrubbing systems. Emission factors are presented in Table 5-2.

CARBON BLACK

Carbon black is produced by the reaction of a hydrocarbon fuel such as oil or gas, or both, with a limited supply of air at temperatures of 2500° to 3000° F (1370° to 1650°C). Part of the fuel is burned to CO_2, CO, and water, thus generating heat for the combustion of fresh feed. The unburned carbon is collected as a black fluffy particle. The three basic processes for producing this compound are the furnace process, accounting for about 83 percent of production; the older channel process, which accounts for about 6 percent of production; and the thermal process.

Channel Black Process[3]

In the channel black process, natural gas is burned with a limited air supply in long, low buildings. The flame from this burning impinges on long steel channel sections that swing continuously over the flame. Carbon black is deposited on the

Table 5-2. EMISSION FACTORS FOR AMMONIA MANUFACTURING WITHOUT CONTROL EQUIPMENT[a]

EMISSION FACTOR RATING: B

Type of source	Carbon monoxide		Hydrocarbons[b]		Ammonia	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Plants with methanator						
Purge gas[c]	Neg	Neg	90	45	3	1.5
Storage and loading[c]	-	-	-	-	200	100
Plants with CO absorber and regeneration system						
Regenerator exit[d]	200	100	-	-	7	3.5
Purge gas[c]	Neg	Neg	90	45	3	1.5
Storage and loading[c]	-	-	-	-	200	100

[a] References 4 and 5.

[b] Expressed as methane.

[c] Ammonia emissions can be reduced by 99 percent by passing through three stages of a packed-tower water scrubber. Hydrocarbons are not reduced.

[d] A two-stage water scrubber and incineration system can reduce these emissions to a negligible amount.

channels, is scraped off, and falls into collecting hoppers. The combustion gases containing the solid carbon that is not collected on the channels, in addition to carbon monoxide and other combustion products, are then vented directly from the building. Approximately 1 to 1.5 pounds of carbon black is produced from the 32 pounds of carbon available in 1000 cubic feet of natural gas (16 to 24 kilograms carbon black from the 513 kilograms in 1000 cubic meters).[6-8] The balance is lost as CO, CO_2, hydrocarbons, and particulates.

Furnace Process[3]

The furnace process is subdivided into either the gas or oil process depending on the primary fuel used to produce the carbon black. In either case, the fuel—gas in the gas process or gas and oil in the oil process—is injected into a reactor with a limited supply of combustion air. The combustion gases containing the hot carbon are then rapidly cooled to a temperature of about 500° F (260° C) by water sprays and by radiant cooling.

The largest and most important portion of the furnace process consists of the particulate or carbon black removal equipment. While many combinations of control equipment exist, an electrostatic precipitator, a cyclone, and a fabric filter system in series are most commonly used to collect the carbon black. Gaseous emissions of carbon monoxide and hydrocarbons are not controlled in the United States.

Thermal Black Process[3]

In thermal black plants, natural gas is decomposed by heat in the absence of air or flame. In this cyclic operation, methane is pyrolyzed or decomposed by passing it over a heated brick checkerwork at a temperature of about 3000° F (1650° C). The decomposed gas is then cooled and the carbon black removed by a series of cyclones and fabric filters. The exit gas, consisting largely of hydrogen (85 percent), methane (5 percent), and nitrogen, is then either recycled to the process burners or used to generate steam in a boiler. Because of the recycling of the effluent gases, there are essentially no atmospheric emissions from this process, other than from product handling.

Table 5-3 presents the emission factors from the various carbon black processes. Nitrogen oxide emissions are not included but are believed to be low because of the lack of available oxygen in the reaction.

Table 5-3. EMISSION FACTORS FOR CARBON BLACK MANUFACTURING[a]

EMISSION FACTOR RATING: C

Type of process	Particulate		Carbon monoxide		Hydrogen sulfide		Hydrocarbons[b]	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Channel	2,300	1,150	33,500	16,750	-	-	11,500	5,750
Thermal	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg
Furnace								
Gas	c	c	5,300	2,650	-	-	1,800	900
Oil	c	c	4,500	2,250	38S[d]	19S[d]	400	200
Gas or oil	220[e]	110[e]						
	60[f]	30[f]						
	10[g]	5[g]						

[a] Based on data in References 6, 7, 9, and 10.

[b] As methane.

[c] Particulate emissions cannot be separated by type of furnace and are listed for either gas or oil furnaces.

[d] S is the weight percent sulfur in feed.

[e] Overall collection efficiency was 90 percent with no collection after cyclone.

[f] Overall collection efficiency was 97 percent with cyclones followed by scrubber.

[g] Overall collection efficiency was 99.5 percent with fabric filter system.

CHARCOAL

Process Description[3]

Charcoal is generally manufactured by means of pyrolysis, or destructive distillation, of wood waste from members of the deciduous hardwood species. In this process, the wood is placed in a retort where it is externally heated for about 20 hours at 500° to 700° F (260° to 370° C). Although the retort has air intakes at the bottom, these are only used during start-up and thereafter are closed. The entire distillation cycle takes approximately 24 hours, the last 4 hours being an exothermic reaction. Four units of hardwood are required to produce one unit of charcoal.

Emissions and Controls[3]

In the pyrolysis of wood, all the gases, tars, oils, acids, and water are driven off, leaving virtually pure carbon. All of these except the gas, which contains methane, carbon monoxide, carbon dioxide, nitrogen oxides, and aldehydes, are useful by-products if recovered. Unfortunately, economics has rendered the recovery of the distillate by-products unprofitable, and they are generally permitted to be discharged to the atmosphere. If a recovery plant is utilized, the gas is passed through water-cooled condensers. The condensate is then refined while the remaining cool, non-condensable gas is discharged to the atmosphere. Gaseous emissions can be controlled by means of an afterburner because the unrecovered by-products are combustible. If the afterburner operates efficiently, no organic pollutants should escape into the atmosphere. Emission factors for the manufacture of charcoal are shown in Table 5-4.

Table 5-4. EMISSION FACTORS FOR CHARCOAL MANUFACTURING[a]

EMISSION FACTOR RATING: C

	Type of operation			
	With chemical recovery plant		Without chemical recovery plant	
Pollutant	lb/ton	kg/MT	lb/ton	kg/MT
Particulate (tar, oil)	-	-	400	200
Carbon monoxide	320[b]	160[b]	320[b]	160[b]
Hydrocarbons[c]	100[b]	50[b]	100[b]	50[b]
Crude methanol	-	-	152	76
Acetic acid	-	-	232	116
Other gases (HCHO, N_2, NO)	60	30	60[b]	30[b]

[a] Calculated values based on data in Reference 11.

[b] Emissions are negligible if afterburner is used.

[c] Expressed as methane.

CHLOR–ALKALI

Process Description[12]

Chlorine and caustic are produced concurrently by the electrolysis of brine in either the diaphragm or mercury cell. In the diaphragm cell, hydrogen is liberated at the cathode and a diaphragm is used to prevent contact of the chlorine produced at the anode with either the alkali hydroxide formed or the hydrogen. In the mercury cell, liquid mercury is used as the cathode and forms an amalgam with the alkali metal. The amalgam is removed from the cell and is allowed to react with water in a separate chamber, called a denuder, to form the alkali hydroxide and hydrogen.

Chlorine gas leaving the cells is saturated with water vapor and then cooled to condense some of the water. The gas is further dried by direct contact with strong sulfuric acid. The dry chlorine gas is then compressed for in-plant use or is cooled further by refrigeration to liquefy the chlorine.

Caustic as produced in a diaphragm-cell plants leaves the cell as a dilute solution along with unreacted brine. The solution is evaporated to increase the concentration to a range of 50 to 73 percent; evaporation also precipitates most of the residual salt, which is then removed by filtration. In mercury-cell plants, high-purity caustic can be produced in any desired strength and needs no concentration.

Emissions and Controls[12]

Emissions from diaphragm- and mercury-cell chlorine plants include chlorine gas, carbon dioxide, carbon monoxide, and hydrogen. Gaseous chlorine is present in the blow gas from liquefaction, from vents in tank cars and tank containers during loading and unloading, and from storage tanks and process transfer tanks. Other emissions include mercury vapor from mercury cathode cells and chlorine from compressor seals, header seals, and the air blowing of depleted brine in mercury-cell plants.

Chlorine emissions from chlor-alkali plants may be controlled by one of three general methods: (1) use of the gas in other plant processes, (2) neutralization in alkaline scrubbers, and (3) recovery of chlorine from effluent gas streams. The effect of specific control practices is shown to some extent in the table on emission factors (Table 5-5).

Table 5-5. EMISSION FACTORS FOR CHLOR-ALKALI PLANTS[a]

EMISSION FACTOR RATING: B

Type of source	Chlorine gas	
	lb/100 tons	kg/100 MT
Liquefaction blow gases		
Diaphragm cell - uncontrolled	2,000 to 10,000	1,000 to 5,000
Mercury cell[b] - uncontrolled	4,000 to 16,000	2,000 to 8,000
Water absorber	25 to 1,000	12.5 to 500
Caustic or lime scrubber	1	0.5
Loading of chlorine		
Tank car vents	450	225
Storage tank vents	1,200	600
Air-blowing of mercury-cell brine	500	250

[a] References 12 and 13.

[b] Mercury cells lose about 1.5 pounds mercury per 100 tons (0.75 kg/100 MT) of chlorine liquefied.

EXPLOSIVES

General

An explosive is a material that, under the influence of thermal or mechanical shock, decomposes rapidly and spontaneously with the evolution of large amounts of heat and gas.[14] Explosives fall into two major categories: high explosives and low explosives. Although a multitude of different types of explosives exists, this section will deal only with an example of each major category: TNT as the high explosive and nitrocellulose as the low explosive.

TNT Production[15]

TNT is usually prepared by a batch three-stage nitration process using toluene, nitric acid, and sulfuric acid as raw materials. A combination of nitric acid and fuming sulfuric acid (oleum) is used as the nitrating agent. Spent acid from the nitration vessels is fortified with make-up nitric acid before entering the next nitrator. The spent acid from the primary nitrator and the fumes from all the nitrators are sent to the acid-fume recovery system. This system supplies the make-up nitric acid needed in the process. After nitration, the undesired by-products are removed from the TNT by agitation with a solution of sodium sulfite and sodium hydrogen sulfite (Sellite process). The wash waste (commonly called red water) from this purification process is either discharged directly into a stream or is concentrated to a slurry and incinerated. The TNT is then solidified, granulated, and moved to the packing house for shipment or storage.

Nitrocellulose[15]

Nitrocellulose is prepared in the United States by the "mechanical dipper" process. This batch process involves dripping the cellulose into a reactor (niter pot) containing a mixture of concentrated nitric acid and a dehydrating agent such as sulfuric acid, phosphoric acid, or magnesium nitrate. When nitration is complete, the reaction mixtures are centrifuged to remove most of the spent acid. The centrifuged nitrocellulose is then "drowned" in water and pumped as a water slurry to the final purification area.

Emissions

Emissions of sulfur oxides and nitrogen oxides from processes that produce some of the raw materials for explosives production, such as nitric acid and sulfuric acid, can be considerable. Because all of the raw materials are not manufactured at the explosives plant, it is imperative to obtain detailed process information for each plant in order to estimate emissions. The emissions from the manufacture of nitric acid and sulfuric acid are not included in this section as they are discussed in other sections of this publication.

The major emissions from the manufacturing of explosives are nitrogen oxides. The nitration reactors for TNT production and the reactor pots and centrifuges for nitrocellulose represent the largest nitrogen oxide sources. Sulfuric acid regenerators or concentrators, considered an integral part of the process, are the major sources of sulfur oxide emissions. Emission factors for explosives manufacturing are presented in Table 5-6.

HYDROCHLORIC ACID

Hydrochloric acid is manufactured by a number of different chemical processes. Approximately 80 percent of the hydrochloric acid, however, is produced by the by-product hydrogen chloride process, which will be the only process discussed in this section. The synthesis process and the Mannheim process are of secondary importance.

Table 5-6. EMISSION FACTORS FOR EXPLOSIVES MANUFACTURING WITHOUT CONTROL EQUIPMENT
EMISSION FACTOR RATING: C

Type of process	Particulate		Sulfur oxides (SO_2)		Nitrogen oxides (NO_2)	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
High explosives						
TNT						
Nitration reactors[a]	-	-	-	-	160	80
Nitric acid concentrators[b]	-	-	-	-	1	0.5
Sulfuric acid regenerators[c]	0.4	0.2	18	9	-	-
Red water incinerator[c,d]	36	18	13	6.5	6	3
Nitric acid manufacture		(See section on nitric acid)				
Low explosives						
Nitrocellulose[e]						
Reactor pots	-	-	-	-	12	6
Sulfuric acid concentrators	-	-	65	32.5	29	14.5

[a] With bubble cap absorption, system is 90 to 95 percent efficient.

[b] References 16 and 17.

[c] Reference 17.

[d] Not employed in manufacture of TNT for commercial use.[18]

[e] Reference 19.

Process Description[20]

By-product hydrogen chloride is produced when chlorine is added to an organic compound such as benzene, toluene, and vinyl chloride. Hydrochloric acid is produced as a by-product of this reaction. An example of a process that generates hydrochloric acid as a by-product is the direct chlorination of benzene. In this process benzene, chlorine, hydrogen, air, and some trace catalysts are the raw materials that produce chlorobenzene. The gases from the reaction of benzene and chlorine consist of hydrogen chloride, benzene, chlorobenzenes, and air. These gases are first scrubbed in a packed tower with a chilled mixture of monochlorobenzene and dichlorobenzene to condense and recover any benzene or chlorobenzene. The hydrogen chloride is then absorbed in a falling film absorption plant.

Emissions

The recovery of the hydrogen chloride from the chlorination of an organic compound is the major source of hydrogen chloride emissions. The exit gas from the absorption or scrubbing system is the actual source of the hydrogen chloride emitted. Emission factors for hydrochloric acid produced as by-product hydrogen chloride are presented in Table 5-7.

Table 5-7. EMISSION FACTORS FOR HYDROCHLORIC ACID MANUFACTURING[a]

EMISSION FACTOR RATING: B

Type of process	Hydrogen chloride emissions	
	lb/ton	kg/MT
By-product hydrogen chloride		
With final scrubber	0.2	0.1
Without final scrubber	3	1.5

[a] Reference 20.

HYDROFLUORIC ACID

Process Description[3]

All hydrofluoric acid in the United States is currently produced by the reaction of acid-grade fluorspar with sulfuric acid for 30 to 60 minutes in externally fired rotary kilns at a temperature of 400° to 500° F (204° to 260° C).[21-23] The resulting gas is then cleaned, cooled, and absorbed in water and weak hydrofluoric acid to form a strong acid solution. Anhydrous hydrofluoric acid is formed by distilling 80 percent hydrofluoric acid and condensing the gaseous HF which is driven off.

Emissions and Controls[3]

Air pollutant emissions are minimized by the scrubbing and absorption systems used to purify and recover the HF. The initial scrubber utilizes concentrated sulfuric acid as a scrubbing medium and is designed to remove dust, SO_2, SO_3, sulfuric acid mist, and water vapor present in the gas stream leaving the primary dust collector. The exit gases from the final absorber contain small amounts of HF, silican tetrafluoride (SiF_4), CO_2, and SO_2 and may be scrubbed with a caustic solution to reduce emissions further. A final water ejector, sometimes used to draw the gases through the absorption system, will reduce fluoride emissions. Dust emissions may also result from raw fluorspar grinding and drying operations. Table 5-8 lists the emission factors for the various operations.

Table 5-8. EMISSION FACTORS FOR HYDROFLUORIC ACID MANUFACTURING[a]

EMISSION FACTOR RATING: C

Type of operation	Fluorides		Particulates	
	lb/ton acid	kg/MT acid	lb/ton fluorspar	kg/MT fluorspar
Rotary kiln				
Uncontrolled	50	25	-	-
Water scrubber	0.2	0.1	-	-
Grinding and drying of fluorspar	-	-	20[b]	10[b]

[a] References 21 and 24.

[b] Factor given for well-controlled plant.

NITRIC ACID

Process Description[25]

The ammonia oxidation process (AOP) is the principal method of producing commercial nitric acid. It involves high-temperature oxidation of ammonia with air over a platinum catalyst to form nitric oxide. The nitric oxide air mixture is cooled, and additional air is added to complete the oxidation to nitrogen dioxide. The nitrogen dioxide is absorbed in water to produce an aqueous solution of nitric acid. The major portion of this 55 to 65 percent HNO_3 is consumed at this strength. However, a fairly substantial amount of this weak acid is concentrated in nitric acid until it is 95 to 99 percent HNO_3; it is then used as the strong acid.

Emissions[25]

The main source of atmospheric emissions from the manufacture of nitric acid is the tail gas from the absorption tower, which contains unabsorbed nitrogen oxides. These oxides are largely in the form of nitric oxide and nitrogen dioxide. In addition, trace amounts of nitric acid mist are present in the gases as they leave the absorption system. Small amounts of nitrogen dioxide are also lost from the acid concentrators and storage tanks. Table 5-9 summarizes the emission factors for nitric acid manufacturing.

Table 5-9. EMISSION FACTORS FOR NITRIC ACID PLANTS WITHOUT CONTROL EQUIPMENT

EMISSION FACTOR RATING: B

Type of process	Nitrogen oxides (NO_x)[a]	
	lb/ton	kg/MT
Ammonia - oxidation		
Old plant[a,b]	57	28.5
New plant[c,d]	2 to 7	1
Nitric acid concentrators		
Old plant[b]	5	2.5
New plant[c]	0.2	0.1

[a] Catalytic combustors can reduce emissions by 36 to 99.8 percent, with 80 percent the average control. Alkaline scrubbers can reduce emissions by 90 percent.

[b] Reference 25.

[c] Reference 26.

[d] Reference 65.

PAINT AND VARNISH

Paint[3]

The manufacture of paint involves the dispersion of a colored oil or pigment in a vehicle, usually an oil or resin, followed by the addition of an organic solvent for viscosity adjustment. Only the physical processes of weighing, mixing, grinding, tinting, thinning, and packaging take place; no chemical reactions are involved.

These processes take place in large mixing tanks at approximately room temperature.

The primary factors affecting emissions from paint manufacture are care in handling dry pigments, types of solvents used, and mixing temperature.[27,28] About 1 or 2 percent of the solvents is lost even under well-controlled conditions. Particulate emissions amount to 0.5 to 1.0 percent of the pigment handled.[29]

Varnish[13]

The manufacture of varnish also involves the mixing and blending of various ingredients to produce a wide range of products. However, in this case chemical reactions are initiated by heating. Varnish is cooked in either open or enclosed gas-fired kettles for periods of 4 to 16 hours at temperatures of 200° to 650° F (93° to 340° C).

Varnish cooking emissions, largely in the form of organic compounds, depend on the cooking temperatures and times, the solvent used, the degree of tank enclosure, and the type of air pollution controls used. Emissions from varnish cooking range from 1 to 6 percent of the raw material.

To reduce hydrocarbons from the manufacture of paint and varnish, control techniques include condensers and/or adsorbers on solvent-handling operations, and scrubbers and afterburners on cooking operations. Emissions factors for paint and varnish are shown in Table 5-10.

Table 5-10. EMISSION FACTORS FOR PAINT AND VARNISH MANUFACTURING WITHOUT CONTROL EQUIPMENT[a,b]

EMISSION FACTOR RATING: C

Type of product	Particulate		Hydrocarbons[c]	
	lb/ton pigment	kg/MT pigment	lb/ton of product	kg/MT pigment
Paint	2	1	30	15
Varnish				
Bodying oil	-	-	40	20
Oleoresinous	-	-	150	75
Alkyd	-	-	160	80
Acrylic	-	-	20	10

[a] References 27 and 29 through 33.

[b] Afterburners can reduce gaseous hydrocarbon emissions by 99 percent and particulates by about 90 percent. A water spray and oil filter system can reduce particulates by about 90 percent.[30]

[c] Expressed as undefined organic compounds whose composition depends upon the type of varnish or paint.

PHOSPHORIC ACID

Phosphoric acid is produced by two principal methods, the wet process and the thermal process. The wet process is usually employed when the acid is to be used for fertilizer production. Thermal-process acid is normally of higher purity and is used in the manufacture of high-grade chemical and food products.

Wet Process[34, 35]

In the wet process, finely ground phosphate rock is fed into a reactor with sulfuric acid to form phosphoric acid and gypsum. There is usually little market value for the gypsum produced, and it is handled as waste material in gypsum ponds. The phosphoric acid is separated from the gypsum and other insolubles by vacuum filtration. The acid is then normally concentrated to about 50 to 55 percent P_2O_5. When super-phosphoric acid is made, the acid is concentrated to between 70 and 85 percent P_2O_5.

Emissions of gaseous fluorides, consisting mostly of silicon tetrafluoride and hydrogen fluoride, are the major problems from wet-process acid. Table 5-11 summarizes the emission factors from both wet-process acid and thermal-process acid.

Table 5-11. EMISSION FACTORS FOR PHOSPHORIC ACID PRODUCTION
EMISSION FACTOR RATING: B

Source	Particulates		Fluorides	
	lb/ton	kg/MT	lb/ton	kg/MT
Wet process (phosphate rock)				
Reactor, uncontrolled	-	-	18[a]	9[a]
Gypsum pond	-	-	1[b]	1.1[b]
Condenser, uncontrolled	-	-	20[a]	10[a]
Thermal process (phosphorous burned[c])				
Packed tower	4.6	2.3	-	-
Venturi scrubber	5.6	2.8	-	-
Glass-fiber mist eliminator	3.0	1.5	-	-
Wire-mesh mist eliminator	2.7	1.35	-	-
High-pressure-drop mist eliminator	0.2	0.1	-	-
Electrostatic precipitator	1.8	0.9	-	-

[a] References 36 and 37.

[b] Pounds per acre per day (kg per hectare per day); approximately 0.5 acre (0.213 hectare) is required to produce 1 ton of P_2O_5 daily.

[c] Reference 38.

Thermal Process[34]

In the thermal process, phosphate rock, siliceous flux, and coke are heated in an electric furnace to produce elemental phosphorous. The gases containing the phosphorous vapors are passed through an electrical precipitator to remove entrained dust. In the "one-step" version of the process, the gases are next mixed with air to form P_2O_5 before passing to a water scrubber to form phosphoric acid. In the "two-step" version of the process, the phosphorous is condensed and pumped to a tower in which it is burned with air, and the P_2O_5 formed is hydrated by a water spray in the lower portion of the tower.

The principal emission from thermal-process acid is P_2O_5 acid mist from the absorber tail gas. Since all plants are equipped with some type of acid-mist collection system, the emission factors presented in Table 5-11 are based on the listed types of control.

PHTHALIC ANHYDRIDE

Process Description[39, 40]

Phthalic anhydride is produced primarily by oxidizing naphthalene vapors with excess air over a catalyst, usually V_2O_5. O-xylene can be used instead of naphthalene, but it is not used as much. Following the oxidation of the naphthalene vapors, the gas stream is cooled to separate the phthalic vapor from the effluent. Phthalic anhydride crystallizes directly from this cooling without going through the liquid phase. The phthalic anhydride is then purified by a chemical soak in sulfuric acid, caustic, or alkali metal salt, followed by a heat soak. To produce 1 ton of phthalic anhydride, 2,500 pounds of naphthalene and 830,000 standard cubic feet (scf) of air are required (or 1,130 kilograms of naphthalene and 23,500 standard cubic meters of air to produce 1 MT of phthalic anhydride).

Emissions and Controls[39]

The excess air from the production of phthalic anhydride contains some uncondensed phthalic anhydride, maleic anhydride, quinones, and other organics. The venting of this stream to the atmosphere is the major source of organic emissions. These emissions can be controlled with catalytic combustion. Table 5-12 presents emission factor data from phthalic anhydride plants.

Table 5-12. EMISSION FACTORS FOR PHTHALIC ANHYDRIDE PLANTS[a]

EMISSION FACTOR RATING: E

Overall plant	Organics (as hexane)	
	lb/ton	kg/MT
Uncontrolled	32	16
Following catalytic combustion	11	5.5

[a] Reference 41.

PLASTICS

Process Description[3]

The manufacture of most resins or plastics begins with the polymerization or linking of the basic compound (monomer), usually a gas or liquid, into high molecular weight non-crystalline solids. The manufacture of the basic monomer is not considered part of the plastics industry and is usually accomplished at a chemical or petroleum plant.

The manufacture of most plastics involves an enclosed reaction or polymerization step, a drying step, and a final treating and forming step. These plastics are polymerized or otherwise combined in completely enclosed stainless steel or glass-lined vessels. Treatment of the resin after polymerization varies with the proposed use. Resins for moldings are dried and crushed or ground into molding powder. Resins such as the alkyd resins that are to be used for protective coatings are normally transferred to an agitated thinning tank, where they are thinned with some type of solvent and then stored in large steel tanks equipped with water-cooled condensers to prevent loss of solvent to the atmosphere. Still other resins are stored in latex form as they come from the kettle.

Emissions and Controls[3]

The major sources of air contamination in plastics manufacturing are the emissions of raw materials or monomers, emissions of solvents or other volatile liquids during the reaction, emissions of sublimed solids such as phthalic anhydride in alkyd production, and emissions of solvents during storage and handling of thinned resins. Emission factors for the manufacture of plastics are shown in Table 5-13.

Table 5-13. EMISSION FACTORS FOR PLASTICS MANUFACTURING
WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: E

Type of plastic	Particulate		Gases	
	lb/ton	kg/MT	lb/ton	kg/MT
Polyvinyl chloride	35[b]	17.5[b]	17[c]	8.5[c]
Polypropylene	3	1.5	0.7[d]	0.35[d]
General	5 to 10	2.5 to 5	-	-

[a] References 42 and 43.

[b] Usually controlled with a fabric filter efficiency of 98 to 99 percent.

[c] As vinyl chloride.

[d] As propylene.

Much of the control equipment used in this industry is a basic part of the system and serves to recover a reactant or product. These controls include floating roof tanks or vapor recovery systems on volatile material, storage units, vapor recovery systems (adsorption or condensers), purge lines that vent to a flare system, and recovery systems on vacuum exhaust lines.

PRINTING INK

Process Description[3]

There are four major classes of printing ink: letterpress and lithographic inks, commonly called oil or paste inks; and flexographic and rotogravure inks, which are referred to as solvent inks. These inks vary considerably in physical appearance, composition, method of application, and drying mechanism. Flexographic and rotogravure inks have many elements in common with the paste inks but differ in that they are of very low viscosity, and they almost always dry by evaporation of highly volatile solvents.[44]

There are three general processes in the manufacture of printing inks: (1) cooking the vehicle and adding dyes, (2) grinding of a pigment into the vehicle using a roller mill, and (3) replacing water in the wet pigment pulp by an ink vehicle (commonly known as the flushing process).[45] The ink "varnish" or vehicle is generally cooked in large kettles at 200° to 600° F (93° to 315° C) for an average of 8 to 12 hours in much the same way that regular varnish is made. Mixing of the pigment and vehicle is done in dough mixers or in large agitated tanks. Grinding is most often carried out in three-roller or five-roller horizontal or vertical mills.

Emissions and Controls[3, 46]

Varnish or vehicle preparation by heating is by far the largest source of ink manufacturing emissions. Cooling the varnish components — resins, drying oils, petroleum oils, and solvents — produces odorous emissions. At about 350° F (175° C) the products begin to decompose, resulting in the emission of decomposition products from the cooking vessel. Emissions continue throughout the cooking process with the maximum rate of emissions occuring just after the maximum temperature has been reached. Emissions from the cooking phase can be reduced by more than 90 percent with the use of scrubbers or condensers followed by afterburners.[46, 47]

Compounds emitted from the cooking of oleoresinous varnish (resin plus varnish) include water vapor, fatty acids, glycerine, acrolein, phenols, aldehydes, ketones, terpene oils, terpenes, and carbon dioxide. Emissions of thinning solvents used in flexographic and rotogravure inks may also occur.

The quantity, composition, and rate of emissions from ink manufacturing depend upon the cooking temperature and time, the ingredients, the method of introducing additives, the degree of stirring, and the extent of air or inert gas blowing. Particulate emissions resulting from the addition of pigments to the vehicle are affected by the type of pigment and its particle size. Emission factors for the manufacture of printing ink are presented in Table 5-14.

Table 5-14. EMISSION FACTORS FOR PRINTING INK MANUFACTURING[a]

EMISSION FACTOR RATING: E

	Gaseous organics[b]		Particulates	
Type of process	lb/ton of product	kg/MT of product	lb/ton of pigment	kg/MT of pigment
Vehicle cooking				
General	120	60	-	-
Oils	40	20	-	-
Oleoresinous	150	75	-	-
Alkyds	160	80	-	-
Pigment mixing	-	-	2	1

[a] Based on data from section on paint and varnish.

[b] Emitted as gas, but rapidly condense as the effluent is cooled.

SOAP AND DETERGENTS

Soap[3]

The manufacture of soap entails the catalytic hydrolysis of various fatty acids with sodium or potassium hydroxide to form a glycerol-soap mixture. This mixture is separated by distillation, then neutralized and blended to produce soap. The main atmospheric pollution problem in the manufacture of soap is odor, and, if a spray drier is used, a particulate emission problem may also occur. Vent lines, vacuum exhausts, product and raw material storage, and waste streams are all potential odor sources. Control of these odors may be achieved by scrubbing all exhaust fumes and, if necessary, incinerating the remaining compounds. Odors emanating from the spray drier may be controlled by scrubbing with an acid solution.

Detergents[3]

The manufacture of detergents generally begins with the sulfuration by sulfuric acid of a fatty alcohol or linear alkylate. The sulfurated compound is then neutralized with caustic solution (NaOH), and various dyes, perfumes, and other compounds are added.[48,49] The resulting paste or slurry is then sprayed under pressure into a vertical drying tower where it is dried with a stream of hot air (400° to 500° F or 204° to 260° C). The dried detergent is then cooled and packaged. The main source of particulate emissions is the spray-drying tower. Odors may also be emitted from the spray-drying operation and from storage and mixing tanks. Particulate emissions from spray-drying operations are shown in Table 5-15.

Table 5-15. PARTICULATE EMISSION FACTORS FOR SPRAY-DRYING DETERGENTS[a]

EMISSION FACTOR RATING: B

Control device	Overall efficiency, %	Particulate emissions	
		lb/ton of product	kg/MT of product
None	-	90	45
Cyclone[b]	85	14	7
Cyclone followed by:			
Spray chamber	92	7	3.5
Packed scrubber	95	5	2.5
Venturi scrubber	97	3	1.5

[a] Based on analysis of data in References 48 through 52.

[b] Some type of primary collector, such as a cyclone, is considered an integral part of the spray-drying system.

SODIUM CARBONATE (Soda Ash)

Process Description[3]

Soda ash is manufactured by three processes: (1) the natural or Lake Brine process, (2) the Solvay process (ammonia-soda), and (3) the electrolytic soda-ash process. Because the Solvay process accounts for over 80 percent of the total production of soda ash, it will be the only one discussed in this section.

In the Solvay process, the basic raw materials are ammonia, coke, limestone (calcium carbonate), and salt (sodium chloride). The salt, usually in the unpurified form of a brine, is first purified in a series of absorbers by precipitation of the heavy metal ions with ammonia and carbon dioxide. In this process sodium bicarbonate is formed. This bicarbonate coke is heated in a rotary kiln, and the resultant soda ash is cooled and conveyed to storage.

Emissions

The major source of emissions from the manufacture of soda ash is the release of ammonia. Small amounts of ammonia are emitted in the gases vented from the brine purification system. Intermittent losses of ammonia can also occur during the unloading of tank trucks into storage tanks. The major sources of dust emissions include rotary dryers, dry solids handling, and processing of lime. Dust emissions of fine soda ash also occur from conveyor transfer points and air classification systems, as well as during tank-car loading and packaging. Emission factors are summarized in Table 5-16.

Table 5-16. EMISSION FACTORS FOR SODA-ASH PLANTS WITHOUT CONTROLS

EMISSION FACTOR RATING: D

Type of source	Particulates		Ammonia	
	lb/ton	kg/MT	lb/ton	kg/MT
Ammonia recovery[a,b]	-	-	7	3.5
Conveying, transferring, loading, etc.[c]	6	3	-	-

[a] Reference 53.

[b] Represents ammonia loss following the recovery system.

[c] Based on data in References 54 through 56.

SULFURIC ACID

Process Description[57]

All sulfuric acid is made by either the chamber or the contact process. Because the contact process accounts for over 90 percent of the total production of sulfuric acid in the United States, it will be the only process discussed in this section. Contact plants may be classified according to the raw materials used: (1) elemental sulfur-burning plants, (2) sulfide ore and smelter gas plants, and (3) spent-acid and hydrogen sulfide burning plants. A separate description of each type of plant will be given.

Elemental Sulfur–Burning Plants[57]

Frasch-process or recovered sulfur from oil refineries is melted, settled, or filtered to remove ash and is then fed into a combustion chamber. The sulfur is burned in clean air that has been dried by scrubbing with 93 to 99 percent sulfuric acid. The gases from the combustion chamber are cooled and then enter the solid catalyst (vanadium pentoxide) converter. Usually, 95 to 98 percent of the sulfur dioxide from the combustion chamber is converted to sulfur trioxide, with an accompanying large evolution of heat. The converter exit gas, after being cooled, enters an absorption tower where the sulfur trioxide is absorbed with 98 to 99 percent sulfuric acid. The sulfur trioxide combines with the water in the acid and forms more sulfuric acid.

Sulfide Ore and Smelter Gas Plants[57]

Sulfur dioxide gas from smelters is emitted from such equipment as copper converters, reverberatory furnaces, roasters, and flash smelters. The sulfur dioxide is contaminated with dust, acid mist, and gaseous impurities. To remove the impurities the gases must be cooled to essentially atmospheric temperature and passed through purification equipment consisting of cyclone dust collectors, electrostatic dust and mist precipitators, and scrubbing and gas-cooling towers. After the gases are cleaned and the excess water vapor removed, they are scrubbed with 66° Bé acid in a drying tower. The remainder of the process is essentially the same as that in the elemental sulfur plants.

Spent—Acid and Hydrogen Sulfide Burning Plants[57]

Two methods are used in the processing of this type of sulfuric acid. In one the sulfur dioxide and other products from the combustion of spent acid and/or hydrogen sulfide with undried atmospheric air are passed through gas-cooling and mist-removal equipment. The air stream next passes through a drying tower. A blower draws the gas from the drying tower and finally discharges the sulfur dioxide gas to the sulfur trioxide converter.

In a "wet-gas plant," the wet gases from the combustion chamber are charged directly to the converter with no intermediate treatment. The gas from the converter then flows to the absorber, through which 60° to 66° Bé sulfuric acid is circulating.

Emissions[57]

The major source of emissions from contact sulfuric acid plants is waste gas from the absorber exit stack. The gas discharged to the atmosphere contains predominantly nitrogen and oxygen, but unreacted sulfur dioxide, unabsorbed sulfur trioxide, and sulfuric acid mist and spray are also present. When the waste gas reaches the atmosphere, sulfur trioxide is converted to acid mist. Minor quantities of sulfur dioxide and sulfur trioxide may come from storage-tank vents, from tank-truck and tank-car vents during loading operations, from sulfuric acid concentrators, and from leaks in process equipment. Emission factors for contact plants are summarized in Table 5-17.

SYNTHETIC FIBERS

Process Description[3]

Synthetic fibers are classified into two major categories, semi-synthetic and "true" synthetic. Semi-synthetics, such as viscose rayon and acetate fibers,

Table 5-17. EMISSION FACTORS FOR SULFURIC ACID PLANTS[a]

EMISSION FACTOR RATING: B

Conversion of SO_2 to SO_3, %	SO_2 emissions	
	lb/ton of 100% H_2SO_4[b]	kg/MT of 100% H_2SO_4[b]
93	97	48.5
94	84	42
95	70	35
96	55	27.5
97	40[c]	20[c]
98	26	13
99	15	7.5
99.5	7	3.5

[a] Acid-mist emissions range from 0.3 to 7.5 pounds per ton (0.15 to 3.75 kilograms per metric ton) of acid produced for plants without acid mist eliminators, to 0.02 to 0.2 pound per ton (0.01 to 0.1 kilogram per metric ton) of acid produced for plants with acid-mist eliminators.

[b] Reference 57.

[c] Use 40 (20) as an average factor if percent conversion of SO_2 to SO_3 is not known.

result when natural polymeric materials such as cellulose are brought into a dissolved or dispersed state and then spun into fine filaments. True synthetic polymers, such as Nylon,* Orlon, and Dacron, result from addition and other polymerization reactions that form long chain molecules.

True synthetic fibers begin with the preparation of extremely long, chainlike molecules. The polymer is spun in one of four ways:[58] (1) melt spinning, in which molten polymer is pumped through spinneret jets, the polymer solidifying as it strikes the cool air; (2) dry spinning, in which the polymer is dissolved in a suitable organic solvent, and the resulting solution is forced through spinnerets; (3) wet spinning, in which the solution is coagulated in a chemical as it emerges from the spinneret; and (4) core spinning, the newest method, in which a continuous filament yarn together with short-length "hard" fibers is introduced onto a spinning frame in such a way as to form a composite yarn.

Emissions and Controls[3]

In the manufacture of viscose Rayon, carbon disulfide and hydrogen sulfide are the major gaseous emissions. Air pollution controls are not normally used to reduce these emissions, but adsorption in activated carbon at an efficiency of 80 to 95 percent, with subsequent recovery of the CS_2, can be accomplished.[59] Emissions of gaseous hydrocarbons may also occur from the drying of the finished

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*Mention of company or product names does not constitute endorsement by the Environmental Protection Agency.

fiber. Table 5-18 presents emission factors for semi-synthetic and true synthetic fibers.

Table 5-18. EMISSION FACTORS FOR SYNTHETIC FIBERS MANUFACTURING
EMISSION FACTOR RATING: E

	Hydrocarbons		Carbon disulfide		Hydrogen sulfide		Oil vapor or mist	
Type of fiber	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Semi-synthetic								
Viscose rayon[a,b]	-	-	55	27.5	6	3	-	-
True synthetic[c]								
Nylon	7	3.5	-	-	-	-	15	7.5
Dacron	-	-	-	-	-	-	7	3.5

[a] Reference 60.

[b] May be reduced by 80 to 95 percent absorption in activated charcoal.[59]

[c] Reference 61.

SYNTHETIC RUBBER

Process Description[3]

Copolymers of butadiene and styrene, commonly known as SBR account for more than 70 percent of all synthetic rubber produced in the United States. In a typical SBR manufacturing process, the monomers of butadiene and styrene are mixed with additives such as soaps and mercaptans. The mixture is polymerized to a conversion point of approximately 60 percent. After being mixed with various ingredients such as oil and carbon black, the latex product is coagulated and precipitated from the latex emulsion. The rubber particles are then dried and baled.

Emissions and Controls[3]

Emissions from the synthetic rubber manufacturing process consist of organic compounds (largely the monomers used) emitted from the reactor and blow-down tanks, and particulate matter and odors from the drying operations.

Drying operations are frequently controlled with fabric filter systems to recover any particulate emissions, which represent a product loss. Potential gaseous emissions are largely controlled by recycling the gas stream back to the process. Emission factors from synthetic rubber plants are summarized in Table 5-19.

TEREPHTHALIC ACID

Process Description[1, 64]

The main use of terephthalic acid is to produce dimethylterephthalate which is used for polyester fibers (like Dacron) and films. Terephthalic acid can be produced in various ways, one of which is the oxidation of paraxylene by nitric

Table 5-19. EMISSION FACTORS FOR SYNTHETIC RUBBER PLANTS: BUTADIENE-ACRYLONITRILE AND BUTADIENE-STYRENE

EMISSION FACTOR RATING: E

Compound	Emissions[a,b]	
	lb/ton	kg/MT
Alkenes		
Butadiene	40	20
Methyl propene	15	7.5
Butyne	3	1.5
Pentadiene	1	0.5
Alkanes		
Dimethylheptane	1	0.5
Pentane	2	1
Ethanenitrile	1	0.5
Carbonyls		
Acrylonitrile	17	8.5
Acrolein	3	1.5

[a] The butadiene emission is not continuous and is greatest right after a batch of partially polymerized latex enters the blow-down tank.

[b] References 62 and 63.

acid. In this process an oxygen-containing gas (usually air), paraxylene, and HNO_3 are all passed into a reactor where oxidation by the nitric acid takes place in two steps. The first step yields primarily N_2O, while the second step yields mostly NO in the offgas. The terephthalic acid precipitated from the reactor effluent is recovered by conventional crystallization, separation, and drying operations.

Emissions

The NO in the offgas from the reactor is the major air contaminant from the manufacture of terephthalic acid. The amount of nitrogen oxides emitted is roughly estimated in Table 5-20.

Table 5-20. NITROGEN OXIDES EMISSION FACTORS FOR TEREPHTHALIC ACID PLANTS[a]

EMISSION FACTOR RATING: D

Type of operation	Emissions (NO)	
	lb/ton	kg/MT
Reactor	13	6.5

[a] Reference 64.

REFERENCES FOR CHAPTER 5

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6. FOOD AND AGRICULTURAL INDUSTRY

Before food and agricultural products are used by the consumer they undergo a number of processing steps, such as refining, preservation, and product improvement, as well as storage and handling, packaging, and shipping. This section deals with the processing of food and agricultural products and the intermediate steps that present an air pollution problem. Emission factors are presented for industries where data were available. The primary pollutant emitted from these processes is particulate matter.

ALFALFA DEHYDRATING

General[1, 2]

An alfalfa dehydrating plant produces an animal feed from alfalfa. The dehydration and grinding of alfalfa that produces alfalfa meal is a dusty operation most commonly carried out in rural areas.

Wet, chopped alfalfa is fed into a direct-fired rotary drier. The dried alfalfa particles are conveyed to a primary cyclone and sometimes a secondary cyclone in series to settle out the product from air flow and products of combustion. The settled material is discharged to the grinding equipment, which is usually a hammer mill. The ground material is collected in an air-meal separator and is either conveyed directly to bagging or storage, or blended with other ingredients.

Emissions and Controls

Sources of dust emissions are the primary cyclone, the grinders, and the air-meal separator. Overall dust losses have been reported as high as 7 percent,[2] but average losses are around 3 percent by weight of the meal produced.[3] The use of a baghouse as a secondary collection system can greatly reduce emissions. Emission factors for alfalfa dehydration are presented in Table 6-1.

Table 6-1. PARTICULATE EMISSION FACTORS
FOR ALFALFA DEHYDRATION[a]
EMISSION FACTOR RATING: E

	Particulate emissions	
Type of operation	lb/ton of meal produced	kg/MT of meal produced
Uncontrolled	60	30
Baghouse collector	3	1.5

[a] Reference 3.

COFFEE ROASTING

Process Description[4, 5]

Coffee, which is imported in the form of green beans, must be cleaned, blended, roasted, and packaged before being sold. In a typical coffee roasting operation, the green coffee beans are freed of dust and chaff by dropping the beans into a current of air. The cleaned beans are then sent to a batch or continuous roaster. During the roasting, moisture is driven off, the beans swell, and chemical changes take place that give the roasted beans their typical color and aroma. When the beans have reached a certain color, they are quenched, cooled, and stoned.

Emissions[4, 5]

Dust, chaff, coffee bean oils (as mists), smoke, and odors are the principal air contaminants emitted from coffee processing. The major source of particulate emissions and practically the only source of aldehydes, nitrogen oxides, and organic acids is the roasting process. In a direct-fired roaster, gases are vented without recirculation through the flame. In the indirect-fired roaster, however, a portion of the roaster gases are recirculated and particulate emissions are reduced. Emissions of both smoke and odors from the roasters can be almost completely removed by a properly designed afterburner.[4, 5]

Particulate emissions also occur from the stoner and cooler. In the stoner, contaminating materials heavier than the roasted beans are separated from the beans by an air stream. In the cooler, quenching the hot roasted beans with water causes emissions of large quantities of steam and some particulate matter.[6] Table 6-2 summarizes emissions from the various operations involved in coffee processing.

Table 6-2. EMISSION FACTORS FOR ROASTING PROCESSES WITHOUT CONTROLS

EMISSION FACTOR RATING: B

	Pollutant							
	Particulates[a]		NO_x[b]		Aldehydes[b]		Organic acids[b]	
Type of process	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Roaster								
Direct-fired	7.6	3.8	0.1	0.05	0.2	0.1	0.9	0.45
Indirect-fired	4.2	2.1	0.1	0.05	0.2	0.1	0.9	0.45
Stoner and cooler[c]	1.4	0.7	-	-	-	-	-	-
Instant coffee spray dryer	1.4[d]	0.7[d]	-	-	-	-	-	-

[a] Reference 6.

[b] Reference 4.

[c] If cyclone is used, emissions can be reduced by 70 percent.

[d] Cyclone plus wet scrubber always used, representing a controlled factor.

COTTON GINNING

General[7]

The primary function of a cotton gin is to take raw seed cotton and separate the seed and the lint. A large amount of trash is found in the seed cotton, and it must also be removed. The problem of collecting and disposing of gin trash falls into two main areas. The first consists of collecting the coarse, heavier trash such as burs, sticks, stems, leaves, sand, and dirt. The second problem is collecting the finer dust, small leaf particles, and fly lint that are discharged from the lint after the fibers are removed from the seed. From 1 ton (0.907 MT) of seed cotton, approximately one 500-pound (226-kilogram) bale of cotton can be made.

Emissions and Controls

The major sources of particulates from cotton ginning include the unloading fan, the cleaner, and the stick and bur machine. From the cleaner and stick and bur machine, a large percentage of the particles settle out in the plant, and an attempt has been made in Table 6-3 to present emission factors that take this into consideration. Where cyclone collectors are used, emissions have been reported to be about 90 percent less.[7]

Table 6-3. EMISSION FACTORS FOR COTTON GINNING OPERATIONS WITHOUT CONTROLS[a]

EMISSION FACTOR RATING: C

Process	Estimated total particulates		Particles >100 μ settled out, %	Estimated emission factor (released to atmosphere)	
	lb/bale	kg/bale		lb/bale	kg/bale
Unloading fan	5	2.27	0	5.0	2.27
Cleaner	1	0.45	70	0.30	0.14
Stick and bur machine	3	1.36	95	0.20	0.09
Miscellaneous	3	1.36	50	1.5	0.68
Total	12	5.44	-	7.0	3.2

[a] References 7 and 8.

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

FEED AND GRAIN MILLS AND ELEVATORS

General[9]

Grain elevators are primarily transfer and storage units and are classified as either the smaller, more numerous country elevators or the larger terminal elevators. At grain elevator locations the following operations can occur:

receiving, transfer and storage, cleaning, drying, and milling or grinding. Many of the large terminal elevators also process grain at the same location. The grain processing may include wet and dry milling (cereals), flour milling, oil-seed crushing, and distilling. Feed manufacturing involves the receiving, conditioning (drying, sizing, cleaning), blending, and pelleting of the grains, and their subsequent bagging or bulk loading.

Emissions[9]

Emissions from feed and grain operations may be separated into those occurring at elevators and those occurring at grain processing operations or feed manufacturing operations. Emission factors for these operations are presented in Table 6-4. Because dust collection systems are generally applied to

Table 6-4. PARTICULATE EMISSION FACTORS FOR GRAIN HANDLING AND PROCESSING

EMISSION FACTOR RATING: B

Type of source	Emissions	
	lb/ton	kg/MT
Terminal elevators[a]		
Shipping or receiving	1	0.5
Transferring, conveying, etc.	2	1
Screening and cleaning	5	2.5
Drying	6	3
Country elevators[b]		
Shipping or receiving	5	2.5
Transferring, conveying, etc.	3	1.5
Screening and cleaning	8	4
Drying	7	3.5
Grain processing		
Corn meal[c]	5	2.5
Soybean processing[b]	7	3.5
Barley or wheat cleaner[d]	0.2[e]	0.1[e]
Milo cleaner[f]	0.4[e]	0.2[e]
Barley flour milling[c]	3[e]	1.5[e]
Feed manufacturing		
Barley[f]	3[e]	1.5[e]

[a] References 10 and 11.

[b] Reference 11.

[c] References 11 and 12.

[d] References 13 and 14.

[e] At cyclone exit (only non-ether-soluble particulates).

[f] Reference 14.

most phases of these operations to reduce product and component losses, the selection of the final emission factor should take into consideration the overall efficiency of these control systems.

Emissions from grain elevator operations are dependent on the type of grain, the moisture content of the grain (usually 10 to 30 percent), the amount of foreign material in the grain (usually 5 percent or less), the degree of enclosure at loading and unloading areas, the type of cleaning and conveying, and the amount and type of control used.

Factors affecting emissions from grain processing operations include the type of processing (wet or dry), the amount of grain processed, the amount of cleaning, the degree of drying or heating, the amount of grinding, the temperature of the process, and the degree of control applied to the particulates generated.

Factors affecting emissions from feed manufacturing operations include the type and amount of grain handled, the degree of drying, the amount of liquid blended into the feed, the type of handling (conveyor or pneumatic), and the degree of control.

FERMENTATION

General Process Description[9]

For the purpose of this report only the fermentation industries associated with food will be considered. This includes the production of beer, whiskey, and wine.

The manufacturing process for each of these is similar. The four main brewing production stages and their respective sub-stages are: (1) brewhouse operations, which include (a) malting of the barley, (b) addition of adjuncts (corn, grits, and rice) to barley mash, (c) conversion of starch in barley and adjuncts to maltose sugar by enzymatic processes, (d) separation of wort from grain by straining, and (e) hopping and boiling of the wort; (2) fermentation, which includes (a) cooling of the wort, (b) additional yeast cultures, (c) fermentation for 7 to 10 days, (d) removal of settled yeast, and (e) filtaation and carbonation; (e) aging, which lasts from 1 to 2 months under refrigeration; and (4) packaging, which includes (a) bottling-pasteurization, and (b) racking draft beer.

The major differences between beer production and whiskey production are the purification and distillation necessary to obtain distilled liquors and the longer period of aging. The primary difference between wine making and beer making is that grapes are used as the initial raw material in wine rather than grains.

Emissions[9]

Emissions from fermentation processes are nearly all gases and primarily consist of carbon dioxide, hydrogen, oxygen, and water vapor, none of which present an air pollution problem. However, emissions of particulates can occur in the handling of the grain for the manufacture of beer and whiskey. Gaseous hydrocarbons are also emitted from the drying of spent grains and yeast in beer and from the whiskey-aging warehouses. No significant emissions have been reported for the production of wine. Emission factors for the various operations associated with beer, wine, and whiskey production are shown in Table 6-5.

Table 6-5. EMISSION FACTORS FOR FERMENTATION PROCESSES
EMISSION FACTOR RATING: E

Type of product	Particulates		Hydrocarbons	
	lb/ton	kg/MT	lb/ton	kg/MT
Beer				
Grain handling[a]	3	1.5	-	-
Drying spent grains, etc.[a]	5	2.5	NA[b]	NA
Whiskey				
Grain handling[a]	3	1.5	-	-
Drying spent grains, etc.[a]	5	2.5	NA	NA
Aging	-	-	10[c]	0.024[d]
Wine	Neg[e]	Neg	Neg[e]	Neg

[a] Based on section on grain processing.

[b] NA: no emission factor available, but emissions do occur.

[c] Pounds per year per barrel of whiskey stored.[15]

[d] Kilograms per year per liter of whiskey stored.

[e] No significant emissions.

FISH PROCESSING

Process Description[16]

The canning, dehydration, and smoking of fish, and the manufacture of fish meal and fish oil are the important segments of fish processing. There are two types of fish canning operations: the "wet-fish" method, in which the trimmed fish are cooked directly in the can, and the "pre-cooked" process, in which the whole fish is cooked and then hand-sorted before canning.

A large fraction of the fish received in a cannery is processed into by-products, the most important of which is fish meal. In the manufacture of fish meal, fish scrap from the canning lines is charged to continuous live-steam cookers. After the material leaves the cooker, it is pressed to remove oil and water. The pressed cake is then broken up, usually in a hammer mill, and dried in a direct-fired rotary drier or in a steam-tube rotary drier.

Emissions and Controls[16]

The biggest problem from fish processing is odorous emissions. The principal odorous gases generated during the cooking portion of fish-meal manufacturing are hydrogen sulfide and trimethylamine. Some of the methods used to control odors include activated-carbon adsorbers, scrubbing with some oxidizing solution, and incineration. The only significant sources of dust emissions in fish processing are the driers and grinders used to handle dried fish meal. Emission factors for fish meal manufacturing are shown in Table 6-6.

Table 6-6. EMISSION FACTORS FOR FISH MEAL PROCESSING

EMISSION FACTOR RATING: C

Emission source	Particulates		Trimethylamine $(CH_3)_3N$		Hydrogen sulfide (H_2S)	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Cookers,[a] lb/ton (kg/MT) of fish meal produced						
Fresh fish	-	-	0.3	0.15	0.01	0.005
Stale fish	-	-	3.5	1.75	0.2	0.10
Driers,[b] lb/ton (kg/MT) of fish scrap	0.1	0.05	-	-	-	-

[a] Reference 17.

[b] Reference 16.

MEAT SMOKEHOUSES

Process Description[9]

Smoking is a diffusion process in which food products are exposed to an atmosphere of hardwood smoke, causing various organic compounds to be absorbed by the food. Smoke is produced commercially in the United States by three major methods: (1) by burning dampened sawdust (20 to 40 percent moisture), (2) by burning dry sawdust (5 to 9 percent moisture) continuously, and (3) by friction. Burning dampened sawdust and kiln-dried sawdust are the most widely used methods. Most large, modern, production meat smokehouses are the recirculating type, in which smoke is circulated at reasonably high temperatures throughout the smokehouse.

Emissions and Controls[9]

Emissions from smokehouses are generated from the burning hardwood rather than from the cooked product itself. Based on approximately 110 pounds of meat smoked per pound of wood burned (110 kilograms of meat per kilogram of wood burned), emission factors have been derived for meat smoking and are presented in Table 6-7.

Emissions from meat smoking are dependent on several factors, including the type of wood, the type of smoke generator, the moisture content of the wood, the air supply, and the amount of smoke recirculated. Both low-voltage electrostatic precipitators and direct-fired afterburners may be used to reduce particulate and organic emissions. These controlled emission factors have also been shown in Table 6-7.

NITRATE FERTILIZERS

General[9, 20]

For this report nitrate fertilizers are defined as the product resulting from the reaction of nitric acid and ammonia to form ammonium nitrate solutions or

Table 6-7. EMISSION FACTORS FOR MEAT SMOKING[a,b]

EMISSION FACTOR RATING: D

Pollutant	Uncontrolled		Controlled[c]	
	lb/ton of meat	kg/MT of meat	lb/ton of meat	kg/MT of meat
Particulates	0.3	0.15	0.1	0.05
Carbon monoxide	0.6	0.3	Neg[d]	Neg
Hydrocarbons (CH_4)	0.07	0.035	Neg	Neg
Aldehydes (HCHO)	0.08	0.04	0.05	0.025
Organic acids (acetic)	0.2	0.10	0.1	0.05

[a] Based on 110 pounds of meat smoked per pound of wood burned (110 kg meat/kg wood burned).

[b] References 18, 19, and section on charcoal production.

[c] Controls consist of either a wet collector and low-voltage precipitator in series or a direct-fired afterburner.

[d] With afterburner.

granules. Essentially three steps are involved in producing ammonium nitrate: neutralization, evaporation of the neutralized solution, and control of the particle size and characteristics of the dry product.

Anhydrous ammonia and nitric acid (57 to 65 percent HNO_3)[21,22] are brought together in the neutralizer to produce ammonium nitrate. An evaporator or concentrator is then used to increase the ammonium nitrate concentration. The resulting solutions may be formed into granules by the use of prilling towers or by ordinary granulators. Limestone may be added in either process in order to produce calcium ammonium nitrate.[23,24]

Emissions and Controls

The main emissions from the manufacture of nitrate fertilizers occur in the neutralization and drying operations. By keeping the neutralization process on the acidic side, losses of ammonia and nitric oxides are kept at a minimum. Nitrate dust or particulate matter is produced in the granulation or prilling operation. Particulate matter is also produced in the drying, cooling, coating, and material handling operations. Additional dust may escape from the bagging and shipping facilities.

Typical operations do not use collection devices on the prilling tower. Wet or dry cyclones, however, are used for various granulating, drying, or cooling operations in order to recover valuable products. Table 6-8 presents emission factors for the manufacture of nitrate fertilizers.

PHOSPHATE FERTILIZERS

Nearly all phosphatic fertilizers are made from naturally occurring phosphorous-containing minerals such as phosphate rock. The phosphorous content of these minerals is not in a form that is readily available to growing plants, so the minerals must be treated to convert the phosphorous to a plant-available form.

Table 6-8. EMISSION FACTORS FOR NITRATE FERTILIZER MANUFACTURING WITHOUT CONTROLS

EMISSION FACTOR RATING: B

	Particulates		Nitrogen oxides (NO_3)		Ammonia	
Type of process[a]	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
With prilling tower[b]						
Neutralizer[c,d]	-	-	-	-	2	1
Prilling tower	0.9	0.45	-	-	-	-
Dryers and coolers[e]	12	6	-	-	-	-
With granulator[b]						
Neutralizer[c,d]	-	-	-	-	2	1
Granulator[e]	0.4	0.2	0.9	0.45	0.5	0.25
Dryers and coolers[e,f]	7	3.5	3	1.5	1.3	0.65

[a] Plants will use either a prilling tower or a granulator but not both.

[b] Reference 25.

[c] Reference 26.

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

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

[f] Use of wet-screen scrubber following cyclone can reduce emissions by 95 to 97 percent.

This conversion can be done either by the process of acidulation or by a thermal process. The intermediate steps of the mining of phosphate rock and the manufacture of phosphoric acid are not included in this section as they are discussed in other sections of this publication; it should be kept in mind, however, that large integrated plants may have all of these operations taking place at one location.

In this section phosphate fertilizers have been divided into three categories: (1) normal superphosphate, (2) triple superphosphate, and (3) ammonium phosphate. Emission factors for the various processes involved are shown in Table 6-9.

NORMAL SUPERPHOSPHATE

General[27,28]

Normal superphosphate (also called single or ordinary superphosphate) is the product resulting from the acidulation of phosphate rock with sulphuric acid. Normal superphosphate contains from 16 to 22 percent phosphoric anhydride (P_2O_5). The physical steps involved in making superphosphate are: (1) mixing rock and acid, (2) allowing the mix to assume a solid form (denning), and (3) storing (curing) the material to allow the acidulation reaction to be completed. After the curing period, the product can be ground and bagged for sale, the cured superphosphate can be sold directly as run of pile product, or the material can be granulated for sale as granulated superphosphate.

Table 6-9. EMISSION FACTORS FOR THE PRODUCTION OF PHOSPHATE FERTILIZERS

EMISSION FACTOR RATING: C

	Particulates[a]		Fluorides[b]	
Type of product	lb/ton	kg/MT	lb/ton	kg/MT
Normal superphosphate[c]				
Grinding, drying	9	4.5	-	-
Main stack	-	-	0.15	0.075
Triple superphosphate[c]				
Run-of-pile (ROP)	-	-	0.03	0.015
Granular	-	-	0.10	0.05
Diammonium phosphate[d]				
Dryer, cooler	80	40	e	e
Ammoniator-granulator	2	1	0.04	0.02

[a] Control efficiencies of 99 percent can be obtained with fabric filters.

[b] Total fluorides, including particulate fluorides. Factors all represent outlet emissions following control devices, and should be used as typical only in the absence of specific plant information.

[c] References 30 through 32.

[d] References 28, 30, and 33 through 36.

[e] Included in ammoniator-granulator total.

Emissions

The gases released from the acidulation of phosphate rock contain silicon tetrafluoride, carbon dioxide, steam, particulates, and sulfur oxides. The sulfur oxide emissions arise from the reaction of phosphate rock and sulfuric acid.[29]

If a granulated superphosphate is produced, the vent gases from the granulator-ammoniator may contain particulates, ammonia, silicon tetrafluoride, hydrofluoric acid, ammonium chloride, and fertilizer dust. Emissions from the final drying of the granulated product will include gaseous and particulate fluorides, ammonia, and fertilizer dust.

TRIPLE SUPERPHOSPHATE

General[27, 28]

Triple superphosphate (also called double or concentrated superphosphate) is the product resulting from the reaction between phosphate rock and phosphoric acid. The product generally contains 44 to 52 percent P_2O_5, which is about three times the P_2O_5 usually found in normal superphosphates.

Presently, there are three principal methods of manufacturing triple superphosphate. One of these uses a cone mixer to produce a pulverized product that is particularly suited to the manufacture of ammoniated fertilizers. This product can be sold as run of pile (ROP), or it can be granulated. The second method produces in a multi-step process a granulated product that is well suited for direct application as a phosphate fertilizer. The third method combines the features of quick drying and granulation in a single step.

Emissions

Most triple superphosphate is the nongranular type. The exit gases from a plant producing the nongranular product will contain considerable quantities of silicon tetrafluoride, some hydrogen fluoride, and a small amount of particulates. Plants of this type also emit fluorides from the curing buildings.

In the cases where ROP triple superphosphate is granulated, one of the greatest problems is the emission of dust and fumes from the dryer and cooler. Emissions from ROP granulation plants include silicon tetrafluoride, hydrogen fluoride, ammonia, particulate matter, and ammonium chloride.

In direct granulation plants, wet scrubbers are usually used to remove the silicon tetrafluoride and hydrogen fluoride generated from the initial contact between the phosphoric acid and the dried rock. Screening stations and bagging stations are a source of fertilizer dust emissions in this type of process.

AMMONIUM PHOSPHATE

General

The two general classes of ammonium phosphates are monoammonium phosphate and diammonium phosphate. The production of these types of phosphate fertilizers is starting to displace the production of other phosphate fertilizers because the ammonium phosphates have a higher plant food content and a lower shipping cost per unit weight of P_2O_5.

There are various processes and process variations in use for manufacturing ammonium phosphates. In general, phosphoric acid, sulphuric acid, and anhydrous ammonia are allowed to react to produce the desired grade of ammonium phosphate. Potash salts are added, if desired, and the product is granulated, dried, cooled, screened, and stored.

Emissions

The major pollutants from ammonium phosphate production are fluoride, particulates, and ammonia. The largest sources of particulate emissions are the cage mills, where oversized products from the screens are ground before being recycled to the ammoniator. Vent gases from the ammoniator tanks are the major source of ammonia. This gas is usually scrubbed with acid, however, to recover the residual ammonia.

STARCH MANUFACTURING

General Process Description[37]

The basic raw material in the manufacture of starch is dent corn, which contains starch. The starch in the corn is separated from the other components by "wet milling."

The shelled grain is prepared for milling in cleaners that remove both the light chaff and any heavier foreign material. The cleaned corn is then softened by soaking (steeping) it in warm water acidified with sulfur dioxide. The softened corn goes through attrition mills that tear the kernels apart, freeing the germ and loosening the hull. The remaining mixture of starch, gluten, and hulls is finely ground, and the coarser fiber particles are removed by screening. The mixture of starch and gluten is then separated by centrifuges, after which the starch is filtered and washed. At this point it is dried and packaged for market.

Emissions

The manufacture of starch from corn can result in significant dust emissions. The various cleaning, grinding, and screening operations are the major sources of dust emissions. Table 6-10 presents emission factors for starch manufacturing.

Table 6-10. EMISSION FACTORS FOR STARCH MANUFACTURING[a]

EMISSION FACTOR RATING: D

	Particulates	
Type of operation	lb/ton	kg/MT
Uncontrolled	8	4
Controlled[b]	0.02	0.01

[a] Reference 38.

[b] Based on centrifugal gas scrubber.

SUGAR CANE PROCESSING

General

The processing of sugar cane starts with the harvesting of the crops, either by hand or by mechanical means. If mechanical harvesting is used, much of the unwanted foliage is left, and it thus is standard practice to burn the cane before mechanical harvesting to remove the greater part of the foliage.

After being harvested, the cane goes through a series of processes to be converted to the final sugar product. It is washed to remove larger amounts of dirt and trash, then crushed and shredded to reduce the size of the stalks. The juice is next extracted by one of two methods, milling or diffusion. In milling the cane is pressed between heavy rollers to press out the juice, and in diffusion the sugar is leached out by water and thin juices. The raw sugar then goes through a series of operations including clarification, evaporation, and crystallization in order to produce the final product.

Most mills operate without supplemental fuel because of the sufficient bagasse (the fibrous residue of the extracted cane) that can be burned as fuel.

Emissions

The largest sources of emissions from sugar cane processing are the open-field burning in the harvesting of the crop and the burning of bagasse as fuel. In the various processes of crushing, evaporation, and crystallization, some particulates are emitted but in relatively small quantities. Emission factors for sugar cane processing are shown in Table 6-11.

Table 6-11. EMISSION FACTORS FOR SUGAR CANE PROCESSING

EMISSION FACTOR RATING: D

Type of process	Particulate	Carbon monoxide	Hydrocarbons	Nitrogen oxides
Field burning,[a,b]				
lb/acre burned	225	1,500	300	30
kg/hectare burned	250	1,680	335	33.5
Bagasse burning,[c]				
lb/ton bagasse	22	-	-	-
kg/MT bagasse	11	-	-	-

[a] Based on emission factors for open burning of agricultural waste.

[b] There are approximately 4 tons/acre (9,000 kg/hectare) of unwanted foliage on the cane and 11 tons/acre (25,000 kg/hectare) of grass and weed, all of which are combustible.[40]

[c] Reference 40.

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7. METALLURGICAL INDUSTRY

The metallurgical industries can be broadly divided into primary and secondary metal production operations. The term primary metals refers to production of the metal from ore. The secondary metals industry includes the recovery of metal from scrap and salvage and the production of alloys from ingot.

The primary metals industries discussed in this section include the nonferrous operations of aluminum ore reduction, copper smelters, lead smelters, and zinc smelters. These industries are characterized by the large quantities of sulfur oxides and particulates emitted. The primary metals industry also includes iron and steel mills, ferroalloy production, and metallurgical coke manufacture.

The secondary metallurgical industries discussed in this section are aluminum operations, brass and bronze ingots, gray iron foundries, lead smelting, magnesium smelting, steel foundries, and zinc processing. The major air contaminants from these operations are particulates in the forms of metallic fumes, smoke, and dust.

PRIMARY METALS INDUSTRY

Aluminum Ore Reduction

Process Description[1-3] - Bauxite, a hydrated oxide of aluminum associated with silicon, titanium, and iron, is the base ore for aluminum production. Most bauxite ore is purified by the Bayer process in which the ore is dried, ground in ball mills, and mixed with sodium hydroxide. Iron oxide, silica, and other impurities are removed by settling, dilution, and filtration. Aluminum hydroxide is precipitated from the diluted, cooled solution and calcined to produce pure alumina, Al_2O_3.

The recovery of the aluminum from the purified oxide is accomplished by an electrolytic process, called the Hall-Herout process, in which alumina is dissolved in a fused mixture of fluoride salts and then reduced to metallic aluminum and oxygen. This takes place in an electrolytic cell commonly known as a pot. Three types of cells are in common use: the Prebake, the Horizontal Stud Soderberg, and the Vertical Stud Soderberg. In the Prebake, the carbon anodes are baked before mounting in the cells. In the Soderberg cells, the carbon post is added continuously and baked by the heat of the bath. The position of the metal studs, with respect to the anode, can either be horizontal or vertical. Four unit weights of bauxite are required to make 2 unit weights of alumina, which yields 1 unit weight of metallic aluminum. To produce 1 ton of aluminum, 16,000 kW-hr of electricity is required (18,000 kW-hr is required to produce 1 MT.)

Emissions - During the pot reduction process, the effluent released contains some fluoride particulates and some gaseous hydrogen fluoride. Particulate matter such as alumina and carbon from the anodes are also emitted. The calcining of aluminum hydroxide for the production of alumina generates vast amounts of dust. Because of the value of this dust, however, extensive controls are employed that reduce these emissions to an insignificant amount. Table 7-1 summarizes emission factors for aluminum production.

Table 7-1. EMISSION FACTORS FOR ALUMINUM ORE REDUCTION WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: B

Type of operation	Particulates[b]		Fluorides[c]	
	lb/ton	kg/MT	lb/ton	kg/MT
Electrolytic cells				
Prebake	55	27.5	80	40
Horizontal stud soderberg	140	70	80	40
Vertical stud soderberg	80	40	80	40
Calcining aluminum hydroxide[d,e]	20	10	-	-

[a] Emission factors expressed as units per unit weight of aluminum produced.

[b] References 4 and 5.

[c] Reference 6.

[d] Reference 1.

[e] Represents controlled factor since all calcining units are controlled to remove the valuable dust.

Metallurgical Coke Manufacturing

Process Description[7] - Coking is the process of heating coal in an atmosphere of low oxygen content, i.e., destructive distillation. During this process organic compounds in the coal break down to yield gases and a residue of relatively non-volatile nature. Two processes are used for the manufacture of metallurgical coke, the beehive process and the by-product process; the by-procuct process accounts for more than 98 percent of the coke produced.

Beehive oven:[7] The beehive is a refractory-lined enclosure with a dome-shaped roof. The coal charge is deposited onto the floor of the beehive and leveled to give a uniform depth of material. Openings to the beehive oven are then restricted to control the amount of air reaching the coal. The carbonization process begins in the coal at the top of the pile and works down through it. The volatile matter being distilled escapes to the atmosphere through a hole in the roof. At the completion of the coking time, the coke is "watered out" or quenched.

By-product process:[7] The by-product process is oriented toward the recovery of the gases produced during the coking cycle. The rectangular coking ovens are grouped together in a series alternately interspersed with heating flues called a coke battery. Coal is charged to the ovens through ports in the top, which are then sealed. Heat is supplied to the ovens by burning some of the coke gas produced. Coking is largely accomplished at temperatures of 2000° to 2100° F (1100° to 1150° C) for a period of about 16 to 20 hours. At the end of the coking period, the coke is pushed from the oven by a ram and quenched with water.

Emissions[7] - Visible smoke, hydrocarbons, carbon monoxide, and other emissions originate from the following by-product coking operations: (1) charging of the coal into the incandescent ovens, (2) oven leakage during the coking period, (3) pushing the coke out of the ovens, and (4) quenching the hot coke. Virtually no attempts have been made to prevent gaseous emissions from beehive ovens. Gaseous emissions from the by-product ovens are drawn off to a collection main and are subjected to various operations for separating ammonia, coke-oven gas, tar, phenol, light oil (benzene, toluene, xylene), and pyridine. These unit operations are potential sources of hydrocarbon emissions.

Oven-charging operations and leakage around poorly sealed coke-oven doors and lids are major sources of gaseous emissions from by-product ovens. Sulfur is present in the coke-oven gas in the form of hydrogen sulfide and carbon disulfide. If the gas is not desulfurized, the combustion process will emit sulfur dioxide.

Associated with both coking processes are the material-handling operations of unloading coal, storing coal, grinding and sizing of coal, screening and crushing coke, and storing and loading coke. All of these operations are potential particulate emission sources. In addition, the operations of oven charging, coke pushing, and quenching produce particulate emissions. The emission factors for coking operations are summarized in Table 7-2.

Copper Smelters

Process Description[12, 13] - Copper is produced primarily from low-grade sulfide ores, which are concentrated by gravity and flotation methods. Copper is recovered from the concentrate by four steps: roasting, smelting, converting, and refining. Copper sulfide concentrates are normally roasted in either multiple-hearth or fluidized bed roasters to remove the sulfur and then calcined in preparation for smelting in a reverberatory furnace. For about half the smelters the roasting step is eliminated. Smelting removes other impurities as a slag with the aid of fluxes. The matter that results from smelting is blown with air to remove the sulfur as sulfur dioxide, and the end product is a crude metallic copper. A refining process further purifies the metal by insertion of green logs or natural gas. This is often followed by electrolytic refining.

Emissions and Controls[13] - The high temperatures attained in roasting, smelting, and converting cause volatilization of a number of the trace elements present in copper ores and concentrates. The raw waste gases from these processes contain not only these fumes but also dust and sulfur oxide. Carbon monoxide and nitrogen oxides may also be emitted, but no quantitative data have been reported in the literature.

The value of the volatilized elements dictates efficient collection of fumes and dusts. A combination of cyclones and electrostatic precipitators seems to be most often used. Table 7-3 summarizes the uncontrolled emissions of particulates and sulfur oxides from copper smelters.

Ferroalloy Production

Process Description[7, 15] - Ferroalloy is the generic term for alloys consisting of iron and one or more other metals. Ferroalloys are used in steel production as

Table 7-2. EMISSION FACTORS FOR METALLURGICAL COKE MANUFACTURE WITHOUT CONTROLS[a]

EMISSION FACTOR RATING: C

Type of operation	Particulates		Sulfur dioxide		Carbon monoxide		Hydrocarbons[b]		Nitrogen oxides[c]		Ammonia	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
By-product coking[d]												
Unloading	0.4	0.2	-	-	-	-	-	-	-	-	-	-
Charging	1.5	0.75	0.02	0.01	0.6	0.3	2.5	1.25	0.03	0.015	0.02	0.01
Coking cycle	0.1	0.05	-	-	0.6	0.3	1.5	0.75	0.01	0.005	0.06	0.03
Discharging	0.6	0.3	-	-	0.07	0.035	0.2	0.1	-	-	0.1	0.05
Quenching	0.9	0.45	-	-	-	-	-	-	-	-	-	-
Underfiring[f]	-	-	10	5	-	-	-	-	-	-	-	-
Beehive ovens[e]	200	100	-	-	1	0.5	8	4	-	-	2	1

[a] Emission factors expressed as units per unit weight of coal charged.

[b] Expressed as methane.

[c] NO_2.

[d] References 8 and 9.

[e] References 7 and 10.

[f] Reference 11. Use a factor of 4 lb/ton (2 kg/MT) of coal for underfiring when coke-oven gas is desulfurized before use in other areas of the process.

Table 7-3. EMISSION FACTORS FOR PRIMARY COPPER SMELTERS WITHOUT CONTROLS[a]

EMISSION FACTOR RATING: C

Type of operation	Particulates[b,c]		Sulfur oxides[d]	
	lb/ton	kg/MT	lb/ton	kg/MT
Roasting	45	22.5	60	30
Smelting (reverberatory furnace)	20	10	320	160
Converting	60	30	870	435
Refining	10	5	-	-
Total uncontrolled	135	67.5	1,250	625

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

[b] References 10, 13, and 14.

[c] Electrostatic precipitators have been reported to reduce emissions by 99.7 percent.

[d] Sulfur oxides can be reduced by about 90 percent by using a combination of sulfuric acid plants and lime slurry scrubbing.

alloying elements and deoxidants. There are three basic types of ferroalloys: (1) silicon-based alloys, including ferrosilicon and calciumsilicon; (2) manganese-based alloys, including ferromanganese and silicomanganese; and (3) chromium-based alloys, including ferrochromium and ferrosilicochrome.

The four major methods used to produce ferroalloy and high-purity metallic additives for steelmaking are: (1) blast furnace, (2) electrolytic deposition, (3) alumina silico-thermic process, and (4) electric smelting furnace. Because over 75 percent of the ferroalloys are produced in electric smelting furnaces, this section deals only with that type of furnace.

The oldest, simplest, and most widely used electric furnaces are the submerged-arc open type, although semi-covered furnaces are also used. The alloys are made in the electric furnaces by reduction of suitable oxides. For example, in making ferrochromium the charge may consist of chrome ore, limestone, quartz (silica), coal, and wood chips, along with scrap iron.

Emissions[16] - The production of ferroalloys has many dust- or fume-producing steps. The dust resulting from raw material handling, mix delivery, and crushing and sizing of the solidified product can be handled by conventional techniques and is ordinarily not a pollution problem. By far the major pollution problem arises from the ferroalloy furnaces themselves. The conventional submerged-arc furnace utilizes carbon reduction of metallic oxides and continuously produces large quantities of carbon monoxide. This escaping gas carries large quantities of particulates of submicron size, making control difficult.

In an open furnace essentially all of the carbon monoxide burns with induced air at the top of the charge, and CO emissions are small. Particulate emissions from the open furnace, however, can be quite large. In the semi-closed furnace, most or all of the CO is withdrawn from the furnace and burns with dilution air introduced into the system. The unburned CO goes through particulate control devices and can be used as boiler fuel or can be flared directly. Particulate emission factors for electric smelting furnaces are presented in Table 7-4. No carbon monoxide emission data have been reported in the literature.

Table 7-4. EMISSION FACTORS FOR FERROALLOY PRODUCTION IN ELECTRIC SMELTING FURNACES[a]

EMISSION FACTOR RATING: C

Type of furnace and product	Particulates	
	lb/ton	kg/MT
Open furnace		
50% FeSi[b]	200	100
75% FeSi[c]	315	157.5
90% FeSi[b]	565	282.5
Silicon metal[d]	625	312.5
Silicomanganese[e]	195	97.5
Semi-covered furnace		
Ferromanganese[e]	45	22.5

[a] Emission factors expressed as units per unit weight of specified product produced.
[b] Reference 17.
[c] References 18 and 19.
[d] References 17 and 20.
[e] Reference 19.

Iron and Steel Mills

General - To make steel, iron ore is reduced to pig iron, and some of its impurities are removed in a blast furnace. The pig iron is further purified in open hearths, basic oxygen furnaces, or electric furnaces. Other operations, including the production of by-product coke and sintering, are not discussed in much detail in this section as they are covered in other sections of this publication.

Blast Furnace - The blast furnace is a large refractory-lined chamber into which iron ore, coke, and limestone are charged and allowed to react with large amounts of hot air to produce molten iron. Slag and blast-furnace gases are by-products from this reaction. To produce 1 unit weight of pig iron requires, on the average, 1.5 unit weights of iron-bearing charge; 0.6 unit weight of coke; 0.2 unit weight of limestone; 0.2 unit weight of cinder, scale, and scrap; and 2.5 unit weights of air. Most of the coke used in the blast furnaces is produced by "by-product" coke ovens. Sintering plants are used to convert iron ore fines and blast-furnace flue dust into products more suitable for charging to the blast furnace.

As blast-furnace gas leaves the top of the furnace, it contains large amounts of particulate matter. This dust contains about 30 percent iron, 15 percent carbon, 10 percent silicon dioxide, and small amounts of aluminum oxide, manganese oxide, calcium oxide, and other materials. Blast-furnace gas-cleaning systems, composed of settling chambers, low-efficiency wet scrubbers, and high-efficiency wet scrubbers or electrostatic precipitators connected in series, are used to reduce particulate emissions. All of the carbon monoxide generated in the blast furnace is normally used for fuel. However, abnormal conditions such as "slips" can cause instantaneous emissions of carbon monoxide. The improvements in techniques for handling blast furnace burden have made slips occur infrequently.

Open-Hearth Furnace[21, 22] - In the open-hearth process for making steel, a mixture of scrap iron, steel, and pig iron is melted in a shallow rectangular basin, or "hearth," in which various liquid or gaseous fuels provide the heat. Impurities are removed in a slag. Oxygen injection (lancing) into the furnace speeds the refining process, saves fuel, and increases steel production.

The fumes from open-hearth furnaces consist predominantly of iron oxides. Oxygen lancing increases the amount of fume and dust produced. Control of iron oxide requires high-efficiency collection equipment such as venturi scrubbers and electrostatic precipitators.

Basic Oxygen Furnaces[21-23] - The basic oxygen process, called the Linz-Donawitz or LD process, is employed to produce steel from hot blast-furnace metal and some added scrap metal by use of a stream of commercially pure oxygen to oxidize the impurities, principally carbon and silicon.

The reaction that converts the crude molten iron into steel generates a considerable amount of particulate matter, largely in the form of oxide. Carbon monoxide is also generated in this process but is emitted only in small amounts after ignition of the gases above the furnace. Electrostatic precipitators, high-energy venturi scrubbers, and baghouse systems have been used to control dust emissions.

Electric Arc Furnaces[21-23] - Electric furnaces are used primarily to produce special alloy steels or to melt large amounts of scrap for reuse. Heat is furnished by direct-arc-type electrodes extending through the roof of the furnace. In recent years, oxygen has been used to increase the rate of uniformity of scrap melt-down and to decrease power consumption.

The dust that occurs when steel is being processed in an electric furnace results from the exposure of molten steel to extremely high temperatures. The excess carbon added to stir and purge the metal when oxidized creates a source of carbon monoxide emissions. For electric furnaces, venturi scrubbers and electrostatic precipitators are the most widely used control devices.

Scarfing[21, 22] - Scarfing is a method of surface preparation of semi-finished steel. A scarfing machine removes surface defects from the steel billets and slabs before they are shaped or rolled by applying jets of oxygen to the surface of the steel, which is at orange heat, thus removing a thin upper layer of the metal by rapid oxidation.[24]

The scarfing process generates an iron oxide fume. The rate of emissions is affected by the steel analysis and amount of metal removal required.

Table 7-5 summarizes emission factors for the production of iron ore and steel and the associated operations.

Lead Smelters

Process Description[27,28] - The ore from which primary lead is produced contains both lead and zinc. Thus, both lead and zinc concentrates are made by concentration and flotation from the ore. The lead concentrate is usually roasted in traveling-grate sintering machines, thereby removing sulfur and forming lead oxide. The lead oxide, sinter, coke, and flux (usually limestone) are fed to the blast furnace, in which oxide is reduced to metallic lead. The lead may be further refined by a variety of other processes, usually including a brass reverberatory furnace.

Emissions and Controls - Effluent gases from the roasting, sintering, and smelting operations contain considerable particulate matter and sulfur dioxide. Dust and fumes are recovered from the gas stream by settling in large flues and by precipitation in Cottrell treaters or filtration in large baghouses. The emission factors for lead smelting are summarized in Table 7-6. The effect of controls has been shown in the footnotes of this table.

Zinc Smelters

Process Description[29,30] - As stated previously, most domestic zinc comes from zinc and lead ores. Another important source of raw material for zinc metal has been zinc oxide from fuming furnaces. For efficient recovery of zinc, sulfur must be removed from concentrates to a level of less than 2 percent. This is done by fluidized beds or multiple-hearth roasting occasionally followed by sintering. Metallic zinc can be produced from the roasted ore by the horizontal or vertical retort process or by the electrolytic process if a high-purity zinc is needed.

Emissions and Controls[29,30] - Dust, fumes, and sulfur dioxide are emitted from zinc concentrate roasting or sintering operations. Particulates may be removed by electrostatic precipitators or baghouses. Sulfur dioxide may be converted directly into sulfuric acid or vented. Emission factors for zinc smelting are presented in Table 7-7.

SECONDARY METALS INDUSTRY

Aluminum Operations

Process Description[31,32] - Secondary aluminum operations involve making lightweight metal alloys for industrial castings and ingots. Copper, magnesium, and silicon are the most common alloying constituents. Aluminum alloys for castings are melted in small crucible furnaces charged by hand with pigs and foundry returns. Larger melting operations use open-hearth reverberatory furnaces charged with the same type of materials but by mechanical means. Small operators sometimes use sweating furnaces to treat dirty scrap in preparation for smelting.

Table 7-5. EMISSION FACTORS FOR IRON AND STEEL MILLS WITHOUT CONTROLS

EMISSION FACTOR RATING: A

Type of operation	Particulates		Carbon monoxide[a]	
	lb/ton	kg/MT	lb/ton	kg/MT
Iron production				
Blast furnace[b,c]				
Ore charge	110	55	1,400 to 2,100[d]	700 to 1,050[d]
Agglomerates charge	40	20	-	-
Coke ovens	(see section on Metallurgical Coke)			
Sintering[e]				
Windbox[f,g]	20	10	-	-
Discharge[h]	22	11	44[i]	22[i]
Steel production				
Open-hearth furnace[c,j]				
Oxygen lance	22	11	-	-
No oxygen lance	12	6	-	-
Basic oxygen furnace[c,k]	46	23	120 to 150[l]	60 to 75[l]
Electric-arc furnace[c,m]				
Oxygen lance	11	5.5	18	9
No oxygen lance	7	3.5	18	9
Scarfing[e]	20	10	-	-

[a] Reference 23. Emission factors expressed as units per unit weight of metal produced.

[b] Preliminary cleaner (settling chamber or dry cyclone) collection efficiency = 60 percent. Primary cleaner (wet scrubber in series with preliminary cleaner) collection efficiency = 90 percent. Secondary cleaner (electrostatic precipitator or venturi scrubber in series with primary cleaner) collection efficiency = 90 percent.

[c] Reference 25.

[d] Represents the amount of CO generated; normally all of the CO generated is used for fuel. Abnormal conditions may cause the emission of CO.

[e] References 24 and 26.

[f] Dry-cyclone collection efficiency = 90 percent. Electrostatic precipitator (in series with dry-cyclone) collection efficiency = 95 percent.

[g] About 3 pounds SO_2 per ton (1.5 kg/MT) of sinter is produced at windbox.

[h] Dry-cyclone collection efficiency = 93 percent.

[i] Pounds per ton (kg per MT) of finished sinter.

[j] Electrostatic precipitator collection efficiency = 98 percent. Venturi scrubber collection efficiency = 85 to 98 percent. Baghouse collection efficiency = 99 percent.

[k] Venturi scrubber collection efficiency = 99 percent. Electrostatic precipitator collection efficiency = 99 percent.

[l] Represents generated CO. After ignition of the gas above the furnace, the CO amounts to 0 to 3 lb/ton (0 to 1.5 kg/MT) of steel produced.

[m] High-efficiency scrubber collection efficiency = up to 98 percent. Electrostatic precipitator collection efficiency = 92 to 97 percent. Baghouse collection efficiency = 93 to 99 percent.

Table 7-6. EMISSION FACTORS FOR PRIMARY LEAD SMELTERS[a]

EMISSION FACTOR RATING: B

Type of operation	Particulates[b]		Sulfur oxides	
	lb/ton	kg/MT	lb/ton	kg/MT
Sintering and sintering crushing[c]	50[d]	25[d]	660	330
Blast furnace[e]	75	37.5	f	f
Reverberatory furnace[e]	12	6	f	f

[a] Approximately 2 unit weights of concentrated ore are required to produce 1 unit weight of lead metal. Emission factors expressed as units per unit weight of concentrated ore produced.

[b] Electrostatic precipitator collection efficiency = 96 percent. Baghouse collection efficiency = 99.5 percent.

[c] References 14 and 28.

[d] Pounds per ton (kg/MT) of sinter.

[e] Reference 10.

[f] Overall plant emissions are about 660 pounds of sulfur oxide per ton (330 kg/MT) of concentrated ore.

Table 7-7. EMISSION FACTORS FOR PRIMARY ZINC SMELTING WITHOUT CONTROLS[a]

EMISSION FACTOR RATING: B

Type of operation	Particulates		Sulfur oxides	
	lb/ton	kg/MT	lb/ton	kg/MT
Roasting (multiple-hearth)[b]	120	60	1100	550
Sintering[c]	90	45	d	d
Horizontal retorts[e]	8	4	-	-
Vertical retorts[e]	100	50	-	-
Electrolytic process	3	1.5	-	-

[a] Approximately 2 unit weights of concentrated ore are required to produce 1 unit weight of zinc metal. Emission factors expressed as units per unit weight of concentrated ore produced.

[b] References 10 and 14.

[c] References 10 and 30.

[d] Included in SO_2 losses from roasting.

[e] Reference 10.

To produce a high-quality aluminum product, fluxing is practiced to some extent in all secondary aluminum melting. Aluminum fluxes are expected to remove dissolved gases and oxide particles from the molten bath. Sodium and various mixtures of potassium or sodium chloride with cryolite and chlorides of aluminum zinc are used as fluxes. Chlorine gas is usually lanced into the molten bath to reduce the magnesium content by reacting to form magnesium and aluminum chlorides.[33,34]

Emissions[32] - Emissions from secondary aluminum operations include fine particulate matter and gaseous chlorine. A large part of the material charged to a reverberatory furnace is low-grade scrap and chips. Paint, dirt, oil, grease, and other contaminants from this scrap cause large quantities of smoke and fumes to be discharged. Even if the scrap is clean, large surface-to-volume ratios require the use of more fluxes, which can cause serious air pollution problems. Table 7-8 presents particulate emission factors for secondary aluminum operations.

Table 7-8. PARTICULATE EMISSION FACTORS FOR SECONDARY ALUMINUM OPERATIONS[a]

EMISSION FACTOR FATING: B

	Uncontrolled		Baghouse		Electrostatic precipitator	
Type of operation	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Sweating furnace	14.5	7.25	3.3	1.65	--	--
Smelting						
Crucible furnace	1.9	0.95	--	--	--	--
Reverberatory furnace	4.3	2.15	1.3	0.65	1.3	0.65
Chlorination station[b]	1000	500	50	25	--	--

[a] Reference 35. Emission factors expressed as units per unit weight of metal processed.

[b] Pounds per ton (kg/MT) of chlorine used.

Brass and Bronze Ingots (Copper Alloys)

Process Description[36] - Obsolete domestic and industrial copper-bearing scrap is the basic raw material of the brass and bronze ingot industry. The scrap frequently contains any number of metallic and non-metallic impurities, which can be removed by such methods as hand sorting, magnetizing, heat methods such as sweating or burning, and gravity separation in a water medium.

Brass and bronze ingots are produced from a number of different furnaces through a combination of melting, smelting, refining, and alloying of the processed scrap material. Reverberatory, rotary, and crucible furnaces are the ones most widely used, and the choice depends on the size of the melt and the alloy desired. Both the reverberatory and the rotary furnaces are normally heated by direct firing, in which the flame and gases come into direct contact with the melt. Processing is essentially the same in any furnace except for the differences in the types of alloy being handled. Crucible furnaces are usually much smaller and are used principally for special-purpose alloys.

Emissions and Controls[36] - The principal source of emissions in the brass and bronze ingot industry is the refining furnace. The exit gas from the furnace may contain the normal combustion products such as fly ash, soot, and smoke. Appreciable amounts of zinc oxide are also present in this exit gas. Other sources of particulate emissions include the preparation of raw materials and the pouring of ingots.

The only air pollution control equipment that is generally accepted in the brass and bronze ingot industry is the baghouse filter, which can reduce emissions by as much as 99.9 percent. Table 7-9 summarizes uncontrolled emissions from various brass and bronze melting furnaces.

Table 7-9. PARTICULATE EMISSION FACTORS FOR BRASS AND BRONZE MELTING FURNACES WITHOUT CONTROLS[a]

EMISSION FACTOR RATING: A

Type of furnace	Uncontrolled emissions[b]	
	lb/ton	kg/MT
Blast[c]	18	9
Crucible	16	8
Cupola	73	36.5
Electric induction	2	1
Reverberatory	70	35
Rotary	60	30

[a] Reference 37. Emission factors expressed as units per unit weight of metal charged.

[b] The use of a baghouse can reduce emissions by 95 to 99.6 percent.

[c] Represents emissions following precleaner

Gray Iron Foundry

Process Description[38] - Three types of furnaces are used to produce gray iron castings: cupolas, reverberatory furnaces, and electric induction furnaces. The cupola is the major source of molten iron for the production of castings. In operation, a bed of coke is placed over the sand bottom in the cupola. After the bed of coke has begun to burn properly, alternate layers of coke, flux, and metal are charged into the cupola. Combustion air is forced into the cupola, causing the coke to burn and melt the iron. The molten iron flows out through a taphole.

Electric furnaces are commonly used where special alloys are to be made. Pig iron and scrap iron are charged to the furnace and melted, and alloying elements and fluxes are added at specific intervals. Induction furnaces are used where high-quality, clean metal is available for charging.

Emissions[38] - Emissions from cupola furnaces include gases, dust, fumes, and smoke and oil vapors. Dust arises from dirt on the metal charge and from fines in the coke and limestone charge. Smoke and oil vapor arise primarily from the partial combustion and distillation of oil from greasy scrap charged to the furnace. Also, the effluent from the cupola furnace has a high carbon monoxide content that can be controlled by an afterburner. Emissions from reverberatory and electric induction furnaces consist primarily of metallurgical fumes and are relatively low. Table 7-10 presents emission factors for the manufacture of iron castings.

Table 7-10. EMISSION FACTORS FOR GRAY IRON FOUNDRIES[a,b,c]

EMISSION FACTOR RATING: B

Type of furnace	Particulates		Carbon monoxide	
	lb/ton	kg/MT	lb/ton	kg/MT
Cupola				
Uncontrolled	17	8.5	145[c,d]	72.5[c,d]
Wet cap	8	4		
Impingement scrubber	5	2.5		
High-energy scrubber	0.8	0.4		
Electrostatic precipitator	0.6	0.3		
Baghouse	0.2	0.1		
Reverberatory	2	1	-	-
Electric induction	1.5	0.75	-	-

[a] References 35, and 39 through 41. Emission factors expressed as units per unit weight of metal charged.

[b] Approximately 85 percent of the total charge is metal. For every unit weight of coke in the charge, 7 unit weights of gray iron are produced.

[c] Reference 42.

[d] A well-designed afterburner can reduce emissions to 9 pounds per ton (4.5 kg/MT) of metal charged.[35]

Secondary Lead Smelting

General Description[7] - Three types of furnaces are used to produce the common types of lead: the pot furnace, the reverberatory furnace, and the blast furnace or cupola. The pot furnaces are used for the production of the purest lead products, and they operate under closely controlled temperature conditions. Reverberatory furnaces are used for the production of semi-soft lead from lead scrap, oxides, and drosses. The third common type of furnace, the blast furnace, is used to produce hard lead (typically averaging 8 percent antimony and up to 2 percent additional metallic impurity).[43] The charge to these furnaces consists of rerun, slag, and reverberatory slags.

Emissions and Controls[7] - The primary emissions from lead smelting are particulates consisting of lead, lead oxides, and contaminants in the lead charged. Carbon monoxide is released by the reduction of lead oxide by carbon in the cupola. Nitrogen oxides are formed by the fixation of atmospheric nitrogen, caused by the high temperatures associated with the smelting.

Factors affecting emissions from the pot furnace include the composition of the charge, the temperature of the pot, and the degree of control (usually hooding followed by a baghouse). Emissions from the reverberatory furnace are affected by the sulfur content in the charge, the temperature in the furnace, and the amount of air pulled across the furnace. Lead blast-furnace emissions are dependent on the amount of air passed through the charge, the temperature of the furnace, and the amount of sulfur and other impurities in the charge. In addition, blast furnaces emit significant quantities of carbon monoxide and hydrocarbons that must be controlled by incineration. Table 7-11 summarizes the emission factors from lead smelting.

Secondary Magnesium Smelting

Process Description[7] - Magnesium smelting is carried out in crucible or pot-type furnaces that are charged with magnesium scrap and fired by gas, oil, or electric heating. A flux is used to cover the surface of the molten metal because magnesium will burn in air at the pouring temperature (approximately 1500° F or 815° C). The molten magnesium, usually cast by pouring into molds, is annealed in ovens utilizing an atmosphere devoid of oxygen.

Emissions[7] - Emissions from magnesium smelting include particulate magnesium (MgO) from the melting, oxides of nitrogen from the fixation of atmospheric nitrogen by the furnace temperatures, sulfur dioxide losses from annealing oven atmospheres. Factors affecting emissions include the capacity of the furnace; the type of flux used on the molten material; the amount of lancing used; the amount of contamination of the scrap, including oil and other hydrocarbons; and the type and extent of control equipment used on the process. The emission factors for a pot furnace are shown in Table 7-12.

Steel Foundries

Process Description[7] - Steel foundries produce steel castings by melting steel metal and pouring it into molds. The melting of steel for castings is accomplished in one of five types of furnaces: direct electric-arc, electric induction, open-hearth, crucible, and pneumatic converter. The crucible and pneumatic converter are not in widespread use, so this section deals only with the remaining three types of furnaces. Raw materials supplied to the various melting furnaces include steel scrap of all types, pig iron, ferroalloys, and limestone. The basic melting process operations are furnace charging, melting, tapping the furnace into a ladle, and pouring the steel into molds. An integral part of the steel foundry operation is the preparation of casting molds, and the shakeout and cleaning of these castings. Some common materials used in molds and cores for hollow casting include sand, oil, clay, and resin. Shakeout is the operation by which the cool casting is separated from the mold. The castings are commonly cleaned by shot-blasting, and surface defects such as fins are removed by burning and grinding.

Emissions[7] - Particulate emissions from steel foundry operations include iron oxide fumes, sand fines, graphite, and metal dust. Gaseous emissions from foundry operations include oxides of nitrogen, oxides of sulfur, and hydrocarbons. Factors affecting emissions from the melting process include the quality and cleanliness of the scrap and the amount of oxygen lancing. The concentrations of oxides of nitrogen are dependent upon operating conditions in the melting unit, such as temperature and the rate of cooling of the exhaust gases. The concentration of carbon monoxide in the exhaust gases is dependent on the amount of draft

Table 7-11. EMISSION FACTORS FOR SECONDARY LEAD SMELTING

EMISSION FACTOR RATING: C

Type of furnace	Particulates				Sulfur oxides			
	Uncontrolled		Controlled		Uncontrolled		Controlled	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Pot furnace[a]	0.8	0.4	Neg	Neg	-	-	-	-
Reverberatory furnace[b]	130	65	1.6	0.8	85	42.5	-	-
Blast (cupola) furnace[c]	190	95	2.3	1.15	90	45	0.8,[d] 46[e]	0.4,[d] 23[e]
Rotary reverberatory furnace[f]	70	35	-	-	-	-	-	-

[a] References 34, and 44 through 46. Emission factors expressed as units per unit weight of metal processed.

[b] References 34, 43, and 46.

[c] References 43, 46, and 47.

[d] With NaOH scrubber.

[e] With water spray chamber.

[f] Reference 45.

Table 7-12. EMISSION FACTORS
FOR MAGNESIUM SMELTING
EMISSION FACTOR RATING: C

Type of furnace	Particulates[a]	
	lb/ton	kg/MT
Pot furnace		
Uncontrolled	4	2
Controlled	0.4	0.2

[a] References 34 and 46. Emission factors expressed as units per unit weight of metal processed.

on the melting furnace. Emissions from the shakeout and cleaning operations, mostly particulate matter, vary according to type and efficiency of dust collection. Gaseous emissions from the mold and baking operations are dependent upon the fuel used by the ovens and the temperature reached in these ovens. Table 7-13 summarizes the emission factors for steel foundries.

Table 7-13. EMISSION FACTORS FOR STEEL FOUNDRIES
EMISSION FACTOR RATING: A

Type of process	Particulates[a]		Nitrogen oxides	
	lb/ton	kg/MT	lb/ton	kg/MT
Melting				
Electric arc[b,c]	13 (4 to 40)	6.5 (2 to 20)	0.2	0.1
Open-hearth[d,e]	11 (2 to 20)	5.5 (1 to 10)	0.01	0.005
Open-hearth oxygen lanced[f,g]	10 (8 to 11)	5 (4 to 5.5)	-	-
Electric induction[h]	0.1	0.05	-	-

[a] Emission factors expressed as units per unit weight of metal processed. If the scrap metal is very dirty or oily, or if increased oxygen lancing is employed, the emission factor should be chosen from the high side of the factor range.

[b] Electrostatic precipitator, 92 to 98 percent control efficiency; baghouse (fabric filter), 98 to 99 percent control efficiency; venturi scrubber, 94 to 98 percent control efficiency.

[c] References 24 and 48 through 56.

[d] Electrostatic precipitator, 95 to 98.5 percent control efficiency; baghouse, 99.9 percent control efficiency; venturi scrubber, 96 to 99 percent control efficiency.

[e] References 24, and 57 through 59.

[f] Electrostatic precipitator, 95 to 98 percent control efficiency; baghouse, 99 percent control efficiency; venturi scrubber, 95 to 98 percent control efficiency.

[g] References 52 and 60.

[h] Usually not controlled.

Secondary Zinc Processing

Process Description[7] - Zinc processing includes zinc reclaiming, zinc oxide manufacturing, and zinc galvanizing. Zinc is separated from scrap containing lead, copper, aluminum, and iron by careful control of temperature in the furnace, allowing each metal to be removed at its melting range. The furnaces typically employed are the pot, muffle, reverberatory, or electric induction. Further refining of the zinc can be done in retort distilling or vaporization furnaces where the vaporized zinc is condensed to the pure metallic form. Zinc oxide is produced by distilling metallic zinc into a dry air stream and capturing the subsequently formed oxide in a baghouse. Zinc galvanizing is carried out in a vat or in bath-type dip tanks utilizing a flux cover. Iron and steel pieces to be coated are cleaned and dipped into the vat through the covering flux.

Emissions[7] - A potential for particulate emissions, mainly zinc oxide, occurs if the temperature of the furnace exceeds 1100° F (595° C). Zinc oxide (ZnO) may escape from condensers or distilling furnaces, and because of its extremely small particle size (0.03 to 0.5 micron), it may pass through even the most efficient collection systems. Some loss of zinc oxides occurs during the galvanizing processes, but these losses are small because of the flux cover on the bath and the relatively low temperature maintained in the bath. Some emissions of particulate ammonium chloride occur when galvanized parts are dusted after coating to improve their finish. Another potential source of emissions of particulates and gaseous zinc is the tapping of zinc-vaporizing muffle furnaces to remove accumulated slag residue. Emissions of carbon monoxide occur when zinc oxide is reduced by carbon. Nitrogen oxide emissions are also possible because of the high temperature associated with the smelting and the resulting fixation of atmospheric nitrogen. Table 7-14 summarizes the emission factors from zinc processing.

Table 7-14. PARTICULATE EMISSION FACTORS FOR SECONDARY ZINC SMELTING[a]

EMISSION FACTOR RATING: C

Type of furnace	Emissions lb/ton	Emissions kg/MT
Retort reduction	47	23.5
Horizontal muffle	45	22.5
Pot furnace	0.1	0.05
Kettle sweat furnace processing[b]		
Clean metallic scrap	Neg	Neg
General metallic scrap	11	5.5
Residual scrap	25	12.5
Reverberatory sweat furnace processing[b]		
Clean metallic scrap	Neg	Neg
General metallic scrap	13	6.5
Residual scrap	32	16
Galvanizing kettles	5	2.5
Calcining kiln	89	44.5

[a] References 34, 45, and 46. Emission factors expressed as units per unit weight of metal produced.

[b] Reference 61.

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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 storage of the finished product because this material is often dry and fine. Particulate emissions from some of the processes such as quarrying, yard storage, and road dust 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.

ASPHALT BATCHING

Process Description[1, 2]

Hot-mix asphalt paving consists of a combination of aggregates uniformly mixed and coated with asphalt cement. The coarse aggregates usually consist of crushed stone, crushed slag, crushed gravel, or combinations of these materials. The fine aggregates usually consist of natural sand and may contain added materials such as crushed stone, slag, or gravel.

An asphalt batch plant involves the use of a rotary dryer, screening and classifying equipment, an aggregate weighing system, a mixer, storage bins, and conveying equipment. Sand and aggregate are charged from bins into a rotary dryer. The dried aggregate is conveyed to the screening equipment, where it is classified and dumped into storage bins. Asphalt and weighed quantities of sized aggregates are then dropped into the mixer, where the batch is mixed and then dumped into trucks for transportation to the paving site.

Emissions and Controls[1, 2]

The largest source of dust emissions is the rotary dryer. Combustion gases and fine dust from the rotary dryer are exhausted through a precleaner, which usually consists of a single cyclone, although twin or multiple cyclones are also used. The exit gas stream of the precleaner usually passes through air pollution control equipment.[3] Other sources of dust emissions include the hot aggregate bucket elevator, vibrating screens, hot aggregate bins, aggregate weigh hopper, and the mixer. Emission factors for asphalt batching plants are presented in Table 8-1.

ASPHALT ROOFING

Process Description[8]

The manufacture of asphalt roofing felts and shingles involves saturating fiber media with asphalt by means of dipping and/or spraying. Although it is not

Table 8-1. PARTICULATE EMISSION FACTORS FOR ASPHALT BATCHING PLANTS[a]

EMISSION FACTOR RATING: B

Source and type of control	Emissions lb/ton	Emissions kg/MT
Rotary dryer[b]		
Uncontrolled[c,d]	35	17.5
Precleaner	5	2.5
High-efficiency cyclone	0.8	0.4
Multiple centrifugal scrubber	0.2	0.1
Baffle spray tower	0.2	0.1
Orifice-type scrubber	0.08	0.04
Baghouse	0.005	0.0025
Other sources, uncontrolled (vibrating screens, hot aggregate bins, aggregate weigh hopper, and mixer)[c]	10	5

[a] Emission factors expressed as units per unit weight of asphalt produced.

[b] References 2 through 5.

[c] References 2, 6, and 7.

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

always done at the same site, preparation of the asphalt saturant is an integral part of the operation. This preparation, called "blowing," consists of oxidizing the asphalt by bubbling air through the liquid asphalt for 8 to 16 hours. The saturant is then transported to the saturation tank or spray area. The saturation of the felts is accomplished by dipping, high-pressure sprays, or both. The final felts are made in various weights: 15, 30, and 55 pounds per 100 square feet (0.72, 1.5, and 2.7 kg/m^2). Regardless of the weight of the final product, the makeup is approximately 40 percent dry felt and 60 percent asphalt saturant.

Emissions and Controls[8]

The major sources of particulate emissions from asphalt roofing plants are the asphalt blowing operations and the felt saturation. Another minor source of particulates is the covering of the roofing material with roofing granules. Gaseous emissions from the saturation process have not been measured but are thought to be slight because of the initial driving off of contaminants during the blowing process.

A common method of control at asphalt saturating plants is the complete enclosure of the spray area and saturator with good ventilation through one or more collection devices, which include combinations of wet scrubbers and two-stage low-voltage electrical precipitators, or cyclones and fabric filters. Emission factors for asphalt roofing are presented in Table 8-2.

Table 8-2. EMISSION FACTORS FOR ASPHALT ROOFING MANUFACTURING WITHOUT CONTROLS[a]

EMISSION FACTOR RATING: D

	Particulates[b]		Carbon monoxide		Hydrocarbons (CH_4)	
Operation	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Asphalt blowing[c]	2.5	1.25	0.9	0.45	1.5	0.75
Felt saturation[d]						
Dipping only	1	0.5	-	-	-	-
Spraying only	3	1.5	-	-	-	-
Dipping and spraying	2	1	-	-	-	-

[a] Approximately 0.65 unit of asphalt input is required to produce 1 unit of saturated felt. Emission factors expressed as units per unit weight of saturated felt produced.

[b] Low-voltage precipitators can reduce emissions by about 60 percent; when they are used in combination with a scrubber, overall efficiency is about 85 percent.

[c] Reference 9.

[d] References 10 and 11.

BRICKS AND RELATED CLAY PRODUCTS

Process Description[8, 12-14]

The manufacture of brick and related products such as clay pipe, pottery, and some types of refractory brick involves the grinding, screening, and blending of the raw materials and the forming, drying or curing, firing, and cutting or shaping of the final product.

The drying and firing of pressed bricks, both common and refractory, are accomplished in many types of ovens, the most popular being the long tunnel oven. Common brick or building brick is prepared by molding a wet mix of 20 to 25 percent water and 75 to 80 percent clay, then baking it in chamber kilns. Common brick is also prepared by extrusion of a stiff mix (10 to 12 percent water), followed by the pressing and baking of sections cut from the extrusion.

Emissions and Controls[8]

Particulate emissions similar to those obtained in clay processing are emitted from the materials handling process in refractory and brick manufacturing. Combustion products are emitted from the fuel consumed in the curing, drying, and firing portion of this process, and fluorides, largely in a gaseous form, are emitted from brick manufacturing operations. Sulfur dioxide may also be emitted from the bricks when firing temperatures are 2500° F (1370° C) or more, or when the fuel contains sulfur.

A variety of control systems may be used to reduce both particulate and gaseous emissions. Almost any type of particulate control system will reduce emissions from the materials handling process. Fluoride emissions can be reduced to very low levels by using a water scrubber. Emission factors for brick manufacturing are presented in Table 8-3.

Table 8-3. EMISSION FACTORS FOR BRICK MANUFACTURING WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: D

Type of process	Particulate		Nitrogen oxides (NO_2)		Fluorides[b]	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Raw material handling[c]						
Drying	70	35	-	-	-	-
Grinding	76	38	-	-	-	-
Storage	34	17	-	-	-	-
Curing and firing[d]						
Gas-fired	Neg	Neg	0.6	0.3	0.8	0.4
Oil-fired	Neg	Neg	1.3	0.65	0.8	0.4
Coal-fired	5A to 10A[e]	2.5A to 5A[e]	1.5	0.75	0.8	0.4

[a] One brick weighs about 6.5 pounds (2.95 kg). Emission factors expressed as units per unit weight of bricks produced.

[b] Expressed as HF and based on a raw material content of 0.05 percent by weight fluoride.

[c] Based on data from section on ceramic clays.

[d] References 13, and 15 through 17.

[e] A is the percentage of ash in the coal, and emissions are given on the basis of pounds per ton (kg/MT) of fuel used. This is an estimate based on coal-fired furnaces.

CALCIUM CARBIDE MANUFACTURING

Process Description[18, 19]

Calcium carbide is manufactured by heating a mixture of quicklime (CaO) and carbon in an electric-arc furnace, where the lime is reduced by the coke to calcium carbide and carbon monoxide. Metallurgical coke, petroleum coke, or anthracite coal is used as the source of carbon. About 1,900 pounds (860 kg) of lime and 1,300 pounds (600 kg) of coke yield 1 ton (1 MT) of calcium carbide. There are two basic types of carbide furnaces: (1) the open furnace, in which the carbon monoxide burns to carbon dioxide when it comes in contact with air above the charge; and (2) the closed furnace, in which the gas is collected from the furnace. The molten calcium carbide from the furnace is poured into chill cars or bucket conveyors and allowed to solidify. The finished calcium carbide is dumped into a jaw crusher and then into a cone crusher to form a product of the desired size.

Emissions and Controls

Particulates, acetylene, sulfur compounds, and some carbon monoxide are emitted from calcium carbide plants. Table 8-4 contains emission factors based on one plant in which some particulate matter escapes from the hoods over each

Table 8-4. EMISSION FACTORS FOR CALCIUM CARBIDE PLANTS[a]
EMISSION FACTOR RATING: C

Type of source	Particulates lb/ton	Particulates kg/MT	Sulfur oxides lb/ton	Sulfur oxides kg/MT	Acetylene lb/ton	Acetylene kg/MT
Electric furnace						
Hoods	18	9	-	-	-	-
Main stack	20	10	3	1.5	-	-
Coke dryer	2	1	3	1.5	-	-
Furnace room vents	26	13	-	-	18	9

[a] Reference 20. Emission factors expressed as units per unit weight of calcium carbide produced.

furnace and the remainder passes through wet-impingement-type scrubbers before being vented to the atmosphere through a stack. The coke dryers and the furnace-room vents are also sources of emissions.

CASTABLE REFRACTORIES

Process Description[8, 21, 22]

Castable or fused-cast refractories are manufactured by carefully blending such components as alumina, zirconia, silica, chrome, and magnesia; melting the mixture in an electric-arc furnace at temperatures of 3200° to 4500° F (1760° to 2480° C); pouring it into molds; and slowly cooling it to the solid state. Fused refractories are less porous and more dense than kiln-fired refractories.

Emissions and Controls[8]

Particulate emissions occur during the drying, crushing, handling, and blending phases of this process, during the actual melting process, and in the molding phase. Fluorides, largely in the gaseous form, may also be emitted during the melting operations.

The general types of particulate controls may be used on the materials handling aspects of refractory manufacturing. Emissions from the electric-arc furnace, however, are largely condensed fumes and consist of very fine particles. Fluoride emissions can be effectively controlled with a scrubber. Emission factors for castable refractories manufacturing are presented in Table 8-5.

PORTLAND CEMENT MANUFACTURING

Process Description[26]

The raw materials required to make cement may be divided into the following components: lime (calcareous), silica (siliceous), alumina (argillaceous), and iron (ferriferous). The four major steps in the production of portland cement are: (1) quarrying and crushing, (2) grinding and blending, (3) clinker production, and (4) finish grinding and packaging.

Table 8-5. PARTICULATE EMISSION FACTORS FOR CASTABLE REFRACTORIES MANUFACTURING[a]

EMISSION FACTOR RATING: C

Type of process	Type of control	Uncontrolled		Controlled	
		lb/ton	kg/MT	lb/ton	kg/MT
Raw material dryer[b]	Baghouse	30	15	0.3	0.15
Raw material crushing and processing[c]	Scrubber			7	3.5
	Cyclone	120	60	45	22.5
Electric-arc melting[d]	Baghouse	50	25	0.8	0.4
	Scrubber			10	5
Curing oven[e]	-	0.2	0.1	-	-
Molding and shakeout[b]	Baghouse	25	12.5	0.3	0.15

[a] Fluoride emissions from the melt average about 1.3 pounds of HF per ton of melt (0.65 kg HF/MT melt). Emission factors expressed as units per unit weight of feed material.

[b] Reference 23.

[c] References 23 through 24.

[d] References 23 through 25.

[e] Reference 24.

In the first step the cement rock limestone, clay, and shale are worked in open quarries. The rock from the quarries is sent through a primary and a secondary crusher. The various crushed raw materials are properly mixed and are then sent through the grinding operations. After the raw materials are crushed and ground, they are introduced into a rotary kiln that is fired with pulverized coal, oil, or gas. In the kiln the materials are dried, decarbonated, and calcined to produce a cement clinker. The clinker is cooled, mixed, ground with gypsum, and bagged for shipment as cement.

Emissions and Controls[26,27]

Particulate matter is the primary emission in the manufacture of portland cement, and it is emitted from crushing operations, storage silos, rotary dryers, and rotary kilns. Dust production in the crusher area depends on the type and moisture content of the raw material and on the characteristics and type of crusher. In the process of conveying the crushed material to storage silos, sheds, or open piles, dust is generated at various conveyor transfer points. A hood is normally placed over each of these points to control particulate emissions.

Another major source of particulate matter is the rotary dryer. Hot gases passing through the rotary dryer will entrain dust from the limestone, shale, or other materials being dried. Control systems in common use include multi-cyclones, electrostatic precipitators, and fabric filters.

The largest source of emissions within cement plants is the kiln operation, which has three units: the feed system, a fuel-firing system, and a clinker-cooling and -handling system. The complications of kiln burning and the large volumes of materials handled have led to many control systems for dust collection. Because of the diversity of these control systems, they will not be discussed in this publication. Table 8-6 summarizes particulate emissions from cement manufacturing. The effect of control devices on emissions is shown in Footnote b.

Table 8-6. PARTICULATE EMISSION FACTORS
FOR CEMENT MANUFACTURING[a]
EMISSION FACTOR RATING: B

Type of process	Uncontrolled emissions[b] lb/bbl	Uncontrolled emissions[b] kg/MT
Dry process		
Kilns[c]	46 (35 to 75)	123
Dryers, grinder, etc.[d]	18 (10 to 30)	48
Wet process		
Kilns[c]	38 (15 to 55)	100
Dryers, grinders, etc.[d]	6 (2 to 10)	16

[a] One barrel of cement weighs 376 pounds (171 kg).

[b] Typical collection efficiencies are: multicyclones, 80 percent; old electrostatic precipitators, 90 percent; multicyclones plus old electrostatic precipitators, 95 percent; multicyclones plus new electrostatic precipitators, 99 percent; and fabric filter units, 99.5 percent.

[c] Reference 26.

[d] Reference 6.

CERAMIC CLAY MANUFACTURING

Process Description[8]

The manufacture of ceramic clay involves the conditioning of the basic ores by several methods. These include the separation and concentration of the minerals by screening, floating, wet and dry grinding, and blending of the desired ore varieties. The basic raw materials in ceramic clay manufacture are kaolinite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) and montmorillonite [$(Mg, Ca) O \cdot Al_2 O_3 \cdot 5SiO_2 \cdot nH_2O$] clays. These clays are refined by separation and bleaching, blended, kiln-dried, and formed into such items as whiteware, heavy clay products (brick, etc.), various stoneware, and other products such as diatomaceous earth used as a filter aid.

Emissions and Controls[8]

Emissions consist primarily of particulates, but some fluorides and acid gases are also emitted in the drying process. The high temperatures of the firing kilns are also conducive to the fixation of atmospheric nitrogen and the subsequent release of NO, but no published information has been found for gaseous emissions. Particulates are also emitted from the grinding process and from storage of the ground product.

Factors affecting emissions include the amount of material processed, the type of grinding (wet or dry), the temperature of the drying kilns, the gas velocities and flow direction in the kilns, and the amount of fluorine in the ores.

Common control techniques include settling chambers, cyclones, wet scrubbers, electrostatic precipitators, and bag filters. The most effective control is provided by cyclones for the coarser material, followed by wet scrubbers, bag filters, or electrostatic precipitators for dry dust. Emission factors for ceramic clay manufacturing are presented in Table 8-7.

Table 8-7. PARTICULATE EMISSION FACTORS FOR CERAMIC CLAY MANUFACTURING[a]

EMISSION FACTOR RATING: A

Type of process	Uncontrolled		Cyclone[b]		Multiple-unit cyclone and scrubber[c]	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Drying[d]	70	35	18	9	7	3.5
Grinding[e]	76	38	19	9.5	-	-
Storage[d]	34	17	8	4	-	-

[a] Emission factors expressed as units per unit weight of input to process.

[b] Approximate collection efficiency: 75 percent.

[c] Approximate collection efficiency: 90 percent.

[d] References 28 through 31.

[e] Reference 28.

CLAY AND FLY-ASH SINTERING

Process Description[8]

Although the processes for sintering fly ash and clay are similar, there are some distinctions that justify a separate discussion of each process. Fly-ash sintering plants are generally located near the source, with the fly ash delivered to a storage silo at the plant. The dry fly ash is moistened with a water solution of lignin and agglomerated into pellets or balls. This material goes to a traveling-grate sintering machine where direct contact with hot combustion gases sinters the individual particles of the pellet and completely burns off the residual carbon in the fly ash. The product is then crushed, screened, graded, and stored in yard piles.

Clay sintering involves the driving off of entrained volatile matter. It is desirable that the clay contain a sufficient amount of volatile matter so that the resultant aggregate will not be too heavy. It is thus sometimes necessary to mix the clay with finely pulverized coke (up to 10 percent coke by weight).[32,33] In the sintering process the clay is first mixed with pulverized coke, if necessary, and pelletized. The clay is next sintered in a rotating kiln or on a traveling grate. The sintered pellets are then crushed, screened, and stored, in a procedure similar to that for fly-ash pellets.

Emissions and Controls[8]

In fly-ash sintering, improper handling of the fly ash creates a dust problem. Adequate design features, including fly-ash wetting systems and particulate collection systems on all transfer points and on crushing and screening operations, would greatly reduce emissions. Normally, fabric filters are used to control emissions from the storage silo, and emissions are low. The absence of this dust collection system, however, would create a major emission problem. Moisture is added at the point of discharge from the silo to the agglomerator, and very few emissions occur there. Normally, there are few emissions from the sintering machine, but if the grate is not properly maintained, a dust problem is created. The consequent crushing, screening, handling, and storage of the sintered product also create dust problems.

In clay sintering, the addition of pulverized coke presents an emission problem because the sintering of coke-impregnated dry pellets produces more particulate emissions than the sintering of natural clay. The crushing, screening, handling, and storage of the sintered clay pellets creates dust problems similar to those encountered in fly-ash sintering. Emission factors for both clay and fly-ash sintering are shown in Table 8-8.

Table 8-8. PARTICULATE EMISSION FACTORS FOR SINTERING OPERATIONS[a]

EMISSION FACTOR RATING: C

Type of material	Sintering operation[b]		Crushing, screening, and yard storage[b,c]	
	lb/ton	kg/MT	lb/ton	kg/MT
Fly ash[d]	110	55	e	e
Clay mixed with coke[f,g]	40	20	15	7.5
Natural clay[h,i]	12	6	12	6

[a] Emission factors expressed as units per unit weight of finished product.

[b] Cyclones would reduce this emission by about 80 percent. Scrubbers would reduce this emission by about 90 percent.

[c] Based on data in section on stone quarrying and processing.

[d] Reference 8.

[e] Included in sintering losses.

[f] 90 percent clay, 10 percent pulverized coke; traveling-grate, single-pass, up-draft sintering machine.

[g] References 30, 31, and 33.

[h] Rotary dryer sinterer.

[i] Reference 32.

COAL CLEANING

Process Description[8]

Coal cleaning is the process by which undesirable materials are removed from bituminous and anthracite coal and lignite. The coal is screened, classified, washed, and dried at coal preparation plants. The major sources of air pollution from these plants are the thermal dryers. Seven types of thermal dryers are presently used: rotary, screen, cascade, continuous carrier, flash or suspension, multilouver, and fluidized bed. The three major types, however, are the flash, multilouver, and fluidized bed.

In the flash dryer, coal is fed into a stream of hot gases where instantaneous drying occurs. The dried coal and wet gases are drawn up a drying column and into the cyclone for separation. In the multilouver dryer, hot gases are passed through falling curtains of coal. The coal is raised by flights of a specially designed conveyor. In the fluidized bed the coal is suspended and dried above a perforated plate by rising hot gases.

Emissions and Controls[8]

Particulates in the form of coal dust constitute the major air pollution problem from coal cleaning plants. The crushing, screening, or sizing of coal are minor sources of dust emissions; the major sources are the thermal dryers. The range of concentration, quantity, and particle size of emissions depends upon the type of collection equipment used to reduce particulate emissions from the dryer stack. Emission factors for coal-cleaning plants are shown in Table 8-9. Footnote b of the table lists various types of control equipment and their possible efficiencies.

Table 8-9. PARTICULATE EMISSION FACTORS
FOR THERMAL COAL DRYERS[a]
EMISSION FACTOR RATING: B

	Uncontrolled emissions[b]	
Type of dryer	lb/ton	kg/MT
Fluidized bed[c]	20	10
Flash[c]	16	8
Multilouvered[d]	25	12.5

[a] Emission factors expressed as units per unit weight of coal dried.

[b] Typical collection efficiencies are: cyclone collectors (product recovery) - 70 percent; multiple cyclones (product recovery) - 85 percent; water sprays following cyclones - 95 percent; and wet scrubber following cyclones - 99 to 99.9 percent.

[c] References 34 and 35.

[d] Reference 36.

CONCRETE BATCHING

Process Description[8, 37, 38]

Concrete batching involves the proportioning of sand, gravel, and cement by means of weight hoppers and conveyors into a mixing receiver such as a transit mix truck. The required amount of water is also discharged into the receiver along with the dry materials. In some cases, the concrete is prepared for on-site building construction work or for the manufacture of concrete products such as pipes and pre-fabricated construction parts.

Emissions and Controls[8]

Particulate emissions consist primarily of cement dust, but some sand and aggregate gravel dust emissions do occur during batching operations. There is also a potential for dust emissions during the unloading and conveying of concrete and aggregates at these plants and during the loading of dry-batched concrete mix. Another source of dust emissions is the traffic of heavy equipment over unpaved or dusty surfaces in and around the concrete batching plant.

Control techniques include the enclosure of dumping and loading areas, the enclosure of conveyors and elevators, filters on storage bin vents, and the use of water sprays. Table 8-10 presents emission factors for concrete batch plants.

Table 8-10. PARTICULATE EMISSION FACTORS FOR CONCRETE BATCHING[a]

EMISSION FACTOR RATING: C

Concrete batching[b]	Emissions	
	lb/yd^3 of concrete	kg/m^3 of concrete
Uncontrolled	0.2	0.12
Good control	0.02	0.012

[a] One cubic yard of concrete weighs 4,000 pounds (1 m^3 = 2,400 kg). The cement content varies with the type of concrete mixed, but 735 pounds of cement per yard (436 kg/m^3) may be used as a typical value.

[b] Reference 28.

FIBER GLASS MANUFACTURING

Process Description[8]

Fiber glass is manufactured by melting various raw materials to form glass, drawing the molten glass into fibers, and coating the fibers with an organic material. The glass-forming reaction takes place at 2800° F (1540° C) in a large, rectangular, gas- or oil-fired reverberatory furnace. These melting furnaces are equipped with either regenerative or recuperative heat-recovery systems. After being refined, the molten glass passes to a forehearth where the glass is either formed into marbles for subsequent remelting or passed directly through orifices to form a filament. The continuous filaments are treated with organic binder material, wound, spooled, and sent to a high-humidity curing area where the binder sets. The product is then cooled by blowing air over it.

Emissions and Controls[8]

The major emissions from fiber glass manufacturing processes are particulates from the glass-melting furnace, the forming line, the curing oven, and the product cooling line. In addition, gaseous organic emissions occur from the forming line and curing oven. Particulate emissions from the glass-melting furnace are affected by basic furnace design, type of fuel (oil or gas), raw material size and composition, and type and volume of the furnace heat-recovery system.[39] Regenerative heat-recovery systems generally allow more particulate matter to escape than do recuperative systems. Control systems are not generally used on the glass-melting furnace. Organic and particulate emissions from the forming line are most affected by the composition and quantity of the binder and by the spraying techniques used to coat the fibers; very fine spray and volatile binders increase emissions. Emissions from the curing oven are affected by the oven temperature and binder composition, but direct-fired afterburners with heat exchangers may be used to control these emissions. Particulate emission factors for fiber glass manufacturing are summarized in Table 8-11.

Table 8-11. PARTICULATE EMISSION FACTORS FOR FIBER GLASS MANUFACTURING WITHOUT CONTROLS[a]

EMISSION FACTOR RATING: C

Type of process	Emissions[b]	
	lb/ton	kg/MT
Glass furnace[c,d]		
Reverberatory		
With regenerative heat exchanger	3	1.5
With recuperative heat exchanger	1	0.5
Electric induction	Neg	Neg
Forming line[e]	50	25
Curing oven[f]	7	3.5

[a] Emission factors expressed as units per unit of weight of material processed

[b] Overall emissions may be reduced by approximately 50 percent by using: (1) an afterburner on the curing oven, (2) a filtration system on the product cooling, and (3) process modifications for the forming line.

[c] Only one type is usually used at any one plant.

[d] References 40 and 41.

[e] References 40 and 42.

[f] References 42 and 43.

FRIT MANUFACTURING

Process Description[44, 45]

Frit is used in enameling iron and steel and in glazing porcelain and pottery. In a typical plant, the raw materials consist of a combination of materials such as borax, feldspar, sodium fluoride or fluorspar, soda ash, zinc oxide, litharge, silica, boric acid, and zircon. Frit is prepared by fusing these various minerals in a smelter, and the molten material is then quenched with air or water. This quenching operation causes the melt to solidify rapidly and shatter into numerous small glass particles, called frit. After a drying process, the frit is finely ground in a ball mill where other materials are added.

Emissions and Controls[45]

Significant dust and fume emissions are created by the frit-smelting operation. These emissions consist primarily of condensed metallic oxide fumes that have volatilized from the molten charge. They also contain mineral dust carry-over and sometimes hydrogen fluoride. Emissions can be reduced by not rotating the smelter too rapidly (to prevent excessive dust carry-over) and by not heating the batch too rapidly or too long (to prevent volatilizing the more fusible elements).

The two most feasible control devices for frit smelters are baghouses and venturi water scrubbers. Emission factors for frit smelters are shown in Table 8-12. Collection efficiencies obtainable for venturi scrubbers are also shown in the table.

Table 8-12. EMISSION FACTORS FOR FRIT SMELTERS WITHOUT CONTROLS[a]

EMISSION FACTOR RATING: C

Type of furnace	Particulates[b]		Fluorides[b]	
	lb/ton	kg/MT	lb/ton	kg/MT
Rotary	16	8	5	2.5

[a] Reference 45. Emission factors expressed as units per unit weight of charge.

[b] A venturi scrubber with a 21-inch (535-mm) water-gauge pressure drop can reduce particulate emissions by 67 percent and fluorides by 94 percent.

GLASS MANUFACTURING

Process Description[37, 46]

Nearly all glass produced commercially is one of five basic types: soda-lime, lead, fused silica, borosilicate, and 96 percent silica. Of these, the modern soda-lime glass constitutes 90 percent of the total glass produced and will thus be the only type discussed in this section. Soda-lime glass is produced on a massive scale in large, direct-fired, continuous-melting furnaces in which the blended raw materials are melted at 2700° F (1480° C) to form glass.

Emissions and Controls[46, 47]

Emissions from the glass-melting operation consist primarily of particulates and fluorides, if fluoride-containing fluxes are used in the process. Because the dust emissions contain particles that are only a few microns in diameter, cyclones and centrifugal scrubbers are not as effective as baghouses or filters in collecting particulate matter. Table 8-13 summarizes the emission factors for glass melting.

Table 8-13. EMISSION FACTORS FOR GLASS MELTING

EMISSION FACTOR RATING: D

Type of glass	Particulates[a]		Fluorides[b]	
	lb/ton	kg/MT	lb/ton	kg/MT
Soda-lime	2	1	4F[c]	2F[c]

[a] Reference 48. Emission factors expressed as units per unit weight of glass produced.

[b] Reference 17.

[c] F equals weight percent of fluoride in input to furnace; e.g., if fluoride content is 5 percent, the emission factor would be 4F or 20 (2F or 10).

GYPSUM MANUFACTURING

Process Description[8]

Gypsum, or hydrated calcium sulfate, is a naturally occurring mineral that is an important building material. When heated gypsum loses its water of hydration, it becomes plaster of paris, or when blended with fillers it serves as wall plaster. In both cases the material hardens as water reacts with it to form the solid crystalline hydrate.[49, 50]

The usual method of calcination of gypsum consists of grinding the mineral and placing it in large, externally heated calciners. Complete calcination of 1 ton (0.907 MT) of plaster takes about 3 hours and requires about 1.0 million Btu (0.25 million kcal).[51, 52]

Emissions[8]

The process of calcining gypsum appears to be devoid of any air pollutants because it involves simply the relatively low-temperature removal of the water of hydration. However, the gases created by the release of the water of crystallization carry gypsum rock dust and partially calcined gypsum dust into the atmosphere.[53] In addition, dust emissions occur from the grinding of the gypsum before calcining and from the mixing of the calcined gypsum with filler. Table 8-14 presents emission factors for gypsum processing.

Table 8-14. PARTICULATE EMISSION FACTORS FOR GYPSUM PROCESSING[a]

EMISSION FACTOR RATING: C

	Uncontrolled emissions		With fabric filter		With cyclone and electrostatic precipitator	
Type of process	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Raw-material dryer (if used)	40	20	0.2	0.1	0.4	0.2
Primary grinder	1	0.5	0.001	0.0005	-	-
Calciner	90	45	0.1	0.05	-	-
Conveying	0.7	0.35	0.001	0.0005	-	-

[a] Reference 54. Emission factors expressed as units per unit weight of process throughput.

LIME MANUFACTURING

General[8]

Lime (CaO) is the high-temperature product of the calcination of limestone ($CaCO_3$). Lime is manufactured in vertical or rotary kilns fired by coal, oil, or natural gas.

Emissions and Controls[8]

Atmospheric emissions in the lime manufacturing industry include particulate emissions from the mining, handling, crushing, screening, and calcining of the limestone and combustion products from the kilns. The vertical kilns, because of a larger size of charge material, lower air velocities, and less agitation, have considerably fewer particulate emissions. Control of emissions from these vertical kilns is accomplished by sealing the exit of the kiln and exhausting the gases through control equipment.

Particulate emission problems are much greater on the rotary kilns because of the smaller size of the charge material, the higher rate of fuel consumption, and the greater air velocities through the rotary chamber. Methods of control on rotary-kiln plants include simple and multiple cyclones, wet scrubbers, baghouses, and electrostatic precipitators.[55] Emission factors for lime manufacturing are summarized in Table 8-15.

Table 8-15. PARTICULATE EMISSION FACTORS FOR LIME MANUFACTURING WITHOUT CONTROLS[a]

EMISSION FACTOR RATING: B

Operation	Emissions[b]	
	lb/ton	kg/MT
Crushing[c]		
Primary	31	15.5
Secondary	2	1
Calcining[d]		
Vertical kiln	8	4
Rotary kiln	200	100

[a] Emission factors expressed as units per unit weight of lime processed.

[b] Cyclones could reduce these factors by about 70 percent. Venturi scrubbers could reduce these factors by about 95 to 99 percent. Fabric filters could reduce these factors by about 99 percent.

[c] Reference 56

[d] References 55, 57, and 58.

MINERAL WOOL MANUFACTURING

Process Description[59, 60]

The product mineral wool used to be divided into three categories: slag wool, rock wool, and glass wool. Today, however, straight slag wool and rock wool as such are no longer manufactured. A combination of slag and rock constitutes the charge material that now yields a product classified as a mineral wool, used mainly for thermal and acoustical insulation.

Mineral wool is made primarily in cupola furnaces charged with blast-furnace slag, silica rock, and coke. The charge is heated to a molten state at about 3000° F (1650° C) and then fed to a blow chamber, where steam atomizes the molten rock into globules that develop long fibrous tails as they are drawn to the other end of the chamber. The wool blanket formed is next conveyed to an oven to cure the binding agent and then to a cooler.

Emissions and Controls

The major source of emissions is the cupola or furnace stack. Its discharge consists primarily of condensed fumes that have volatilized from the molten charge and gases such as sulfur oxides and fluorides. Minor sources of particulate emissions include the blowchamber, curing oven, and cooler. Emission factors for various stages of mineral wool processing are shown in Table 8-16. The effect of control devices on emissions is shown in footnotes to the table.

Table 8-16. EMISSION FACTORS FOR MINERAL WOOL PROCESSING WITHOUT CONTROLS[a]

EMISSION FACTOR RATING: C

	Particulates		Sulfur oxides	
Type of process	lb/ton	kg/MT	lb/ton	kg/MT
Cupola	22	11	0.02	0.01
Reverberatory furnace	5	2.5	Neg	Neg
Blow chamber[b]	17	8.5	Neg	Neg
Curing oven[c]	4	2	Neg	Neg
Cooler	2	1	Neg	Neg

[a] Reference 60. Emission factors expressed as units per unit weight of charge.

[b] A centrifugal water scrubber can reduce particulate emissions by 60 percent.

[c] A direct-flame afterburner can reduce particulate emissions by 50 percent.

PERLITE MANUFACTURING

Process Description[61, 62]

Perlite is a glassy volcanic rock consisting of oxides of silicon and aluminum combined as a natural glass by water of hydration. By a process called exfoliation, the material is rapidly heated to release water of hydration and thus to expand the spherules into low-density particles used primarily as aggregate in plaster and concrete. A plant for the expansion of perlite consists of ore unloading and storage facilities, a furnace-feeding device, an expanding furnace, provisions for gas and product cooling, and product-classifying and product-collecting equipment. Vertical furnaces, horizontal stationary furnaces, and horizontal rotary furnaces are used for the exfoliation of perlite, although the vertical types are the most numerous. Cyclone separators are used to collect the product.

Emissions and Controls[62]

A fine dust is emitted from the outlet of the last product collector in a perlite expansion plant. The fineness of the dust varies from one plant to another, depending upon the desired product. In order to achieve complete control of these particulate emissions, a baghouse is needed. Simple cyclones and small multiple cyclones are not adequate for collecting the fine dust from perlite furnaces. Table 8-17 summarizes the emissions from perlite manufacturing.

Table 8-17. PARTICULATE EMISSION FACTORS
FOR PERLITE EXPANSION FURNACES
WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: C

Type of furnace	Emissions[b]	
	lb/ton	kg/MT
Vertical	21	10.5

[a] Reference 63. Emission factors expressed as units per unit weight of charge.

[b] Primary cyclones will collect 80 percent of the particulates above 20 microns, and baghouses will collect 96 percent of the particles above 20 microns.[62]

PHOSPHATE ROCK PROCESSING

Process Description[64]

Phosphate rock preparation involves beneficiation to remove impurities, drying to remove moisture, and grinding to improve reactivity. Usually, direct-fired rotary kilns are used to dry phosphate rock. These dryers burn natural gas or fuel oil and are fired counter-currently. The material from the dryers may be ground before storage in large storage silos. Air-swept ball mills are preferred for grinding phosphate rock.

Emissions and Controls[64]

Although there are no significant emissions from phosphate rock beneficiation plants, emissions in the form of fine rock dust may be expected from drying and grinding operations. Phosphate rock dryers are usually equipped with dry cyclones followed by wet scrubbers. Particulate emissions are usually higher when drying pebble rock than when drying concentrate because of the small adherent particles of clay and slime on the rock. Phosphate rock grinders can be a considerable source of particulates. Because of the extremely fine particle size, baghouse collectors are normally used to reduce emissions. Emission factors for phosphate rock processing are presented in Table 8-18.

STONE QUARRYING AND PROCESSING

Process Description[8]

Rock and gravel products are loosened by drilling and blasting them from their deposit beds, and they are removed with the use of heavy earth-moving equipment. This mining of rock is done primarily in open pits. The use of pneumatic drilling and cutting, as well as blasting and transferring, causes considerable dust formation. Further processing includes crushing, regrinding, and removal of fines.[69] Dust emissions can occur from all of these operations, as well as from quarrying, transferring, loading, and storage operations. Drying operations, when used, can also be a source of dust emissions.

Table 8-18. PARTICULATE EMISSION FACTORS FOR PHOSPHATE ROCK PROCESSING WITHOUT CONTROLS[a]

EMISSION FACTOR RATING: C

Type of source	Emissions	
	lb/ton	kg/MT
Drying[b,c]	15	7.5
Grinding[b,d]	20	10
Transfer and storage[d,e]	2	1
Open storage piles[f]	40	20

[a] Emission factors expressed as units per unit weight of phosphate rock.

[b] References 65 through 67.

[c] Dry cyclones followed by wet scrubbers can reduce emissions by 95 to 99 percent.

[d] Dry cyclones followed by fabric filters can reduce emissions by 99.5 to 99.9 percent.

[e] Reference 66.

[f] Reference 68.

Emissions[8]

As enumerated above, dust emissions occur from many operations in stone quarrying and processing. Although a big portion of these emissions is heavy particles that settle out within the plant, an attempt has been made to estimate the suspended particulates. These emission factors are shown in Table 8-19. Factors affecting emissions include the amount of rock processed; the method of transfer of the rock; the moisture content of the raw material; the degree of enclosure of the transferring, processing, and storage areas; and the degree to which control equipment is used on the processes.

Table 8-19. PARTICULATE EMISSION FACTORS FOR ROCK-HANDLING PROCESSES

EMISSION FACTOR RATING: C

Type of process	Uncontrolled total[a]		Settled out in plant, %	Suspended emission	
	lb/ton	kg/MT		lb/ton	kg/MT
Crushing operations[b,c]					
Primary crushing	0.5	0.25	80	0.1	0.05
Secondary crushing and screening	1.5	0.75	60	0.6	0.3
Tertiary crushing and screening (if used)	6	3	40	3.6	1.8
Recrushing and screening	5	2.5	50	2.5	1.25
Fines mill	6	3	25	4.5	2.25
Miscellaneous operations[d]					
Screening, conveying, and handling[e]	2	1			
Storage pile losses[f]	10	5			

[a] Typical collection efficiencies: cyclone, 70 to 85 percent; fabric filter, 99 percent.

[b] All values are based on raw material entering primary crusher, except those for recrushing and screening, which are based on throughput for that operation.

[c] Reference 70.

[d] Based on units of stored product.

[e] Reference 71.

[f] The significance of storage pile losses is mentioned in Reference 72. The factor assigned here is the author's estimate for uncontrolled total emissions. Use of this factor should be tempered with knowledge about the size of materials stored, the local meteorological factors, the frequency with which the piles are disturbed, etc.

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9. PETROLEUM INDUSTRY

PETROLEUM REFINERY

General[1]

Although a modern refinery is a complex system of many processes, the entire operation can be divided into four major steps: separating, converting, treating, and blending. The crude oil is first separated into selected fractions (e.g., gasoline, kerosene, fuel oil, etc.). Because the relative volumes of each fraction produced by merely separating the crude may not conform to the relative demand for each fraction, some of the less valuable products, such as heavy naphtha, are converted to products with a greater sale value, such as gasoline. This is done by splitting, uniting, or rearranging the original molecules. The final step is the blending of the refined base stocks with each other and with various additives to meet final product specifications. The various unit operations involved at petroleum refineries will be briefly discussed in the following sections.

Crude Oil Distillation[1] - Because crude oil is composed of hydrocarbons of different physical properties, it can be separated by physical means into its various constituents. The primary separation is usually accomplished by distillation. The fractions from the distillation include refinery gas, gasoline, kerosene, light fuel oil, diesel oils, gas oil, lube distillate, and heavy bottoms. These "straight-run products" are treated to remove impurities and used as base stocks or feedstock for other refinery units, or sold as finished products.

Catalytic Cracking[1] - To obtain the desired product distribution and quality, heavy hydrocarbon molecules are cracked or split to form low-boiling hydrocarbons in the gasoline range. Catalytic cracking units are classified according to the method used for catalyst transfer. The two most widely used methods are the moving-bed, typified by the Thermofor catalytic cracking units (TCC), and the fluidized bed, system of fluid catalytic cracking units (FCC).

In a typical "cat" cracker, the catalyst in the form of a fine powder for an FCC unit and beads or pellets for a TCC unit, passes through the reactor, then through a regeneration zone where coke deposited on the catalyst is burned off in a continuous process.

Catalytic Reforming[1] - Unlike catalytic cracking, catalytic reforming does not increase the gasoline yield from a barrel of crude oil. Reforming uses gasoline as a feedstock and by molecular rearrangement, which usually includes hydrogen removal, produces a gasoline of higher quality and octane number. Coke deposition is not severe in reforming operations, and thus catalyst regeneration is not always used. If this is the case, the catalyst is physically removed and replaced periodically. Some of the fixed-bed catalytic reforming processes that require catalyst regeneration include Fixed-Bed Hydroforming, Ultraforming, and Powerforming. Some of the fixed-bed processes in which the catalyst is infrequently regenerated include Platforming, Rexforming, and Catforming.

Polymerization, Alkylation, Isomerization[1] - Polymerization and alkylation are processes used to produce gasoline from the gaseous hydrocarbons formed during cracking operations. Polymerization joins two or more olefins, and alkylation unites an olefin and an isoparaffin. In the process of isomerization, the arrangement of the atoms in a molecule is altered, usually to form branched-chain hydrocarbons.

Treating, Blending[1] - The products from both the separation and the conversion steps are treated, usually for the removal of sulfur compounds and gum-forming materials. As a final step, the refined base stocks are blended with each other and with various additives to meet product specifications.

Emissions[1]

Emissions from refineries vary greatly in both quantity and type. The most important factors affecting refinery emissions are crude oil capacity, air pollution control equipment used, general level of maintenance, and processing scheme used. The major pollutants emitted are sulfur oxides, nitrogen oxides, hydrocarbons, carbon monoxide, and malodorous materials. Other emissions of lesser importance include particulates, aldehydes, ammonia, and organic acids. Boilers, process heaters, and catalytic cracking unit regenerators are major sources of sulfur oxides, nitrogen oxides, and particulates. The catalytic cracking unit regenerators are also large sources of carbon monoxide, aldehydes, and ammonia. The many hydrocarbon sources include waste-water separators, blow-down systems, catalyst regenerators, pumps, valves, cooling towers, vacuum jets, compressor engines, process heaters, and boilers. Emission factors for the various refinery operations are summarized in Table 9-1.

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Table 9-1. EMISSION FACTORS FOR PETROLEUM REFINERIES[a]

EMISSION FACTOR RATING: B

Type of process	Particulates	Sulfur oxides	Carbon monoxide	Hydrocarbons	Nitrogen oxides	Aldehydes	Ammonia
Boilers and process heaters							
lb/10^3 bbl oil burned	840	NA[b]	Neg	140	2,900	25	-
kg/10^3 liters oil burned	2.4	NA	Neg	0.4	8.3	0.071	-
lb/10^3 ft^3 gas burned	0.02	NA	Neg	0.03	0.23	0.003	-
kg/10^3 m^3 gas burned	0.32	NA	Neg	0.48	3.7	0.048	-
Fluid catalytic cracking units (FCC)							
lb/10^3 bbl fresh feed	61	525	13,700	220	63	19	54
kg/10^3 liters fresh feed	0.175	1.5	39.2	0.630	0.180	0.054	0.155
Moving-bed catalytic cracking units (TCC)							
lb/10^3 bbl fresh feed	17	60	3,800	87	5	12	6
kg/10^3 liters fresh feed	0.049	0.171	10.8	0.250	0.014	0.034	0.017
Compressor internal combustion engines							
lb/10^3 ft^3 gas burned	-	-	Neg	1.2	0.9	0.1	0.2
kg/10^3 m^3 gas burned	-	-	Neg	19.3	14.4	1.61	3.2
Blowdown systems							
lb/10^3 bbl refinery capacity							
With control	-	-	-	5	-	-	-
Without control	-	-	-	300	-	-	-
kg/10^3 liters refinery capacity							
With control	-	-	-	0.014	-	-	-
Without control	-	-	-	0.860	-	-	-

Table 9-1 (continued). EMISSION FACTORS FOR PETROLEUM REFINERIES[a]

EMISSION FACTOR RATING: B

Type of process	Particulates	Sulfur oxides	Carbon monoxide	Hydrocarbons	Nitrogen oxides	Aldehydes	Ammonia
Process drains							
$lb/10^3$ bbl waste water							
With control	-	-	-	8	-	-	-
Without control	-	-	-	210	-	-	-
$kg/10^3$ liters waste water							
With control	-	-	-	0.023	-	-	-
Without control	-	-	-	0.600	-	-	-
Vacuum jets							
$lb/10^3$ bbl vacuum distillation							
With control	-	-	-	Neg	-	-	-
Without control	-	-	-	130	-	-	-
$kg/10^3$ liters vacuum distillation							
With control	-	-	-	Neg	-	-	-
Without control	-	-	-	0.370	-	-	-
Cooling tower							
$lb/10^6$ gal cooling water	-	-	-	6	-	-	-
$kg/10^6$ liters cooling water	-	-	-	0.72	-	-	-
Miscellaneous losses, $lb/10^3$ bbl refinery capacity[c]							
Pipeline valves and flanges	-	-	-	28 (0.080)	-	-	-
Vessel relief valves	-	-	-	11 (0.031)	-	-	-
Pump seals	-	-	-	17 (0.049)	-	-	-
Compressor seals	-	-	-	5 (0.014)	-	-	-
Others (air blowing, sampling, etc)	-	-	-	10 (0.029)	-	-	-

[a] Reference 1.

[b] NA = information not available.

[c] $kg/10^3$ liters shown in parentheses.

10. WOOD PROCESSING

Wood processing involves the conversion of raw wood to either pulp or pulpboard. This section presents emission data both for wood pulping operations and for the manufacture of two types of pulpboard: paperboard and fiber board. The burning of wood waste in boilers and conical burners is not included as it is discussed in other sections of this publication.

WOOD PULPING

General[1]

Wood pulping involves the production of cellulose from wood by dissolving the lignin that binds the cellulose fiber together. The three major chemical processes for pulp production are the kraft or sulfate process, the sulfite process, and the neutral sulfite semichemical process. The choice of pulping process is determined by the product being made, by the type of wood species available, and by economic considerations. There is a lack of valid emission data for the sulfite and neutral sulfite semichemical processes; therefore, only the kraft process will be discussed in this section.

Process Description (Kraft Process)[1, 2]

The kraft process involves the cooking of wood chips under pressure in the presence of a cooking liquor in either a batch or continuous digester. The cooking liquor, an aqueous solution of sodium sulfide and sodium hydroxide, dissolves the lignin that binds the cellulose fibers tobether.

When cooking is completed, the bottom of the digester is suddenly opened, and its contents are forced into the blow tank. Here the major portion of the spent cooking liquor, which contains the dissolved lignin, is drained, and the pulp enters the initial stage of washing. From the blow tank the pulp passes through the knotter, where unreacted chunks of wood are removed. The pulp is then processed through intermittent stages of washing and bleaching, after which it is pressed and dried into the finished product.

Most of the chemicals from the spent cooking liquor are recovered for reuse in subsequent cooks. These spent chemicals and organics, called "black liquor," are concentrated in multiple-effect evaporators and/or direct-contact evaporators.

The concentrated black liquor is then sprayed into the recovery furnace, where the organic content supports combustion. The inorganic compounds fall to the bottom of the furnace and are withdrawn as a molten smelt, which is dissolved to form a solution called "green liquor." The green liquor is then pumped from the smelt-dissolving tank, treated with slaked lime, and clarified. The resulting liquor, referred to as "white liquor," is the cooking liquor used in the digesters.

Emissions and Controls[3]

Particulate emissions from the kraft process occur primarily from the recovery furnace, the lime kiln, and the smelt-dissolving tank. They are caused mainly by the carryover of solids plus the sublimation and condensation of inorganic chemicals.

The characteristic kraft-mill odor is caused principally by the presence of a variable mixture of hydrogen sulfide and dimethyl disulfide. Hydrogen sulfide is emitted from the breakdown of the weak base, sodium sulfide, which is characteristic of kraft cooking liquor. It may also be generated by improper operation of a recovery furnace. Methyl mercaptan and dimethyl sulfide are formed in reactions with the wood component lignin. Dimethyl disulfide is formed through the oxidation of mercaptan groups derived from the lignins.

Sulfur dioxide emissions in the kraft process result from the oxidation of reduced sulfur compounds. A potential source of sulfur dioxide is the recovery boilers, where reduced sulfur gases present can be oxidized in the furnace atmosphere.

Potential sources of carbon monoxide emissions from the kraft process include the recovery furnace and lime kilns. The major cause of carbon monoxide emissions is furnace operation well above rated capacity, making it impossible to maintain oxidizing conditions.

Rather than presenting a lengthy discussion on the control techniques presently available for each phase of the kraft process, the most widely used controls are shown, where applicable, in the table for emission factors. Table 10-1 presents these emission factors for both controlled and uncontrolled sources.

PULPBOARD

General[4]

Pulpboard manufacturing includes the manufacture of fibrous boards from a pulp slurry. This includes two distinct types of product, paperboard and fiberboard. Paperboard is a general term that describes a sheet 0.012 inch (0.30 mm) or more in thickness made of fibrous material on a paper machine.[5] Fiberboard, also referred to as particle board, is much thicker than paperboard and is made somewhat differently.

There are two distinct phases in the conversion of wood to pulpboard: (1) the manufacture of pulp from the raw wood, and (2) the manufacture of pulpboard from the pulp. This section deals only with the latter as the first is covered under the section on wood pulping industry.

Process Description[4]

In the manufacture of paperboard, the stock is sent through screens into the head box, from which it flows onto a moving screen. Approximately 15 percent of the water is removed by suction boxes located under the screen. Another 50 to 60 percent of the moisture content is removed in the drying section. The dried board then enters the calendar stack, which imparts the final surface to the product.

Table 10-1. EMISSION FACTORS FOR SULFATE PULPING[a]

(unit weights of air-dried unbleached pulp)

EMISSION FACTOR RATING: A

Source	Type of control	Particulates[b]		Sulfur dioxides (SO_2)[b]		Carbon monoxide[c]		Hydrogen sulfide[b]		RSH, RSR, RSSR[d]	
		lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Blow tank accumulator	Untreated	-	-	-	-	-	-	0.1	0.05	3.0	1.5
Washers and screens	Untreated	-	-	-	-	-	-	0.02	0.01	0.2	0.1
Multiple-effect evaporators	Untreated	-	-	-	-	-	-	0.5	0.25	0.4	0.2
Recovery boilers and direct-contact evaporators	Untreated	151	75.5	5.0	2.5	60	30	12	6	0.9	0.45
	Electrostatic precipitators	15	7.5	5.0	2.5	60	30	12	6	0.9	0.45
	Venturi scrubber	47	23.5	5.0	2.5	60	30	12	6	0.9	0.45
Smelt dissolving tank	Untreated	2	1	-	-	-	-	0.03	0.015	0.04	0.02
Lime kilns	Untreated	45	22.5	-	-	10	5	1.0	0.5	0.6	0.3
	Scrubber	4	2	-	-	10	5	1.0	0.5	0.6	0.3
Turpentine condenser	Untreated	-	-	-	-	-	-	0.01	0.005	0.5	0.25
Fluidized-bed calciner[e]	Untreated	72	36	-	-	-	-	-	-	-	-
	Scrubber	0.7	0.35	-	-	-	-	-	-	-	-

[a] For more detailed data on specific types of plants, consult Reference 1.

[b] Reference 1.

[c] Reference 6.

[d] RSH - Mercaptans, RSR - Sulfides, RSSR - Disulfides.

[e] Only a few plants in the western United States use this process.

In the manufacture of fiberboard, the slurry that remains after pulping is washed and sent to the stock chests where sizing is added. The refined fiber from the stock chests is fed to the head box of the board machine. The stock is next fed onto the forming screens and sent to dryers, after which the dry product is finally cut and fabricated.

Emissions[4]

Emissions from the paperboard machine consist only of water vapor,[7-9] and little or no particulate matter is emitted from the dryers. Particulates are emitted, however, from the drying operation of fiberboard. Additional particulate emissions occur from the cutting and sending operations, but no data were available to estimate these emissions. Emission factors for pulpboard manufacturing are shown in Table 10-2.

Table 10-2. PARTICULATE EMISSION FACTORS FOR PULPBOARD MANUFACTURING[a]

EMISSION FACTOR RATING: E

	Emissions	
Type of product	lb/ton	kg/MT
Paperboard	Neg	Neg
Fiberboard[b]	0.6	0.3

[a] Emission factors expressed as units per unit weight of finished product.

[b] Reference 10.

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APPENDIX

Table A-1. PERCENTAGE DISTRIBUTION BY SIZE OF PARTICLES FROM SELECTED SOURCES WITHOUT CONTROL EQUIPMENT

Type of source	Particles by size range, %				
	<5 μ	5 to 10 μ	10 to 20 μ	20 to 44 μ	>44 μ
Stationary combustion					
Bituminous coal					
Pulverized	15	17	20	23	25
Cyclone	65	10	8	7	10
Stoker	4	6	11	18	61
Anthracite coal	35	5	8	7	45
Fuel oil	50	NA[a]	NA	NA	0
Natural gas	100	-	-	-	-
Solid waste disposal					
Refuse incineration	12	10	15	18	45
Mobile combustion					
Gasoline-powered motor vehicles	100	-	-	-	-
Diesel-powered motor vehicles	63	NA	NA	0	0
Aircraft	100	-	-	-	-
Chemical process					
Phosphoric acid	100	-	-	-	-
Soap and Detergents	5	15	40	30	10
Sulfuric acid	100	-	-	-	-
Food and agriculature					
Alfalfa dehydrating	Average size 2 to 10 μ		-	-	-
Cotton ginning	NA	NA	NA	NA	40
Feed and grain	5	15	20	45	15
Fish meal	1	1	3	8	87
Phosphate fertilizer	6	6	10	8	70
Metallurgical					
Primary aluminum	13	12	12	13	50
Primary zinc	14	17	40	NA	NA
Iron and steel					
Sintering	0	0	0	15	85
Blast furnace	NA	NA	NA	NA	70
Open hearth	46	22	17	10	5
Basic oxygen	99.5	0.5	0	0	0
Bessemer converter	-	-	-	100	-
Secondary aluminum	34	30	23	10	3
Brass and bronze	100	-	-	-	-
Gray iron foundry	18	8	12	14	48
Secondary lead	95	3	2	0	0
Secondary steel	60	14	11	9	6
Secondary zinc	100	-	-	-	-
Mineral products					
Asphalt batching	35	25	17	20	3
Asphalt roofing	100	-	-	-	-
Ceramic clay	36	NA	NA	40	6
Castable refractories	100	-	-	-	-
Cement	22	25	25	20	8
Concrete	13	21	27	25	14
Frit	45	15	15	15	10
Glass	26	NA	NA	NA	0
Gypsum	95% <10 μ		NA	NA	NA

Table A-1 (continued). PERCENTAGE DISTRIBUTION BY SIZE OF PARTICLES FROM SELECTED SOURCES WITHOUT CONTROL EQUIPMENT

Type of source	Particles by size range, %				
	<5 μ	5 to 10 μ	10 to 20 μ	20 to 44 μ	>44 μ
Mineral products (continued)					
Lime	2	8	24	38	28
Mineral wool	0.5	2.5	10	27	60
Perlite	32	10	10	13	35
Phosphate rock	80	15	5	0	0
Stone quarrying and processing					
Crushing	5	5	5	10	75
Conveying and screening	30	20	20	18	12
Petroleum refinery					
Catalyst regenerator	50	15	NA	NA	NA
Wood processing					
Fiberboard	NA	NA	NA	NA	25

[a] NA = no further breakdown of particle distribution available.

Table A-2. NATIONWIDE EMISSIONS FOR 1968[a]

Source	Particulates		Sulfur oxides		Carbon monoxide		Hydrocarbons		Nitrogen oxides	
	10^6 tons/yr	10^6 MT/yr	10^6 tons/yr	10^6 MT/yr	10^6 tons/yr	10^6 MT/yr	10^6 tons/yr	10^6 MT/yr	10^6 tons/yr	10^6 MT/yr
Stationary combustion	8.9	8.1	24.4	22.1	1.9	1.7	0.7	0.6	10.0	9.1
Solid waste disposal	1.1	1.0	0.1	0.1	7.8	7.1	1.6	1.5	0.6	0.5
Mobile combustion	1.2	1.1	0.8	0.7	63.8	57.9	16.6	15.1	8.1	7.3
Industrial process	7.5	6.8	7.3	6.6	9.7	8.8	4.6	4.2	0.2	0.2
Miscellaneous	9.6	8.7	0.6	0.5	16.9	15.3	8.5	7.7	1.7	1.5
Total	28.3	25.7	33.2	30.0	100.1	90.8	32.0	29.1	20.6	18.6

[a] Reference 1.

Table A-3. DISTRIBUTION BY PARTICLE SIZE OF AVERAGE COLLECTION EFFICIENCIES FOR VARIOUS PARTICULATE CONTROL EQUIPMENT[a,b]

Type of collector	Efficiency, %					
		Particle size range, μ				
	Overall	0 to 5	5 to 10	10 to 20	20 to 44	>44
Baffled settling chamber	58.6	7.5	22	43	80	90
Simple cyclone	65.3	12	33	57	82	91
Long-cone cyclone	84.2	40	79	92	95	97
Multiple cyclone (12-in. diameter)	74.2	25	54	74	95	98
Multiple cyclone (6-in. diameter)	93.8	63	95	98	99.5	100
Irrigated long-cone cyclone	91.0	63	93	96	98.5	100
Electrostatic precipitator	97.0	72	94.5	97	99.5	100
Irrigated electrostatic precipitator	99.0	97	99	99.5	100	100
Spray tower	94.5	90	96	98	100	100
Self-induced spray scrubber	93.6	85	96	98	100	100
Disintegrator scrubber	98.5	93	98	99	100	100
Venturi scrubber	99.5	99	99.5	100	100	100
Wet-impingement scrubber	97.9	96	98.5	99	100	100
Baghouse	99.7	99.5	100	100	100	100

[a] References 2 and 3.

[b] Data based on standard silica dust with the following particle size and weight distribution:

Particle size range, μ	Percent by weight
0 to 5	20
5 to 10	10
10 to 20	15
20 to 44	20
>44	35

Table A-4. THERMAL EQUIVALENTS FOR VARIOUS FUELS

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

Table A-5. WEIGHTS OF SELECTED SUBSTANCES

Type of substance	lb/gal	g/liter
Asphalt	8.57	1,030
Butane, liquid at 60° F	4.84	579
Crude oil	7.08	850
Distillate oil	7.05	845
Gasoline	6.17	739
Propane, liquid at 60° F	4.24	507
Residual oil	7.88	944
Water	8.4	1,000

Table A-6. GENERAL CONVERSION FACTORS

Type of substance	Conversion factors
Fuel	
Oil	1 bbl = 42 gal = 159 liters
Natural gas	1 therm = 100,000 Btu = 95 ft^3 1 therm = 25,000 kcal = 2.7 m^3
Agricultural products	
Corn	1 bu = 56 lb = 25.4 kg
Milo	1 bu = 56 lb = 25.4 kg
Oats	1 bu = 32 lb = 14.5 kg
Barley	1 bu = 48 lb = 21.8 kg
Wheat	1 bu = 60 lb = 27.2 kg
Cotton	1 bale = 500 lb = 226 kg
Mineral products	
Brick	1 brick = 6.5 lb = 2.95 kg
Cement	1 bbl = 375 lb = 170 kg
Cement	1 yd^3 = 2500 lb = 1130 kg
Concrete	1 yd^3 = 4000 lb = 1820 kg
Mobile sources	
Gasoline-powered motor vehicle	12.5 mi/gal = 5.32 km/liter
Diesel-powered motor vehicle	5.1 mi/gal = 2.16 km/liter
Steamship	44 gal/naut mi = 90 liters/km
Motorship	14 gal/naut mi = 28.6 liters/km
Other substances	
Paint	1 gal = 10 to 15 lb = 4.5 to 6.82 kg
Varnish	1 gal = 7 lb = 3.18 kg
Whiskey	1 bbl = 50 gal = 188 liters
Water	1 gal = 8.4 lb = 3.81 kg
Miscellaneous factors	1 lb = 7000 grains = 453.6 grams 1 ft^3 = 7.48 gal = 28.32 liters
Metric system	1 ft = 0.3048 m 1 mi = 1609 m 1 lb = 453.6 g 1 ton (short) = 907.2 kg 1 ton (short) = 0.9072 MT (metric ton)

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