AP-42
Supplement A
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SUPPLEMENT A

TO

COMPILATION
OF
AIR POLLUTANT
EMISSION FACTORS

Volume I:
Stationary Point
And Area Sources

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of Air Pollutant Emission Factors, Volume I Stationary Point and Area Sources.* EPA has made this available for historical reference purposes.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/

U.S. ENVIRONMENTAL PROTECTION AGENCY
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Volume I
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INSTRUCTIONS FOR INSERTING SUPPLEMENT A

INTO AP-42

Pp. iii and iv (blank) replace same. New Publications In Series.
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Pp. 8.19.2-5 and -6 replace same. Minor Revision.
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Add pp. B-1 and -2 (blank). Reserved for future use.
Add Appendix C.1. New Information.
Add Appendix C.2. New Information.

PUBLICATIONS IN SERIES

		Issue
COMPILATION OF AIR POLLUTANT EMISSION FACTORS (Fourth Edition)		9/85
SUPPLEMENT A		10/86
Introduction		
Section 1.1	Bituminous And Subbituminous Coal Combustion	
1.2	Anthracite Coal Combustion	
1.3	Fuel Oil Combustion	
1.4	Natural Gas Combustion	
1.6	Wood Waste Combustion In Boilers	
1.7	Lignite Combustion	
5.16	Sodium Carbonate	
7.1	Primary Aluminum Production	
7.2	Coke Production	
7.3	Primary Copper Smelting	
7.4	Ferroalloy Production	
7.5	Iron And Steel Production	
7.6	Primary Lead Smelting	
7.7	Zinc Smelting	
7.8	Secondary Aluminum Operations	
7.10	Gray Iron Foundries	
7.11	Secondary Lead Smelting	
8.1	Asphaltic Concrete Plants	
8.3	Bricks And Related Clay Products	
8.6	Portland Cement Manufacturing	
8.10	Concrete Batching	
8.13	Glass Manufacturing	
8.15	Lime Manufacturing	
8.19.2	Crushed Stone Processing	
8.22	Taconite Ore Processing	
8.24	Western Surface Coal Mining	
10.1	Chemical Wood Pulping	
11.2.6	Industrial Paved Roads	
Appendix C.1	Particle Size Distribution Data And Sized Emission Factors For Selected Sources	
Appendix C.2	Generalized Particle Size Distributions	

CONTENTS

APPENDIX B (Reserved For Future Use)

COMPILATION OF AIR POLLUTANT EMISSION FACTORS

VOLUME I:
STATIONARY POINT AND AREA SOURCES

Introduction

What is an emission factor?

An emission factor is an average value which relates the quantity of a pollutant released to the atmosphere with the activity associated with the release of that pollutant. It is usually expressed as the weight of pollutant divided by a unit weight, volume, distance or duration of the activity that emits the pollutant (e. g., kilograms of particulate emitted per megagram of coal combusted). Using such factors permits the estimation of emissions from various sources of air pollution. In most cases, these factors are simply averages of all available data of acceptable quality, generally without consideration for the influence of various process parameters such as temperature, reactant concentrations, etc. For a few cases, however, such as in the estimation of volatile organic emissions from petroleum storage tanks, this document contains empirical formulae which can relate emissions to such variables as tank diameter, liquid temperature and wind velocity. Emission factors correlated with such variables tend to yield more precise estimates than would factors derived from broader statistical averages.

Recommended uses of emission factors

Emission factors are very useful tools for estimating emissions of air pollutants. However, because such factors are averages obtained from data of wide range and varying degrees of accuracy, emissions calculated this way for a given facility are likely to differ from that facility's actual emissions. Because they are averages, factors will indicate higher emission estimates than are actual for some sources, and lower for others. Only specific source measurement can determine the actual pollutant contribution from a source, under conditions existing at the time of the test. For the most accurate emissions estimate, it is recommended that source specific data be obtained whenever possible. Emission factors are more appropriately used to estimate the collective emissions of a number of sources, such as is done in emissions inventory efforts for a particular geographic area.

If factors are used to predict emissions from new or proposed sources, users should review the latest literature and technology to determine if such sources would likely exhibit emissions characteristics different from those of typical existing sources.

In a few AP-42 Sections, emission factors are presented for facilities having air pollution control equipment in place. These factors are not intended to be used as regulatory standards. They do not represent best available control technology (BACT), such as may be reflected in New Source Performance Standards (NSPS), or reasonably available control technology (RACT) for existing sources . Rather, they relate to the average level of controls found on existing facilities for which data are available. The usefulness of this information should be considered carefully, in light of changes in air pollution control technology. In using this information with respect to any specific source, the user should consider the age, level of maintenance and other aspects which may influence equipment efficacy.

Examples of various factor applications

Calculating carbon monoxide (CO) emissions from distillate oil combustion serves as an example of the simplest use of emission factors. Consider an industrial boiler which burns 90,000 liters of distillate oil per day. In Section 1.3 of AP-42, the CO emission factor for industrial boilers burning distillate oil is 0.6 kg CO per 10^3 liters of oil burned.

Then CO emissions

= CO emission factor x distillate oil burned/day
= 0.6 x 90
= 54 kg/day

In a somewhat more complex case, suppose a sulfuric acid (H_2SO_4) plant produces 200 Mg of 100% H_2SO_4 per day by converting sulfur dioxide (SO_2) into sulfur trioxide (SO_3) at 97.5% efficiency. In Section 5.17, the SO_2 emission factors are listed according to SO_2 to SO_3 conversion efficiencies, in whole numbers. The reader is directed to Footnote b, an interpolation formula which may be used to obtain the emission factor for 97.5% SO_2 to SO_3 conversion.

Emission factor for kg SO_2/Mg 100% H_2SO_4

= 682 - [(6.82)(% SO_2 to SO_3 conversion)]
= 682 - [(6.82)(97.5)]
= 682 - 665
= 17

For production of 200 Mg of 100% H_2SO_4 per day, SO_2 emissions are calculated as

SO_2 emissions

= 17 kg SO_2 emissions/Mg 100% H_2SO_4 x 200 Mg 100% H_2SO_4/day
= 3400 kg/day

Emission Factor Ratings

To help users understand the reliability and accuracy of AP-42 emission factors, each Table (and sometimes individual factors within a Table) is given a rating (A through E, with A being the best) which reflects the quality and the amount of data on which the factors are based. In general, factors based on many observations or on more widely accepted test procedures are assigned higher rankings. For instance, an emission factor based on ten or more source tests on different plants would likely get an A rating, if all tests were conducted using a single valid reference measurement method or equivalent techniques. Conversely, a factor based on a single observation of questionable quality, or one extrapolated from another factor for a similar process, would probably be labeled D or E. Several subjective schemes have been used in the past to assign these ratings, depending upon data availability, source characteristics, etc. Because these ratings are subjective and take no account of the inherent scatter among the data used to calculate factors, they should be used only as approximations, to infer error bounds or confidence intervals about each emission factor. At most, a rating should be considered an indicator of the accuracy and precision of a given factor used to estimate emissions from a large number of sources. This indicator will largely reflect the professional judgment of the authors and reviewers of AP-42 Sections concerning the reliability of any estimates derived with these factors.

1.1 BITUMINOUS AND SUBBITUMINOUS COAL COMBUSTION

1.1.1 General[1]

Coal is a complex combination of organic matter and inorganic ash formed over eons from successive layers of fallen vegetation. Coal types are broadly classified as anthracite, bituminous, subbituminous or lignite, and classification is made by heating values and amounts of fixed carbon, volatile matter, ash, sulfur and moisture. Formulas for differentiating coals based on these properties are given in Reference 1. See Sections 1.2 and 1.7 for discussions of anthracite and lignite, respectively.

There are two major coal combustion techniques, suspension firing and grate firing. Suspension firing is the primary combustion mechanism in pulverized coal and cyclone systems. Grate firing is the primary mechanism in underfeed and overfeed stokers. Both mechanisms are employed in spreader stokers.

Pulverized coal furnaces are used primarily in utility and large industrial boilers. In these systems, the coal is pulverized in a mill to the consistency of talcum powder (i. e., at least 70 percent of the particles will pass through a 200 mesh sieve). The pulverized coal is generally entrained in primary air before being fed through the burners to the combustion chamber, where it is fired in suspension. Pulverized coal furnaces are classified as either dry or wet bottom, depending on the ash removal technique. Dry bottom furnaces fire coals with high ash fusion temperatures, and dry ash removal techniques are used. In wet bottom (slag tap) furnaces, coals with low ash fusion temperatures are used, and molten ash is drained from the bottom of the furnace. Pulverized coal furnaces are further classified by the firing position of the burners, i. e., single (front or rear) wall, horizontally opposed, vertical, tangential (corner fired), turbo or arch fired.

Cyclone furnaces burn low ash fusion temperature coal crushed to a 4 mesh size. The coal is fed tangentially, with primary air, to a horizontal cylindrical combustion chamber. In this chamber, small coal particles are burned in suspension, while the larger particles are forced against the outer wall. Because of the high temperatures developed in the relatively small furnace volume, and because of the low fusion temperature of the coal ash, much of the ash forms a liquid slag which is drained from the bottom of the furnace through a slag tap opening. Cyclone furnaces are used mostly in utility and large industrial applications.

In spreader stokers, a flipping mechanism throws the coal into the furnace and onto a moving fuel bed. Combustion occurs partly in suspension and partly on the grate. Because of significant carbon in the particulate, flyash reinjection from mechanical collectors is commonly employed to improve boiler efficiency. Ash residue in the fuel bed is deposited in a receiving pit at the end of the grate.

TABLE 1.1-1. EMISSION FACTORS FOR EXTERNAL BITUMINOUS AND SUBBITUMINOUS COAL COMBUSTION[a]

Firing Configuration	Particulate[b]		Sulfur Oxides[c]		Nitrogen Oxides[d]		Carbon Monoxide[e]		Nonmethane VOC[e,f]		Methane[e]	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Pulverized coal fired Dry bottom	5A	10A	19.5S(17.5S)	39S(35S)	10.5(7.5)[g]	21(15)[g]	0.3	0.6	0.04	0.07	0.015	0.03
Wet bottom	3.5A[h]	7A[h]	19.5S(17.5S)	39S(35S)	17	34	0.3	0.6	0.04	0.07	0.015	0.03
Cyclone furnace	1A[h]	2A[h]	19.5S(17.5S)	39S(35S)	16.5	33	0.3	0.6	0.04	0.07	0.015	0.03
Spreader stoker Uncontrolled	30[j]	60[j]	19.5S(17.5S)	39S(35S)	7	14	2.5	5	0.04	0.07	0.015	0.03
After multiple cyclone With fly ash reinjection from multiple cyclone	8.5	17	19.5S(17.5S)	39S(35S)	7	14	2.5	5	0.04	0.07	0.015	0.03
No fly ash reinjection from multiple cyclone	6	12	19.5S(17.5S)	39S(35S)	7	14	2.5	5	0.04	0.07	0.015	0.03
Overfeed stoker[k] Uncontrolled	8[m]	16[m]	19.5S(17.5S)	39S(35S)	3.25	7.5	3	6	0.04	0.07	0.015	0.03
After multiple cyclone	4.5[n]	9[n]	19.5S(17.5S)	39S(35S)	3.25	7.5	3	6	0.04	0.07	0.015	0.03
Underfeed stoker Uncontrolled	7.5[p]	15[p]	15.5S	31S	4.75	9.5	5.5	11	0.65	1.3	0.4	0.8
After multiple cyclone	5.5[n]	11[n]	15.5S	31S	4.75	9.5	5.5	11	0.65	1.3	0.4	0.8
Handfired units	7.5	15	15.5S	31S	1.5	3	45	90	5	10	4	8

[a] Factors represent uncontrolled emissions unless otherwise specified and should be applied to coal consumption as fired.

[b] Based on EPA Method 5 (front half catch) as described in Reference 12. Where particulate is expressed in terms of coal ash content, A, factor is determined by multiplying weight % ash content of coal (as fired) by the numerical value preceding the "A". For example, if coal having 8% ash is fired in a dry bottom unit, the particulate emission factor would be 5 x 8, or 40 kg/Mg (80 lb/ton). The "condensible" matter collected in back half catch of EPA Method 5 averages <5% of front half, or "filterable", catch for pulverized coal and cyclone furnaces; 10% for spreader stokers; 15% for other stokers; and 50% for handfired units (References 6, 19, 49).

[c] Expressed as SO_2, including SO_2, SO_3 and gaseous sulfates. Factors in parentheses should be used to estimate gaseous SO_x emissions for subbituminous coal. In all cases, "S" is weight % sulfur content of coal as fired. See Footnote b for example calculation. On average for bituminous coal, 97% of fuel sulfur is emitted as SO_2, and only about 0.7% of fuel sulfur is emitted as SO_3 and gaseous sulfate. An equally small percent of fuel sulfur is emitted as particulate sulfate (References 9, 13). Small quantities of sulfur are also retained in bottom ash. With subbituminous coal generally about 10% more fuel sulfur is retained in the bottom ash and particulate because of the more alkaline nature of the coal ash. Conversion to gaseous sulfate appears about the same as for bituminous coal.

[d] Expressed as NO_2. Generally, 95 - 99 volume % of nitrogen oxides present in combustion exhaust will be in the form of NO, the rest NO_2 (Reference 11). To express factors as NO, multiply by factor of 0.66. All factors represent emission at baseline operation (i.e., 60 - 110% load and no NO_x control measures, as discussed in text).

[e] Nominal values achieveable under normal operating conditions. Values one or two orders of magnitude higher can occur when combustion is not complete.

[f] Nonmethane volatile organic compounds (VOC), expressed as C_2 to C_{16} n-alkane equivalents (Reference 58). Because of limited data on NMVOC available to distinguish the effects of firing configuration, all data were averaged collectively to develop a single average for pulverized coal units, cyclones, spreaders and overfeed stokers.

[g] Parenthetic value is for tangentially fired boilers.

[h] Uncontrolled particulate emissions, when no fly ash reinjection is employed. When control device is installed, and collected fly ash is reinjected to boiler, particulate from boiler reaching control equipment can increase by up to a factor of two.

[j] Accounts for fly ash settling in an economizer, air heater or breeching upstream of control device or stack. (Particulate directly at boiler outlet typically will be twice this level.) Factor should be applied even when fly ash is reinjected to boiler from boiler, air heater or economizer dust hoppers.

[k] Includes traveling grate, vibrating grate and chain grate stokers.

[m] Accounts for fly ash settling in breeching or stack base. Particulate loadings directly at boiler outlet typically can be 50% higher.

[n] See text for discussion of apparently low multiple cyclone control efficiencies, regarding uncontrolled emissions.

[p] Accounts for fly ash settling in breeching downstream of boiler outlet.

TABLE 1.1-2. EMISSION FACTOR RATINGS* AND REFERENCES FOR BITUMINOUS AND SUBBITUMINOUS COAL COMBUSTION

Firing Configuration	Particulate		Sulfur Oxides		Nitrogen Oxides		Carbon Monoxide		Nonmethane VOC		Methane	
	Rating	Ref.	Rating	Ref.	Rating	Ref.	Rating	Ref.	Rating	Ref.	Rating	Ref.
Pulverized coal fired												
Dry bottom	A	14-25	A	9,16-19,21, 31-37,39, 41-46,51-55	A	11,14,16-17, 21,46,56	A	16,18-19,21 47,57	A	55,58	A	58
Wet bottom	D	14,16,26	A	"	C	14,16	A	"	A	58	A	"
Cyclone furnace	D	14,19,22, 27-29	A	"	B	11	A	"	A	"	A	"
Spreader stoker												
Uncontrolled	B	17,30-35	A	"	A	11,17,31-37 39-40,46	A	17,19,31-34, 36,47,51	A	"	A	"
After multiple cyclone												
With flyash reinjection from cyclone	B	14,32,36-38	A	"	A	"	A	"	A	"	A	"
No flyash reinjection from cyclone	A	17,31-35, 39,40,59	A	"	A	"	A	"	A	"	A	"
Overfeed stoker												
Uncontrolled	B	6,17,41-43, 45-47	A	"	A	11,17,19, 41-45	B	17,41-42,45, 47,51	A	"	A	"
After multiple cyclone	B	6,41,44-45	A	"	A	"	B	"	A	"	A	"
Underfeed stoker												
Uncontrolled	B	6,19,47-48	B	19,48	B	19,47-48	B	19,47-48	A	47,58	A	47,58
After multiple cyclone	C	6	B	"	B	"	B	"	A	"	A	"
Handfired units	D	49-50	D	"	D	50	D	50	D	50,58	D	50,58

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[*] These ratings, in the context of this Section, refer to the number of test data on which each emission factor is based. An "A" rating means the factor is based on tests at ten or more boilers, a "B" rating on six to nine test data, and a "C" rating on test data for two to five boilers. A "D" rating indicates the factor is based on only a single datum or extrapolated from a secondary reference. These ratings are not a measure of the scatter in the underlying test data. However, a higher rating will generally increase confidence that a given factor will better approximate the average emissions for a particular boiler category.

In overfeed stokers, coal is fed onto a traveling or vibrating grate, and it burns on the fuel bed as it progresses through the furnace. Ash particles fall into an ash pit at the rear of the stoker. The term "overfeed" applies because the coal is fed onto the moving grate under an adjustable gate. Conversely, in "underfeed" stokers, coal is fed into the firing zone from underneath by mechanical rams or screw conveyers. The coal moves in a channel, known as a retort, from which it is forced upward, spilling over the top of each side to form and to feed the fuel bed. Combustion is completed by the time the bed reaches the side dump grates from which the ash is discharged to shallow pits. Underfeed stokers include single retort units and multiple retort units, the latter having several retorts side by side.

1.1.2 Emissions And Controls

The major pollutants of concern from external coal combustion are particulate, sulfur oxides and nitrogen oxides. Some unburnt combustibles, including numerous organic compounds and carbon monoxide, are generally emitted even under proper boiler operating conditions.

Particulate[2-4] - Particulate composition and emission levels are a complex function of firing configuration, boiler operation and coal properties. In pulverized coal systems, combustion is almost complete, and thus particulate largely comprises inorganic ash residue. In wet bottom pulverized coal units and cyclones, the quantity of ash leaving the boiler is less than in dry bottom units, since some of the ash liquifies, collects on the furnace walls, and drains from the furnace bottom as molten slag. To increase the fraction of ash drawn off as wet slag, and thus to reduce the flyash disposal problem, flyash may be reinjected from collection equipment into slag tap systems. Dry bottom unit ash may also be reinjected into wet bottom boilers for the same purpose.

Because a mixture of fine and coarse coal particles is fired in spreader stokers, significant unburnt carbon can be present in the particulate. To improve boiler efficiency, flyash from collection devices (typically multiple cyclones) is sometimes reinjected into spreader stoker furnaces. This practice can dramatically increase the particulate loading at the boiler outlet and, to a lesser extent, at the mechanical collector outlet. Flyash can also be reinjected from the boiler, air heater and economizer dust hoppers. Flyash reinjection from these hoppers does not increase particulate loadings nearly so much as from multiple cyclones.[5]

Uncontrolled overfeed and underfeed stokers emit considerably less particulate than do pulverized coal units and spreader stokers, since combustion takes place in a relatively quiescent fuel bed. Flyash reinjection is not practiced in these kinds of stokers.

Other variables than firing configuration and flyash reinjection can affect emissions from stokers. Particulate loadings will often increase as load increases (especially as full load is approached) and with sudden load changes. Similarly, particulate can increase as the ash and fines contents increase. ("Fines", in this context, are coal particles smaller than about 1.6 millimeters, or one sixteenth inch, in diameter.) Conversely, particulate can be reduced significantly when overfire air pressures are increased.[5]

The primary kinds of particulate control devices used for coal combustion include multiple cyclones, electrostatic precipitators, fabric filters (baghouses) and scrubbers. Some measure of control will even result from ash settling in boiler/air heater/economizer dust hoppers, large breeches and chimney bases. To the extent possible from the existing data base, the effects of such settling are reflected in the emission factors in Table 1.1-1.

Electrostatic precipitators (ESP) are the most common high efficiency control device used on pulverized coal and cyclone units, and they are being used increasingly on stokers. Generally, ESP collection efficiencies are a function of collection plate area per volumetric flow rate of flue gas through the device. Particulate control efficiencies of 99.9 weight percent are obtainable with ESPs. Fabric filters have recently seen increased use in both utility and industrial applications, generally effecting about 99.8 percent efficiency. An advantage of fabric filters is that they are unaffected by high flyash resistivities associated with low sulfur coals. ESPs located after air preheaters (i. e., cold side precipitators) may operate at significantly reduced efficiencies when low sulfur coal is fired. Scrubbers are also used to control particulate, although their primary use is to control sulfur oxides. One drawback of scrubbers is the high energy requirement to achieve control efficiencies comparable to those of ESPs and baghouses.[2]

Mechanical collectors, generally multiple cyclones, are the primary means of control on many stokers and are sometimes installed upsteam of high efficiency control devices in order to reduce the ash collection burden. Depending on application and design, multiple cyclone efficiencies can vary tremendously. Where cyclone design flow rates are not attained (which is common with underfeed and overfeed stokers), these devices may be only marginally effective and may prove little better in reducing particulate than large breeching. Conversely, well designed multiple cyclones, operating at the required flow rates, can achieve collection efficiencies on spreader stokers and overfeed stokers of 90 to 95 percent. Even higher collection efficiencies are obtainable on spreader stokers with reinjected flyash, because of the larger particle sizes and increased particulate loading reaching the controls.[5-6]

Sulfur Oxides[7-9] - Gaseous sulfur oxides from external coal combustion are largely sulfur dioxide (SO_2) and much less quantity of sulfur trioxide (SO_3) and gaseous sulfates. These compounds form as the organic and pyritic sulfur in the coal is oxidized during the combustion process. On average, 98 percent of the sulfur present in bituminous coal will be emitted as gaseous sulfur oxides, whereas somewhat less will be emitted when subbituminous coal is fired. The more alkaline nature of the ash in some subbituminous coal causes some of the sulfur to react to form various sulfate salts that are retained in the boiler or in the flyash. Generally, boiler size, firing configuration and boiler operations have little effect on the percent conversion of fuel sulfur to sulfur oxides.

Several techniques are used to reduce sulfur oxides from coal combustion. One way is to switch to lower sulfur coals, since sulfur oxide emissions are proportional to the sulfur content of the coal. This alternative may not be possible where lower sulfur coal is not readily available or where a different grade of coal can not be satisfactorily fired. In some cases, various cleaning processes may be employed to reduce the fuel sulfur content. Physical coal cleaning removes mineral sulfur such as pyrite but is not effective in removing organic sulfur. Chemical cleaning and solvent refining processes are being developed to remove organic sulfur.

Many flue gas desulfurization techniques can remove sulfur oxides formed during combustion. Flue gases can be treated through wet, semidry or dry desulfurization processes of either the throwaway type, in which all waste streams are discarded, or the recovery (regenerable) type, in which the SO_x absorbent is regenerated and reused. To date, wet systems are the most commonly applied. Wet systems generally use alkali slurries as the SO_x absorbent medium and can be designed to remove well in excess of 90 percent of the incoming SO_x. Particulate reduction of up to 99 percent is also possible with wet scrubbers, but flyash is often collected by upsteam ESPs or baghouses, to avoid erosion of the desulfurization equipment and possible interference with the process reactions.[7] Also, the volume of scrubber sludge is reduced with separate flyash removal, and contamination of the reagents and byproducts is prevented. References 7 and 8 give more details on scrubbing and other SO_x removal techniques.

Nitrogen Oxides [10-11] - Nitrogen oxides (NO_x) emissions from coal combustion are primarily nitrogen oxide (NO). Only a few volume percent are nitrogen dioxide (NO_2). NO results from thermal fixation of atmospheric nitrogen in the combustion flame and from oxidation of nitrogen bound in the coal. Typically, only 20 to 60 percent of the fuel nitrogen is converted to nitrogen oxides. Bituminous and subbituminous coals usually contain from 0.5 to 2 weight percent nitrogen, present mainly in aromatic ring structures. Fuel nitrogen can account for up to 80 percent of total NO_x from coal combustion.

A number of combustion modifications can be made to reduce NO_x emissions from boilers. Low excess air (LEA) firing is the most widespread control modification, because it can be practiced in both old and new units and in all sizes of boilers. LEA firing is easy to implement and has the added advantage of increasing fuel use efficiency. LEA firing is generally effective only above 20 percent excess air for pulverized coal units and above 30 percent excess air for stokers. Below these levels, the NO_x reduction from decreased O_2 availability is offset by increased NO_x because of increased flame temperature. Another NO_x reduction technique is simply to switch to a coal having a lower nitrogen content, although many boilers may not properly fire coals of different properties.

Off-stoichiometric (staged) combustion is also an effective means of controlling NO_x from coal fired equipment. This can be achieved by using overfire air or low NO_x burners designed to stage combustion in the flame zone. Other NO_x reduction techniques include flue gas recirculation, load reduction, and steam or water injection. However, these techniques are not very effective for use on coal fired equipment because of the fuel nitrogen effect. Ammonia injection is another technique which can be used, but it is costly. The net reduction of NO_x from any of these techniques or combinations thereof varies considerably with boiler type, coal properties and existing operating practices. Typical reductions will range from 10 to 60 percent. References 10 and 60 should be consulted for a detailed discussion of each of these NO_x reduction techniques. To date, flue gas treatment is not used to reduce nitrogen oxide emissions because of its higher cost.

Volatile Organic Compounds And Carbon Monoxide - Volatile organic compounds (VOC) and carbon monoxide (CO) are unburnt gaseous combustibles which generally are emitted in quite small amounts. However, during startups, temporary upsets or other conditions preventing complete combustion, unburnt combustible emissions may increase dramatically. VOC and CO emissions per unit of fuel fired are normally lower from pulverized coal or cyclone furnaces than from smaller stokers and handfired units where operating conditions are not so well controlled. Measures used for NO_x control can increase CO emissions, so to reduce the risk of explosion, such measures are applied only to the point at which CO in the flue gas reaches a maximum of about 200 parts per million. Other than maintaining proper combustion conditions, control measures are not applied to control VOC and CO.

Emission Factors And References - Emission factors for several pollutants are presented in Table 1.1-1, and factor ratings and references are presented in Table 1.1-2. The factors for uncontrolled underfeed stokers and hand fired units also may be applied to hot air furnaces. Tables 1.1-3 through 1.1-8 present cumulative size distribution data and size specific emission factors for particulate emissions from the combustion sources discussed above. Uncontrolled and controlled size specific emission factors are presented in Figures 1.1-1 through 1.1-6.

TABLE 1.1-3. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR DRY BOTTOM BOILERS BURNING PULVERIZED BITUMINOUS COAL[a]

EMISSION FACTOR RATING: C (uncontrolled)
D (scrubber and ESP controlled
E (multiple cyclone and baghouse)

Particle size[b] (um)	Cumulative mass % ≤ stated size					Cumulative emission factor[c] [kg/Mg (lb/ton) coal, as fired]				
	Uncontrolled	Controlled				Uncontrolled	Controlled[d]			
		Multiple cyclone	Scrubber	ESP	Baghouse		Multiple cyclone	Scrubber	ESP	Baghouse
15	32	54	81	79	97	1.6A (3.2A)	0.54A (1.08A)	0.24A (0.48A)	0.032A (0.06A)	0.010A (0.02A)
10	23	29	71	67	92	1.15A (2.3A)	0.29A (0.58A)	0.21A (0.42A)	0.027A (0.05A)	0.009A (0.02A)
6	17	14	62	50	77	0.85A (1.7A)	0.14A (0.28A)	0.19A (0.38A)	0.020A (0.04A)	0.008A (0.02A)
2.5	6	3	51	29	53	0.30A (0.6A)	0.03A (0.06A)	0.15A (0.3A)	0.012A (0.02A)	0.005A (0.01A)
1.25	2	1	35	17	31	0.10A (0.2A)	0.01A (0.02A)	0.11A (0.22A)	0.007A (0.01A)	0.003A (0.006A)
1.00	2	1	31	14	25	0.10A (0.2A)	0.01A (0.02A)	0.09A (0.18A)	0.006A (0.01A)	0.003A (0.006A)
0.625	1	1	20	12	14	0.05A (0.10)	0.01A (0.02A)	0.06A (0.12A)	0.005A (0.01A)	0.001A (0.002A)
TOTAL	100	100	100	100	100	5A (10A)	1A (2A)	0.3A (0.6A)	0.04A (0.08A)	0.01A (0.02A)

[a] Reference 61. ESP = electrostatic precipitator.
[b] Expressed as aerodynamic equivalent diameter.
[c] A = coal ash weight %, as fired.
[d] Estimated control efficiency for multiple cyclone, 80%; scrubber, 94%; ESP, 99.2%; baghouse, 99.8%.

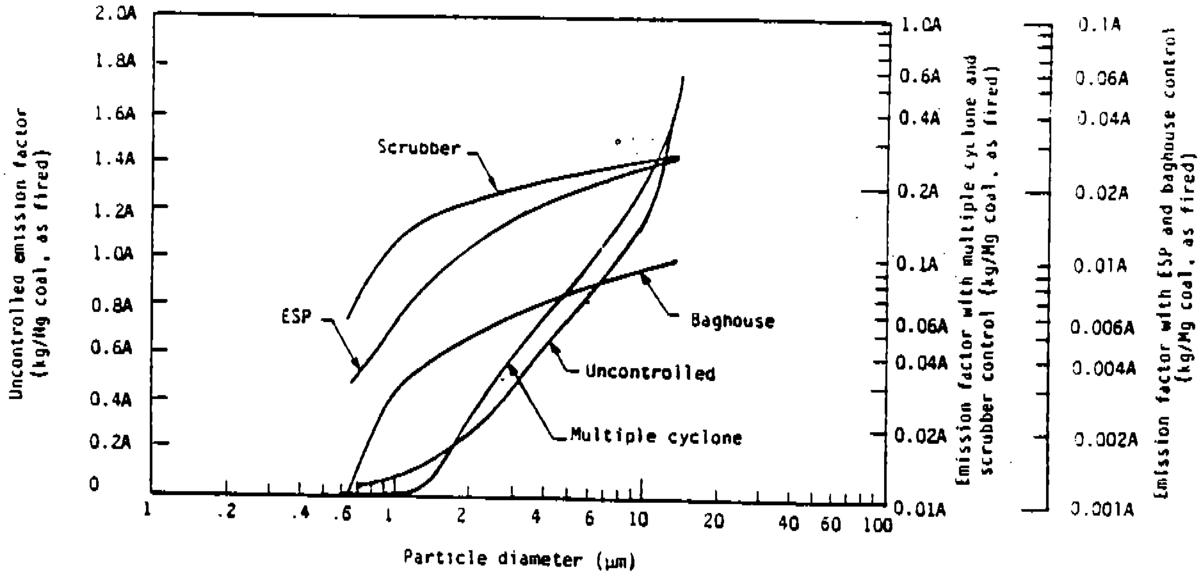

Figure 1.1-1. Cumulative size specific emission factors for dry bottom boilers burning pulverized bituminous coal.

TABLE 1.1-4. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR WET BOTTOM BOILERS BURNING PULVERIZED BITUMINOUS COAL[a]

EMISSION FACTOR RATING: E

Particle size[b] (μm)	Cumulative mass % ≤ stated size			Cumulative emission factor[c] [kg/Mg (lb/ton) coal, as fired]		
	Uncontrolled	Controlled		Uncontrolled	Controlled[d]	
		Multiple cyclone	ESP		Multiple cyclone	ESP
15	40	99	83	1.4A (2.8A)	0.69A (1.38A)	0.023A (0.046A)
10	37	93	75	1.30A (2.6A)	0.65A (1.3A)	0.021A (0.042A)
6	33	84	63	1.16A (2.32A)	0.59A (1.18A)	0.018A (0.036A)
2.5	21	61	40	0.74A (1.48A)	0.43A (0.86A)	0.011A (0.022A)
1.25	6	31	17	0.21A (0.42A)	0.22A (0.44A)	0.005A (0.01A)
1.00	4	19	8	0.14A (0.28A)	0.13A (0.26A)	0.002A (0.004A)
0.625	2	e	e	0.07A (0.14A)	e	e
TOTAL	100	100	100	3.5A (7.0A)	0.7A (1.4A)	0.028A (0.056A)

[a] Reference 61. ESP = electrostatic precipitator.
[b] Expressed as aerodynamic equivalent diameter.
[c] A = coal ash weight %, as fired.
[d] Estimated control efficiency for multiple cyclone, 80%; ESP, 99.2%.
[e] Insufficient data.

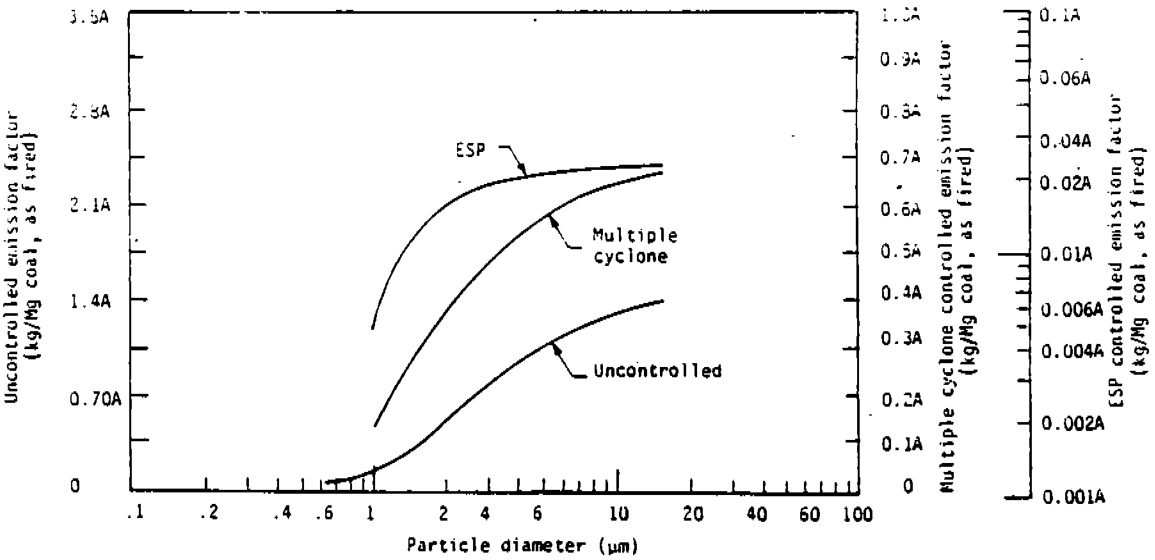

Figure 1.1-2. Cumulative size specific emission factors for wet bottom boilers burning pulverized bituminous coal

TABLE 1.1-5. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR CYCLONE FURNACES BURNING BITUMINOUS COAL[a]

EMISSION FACTOR RATING: E

Particle size[b] (µm)	Cumulative mass % ≤ stated size			Cumulative emission factor[c] [kg/Mg (lb/ton) coal, as fired]		
	Uncontrolled	Controlled		Uncontrolled	Controlled[e]	
		Scrubber	ESP		Scrubber	ESP
15	33	95	90	0.33A (0.66A)	0.057A (0.114A)	0.0064A (0.013A)
10	13	94	68	0.13A (0.26A)	0.056A (0.112A)	0.0054A (0.011A)
6	8	93	56	0.08A (0.16A)	0.056A (0.112A)	0.0045A (0.009A)
2.5	0	92	36	0 (0)	0.055A (0.11A)	0.0029A (0.006A)
1.25	0	85	22	0 (0)	0.051A (0.10A)	0.0018A (0.004A)
1.00	0	82	17	0 (0)	0.049A (0.10A)	0.0014A (0.003A)
0.625	0	d	d	0 (0)	d	d
TOTAL	100	100	100	1A (2A)	0.06A (0.12A)	0.008A (0.016A)

[a] Reference 61. ESP = electrostatic precipitator.

[b] Expressed as aerodynamic equivalent diameter.

[c] A = coal ash weight %, as fired.

[d] Insufficient data.

[e] Estimated control efficiency for scrubber, 94%; ESP, 99.2%.

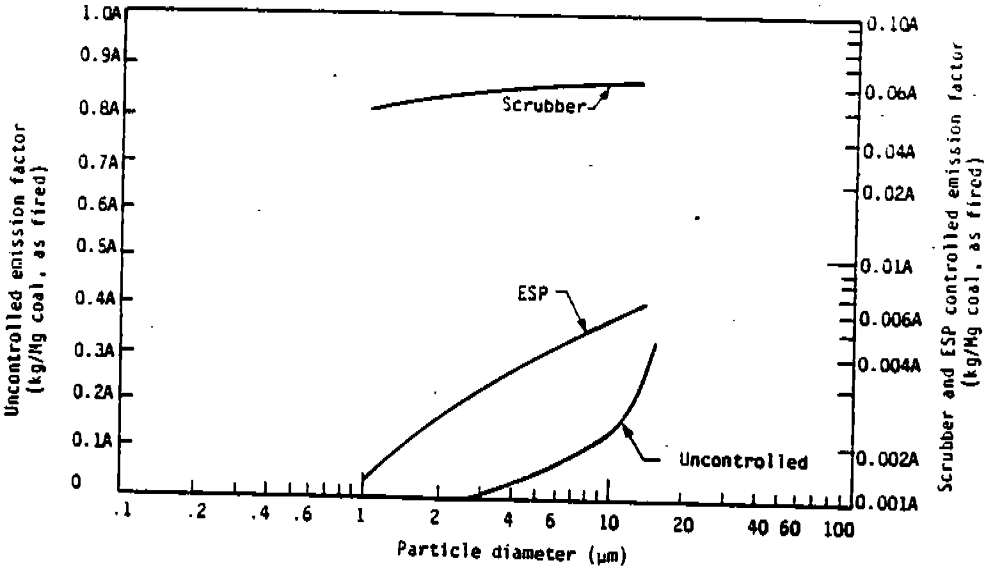

Figure 1.1-3. Cumulative size specific emission factors for cyclone furnaces burning bituminous coal

TABLE 1.1-6. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR SPREADER STOKERS BURNING BITUMINOUS COAL[a]

EMISSION FACTOR RATING: C (uncontrolled and controlled for multiple cyclone without flyash reinjection, and with baghouse)
E (multiple cyclone controlled with flyash reinjection, and ESP controlled)

Particle size[b] (μm)	Cumulative mass % ≤ stated size					Cumulative emission factor [kg/Mg (lb/ton) coal, as fired]				
	Uncontrolled	Controlled				Uncontrolled	Controlled			
		Multiple cyclone[c]	Multiple cyclone[d]	ESP	Baghouse		Multiple cyclone[c]	Multiple cyclone[d]	ESP	Baghouse
15	28	86	74	97	72	8.4 (16.8)	7.3 (14.6)	4.4 (8.8)	0.23 (0.46)	0.043 (0.086)
10	20	73	65	90	60	6.0 (12.0)	6.2 (12.4)	3.9 (7.8)	0.22 (0.44)	0.036 (0.072)
6	14	51	52	82	46	4.2 (8.4)	4.3 (8.6)	3.1 (6.2)	0.20 (0.40)	0.028 (0.056)
2.5	7	8	27	61	26	2.1 (4.2)	0.7 (1.4)	1.6 (3.2)	0.15 (0.30)	0.016 (0.032)
1.25	5	2	16	46	18	1.5 (3.0)	0.2 (0.4)	1.0 (2.0)	0.11 (0.22)	0.011 (0.022)
1.00	5	2	14	41	15	1.5 (3.0)	0.2 (0.4)	0.8 (1.6)	0.10 (0.20)	0.009 (0.018)
0.625	4	1	9	[e]	7	1.2 (2.4)	0.1 (0.2)	0.5 (1.0)	[e]	0.004 (0.008)
TOTAL	100	100	100	100	100	30.0 (60.0)	8.5 (17.0)	6.0 (12.0)	0.24 (0.48)	0.06 (0.12)

[a] Reference 61. ESP = electrostatic precipitator.
[b] Expressed as aerodynamic equivalent diameter.
[c] With flyash reinjection.
[d] Without flyash reinjection.
[e] Insufficient data.
[f] Estimated control efficiency for ESP, 99.2%; baghouse, 99.8%.

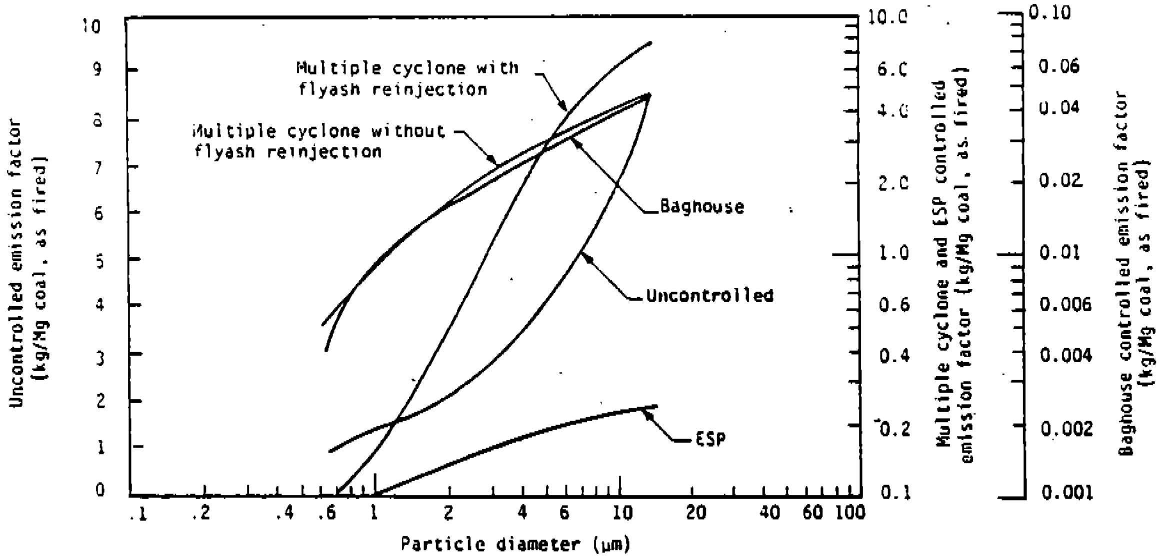

Figure 1.1-4. Cumulative size specific emission factors for spreader stokers burning bituminous coal

TABLE 1.1-7. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR OVERFEED STOKERS BURNING BITUMINOUS COAL[a]

EMISSION FACTOR RATING: C (uncontrolled)
E (multiple cyclone controlled)

Particle size[b] (µm)	Cumulative mass % ≤ stated size		Cumulative emission factor [kg/Mg (lb/ton) coal, as fired]	
	Uncontrolled	Multiple cyclone controlled	Uncontrolled	Multiple cyclone controlled[d]
15	49	60	3.9 (7.8)	2.7 (5.4)
10	37	55	3.0 (6.0)	2.5 (5.0)
6	24	49	1.9 (3.8)	2.2 (4.4)
2.5	14	43	1.1 (2.2)	1.9 (3.8)
1.25	13	39	1.0 (2.0)	1.8 (3.6)
1.00	12	39	1.0 (2.0)	1.8 (3.6)
0.625	c	16	c	0.7 (1.4)
TOTAL	100	100	8.0 (16.0)	4.5 (9.0)

[a] Reference 61.
[b] Expressed as aerodynamic equivalent diameter.
[c] Insufficient data.
[d] Estimated control efficiency for multiple cyclone, 80%.

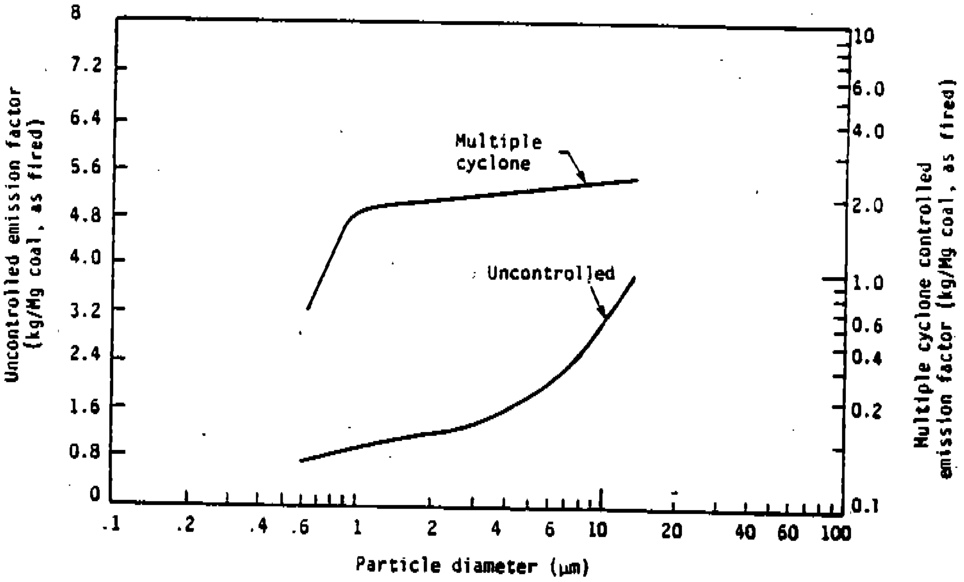

Figure 1.1-5. Cumulative size specific emission factors for overfeed stokers burning bituminous coal

TABLE 1.1-8. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR UNDERFEED STOKERS BURNING BITUMINOUS COAL[a]

EMISSION FACTOR RATING: C

Particle size[b] (µm)	Cumulative mass % ≤ stated size	Uncontrolled cumulative emission factor[c] [kg/Mg (lb/ton) coal, as fired]
15	50	3.8 (7.6)
10	41	3.1 (6.2)
6	32	2.4 (4.8)
2.5	25	1.9 (3.8)
1.25	22	1.7 (3.4)
1.00	21	1.6 (3.2)
0.625	18	1.4 (2.7)
TOTAL	100	7.5 (15.0)

[a] Reference 61.
[b] Expressed as aerodynamic equivalent diameter.
[c] May also be used for uncontrolled hand fired units.

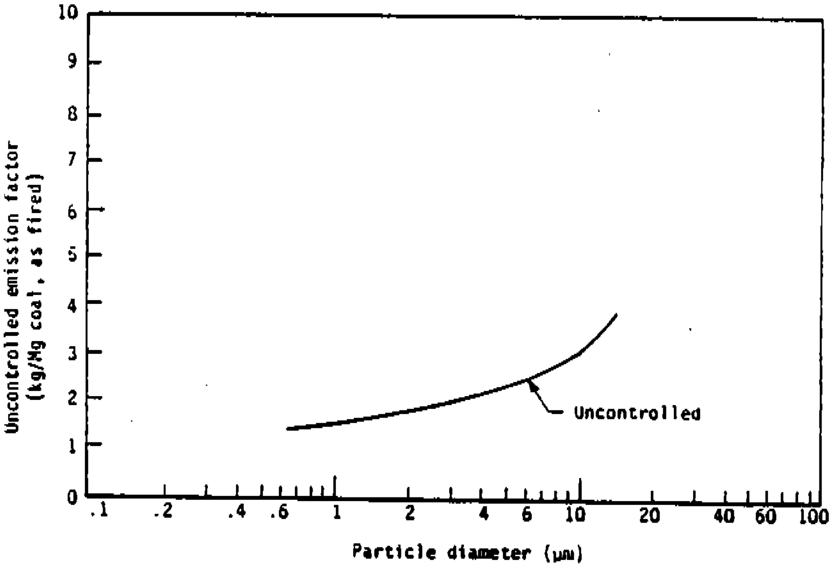

Figure 1.1-6. Cumulative size specific emission factors for underfeed stokers burning bituminous coal.

References for Section 1.1

1. Steam, 38th Edition, Babcock and Wilcox, New York, 1975.

2. Control Techniques for Particulate Emissions from Stationary Sources, Volume I, EPA-450/3-81-005a, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1981.

3. ibidem, Volume II, EPA-450/3-81-0005b.

4. Electric Utility Steam Generating Units: Background Information for Proposed Particulate Matter Emission Standard, EPA-450/2-78-006a, U. S. Environmental Protection Agency, Research Triangle Park, NC, July 1978.

5. W. Axtman and M. A. Eleniewski, "Field Test Results of Eighteen Industrial Coal Stoker Fired Boilers for Emission Control and Improved Efficiency", Presented at the 74th Annual Meeting of the Air Pollution Control Association, Philadelphia, PA, June 1981.

6. Field Tests of Industrial Stoker Coal Fired Boilers for Emission Control and Efficiency Improvement - Sites L1-17, EPA-600/7-81-020a, U. S. Environmental Protection Agency, Washington, DC, February 1981.

7. Control Techniques for Sulfur Dioxide Emissions from Stationary Sources, 2nd Edition, EPA-450/3-81-004, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1981.

8. Electric Utility Steam Generating Units: Background Information for Proposed SO_2 Emission Standards, EPA-450/2-78-007a, U. S. Environmental Protection Agency, Research Triangle Park, NC, July 1978. Environmental Protection Agency, Washington, DC, February 1981.

9. Carlo Castaldini and Meredith Angwin, Boiler Design and Operating Variables Affecting Uncontrolled Sulfur Emissions from Pulverized Coal Fired Steam Generators, EPA-450/3-77-047, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1977.

10. Control Techniques for Nitrogen Oxides Emissions from Stationary Sources, 2nd Edition, EPA-450/1-78-001, U. S. Environmental Protection Agency, Research Triangle Park, NC, January 1978.

11. Review of NO_x Emission Factors for Stationary Fossil Fuel Combustion Sources, EPA-450/4-79-021, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1979.

12. Standards of Performance for New Stationary Sources, 36 FR 24876, December 23, 1971.

13. L. Scinto, Primary Sulfate Emissions from Coal and Oil Combustion, EPA Contract Number 68-02-3138, TRW Inc., Redondo Beach, CA, February 1980.

14. S. T. Cuffe and R. W. Gerstele, Emissions from Coal Fired Power Plants: A Comprehensive Summary, 999-AP-35, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1967.

15. Field Testing: Application of Combustion Modifications To Control NO_x Emissions from Utility Boilers, EPA-650/2-74-066, U. S. Environmental Protection Agency, Washington, DC, June 1974.

16. Control of Utility Boiler and Gas Turbine Pollutant Emissions by Combustion Modification - Phase I, EPA-600/7-78-036a, U. S. Environmental Protection Agency, Washington, DC, March 1978.

17. Low-sulfur Western Coal Use in Existing Small and Intermediate Size Boilers, EPA-600/7-78-153a, U. S. Environmental Protection Agency, Washington, DC, July 1978.

18. Hazardous Emission Characterization of Utility Boilers, EPA-650/2-75-066, U. S. Environmental Protection Agency, Washington, DC, July 1975.

19. Application of Combustion Modifications To Control Pollutant Emissions from Industrial Boilers - Phase I, EPA-650/2-74-078a, U. S. Environmental Protection Agency, Washington, DC, October 1974.

20. Field Study To Obtain Trace Element Mass Balances at a Coal Fired Utility Boiler, EPA-600/7-80-171, U. S. Environmental Protection Agency, Washington, DC, October 1980.

21. Environmental Assessment of Coal and Oil Firing in a Controlled Industrial Boiler, Volume II, EPA-600/7-78-164b, U. S. Environmental Protection Agency, Washington, DC, August 1978.

22. Coal Fired Power Plant Trace Element Study, U. S. Environmental Protection Agency, Denver, CO, September 1975.

23. Source Testing of Duke Power Company, Plezer, SC, EMB-71-CI-01, U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1971.

24. J. W. Kaakinen, et al., "Trace Element Behavior in Coal-fired Power Plants", Environmental Science and Technology, 9(9):862-869, September 1975.

25. Five Field Performance Tests on Koppers Company Precipitators, Docket No. OAQPS-78-1, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, February-March 1974.

26. H. M. Rayne and L. P. Copian, Slag Tap Boiler Performance Associated with Power Plant Flyash Disposal, Western Electric Company, Hawthorne Works, Chicago, IL, undated.

27. A. B. Walker, "Emission Characteristics for Industrial Boilers", Air Engineering, 9(8):17-19, August 1967.

28. Environmental Assessment of Coal-fired Controlled Utility Boiler, EPA-600/7-80-086, U. S. Environmental Protection Agency, Washington, DC, April 1980.

29. Steam, 37th Edition, Babcock and Wilcox, New York, 1963.

30. *Industrial Boiler: Emission Test Report, Formica Corporation, Cincinnati, Ohio*, EMB-80-IBR-7, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1980.

31. *Field Tests of Industrial Stoker Coal-fired Boilers for Emissions Control and Efficiency Improvement - Site A*, EPA-600/7-78-135a, U. S. Environmental Protection Agency, Washington, DC, July 1978.

32. *ibidem-Site C*, EPA-600/7-79-130a, May 1979.

33. *ibidem-Site E*, EPA-600/7-80-064a, March 1980.

34. *ibidem-Site F*, EPA-600/7-80-065a, March 1980.

35. *ibidem-Site G*, EPA-600/7-80-082a, April 1980.

36. *ibidem-Site B*, EPA-600/7-79-041a, February 1979.

37. *Industrial Boilers: Emission Test Report, General Motors Corporation, Parma, Ohio, Volume I*, EMB-80-IBR-4, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1980.

38. *A Field Test Using Coal: dRDF Blends in Spreader Stoker-fired Boilers*, EPA-600/2-80-095, U. S. Environmental Protection Agency, Cincinnati, OH, August 1980.

39. *Industrial Boilers: Emission Test Report, Rickenbacker Air Force Base, Columbus, Ohio*, EMB-80-IBR-6, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1980.

40. *Thirty-day Field Tests of Industrial Boilers: Site 1*, EPA-600/7-80-085a, U. S. Environmental Protection Agency, Washington, DC, April 1980.

41. *Field Tests of Industrial Stoker Coal-fired Boilers for Emissions Control and Efficiency Improvement - Site D*, EPA-600/7-79-237a, U. S. Environmental Protection Agency, Washington, DC, November 1979.

42. *ibidem-Site H*, EPA-600/7-80-112a, May 1980.

43. *ibidem-Site I*, EPA-600/7-80-136a, May 1980.

44. *ibidem-Site J*, EPA-600/7-80-137a, May 1980.

45. *ibidem-Site K*, EPA-600/7-80-138a, May 1980.

46. *Regional Air Pollution Study: Point Source Emission Inventory*, EPA-600/4-77-014, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1977.

47. R. P. Hangebrauck, *et al.*, "Emissions of Polynuclear Hydrocarbons and Other Pollutants from Heat Generation and Incineration Process", *Journal of the Air Pollution Control Association*, *14*(7):267-278, July 1964.

48. Source Assessment: Coal-fired Industrial Combustion Equipment Field Test, EPA-600/2-78-004o, U. S. Environmental Protection Agency, Washington, DC, June 1978.

49. Source Sampling Residential Fireplaces for Emission Factor Development, EPA-450/3-76-010, U. S. Environmental Protection Agency, Research Triangle Park, NC, November 1975.

50. Atmospheric Emissions from Coal Combustion: An Inventory Guide, 999-AP-24, U. S. Environmental Protection Agency, Washington, DC, April 1966.

51. Application of Combustion Modification To Control Pollutant Emissions from Industrial Boilers - Phase II, EPA-600/2-76-086a, U. S. Environmental Protection Agency, Washington, DC, April 1976.

52. Continuous Emission Monitoring for Industrial Boiler, General Motors Corporation, St. Louis, Missouri, Volume I, EPA Contract Number 68-02-2687, GCA Corporation, Bedford, MA, June 1980.

53. Survey of Flue Gas Desulfurization Systems: Cholla Station, Arizona Public Service Company, EPA-600/7-78-048a, U. S. Environmental Protection Agency, Washington, DC, March 1978.

54. ibidem: La Cygne Station, Kansas City Power and Light, EPA-600/7-78-048d, March 1978.

55. Source Assessment: Dry Bottom Utility Boilers Firing Pulverized Bituminous Coal, EPA-600/2-79-019, U. S. Environmental Protection Agency, Washington, DC, August 1980.

56. Thirty-day Field Tests of Industrial Boilers: Site 3 - Pulverized - Coal Fired Boiler, EPA-600/7-80-085c, U. S. Environmental Protection Agency, Washington, DC, April 1980.

57. Systematic Field Study of Nitrogen Oxide Emission Control Methods for Utility Boilers, APTD-1163, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1971.

58. Emissions of Reactive Volatile Organic Compounds from Utility Boilers, EPA-600/7-80-111, U. S. Environmental Protection Agency, Washington, DC, May 1980.

59. Industrial Boilers: Emission Test Report, DuPont Corporation, Parkersburg, West Virginia, EMB-80-IBR-12, U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1982.

60. Technology Assessment Report for Industrial Boiler Applications: NO_x Combustion Modification, EPA-600/7-79-178f, U. S. Environmental Protection Agency, Washington, DC, December 1979.

61. Inhalable Particulate Source Category Report for External Combustion Sources, EPA Contract No. 68-02-3156, Acurex Corporation, Mountain View, CA, January 1985.

1.2 ANTHRACITE COAL COMBUSTION

1.2.1 General[1-2]

Anthracite coal is a high rank coal with more fixed carbon and less volatile matter than either bituminous coal or lignite, and it has higher ignition and ash fusion temperatures. Because of its low volatile matter content and slight clinkering, anthracite is most commonly fired in medium sized traveling grate stokers and small hand fired units. Some anthracite (occasionally with petroleum coke) is used in pulverized coal fired boilers. It is also blended with bituminous coal. None is fired in spreader stokers. For its low sulfur content (typically less than 0.8 weight percent) and minimal smoking tendencies, anthracite is considered a desirable fuel where readily available.

In the United States, all anthracite is mined in northeastern Pennsylvania and is consumed mostly in Pennsylvania and several surrounding states. The largest use of anthracite is for space heating. Lesser amounts are employed for steam/electric production; coke manufacturing, sintering and pelletizing; and other industrial uses. Anthracite currently is only a small fraction of the total quantity of coal combusted in the United States.

1.2.2 Emissions And Controls[2-14]

Particulate emissions from anthracite combustion are a function of furnace firing configuration, firing practices (boiler load, quantity and location of underfire air, sootblowing, flyash reinjection, etc.), and the ash content of the coal. Pulverized coal fired boilers emit the highest quantity of particulate per unit of fuel because they fire the anthracite in suspension, which results in a high percentage of ash carryover into exhaust gases. Pulverized anthracite fired boilers operate in the dry tap or dry bottom mode, because of anthracite's characteristically high ash fusion temperature. Traveling grate stokers and hand fired units produce much less particulate per unit of fuel fired, because combustion takes place in a quiescent fuel bed without significant ash carryover into the exhaust gases. In general, particulate emissions from traveling grate stokers will increase during sootblowing and flyash reinjection and with higher fuel bed underfeed air from forced draft fans. Smoking is rarely a problem, because of anthracite's low volatile matter content.

Limited data are available on the emission of gaseous pollutants from anthracite combustion. It is assumed from bituminous coal combustion data that a large fraction of the fuel sulfur is emitted as sulfur oxides. Also, because combustion equipment, excess air rates, combustion temperatures, etc., are similar between anthracite and bituminous coal combustion, nitrogen oxide and carbon monoxide emissions are assumed to be similar, too. Volatile organic compound (VOC) emissions, however, are expected to be considerably lower, since the volatile matter content of anthracite is significantly less than that of bituminous coal.

TABLE 1.2-1. UNCONTROLLED EMISSION FACTORS FOR ANTHRACITE COMBUSTION[a]

Boiler type	Particulate[b]		Sulfur oxides[c]		Nitrogen oxides[d]		Carbon monoxide[e]		Volatile organics	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	Nonmethane	Methane
Pulverized coal fired	f	f	19.5S	39S	9	18	f	f	f	f
Traveling grate stoker	4.6[g]	9.1[g]	19.5S	39S	5	10	0.3	0.6	f	f
Hand fed units	5[h]	10[h]	19.5S	39S	1.5	3	f	f	f	f

[a] Factors are for uncontrolled emissions and should be applied to coal consumption as fired.

[b] Based on EPA Method 5 (front half catch).

[c] Assumes, as with bituminous coal combustion, most fuel sulfur is emitted as SO_x. Limited data in Reference 5 verify this for pulverized anthracite fired boilers. Emissions are mostly SO_2, with 1 - 3% SO_3. S indicates that weight % sulfur should be multiplied by the value given.

[d] For pulverized anthracite fired boilers and hand fed units, assumed to be similar to bituminous coal combustion. For traveling grate stokers, see References 8, 11.

[e] May increase by several orders of magnitude with boilers not properly operated or maintained. For traveling grate stokers, based on limited information in Reference 8. For pulverized coal fired boilers, substantiated by additional data in Reference 14.

[f] Factors in Table 1.1-1 may be used, based on similarity of anthracite and bituminous coal.

[g] References 12-13, 15-18. Accounts for limited fallout that may occur in fallout chambers and stack breeching. Factors for individual boilers may be 2.5 - 25 kg/Mg (5 - 50 lb/ton), highest during soot blowing.

[h] Reference 2.

Controls on anthracite emissions mainly have been applied to particulate matter. The most efficient particulate controls, fabric filters, scrubbers and electrostatic precipitators, have been installed on large pulverized anthracite fired boilers. Fabric filters and venturi scrubbers can effect collection efficiencies exceeding 99 percent. Electrostatic precipitators typically are only 90 to 97 percent efficient, because of the characteristic high resistivity of low sulfur anthracite fly ash. It is reported that higher efficiencies can be achieved using larger precipitators and flue gas conditioning. Mechanical collectors are frequently employed upstream from these devices for large particle removal.

Traveling grate stokers are often uncontrolled. Indeed, particulate control has often been considered unnecessary, because of anthracite's low smoking tendencies and of the fact that a significant fraction of large size flyash from stokers is readily collected in flyash hoppers as well as in the breeching and base of the stack. Cyclone collectors have been employed on traveling grate stokers, and limited information suggests these devices may be up to 75 percent efficient on particulate. Flyash reinjection, frequently used in traveling grate stokers to enhance fuel use efficiency, tends to increase particulate emissions per unit of fuel combusted.

Emission factors for pollutants from anthracite coal combustion are given in Table 1.2-1, and factor ratings in Table 1.2-2. Cumulative size distribution data and size specific emission factors and ratings for particulate emissions are in Tables 1.2-3 and 1.2-4. Uncontrolled and controlled size specific emission factors are presented in Figures 1.2-1 and 1.2-2. Size distribution data for bituminous coal combustion may be used for uncontrolled emissions from pulverized anthracite fired furnaces, and data for anthracite fired traveling grate stokers may be used for hand fired units.

TABLE 1.2-2. ANTHRACITE COAL EMISSION FACTOR RATINGS

Furnace type	Particulate	Sulfur oxides	Nitrogen oxides	Carbon monoxide	Volatile organics	
					Nonmethane	Methane
Pulverized coal	B	B	B	B	C	C
Traveling grate stoker	B	B	B	B	C	C
Hand fired units	B	B	B	B	D	D

TABLE 1.2-3. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR DRY BOTTOM BOILERS BURNING PULVERIZED ANTHRACITE COAL[a]

EMISSION FACTOR RATING: D

Particle size[b] (µm)	Cumulative mass % ≤ stated size			Cumulative emission factor[c] [kg/Mg (lb/ton) bark, as fired]		
	Uncontrolled	Controlled		Uncontrolled	Controlled[d]	
		Multiple cyclone	Baghouse		Multiple cyclone	Baghouse
15	32	63	79	1.6A (3.2A)	0.63A (1.26A)	0.0079A (0.016A)
10	23	55	67	1.2A (2.3A)	0.55A (1.10A)	0.0067A (0.013A)
6	17	46	51	0.9A (1.7A)	0.46A (0.92A)	0.0051A (0.010A)
2.5	6	24	32	0.3A (0.6A)	0.24A (0.48A)	0.0032A (0.006A)
1.25	2	13	21	0.1A (0.2A)	0.13A (0.26A)	0.0021A (0.004A)
1.00	2	10	18	0.1A (0.2A)	0.10A (0.20A)	0.0018A (0.004A)
0.625	1	7		0.05A (0.1A)	0.07A (0.14A)	e
TOTAL	100	100	100	5A (10A)	1A (2A)	0.01A (0.02A)

[a] Reference 19.

[b] Expressed as aerodynamic equivalent diameter.

[c] A = coal ash weight, as fired.

[d] Estimated control efficiency for multiple cyclone, 80%; baghouse, 99.8%.

[e] Insufficient data.

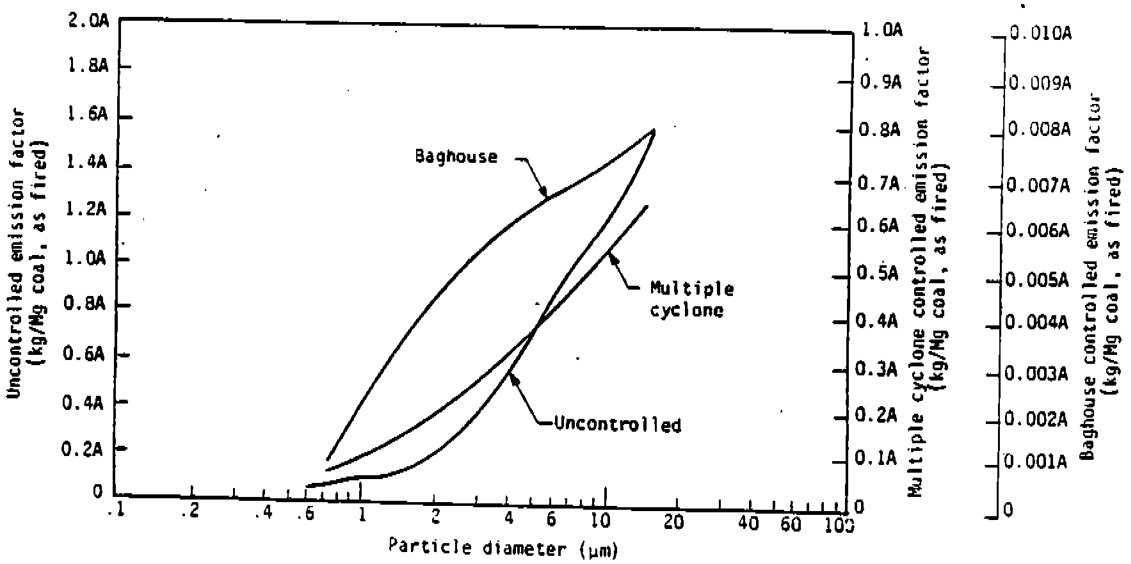

Figure 1.2-1. Cumulative size specific emission factors for dry bottom boilers burning pulverized anthracite coal.

TABLE 1.2-4. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR TRAVELING GRATE STOKERS BURNING ANTHRACITE COAL[a]

EMISSION FACTOR RATING: E

Particle size[b] (um)	Cumulative mass % ≤ stated size	Cumulative emission factor [kg/Mg (lb/ton) coal, as fired]
	Uncontrolled[c]	Controlled
15	64	2.9 (5.8)
10	52	2.4 (4.8)
6	42	1.9 (3.8)
2.5	27	1.2 (2.4)
1.25	24	1.1 (2.2)
1.00	23	1.1 (2.2)
0.625	d	d
TOTAL	100	4.6 (9.2)

[a] Reference 19.
[b] Expressed as aerodynamic equivalent diameter.
[c] May also be used for uncontrolled hand fired units.
[d] Insufficient data.

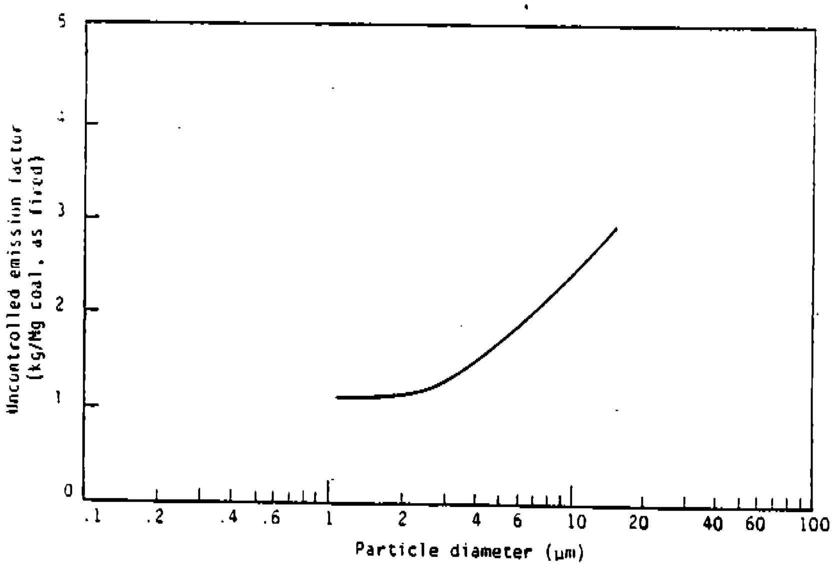

Figure 1.2-2. Cumulative size specific emission factors for traveling grate stokers burning anthracite coal.

References for Section 1.2

1. Minerals Yearbook, 1978-79, Bureau of Mines, U. S. Department of the Interior, Washington, DC, 1981.
2. Air Pollutant Emission Factors, APTD-0923, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1970.
3. Steam, 38th Edition, Babcock and Wilcox, New York, NY, 1975.
4. Fossil Fuel Fired Industrial Boilers - Background Information for Proposed Standards, Draft, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1980.
5. R. W. Cass and R. W. Bradway, Fractional Efficiency of a Utility Boiler Baghouse: Sunbury Steam Electric Station, EPA-600/2-76-077a, U. S. Environmental Protection Agency, Washington, DC, March 1976.
6. R. P. Janaso, "Baghouse Dust Collectors on a Low Sulfur Coal Fired Utility Boiler", Presented at the 67th Annual Meeting of the Air Pollution Control Association, Denver, CO, June 1974.
7. J. H. Phelan, et al., Design and Operation Experience with Baghouse Dust Collectors for Pulverized Coal Fired Utility Boilers - Sunbury Station, Holtwood Station, Proceedings of the American Power Conference, Denver, CO, 1976.
8. Source Test Data on Anthracite Fired Traveling Grate Stokers, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1975.
9. Source and Emissions informationT on Anthracite Fired Traveling Grate Stokers, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1975.
10. R. J. Milligan, et al., Review of NO_x Emission Factors for Stationary Fossil Fuel Combustion Sources, EPA-450/4-79-021, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1979.
11. N. F. Suprenant, et al., Emissions Assessment of Conventional Stationary Combustion Systems, Volume IV: Commercial/Institutional Combustion Sources, EPA Contract No. 68-02-2197, GCA Corporation, Bedford, MA, October 1980.
12. Source Sampling of Anthracite Coal Fired Boilers, RCA-Electronic Components, Lancaster, Pennsylvania, Final Report, Scott Environmental Technology, Inc., Plumsteadville, PA, April 1975.
13. Source Sampling of Anthracite Coal Fired Boilers, Shippensburg State College, Shippensburg, Pennsylvania, Final Report, Scott Environmental Technology, Inc., Plumsteadville, PA, May 1975.

14. W. Bartok, *et al.*, *Systematic Field Study of NO_x Emission Control Methods for Utility Boilers*, APTD-1163, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1971.

15. *Source Sampling of Anthracite Coal Fired Boilers, Ashland State General Hospital, Ashland, Pennsylvania, Final Report*, Pennsylvania Department of Environmental Resources, Harrisburg, PA, March 16, 1977.

16. *Source Sampling of Anthracite Coal Fired Boilers, Norristown State Hospital, Norristown, Pennsylvania, Final Report*, Pennsylvania Department of Environmental Resources, Harrisburg, PA, January 19, 1980.

17. *Source Sampling of Anthracite Coal Fired Boilers, Pennhurst Center, Spring City, Pennsylvania, Final Report*, TRC Environmental Consultants, Inc., Wethersfield, CT, January 23, 1980.

18. *Source Sampling of Anthracite Coal Fired Boilers, West Chester State, West Chester, Pennsylvania, Final Report*, Roy Weston, Inc., West Chester, PA, April 4, 1977.

19. *Inhalable Particulate Source Category Report for External Combustion Sources*, EPA Contract No. 68-02-3156, Acurex Corporation, Mountain View, CA, January 1985.

1.3 FUEL OIL COMBUSTION

1.3.1 General[1-2,22]

Fuel oils are broadly classified into two major types, distillate and residual. Distillate oils (fuel oil grade Nos. 1 and 2) are used mainly in domestic and small commercial applications in which easy fuel burning is required. Distillates are more volatile and less viscous that residual oils, having negligible ash and nitrogen contents and usually containing less than 0.3 weight percent sulfur. Residual oils (grade Nos. 4, 5 and 6), on the other hand, are used mainly in utility, industrial and large commercial applications with sophisticated combustion equipment. No. 4 oil is sometimes classified as a distillate, and No. 6 is sometimes referred to as Bunker C. Being more viscous and less volatile than distillate oils, the heavier residual oils (Nos. 5 and 6) must be heated to facilitate handling and proper atomization. Because residual oils are produced from the residue after lighter fractions (gasoline, kerosene and distillate oils) have been removed from the crude oil, they contain significant quantities of ash, nitrogen and sulfur. Properties of typical fuel oils can be found in Appendix A.

1.3.2 Emissions

Emissions from fuel oil combustion depend on the grade and composition of the fuel, the type and size of the boiler, the firing and loading practices used, and the level of equipment maintenance. Table 1.3-1 presents emission factors for fuel oil combustion pollutants, and Tables 1.3-2 through 1.3-5 present cumulative size distribution data and size specific emission factors for particulate emissions from fuel oil combustion. Uncontrolled and controlled size specific emission factors are presented in Figures 1.3-1 through 1.3-4. Distillate and residual oil categories are given separately, because their combustion produces significantly different particulate, SO_2 and NO_x emissions.

Particulate Matter[3-7,12-13,24,26-27] - Particulate emissions depend most on the grade of fuel fired. The lighter distillate oils result in particulate formation significantly lower than with heavier residual oils. Among residual oils, Nos. 4 and 5 usually produce less particulate than does the heavier No. 6.

In boilers firing No. 6, particulate emissions can be described, on the average, as a function of the sulfur content of the oil. As shown in Table 1.3-1), particulate emissions can be reduced considerably when low sulfur No. 6 oil is fired. This is because low sulfur No. 6, either refined from naturally low sulfur crude oil or desulfurized by one of several current processes, exhibits substantially lower viscosity and reduced asphaltene, ash and sulfur, which results in better atomization and cleaner combustion.

Boiler load can also affect particulate emissions in units firing No. 6 oil. At low load conditions, particulate emissions may be lowered 30 to 40 percent from utility boilers and by as much as 60 percent from small industrial and commercial units. No significant particulate reductions have been noted at

TABLE 1.3-1. UNCONTROLLED EMISSION FACTORS FOR FUEL OIL COMBUSTION

EMISSION FACTOR RATING: A

Boiler Type[a]	Particulate Matter[b]		Sulfur Dioxide[c]		Sulfur Trioxide		Carbon Monoxide[d]		Nitrogen Oxide[e]		Volatile Organics[f] Nonmethane		Methane	
	$kg/10^3 l$	$lb/10^3 gal$	$kg/10^3 l$	$lb/10^3 gal$	$kg/10^3 l$	$lb/10^3 gal$	$kg/10^3 l$	$lb/10^3 gal$	$kg/10^3 l$	$lb/10^3 gal$	$kg/10^3 l$	$lb/10^3 gal$	$kg/10^3 l$	$lb/10^3 gal$
Utility Boilers														
Residual Oil	g	g	19S	157S	0.34S[h]	2.9S[h]	0.6	5	8.0 (12.6)(5)[i]	67 (105)(42)[i]	0.09	0.76	0.03	0.28
Industrial Boilers														
Residual Oil	g	g	19S	157S	0.24S	2S	0.6	5	6.6[j]	55[j]	0.034	0.28	0.12	1.0
Distillate Oil	0.24	2	17S	142S	0.24S	2S	0.6	5	2.4	20	0.024	0.2	0.006	0.052
Commercial Boilers														
Residual Oil	g	g	19S	157S	0.24S	2S	0.6	5	6.6	55	0.14	1.13	0.057	0.475
Distillate Oil	0.24	2	17S	142S	0.24S	2S	0.6	5	2.4	20	0.04	0.34	0.026	0.216
Residential Furnaces														
Distillate Oil	0.3	2.5	17S	142S	0.24S	2S	0.6	5	2.2	18	0.085	0.713	0.214	1.78

[a] Boilers can be approximately classified according to their gross (higher) heat rate as shown below:
Utility (power plant) boilers: $>106 \times 10^9$ J/hr ($>100 \times 10^6$ Btu/hr)
Industrial boilers: 10.6×10^9 to 106×10^9 J/hr (10×10^6 to 100×10^6 Btu/hr)
Commercial boilers: 0.5×10^9 to 10.6×10^9 J/hr (0.5×10^6 to 10×10^6 Btu/hr)
Residential furnaces: $<0.5 \times 10^9$ J/hr ($<0.5 \times 10^6$ Btu/hr)

[b] References 3-7 and 24-25. Particulate matter is defined in this section as that material collected by EPA Method 5 (front half catch).

[c] References 1-5. S indicates that the weight % of sulfur in the oil should be multiplied by the value given.

[d] References 3-5 and 8-10. Carbon monoxide emissions may increase by factors of 10 to 100 if the unit is improperly operated or not well maintained.

[e] Expressed as NO_2. References 1-5, 8-11, 17 and 26. Test results indicate that at least 95% by weight of NO_x is NO for all boiler types except residential furnaces, where about 75% is NO.

[f] References 18-21. Volatile organic compound emissions are generally negligible unless boiler is improperly operated or not well maintained, in which case emissions may increase by several orders of magnitude.

[g] Particulate emission factors for residual oil combustion are, on average, a function of fuel oil grade and sulfur content:
Grade 6 oil: $1.25(S) + 0.38$ kg/10^3 liter [$10(S) + 3$ lb/10^3 gal] where S is the weight % of sulfur in the oil. This relationship is based on 81 individual tests and has a correlation coefficient of 0.65.
Grade 5 oil: 1.25 kg/10^3 liter (10 lb/10^3 gal)
Grade 4 oil: 0.88 kg/10^3 liter (7 lb/10^3 gal)

[h] Reference 25.

[i] Use 5 kg/10^3 liters (42 lb/10^3 gal) for tangentially fired boilers, 12.6 kg/10^3 liters (105 lb/10^3gal) for vertical fired boilers, and 8.0 kg/10^3 liters (67 lb/10^3 gal) for all others, at full load and normal (>15%) excess air. Several combustion modifications can be employed for NO_x reduction: (1) limited excess air can reduce NO_x emissions 5-20%, (2) staged combustion 20-40%, (3) using low NO_x burners 20-50%, and (4) ammonia injection can reduce NO_x emissions 40-70% but may increase emissions of ammonia. Combinations of these modifications have been employed for further reductions in certain boilers. See Reference 23 for a discussion of these and other NO_x reducing techniques and their operational and environmental impacts.

[j] Nitrogen oxides emissions from residual oil combustion in industrial and commercial boilers are strongly related to fuel nitrogen content, estimated more accurately by the empirical relationship:
kg $NO_2/10^3$ liters $= 2.75 + 50(N)^2$ [lb $NO_2/10^3$gal $= 22 + 400(N)^2$] where N is the weight % of nitrogen in the oil. For residual oils having high (>0.5 weight %) nitrogen content, use 15 kg $NO_2/10^3$ liter (120 lb $NO_2/10^3$gal) as an emission factor.

low loads from boilers firing any of the lighter grades, however. At too low a load condition, proper combustion conditions cannot be maintained, and particulate emissions may increase drastically. It should be noted, in this regard, that any condition that prevents proper boiler operation can result in excessive particulate formation.

Sulfur Oxides [1-5,25,27] - Total SO_x emissions are almost entirely dependent on the sulfur content of the fuel and are not affected by boiler size, burner design, or grade of fuel being fired. On the average, more than 95 percent of the fuel sulfur is emitted as SO_2, about 1 to 5 percent as SO_3 and about 1 to 3 percent as sulfate particulate. SO_3 readily reacts with water vapor (in both air and flue gases) to form a sulfuric acid mist.

Nitrogen Oxides [1-11,4,17,23,27] - Two mechanisms form NO_x, oxidation of fuelbound nitrogen and thermal fixation of the nitrogen in combustion air. Fuel NO_x is primarily a function of the nitrogen content of the fuel and the available oxygen. On average, about 45 percent of the fuel nitrogen is converted to NO_x, but this may vary from 20 to 70 percent. Thermal NO_x, rather, is largely a function of peak flame temperature and available oxygen, factors which depend on boiler size, firing configuration and operating practices.

Fuel nitrogen conversion is the more important NO_x forming mechanism in residual oil boilers. Except in certain large units having unusually high peak flame temperatures, or in units firing a low nitrogen residual oil, fuel NO_x will generally account for over 50 percent of the total NO_x generated. Thermal fixation, on the other hand, is the dominant NO_x forming mechanism in units firing distillate oils, primarily because of the negligible nitrogen content in these lighter oils. Because distillate oil fired boilers usually have low heat release rates, however, the quantity of thermal NO_x formed in them is less than that of larger units.

A number of variables influence how much NO_x is formed by these two mechanisms. One important variable is firing configuration. Nitrogen oxide emissions from tangentially (corner) fired boilers are, on the average, less than those of horizontally opposed units. Also important are the firing practices employed during boiler operation. Limited excess air firing, flue gas recirculation, staged combustion, or some combination thereof may result in NO_x reductions of 5 to 60 percent. See Section 1.4 for a discussion of these techniques. Load reduction can likewise decrease NO_x production. Nitrogen oxide emissions may be reduced from 0.5 to 1 percent for each percentage reduction in load from full load operation. It should be noted that most of these variables, with the exception of excess air, infuence the NO_x emissions only of large oil fired boilers. Limited excess air firing is possible in many small boilers, but the resulting NO_x reductions are not nearly so significant.

Other Pollutants[18-21] - As a rule, only minor amounts of volatile organic compounds (VOC) and carbon monoxide will be emitted from the combustion of fuel oil. The rate at which VOCs are emitted depends on combustion efficiency. Emissions of trace elements from oil fired boilers are relative to the trace element concentrations of the oil.

TABLE 1.3-2. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR UTILITY BOILERS FIRING RESIDUAL OIL[a]

EMISSION FACTOR RATING: C (uncontrolled)
E (ESP controlled)
D (scrubber controlled)

Particle size[b] (μm)	Cumulative mass % ≤ stated size			Cumulative emission factor[c] [kg/10^3 l (lb/10^3 gal)]		
	Uncontrolled	Controlled		Uncontrolled	Controlled[d]	
		ESP	Scrubber		ESP	Scrubber
15	80	75	100	0.80A (6.7A)	0.0060A (0.05A)	0.06A (0.50A)
10	71	63	100	0.71A (5.9A)	0.0050A (0.042A)	0.06A (0.50A)
6	58	52	100	0.58A (4.8A)	0.0042A (0.035A)	0.06A (0.50A)
2.5	52	41	97	0.52A (4.3A)	0.0033A (0.028A)	0.058A (0.48A)
1.25	43	31	91	0.43A (3.6A)	0.0025A (0.021A)	0.055A (0.46A)
1.00	39	28	84	0.39A (3.3A)	0.0022A (0.018A)	0.050A (0.42A)
0.625	20	10	64	0.20A (1.7A)	0.0008A (0.007A)	0.038A (0.32A)
TOTAL	100	100	100	1A (8.3A)	0.008A (0.067A)	0.06A (0.50A)

[a] Reference 29. ESP = electrostatic precipitator.

[b] Expressed as aerodynamic equivalent diameter.

[c] Particulate emission factors for residual oil combustion without emission controls are, on average, a function of fuel oil grade and sulfur content:

Grade 6 Oil: A = 1.25(S) + 0.38
Where S is the weight % of sulfur in the oil.
Grade 5 Oil: A = 1.25
Grade 4 Oil: A = 0.88

[d] Estimated control efficiency for scrubber, 94%; ESP, 99.2%.

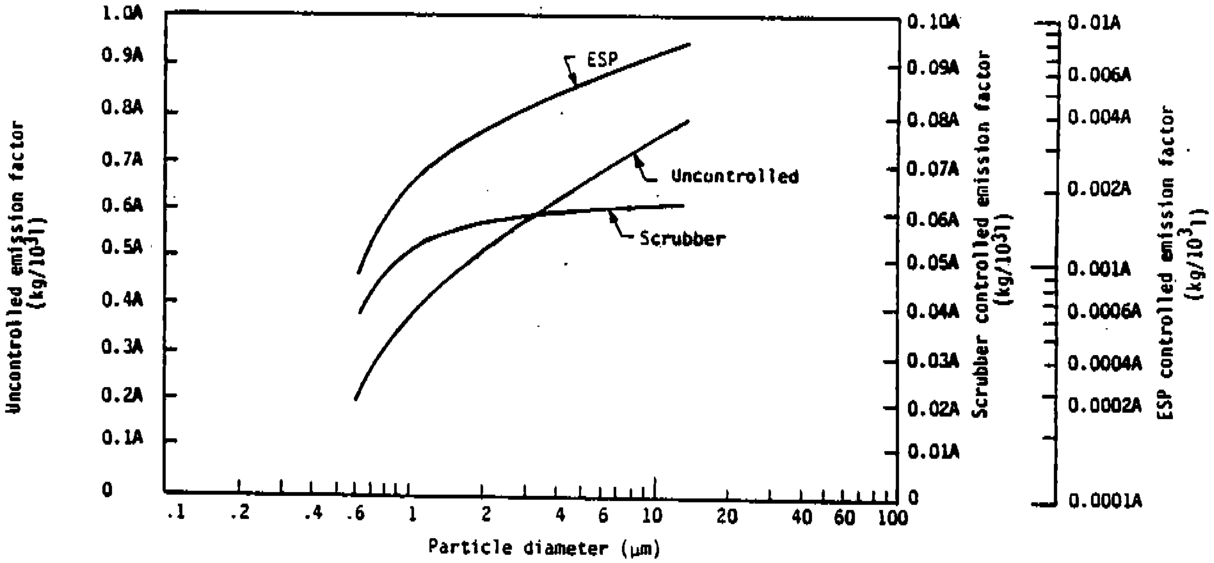

Figure 1.3-1. Cumulative size specific emission factors for utility boilers firing residual oil.

TABLE 1.3-3. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR INDUSTRIAL BOILERS FIRING RESIDUAL OIL[a]

EMISSION FACTOR RATING: D (uncontrolled)
E (multiple cyclone controlled)

Particle size[b] (um)	Cumulative mass % ≤ stated size		Cumulative emission factor[c] kg/10^3 l (lb/10^3 gal)	
	Uncontrolled	Multiple cyclone controlled	Uncontrolled	Multiple cyclone controlled[e]
15	91	100	0.91A (7.59A)	0.20A (1.67A)
10	86	95	0.86A (7.17A)	0.19A (1.58A)
6	77	72	0.77A (6.42A)	0.14A (1.17A)
2.5	56	22	0.56A (4.67A)	0.04A (0.33A)
1.25	39	21	0.39A (3.25A)	0.04A (0.33A)
1.00	36	21	0.36A (3.00A)	0.04A (0.33A)
0.625	30	d	0.30A (2.50A)	d
TOTAL	100	100	1A (8.34A)	0.2A (1.67A)

[a] Reference 29.

[b] Expressed as aerodynamic equivalent diameter.

[c] Particulate emission factors for residual oil combustion without emission controls are, on average, a function of fuel oil grade and sulfur content:

Grade 6 Oil: A = 1.25(S) + 0.38
Where S is the weight % of sulfur in the oil
Grade 5 Oil: A = 1.25
Grade 4 Oil: A = 0.88

[d] Insufficient data.

[e] Estimated control efficiency for multiple cyclone, 80%.

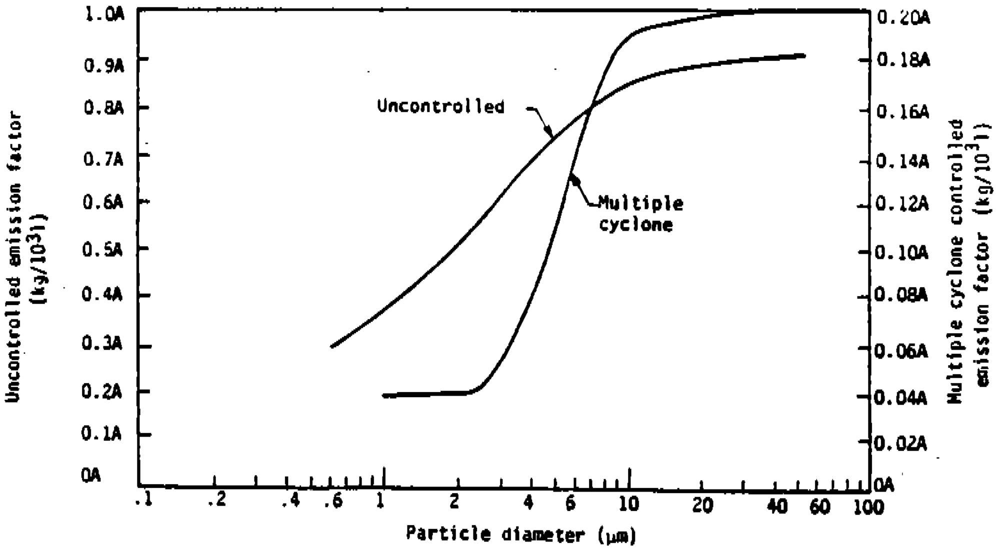

Figure 1.3-2. Cumulative size specific emission factors for industrial boilers firing residual oil.

TABLE 1.3-4. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR UNCONTROLLED INDUSTRIAL BOILERS FIRING DISTILLATE OIL[a]

EMISSION FACTOR RATING: E

Particle size[b] (um)	Cumulative mass % ≤ stated size	Cumulative emission factor kg/10^3 l (lb/10^3 gal)
	Uncontrolled	Uncontrolled
15	68	0.16 (1.33)
10	50	0.12 (1.00)
6	30	0.07 (0.58)
2.5	12	0.03 (0.25)
1.25	9	0.02 (0.17)
1.00	8	0.02 (0.17)
0.625	2	0.005 (0.04)
TOTAL	100	0.24 (2.00)

[a] Reference 29.

[b] Expressed as aerodynamic equivalent diameter.

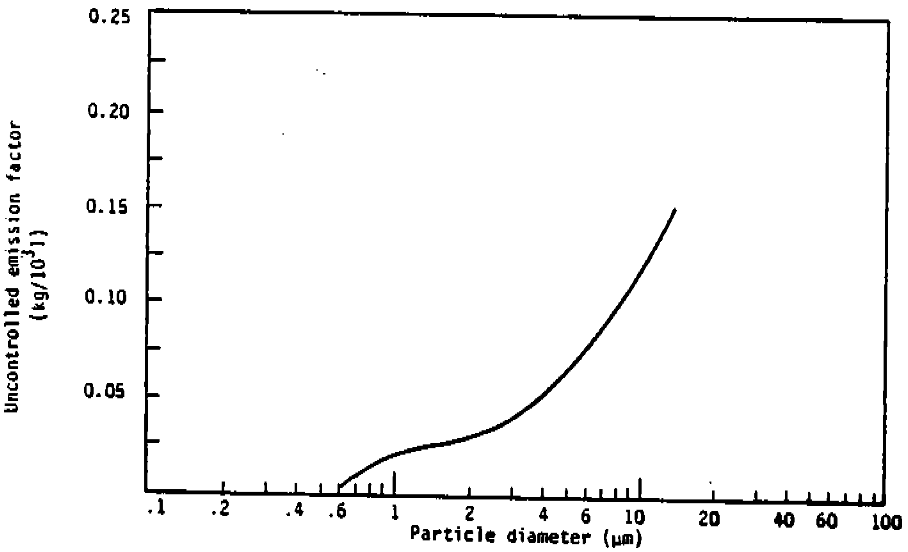

Figure 1.3-3. Cumulative size specific emission factors for uncontrolled industrial boilers firing distillate oil.

TABLE 1.3-5. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR UNCONTROLLED COMMERCIAL BOILERS BURNING RESIDUAL AND DISTILLATE OIL[a]

EMISSION FACTOR RATING: D

Particle size[b] (um)	Cumulative mass % $\leq$ stated size		Cumulative emission factor kg/10^3 l (lb/10^3 gal)	
	Uncontrolled with residual oil	Uncontrolled with distillate oil[c]	Uncontrolled with residual oil	Uncontrolled with distillate oil
15	78	60	0.78A (6.50A)	0.14 (1.17)
10	62	55	0.62A (5.17A)	0.13 (1.08)
6	44	49	0.44A (3.67A)	0.12 (1.00)
2.5	23	42	0.23A (1.92A)	0.10 (0.83)
1.25	16	38	0.16A (1.33A)	0.09 (0.75)
1.00	14	37	0.14A (1.17A)	0.09 (0.75)
0.625	13	35	0.13A (1.08A)	0.08 (0.67)
TOTAL	100	100	1A (8.34A)	0.24 (2.00)

[a] Reference 29.

[b] Expressed as aerodynamic equivalent diameter.

[c] Particulate emission factors for residual oil combustion without emission controls are, on average, a function of fuel oil grade and sulfur content:

Grade 6 Oil: A = 1.25 (S) + 0.38
Where S is the weight % of sulfur in the oil
Grade 5 Oil: A = 1.25
Grade 4 Oil: A = 0.88

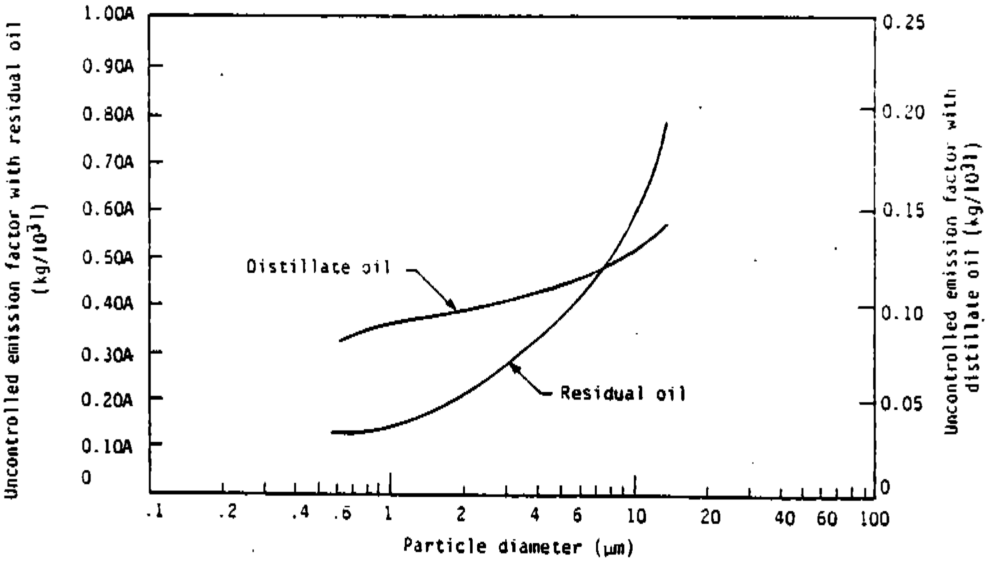

Figure 1.3-4. Cumulative size specific emission factors for uncontrolled commercial boilers burning residual and distillate oil.

Organic compounds present in the flue gas streams of boilers include aliphatic and aromatic hydrocarbons, esters, ethers, alcohols, carbonyls, carboxylic acids and polycylic organic matter. The last includes all organic matter having two or more benzene rings.

Trace elements are also emitted from the combustion of fuel oil. The quantity of trace elements emitted depends on combustion temperature, fuel feed mechanism and the composition of the fuel. The temperature determines the degree of volatilization of specific compounds contained in the fuel. The fuel feed mechanism affects the separation of emissions into bottom ash and fly ash.

If a boiler unit is operated improperly or is poorly maintained, the concentrations of carbon monoxide and VOCs may increase by several orders of magnitude.

1.3.3 Controls

The various control devices and/or techniques employed on oil fired boilers depend on the type of boiler and the pollutant being controlled. All such controls may be classified into three categories, boiler modification, fuel substitution and flue gas cleaning.

Boiler Modification [1-4,8-9,13-14,23]- Boiler modification includes any physical change in the boiler apparatus itself or in its operation. Maintenance of the burner system, for example, is important to assure proper atomization and subsequent minimization of any unburned combustibles. Periodic tuning is important in small units for maximum operating efficiency and emission control, particularly of smoke and CO. Combustion modifications, such as limited excess air firing, flue gas recirculation, staged combustion and reduced load operation, result in lowered NO_x emissions in large facilities. See Table 1.3-1 for specific reductions possible through these combustion modifications.

Fuel Substitution[3,5,12,28]- Fuel substitution, the firing of "cleaner" fuel oils, can substantially reduce emissions of a number of pollutants. Lower sulfur oils, for instance, will reduce SO_x emissions in all boilers, regardless of size or type of unit or grade of oil fired. Particulates generally will be reduced when a lighter grade of oil is fired. Nitrogen oxide emissions will be reduced by switching to either a distillate oil or a residual oil with less nitrogen. The practice of fuel substitution, however, may be limited by the ability of a given operation to fire a better grade of oil and by the cost and availability thereof.

Flue Gas Cleaning[15-16,28] - Flue gas cleaning equipment generally is employed only on large oil fired boilers. Mechanical collectors, a prevalent type of control device, are primarily useful in controlling particulates generated during soot blowing, during upset conditions, or when a very dirty heavy oil is fired. During these situations, high efficiency cyclonic collectors can effect up to 85 percent control of particulate. Under normal firing conditions, or when a clean oil is combusted, cyclonic collectors will not be nearly so effective because of the high percentage of small particles (less than 3 micrometers diameter) emitted.

Electrostatic precipitators are commonly used in oil fired power plants. Older precipitators, usually small, remove generally 40 to 60 percent of the particulate matter. Because of the low ash content of the oil, greater collection efficiency may not be required. Today, new or rebuilt electrostatic precipitators have collection efficiencies of up to 90 percent.

Scrubbing systems have been installed on oil fired boilers, especially of late, to control both sulfur oxides and particulate. These systems can achieve SO_2 removal efficiencies of 90 to 95 percent and particulate control efficiencies of 50 to 60 percent.

References for Section 1.3

1. W. S. Smith, Atmospheric Emissions from Fuel Oil Combustion: An Inventory Guide, 999-AP-2, U. S. Environmental Protection Agency, Washington, DC, November 1962.

2. J. A. Danielson (ed.), Air Pollution Engineering Manual, Second Edition, AP-40, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1973. Out of Print.

3. A. Levy, et al., A Field Investigation of Emissions from Fuel Oil Combustion for Space Heating, API Bulletin 4099, Battelle Columbus Laboratories, Columbia, OH, November 1971.

4. R. E. Barrett, et al., Field Investigation of Emissions from Combustion Equipment for Space Heating, EPA-R2-73-084a, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1973.

5. G. A. Cato, et al., Field Testing: Application of Combustion Modifications To Control Pollutant Emissions from Industrial Boilers - Phase I, EPA-650/2-74-078a, U. S. Environmental Protection Agency, Washington, DC, October 1974.

6. G. A. Cato, et al., Field Testing: Application of Combustion Modifications To Control Pollutant Emissions from Industrial Boilers - Phase II, EPA-600/2-76-086a, U. S. Environmental Protection Agency, Washington, DC, April 1976.

7. Particulate Emission Control Systems for Oil Fired Boilers, EPA-450/3-74-063, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1974.

8. W. Bartok, et al., Systematic Field Study of NO_x Emission Control Methods for Utility Boilers, APTD-1163, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1971.

9. A. R. Crawford, et al., Field Testing: Application of Combustion Modifications To Control NO_x Emissions from Utility Boilers, EPA-650/2-74-066, U. S. Environmental Protection Agency, Washington, DC, June 1974.

10. J. F. Deffner, et al., Evaluation of Gulf Econojet Equipment with Respect to Air Conservation, Report No. 731RC044, Gulf Research and Development Company, Pittsburgh, PA, December 18, 1972.

11. C. E. Blakeslee and H. E. Burbach, "Controlling NO_x Emissions from Steam Generators", Journal of the Air Pollution Control Association, 23:37-42, January 1973.

12. C. W. Siegmund, "Will Desulfurized Fuel Oils Help?", American Society of Heating, Refrigerating and Air Conditioning Engineers Journal, 11:29-33, April 1969.

13. F. A. Govan, et al., "Relationships of Particulate Emissions Versus Partial to Full Load Operations for Utility-sized Boilers", Proceedings of Third Annual Industrial Air Pollution Control Conference, Knoxville, TN, March 29-30, 1973.

14. R. E. Hall, et al., A Study of Air Pollutant Emissions from Residential Heating Systems, EPA-650/2-74-003, U. S. Environmental Protection Agency, Washington, DC, January 1974.

15. Flue Gas Desulfurization: Installations and Operations, PB 257721, National Technical Information Service, Springfield, VA, September 1974.

16. Proceedings: Flue Gas Desulfurization Symposium - 1973, EPA-650/2-73-038, U. S. Environmental Protection Agency, Washington, DC, December 1973.

17. R. J. Milligan, et al., Review of NO_x Emission Factors for Stationary Fossil Fuel Combustion Sources, EPA-450/4-79-021, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1979.

18. N. F. Suprenant, et al., Emissions Assessment of Conventional Stationary Combustion Systems, Volume I: Gas and Oil Fired Residential Heating Sources, EPA-600/7-79-029b, U. S. Environmental Protection Agency, Washington, DC, May 1979.

19. C. C. Shih, et al., Emissions Assessment of Conventional Stationary Combustion Systems, Volume III: External Combustion Sources for Electricity Generation, EPA Contract No. 68-02-2197, TRW, Inc., Redondo Beach, CA, November 1980.

20. N. F. Suprenant, et al., Emissions Assessement of Conventional Stationary Combustion System, Volume IV: Commercial Institutional Combustion Sources, EPA Contract No. 68-02-2197, GCA Corporation, Bedford, MA, October 1980.

21. N. F. Suprenant, et al., Emissions Assessment of Conventional Stationary Combustion Systems, Volume V: Industrial Combustion Sources, EPA Contract No. 68-02-2197, GCA Corporation, Bedford, MA, October 1980.

22. Fossil Fuel Fired Industrial Boilers - Background Information for Proposed Standards (Draft EIS), Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1980.

23. K. J. Lim, et al., Technology Assessment Report for Industrial Boiler Applications: NO_x Combustion Modification, EPA-600/7-79-178f, U. S. Environmental Protection Agency, Washington, DC, December 1979.

24. Emission Test Reports, Docket No. OAQPS-78-1, Category II-I-257 through 265, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1972 through 1974.

25. Primary Sulfate Emissions from Coal and Oil Combustion, EPA Contract No. 68-02-3138, TRW, Inc., Redondo Beach, CA, February 1980.

26. C. Leavitt, et al., Environmental Assessment of an Oil Fired Controlled Utility Boiler, EPA-600/7-80-087, U. S. Environmental Protection Agency, Washington, DC, April 1980.

27. W. A. Carter and R. J. Tidona, Thirty-day Field Tests of Industrial Boilers: Site 2 - Residual-oil-fired Boiler, EPA-600/7-80-085b, U. S. Environmental Protection Agency, Washington, DC, April 1980.

28. G. R. Offen, et al., Control of Particulate Matter from Oil Burners and Boilers, EPA-450/3-76-005, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1976.

29. Inhalable Particulate Source Category Report for External Combustion Sources, EPA Contract No. 68-02-3156a, Acurex Corporation, Mountain View, CA, January 1985.

1.4 NATURAL GAS COMBUSTION

1.4.1 General[1-2]

Natural gas is one of the major fuels used throughout the country. It is used mainly for power generation, for industrial process steam and heat production, and for domestic and commercial space heating. The primary component of natural gas is methane, although varying amounts of ethane and smaller amounts of nitrogen, helium and carbon dioxide are also present. Gas processing plants are required for recovery of liquefiable constitutents and removal of hydrogen sulfide (H_2S) before the gas is used (see Natural Gas Processing, Section 9.2). The average gross heating value of natural gas is approximately 9350 kilocalories per standard cubic meter (1050 British thermal units/standard cubic foot), usually varying from 8900 to 9800 kcal/scm (1000 to 1100 Btu/scf).

1.4.2 Emission And Controls[3-26]

Even though natural gas is considered to be a relatively clean fuel, some emissions can occur from the combustion reaction. For example, improper operating conditions, including poor mixing, insufficient air, etc., may cause large amounts of smoke, carbon monoxide and hydrocarbons. Moreover, because a sulfur containing mercaptan is added to natural gas to permit detection, small amounts of sulfur oxides will also be produced in the combustion process.

Nitrogen oxides are the major pollutants of concern when burning natural gas. Nitrogen oxide emissions are functions of combustion chamber temperature and combustion product cooling rate. Emission levels vary considerably with the type and size of unit and with operating conditions.

In some large boilers, several operating modifications may be used for NO_x control. Staged combustion, for example, including off-stoichiometric firing and/or two stage combustion, can reduce emissions by 5 to 50 percent.[26] In off-stoichiometric firing, also called "biased firing", some burners are operated fuel rich, some fuel lean, and others may supply air only. In two stage combustion, the burners are operated fuel rich (by introducing only 70 to 90 percent stoichiometric air), with combustion being completed by air injected above the flame zone through second stage "NO ports". In staged combustion, NO_x emissions are reduced because the bulk of combustion occurs under fuel rich conditions.

Other NO_x reducing modifications include low excess air firing and flue gas recirculation. In low excess air firing, excess air levels are kept as low as possible without producing unacceptable levels of unburned combustibles (carbon monoxide, volatile organic compounds and smoke) and/or other operating problems. This technique can reduce NO_x emissions 5 to 35 percent, primarily because of lack of oxygen during combustion. Flue gas recirculation into the primary combustion zone, because the flue gas is relatively cool and oxygen deficient, can also lower NO_x emissions 4 to 85 percent, depending on the amount of gas recirculated. Flue gas recirculation is best suited for new boilers. Retrofit application would require extensive burner modifications.

TABLE 1.4-1. UNCONTROLLED EMISSION FACTORS FOR NATURAL GAS COMBUSTION[a]

Furnace size & type (10^6 Btu/hr heat input)	Particulate[b]		Sulfur dioxide[c]		Nitrogen oxides[d]		Carbon monoxide[e]		Volatile organics			
									Nonmethane		Methane	
	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/$10^6 m^3$	lb/10^6 ft^3	kg/$10^6 m^3$	lb/10^6 ft^3
Utility boilers (> 100)	16 - 80	1 - 5	9.6	0.6	8800[h]	550[h]	640	40	23	1.4	4.8	0.3
Industrial boilers (10 - 100)	16 - 80	1 - 5	9.6	0.6	2240	140	560	35	44	2.8	48	3
Domestic and commercial boilers (< 10)	16 - 80	1 - 5	9.6	0.6	1600	100	320	20	84	5.3	43	2.7

[a] Expressed as weight/volume fuel fired.

[b] References 15-18.

[c] Reference 4. Based on avg. sulfur content of natural gas, 4600 g/10^6 Nm^3 (2000 gr/10^6 scf).

[d] References 4-5, 7-8, 11, 14, 18-19, 21.

[e] Expressed as NO_2. Tests indicate about 95 weight % NO_x is NO_2.

[f] References 4, 7-8, 16, 18, 22-25.

[g] References 16, 18. May increase 10 - 100 times with improper operation or maintenance.

[h] For tangentially fired units, use 4400 kg/10^6 m^3 (275 lb/10^6 ft^3). At reduced loads, multiply factor by load reduction coefficient in Figure 1.4-1. For potential NO_x reductions by combustion modification, see text. Note that NO_x reduction from these modifications will also occur at reduced load conditions.

Studies indicate that low NO_x burners (20 to 50 percent reduction) and ammonia injection (40 to 70 percent reduction) also offer NO_x emission reductions.

Combinations of the above combustion modifications may also be employed to reduce NO_x emissions further. In some boilers, for instance, NO_x reductions as high as 70 to 90 percent have been produced by employing several of these techiques simultaneously. In general, however, because the net effect of any of these combinations varies greatly, it is difficult to predict what the reductions will be in individual applications.

Although not measured, all particulate has been estimated to be less than 1 micrometer in size.[27] Emission factors for natural gas combustion are presented in Table 1.4-1, and factor ratings in Table 1.4-2.

TABLE 1.4-2. FACTOR RATINGS FOR NATURAL GAS COMBUSTION

Furnace type	Particulate	Sulfur oxides	Nitrogen oxides	Carbon monoxide	Volatile organics	
					Nonmethane	Methane
Utility boiler	B	A	A	A	C	C
Industrial boiler	B	A	A	A	C	C
Commercial boiler	B	A	A	A	D	D
Residential furnace	B	A	A	A	D	D

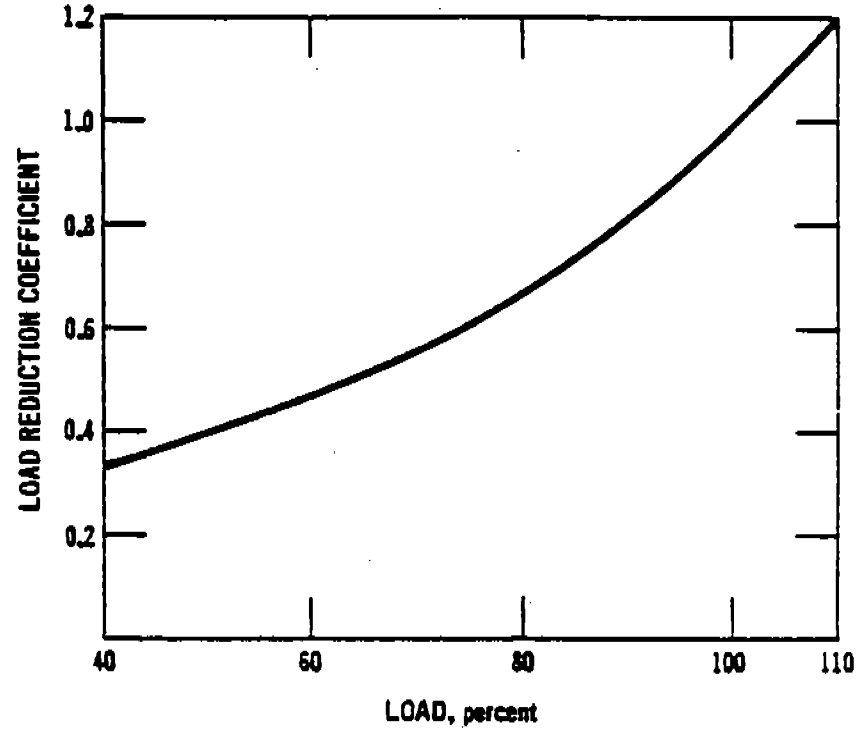

Figure 1.4-1. Load reduction coefficient as function of boiler load. (Used to determine NO_x reductions at reduced loads in large boilers.)

References for Section 1.4

1. D. M. Hugh, et al., Exhaust Gases from Combustion and Industrial Processes, EPA Contract No. EHSD 71-36, Engineering Science, Inc., Washington, DC, October 2, 1971.

2. J. H. Perry (ed.), Chemical Engineer's Handbook, 4th Edition, McGraw-Hill, New York, NY, 1963.

3. H. H. Hovey, et al., The Development of Air Contaminant Emission Tables for Non-process Emissions, New York State Department of Health, Albany, NY, 1965.

4. W. Bartok, et al., Systematic Field Study of NO_x Emission Control Methods for Utility Boilers, APTD-1163, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1971.

5. F. A. Bagwell, et al., "Oxides of Nitrogen Emission Reduction Program for Oil and Gas Fired Utility Boilers", Proceedings of the American Power Conference, 14:683-693, April 1970.

6. R. L. Chass and R. E. George, "Contaminant Emissions from the Combustion of Fuels", Journal of the Air Pollution Control Association, 10:34-43, February 1980.

7. H. E. Dietzmann, A Study of Power Plant Boiler Emissions, Final Report No. AR-837, Southwest Research Institute, San Antonio, TX, August 1972.

8. R. E. Barrett, et al., Field Investigation of Emissions from Combustion Equipment for Space Heating, EPA-R2-73-084, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1973.

9. Confidential information, American Gas Association Laboratories, Cleveland, OH, May 1970.

10. Unpublished data on domestic gas fired units, U. S. Environmental Protection Agency, Cincinnati, OH, 1970.

11. C. E. Blakeslee and H. E. Burbock, "Controlling NO_x Emissions from Steam Generators", Journal of the Air Pollution Control Association, 23:37-42, January 1979.

12. L. K. Jain, et al., "State of the Art" for Controlling NO_x Emissions: Part 1, Utility Boilers, EPA-Contract No. 68-02-0241, Catalytic, Inc., Charlotte, NC, September 1972.

13. J. W. Bradstreet and R. J. Fortman, "Status of Control Techniques for Achieving Compliance with Air Pollution Regulations by the Electric Utility Industry", Presented at the 3rd Annual Industrial Air Pollution Control Conference, Knoxville, TN, March 1973.

14. Study of Emissions of NO_x from Natural Gas Fired Steam Electric Power Plants in Texas, Phase II, Volume II, Radian Corporation, Austin, TX, May 8, 1972.

15. N. F. Suprenant, et al., Emissions Assessment of Conventional Stationary Combustion Systems, Volume I: Gas and Oil Fired Residential Heating Sources, EPA-600/7-79-029b, U. S. Environmental Protection Agency, Washington, DC, May 1979.

16. C. C. Shih, et al., Emissions Assessment of Conventional Stationary Combustion Systems, Volume III: External Combustion Sources for Electricity Generation, EPA Contract No. 68-02-2197, TRW, Inc., Redondo Beach, CA, November 1980.

17. N. F. Suprenant, et al., Emissions Assessment of Conventional Stationary Combustion Sources, Volume IV: Commercial Institutional Combustion Sources, EPA Contract No. 68-02-2197, GCA Corporation, Bedford, MA, October 1980.

18. N. F. Suprenant, et al., Emissions Assessment of Conventional Stationary Combustion Systems, Volume V: Industrial Combustion Sources, EPA Contract No. 68-02-2197, GCA Corporation, Bedford, MA, October 1980.

19. R. J. Milligan, et al., Review of NO_x Emission Factors for Stationary Fossil Fuel Combustion Sources, EPA-450/4-79-021, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1979.

20. W. H. Thrasher and D. W. Dewerth, Evaluation of the Pollutant Emissions from Gas Fired Water Heaters, Research Report No. 1507, American Gas Association, Cleveland, OH, April 1977.

21. W. H. Thrasher and D. W. Dewerth, Evaluation of the Pollutant Emissions from Gas Fired Forced Air Furnaces, Research Report No. 1503, American Gas Association, Cleveland, OH, May 1975.

22. G. A. Cato, et al., Field Testing: Application of Combustion Modification To Control Pollutant Emissions from Industrial Boilers, Phase I, EPA-650/2-74-078a, U. S. Environmental Protection Agency, Washington, DC, October 1974.

23. G. A. Cato, et al., Field Testing: Application of Combustion Modification To Control Pollutant Emissions from Industrial Boilers, Phase II, EPA-600/2-76-086a, U. S. Environmental Protection Agency, Washington, DC, April 1976.

24. W. A. Carter and H. J. Buening, Thirty-day Field Tests of Industrial Boilers - Site 5, EPA Contract No. 68-02-2645, KVB Engineering, Inc., Irvine, CA, May 1981.

25. W. A. Carter and H. J. Buening, Thirty-day Field Tests of Industrial Boilers - Site 6, EPA Contract No. 68-02-2645, KVB Engineering, Inc., Irvine, CA, May 1981.

26. K. J. Lim, et al., Technology Assessment Report for Industrial Boiler Applications: NO_x Combustion Modification, EPA Contract No. 68-02-3101, Acurex Corporation, Mountain View, CA, December 1979.

27. H. J. Taback, et al., Fine Particle Emissions From Stationary and Miscellaneous Sources in the South Coast Air Basin, California Air Resources Board Contract No. A6-191-30, KVB, Inc., Tustin, CA, February 1979.

1.6 WOOD WASTE COMBUSTION IN BOILERS

1.6.1 General[1-3]

The burning of wood waste in boilers is mostly confined to those industries where it is available as a byproduct. It is burned both to obtain heat energy and to alleviate possible solid waste disposal problems. Wood waste may include large pieces like slabs, logs and bark strips, as well as cuttings, shavings, pellets and sawdust, and heating values for this waste range from about 4,400 to 5,000 kilocalories per kilogram of fuel dry weight (7,940 to 9,131 Btu/lb). However, because of typical moisture contents of 40 to 75 percent, the heating values for many wood waste materials as actually fired are as low as 2,200 to 3,300 kilocalories per kilogram of fuel. Generally, bark is the major type of waste burned in pulp mills, and either a varying mixture of wood and bark waste or wood waste alone are most frequently burned in the lumber, furniture and plywood industries.

1.6.2 Firing Practices[1-3]

Varied boiler firing configurations are used in burning wood waste. One common type in smaller operations is the dutch oven, or extension type of furnace with a flat grate. This unit is widely used because it can burn fuels with very high moisture. Fuel is fed into the oven through apertures atop a firebox and is fired in a cone shaped pile on a flat grate. The burning is done in two stages, drying and gasification, and combustion of gaseous products. The first stage takes place in a cell separated from the boiler section by a bridge wall. The combustion stage takes place in the main boiler section. The dutch oven is not responsive to changes in steam load, and it provides poor combustion control.

In another type, the fuel cell oven, fuel is dropped onto suspended fixed grates and is fired in a pile. Unlike the dutch oven, the fuel cell also uses combustion air preheating and repositioning of the secondary and tertiary air injection ports to improve boiler efficiency.

In many large operations, more conventional boilers have been modified to burn wood waste. These units may include spreader stokers with traveling grates, vibrating grate stokers, etc., as well as tangentially fired or cyclone fired boilers. The most widely used of these configurations is the spreader stoker. Fuel is dropped in front of an air jet which casts the fuel out over a moving grate, spreading it in an even thin blanket. The burning is done in three stages in a single chamber, (1) drying, (2) distillation and burning of volatile matter and (3) burning of carbon. This type of operation has a fast response to load changes, has improved combustion control and can be operated with multiple fuels. Natural gas or oil are often fired in spreader stoker boilers as auxiliary fuel. This is done to maintain constant steam when the wood waste supply fluctuates and/or to provide more steam than is possible from the waste supply alone.

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TABLE 1.6-1. EMISSION FACTORS FOR WOOD AND BARK COMBUSTION IN BOILERS

Pollutant/Fuel type	kg/Mg	lb/ton	Emission Factor Rating
Particulate[a]			
Bark[b]			
Multiclone, with flyash reinjection[c]	7	14	B
Multiclone, without flyash reinjection[c]	4.5	9	B
Uncontrolled	24	47	B
Wood/bark mixture[d]			
Multiclone, with flyash reinjection[c,e]	3	6	C
Multiclone, without flyash reinjection[c,e]	2.7	5.3	C
Uncontrolled[f]	3.6	7.2	C
Wood[g]			
Uncontrolled	4.4	8.8	C
Sulfur dioxide[h]	0.075 (0.01 - 0.2)	0.15 (0.02 - 0.4)	B
Nitrogen oxides (as NO_2)[j]			
50,000 - 400,000 lb steam/hr	1.4	2.8	B
<50,000 lb steam/hr	0.34	0.68	B
Carbon monoxide[k]	2 - 24	4 - 47	C
VOC			
Nonmethane[m]	0.7	1.4	D
Methane[n]	0.15	0.3	E

[a] References 2, 4, 9, 17-18, 20. With gas or oil as auxiliary fuel, all particulate assumed to result from only wood waste fuel. May include condensible hydrocarbons of pitches and tars, mostly from back half catch of EPA Method 5. Tests indicate condensible hydrocarbons about 4% of total particulate weight.

[b] Based on fuel moisture content about 50%.

[c] References 4,7-8. After control equipment, assuming an average collection efficiency of 80%. Data indicate that 50% flyash reinjection increases dust load at cyclone inlet 1.2 to 1.5 times, and 100% flyash reinjection increases the load 1.5 to 2 times.

[d] Based on fuel moisture content of 33%.

[e] Based on large dutch ovens and spreader stokers (avg. 23,430 kg steam/hr) with steam pressures 20 - 75 kps (140 - 530 psi).

[f] Based on small dutch ovens and spreader stokers (usually ≤9075 kg steam/hr), with steam pressures 5 - 30 kpa (35 - 230 psi). Careful air adjustments and improved fuel separation and firing sometimes used, but effects can not be isolated.

[g] References 12-13, 19, 27. Wood waste includes cuttings, shavings, sawdust and chips, but not bark. Moisture content ranges 3 - 50 weight %. Based on small units (≤3000 kg steam/hr).

[h] Reference 23. Based on dry weight of fuel. From tests of fuel sulfur content and SO_2 emissions at 4 mills burning bark. Lower limit of range (in parentheses) should be used for wood, and higher values for bark. Heating value of 5000 kcal/kg (9000 Btu/lb) is assumed.

[j] References 7, 24-26. Several factors can influence emission rates, including combustion zone, temperature, excess air, boiler operating conditions, fuel moisture and fuel nitrogen content.

[k] Reference 30.

[m] References 20, 30. Nonmethane VOC reportedly consists of compounds with high vapor pressure, such as alpha pinene.

[n] Reference 30. Based on approximation of methane/nonmethane ratio, quite variable. Methane, expressed as % total VOC, varied 0 - 74 weight %.

Sander dust is often burned in various boiler types at plywood, particle board and furniture plants. Sander dust contains fine wood particles with low moisture content (less than 20 weight percent). It is fired in a flaming horizontal torch, usually with natural gas as an ignition aid or supplementary fuel.

1.6.3 Emissions And Controls[4-28]

The major emission of concern from wood boilers is particulate matter, although other pollutants, particularly carbon monoxide, may be emitted in significant amounts under poor operating conditions. These emissions depend on a number of variables, including (1) the composition of the waste fuel burned, (2) the degree of flyash reinjection employed and (3) furnace design and operating conditions.

The composition of wood waste depends largely on the industry whence it originates. Pulping operations, for example, produce great quantities of bark that may contain more than 70 weight percent moisture and sand and other noncombustibles. Because of this, bark boilers in pulp mills may emit considerable amounts of particulate matter to the atmosphere unless they are well controlled. On the other hand, some operations, such as furniture manufacturing, produce a clean dry wood waste, 5 to 50 weight percent moisture, with relatively little particulate emission when properly burned. Still other operations, such as sawmills, burn a varying mixture of bark and wood waste that results in particulate emissions somewhere between these two extremes.

Furnace design and operating conditions are particularly important when firing wood waste. For example, because of the high moisture content that can be present in this waste, a larger than usual area of refractory surface is often necessary to dry the fuel before combustion. In addition, sufficient secondary air must be supplied over the fuel bed to burn the volatiles that account for most of the combustible material in the waste. When proper drying conditions do not exist, or when secondary combustion is incomplete, the combustion temperature is lowered, and increased particulate, carbon monoxide and hydrocarbon emissions may result. Lowering of combustion temperature generally means decreased nitrogen oxide emissions. Also, short term emissions can fluctuate with significant variations in fuel moisture content.

Flyash reinjection, which is common to many larger boilers to improve fuel efficiency, has a considerable effect on particulate emissions. Because a fraction of the collected flyash is reinjected into the boiler, the dust loading from the furnace, and consequently from the collection device, increases significantly per unit of wood waste burned. It is reported that full reinjection can cause a tenfold increase in the dust loadings of some systems, although increase of 1.2 to 2 times are more typical for boilers using 50 to 100 percent reinjection. A major factor affecting this dust loading increase is the extent to which the sand and other noncombustibles can be separated from the flyash before reinjection to the furnace.

Although reinjection increases boiler efficiency from 1 to 4 percent and reduces emissions of uncombusted carbon, it increases boiler maintenance requirements, decreases average flyash particle size and makes collection more difficult. Properly designed reinjection systems should separate sand and char

TABLE 1.6-2. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR BARK FIRED BOILERS[a]

EMISSION FACTOR RATING: D

Particle size[b] (µm)	Cumulative mass % ≤ stated size				Cumulative emission factor [kg/Mg (lb/ton) bark, as fired]			
	Uncontrolled	Controlled			Uncontrolled	Controlled		
		Multiple cyclone[c]	Multiple cyclone[d]	Scrubber[e]		Multiple cyclone[c]	Multiple cyclone[d]	Scrubber[e]
15	42	90	40	92	10.1 (20.2)	6.3 (12.6)	1.8 (3.6)	1.32 (2.64)
10	35	79	36	87	8.4 (16.8)	5.5 (11.0)	1.62 (3.24)	1.25 (2.50)
6	28	64	30	78	6.7 (13.4)	4.5 (9.0)	1.35 (2.7)	1.12 (2.24)
2.5	21	40	19	56	5.0 (10.0)	2.8 (5.6)	0.86 (1.72)	0.81 (1.62)
1.25	15	26	14	29	3.6 (7.2)	1.8 (3.6)	0.63 (1.26)	0.42 (0.84)
1.00	13	21	11	23	3.1 (6.2)	1.5 (3.0)	0.5 (1.0)	0.33 (0.66)
0.625	9	15	8	14	2.2 (4.4)	1.1 (2.2)	0.36 (0.72)	0.20 (0.40)
TOTAL	100	100	100	100	24 (48)	7 (14)	4.5 (9.0)	1.44 (2.88)

[a] Reference 31. All spreader stoker boilers.
[b] Expressed as aerodynamic equivalent diameter.
[c] With flyash reinjection.
[d] Without flyash reinjection.
[e] Estimated control efficiency for scrubber, 94%.

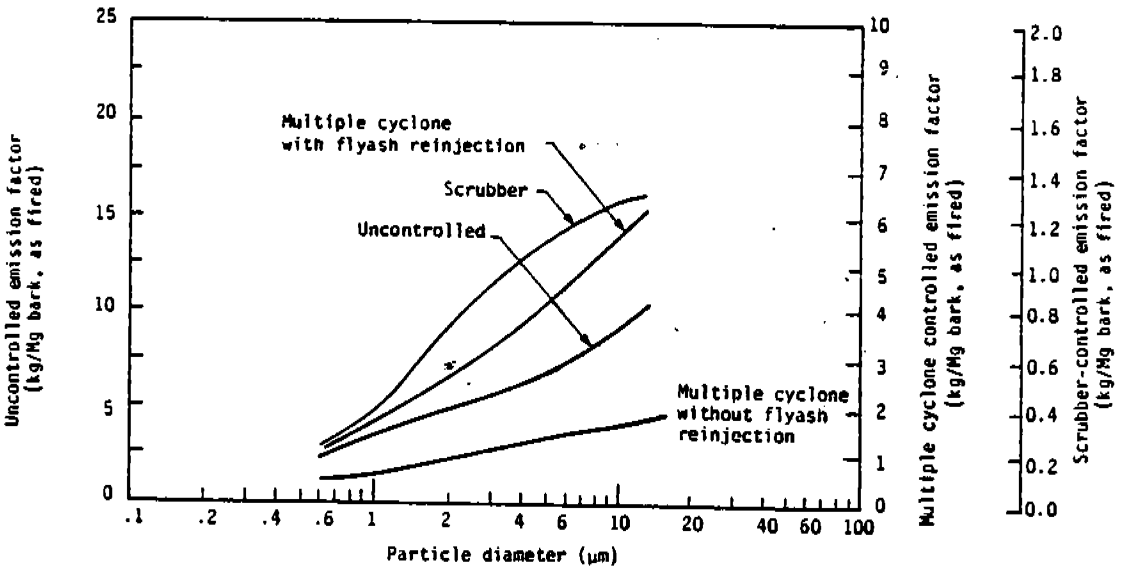

Figure 1.6-1. Cumulative size specific emission factors for bark fired boilers.

from the exhaust gases, to reinject the larger carbon particles to the furnace and to divert the fine sand particles to the ash disposal system.

Several factors can influence emissions, such as boiler size and type, design features, age, load factors, wood species and operating procedures. In addition, wood is often cofired with other fuels. The effect of these factors on emissions is difficult to quantify. It is best to refer to the references for further information.

The use of multitube cyclone mechanical collectors provides particulate control for many hogged boilers. Usually, two multicyclones are used in series, allowing the first collector to remove the bulk of the dust and the second to remove smaller particles. The efficiency of this arrangement is from 65 to 95 percent. Low pressure drop scrubbers and fabric filters have been used extensively for many years, and pulse jets have been used in the western U. S.

Emission factors and emission factor ratings for wood waste boilers are presented in Table 1.6-1, except for cumulative size distribution data, size specific emission factors for particulate, and emission factor ratings for the cumulative particle size distribution, all presented in Tables 1.6-2 through 1.6-3. Uncontrolled and controlled size specific emission factors are in Figures 1.6-1 and 1.6-2.

TABLE 1.6-3. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR WOOD/BARK FIRED BOILERS[a]

EMISSION FACTOR RATING: E (A for dry electrostatic granular filter [DEGF])

Particle size[b] (µm)	Cumulative mass % ≤ stated size					Cumulative emission factors [kg/Mg (lb/ton) wood/bark, as fired]				
	Uncontrolled[c]	Controlled				Uncontrolled[c]	Controlled			
		Multiple cyclone[d]	Multiple cyclone[e]	Scrubber[f]	DEGF		Multiple cyclone[d]	Multiple cyclone[e]	Scrubber[f]	DEGF[d]
15	94	96	35	98	77	3.38 (6.77)	2.88 (5.76)	0.95 (1.90)	0.216 (0.431)	0.123 (0.246)
10	90	91	32	98	74	3.24 (6.48)	2.73 (5.46)	0.86 (1.72)	0.216 (0.432)	0.118 (0.236)
6	86	80	27	98	69	3.10 (6.20)	2.40 (4.80)	0.73 (1.46)	0.216 (0.432)	0.110 (0.220)
2.5	76	54	16	98	65	2.74 (5.47)	1.62 (3.24)	0.43 (0.86)	0.216 (0.432)	0.104 (0.208)
1.25	69	30	8	96	61	2.48 (4.97)	0.90 (1.80)	0.22 (0.44)	0.211 (0.422)	0.098 (0.196)
1.00	67	24	6	95	58	2.41 (4.82)	0.72 (1.44)	0.16 (0.32)	0.209 (0.418)	0.093 (0.186)
0.625	-	16	3	-	51	-	0.48 (0.96)	0.081 (0.162)	-	0.082 (0.164)
TOTAL	100	100	100	100	100	3.6 (7.2)	3.0 (6.0)	2.7 (5.4)	0.22 (0.44)	0.16 (0.32)

[a] Reference 31. Dash = insufficient data.
[b] Expressed as aerodynamic equivalent diameter.
[c] From data on underfeed stokers. May also be used as size distribution for wood fired boilers.
[d] From data on spreader stokers. With fly ash reinjection.
[e] From data on spreader stokers. Without fly ash reinjection.
[f] From data on dutch ovens. Estimated control efficiency, 94%.

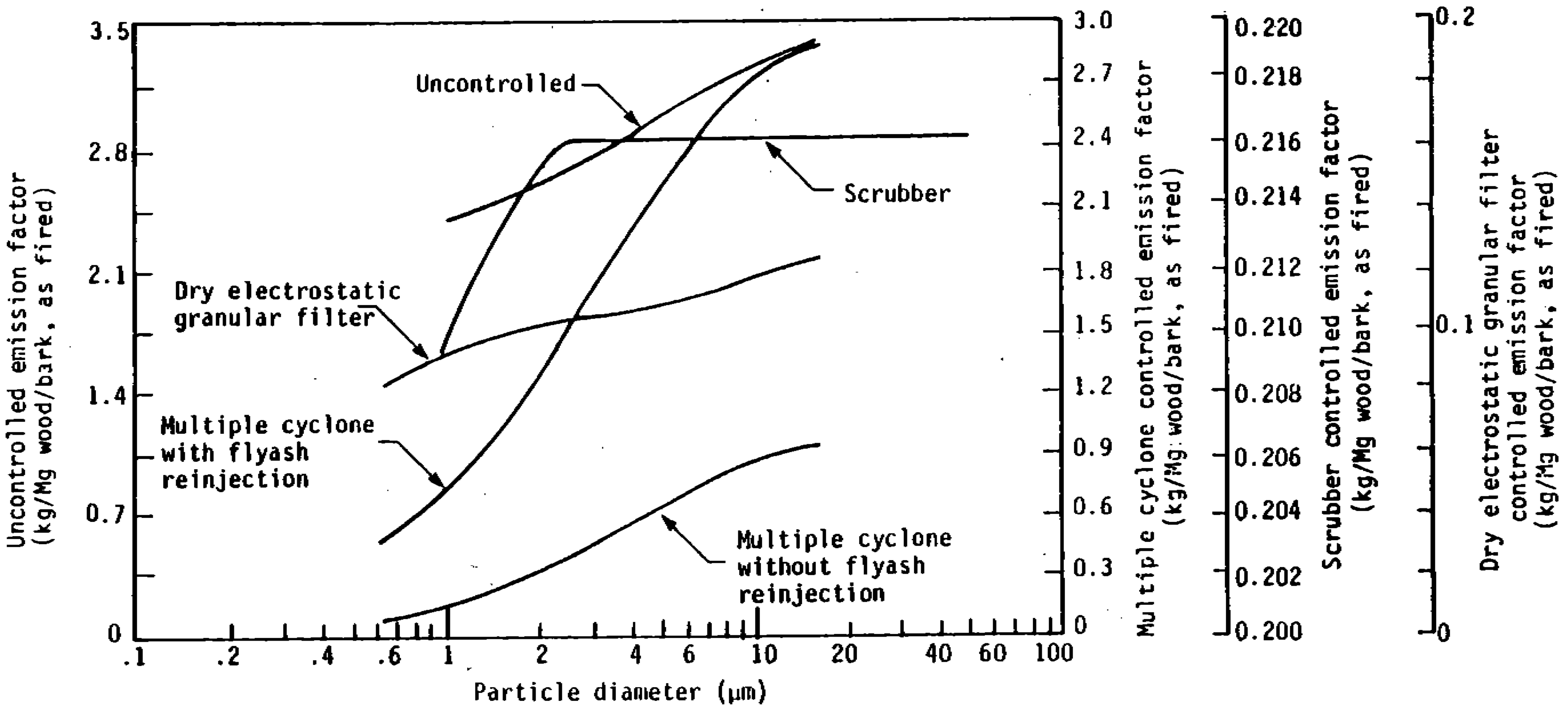

Figure 1.6-2. Cumulative size specific emission factors for wood/bark fired boilers.

References for Section 1.6

1. Steam, 38th Edition, Babcock and Wilcox, New York, NY, 1972.

2. Atomspheric Emissions from the Pulp and Paper Manufacturing Industry, EPA-450/1-73-002, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1973.

3. C-E Bark Burning Boilers, C-E Industrial Boiler Operations, Combustion Engineering, Inc., Windsor, CT, 1973.

4. A. Barron, Jr., "Studies on the Collection of Bark Char throughout the Industry", Journal of the Technical Association of the Pulp and Paper Industry, 53(8):1441-1448, August 1970.

5. H. Kreisinger, "Combustion of Wood Waste Fuels", Mechanical Engineering, 61:115-120, February 1939.

6. P. L. Magill (ed.), Air Pollution Handbook, McGraw-Hill Book Co., New York, NY, 1956.

7. Air Pollutant Emission Factors, APTD-0923, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1970.

8. J. F. Mullen, A Method for Determining Combustible Loss, Dust Emissions, and Recirculated Refuse for a Solid Fuel Burning System, Combustion Engineering, Inc., Windsor, CT, 1966.

9. Source test data, Alan Lindsey, U. S. Environmental Protection Agency, Atlanta, GA, May 1973.

10. H. K. Effenberger, et al., "Control of Hogged Fuel Boiler Emissions: A Case History", Journal of the Technical Association of the Pulp and Paper Industry, 56(2):111-115, February 1973.

11. Source test data, Oregon Department of Environmental Quality, Portland, OR, May 1973.

12. Source test data, Illinois Environmental Protection Agency, Springfield, IL, June 1973.

13. J. A. Danielson (ed.), Air Pollution Engineering Manual, Second Edition, AP-40, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1973. Out of Print.

14. H. Droege and G. Lee, "The Use of Gas Sampling and Analysis for the Evaluation of Teepee Burners", presented at the Seventh Conference on the Methods in Air Pollution Studies, Los Angeles, CA, January 1967.

15. D. C. Junge and K. Kwan, "An Investigation of the Chemically Reactive Constituents of Atmospheric Emissions from Hog-fuel Boilers in Oregon", Northwest International Section of the Air Pollution Control Association, November 1973.

16. S. F. Galeano and K. M. Leopold, "A Survey of Emissions of Nitrogen Oxides in the Pulp Mill", Journal of the Technical Association of the Pulp and Paper Industry, 56(3):74-76, March 1973.

17. P. B. Bosserman, "Wood Waste Boiler Emissions in Oregon State", presented at the Annual Meeting of the Pacific Northwest International Section of the Air Pollution Control Association, September 1976.

18. Source test data, Oregon Department of Environmental Quality, Portland, OR, September 1975.

19. Source test data, New York State Department of Environmental Conservation, Albany, NY, May 1974.

20. P. B. Bosserman, "Hydrocarbon Emissions from Wood Fired Boilers", presented at the Annual Meeting of the Pacific Northwest International Section of the Air Pollution Control Association, November 1977.

21. Control of Particulate Emissions from Wood Fired Boilers, EPA-340/1-77-026, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1978.

22. Wood Residue Fired Steam Generator Particulate Matter Control Technology Assessment, EPA-450/2-78-044, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1978.

23. H. S. Oglesby and R. O. Blosser, "Information on the Sulfur Content of Bark and Its Contribution to SO_2 Emissions When Burned as a Fuel", Journal of the Air Pollution Control Association, 30(7):769-772, July 1980.

24. A Study of Nitrogen Oxides Emissions from Wood Residue Boilers, Technical Bulletin No. 102, National Council of the Paper Industry for Air and Steam Improvement, New York, NY, November 1979.

25. R. A. Kester, Nitrogen Oxide Emissions from a Pilot Plant Spreader Stoker Bark Fired Boiler, Department of Civil Engineering, University of Washington, Seattle, WA, December 1979.

26. A. Nunn, NO_x Emission Factors for Wood Fired Boilers, EPA-600/7-79-219, U. S. Environmental Protection Agency, September 1979.

27. C. R. Sanborn, Evaluation of Wood Fired Boilers and Wide Bodied Cyclones in the State of Vermont, U. S. Environmental Protection Agency, Boston, MA, March 1979.

28. Source test data, North Carolina Department of Natural Resources and Community Development, Raleigh, NC, June 1981.

29. Nonfossil Fueled Boilers - Emission Test Report: Weyerhaeuser Company, Longview, Washington, EPA-80-WFB-10, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1981.

30. A Study of Wood Residue Fired Power Boiler Total Gaseous Nonmethane Organic Emissions in the Pacific Northwest, Technical Bulletin No. 109, National Council of the Paper Industry for Air and Steam Improvement, New York, NY, September 1980.

31. Inhalable Particulate Source Category Report for External Combustion Sources, EPA Contract No. 68-02-3156, Acurex Corporation, Mountain View, CA, January 1985.

1.7 LIGNITE COMBUSTION

1.7.1 General[1-4]

Lignite is a relatively young coal with properties intermediate to those of bituminous coal and peat. It has a high moisture content (35 to 40 weight percent) and a low wet basis heating value (1500 to 1900 kilocalories) and generally is burned only near where it is mined, in some midwestern states and Texas. Although a small amount is used in industrial and domestic situations, lignite is used mainly for steam/electric production in power plants. In the past, lignite has been burned mainly in small stokers, but today the trend is toward use in much larger pulverized coal fired or cyclone fired boilers.

The major advantages of firing lignite are that, in certain geographical areas, it is plentiful, relatively low in cost and low in sulfur content (0.4 to 1 wet basis weight percent). Disadvantages are that more fuel and larger facilities are necessary to generate a unit of power than is the case with bituminous coal. The several reasons for this are (1) the higher moisture content means that more energy is lost in the gaseous products of combustion, which reduces boiler efficiency; (2) more energy is required to grind lignite to combustion specified size, especially in pulverized coal fired units; (3) greater tube spacing and additional soot blowing are required because of the higher ash fouling tendencies; and (4) because of its lower heating value, more fuel must be handled to produce a given amount of power, since lignite usually is not cleaned or dried before combustion (except for some drying in the crusher or pulverizer and during transfer to the burner). No major problems exist with the handling or combustion of lignite when its unique characteristics are taken into account.

1.7.2 Emissions And Controls[2-11]

The major pollutants from firing lignite, as with any coal, are particulate, sulfur oxides, and nitrogen oxides. Volatile organic compounds (VOC) and carbon monoxide emissions are quite low under normal operating conditions.

Particulate emission levels appear most dependent on the firing configuration in the boiler. Pulverized coal fired units and spreader stokers, which fire much or all of the lignite in suspension, emit the greatest quantity of flyash per unit of fuel burned. Cyclone furnaces, which collect much of the ash as molten slag in the furnace itself, and stokers (other than spreader), which retain a large fraction of the ash in the fuel bed, both emit less particulate matter. In general, the relatively high sodium content of lignite lowers particulate emissions by causing more of the resulting flyash to deposit on the boiler tubes. This is especially so in pulverized coal fired units wherein a high fraction of the ash is suspended in the combustion gases and can readily come into contact with the boiler surfaces.

Nitrogen oxide emissions are mainly a function of the boiler firing configuration and excess air. Stokers produce the lowest NO_x levels, mainly

TABLE 1.7-1. EMISSION FACTORS FOR EXTERNAL COMBUSTION OF LIGNITE COAL[a]

Firing configuration	Particulate[b]		Sulfur oxides[c]		Nitrogen oxides[d]		Carbon monoxide	Volatile organics	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton		Nonmethane	Methane
Pulverized coal fired dry bottom	3.1A	6.3A	15S	30S	6[e,f]	12[e,f]	g	g	g
Cyclone furnace	3.3A	6.7A	15S	30S	8.5	17	g	g	g
Spreader stoker	3.4A	6.8A	15S	30S	3	6	g	g	g
Other stoker	1.5A	2.9A	15S	30S	3	6	g	g	g

[a] For lignite consumption as fired.

[b] References 5-6, 9, 12. A = wet basis % ash content of lignite.

[c] References 2, 5-6, 10-11. S = wet basis weight % sulfur content of lignite. For high sodium/ash lignite (Na_2O >8%), use 8.5S kg/Mg (17S lb/ton); for low sodium/ash lignite (Na_2O <2%), use 17.5S kg/Mg (35S lb/ton). If unknown, use 15S kg/Mg (30S lb/ton). The conversion of SO_2 is shown to be a function of alkali ash constituents.

[d] References 2, 5, 7-8. Expressed as NO_2.

[e] Use 7 kg/Mg (14 lb/ton) for front wall fired and horizontally opposed wall fired units, and 4 kg/Mg (8 lb/ton) for tangentially fired units.

[f] May be reduced 20 - 40% with low excess firing and/or staged combustion in front fired and opposed wall fired units and cyclones.

[g] Factors in Table 1.1-1 may be used, based on combustion similarity of lignite and bituminous coal.

because most existing units are relatively small and have lower peak flame temperatures. In most boilers, regardless of firing configuration, lower excess combustion air means lower NO_x emissions.

Sulfur oxide emissions are a function of the alkali (especially sodium) content of the lignite ash. Unlike most fossil fuel combustion, in which over 90 percent of the fuel sulfur is emitted as SO_2, a significant fraction of the sulfur in lignite reacts with the ash components during combustion and is retained in the boiler ash deposits and fly ash. Tests have shown that less than 50 percent of the available sulfur may be emitted as SO_2 when a high sodium lignite is burned, whereas more than 90 percent may be emitted from low sodium lignite. As a rough average, about 75 percent of the fuel sulfur will be emitted as SO_2, the remainder being converted to various sulfate salts.

Newer lignite fired utility boilers are equipped with large electrostatic precipitators with as high as 99.5 percent particulate control. Older and smaller electrostatic precipitators operate at about 95 percent efficiency. Older industrial and commercial units use cyclone collectors that normally achieve 60 to 80 percent collection efficiency on lignite flyash. Flue gas desulfurization systems identical to those on bituminous coal fired boilers are in current operation on several lignite fired utility boilers. (See Section 1.1).

Nitrogen oxide reductions of up to 40 percent can be achieved by changing the burner geometry, controlling excess air and making other changes in operating procedures. The techniques for bituminous and lignite coal are identical.

TABLE 1.7-2. EMISSION FACTOR RATINGS FOR LIGNITE COMBUSTION

Firing configuration	Particulate	Sulfur dioxide	Nitrogen oxides
Pulverized coal fired dry bottom	A	A	A
Cyclone furnace	C	A	A
Spreader stoker	B	B	C
Other stokers	B	C	D

TABLE 1.7-3. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR BOILERS BURNING PULVERIZED LIGNITE COAL[a]

EMISSION FACTOR RATING: E

Particle size[b] (μm)	Cumulative mass % ≤ stated size		Cumulative emission factor[c] [kg/Mg (lb/ton) coal, as fired]	
	Uncontrolled	Multiple cyclone controlled	Uncontrolled	Multiple cyclone controlled[d]
15	51	77	1.58A (3.16A)	0.477A (0.954A)
10	35	67	1.09A (2.18A)	0.415A (0.830A)
6	26	57	0.81A (1.62A)	0.353A (0.706A)
2.5	10	27	0.31A (0.62A)	0.167A (0.334A)
1.25	7	16	0.22A (0.44A)	0.099A (0.198A)
1.00	6	14	0.19A (0.38A)	0.087A (0.174A)
0.625	3	8	0.09A (0.18A)	0.050A (0.100A)
TOTAL	100	100	3.1A (6.2A)	0.62A (1.24A)

[a] Reference 13.
[b] Expressed as aerodynamic equivalent diameter.
[c] A = coal ash weight % content, as fired.
[d] Estimated control efficiency for multiple cyclone, 80%.

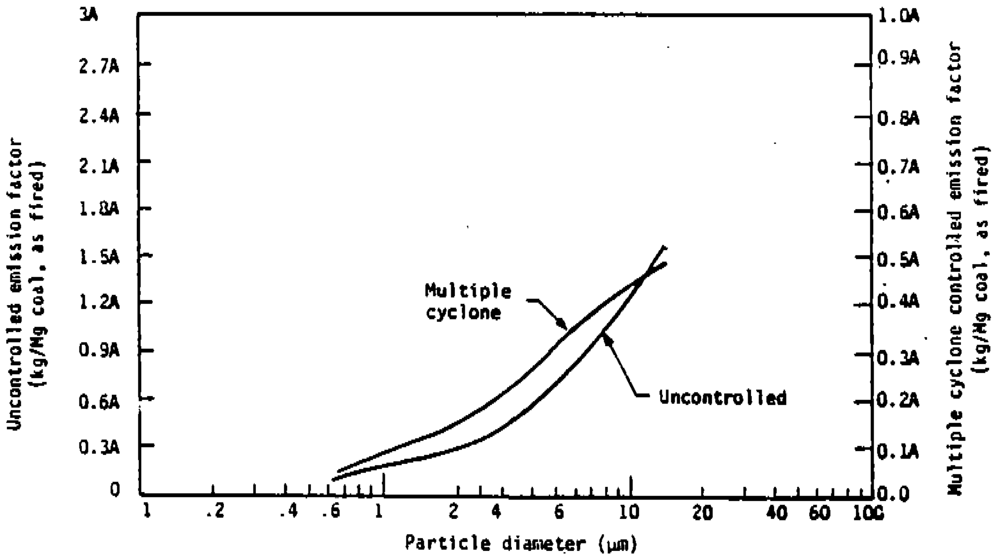

Figure 1.7-1. Cumulative size specific emission factors for boilers burning pulverized lignite coal.

TABLE 1.7-4 CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR LIGNITE FUELED SPREADER STOKERS[a]

EMISSION FACTOR RATING: E

Particle size[b] (μm)	Cumulative mass % ≤ stated size		Cumulative emission factor[c] [kg/Mg (lb/ton) coal, as fired]	
	Uncontrolled	Multiple cyclone controlled	Uncontrolled	Multiple cyclone controlled[d]
15	28	55	0.95A (1.9A)	0.374A (0.748A)
10	20	41	0.68A (1.36A)	0.279A (0.558A)
6	14	31	0.48A (0.96A)	0.211A (0.422A)
2.5	7	26	0.24A (0.48A)	0.177A (0.354A)
1.25	5	23	0.17A (0.34A)	0.156A (0.312A)
1.00	5	22	0.17A (0.34A)	0.150A (0.300A)
0.625	4	e	0.14A (0.28A)	e
TOTAL	100	100	3.4A (6.8A)	0.68A (1.36A)

[a] Reference 13.

[b] Expressed as aerodynamic equivalent diameter.

[c] Coal ash weight % content, as fired.

[d] Estimated control efficiency for multiple cyclone, 80%.

[e] Insufficient data.

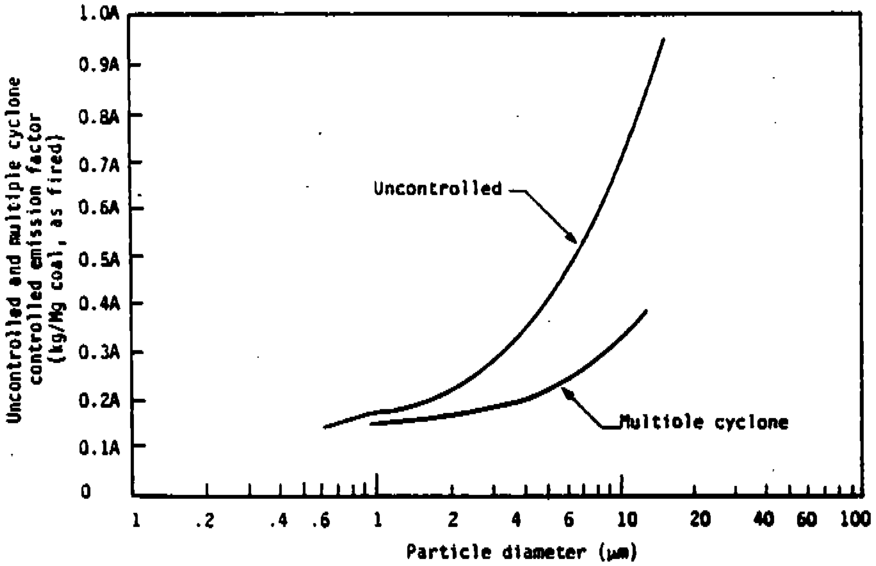

Figure 1.7-2. Cumulative size specific emission factors for lignite fueled spreader stokers.

Emission factors for particulate, sulfur dioxide and nitrogen oxides are presented in Table 1.7-1, and emission factor ratings in Table 1.7-2. Specific emission factors for particulate emissions, and emission factor ratings for the cumulative particle size distributions, are given in Tables 1.7-3 and 11.7-4. Uncontrolled and controlled size specific emission factors are presented in Figures 1.7-1 and 1.7-2. Based on the similarity of lignite combustion and bituminous coal combustion, emission factors for carbon monoxide and volatile organic compounds (Table 1.1-1), and cumulative particle size distributions for cyclone furnaces, uncontrolled spreader stokers and other stokers (Tables 1.1-5 through 1.1-8) may be used.

References for Section 1.7

1. Kirk-Othmer Encyclopedia of Chemical Technology, Second Edition, Volume 12, John Wiley and Sons, New York, NY, 1967.

2. G. H. Gronhovd, et al., "Some Studies on Stack Emissions from Lignite Fired Powerplants", Presented at the 1973 Lignite Symposium, Grand Forks, NB, May 1973.

3. Standards Support and Environmental Impact Statement: Promulgated Standards of Performance for Lignite Fired Steam Generators: Volumes I and II, EPA-450/2-76-030a and 030b, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1976.

4. 1965 Keystone Coal Buyers Manual, McGraw-Hill, Inc., New York, NY, 1965.

5. Source test data on lignite fired power plants, North Dakota State Department of Health, Bismarck, ND, December 1973.

6. G. H. Gronhovd, et al., "Comparison of Ash Fouling Tendencies of High and Low Sodium Lignite from a North Dakota Mine", Proceedings of the American Power Conference, Volume XXVIII, 1966.

7. A. R. Crawford, et al., Field Testing: Application of Combustion Modification To Control NO_x Emissions from Utility Boilers, EPA-650/2-74-066, U. S. Environmental Protection Agency, Washington, DC, June 1974.

8. "Nitrogen Oxides Emission Measurements for Lignite Fired Power Plant", Source Test No. 75-LSG-33, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1974.

9. Coal Fired Power Plant Trace Element Study, A Three Station Comparison, U. S. Environmental Protection Agency, Denver, CO, September 1975.

10. C. Castaldini and M. Angwin, Boiler Design and Operating Variables Affecting Uncontrolled Sulfur Emissions from Pulverized Coal Fired Steam Generators, EPA-450/3-77-047, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1977.

11. C. C. Shih, *et al.*, *Emissions Assessment of Conventional Stationary Combustion Systems, Volume III: External Combustion Sources for Electricity Generation*, EPA Contract No. 68-02-2197, TRW Inc., Redondo Beach, CA, November 1980.

12. Source test data on lignite fired cyclone boilers, North Dakota State Department of Health, Bismarck, ND, March 1982.

13. *Inhalable Particulate Source Category Report for External Combustion Sources*, EPA Contract No. 68-02-3156, Acurex Corporation, Mountain View, CA, January 1985.

3.0 Stationary Internal Combustion Sources

Internal combustion engines included in this source category generally are used in applications similar to those associated with external combustion sources. The major items within this category are gas turbines and large heavy duty general utility reciprocating engines. Most stationary internal combustion engines are used to generate electric power, to pump gas or other fluids, or to compress air for pneumatic machinery.

3.1 Stationary Gas Turbines for Electric Utility Power Plants

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

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

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

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

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

If it is assumed that time spent at off-design conditions includes 15 percent at zero load and 2 percent each at 25 percent, 50 percent, and 75 percent load, then the percentages of operating time at rated load (100 percent) and peak load (assumed to be 125 percent of rated) can be calculated to produce an 86.8 percent load factor. These percentages turn out to be 19 percent at peak load and 60 percent at rated load; the postulated cycle based on this line of reasoning is summarized in Table 3.1-1.

Table 3.1-1. TYPICAL OPERATING CYCLE FOR ELECTRIC UTILITY TURBINES

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

The operating cycle in Table 3.1-1 is used to compute emission factors, although it is only an estimate of actual operating patterns.

Table 3.1-2. COMPOSITE EMISSION FACTORS FOR 1971 POPULATION OF ELECTRIC UTILITY TURBINES EMISSION FACTOR RATING: B

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

[a] Rated load expressed in megawatts.

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

Table 3.1-2 is the resultant composite emission factors based on the operating cycle of Table 3.1-1 and the 1971 population of electric utility turbines.

3.2 Heavy Duty Natural Gas Fired Pipeline Compressor Engines

3.2.1 General[1] – Engines in the natural gas industry are used primarily to power compressors used for pipeline transportation, field gathering (collecting gas from wells), underground storage, and gas processing plant applications. Pipeline engines are concentrated in the major gas producing states (such as those along the Gulf Coast) and along the major gas pipelines. Both reciprocating engines and gas turbines are utilized, but the trend has been toward use of large gas turbines. Gas turbines emit considerably fewer pollutants than do reciprocating engines; however, reciprocating engines are generally more efficient in their use of fuel.

3.2.2 Emissions and Controls[1,2] – The primary pollutant of concern is NO_x, which readily forms in the high temperature, pressure, and excess air environment found in natural gas fired compressor engines. Lesser amounts of carbon monoxide and hydrocarbons are emitted, although for each unit of natural gas burned, compressor engines (particularly reciprocating engines) emit significantly more of these pollutants than do external combustion boilers. Sulfur oxides emissions are proportional to the sulfur content of the fuel and will usually be quite low because of the negligible sulfur content of most pipeline gas.

The major variables affecting NO_x emissions from compressor engines include the air fuel ratio, engine load (defined as the ratio of the operating horsepower divided by the rated horsepower), intake (manifold) air temperature, and absolute humidity. In general, NO_x emissions increase with increasing load and intake air temperature and decrease with increasing absolute humidity and air fuel ratio. (The latter already being, in most compressor engines, on the "lean" side of that air fuel ratio at which maximum NO_x formation occurs.) Quantitative estimates of the effects of these variables are presented in Reference 2.

Because NO_x is the primary pollutant of significance emitted from pipeline compressor engines, control measures to date have been directed mainly at limiting NO_x emissions. For gas turbines, the most effective method of controlling NO_x emissions is the injection of water into the combustion chamber. Nitrogen oxides reductions as high as 80 percent can be achieved by this method. Moreover, water injection results in only nominal reductions in overall turbine efficiency. Steam injection can also be employed, but the resulting NO_x reductions may not be as great as with water injection, and it has the added disadvantage that a supply of steam must be readily available. Exhaust gas recirculation, wherein a portion of the exhaust gases is recirculated back into the intake manifold, may result in NO_x reductions of up to 50 percent. This technique, however, may not be practical in many cases because the recirculated gases must be cooled to prevent engine malfunction. Other combustion modifications, designed to reduce the temperature and/or residence time of the combustion gases, can also be effective in reducing NO_x emissions by 10 to 40 percent in specific gas turbine units.

For reciprocating gas-fired engines, the most effective NO_x control measures are those that change the air-fuel ratio. Thus, changes in engine torque, speed, intake air temperature, etc., that in turn increase the air-fuel ratio, may all result in lower NO_x emissions. Exhaust gas recirculation may also be effective in lowering NO_x emissions although, as with turbines, there are practical limits because of the large quantities of exhaust gas that must be cooled. Available data suggest that other NO_x control measures, including water and steam injection, have only limited application to reciprocating gas fired engines.

Emission factors for natural gas fired pipeline compressor engines are presented in Table 3.2-1.

Table 3.2-1. EMISSION FACTORS FOR HEAVY DUTY NATURAL GAS FIRED PIPELINE COMPRESSOR ENGINES[a]

EMISSION FACTOR RATING: A

	Nitrogen oxides (as NO_2)[b]	Carbon monoxide	Hydrocarbons (as C)[c]	Sulfur dioxide[d]	Particulate[e]
Reciprocating engines					
lb/10^3 hp-hr	24	3.1	9.7	0.004	NA
g/hp-hr	11	1.4	4.4	0.002	NA
g/kW-hr	15	1.9	5.9	0.003	NA
lb/10^6 scf[f]	3,400	430	1,400	0.6	NA
kg/10^6 Nm^3[f]	55,400	7,020	21,800	9.2	NA
Gas turbines					
lb/10^3 hp-hr	2.9	1.1	0.2	0.004	NA
g/hp-hr	1.3	0.5	0.1	0.002	NA
g/kW-hr	1.7	0.7	0.1	0.003	NA
lb/10^6 scf[g]	300	120	23	0.6	NA
kg/10^6 Nm^3[g]	4,700	1,940	280	9.2	NA

[a] All factors based on References 2 and 3.

[b] These factors are for compressor engines operated at rated load. In general, NO_x emissions will increase with increasing load and intake (manifold) air temperature and decrease with increasing air-fuel ratios (excess air rates) and absolute humidity. Quantitative estimates of the effects of these variables are presented in Reference 2.

[c] These factors represent total hydrocarbons. Nonmethane hydrocarbons are estimated to make up to 5 to 10 percent of these totals, on the average.

[d] Based on an assumed sulfur content of pipeline gas of 2000 gr/10^6 scf (4600 g/Nm^3). If pipeline quality natural gas is not fired, a material balance should be performed to determine SO_2 emissions based on the actual sulfur content.

[e] Not available from existing data.

[f] These factors are calculated from the above factors for reciprocating engines assuming a heating value of 1050 Btu/scf (9350 kcal/Nm^3) for natural gas and an average fuel consumption of 7500 Btu/hp-hr (2530 kcal/kW-hr).

[g] These factors are calculated from the above factors for gas turbines assuming a heating value of 1,050 Btu/scf (9,350 kcal/Nm^3) of natural gas and an average fuel consumption of 10,000 Btu/hp-hr (3,380 kcal/kW-hr).

References for Section 3.2

1. Standard Support Document and Environmental Impact Statement - Stationary Reciprocating Internal Combustion Engines. Aerotherm/Acurex Corp., Mountain View, Calif. Prepared for Environmental Protection Agency, Research Triangle Park, N.C. under Contract No. 68-02-1318, Task Order No. 7, November 1974.

2. Urban, C.M. and K.J. Springer. Study of Exhaust Emissions from Natural Gas Pipeline Compressor Engines. Southwest Research Institute, San Antonio, Texas. Prepared for American Gas Association, Arlington, Va. February 1975.

3. Dietzmann, H.E. and K.J. Springer. Exhaust Emissions from Piston and Gas Turbine Engines Used in Natural Gas Transmission. Southwest Research Institute, San Antonio, Texas. Prepared for American Gas Association, Arlington, Va. January 1974.

Different values for time at base and peak loads are obtained by changing the total time at lower loads (0 through 75 percent) or by changing the distribution of time spent at lower loads. The cycle given in Table 3.1-1 seems reasonable, however, considering the fixed load factor and the economies of turbine operation. Note that the cycle determines *only* the importance of each load condition in computing composite emission factors for each type of turbine, *not* overall operating hours.

The top portion of Table 3.1-2 gives separate factors for gas-fired and oil-fired units, and the bottom portion gives fuel-based factors that can be used to estimate emission rates when overall fuel consumption data are available. Fuel-based emission factors on a mode basis would also be useful but present fuel consumption data are not adequate for this purpose.

References for Section 3.1

1. O'Keefe, W. and R. G. Schwieger. Prime Movers. Power. *115*(11): 522-531. November 1971.

2. Hare, C. T. and K. J. Springer. Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines. Final Report. Part 6: Gas Turbine Electric Utility Power Plants. Southwest Research Institute, San Antonio, Tex. Prepared for Environmental Protection Agency, Research Triangle Park, N.C., under Contract No. EHS 70-108, February 1974.

3. Sawyer, V. W. and R. C. Farmer. Gas Turbines in U.S. Electric Utilities. Gas Turbine International. January – April 1973.

3.3 Gasoline and Diesel Industrial Engines

3.3.1 General – This engine category covers a wide variety of industrial applications of both gasoline and diesel internal combustion power plants, such as fork lift trucks, mobile refrigeration units, generators, pumps, and portable well-drilling equipment. The rated power of these engines covers a rather substantial range--from less than 15 kW to 186 kW (20 to 250 hp) for gasoline engines and from 34 kW to 447 kW (45 to 600 hp) for diesel engines. Understandably, substantial differences in both annual usage (hours per year) and engine duty cycles also exist. It was necessary, therefore, to make reasonable assumptions concerning usage in order to formulate emission factors.[1]

3.3.2 Emissions – Once reasonable usage and duty cycles for this category were ascertained, emission values from each of the test engines [1] were aggregated (on the basis of nationwide engine population statistics) to arrive at the factors presented in Table 3.3-1. Because of their aggregate nature, data contained in this table must be applied to a population of industrial engines rather than to an individual power plant.

The best method for calculating emissions is on the basis of "brake specific" emission factors (g/kWh or lb/hphr). Emissions are calculated by taking the product of the brake specific emission factor, the usage in hours (that is, hours per year or hours per day), the power available (rated power), and the load factor (the power actually used divided by the power available).

Table 3.3-1. EMISSION FACTORS FOR GASOLINE AND DIESEL POWERED INDUSTRIAL EQUIPMENT
EMISSION FACTOR RATING: C

Pollutant[a]	Engine category[b]	
	Gasoline	Diesel
Carbon monoxide		
g/hr	5700.	197.
lb/hr	12.6	0.434
g/kWh	267.	4.06
g/hphr	199.	3.03
kg/10^3 liter	472.	12.2
lb/10^3 gal	3940.	102.
Exhaust hydrocarbons		
g/hr	191.	72.8
lb/hr	0.421	0.160
g/kWh	8.95	1.50
g/hphr	6.68	1.12
kg/10^3 liter	15.8	4.49
lb/10^3 gal	132.	37.5
Evaporative hydrocarbons		
g/hr	62.0	–
lb/hr	0.137	–
Crankcase hydrocarbons		
g/hr	38.3	–
lb/hr	0.084	–

Table 3.3-1 (continued). EMISSION FACTORS FOR GASOLINE AND DIESEL POWERED INDUSTRIAL EQUIPMENT
EMISSION FACTOR RATING: C

Pollutant[a]	Engine category[b]	
	Gasoline	Diesel
Nitrogen oxides		
g/hr	148.	910.
lb/hr	0.326	2.01
g/kWh	6.92	18.8
g/hphr	5.16	14.0
kg/10^3 liter	12.2	56.2
lb/10^3 gal	102.	469.
Aldehydes		
g/hr	6.33	13.7
lb/hr	0.014	0.030
g/kWh	0.30	0.28
g/hphr	0.22	0.21
kg/10^3 liter	0.522	0.84
lb/10^3 gal	4.36	7.04
Sulfur oxides		
g/hr	7.67	60.5
lb/hr	0.017	0.133
g/kWh	0.359	1.25
g/hphr	0.268	0.931
kg/10^3 liter	0.636	3.74
lb/10^3 gal	5.31	31.2
Particulate		
g/hr	9.33	65.0
lb/hr	0.021	0.143
g/kWh	0.439	1.34
g/hphr	0.327	1.00
kg/10^3 liter	0.775	4.01
lb/10^3 gal	6.47	33.5

[a] References 1 and 2.

[b] As discussed in the text, the engines used to determine the results in this table cover a wide range of uses and power. The listed values do not, however, necessarily apply to some very large stationary diesel engines.

References for Section 3.3

1. Hare, C. T. and K. J. Springer. Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines. Final Report. Part 5: Heavy-Duty Farm, Construction, and Industrial Engines. Southwest Research Institute. San Antonio, Texas. Prepared for Environmental Protection Agency, Research Triangle Park, N.C., under Contract No. EHS 70-108. October 1973. 105 p.

2. Hare, C. T. Letter to C. C. Masser of the Environmental Protection Agency concerning fuel-based emission rates for farm, construction, and industrial engines. San Antonio, Tex. January 14, 1974.

3.4 STATIONARY LARGE BORE DIESEL AND DUAL FUEL ENGINES

3.4.1 General

The primary domestic use of large bore diesel engines, i.e., those greater than 560 cubic inch displacement per cylinder (CID/CYL), is in oil and gas exploration and production. These engines, in groups of three to five, supply mechanical power to operate drilling (rotary table), mud pumping and hoisting equipment, and may also operate pumps or auxiliary power generators. Another frequent application of large bore diesels is electricity generation for both base and standby service. Smaller uses include irrigation, hoisting and nuclear power plant emergency cooling water pump operation.

Dual fuel engines were developed to obtain compression ignition performance and the economy of natural gas, using a minimum of 5 to 6 percent diesel fuel to ignite the natural gas. Dual fuel large bore engines (greater than 560 CID/CYL) have been used almost exclusively for prime electric power generation.

3.4.2 Emissions and Controls

The primary pollutant of concern from large bore diesel and dual fuel engines is NO_x, which readily forms in the high temperature, pressure and excess air environment found in these engines. Lesser amounts of carbon monoxide and hydrocarbons are also emitted. Sulfur dioxide emissions will usually be quite low because of the negligible sulfur content of diesel fuels and natural gas.

The major variables affecting NO_x emissions from diesel engines are injection timing, manifold air temperature, engine speed, engine load and ambient humidity. In general, NO_x emissions decrease with increasing humidity.

Because NO_x is the primary pollutant from diesel and dual fuel engines, control measures to date have been directed mainly at limiting NO_x emissions. The most effective NO_x control technique for diesel engines is fuel injection retard, achieving reductions (at eight degrees of retard) of up to 40 percent. Additional NO_x reductions are possible with combined retard and air/fuel ratio change. Both retarded fuel injection (8°) and air/fuel ratio change of five percent are also effective in reducing NO_x emissions from dual fuel engines, achieving nominal NO_x reductions of about 40 percent and maximum NO_x reductions of up to 70 percent.

Other NO_x control techniques exist but are not considered feasible because of excessive fuel penalties, capital cost, or maintenance or operational problems. These techniques include exhaust gas recirculation (EGR), combustion chamber modification, water injection and catalytic reduction.

TABLE 3.4-1. EMISSION FACTORS FOR STATIONARY LARGE BORE DIESEL AND DUAL FUEL ENGINES[a]

EMISSION FACTOR RATING: C

Engine type	Particulate[b]	Nitrogen oxides[c]	Carbon monoxide	VOC[d] Methane	VOC[d] Nonmethane	Sulfur dioxide[e]
Diesel						
$lb/10^3$ hph	2.4	24	6.4	0.07	0.63	2.8
g/hph	1.1	11	2.9	0.03	0.29	1.3
g/kWh	1.5	15	3.9	0.04	0.4	1.7
$lb/10^3$ gal[f]	50	500	130	1	13	60
g/l	6	60	16	0.2	1.6	7.2
Dual fuel						
$lb/10^3$ hph	NA	18	5.9	4.7	1.5	0.70
g/hph	NA	8	2.7	2.1	0.7	0.32
g/kWh	NA	11	3.6	2.9	0.9	0.43

[a] Representative uncontrolled levels for each fuel, determined by weighting data from several manufacturers. Weighting based on % of total horsepower sold by each manufacturer during a five year period. NA = not available.

[b] Emission Factor Rating: E. Approximation based on test of a medium bore diesel. Emissions are minimum expected for engine operating at 50 - 100% full rated load. At 0% load, emissions would increase to 30 g/l. Reference 2.

[c] Measured as NO_2. Factors are for engines operated at rated load and speed.

[d] Nonmethane VOC is 90% of total VOC from diesel engines but only 25% of total VOC emissions from dual fuel engines. Individual chemical species within the nonmethane fraction are not identified. Molecular weight of nonmethane gas stream is assumed to be that of methane.

[e] Based on assumed sulfur content of 0.4 weight % for diesel fuel and 0.46 g/scm (0.20 gr/scf) for pipeline quality natural gas. Dual fuel SO_2 emissions based on 5% oil/95% gas mix. Emissions should be adjusted for other fuel ratios.

[f] These factors calculated from the above factors, assuming heating values of 40 MJ/l (145,000 Btu/gal) for oil and 41 MJ/scm (1100 Btu/scf) for natural gas, and an average fuel consumption of 9.9 MJ/kWh (7000 Btu/hph).

References for Section 3.4

1. Standards Support And Environmental Impact Statement, Volume I: Stationary Internal Combustion Engines, EPA-450/2-78-125a, U. S. Environmental Protection Agency, Research Triangle Park, NC, July 1979.

2. Telephone communication between William H. Lamason, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, and John H. Wasser, Office Of Research And Development, U. S. Environmental Protection Agency, Research Triangle Park, NC, July 15, 1983.

not more than 540°C (1000°F) to prevent warping of the drum. Emissions are vented to an afterburner or secondary combustion chamber, where the gases are raised to at least 760°C (1400°F) for a minimum of 0.5 seconds. The average amount of material removed from each drum is 2 kilograms (4.4 pounds).

TABLE 4.8-2. EMISSION FACTORS FOR TANK TRUCK CLEANING[a]

EMISSION FACTOR RATING: D

Compound	Chemical class		Total emissions	
	Vapor pressure	Viscosity	g/truck	lb/truck
Acetone	high	low	311	0.686
Perchloroethylene	high	low	215	0.474
Methyl methacrylate	medium	medium	32.4	0.071
Phenol	low	low	5.5	0.012
Propylene glycol	low	high	1.07	0.002

[a] Reference 1. One hour test duration.

4.8.2 Emissions And Controls

4.8.2.1 Rail Tank Cars And Tank Trucks - Atmospheric emissions from tank car and truck cleaning are predominantly volatile organic chemical vapors. To achieve a practical but representative picture of these emissions, the organic chemicals hauled by the carriers must be known by classes of high, medium and low viscosities and of high, medium and low vapor pressures. High viscosity materials do not drain readily, affecting the quantity of material remaining in the tank, and high vapor pressure materials volatilize more readily during cleaning and tend to lead to greater emissions.

Practical and economically feasible controls of atmospheric emissions from tank car and truck cleaning do not exist, except for containers transporting commodities that produce combustible gases and water soluble vapors (such as ammonia and chlorine). Gases displaced as tanks are filled are sent to a flare and burned. Water soluble vapors are absorbed in water and are sent to the wastewater system. Any other emissions are vented to the atmosphere.

Tables 4.8-1 and 4.8-2 give emission factors for representative organic chemicals hauled by tank cars and trucks.

4.8.2.2 Drums - There is no control for emissions from steaming of drums. Solution or caustic washing yields negligible air emissions, because the drum is closed during the wash cycle. Atmospheric emissions from steaming or washing drums are predominantly organic chemical vapors.

Air emissions from drum burning furnaces are controlled by proper operation of the afterburner or secondary combustion chamber, where gases are raised to at least 760°C (1400°F) for a minimum of 0.5 seconds. This normally ensures complete combustion of organic materials and prevents the formation, and subsequent release, of large quantities of NO_x, CO and particulate. In open burning, however, there is no feasible way of controlling the release of incomplete combustion products to the atmosphere. The conversion of open cleaning operations to closed cycle cleaning and the elimination of open air drum burning seem to be the only control alternatives immediately available.

Table 4.8-3 gives emission factors for representative criteria pollutants emitted from drum burning and cleaning.

TABLE 4.8-3. EMISSION FACTORS FOR DRUM BURNING[a]

EMISSION FACTOR RATING: E

Pollutant	Total emissions			
	Controlled		Uncontrolled	
	g/drum	lb/drum	g/drum	lb/drum
Particulate	12[b]	0.02646	16	0.035
NO_x	0.018	0.00004	0.89	0.002
VOC	negligible		negligible	

[a] Reference 1. Factors are for weight of pollutant released/drum burned, except for VOC, which are per drum washed.

[b] Reference 1, Table 17 and Appendix A.

Reference for Section 4.8

1. T. R. Blackwood, *et al.*, *Source Assessment: Rail Tank Car, Tank Truck, and Drum Cleaning, State of the Art*, EPA-600/2-78-004g, U. S. Environmental Protection Agency, Cincinnati, OH, April 1978.

5.16 SODIUM CARBONATE

5.16.1 General[1,2]

Processes to produce sodium carbonate (Na_2CO_3), or soda ash, are classified as either natural or synthetic. Natural processes recover sodium carbonate from natural deposits of trona ore (primarily sodium sesquicarbonate, $Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$), or from brine that contains sodium sesquicarbonate and sodium carbonate. The synthetic (Solvay) process produces sodium carbonate by reacting ammoniated sodium chloride with carbon dioxide. For about a century, almost all sodium carbonate production was by the Solvay process. However, since the mid-1960s, Solvay process production has declined substantially, having been replaced by natural production. Only one plant in the U. S. now uses the Solvay process. Available data on emissions from the Solvay process are also presented, but because the natural processes are more prevalent in this country, this Section addresses emissions from these processes.

Three different natural processes are currently in use, sesquicarbonate, monohydrate, and direct carbonation. The sesquicarbonate process, the first of the natural processes, is used at only one plant and is not expected to be the process at future plants. Since data on uncontrolled emissions from the sesquicarbonate process are not available, it is not discussed here. Monohydrate and direct carbonation processes and emissions are described here. These processes differ only in raw materials processing.

In the monohydrate process, sodium carbonate is produced from trona ore, which consists of 86 to 95 percent sodium sesquicarbonate, 5 to 12 percent gangues (clays and other insoluble impurities) and water. The mined trona ore is crushed, screened and calcined to drive off carbon dioxide and water, forming crude sodium carbonate. Most calciners are rotary gas fired, but the newest plants use coal fired calciners. Future plants are also likely to have coal fired calciners for economic reasons.

The crude sodium carbonate is dissolved and separated from the insoluble impurities. Sodium carbonate monohydrate ($Na_2CO_3 \cdot H_2O$) is crystallized from the purified liquid by means of multiple effect evaporators, then dried to remove the free and bound water, producing the final product. Rotary steam tube, fluid bed steam tube, and rotary gas fired dryers are used, with steam tube dryers most likely in future plants.

In the direct carbonation process, sodium carbonate is produced from brine containing sodium sesquicarbonate, sodium carbonate, and other salts. The brine is prepared by pumping a dilute aqueous liquor into salt deposits, where the salts are dissolved in the liquor. The recovered brine is carbonated by contact with carbon dioxide which converts all of the sodium carbonate present into sodium bicarbonate. The sodium bicarbonate is then recovered from the brine by crystallization in vacuum crystallizers. The crystal slurry is filtered, and the crystals transferred to steam heated predryers to evaporate some of the moisture. The partially dried sodium bicarbonate goes to a steam heated calciner to drive off carbon dioxide and the remaining water, forming impure sodium carbonate. The carbon dioxide is recycled to the brine carbonators. The sodium carbonate is treated with sodium nitrate in a gas fired rotary bleacher to remove discoloring impurities, then is dissolved and recrystallized. The resulting crystals of sodium carbonate monohydrate are dried as in the monohydrate process.

In the Solvay process, sodium chloride brine, ammonia, calcium carbonate (limestone), and coke are the raw materials. The sodium chloride brine is purified in a series of reactors and clarifiers by precipitating magnesium and calcium ions with soda ash and sodium hydroxide. Sodium bicarbonate ($NaHCO_3$) is formed by carbonating a solution of ammonia in the purified, saturated brine.
Reaction:

$$\underset{\text{brine}}{NaCl} + H_2O + NH_3 + CO_2 \longrightarrow \underset{\substack{\text{sodium}\\\text{bicarbonate}}}{NaHCO_3} + NH_4CL$$

The sodium bicarbonate is virtually insoluble in the resulting solution, crystallizes and is separated from the solution liquor by filtration. The crystals are fed to either steam or gas heated rotary dryers where the bicarbonate is converted (by calcining) to sodium carbonate.

5.16.2 Emissions and Controls

The principal emission points in the monohydrate and direct carbonation processes are shown in Figures 5.16-1 and 5.16-2. The major emission sources in the monohydrate process are calciners and dryers, and the major sources in the direct carbonation process are bleachers, dryers and predryers. Emission factors for these sources are presented in Table 5.16-1, and emission factors for the Solvay process are presented in Table 5.16-2.

In addition to the major emission points, emissions may also arise from crushing and dissolving operations, elevators, conveyor transfer points, product loading and storage piles. Emissions from these sources have not been quantified.

Particulate matter is the only pollutant of concern from sodium carbonate plants. Emissions of sulfur dioxide (SO_2) arise from calciners fired with coal, but reaction of the evolved SO_2 with the sodium carbonate in the calciner keeps SO_2 emissions low. Small amounts of volatile organic compounds (VOC) may also be emitted from calciners, possibly from oil shale associated with the trona ore, but these emissions have not been quantified.

Particulate matter emission rates from calciners, dryers, predryers and bleachers are affected by the gas velocity through the unit and by the particle size distribution of the feed material. The latter affects the emission rate because small particles are more easily entrained in a moving stream of gas than are large particles. Particle size distributions and emission factors for predryers, calciners, bleachers, and dryers in natural process sodium carbonate plants are presented in Table 5.16-3. Gas velocity through the unit affects the degree of turbulence and agitation. As the gas velocity increases, so does the rate of increase in total particulate matter emissions. Thus, coal fired calciners may have higher particulate emission factors than gas fired calciners because of higher gas flow rates. The additional particulate from coal fly ash represents less than one percent of total particulate

Figure 5.16-1. Sodium carbonate production by monohydrate process.

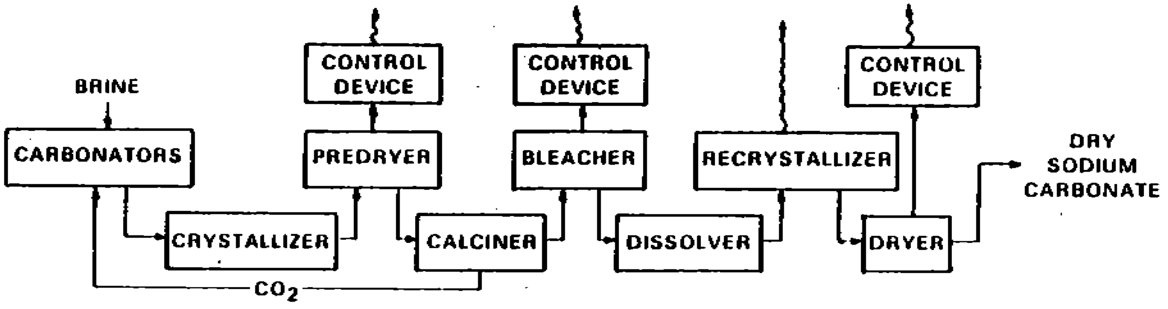

Figure 5.16-2. Sodium carbonate production by direct carbonation process.

TABLE 5.16-1. PARTICULATE EMISSION FACTORS FOR UNCONTROLLED NATURAL PROCESS SODIUM CARBONATE PLANTS[a]

Emission Factor Rating: B

Source	Particulate	
	kg/Mg	lb/ton
Rotary steam heated predryer[b]	1.55	3.1
Gas fired calciner[c]	184.0	368.0
Coal fired calciner[c]	195.0	390.0
Rotary gas fired bleacher[d]	155.0	311.0
Rotary steam tube dryer[e]	33.0	67.0
Fluid bed steam tube dryer[e]	73.0	146.0

[a] References 3-5. Values are averages of 2 - 3 test runs.

[b] Factors are kg/Mg (lb/ton) of dry $NaHCO_3$ feed.

[c] Factors are kg/Mg (lb/ton) of ore fed to calciner and includes particulate emissions from coal fly ash (< 1% of total). SO_2 from coal is roughly 0.007 kg/Mg (0.014 lb/ton) of ore feed.

[d] Factors are kg/Mg (lb/ton) of dry feed to bleacher.

[e] Factors are kg/Mg (lb/ton) of dry product from dryer.

TABLE 5.16-2. EMISSION FACTORS FOR UNCONTROLLED SYNTHETIC SODA ASH (SOLVAY) PLANT[a]

Emission Factor Rating: D

Pollutant	kg/Mg	lb/ton
Ammonia losses[b]	2	4
Particulate[c]	25	50

[a] Reference 6. Factors are kg/Mg (lb/ton) of product.

[b] Calculated by subtracting measured ammonia effluent discharged from ammonia purchased.

[c] Maximum uncontrolled emissions, from New York State process certificates to operate. Does not include emissions from fugitive or external combustion sources.

emissions, and the emission factor for coal fired calciners is about 6 percent higher than that for gas fired calciners. Fluid bed steam tube dryers have higher gas flow rates and particulate emission factors than do rotary steam tube dryers. No data are available on uncontrolled particulate emissions from gas fired dryers, but these dryers also have higher gas flow rates than do rotary steam tube dryers and would probably have higher particulate emissions.

The particulate emission factors presented in Table 5.16-1 represent emissions measured at the inlet to the control devices. Even in the absence of air pollution regulations, these emissions usually are controlled to some degree to prevent excessive loss of product. Particulate emissions from calciners and bleachers are most commonly controlled by cyclones in series with electrostatic precipitators (ESPs). Venturi scrubbers are also used, but with less efficiency. Cyclone/ESP combinations have achieved removal efficiencies from 99.5 to 99.96 percent for new coal fired calciners, and 99.99 percent for bleachers. Comparable efficiencies should be possible for new gas fired calciners. Emissions from dryers and predryers are most commonly controlled with venturi scrubbers because of the high moisture content of the exit gas. Cyclones are used in series with the scrubbers for predryers and fluid bed steam tube dryers. Removal efficiencies averaging 99.88 percent have been achieved for venturi scrubbers on rotary steam tube dryers, at a pressure drop of 6.2 kilopascals (kPa) (25 inches water). Acceptable collection efficiencies may be achieved with lower pressure drops. Efficiencies of 99.9 percent have been achieved for a cyclone/venturi scrubber on a fluid bed steam tube dryer, at a pressure drop of 9.5 kPa (38 inches water). Efficiencies over 98 percent have been achieved for a cyclone/ venturi scrubber on a predryer.

There are significant fugitive emissions from limestone handling and processing operations, product drying operations, and dry solids handling (conveyance and bulk loading) in the manufacture of soda ash by the Solvay process, but these fugitive emissions have not been quantified. Ammonia losses also occur because of leaks at pipe fittings and pump seals, discharges of absorber exhaust, and exposed bicarbonate cake on filter wheels and on feed floor prior to calcining.

PARTICLE SIZE DISTRIBUTIONS AND SIZE SPECIFIC EMISSION FACTORS
FOR
NATURAL PROCESS SODIUM CARBONATE MANUFACTURING

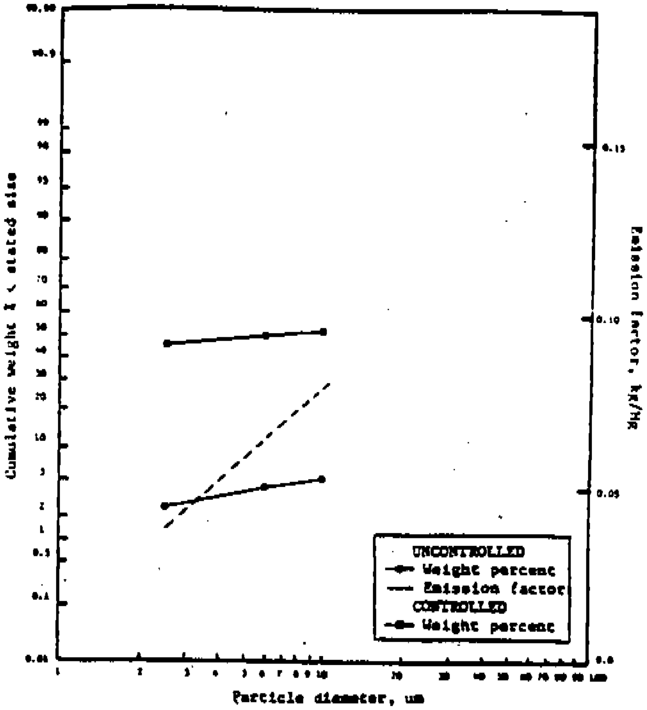

Figure 5.16-3. Predryer.

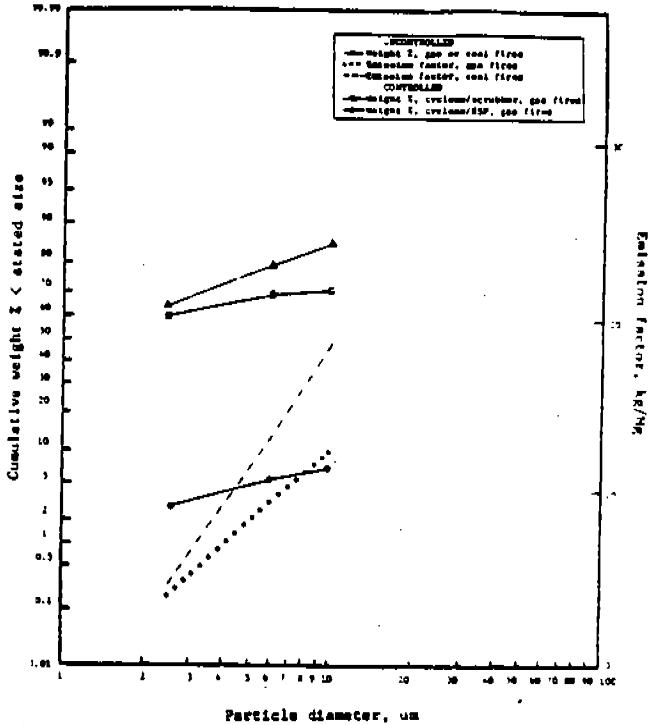

Figure 5.16-4. Calciner.

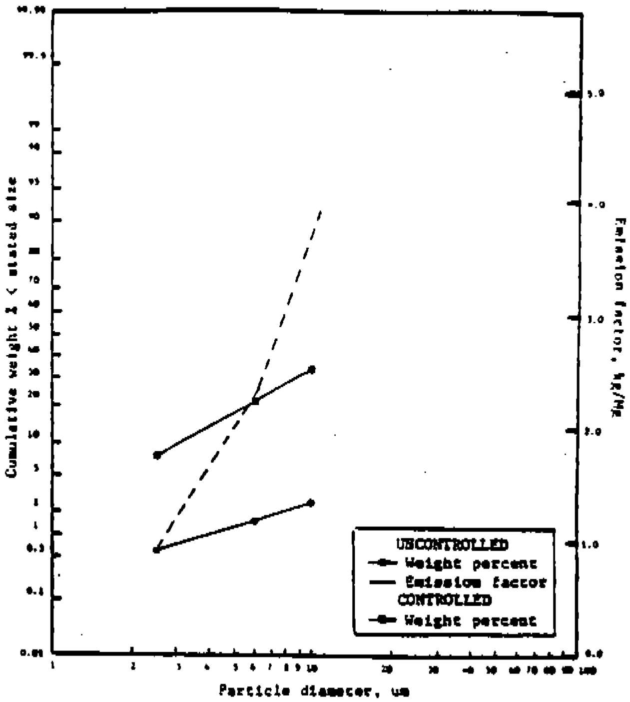

Figure 5.16-5. Bleacher.

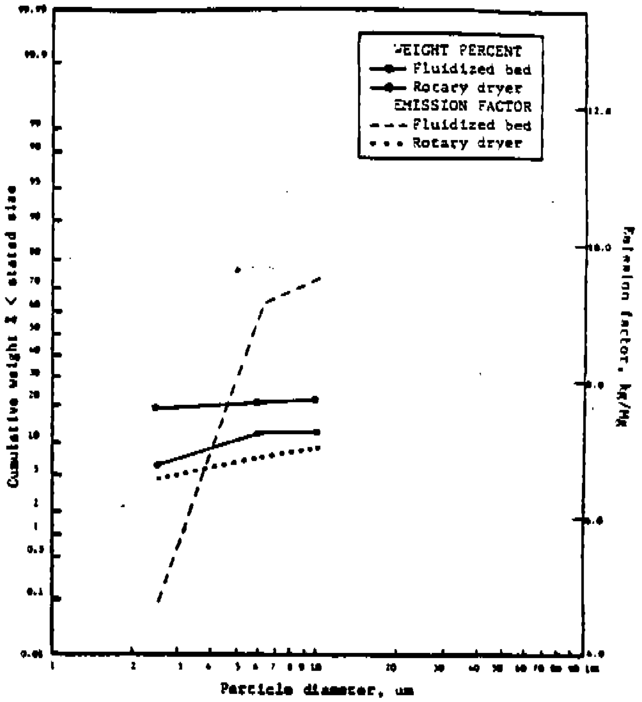

Figure 5.16-6. Dryer.

TABLE 5.16-3. PARTICLE SIZE DISTRIBUTIONS AND EMISSION FACTORS FOR NATURAL PROCESS SODIUM CARBONATE PLANTS[a]

Operation/Particle size[a]	Particle size distribution[b]			Size specific emission factors for corresponding particle size ranges[c,d]			Total particulate emission factor[d,e] kg/Mg	Rating of distribution and size specific emission factor data
	2.5	6.0	10.0	2.5	6.0	10.0		
Rotary predryer[f]								
Uncontrolled	2.8	4.2	5.2	0.04	0.065	0.08	1.55	C
After cyclone/scrubber	46.0	51.0	52.5	-	-	-	-	D
Calciner[g]								
Gas fired, uncontrolled	2.8	5.2	6.7	5.2	9.6	12.3	184	C
Gas fired, after cyclone/ESP	64.5	79.0	86.0	-	-	-	-	E
Gas fired, after cyclone/scrubber	60.0	69.5	71.0	-	-	-	-	E
Coal fired, uncontrolled	2.0	6.5	9.5	3.9	12.7	18.5	195	E
Rotary gas fired bleacher[f]								
Uncontrolled	0.6	1.5	2.5	0.9	2.3	3.9	155	C
After cyclone/ESP	8.0	22.0	35.0	-	-	-	-	D
Product dryer[g]								
Fluid bed steam tube, uncontrolled	6.5	12.5	13.0	4.7	9.1	9.5	73	E
Rotary steam tube, uncontrolled	20.0	20.5	21.0	6.6	6.8	6.9	33	E

[a] Particle size is aerodynamic particle diameter in um.

[b] Cumulative weight % of particles < stated particle size.

[c] Size specific emission factor = total particulate emission factor x particle size distribution, %/100.

[d] For predryers, calciners, and bleachers, emission factors are kg particulate/Mg of feed to process unit. For product dryers, factors are kg particulate/Mg of product. Dash equals no available data.

[e] From Table 5.16-1.

[f] Reference 5.

[g] Reference 3-4.

References for Section 5.16

1. Sodium Carbonate Industry - Background Information for Proposed Standards, EPA-450/3-80-029a, U. S. Environmental Protection Agency, Research Triangle Park, NC, August 1980.

2. Air Pollutant Emission Factors, APTD-0923, Final Report, HEW Contract Number CPA-22-69-119, Resources Research, Inc., Reston, VA, April 1970.

3. Sodium Carbonate Manufacturing Plant, EMB-79-SOD-1, U. S. Environmental Protection Agency, Research Triangle Park, NC, August 1979.

4. Source Test Of A Sodium Carbonate Manufacturing Plant, EMB-79-SOD-2, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1980.

5. Source Test Of Particulate Emissions From The Kerr-McGee Chemical Corporation Sodium Carbonate Plant, EMB-79-SOD-3, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1980.

6. Written communication from W. S. Turetsky, Allied Chemical Company, Morristown, NJ, to Frank M. Noonan, U. S. Environmental Protecton Agency, Research Triangle Park, NC, June 1982.

7.1 PRIMARY ALUMINUM PRODUCTION

7.1.1 Process Description[1-2]

The base ore for primary aluminum production is bauxite, a hydrated oxide of aluminum consisting of 30 to 70 percent alumina (Al_2O_3) and lesser amounts of iron, silicon and titanium. Bauxite ore is purified to alumina by the Bayer process and then is reduced to elemental aluminum. The production of alumina and the reduction of alumina to aluminum are seldom accomplished at the same facility. A schematic diagram of the primary production of aluminum is shown at Figure 7.1-1.

In the Bayer process, the ore is dried, ground in ball mills and mixed with a leaching solution of sodium hydroxide at an elevated temperature and pressure, producing a sodium aluminate solution which is separated from the bauxite impurities and cooled. As the solution cools, hydrated aluminum oxide ($Al_2O_3 \cdot 3H_2O$) precipitates. After separation and washing to remove sodium hydroxide and other impurities, the hydrated aluminum oxide is dried and is calcined to produce a crystalline form of alumina, advantageous for electrolysis.

To produce aluminum metal, the crystalline Al_2O_3 is put through the Hall-Heroult process, an electrolytic reduction of alumina dissolved in a molten salt bath of cryolite (Na_3AlF_6) and various salt additives:

$$\underset{\text{(Alumina)}}{2Al_2O_3} \quad \underset{\text{(Reduction)}}{\xrightarrow{\text{Electrolysis}}} \quad \underset{\text{(Aluminum)}}{4Al} \quad + \quad \underset{\text{(Oxygen)}}{3O_2}$$

The electrolytic reduction occurs in shallow rectangular cells, or "pots", which which are steel shells lined with carbon. Carbon electrodes extending into the pot serve as the anodes and the carbon lining the steel shell is the cathode. Molten cryolite functions as both the electrolyte and the solvent for the alumina. Electrical resistance to the current passing between the electrodes generates heat that maintains cell operating temperatures between 950° and 1000°C (1730° and 1830°F). Aluminum is deposited at the cathode, where it remains as molten metal below the surface of the cryolite bath. The carbon anodes are continuously depleted by the reaction of oxygen (formed during the reaction) and anode carbon, producing carbon monoxide and carbon dioxide. Carbon consumption and other raw material and energy requirements for aluminum production are summarized in Table 7.1-1. The aluminum product is periodically tapped beneath the cryolite cover and fluxed to remove trace impurities.

Three types of aluminum reduction cells are now in use, distinguished by anode type and pot configuration: prebaked (PB), horizontal stud Soderberg (HSS), and vertical stud Soderberg (VSS).

Most of the aluminum produced in the U. S. is processed in PB cells. Anodes are produced as an ancillary operation at a reduction plant. In a paste preparation plant, petroleum coke is mixed with a pitch binder to form a paste which is used both for Soderberg cell anodes and for green anodes used in

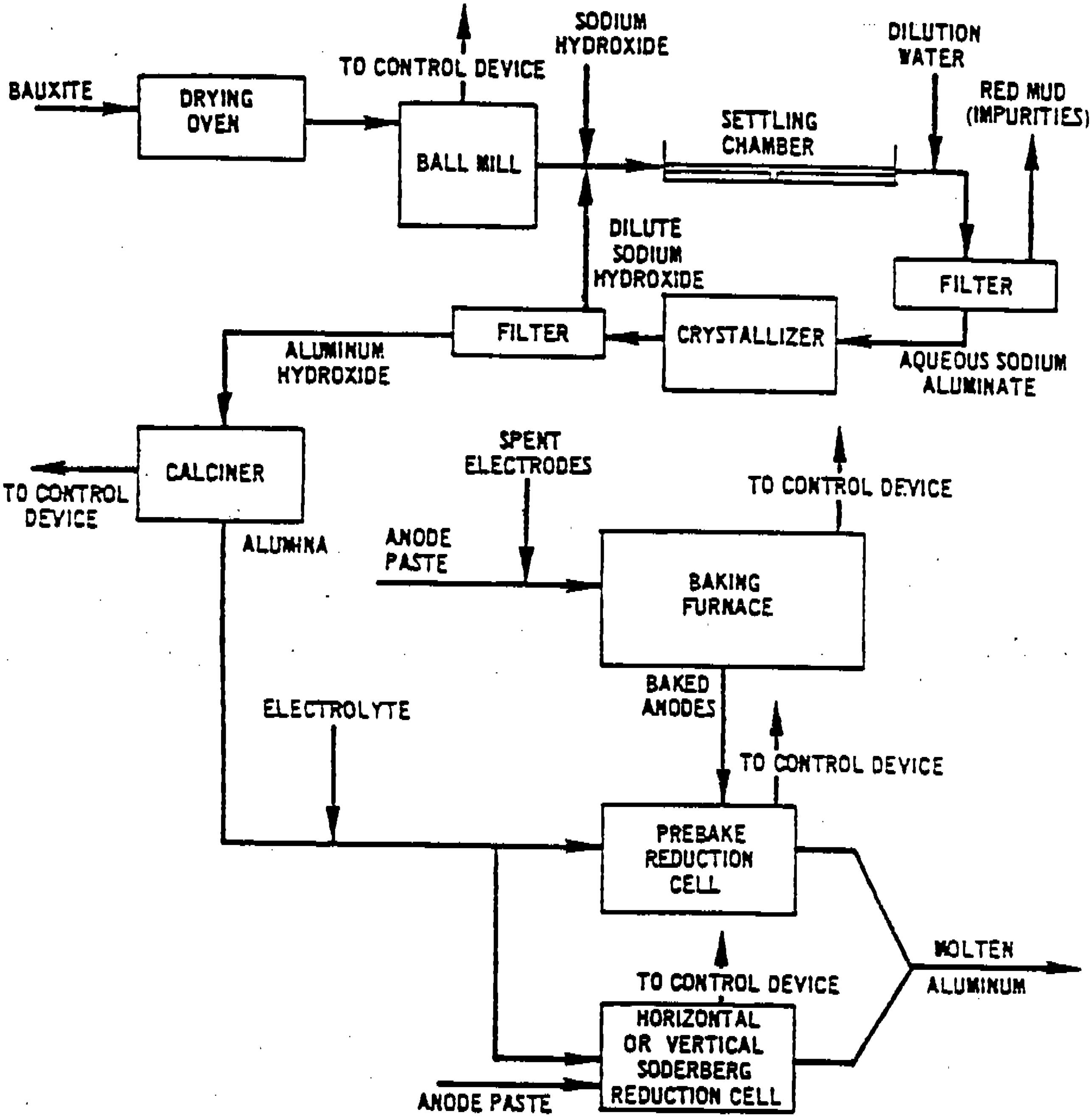

Figure 7.1-1. Schematic diagram of aluminum production process.

prebake cells. Paste preparation includes crushing, grinding and screening of coke and cleaned spent anodes (butts), and blending with a pitch binder in a steam jacketed mixer. For Soderberg anodes, the thick paste mixture is transferred directly to the pot room and added to the anode casings. In prebake anode preparation, the paste mixture is molded to form self supporting green anode blocks. These blocks are baked in a direct fired ring furnace or an indirect fired tunnel kiln. Baked anodes are then transferred to the rodding room for attachment of electrical connections. Volatile organic vapors from the pitch paste are emitted during anode baking, most of which are destroyed in the baking furnace. The baked anodes, typically 14 to 24 per cell, are attached to metal rods and are expended as they are used.

In the electrolytic reduction of alumina, the carbon anodes are lowered into the cell and are consumed at a rate of about 2.5 centimeters (1 inch) per day. PB cells are preferred over Soderberg cells for their lower power requirements, reduced generation of volatile pitch vapors from the carbon anodes, and provision for better cell hooding to capture emissions.

The next most common reduction cell is the horizontal stud Soderberg. This type of cell uses a "continuous" carbon anode. Green anode paste is periodically added at the top of the anode casing of the pot and is baked by the heat of the cell into a solid carbon mass, as the material moves down the casing. The cell casing is of aluminum or steel sheeting, permanent steel skirt and perforated steel channels, through which electrode connections (studs) are inserted horizontally into the anode paste. During reduction, as the baking anode is lowered, the lower row of studs and the bottom channel are removed, and the flexible electrical connectors are moved to a higher row of studs.

TABLE 7.1-1. RAW MATERIAL AND ENERGY REQUIREMENTS FOR ALUMINUM PRODUCTION

Parameter	Typical value
Cell operating temperature	950°C (1740°F)
Current through pot line	60,000 to 280,000 amperes
Voltage drop per cell	4.0 to 5.2
Current efficiency	85 to 95 %
Energy required	13.2 to 18.7 kwh/kg (6.0 to 8.5 kwh/lb) aluminum
Weight alumina consumed	1.89 to 1.92 kg (lb) Al_2O_3/ kg (lb) aluminum
Weight electrolyte fluoride consumed	0.03 to 0.10 kg (lb) fluoride/
Weight carbon electrode consumed	0.45 to 0.55 kg (lb) electrode/ kg (lb) aluminum

High molecular weight organics from the anode paste are released, along with other emissions. The heavy tars can cause plugging of exhaust ducts, fans and emission control equipment.

The vertical stud Soderberg cell is similar to the HSS cell, except that the studs are mounted vertically in the anode paste. Gases from the VSS cells can be ducted to gas burners, and the tars and oils combusted. VSS cell construction prevents the installation of an integral gas collection device, and hooding is restricted to a canopy or skirt at the base of the cell where the hot anode enters the cell bath.

Casting involves pouring molten aluminum into molds and cooling it with water. At some plants before casting, the molten aluminum may be batch treated in furnaces to remove oxide, gaseous impurities and active metals such as sodium and magnesium. One process consists of adding a flux of chloride and fluoride salts and then bubbling chlorine gas, usually mixed with an inert gas, through the molten mixture. Chlorine reacts with the impurities to form HCl, Al_2O_3 and metal chloride emissions. A dross forms to float on the molten aluminum and is removed before casting.[12]

7.1.2 Emissions And Controls[1-8,11]

Controlled and uncontrolled emission factors for total particulate matter, fluoride and sulfur oxides are in Table 7.1-2. Fugitive particulate and fluoride emission factors for reduction cells are also presented in this Table. Tables 7.1-3 through 7.1-5 and Figures 7.1-2 through 7.1-4 give size specific particulate matter emissions for primary aluminum industry processes for which this information is available.

Large amounts of particulate are generated during the calcining of hydrated aluminum oxide, but the economic value of this dust is such that extensive controls are used to reduce emissions to relatively small quantities. Small amounts of particulate are emitted from the bauxite grinding and materials handling processes.

Emissions from aluminum reduction processes are primarily gaseous hydrogen fluoride and particulate fluorides, alumina, carbon monoxide, volatile organics, and sulfur dioxide from the reduction cells; and fluorides, vaporized organics and sulfur dioxide from the anode baking furnaces.

The source of fluoride emissions from reduction cells is the fluoride electrolyte, which contains cryolite, aluminum fluoride (AlF_3) and fluorspar (CaF_2). For normal operation, the weight, or "bath", ratio of sodium fluoride (NaF) to AlF_3 is kept between 1.36 and 1.43 by the addition of AlF3. This increases the cell current efficiency and lowers the bath melting point permitting lower operating temperatures in the cell. All fluoride emissions are also decreased by lowering the operating temperature. The ratio of gaseous (mainly hydrogen fluoride and silicon tetrafluoride) to particulate fluorides varies from 1.2 to 1.7 with PB and HSS cells, but attains a value of approximately 3.0 with VSS cells.

Particulate emissions from reduction cells are alumina and carbon from anode dusting, cryolite, aluminum fluoride, calcium fluoride, chiolite

TABLE 7.1-2. EMISSION FACTORS FOR PRIMARY ALUMINUM PRODUCTION PROCESSES[a,b]

EMISSION FACTOR RATING: A

Operation	Total particulate[c]		Gaseous fluoride		Particulate fluoride		Reference
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	
Bauxite grinding							
Uncontrolled	3.0	6.0	Neg		NA		1,3
Spray tower	0.9	1.8	Neg		NA		1,3
Floating bed scrubber	0.85	1.7	Neg		NA		1,3
Quench tower and spray screen	0.5	1.0	Neg		NA		1,3
Aluminum hydroxide calcining							
Uncontrolled[d]	100.0	200.0	Neg		NA		1,3
Spray tower	30.0	60.0	Neg		NA		1,3
Floating bed scrubber	28.0	56.0	Neg		NA		1,3
Quench tower	17.0	34.0	Neg		NA		1,3
ESP	2.0	4.0	Neg		NA		1,3
Anode baking furnace							
Uncontrolled	1.5	3.0	0.45	0.9	0.05	0.1	2,10-11
Fugitive	NA	NA	NA	NA	NA	NA	
Spray tower	0.375	0.75	0.02	0.04	0.015	0.03	10
ESP	0.375	0.75	0.02	0.04	0.015	0.03	2
Dry alumina scrubber	0.03	0.06	0.0045	0.009	0.001	0.002	2,10
Prebake cell							
Uncontrolled	47.0	94.0	12.0	24.0	10.0	20.0	1-2,10-11
Fugitive	2.5	5.0	0.6	1.2	0.5	1.0	2,10
Emissions to collector	44.5	89.0	11.4	22.8	9.5	19.0	2
Multiple cyclones	9.8	19.6	11.4	22.8	2.1	4.2	2
Dry alumina scrubber	0.9	1.8	0.1	0.2	0.2	0.4	2,10
Dry ESP plus spray tower	2.25	4.5	0.7	1.4	1.7	3.4	2,10
Spray tower	8.9	17.8	0.7	1.4	1.9	3.8	2
Floating bed scrubber	8.9	17.8	0.25	0.5	1.9	3.8	2
Coated bag filter dry scrubber	0.9	1.8	1.7	3.4	0.2	0.4	2
Cross flow packed bed	13.15	26.3	3.25	6.7	2.8	5.6	10
Dry plus secondary scrubber	0.35	0.7	0.2	0.4	0.15	0.3	10
Vertical Soderberg stud cell							
Uncontrolled	39.0	78.0	16.5	33.0	5.5	11.0	2,10
Fugitive	6.0	12.0	2.45	4.9	0.85	1.7	10
Emissions to collector	33.0	66.0	14.05	28.1	4.65	9.3	10
Spray tower	8.25	16.5	0.15	0.3	1.15	2.3	2
Venturi scrubber	1.3	2.6	0.15	0.3	0.2	0.4	2
Multiple cyclones	16.5	33.0	14.05	28.1	2.35	4.7	2
Dry alumina scrubber	0.65	1.3	0.15	0.3	0.1	0.2	2
Scrubber plus ESP plus spray screen and scrubber	3.85	7.7	0.75	1.5	0.65	1.3	2
Horizontal Soderberg stud cell							
Uncontrolled	49.0	98.0	11.0	22.0	6.0	12.0	2,10
Fugitive	5.0	10.0	1.1	2.2	0.6	1.2	2,10
Emissions to collector	44.0	88.0	9.9	19.8	5.4	10.8	2,10
Spray tower	11.0	22.0	3.75	7.5	1.35	2.7	2,10
Floating bed scrubber	9.7	19.4	0.2	0.4	1.2	2.4	2
Scrubber plus wet ESP	0.9	1.8	0.1	0.2	0.1	0.2	2,10
Wet ESP	0.9	1.8	0.5	1.0	0.1	0.2	10
Dry alumina scrubber	0.9	1.8	0.2	0.4	0.1	0.2	10

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[a] For bauxite grinding, expressed as kg/Mg (lb/ton) of bauxite processed. For aluminum hydroxide calcining, expressed as kg/Mg (lb/ton) of alumina produced. All other factors are/Mg (ton) of molten aluminum product. ESP= electrostatic precipitator. NA = not available. Neg = negligible.

[b] Sulfur oxides may be estimated, with an Emission Factor Rating of C, by the following calculations.

Anode baking furnace, uncontrolled SO_2 emissions (excluding furnace fuel combustion emissions):

$$20(C)(S)(1-0.01\ K)\ \text{kg/Mg}\ [40(C)(S)(1-0.01\ K)\ \text{lb/ton}]$$

Prebake (reduction) cell, uncontrolled SO_2 emissions:

$$0.2(C)(S)(K)\ \text{kg/Mg}\ [0.4(C)(S)(K)\ \text{lb/ton}]$$

Where: C = Anode consumption* during electrolysis, lb anode consumed/lb Al produced
S = % sulfur in anode before baking
K = % of total SO_2 emitted by prebake (reduction) cells.

*Anode consumption weight is weight of anode paste (coke + pitch) before baking.

[c] Includes particulate fluorides.

[d] After multicyclone.

TABLE 7.1-3. UNCONTROLLED EMISSION FACTORS AND PARTICLE SIZE DISTRIBUTION FOR ROOF MONITOR FUGITIVE EMISSIONS FROM PREBAKE ALUMINUM CELLS[a]

EMISSION FACTOR RATING: C

Particle size[b] (um)	Cumulative mass % ≤stated size	Cumulative emission factor	
		kg/Mg Al	lb/ton Al
15	65	1.62	3.23
10	58	1.45	2.90
5	43	1.08	2.15
2.5	28	0.70	1.40
1.25	18	0.46	0.92
0.625	13	0.33	0.67
Total	100	2.5	5.0

[a] Reference 4.

[b] Expressed as equivalent aerodynamic particle diameter.

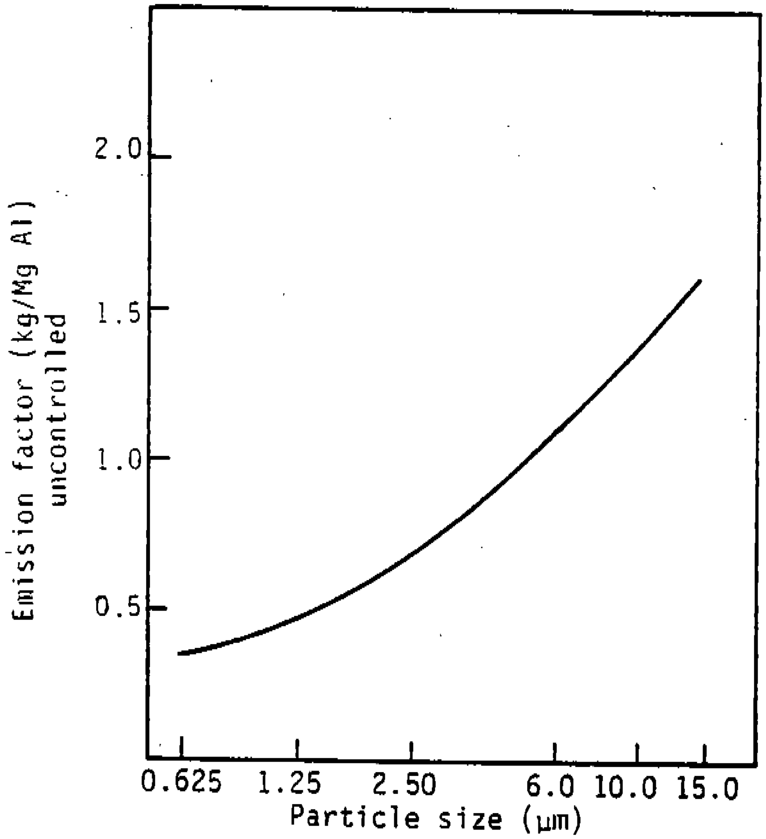


Figure 7.1-2. Emission factors less than stated particle size for fugitive emissions from prebake aluminum cells.

TABLE 7.1-4. UNCONTROLLED EMISSION FACTORS AND PARTICLE SIZE DISTRIBUTION FOR ROOF MONITOR FUGITIVE EMISSIONS FROM HSS ALUMINUM CELLS[a]

EMISSION FACTOR RATING: D

Particle size[b] (um)	Cumulative mass % ≤stated size	Cumulative emission factors	
		kg/Mg Al	lb/ton Al.
15	39	1.95	3.9
10	31	1.55	3.1
5	23	1.15	2.3
2.5	17	0.85	1.7
1.25	13	0.65	1.3
0.625	8	0.40	0.8
Total	100	5.0	10.0

[a] Reference 4.

[b] Expressed as equivalent aerodynamic particle diameter.

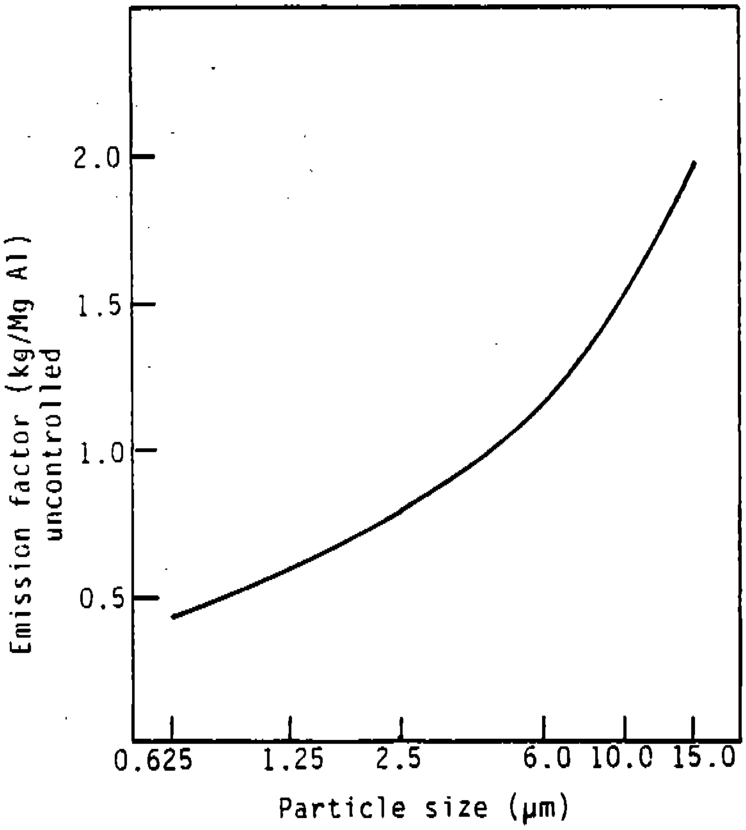


Figure 7.1-3. Emission factors less than stated particle size for fugitive emissions from HSS aluminum cells.

TABLE 7.1-5. UNCONTROLLED EMISSION FACTORS AND PARTICLE SIZE DISTRIBUTION FOR PRIMARY EMISSIONS FROM HSS REDUCTION CELLS[a]

EMISSION FACTOR RATING: D

Particle size[b] (um)	Cumulative mass % ≤stated size	Cumulative emission factors	
		kg/Mg Al	lb/ton Al
15	63	30.9	61.7
10	58	28.4	56.8
5	50	24.5	49.0
2.5	40	19.6	39.2
1.25	32	15.7	31.4
0.625	26	12.7	25.5
Total	100	49.0	98.0

[a] Reference 4.

[b] Expressed as equivalent aerodynamic particle diameter.

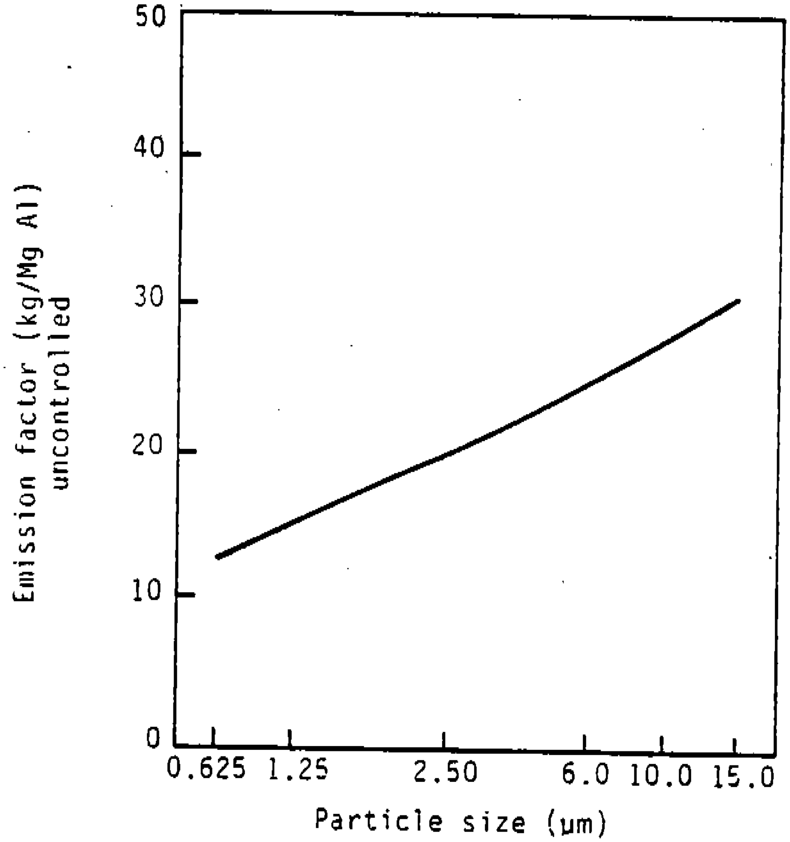


Figure 7.1-4. Cumulative emission factors less than stated particle size for primary emissions from HSS reduction cells.

($Na_5Al_3F_{14}$) and ferric oxide. Representative size distributions for fugitive emissions from PB and HSS plants and for particulate emissions from HSS cells are presented in Tables 7.1-3 through 7.1-5.

Emissions from reduction cells also include hydrocarbons or organics, carbon monoxide and sulfur oxides. Small amounts of hydrocarbons are released by PB pots, and larger amounts are emitted from HSS and VSS pots. In vertical cells, these organics are incinerated in integral gas burners. Sulfur oxides originate from sulfur in the anode coke and pitch, and concentrations of sulfur oxides in VSS cell emissions range from 200 to 300 parts per million. Emissions from PB plants usually have SO_2 concentrations ranging from 20 to 30 parts per million.

Emissions from anode bake ovens include the products of fuel combustion; high boiling organics from the cracking, distillation, and oxidation of paste binder pitch; sulfur dioxide from the sulfur in carbon paste, primarily from the petroleum coke; fluorides from recycled anode butts; and other particulate matter. Concentrations of uncontrolled SO2 emissions from anode baking furnaces range from 5 to 47 parts per million (based on 3 percent sulfur in coke).[9]

A variety of control devices has been used to abate emissions from reduction cells and anode baking furnaces. To control gaseous and particulate fluorides and particulate emissions, one or more types of wet scrubbers (spray tower and chambers, quench towers, floating beds, packed beds, venturis) have been applied to all three types of reduction cells and to anode baking furnaces. Also, particulate control methods such as wet and dry electrostatic precipitators, multiple cyclones and dry alumina scrubbers (fluid bed, injected, and coated filter types) are used with baking furnaces and on all three cell types. Also, the alumina adsorption systems are being used on all three cell types to control both gaseous and particulate fluorides by passing the pot offgases through the entering alumina feed, which adsorbs the fluorides. This technique has an overall control efficiency of 98 to 99 percent. Baghouses are then used to collect residual fluorides entrained in the alumina and recycle them to the reduction cells. Wet ESPs approach adsorption in particulate removal efficiency, but they must be coupled to a wet scrubber or coated baghouse to catch hydrogen fluoride.

Scrubber systems also remove a portion of the SO_2 emissions. These emissions could be reduced by wet scrubbing or by reducing the quantity of sulfur in the anode coke and pitch, i. e., calcining the coke.

In hydrated aluminum oxide calcining, bauxite grinding, and materials handling operations, various dry dust collection devices (centrifugal collectors, multiple cyclones, or ESPs and/or wet scrubbers) have been used.

Potential sources of fugitive particulate emissions in the primary aluminum industry are bauxite grinding, materials handling, anode baking, and three types of reduction cells (see Table 7.1-2). These fugitives probably have particulate size distributions similar to those presented in Table 7.1-3.

References for Section 7.1

1. Engineering and Cost Effectiveness Study of Fluoride Emissions Control, Volume I, APTD-0945, U. S. Environmental Protection Agency, Research Triangle Park, NC, January 1972.
2. Air Pollution Control in the Primary Aluminum Industry, Volume I, EPA-450/3-73-004a, U. S. Environmental Protection Agency, Research Triangle Park, NC, July 1973.
3. Particulate Pollutant System Study, Volume I, APTD-0743, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1971.
4. Inhalable Particulate Source Category Report For The Nonferrous Industry, Contract No. 68-02-3159, Acurex Corporation, Mountain View, CA, October 1985.
5. Emissions from Wet Scrubbing System, Y-7730-E, York Research Corporation, Stamford, CT, May 1972.
6. Emissions From Primary Aluminum Smelting Plant, Y-7730-B, York Research Corporation, Stamford, CT, June 1972.
7. Emissions from the Wet Scrubber System, Y-7730-F, York Research Corporation, Stamford, CT, June 1972.
8. T. R. Hanna and M. J. Pilat, "Size Distribution of Particulates Emitted from a Horizontal Spike Soderberg Aluminum Reduction Cell", Journal of the Air Pollution Control Association, 22:533-536, July 1972.
9. Background Information for Standards of Performance: Primary Aluminum Industry: Volume I, Proposed Standards, EPA-450/2-74-020a, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1974.
10. Primary Aluminum: Guidelines for Control of Fluoride Emissions from Existing Primary Aluminum Plants, EPA-450/2-78-049b, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1979.
11. Written communication from T. F. Albee, Reynolds Aluminum, Richmond, VA, to A. A. McQueen, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 20, 1982.
12. Environmental Assessment: Primary Aluminum, Interim Report, U. S. Environmental Protection Agency, Cincinnati, OH, October 1978.

7.2 COKE MANUFACTURING

7.2.1 Process Description

Metallurgical coke is manufactured by destructive distillation of coal in a byproduct coke oven battery. The distillation, termed "coking", is accomplished in a series of ovens in the absence of oxygen. Volatile compounds are driven from the coal, collected from each oven, and processed in an adjacent plant for recovery of combustible gases and other coal byproducts. Virtually all metallurgical coke is produced by this process, termed the "byproduct" method. Metallurgical coke is used in blast furnaces for production of iron.

Coke is produced in narrow, slot type ovens constructed of silica brick. A coke oven battery may have a series of 10 to 100 individual ovens, with a heating flue between each oven pair. Ovens are charged with pulverized coal, through ports in the oven top, by a larry car traveling on tracks along the top of each battery. After charging, the ports are sealed, and the coking process begins. Combustion of gases in burners in the flues between the ovens provides heat for the process. Coke oven gas from the byproduct recovery plant is the common fuel for underfiring the ovens at most plants, but blast furnace gas and, infrequently, natural gas may also be used.

After a coking time typically between 12 and 20 hours, almost all volatile matter is driven from the coal mass, and the coke is formed. Maximum temperature at the center of the coke mass is usually 1100 to 1150°C (2000 to 2100°F).

After coking, machinery located on tracks on each side of the battery removes the vertical door on each end of an oven, and a long ram pushes the coke from the oven into a rail quench car, whence it goes to a quench tower, where several thousand gallons of water are sprayed onto the coke mass to cool it. The car then discharges the coke onto a wharf along the battery for further cooling and drainage of water. From here, coke is screened and sent to the blast furnace or to storage in outdoor piles.

After the coke is pushed from an oven, the doors are cleaned and repositioned, and the oven is then ready to receive another charge of coal. Figure 7.2-1 is a diagram of a typical byproduct coke process.

During the coking cycle, volatile matter driven from the coal mass is collected by offtakes located at one or both ends of the oven. A common collector main transports the gases from each oven to the byproduct recovery plant. Here, coke oven gas is separated, cleaned and returned to heat the ovens. Only 40 percent of recovered coke oven gas is required for underfiring, and the remainder is used throughout the steel plant. Other coal byproducts also are recovered in the byproduct plant for reuse, sale or disposal.

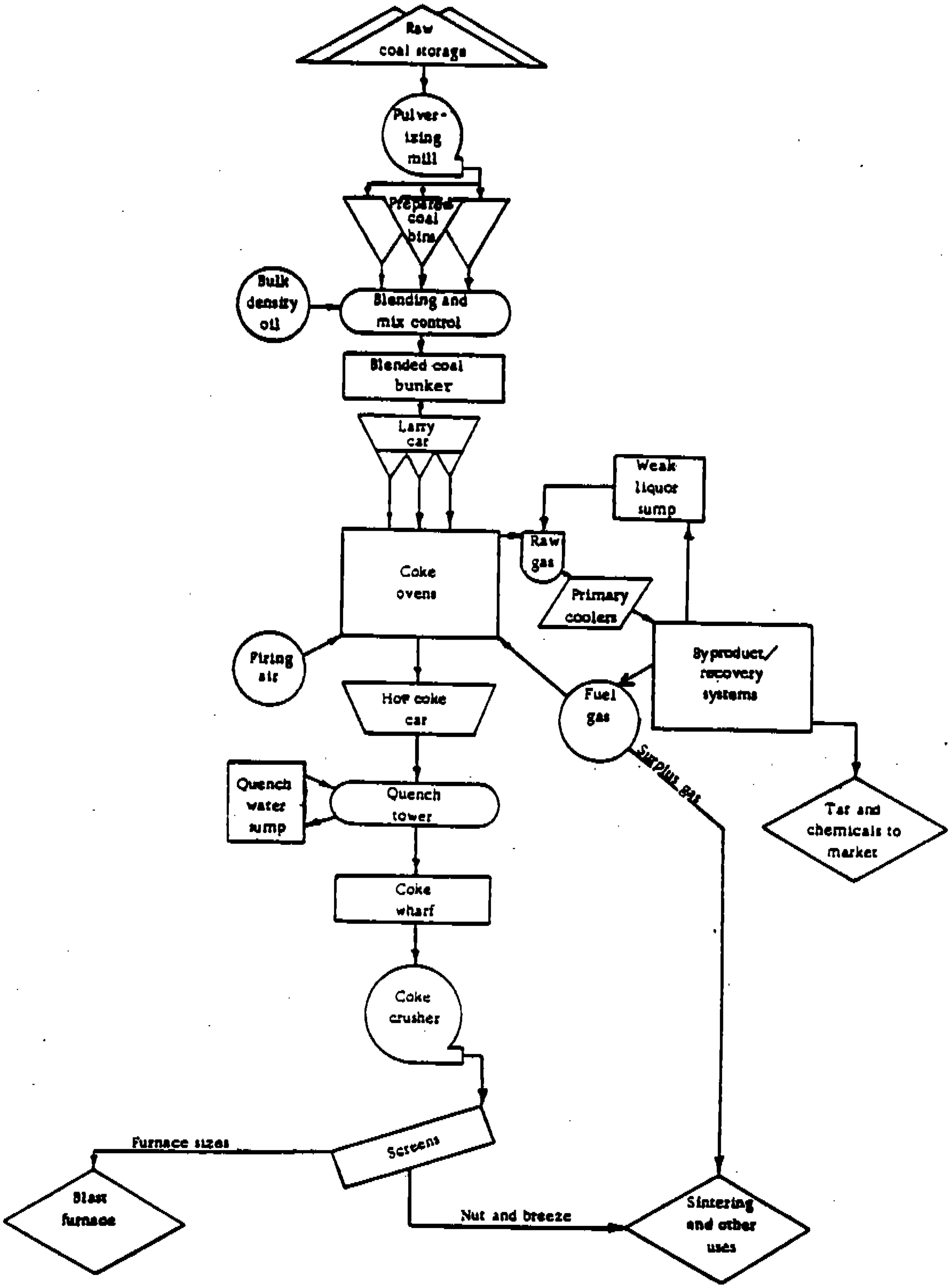


Figure 7.2-1. The major steps in the carbonization of coal with the byproduct process.

7.2.2 Emissions And Controls

Particulate, volatile organic compounds, carbon monoxide and other emissions originate from several byproduct coking operations: (1) coal preparation, (2) coal preheating (if used), (3) charging coal into ovens incandescent with heat, (4) oven leakage during the coking period, (5) pushing the coke out of the ovens, (6) quenching the hot coke and (7) underfire combustion stacks. Gaseous emissions collected from the ovens during the coking process in the byproduct plant 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 volatile organic compound emissions.

Coal preparation consists of pulverizing, screening, blending of several coal types, and adding oil or water for bulk density control. Particulate emissions are sometimes controlled by evacuated or unevacuated enclosures. A few domestic plants heat coal to about 260°C (500°F) before charging, using a flash drying column heated by combustion of coke oven or natural gas. The air steam that conveys the coal through the drying column usually is passed through conventional wet scrubbers for particulate removal before discharge to the atmosphere.

Oven charging can produce emissions of particulate matter and volatile organic compounds from coal decomposition. The stage, or sequential, charging techniques used on virtually all batteries draw most charging emissions into the battery collector main and on to the byproduct plant. During the coking cycle, volatile organic emissions from the thermal distillation process occasionally leak to the atmosphere through poorly sealed doors, charge lids and offtake caps, and through cracks which may develop in oven brickwork, the offtakes and collector mains. Door leaks are controlled by diligent door cleaning and maintenance, rebuilding of doors, and in some plants, by manual application of lute (seal) material. Charge lid and offtake leaks are controlled by an effective patching and luting program.

Pushing coke into the quench car is another major source of particulate emissions, and if the coke mass is not fully coked, also of volatile organic compounds and combustion products. Most batteries use pushing emission controls such as hooded, mobile scrubber cars; shed enclosures evacuated to a gas cleaning device; or traveling hoods with a fixed duct leading to a stationary gas cleaner. The quench tower activity emits particulate from the coke mass, and dissolved solids from the quench water may become entrained in the steam plume rising from the tower. Trace organic compounds also may be present.

The gas combustion in the battery flues produces emissions through the underfire or combustion stack. If coke oven gas is not desulfurized, sulfur oxide emissions accompany the particulate and combustion emissions. If oven wall brickwork is damaged, coal fines and coking decomposition products from a recently charged oven may leak into the waste combustion gases. Figure 7.2-2 portrays major air pollution sources from a typical coke oven battery.

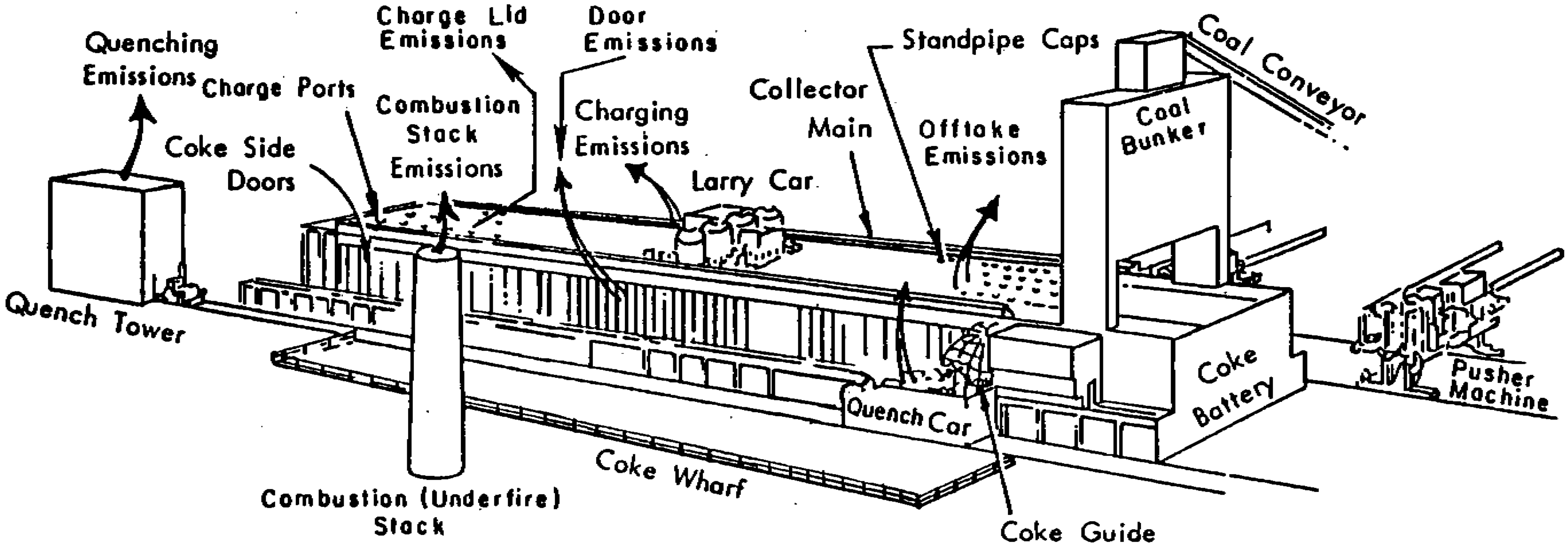


Figure 7.2-2. Byproduct coke oven battery, with major emission points shown.

Associated with the byproduct coke production are open source fugitive dust operations from material handling. These operations consist of unloading, storing grinding and sizing of coal; and screening, crushing, storing and loading of coke. Fugitive emissions may also result from vehicles traveling on paved and unpaved surfaces. The emission factors available for coking operations for total particulate, sulfur dioxide, carbon monoxide, volatile organic compounds, nitrogen oxides and ammonia are given in Table 7.2-1. Table 7.2-2 gives available size specific emission factors. Figures 7.2-3 through 7.2-13 present emission factor data by particle size. Extensive information on the data used to develop the particulate emission factors can be found in Reference 1.

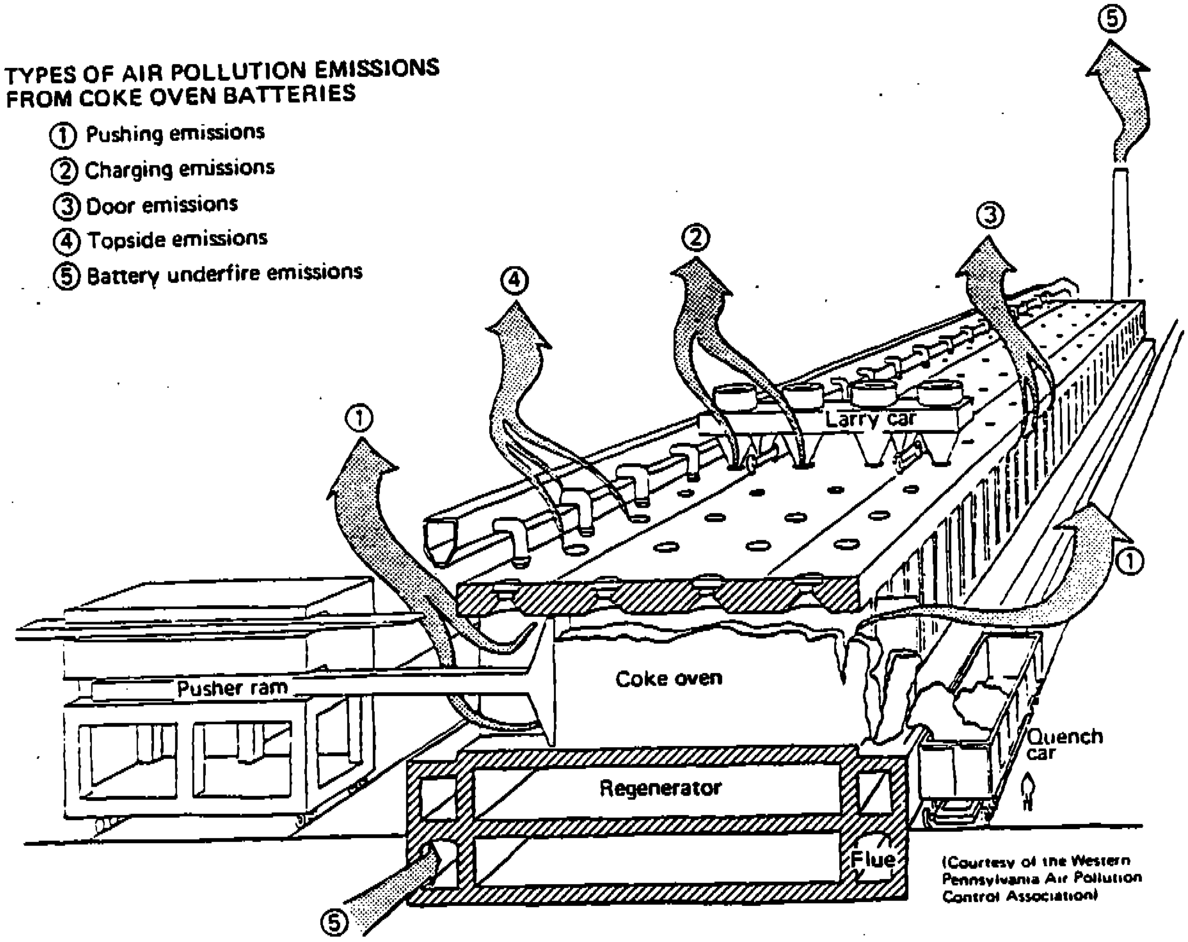


TABLE 7.2-1. EMISSION FACTORS FOR COKE MANUFACTURING[a]

EMISSION FACTOR RATING: D (except Particulate)

Type of operation	Particulate Emission Factor Rating[b]	Particulate[b]		Sulfur dioxide[c]		Carbon monoxide[c]		Volatile organics[c,d]		Nitrogen oxides[c]		Ammonia[c]	
		kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Coal crushing													
with cyclone	D	0.055	0.11	-	-	-	-	-	-	-	-	-	-
Coal preheating													
Uncontrolled[e]	C	1.75	3.50	-	-	-	-	-	-	-	-	-	-
With scrubber	C	0.125	0.25	-	-	-	-	-	-	-	-	-	-
With wet ESP	C	0.006	0.012	-	-	-	-	-	-	-	-	-	-
Wet coal charging[f]													
Larry car													
Uncontrolled	E	0.24	0.48	0.01	0.02	0.3	0.6	1.25	2.5	0.015	0.03	0.01	0.02
With sequential charging	E	0.008	0.016	-	-	-	-	-	-	-	-	-	-
With scrubber	E	0.007	0.014	-	-	-	-	-	-	-	-	-	-
Door leak													
Uncontrolled	D	0.27	0.54	-	-	0.3	0.6	0.75	1.5	0.005	0.01	0.03	0.06
Coke pushing													
Uncontrolled	B	0.58	1.15	-	-	0.035	0.07	0.1	0.2	-	-	0.05	0.1
With ESP[g]	C	0.225	0.45	-	-	-	-	-	-	-	-	-	-
With venturi scrubber[h]	D	0.09	0.18	-	-	-	-	-	-	-	-	-	-
With baghouse[h]	D	0.045	0.09	-	-	-	-	-	-	-	-	-	-
With mobile scrubber car[j]	C	0.036	0.072	-	-	-	-	-	-	-	-	-	-

TABLE 7.2-1 (cont.). EMISSION FACTORS FOR COKE MANUFACTURING[a]

Type of operation	Particulate Emission Factor Rating[b]	Particulate[b]		Sulfur dioxide[c]		Carbon monoxide[c]		Volatile organics[c,d]		Nitrogen oxides[c]		Ammonia[c]	
		kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Quenching													
Uncontrolled													
Dirty water[k]	D	2.62	5.24	-	-	-	-	-	-	-	-	-	-
Clean water[m]	D	0.57	1.13	-	-	-	-	-	-	-	-	-	-
With baffles													
Dirty water[k]	B	0.65	1.30	-	-	-	-	-	-	-	-	-	-
Clean water[m]	B	0.27	0.54	-	-	-	-	-	-	-	-	-	-
Combustion stack													
Uncontrolled (COG)	A	0.234	0.47	2.0[n]	4.0[n]	-	-	-	-	-	-	-	-
Uncontrolled (BFG)	A	0.085	0.17	-	-	-	-	-	-	-	-	-	-
With ESP (COG)	D	0.046	0.091	-	-	-	-	-	-	-	-	-	-
With baghouse (COG)	D	0.055	0.11	-	-	-	-	-	-	-	-	-	-
Coke handling													
With cyclone[p]	D	0.003	0.006	-	-	-	-	-	-	-	-	-	-
Combined operations[q]	D	-	-	-	-	-	-	-	-	-	-	-	-

[a] Expressed as units/unit of coal charged. Dash = no data. ESP = electrostatic precipitator. COG = coke oven gas. BFG = blast furnace gas.

[b] Reference 1.

[c] References 2-3.

[d] Expressed as methane.

[e] Exhaust gas discharged from series of primary and secondary cyclones used to separate flash dried coal from hot gas.

[f] Charged coal has not been dried.

[g] Emissions captured by coke side shed.

[h] Emissions captured by traveling hood.

[j] Emissions captured by quench car enclosure.

[k] Dirty water $\geq$5000 mg/l total dissolved solids.

[m] Clean water $\leq$1500 mg/l total dissolved solids.

[n] Reference 4. Factor for SO_2 is based on these representative conditions: (1) sulfur content of coal charged to oven is 0.8 weight %; (2) about 33 weight % of total sulfur in coal charged to oven is transferred to coke oven gas; (3) about 40% of coke oven gas is burned during underfiring operation, and about 60% is used in other operations where the rest of the SO_2 [3 kg/Mg (6 lb/ton) of coal charged] is discharged; (4) gas used in underfiring has not been desulfurized.

[p] Defined as crushing and screening.

[q] References 19-20. Uncontrolled lead emissions are 0.00018 kg/Mg (0.00035 lb/ton).

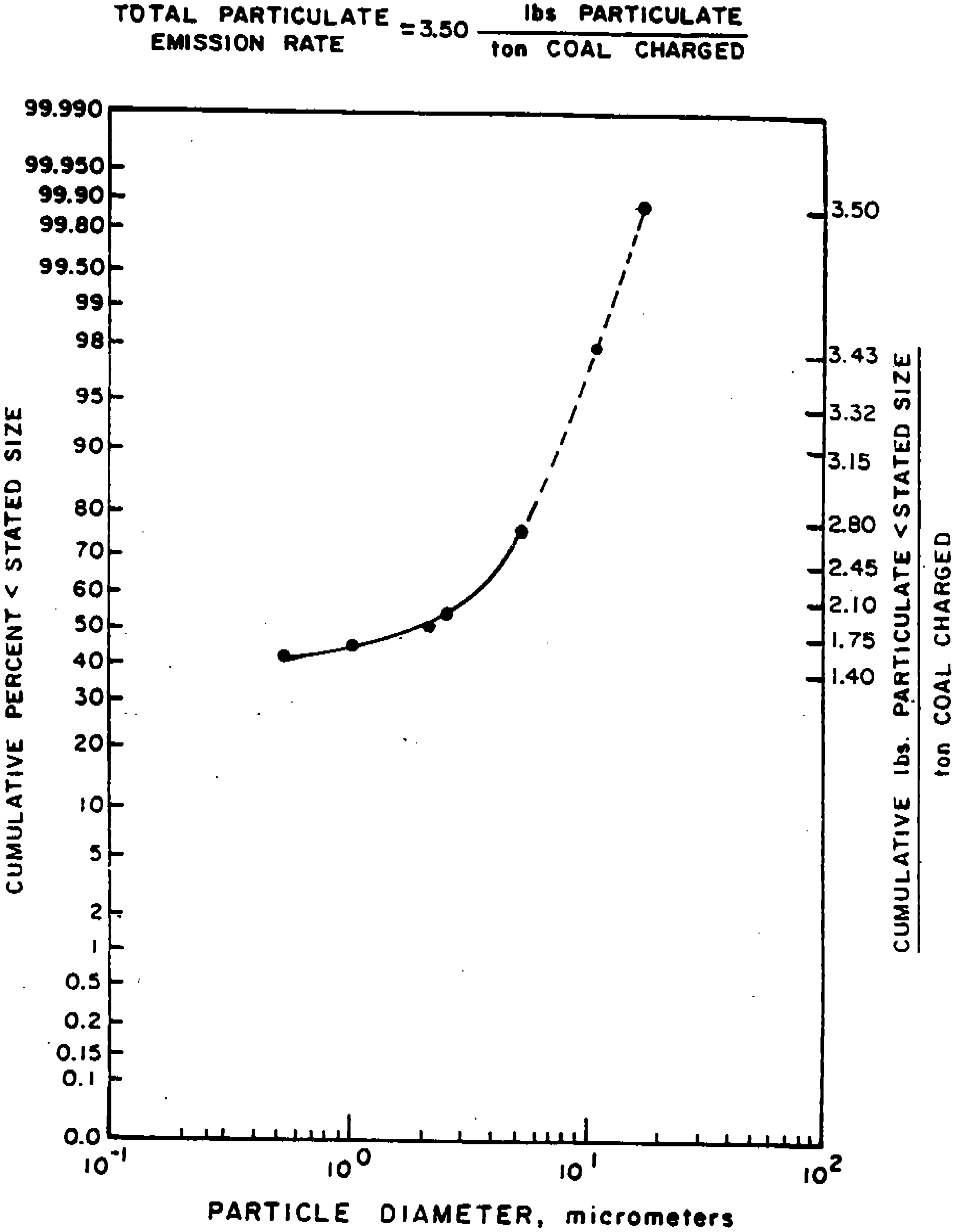
TABLE 7.2-2. SIZE SPECIFIC EMISSION FACTORS FOR COKE MANUFACTURING

Process	Particulate emission factor rating	Particle size (µm)	Cumulative mass % ≤ stated size	Cumulative mass emission factors kg/Mg	Cumulative mass emission factors lb/ton	Reference source number
Coal preheating Uncontrolled	D	0.5	44	0.8	1.5	6
		1.0	48.5	0.8	1.7	
		2.0	55	1.0	1.9	
		2.5	59.5	1.0	2.1	
		5.0	79.5	1.4	2.8	
		10.0	97.5	1.7	3.4	
		15.0	99.9	1.7	3.5	
			100	1.7	3.5	
Controlled with venturi scrubber	D	0.5	78	0.10	0.20	6
		1.0	80	0.10	0.20	
		2.0	83	0.10	0.21	
		2.5	84	0.11	0.21	
		5.0	88	0.11	0.22	
		10.0	94	0.12	0.24	
		15.0	96.5	0.12	0.24	
			100	0.12	0.25	
Coal charging Sequential or stage	E	0.5	13.5	0.001	0.002	7
		1.0	25.2	0.002	0.004	
		2.0	33.6	0.003	0.005	
		2.5	39.1	0.003	0.006	
		5.0	45.8	0.004	0.007	
		10.0	48.9	0.004	0.008	
		15.0	49.0	0.004	0.008	
			100	0.008	0.016	
Coke pushing Uncontrolled	D	0.5	3.1	0.02	0.04	8-13
		1.0	7.7	0.04	0.09	
		2.0	14.8	0.09	0.17	
		2.5	16.7	0.10	0.19	
		5.0	26.6	0.15	0.30	
		10.0	43.3	0.25	0.50	
		15.0	50.0	0.29	0.58	
			100	0.58	1.15	
Controlled with Venturi scrubber	D	0.5	24	0.02	0.04	8,10
		1.0	47	0.04	0.08	
		2.0	66.5	0.06	0.12	
		2.5	73.5	0.07	0.13	
		5.0	75	0.07	0.13	
		10.0	87	0.08	0.16	
		15.0	92	0.08	0.17	
			100	0.09	0.18	

(continued)

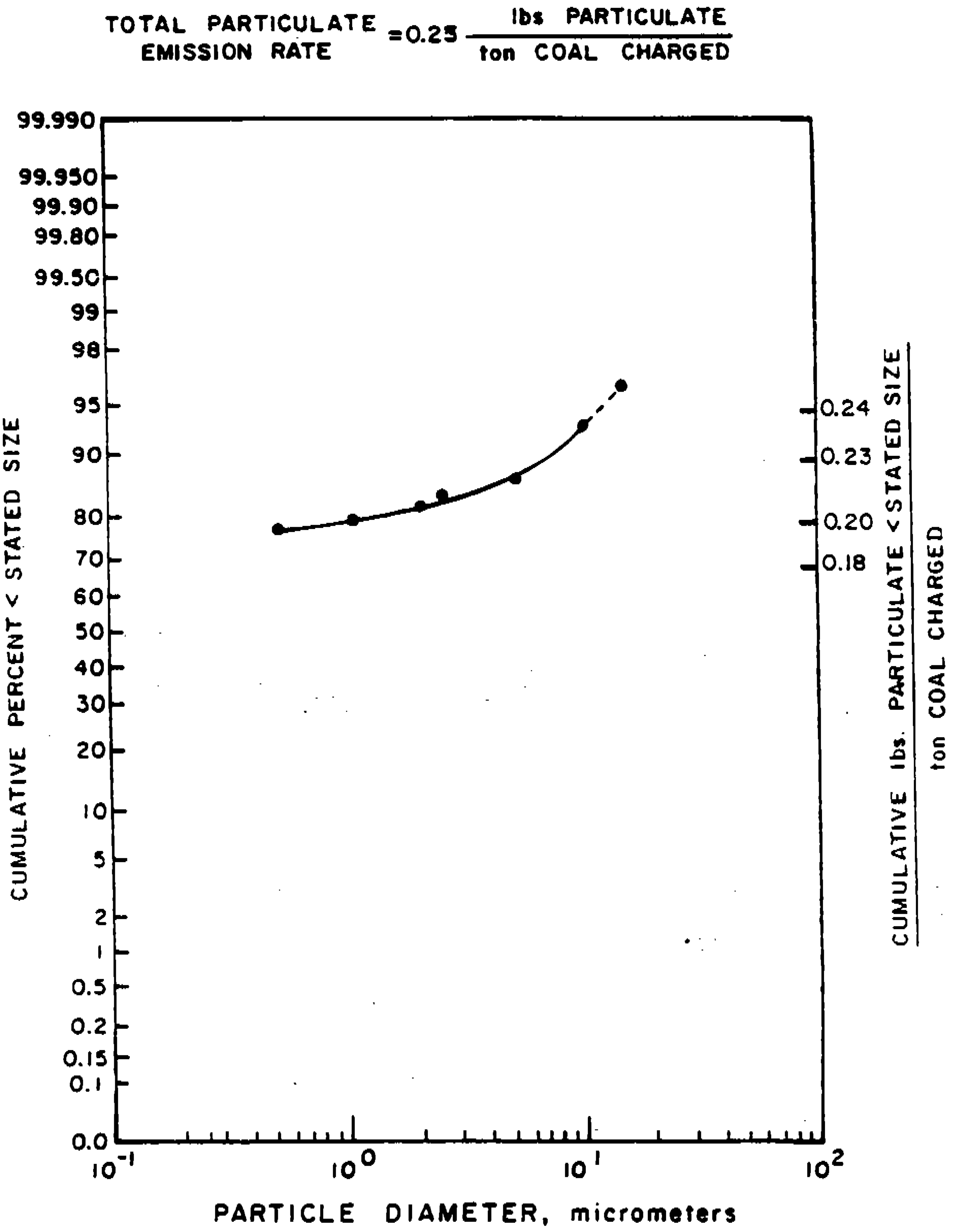
TABLE 7.2-2 (continued)

Process	Particulate emission factor rating	Particle size (μm)	Cumulative mass % ≤ stated size	Cumulative mass emission factors		Reference source number
				kg/Mg	lb/ton	
Mobile scrubber car	D	1.0	28.0	0.010	0.020	14
		2.0	29.5	0.011	0.021	
		2.5	30.0	0.011	0.022	
		5.0	30.0	0.011	0.022	
		10.0	32.0	0.012	0.024	
		15.0	35.0	0.013	0.023	
			100	0.036	0.072	
Quenching Uncontrolled (dirty water)	D	1.0	13.8	0.36	0.72	15
		2.5	19.3	0.51	1.01	
		5.0	21.4	0.56	1.12	
		10.0	22.8	0.60	1.19	
		15.0	26.4	0.69	1.38	
			100	2.62	5.24	
Uncontrolled (clean water)	B	1.0	4.0	0.02	0.05	15
		2.5	11.1	0.06	0.13	
		5.0	19.1	0.11	0.22	
		10.0	30.1	0.17	0.34	
		15.0	37.4	0.21	0.42	
			100	0.57	1.13	
With baffles (dirty water)	D	1.0	8.5	0.06	0.11	15
		2.5	20.4	0.13	0.27	
		5.0	24.8	0.16	0.32	
		10.0	32.3	0.21	0.42	
		15.0	49.8	0.32	0.65	
			100	0.65	1.30	
With baffles (clean water)	D	1.0	1.2	0.003	0.006	15
		2.5	6.0	0.02	0.03	
		5.0	7.0	0.02	0.04	
		10.0	9.8	0.03	0.05	
		15.0	15.1	0.04	0.08	
			100	0.27	0.54	
Combustion stack Uncontrolled	D	1.0	77.4	0.18	0.36	16-18
		2.0	85.7	0.20	0.40	
		2.5	93.5	0.22	0.44	
		5.0	95.8	0.22	0.45	
		10.0	95.9	0.22	0.45	
		15.0	96	0.22	0.45	
			100	0.23	0.47	



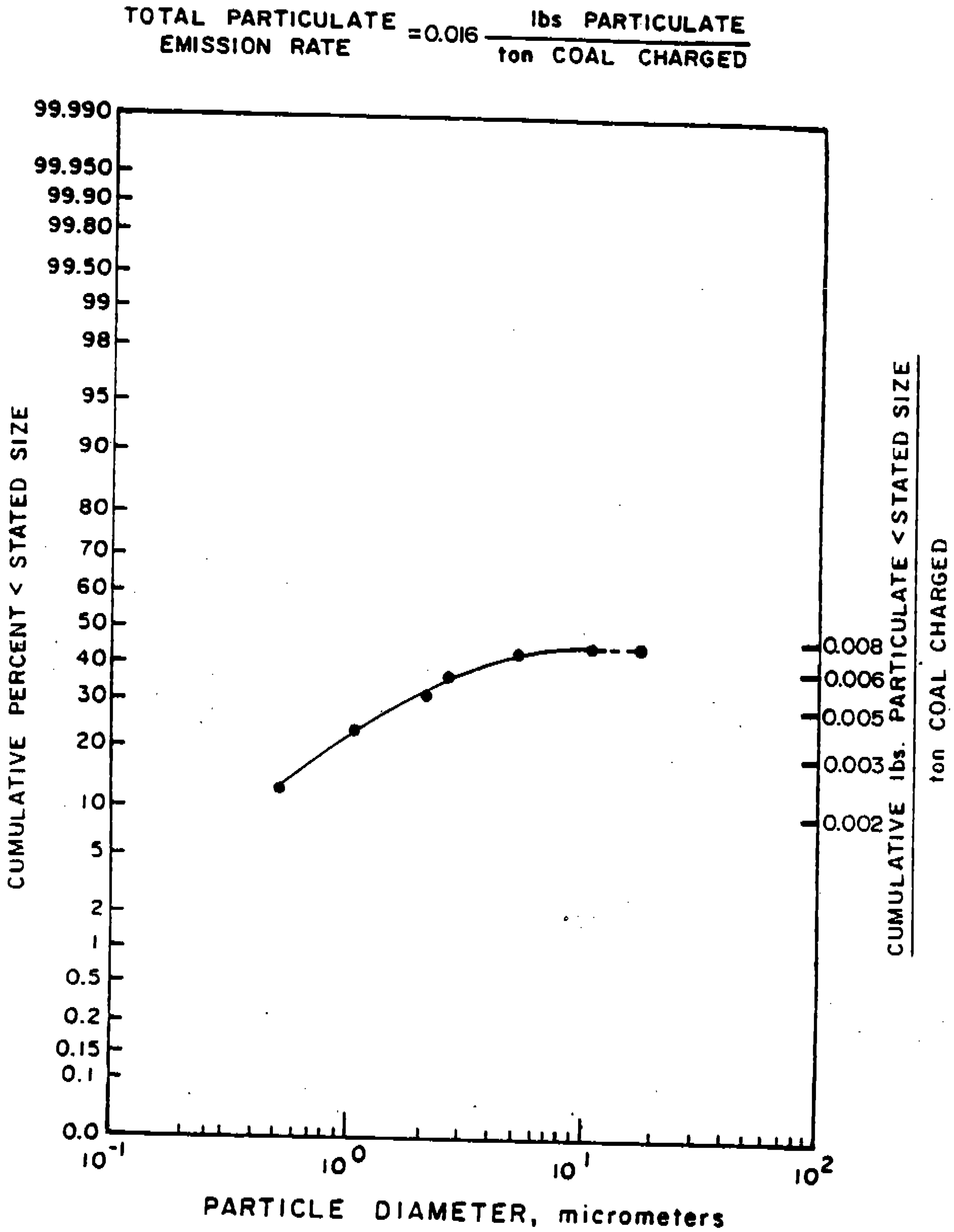
Note: **Extrapolated to the 15 μm size, using engineering estimates.**

Figure 7.2-3. Coal preheating (uncontrolled).



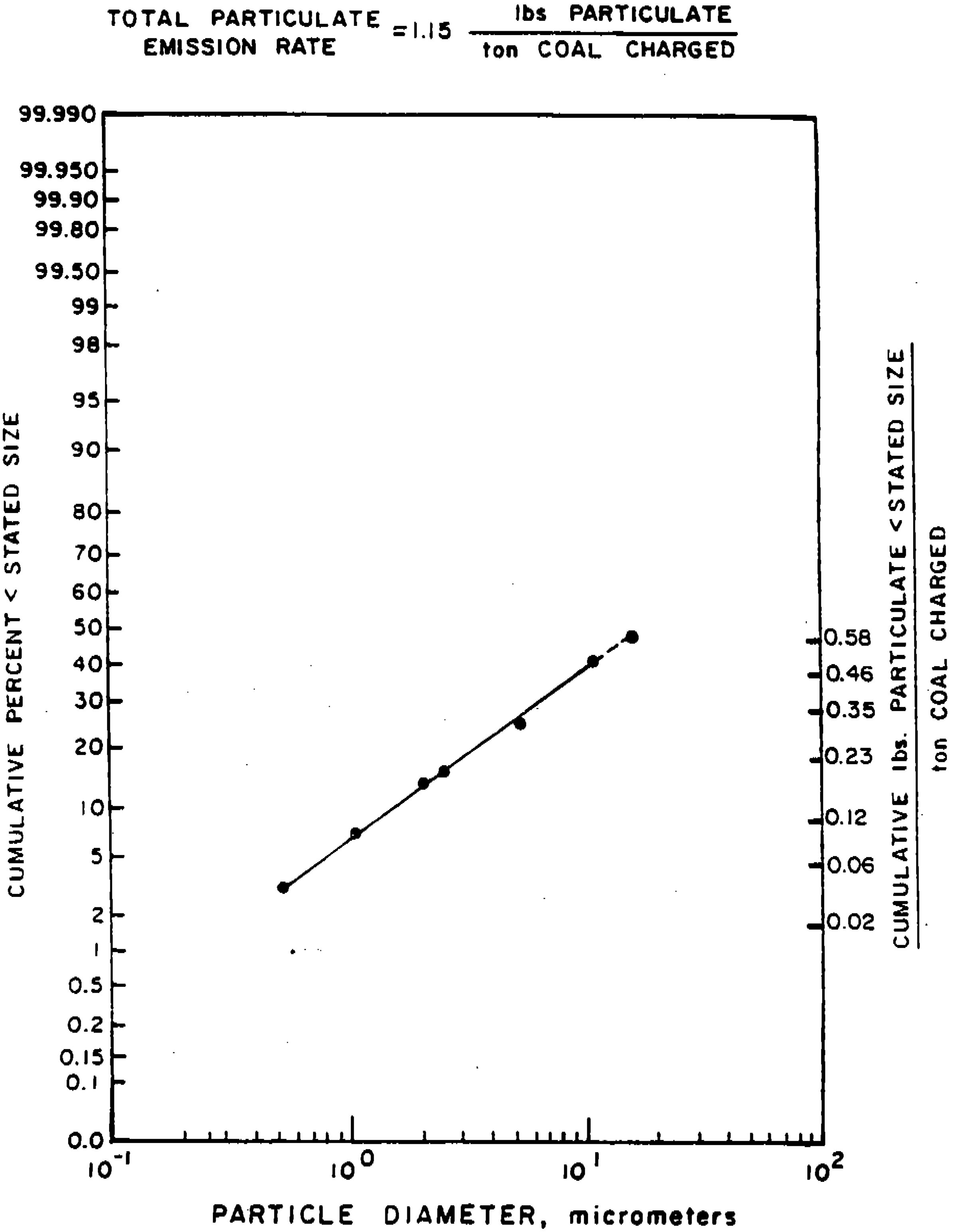
Note: **Extrapolated to the 15 μm size, using engineering estimates.**

Figure 7.2-4. Coal preheating (controlled with scrubber).



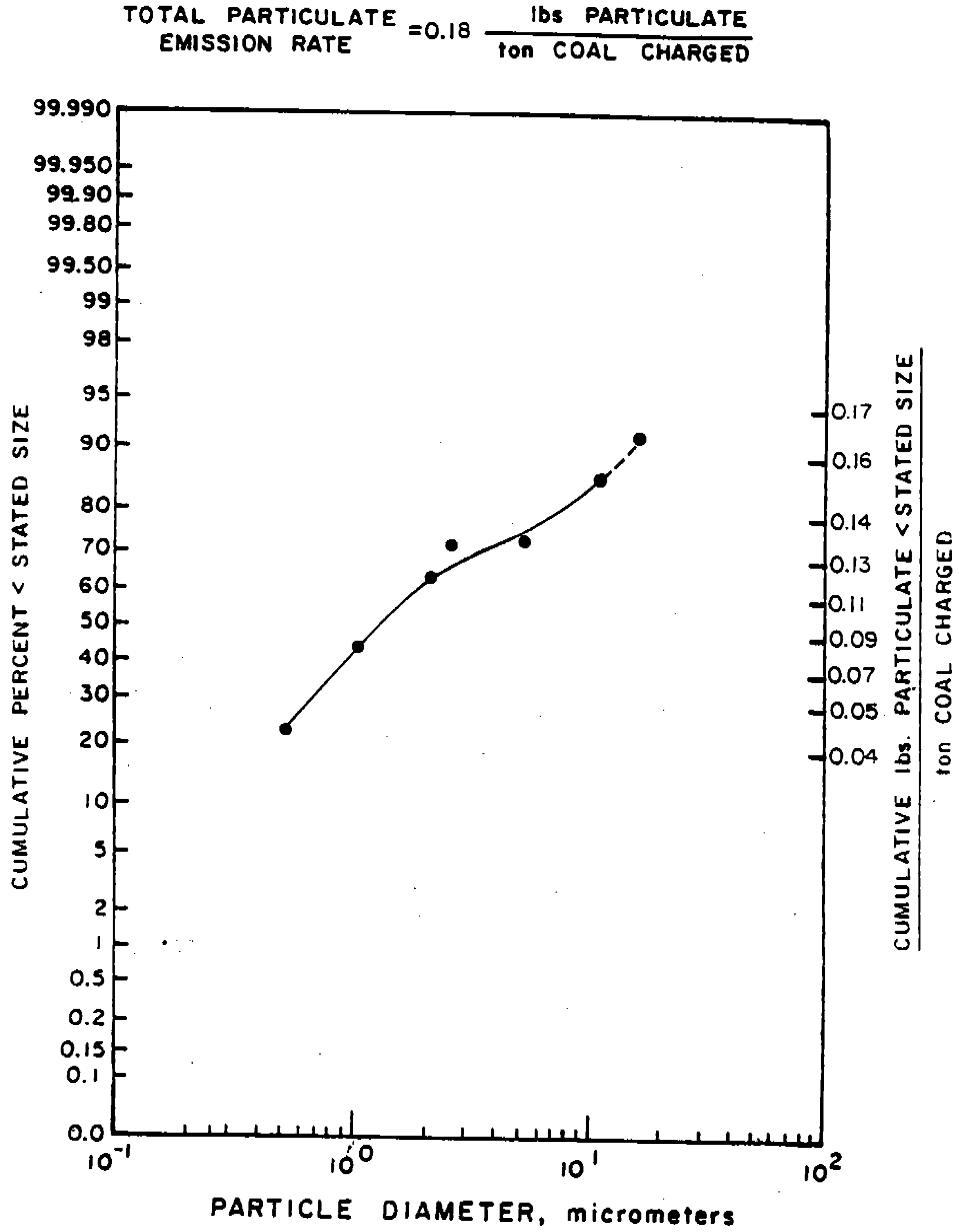
Note: Extrapolated to the 15 μm size, using engineering estimates.

Figure 7.2-5. Coal charging (sequential) average of 2 tests.



Note: Extrapolated to the 15 μm size, using engineering estimates.

Figure 7.2-6. Pushing (uncontrolled) average of 6 sites.



Note: Extrapolated to the 15 µm size, using engineering estimates.

Figure 7.2-7. Pushing (controlled with scrubber) average of 2 sites.

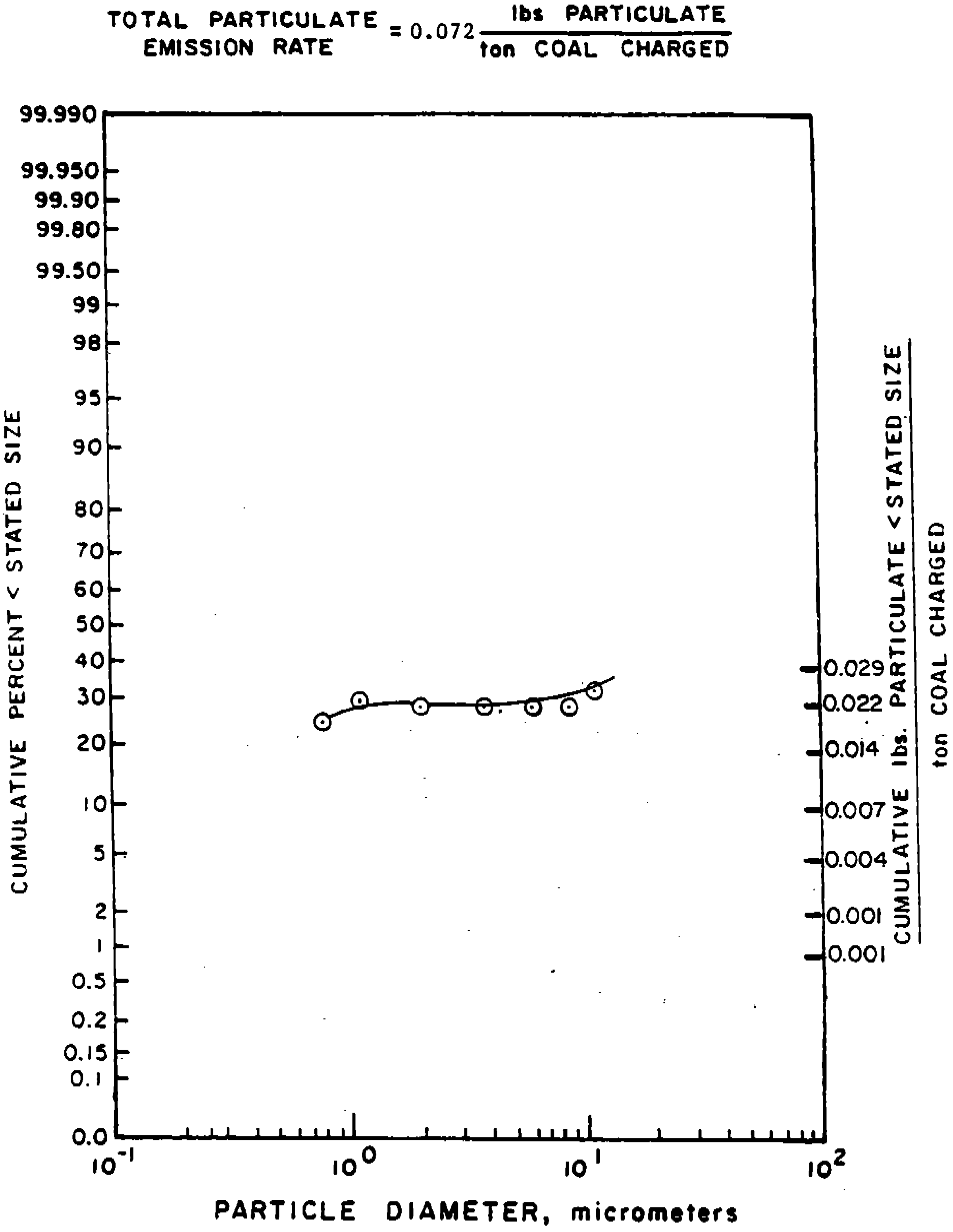


Figure 7.2-8. Mobile scrubber cars.

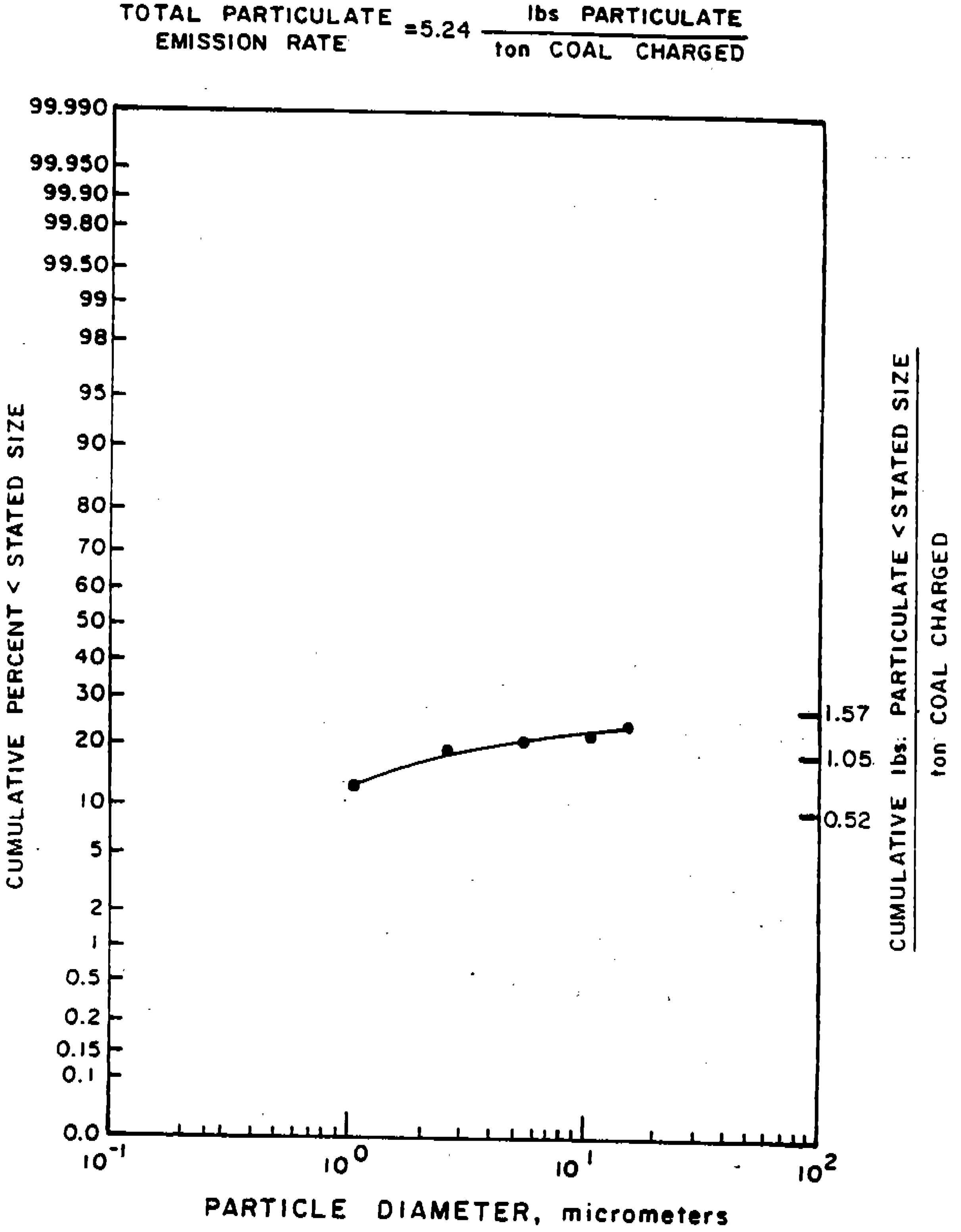


Figure 7.2-9. Quenching (uncontrolled) dirty water >5,000 mg/L TDS.

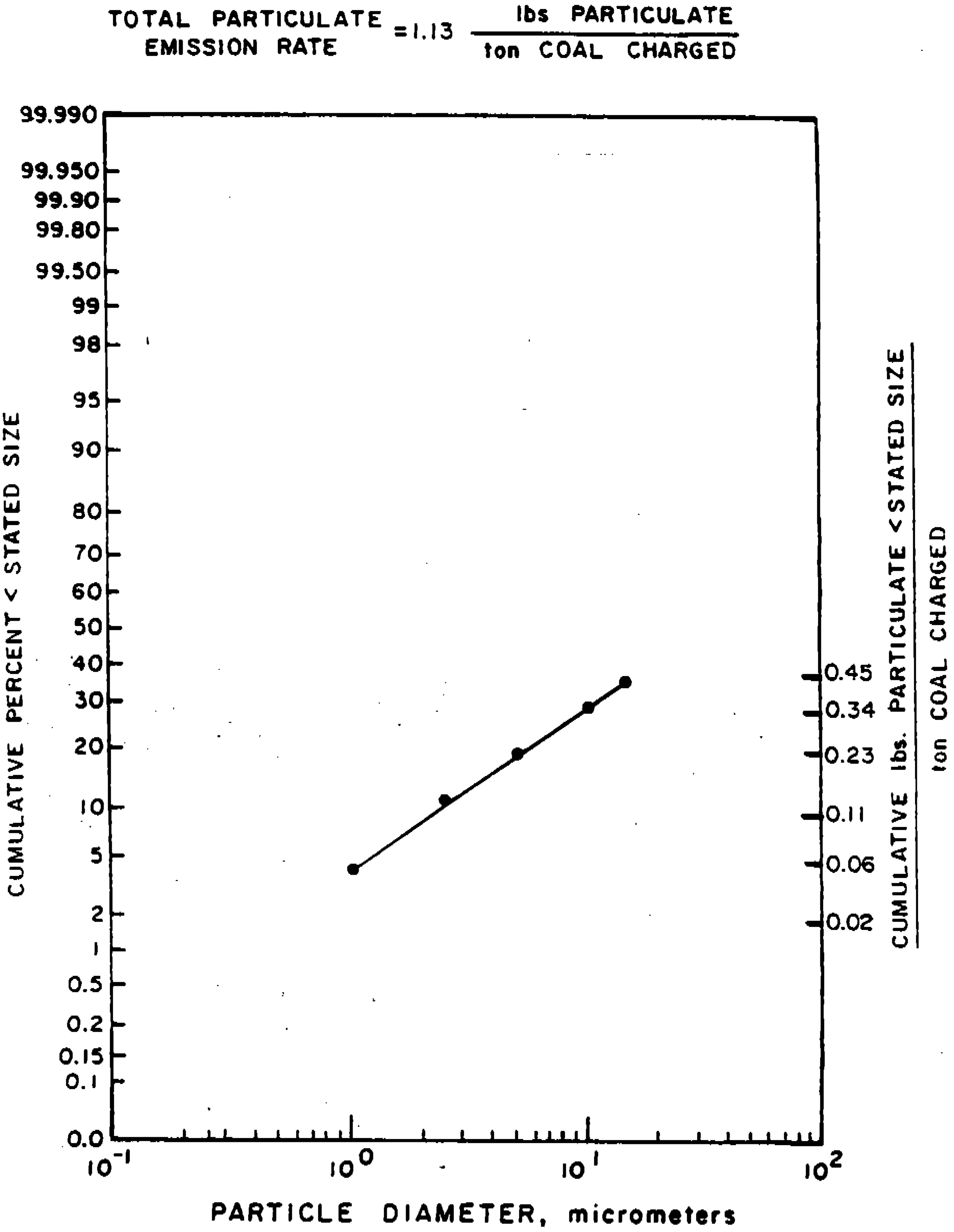


Figure 7.2-10. Quenching (uncontrolled) clean water <1,500 mg/L TDS.

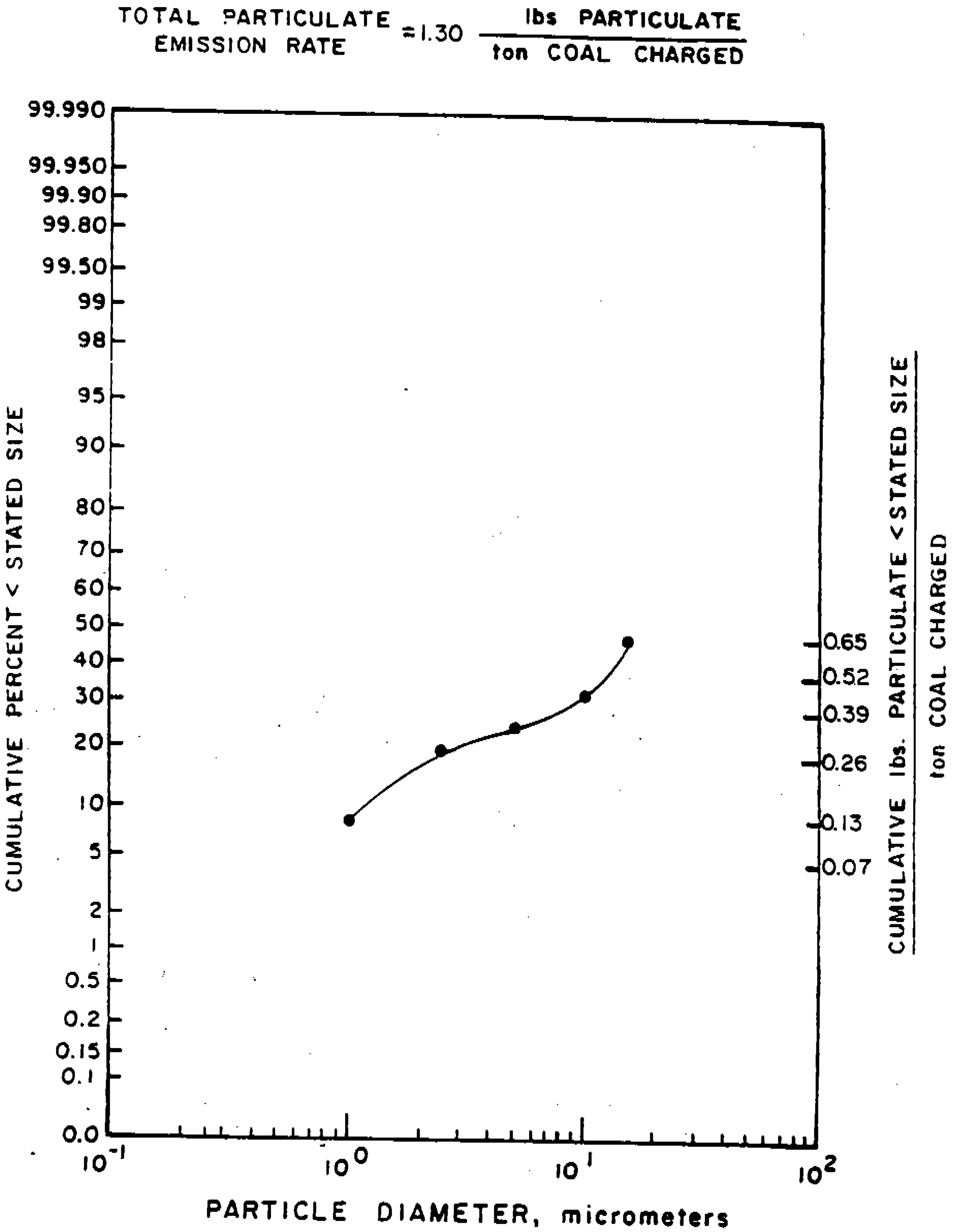


Figure 7.2-11. Quenching (controlled with baffles) dirty water >5,000 mg/L TDS.

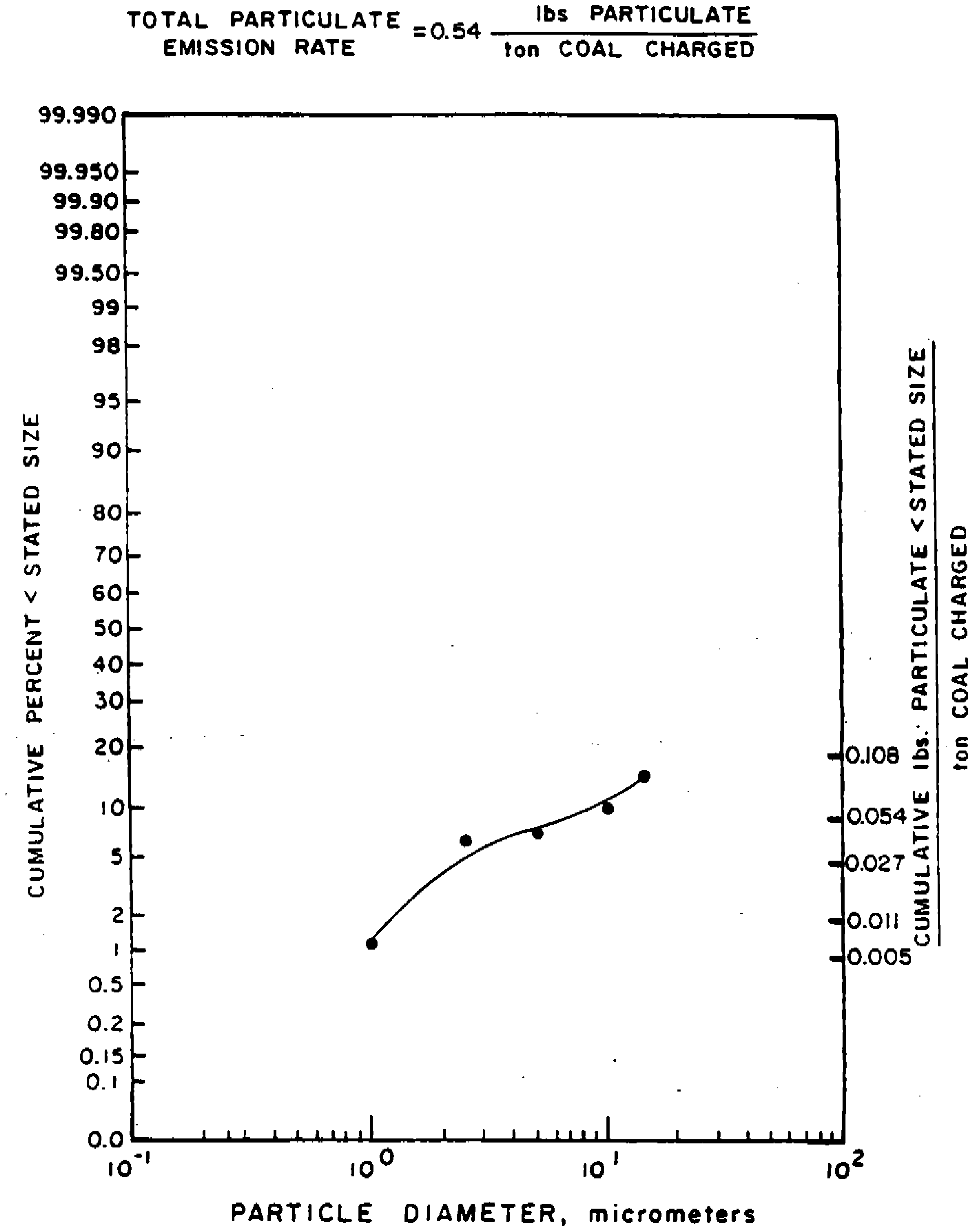
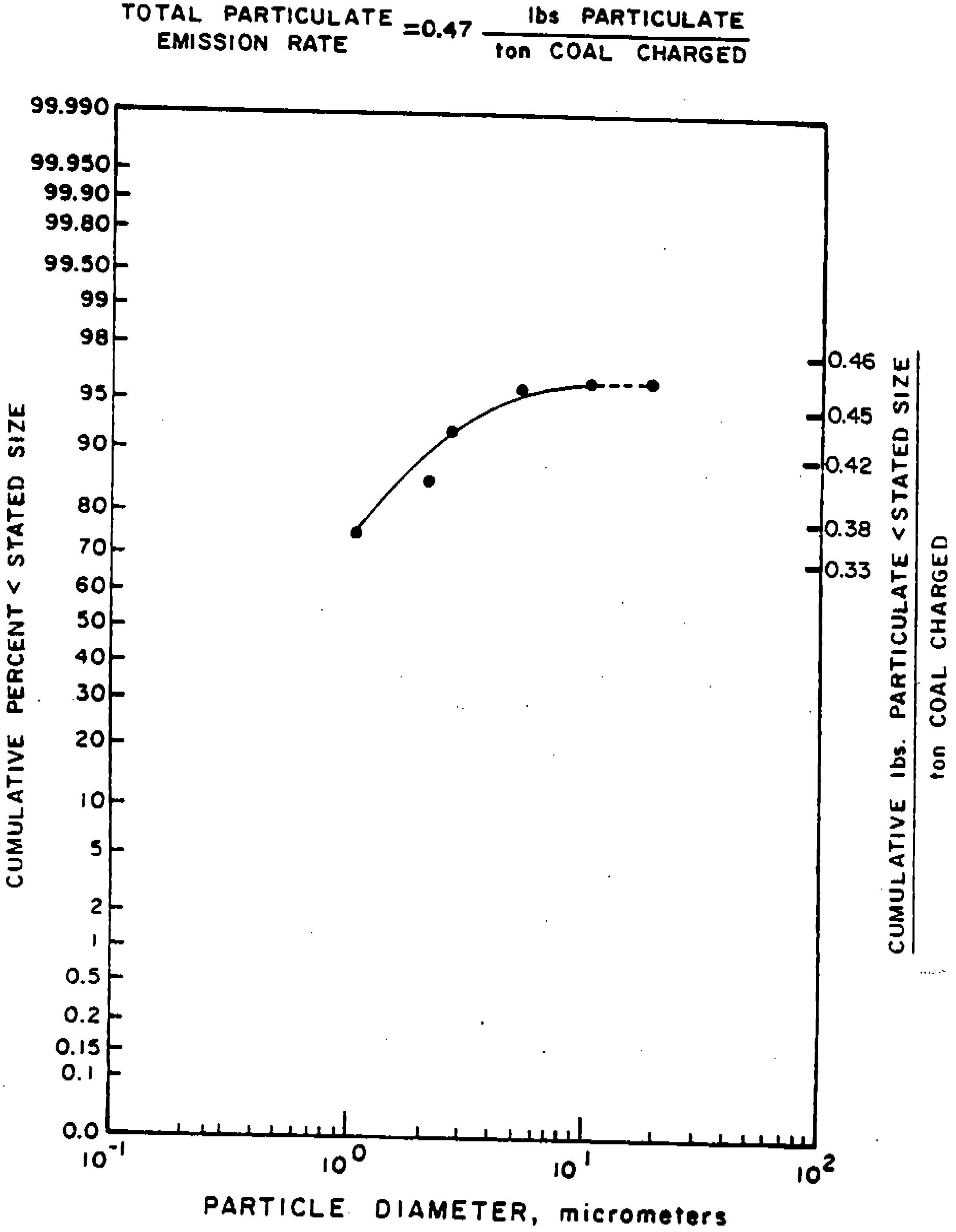


Figure 7.2-12. Quenching (controlled with baffles) clean water <1,500 mg/L TDS.



Note: Extrapolated to the 15 µm size, using engineering estimates.

Figure 7.2-13. Combustion stacks (uncontrolled) average of 3 sites.

References for Section 7.2

1. John Fitzgerald, et al., Inhalable Particulate Source Category Report For The Metallurgical Coke Industry, TR-83-97-G, Contract No. 68-02-3157, GCA Corporation, Bedford, MA, July 1986.

2. Air Pollution By Coking Plants, United Nations Report: Economic Commission for Europe, ST/ECE/Coal/26, 1968.

3. R. W. Fullerton, "Impingement Baffles To Reduce Emissions from Coke Quenching", Journal of the Air Pollution Control Association, 17:807-809, December 1967.

4. J. Varga and H. W. Lownie, Jr., Final Technological Report On A Systems Analysis Study Of The Integrated Iron And Steel Industry, Contract No. PH-22-68-65, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1969.

5. Particulate Emissions Factors Applicable To The Iron And Steel Industry, EPA-450/4-79-028, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1979.

6. Stack Test Report for J & L Steel, Aliquippa Works, Betz Environmental Engineers, Plymouth Meeting, PA, April 1977.

7. R. W. Bee, et al., Coke Oven Charging Emission Control Test Program, Volume I, EPA-650/2-74-062-1, U. S. Environmental Protection Agency, Washington, DC, July 1974.

8. Emission Testing And Evaluation Of Ford/Koppers Coke Pushing Control System, EPA-600/2-77-187b, U. S. Environmental Protection Agency, Washington, DC, September 1977.

9. Stack Test Report, Bethlehem Steel, Burns Harbor, IN, Bethlehem Steel, Bethlehem, PA, September 1974.

10. Stack Test Report for Inland Steel Corporation, East Chicago, IN Works, Betz Environmental Engineers, Pittsburgh, PA, June 1976.

11. Stack Test Report for Great Lakes Carbon Corporation, St. Louis, MO, Clayton Environmental Services, Southfield, MO, April 1975.

12. Source Testing Of A Stationary Coke Side Enclosure, Bethlehem Steel, Burns Harbor Plant, EPA-340/1-76-012, U. S. Environmental Protection Agency, Washington, DC, May 1977.

13. Stack Test Report for Allied Chemical Corporation, Ashland, KY, York Research Corporation, Stamford, CT, April 1979.

14. Stack Test Report, Republic Steel Company, Cleveland, OH, Republic Steel, Cleveland, OH, November 1979.

15. J. Jeffrey, Wet Coke Quench Tower Emission Factor Development, Dofasco, Ltd., EPA-600/X-85-340, U. S. Environmental Protection Agency, Research Triangle Park, NC, August 1982.

16. Stack Test Report for Shenango Steel, Inc., Neville Island, PA, Betz Environmental Engineers, Plymouth Meeting, PA, July 1976.

17. Stack Test Report for J & L Steel Corporation, Pittsburgh, PA, Mostardi-Platt Associates, Bensenville, IL, June 1980.

18. Stack Test Report for J & L Steel Corporation, Pittsburgh, PA, Wheelabrator Frye, Inc., Pittsburgh, PA, April 1980.

19. R. B. Jacko, et al., By-product Coke Oven Pushing Operation: Total And Trace Metal Particulate Emissions, Purdue University, West Lafayette, IN, June 27, 1976.

20. Control Techniques For Lead Air Emissions, EPA-450/2-77-012, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1977.

7.3 PRIMARY COPPER SMELTING

7.3.1 Process Description[1-3]

In the United States, copper is produced from sulfide ore concentrates, principally by pyrometallurgical smelting methods. Because the ores usually contain less than 1 percent copper, they must be concentrated before transport to smelters. Concentrations of 15 to 35 percent copper are accomplished at the mine site by crushing, grinding and flotation. Sulfur content of the concentrate ranges from 25 to 35, percent and most of the remainder is iron (25 percent) and water (10 percent). Some concentrates also contain significant quantities of arsenic, cadmium, lead, antimony, and other heavy metals.

A conventional pyrometallurgical copper smelting process is illustrated in Figure 7.3-1. The process includes roasting of ore concentrates to produce calcine, smelting of roasted (calcine feed) or unroasted (green feed) ore concentrates to produce matte, and converting of the matte to yield blister copper product (about 99 percent pure). Typically, the blister copper is fire refined in an anode furnace, cast into "anodes" and sent to an electrolytic refinery for further impurity elimination.

In roasting, charge material of copper concentrate mixed with a siliceous flux (often a low grade ore) is heated in air to about 650°C (1200°F), eliminating 20 to 50 percent of the sulfur as sulfur dioxide (SO_2). Portions of such impurities as antimony, arsenic and lead are driven off, and some iron is converted to oxide. The roasted product, calcine, serves as a dried and heated charge for the smelting furnace. Either multiple hearth or fluidized bed roasters are used for roasting copper concentrate. Multiple hearth roasters accept moist concentrate, whereas fluid bed roasters are fed finely ground material (60 percent minus 200 mesh). With both of these types, the roasting is autogenous. Because there is less air dilution, higher SO_2 concentrations are present in fluidized bed roaster gases than in multiple hearth roaster gases.

In the smelting process, either hot calcines from the roaster or raw unroasted concentrate is melted with siliceous flux in a smelting furnace to produce copper matte, a molten mixture of cuprous sulfide (Cu_2S), ferrous sulfide (FeS) and some heavy metals. The required heat comes from partial oxidation of the sulfide charge and from burning external fuel. Most of the iron and some of the impurities in the charge oxidize with the fluxes to form atop the molten bath a slag, which is periodically removed and discarded. Copper matte remains in the furnace until tapped. Mattes produced by the domestic industry range from 35 to 65 percent copper, with 45 percent the most common. The copper content percentage is referred to as the matte grade. Currently, five smelting furnace technologies are used in the U. S., reverberatory, electric, Noranda, Outokumpu (flash), and Inco (flash).

Reverberatory furnace operation is a continuous process, with frequent charging of input materials and periodic tapping of matte and skimming of slag.

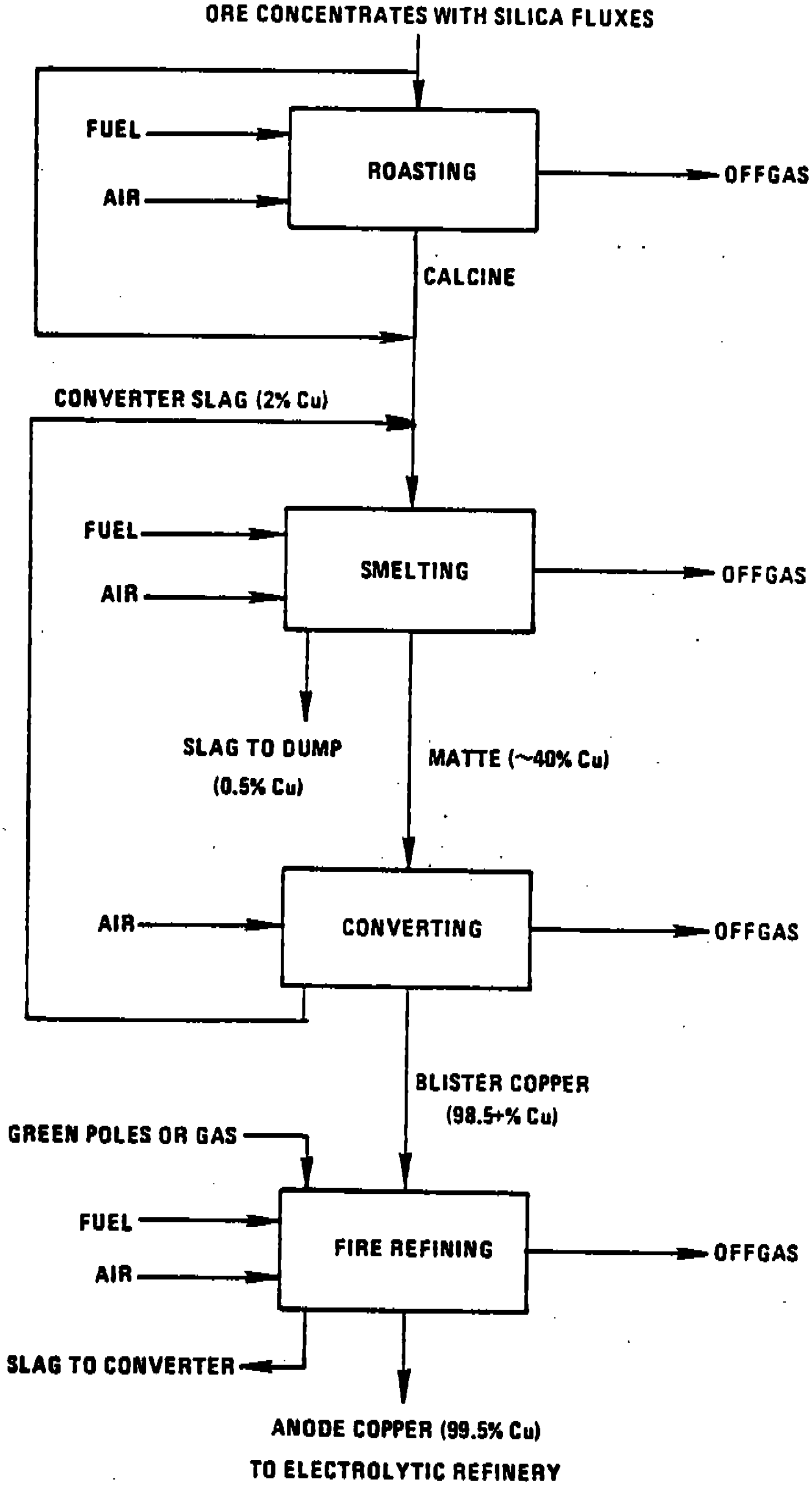


Figure 7.3-1. Typical primary copper smelter process.

1300 tons) of charge per day. Heat is supplied by combustion of oil, gas or pulverized coal, and furnace temperature may exceed 1500°C (2730°F).

For smelting in electric arc furnaces, heat is generated by the flow of an electric current in carbon electrodes lowered through the furnace roof and submerged in the slag layer of the molten bath. The feed generally consists of dried concentrates or calcines, and charging wet concentrates is avoided. The chemical and physical changes occurring in the molten bath are similar to those occurring in the molten bath of a reverberatory furnace. Also, the matte and slag tapping practices are similar at both furnaces. Electric furnaces do not produce fuel combustion gases, so flow rates are lower and SO_2 concentrations higher in the effluent gas than in that of reverberatory furnaces.

Flash furnace smelting combines the operations of roasting and smelting to produce a high grade copper matte from concentrates and flux. In flash smelting, dried ore concentrates and finely ground fluxes are injected, together with oxygen, preheated air, or a mixture of both, into a furnace of special design, where temperature is maintained at approximately 1000°C (1830°F). Flash furnaces, in contrast to reverberatory and electric furnaces, use the heat generated from partial oxidation of their sulfide charge to provide much or all of the energy (heat) required for smelting. They also produce offgas streams containing high concentrations of SO_2.

Slag produced by flash furnace operations contains significantly higher amounts of copper than does that from reverberatory or electric furnace operations. As a result, the flash furnace and converter slags are treated in a slag cleaning furnace to recover the copper. Slag cleaning furnaces usually are small electric furnaces. The flash furnace and converter slags are charged to a slag cleaning furnace and are allowed to settle under reducing conditions, with the addition of coke or iron sulfide. The copper, which is in oxide form in the slag, is converted to copper sulfide, is subsequently removed from the furnace and is charged to a converter with regular matte. If the slag's copper content is low, the slag is discarded.

The Noranda process, as originally designed, allowed the continuous production of blister copper in a single vessel by effectively combining roasting, smelting and converting into one operation. Metallurgical problems, however, led to the operation of these reactors for the production of copper matte. As in flash smelting, the Noranda process takes advantage of the heat energy available from the copper ore. The remaining thermal energy required is supplied by oil burners, or by coal mixed with the ore concentrates.

The final step in the production of blister copper is converting, with the purposes of eliminating the remaining iron and sulfur present in the matte and leaving molten "blister" copper. All but one U. S. smelter uses Pierce-Smith converters, which are refractory lined cylindrical steel shells mounted on trunnions at either end, and rotated about the major axis for charging and pouring. An opening in the center of the converter functions as a mouth through which molten matte, siliceous flux, and scrap copper are charged and gaseous products are vented. Air or oxygen rich air is blown through the molten matte. Iron sulfide (FeS) is oxidized to iron oxide (FeO) and SO_2, and the FeO blowing and slag skimming are repeated until an adequate amount of relatively pure Cu_2S, called "white metal", accumulates in the bottom of the converter. A renewed air blast oxidizes the copper sulfide sulfur to SO_2, leaving blister copper in the converter. The blister copper is subsequently removed and transferred to refining facilities. This segment of converter operation is termed the finish blow. The SO_2 produced throughout the operation is vented to pollution control devices.

One domestic smelter uses Hoboken converters, the primary advantage of which lies in emission control. The Hoboken converter is essentially like a conventional Pierce-Smith converter, except that this vessel is fitted with a side flue at one end shaped as an inverted U. This flue arrangement permits siphoning of gases from the interior of the converter directly to the offgas collection system, leaving the converter mouth under a slight vacuum.

Blister copper usually contains from 98.5 to 99.5 percent pure copper. Impurities may include gold, silver, antimony, arsenic, bismuth, iron, lead, nickel, selenium, sulfur, tellurium, and zinc. To purify blister copper further, fire refining and electrolytic refining are used. In fire refining, blister copper is placed in a fire refining furnace, a flux is usually added, and air is blown through the molten mixture to oxidize remaining impurities, which are removed as a slag. The remaining metal bath is subjected to a reducing atmosphere to reconvert cuprous oxide to copper. Temperature in the furnace is around 1100°C (2010°F). The fire refined copper is cast into anodes, after which, further electrolytic refining separates copper from impurities by electrolysis in a solution containing copper sulfate and sulfuric acid. Metallic impurities precipitate from the solution and form a sludge that is removed and treated to recover precious metals. Copper is dissolved from the anode and deposited at the cathode. Cathode copper is remelted and made into bars, ingots or slabs for marketing purpose. The copper produced is 99.95 to 99.97 percent pure.

7.3.2 Emissions And Controls

Particulate matter and sulfur dioxide are the principal air contaminants emitted by primary copper smelters. These emissions are generated directly from the processes involved, as in the liberation of SO_2 from copper concentrate during roasting, or in the volatilization of trace elements as oxide fumes. Fugitive emissions are generated by leaks from major equipment during material handling operations.

Roasters, smelting furnaces and converters are sources of both particulate matter and sulfur oxides. Copper and iron oxides are the primary constituents of the particulate matter, but other oxides, such as arsenic, antimony, cadmium, lead, mercury and zinc, may also be present, with metallic sulfates and sulfuric acid mist. Fuel combustion products also contribute to the particulate emissions from multiple hearth roasters and reverberatory furnaces.

Single stage electrostatic precipitators (ESP) are widely used in the primary copper industry to control particulate emissions from roasters, smelting furnaces and converters. Many of the existing ESPs are operated at elevated temperatures, usually from 200° to 340°C (400° to 650°F) and are termed "hot ESPs". If properly designed and operated, these ESPs remove 99 percent or more of the condensed particulate matter present in gaseous effluents. However, at these elevated temperatures, a significant amount of volatile emissions such as arsenic trioxide (As_2O_3) and sulfuric acid mist is present as vapor in the gaseous effluent and thus can not be collected by the particulate control device at elevated temperatures. At these temperatures, the arsenic trioxide in the vapor state will pass through an ESP. Therefore, the gas stream to be treated must be cooled sufficiently to assure that most of the arsenic present is condensed before entering the control device for collection. At some smelters, the gas effluents are cooled to about 120°C (250°F) temperature before entering a particulate control system, usually an ordinary ("cold") ESP. Spray chambers or air infiltration are used for gas cooling. Fabric filters can also be used for particulate matter collection.

Gas effluents from roasters usually are sent to an ESP or spray chamber/ESP system or are combined with smelter furnace gas effluents before particulate collection. Overall, the hot ESPs remove only 20 to 80 percent of the total particulate (condensed and vapor) present in the gas. Cold ESPs may remove more than 95 percent of the total particulate present in the gas. Particulate collection systems for smelting furnaces are similar to those for roasters. Reverberatory furnace offgases are usually routed through waste heat boilers and low velocity balloon flues to recover large particles and heat, then are routed through an ESP or spray chamber/ESP system.

In the standard Pierce—Smith converter, flue gases are captured during the blowing phase by the primary hood over the converter mouth. To prevent the hood's binding to the converter with splashing molten metal, there is a gap between the hood and the vessel. During charging and pouring operations, significant fugitives may be emitted when the hood is removed to allow crane access. Converter offgases are treated in ESPs to remove particulate matter and in sulfuric acid plants to remove SO_2.

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

Control of SO_2 emissions from smelter sources is most commonly performed in a single or double contact sulfuric acid plant. Use of a sulfuric acid plant to treat copper smelter effluent gas streams requires that gas be free from particulate matter and that a certain minimum SO_2 concentration be maintained. Practical limitations have usually restricted sulfuric acid plant application to gas streams that contain at least 3 percent SO_2. Table 7.3-1 shows typical average SO_2 concentrations for the various smelter unit offgases. Currently, converter gas effluents at most smelters are treated for SO_2 control in sulfuric acid plants. Gas effluents of some multiple hearth roaster operations and of all fluid bed roaster operations also are treated in sulfuric acid plants. The weak SO_2 content gas effluents from reverberatory furnace operations are usually released to the atmosphere with no reduction of SO_2. The gas effluents from the other types of smelter furnaces, because of their higher contents of SO_2, are treated in sulfuric acid plants before being vented. Typically, single contact acid plants achieve 92.5 to 98 percent conversion of SO_2 to acid, with approximately 2000 parts per million SO_2 remaining in the acid plant effluent gas. Double contact acid plants collect from 98 to more than 99 percent of the SO_2 and emit about 500 parts per million SO_2. Absorption of the SO_2 in dimethylaniline (DMA) solution has also been used in U. S. smelters to produce liquid SO_2.

TABLE 7.3-1. TYPICAL SULFUR DIOXIDE CONCENTRATIONS IN OFFGASES FROM PRIMARY COPPER SMELTING SOURCES

Unit	SO_2 concentration (volume %)
Multiple hearth roaster	1.5 to 3
Fluidized bed roaster	10 to 12
Reverberatory furnace	0.5 to 1.5
Electric arc furnace	4 to 8
Flash smelting furnace	10 to 70
Continuous smelting furnace	5 to 15
Pierce-Smith converter	4 to 7
Hoboken converter	8
Single contact H_2SO_4 plant	0.2 to 0.26
Double contact H_2SO_4 plant	0.05

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

Actual emissions from a particular smelter unit depend upon the configuration of equipment in that smelting plant and its operating parameters. Table 7.3-2 gives the emission factors for various smelter configurations, and Tables 7.3-3 through 7.3-5 and Figures 7.3-2 through 7.3-4 give size specific emission factors for those copper production processes, where information is available.

7.3.3 Fugitive Emissions

The process sources of particulate matter and SO_2 emission are also the potential fugitive sources of these emissions: roasting, smelting, converting, fire refining and slag cleaning. Table 7.3-6 presents the potential fugitive emission factors for these sources, while Tables 7.3-7 through 7.3-9 and Figures 7.3-5 through 7.3-7 present cumulative size specific particulate emission factors for fugitive emissions from reverberatory furnace matte, slag tapping, converter slag, and copper blow operations. The actual quantities of emissions from these sources depend on the type and condition of the equipment and on the smelter operating techniques. Although emissions from many of these sources are released inside a building, ultimately they are discharged to the atmosphere.

TABLE 7.3-2. EMISSION FACTORS FOR PRIMARY COPPER SMELTERS[a,b]

EMISSION FACTOR RATING: B

Configuration[c]	By unit	Particulate		Sulfur dioxide[d]		References
		kg/Mg	lb/ton	kg/Mg	lb/ton	
Reverberatory furnace (RF)	RF	25	50	160	320	4-10,
followed by converters (C)	C	18	36	370	740	9,11-15
Multiple hearth roaster (MHR)	MHR	22	45	140	280	4-5,16-17
followed by reverberatory	RF	25	50	90	180	4-9,18-19
furnace (RF) and converters (C)	C	18	36	300	600	8,11-13
Fluid bed roaster (FBR) followed	FBR	NA	NA	180	360	20
by reverberatory furnace (RF)	RF	25	50	90	160	e
and converters (C)	C	18	36	270	540	e
Concentrate dryer (CD) followed	CD	5	10	0.5	1	21-22
by electric furnace (EF) and	EF	50	100	120	240	15
converters (C)	C	18	36	410	820	8,11-13,15
Fluid bed roaster (FBR) followed	FBR	NA	NA	180	360	20
by electric furnace (EF) and	EF	50	100	45	90	15,23
converters (C)	C	18	36	300	600	e
Concentrate dryer (DC) followed	CD	5	10	0.5	1	21-22
by flash furnace (FF),	FF	70	140	410	820	24
cleaning furnace (SS) and	SS[f]	5	10	0.5	1	22
converters (C)	C[e]	NA[g]	NA[g]	120	240	22
Concentrate dryer (CD) followed	CD	5	10	0.5	1	21-22
by Noranda reactors (NR) and	NR	NA	NA	NA	NA	
converters (C)	C	NA	NA	NA	NA	

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[a] Expressed as units/unit weight of concentrated ore processed by the smelter. Approximately 4 unit weights of concentrate are required to produce 1 unit weight of blister copper. NA = not available.

[b] For particulate matter removal, gaseous effluents from roasters, smelting furnaces and converters usually are treated in hot ESPs at 200 to 340°C (400 to 650°F) or in cold ESPs with gases cooled to about 120°C (250°F) before ESP. Particulate emissions from copper smelters contain volatile metallic oxides which remain in vapor form at higher temperatures (120°C or 250°F). Therefore, overall particulate removal in hot ESPs may range 20 to 80% and in cold ESPs may be 99%. Converter gas effluents and, at some smelters, roaster gas effluents are treated in single contact acid plants (SCAP) or double contact acid plants (DCAP) for SO_2 removal. Typical SCAPs are about 96% efficient, and DCAPs are up to 99.8% efficient in SO_2 removal. They also remove over 99% of particulate matter. Noranda and flash furnace offgases are also processed through acid plants and are subject to the same collection efficiencies as cited for converters and some roasters.

[c] In addition to sources indicated, each smelter configuration contains fire refining anode furnaces after the converters. Anode furnaces emit negligible SO_2. No particulate emission data are available for anode furnaces.

[d] Factors for all configurations except reverberatory furnace followed by converters have been developed by normalizing test data for several smelters to represent 30% sulfur content in concentrated ore.

[e] Based on the test data for the configuration multiple hearth roaster followed by reverberatory furnace and converters.

[f] Used to recover copper from furnace slag and converter slag.

[g] Since converters at flash furnace and Noranda furnace smelters treat high copper content matte, converter particulate emissions from flash furnace smelters are expected to be lower than those from conventional smelters with multiple hearth roasters, reverberatory furnace and converters.

TABLE 7.3-3. PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR MULTIPLE HEARTH ROASTER AND REVERBERATORY SMELTER OPERATIONS[a]

EMISSION FACTOR RATING: D

	Cumulative mass % ≤ stated size		Cumulative emission factors			
Particle size[b] (um)	Uncontrolled	ESP controlled	Uncontrolled Kg/Mg	Uncontrolled lb/ton	ESP controlled[c] Kg/Mg	ESP controlled[c] lb/ton
15	100	100	47	95	0.47	0.95
10	100	99	47	94	0.47	0.94
5	100	98	47	93	0.46	0.93
2.5	97	84	46	80	0.40	0.80
1.25	66	76	31	72	0.36	0.72
0.625	25	62	12	59	0.29	0.59
Total	100	100	47	95	0.47	0.95

[a] Reference 25. Expressed as units/unit weight of concentrated ore processed by the smelter.

[b] Expressed as aerodynamic equivalent diameter.

[c] Nominal particulate removal efficiency is 99%.

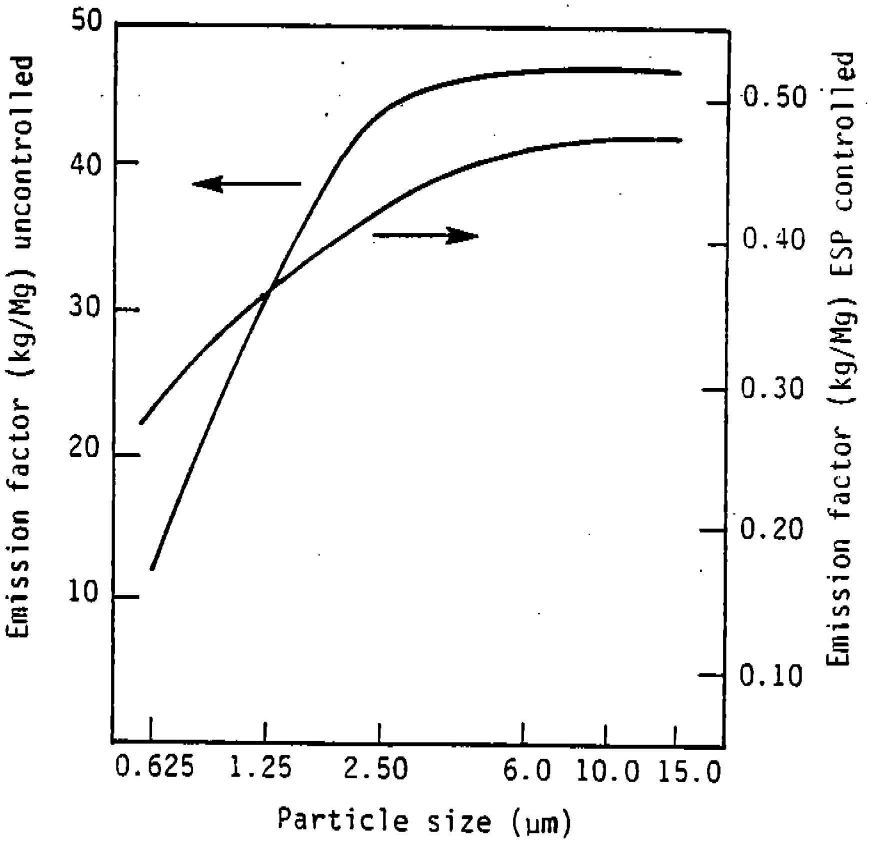

Figure 7.3-2. Size specific emission factors for multiple hearth roaster and reverberatory smelter.

TABLE 7.3-4. PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR REVERBERATORY SMELTER OPERATIONS[a]

EMISSION FACTOR RATING: E

	Cumulative mass % ≤ stated size		Cumulative emission factors			
Particle size[b] (um)	Uncontrolled	ESP controlled	Uncontrolled Kg/Mg	Uncontrolled lb/ton	ESP controlled[c] Kg/Mg	ESP controlled[c] lb/ton
15	NR	83	NR	NR	0.21	0.42
10	27	78	6.8	13.6	0.20	0.40
5	23	69	5.8	11.6	0.18	0.36
2.5	21	56	5.3	10.6	0.14	0.28
1.25	16	40	4.0	8.0	0.10	0.20
0.625	9	32	2.3	4.6	0.08	0.16
Total	100	100	25	50	0.25	0.50

[a] Reference 25. Expressed as units/unit weight of concentrated ore processed by the smelter. NR = not reported because of excessive extrapolation.

[b] Expressed as aerodynamic equivalent diameter.

[c] Nominal particulate removal efficiency is 99%.

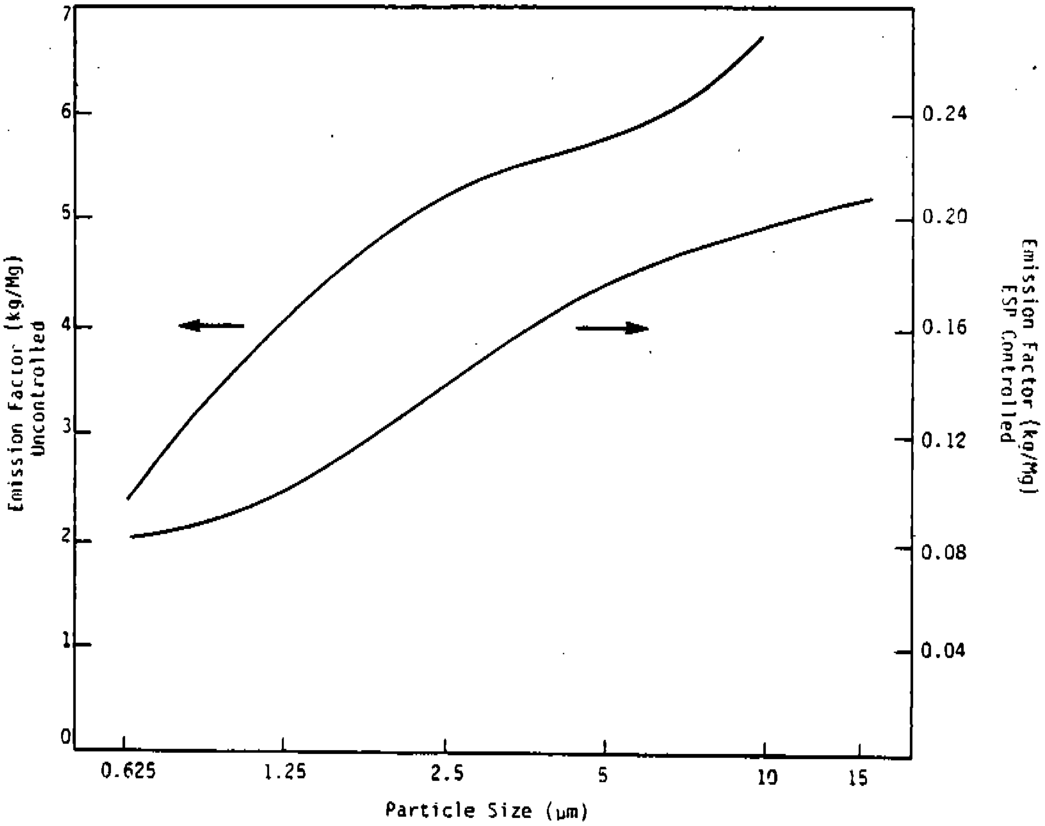

Figure 7.3-3. Size specific emission factors for reverberatory smelting.

TABLE 7.3-5. PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR COPPER CONVERTER OPERATIONS[a]

EMISSION FACTOR RATING: E

Particle size[b] (um)	Cumulative mass % ≤ stated size		Cumulative emission factors			
	Uncontrolled	ESP controlled	Uncontrolled		ESP controlled[c]	
			Kg/Mg	lb/ton	Kg/Mg	lb/ton
15	NR	100	NR	NR	0.18	0.36
10	59	99	10.6	21.2	0.17	0.36
5	32	72	5.8	11.5	0.13	0.26
2.5	12	56	2.2	4.3	0.10	0.20
1.25	3	42	0.5	1.1	0.08	0.15
0.625	1	30	0.2	0.4	0.05	0.11
Total	100	100	18	36	0.18	0.36

[a] Reference 25. Expressed as units/unit weight of concentrated ore processed by the smelter. NR = not reported because of excessive extrapolation.

[b] Expressed as aerodynamic equivalent diameter.

[c] Nominal particulate removal efficiency is 99 %.

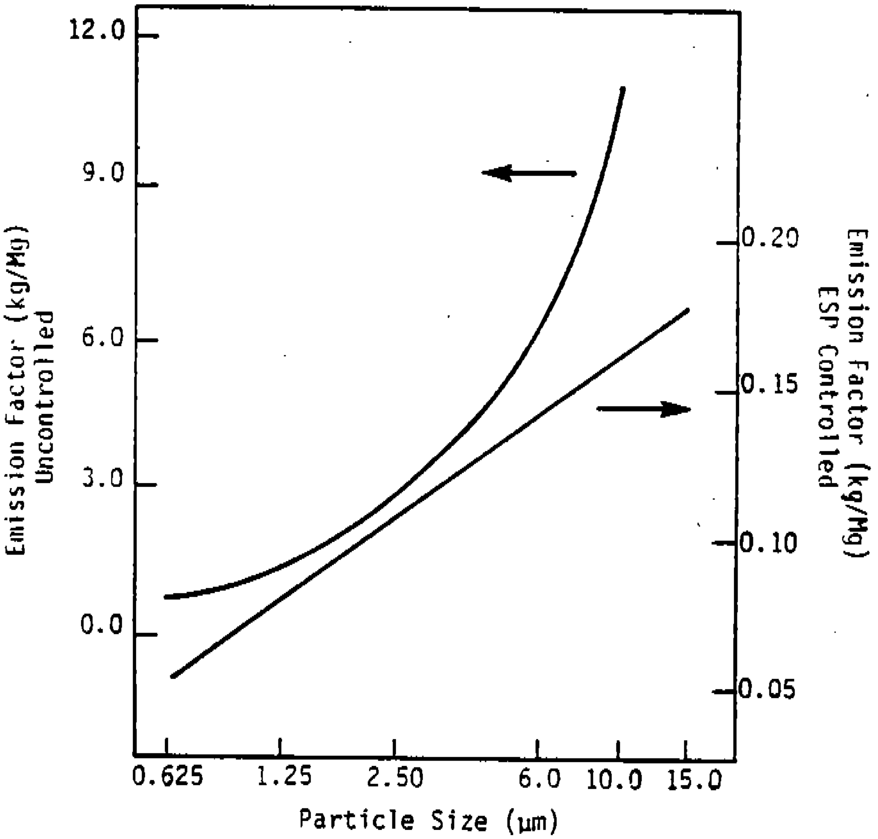

Figure 7.3-4. Size specific emission factors for copper converting.

Fugitive emissions are generated during the discharge and transfer of hot calcine from multiple hearth roasters, with negligible amounts possible from the charging of these roasters. Fluid bed roasting, a closed loop operation, has negligible fugitive emissions.

Matte tapping and slag skimming operations are sources of fugitive emissions from smelting furnaces. Fugitive emissions can also result from charging of a smelting furnace or from leaks, depending upon the furnace type and condition. A typical single matte tapping operation lasts from 5 to 10 minutes and a single slag skimming operation lasts from 10 to 20 minutes. Tapping frequencies vary with furnace capacity and type. In an 8 hour shift, matte is tapped 5 to 20 times, and slag is skimmed 10 to 25 times.

Each of the various stages of converter operation - the charging, blowing, slag skimming, blister pouring, and holding - is a potential source of fugitive emissions. During blowing, the converter mouth is in stack (i. e., a close fitting primary hood is over the mouth to capture offgases). Fugitive emissions escape from the hoods. During charging, skimming and pouring operations, the converter mouth is out of stack (i. e., the converter mouth is rolled out of its vertical position, and the primary hood is isolated). Fugitive emissions are discharged during rollout.

TABLE 7.3-6. FUGITIVE EMISSION FACTORS FOR PRIMARY COPPER SMELTERS[a]

EMISSION FACTOR RATING: B

Source of emission	Particulate		SO_2	
	kg/Mg	lb/ton	kg/Mg	lb/ton
Roaster calcine discharge	1.3	2.6	0.5	1
Smelting furnace[b]	0.2	0.4	2	4
Converter	2.2	4.4	65	130
Converter slag return	NA	NA	0.05	0.1
Anode furnace	0.25	0.5	0.05	0.1
Slag cleaning furnace[c]	4	8	3	6

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[a] References 16,22,25-32. Expressed as mass units/unit weight of concentrated ore processed by the smelter. Approximately 4 unit weights of concentrate are required to produce 1 unit weight of copper metal. Factors for flash furnace smelters and Noranda furnace smelters may be lower than reported values. NA = not available.

[b] Includes fugitive emissions from matte tapping and slag skimming operations. About 50% of fugitive particulate emissions and about 90% of total SO_2 emissions are from matte tapping operations, with remainder from slag skimming.

[c] Used to treat slags from smelting furnaces and converters at the flash furnace smelter.

TABLE 7.3-7. UNCONTROLLED PARTICLE SIZE AND SIZE SPECIFIC EMISSION FACTORS FOR FUGITIVE EMISSIONS FROM REVERBERATORY FURNACE MATTE TAPPING OPERATIONS[a]

EMISSION FACTOR RATING: D

Particle size[b] (um)	Cumulative mass % ≤ stated size	Cumulative emission factors	
		kg/Mg	lb/ton
15	76	0.076	0.152
10	74	0.074	0.148
5	72	0.072	0.144
2.5	69	0.069	0.138
1.25	67	0.067	0.134
0.625	65	0.065	0.130
Total	100	0.100	0.200

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[a] Reference 25. Expressed as units/unit weight of concentrated ore processed by the smelter.

[b] Expressed as aerodynamic equivalent diameter.

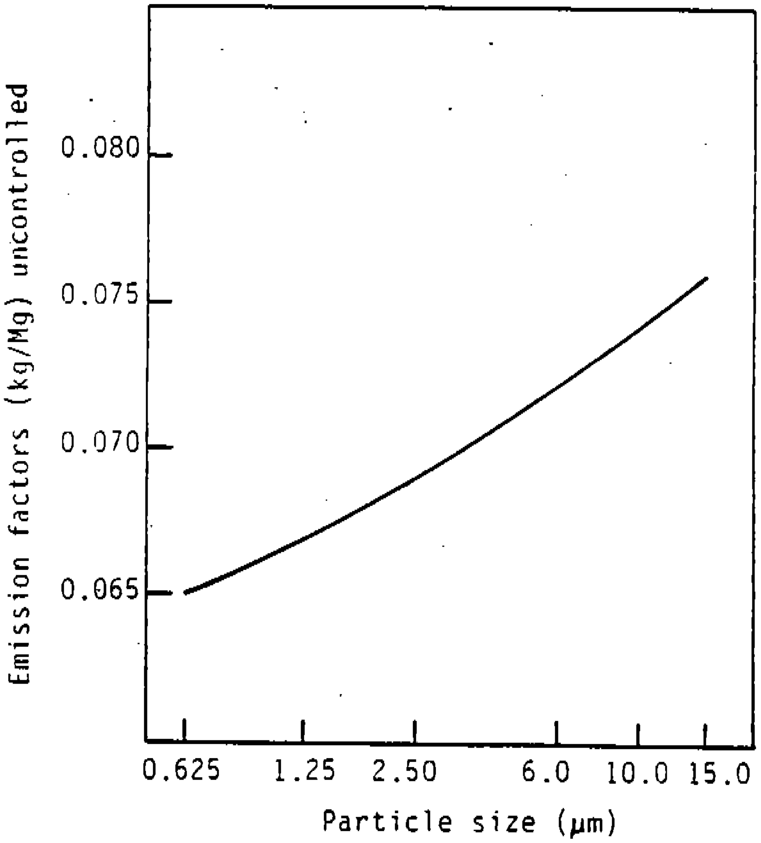


Figure 7.3-5. Size specific fugitive emission factors for reverberatory furnace matte tapping operations.

TABLE 7.3-8. PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR FUGITIVE EMISSIONS FROM REVERBERATORY FURNACE SLAG TAPPING OPERATIONS[a]

EMISSION FACTOR RATING: D

Particle size[b] (um)	Cumulative mass % ≤ stated size	Cumulative emission factors	
		kg/Mg	lb/ton
15	33	0.033	0.066
10	28	0.028	0.056
5	25	0.025	0.050
2.5	22	0.022	0.044
1.25	20	0.020	0.040
0.625	17	0.017	0.034
Total	100	0.100	0.200

[a] Reference 25. Expressed as units/unit weight of concentrated ore processed by the smelter.

[b] Expressed as aerodynamic equivalent diameter.

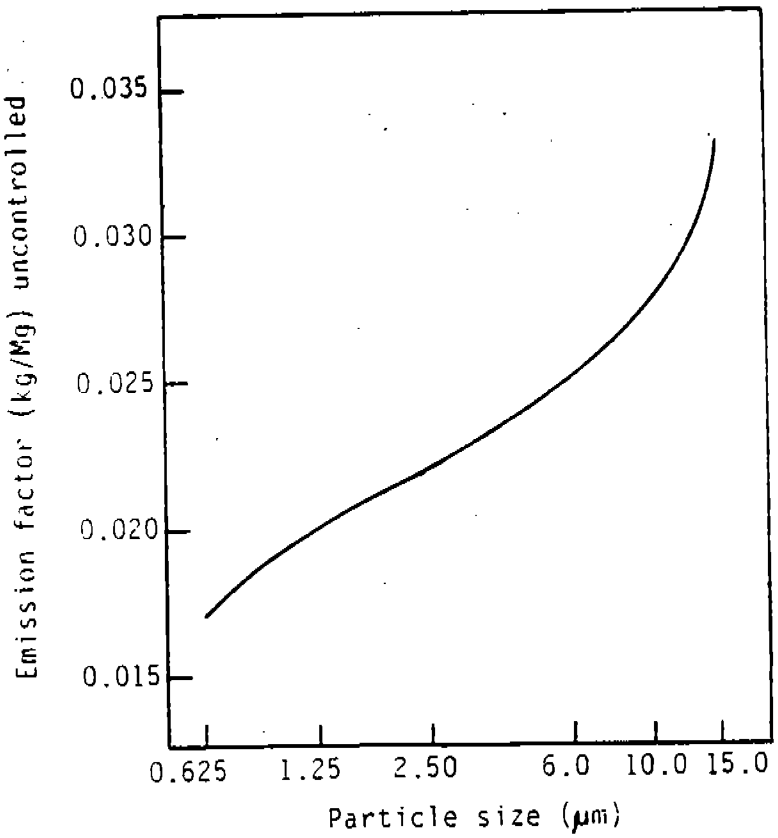


Figure 7.3-6. Size specific fugitive emission factors for reverberatory furnace slag tapping operations.

TABLE 7.3-9. PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR FUGITIVE EMISSIONS FROM CONVERTER SLAG AND COPPER BLOW OPERATIONS[a]

EMISSION FACTOR RATING: D

Particle size[b] (um)	Cumulative mass % ≤ stated size	Cumulative emission factors	
		kg/Mg	lb/ton
15	98	2.2	4.3
10	96	2.1	4.2
5	87	1.9	3.8
2.5	60	1.3	2.6
1.25	47	1.0	2.1
0.625	38	0.8	1.7
Total	100	2.2	4.4

[a] Reference 25. Expressed as units/unit weight of concentrated ore processed by the smelter.

[b] Expressed as aerodynamic equivalent diameter.

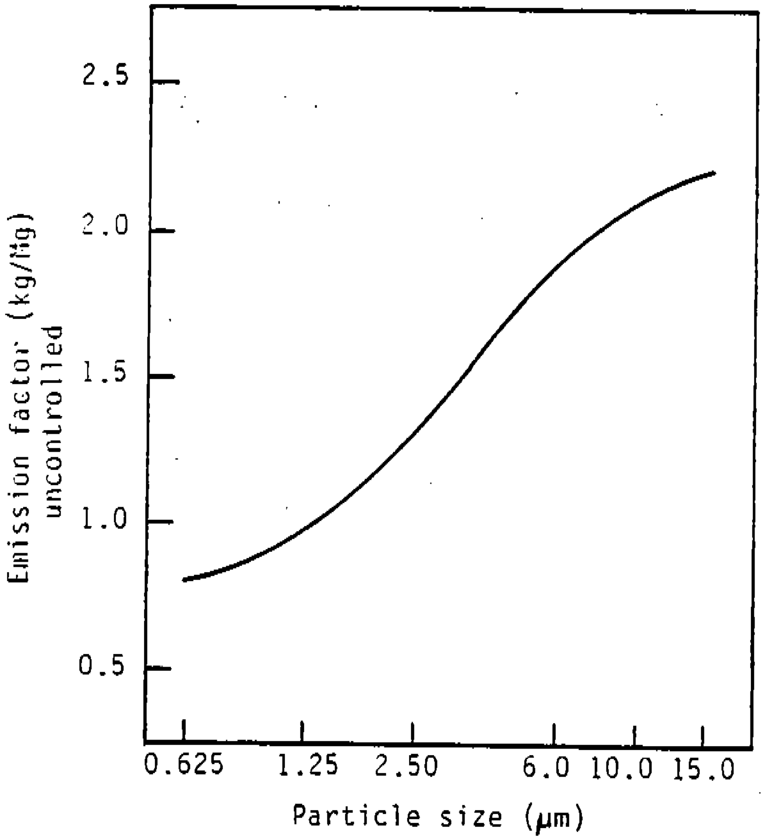


Figure 7.3-7. Size specific fugitive emission factors for converter slag and copper blow operations.

At times during normal smelting operations, slag or blister copper can not be transferred immediately from or to the converters. This condition, holding stage, may occur for several reasons, including insufficient matte in the smelting furnace, the unavailability of a crane, and others. Under these conditions, the converter is rolled out of its vertical position and remains in a holding position and fugitive emissions may result.

7.3.4 Lead Emissions

At primary copper smelters, both process emissions and fugitive particulate from various pieces of equipment contain oxides of many inorganic elements, including lead. The lead content of particulate emissions depends upon both the lead content of the smelter feed and the process offgas temperature. Lead emissions are effectively removed in particulate control systems operating at low temperatures, about 120°C (250°F).

Table 7.3-10 presents process and fugitive lead emission factors for various operations of primary copper smelters.

TABLE 7.3-10. LEAD EMISSION FACTORS FOR PRIMARY COPPER SMELTERS[a]

EMISSION FACTOR RATING: C

Operation	Emission factor[b]	
	kg/Mg	lb/ton
Roasting	0.075	0.15
Smelting	0.036	0.072
Converting	0.13	0.27
Refining	NA	NA

[a] Reference 33. Expressed as units/unit weight of concentrated ore processed by smelter. Approximately four unit weights of concentrate are required to produce one unit weight of copper metal. Based on test data for several smelters with 0.1 to 0.4 % lead in feed throughput. NA = not available.

[b] For process and fugitive emissions totals.

[c] Based on test data on multihearth roasters. Includes total of process emissions and calcine transfer fugutive emissions. The latter are about 10% of total process and fugitive emissions.

[d] Based on test data on reverberatory furnaces. Includes total process emissions and fugitive emissions from matte tapping and slag skimming operations. Fugitive emissions from matte tapping and slag skimming operations amount to about 35% and 2%, respectively.

[e] Includes total of process and fugitive emissions. Fugitives constitute about 50% of total.

Fugitive emissions from primary copper smelters are captured by applying either local ventilation or general ventilation techniques. Once captured, emissions may be vented directly to a collection device or be combined with process offgases before collection. Close fitting exhaust hood capture systems are used for multiple hearth roasters and hood ventilation systems for smelt matte tapping and slag skimming operations. For converters, secondary hood systems or building evacuation systems are used.

References for Section 7.3

1. Background Information for New Source Performance Standards: Primary Copper, Zinc and Lead Smelters, Volume I, Proposed Standards, EPA-450/2-74-002a, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1974.
2. Arsenic Emissions from Primary Copper Smelters - Background Information for Proposed Standards, Preliminary Draft, EPA Contract No. 68-02-3060, Pacific Environmental Services, Durham, NC, February 1981.
3. Background Information Document for Revision of New Source Performance Standards for Primary Copper Smelters, EPA Contract No. 68-02-3056, Research Triangle Institute, Research Triangle Park, NC, March 31, 1982.
4. Air Pollution Emission Test: Asarco Copper Smelter, El Paso, TX, EMB-77-CUS-6, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1977.
5. Written communications from W. F. Cummins, Inc., El Paso, TX, to A. E. Vervaert, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1977.
6. AP-42 Background Files, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1978.
7. Source Emissions Survey of Kennecott Copper Corporation, Copper Smelter Converter Stack Inlet and Outlet and Reverberatory Electrostatic Precipitator Inlet and Outlet, Hurley, NM, EA-735-09, Ecology Audits, Inc., Dallas, TX, April 1973.
8. Trace Element Study at a Primary Copper Smelter, EPA-600/2-78-065a and 065b, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1978.
9. Systems Study for Control of Emissions, Primary Nonferrous Smelting Industry, Volume II: Appendices A and B, PB 184885, National Technical Information Service, Springfield, VA, June 1969.
10. Design and Operating Parameters for Emission Control Studies: White Pine Copper Smelter, EPA-600/2-76-036a, U. S. Environmental Protection Agency, Washington, DC, February 1976.

11. R. M. Statnick, Measurements of Sulfur Dioxide, Particulate and Trace Elements in Copper Smelter Converter and Roaster/Reverberatory Gas Streams, PB 238095, National Technical Information Service, Springfield,VA, October 1974.

12. AP-42 Background Files, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC.

13. Design and Operating Parameters for Emission Control Studies, Kennecott-McGill Copper Smelter, EPA-600/2-76-036c, U. S. Environmental Protection Agency, Washington, DC, February 1976.

14. Emission Test Report (Acid Plant) of Phelps Dodge Copper Smelter, Ajo, AZ, EMB-78-CUS-11, Office Of Air Quality Planning And Standards, Research Triangle Park, NC, March 1979.

15. S. Dayton, "Inspiration's Design for Clean Air", Engineering and Mining Journal, 175:6, June 1974.

16. Emission Testing of Asarco Copper Smelter, Tacoma, WA, EMB-78-CUS-12, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1979.

17. Written communication from A. L. Labbe, Asarco, Inc., Tacoma, WA, to S. T. Cuffe, U. S. Environmental Protection Agency, Research Triangle Park, NC, November 20, 1978.

18. Design and Operating Parameters for Emission Control Studies: Asarco-Hayden Copper Smelter, EPA-600/2-76-036j, U. S. Environmental Protection Agency, Washington, DC, February 1976.

19. Design and Operating Parameters for Emission Control Studies: Kennecott, Hayden Copper Smelter, EPA-600/2-76-036b, U. S. Environmental Protection Agency, Washington, DC, February 1976.

20. R. Larkin, Arsenic Emissions at Kennecott Copper Corporation, Hayden, AZ, EPA-76-NFS-1, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1977.

21. Emission Compliance Status, Inspiration Consolidated Copper Company, Inspiration, AZ, U. S. Environmental Protection Agency, San Francisco, CA, 1980.

22. Written communication from M. P. Scanlon, Phelps Dodge Corporation, Hidalgo, AZ, to D. R. Goodwin, U. S. Environmenal Protection Agency, Research Triangle Park, NC, October 18, 1978.

23. Written communication from G. M. McArthur, The Anaconda Company, to D. R. Goodwin, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 2, 1977.

24. Telephone communication from V. Katari, Pacific Environmental Services, Durham, NC, to R. Winslow, Hidalgo Smelter, Phelps Dodge Corporation, Hidalgo, AZ, April 1, 1982.

25. Inhalable Particulate Source Category Report for the Nonferrous Industry, Contract 68-02-3159, Acurex Corp., Mountain View, CA, August 1986.

26. Emission Test Report, Phelps Dodge Copper Smelter, Douglas, AZ, EMB-78-CUS-8, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1979.

27. Emission Testing of Kennecott Copper Smelter, Magna, UT, EMB-78-CUS-13, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1979.

28. Emission Test Report, Phelps Dodge Copper Smelter, Ajo, AZ, EMB-78-CUS-9, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1979.

29. Written communication from R. D. Putnam, Asarco, Inc., to M. O. Varner, Asarco, Inc., Salt Lake City, UT, May 12, 1980.

30. Emission Test Report, Phelps Dodge Copper Smelter, Playas, NM, EMB-78-CUS-10, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1979.

31. Asarco Copper Smelter, El Paso, TX, EMB-78-CUS-7, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 25, 1978.

32. A. D. Church, et al., "Measurement of Fugitive Particulate and Sulfur Dioxide Emissions at Inco's Copper Cliff Smelter", Paper A-79-51, The Metallurgical Society, American Institute of Mining, Metallurgical and Petroleum Engineers (AIME), New York, NY.

33. Copper Smelters, Emission Test Report - Lead Emissions, EMB-79-CUS-14, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1979.

7.4 FERROALLY PRODUCTION

7.4.1 General

A ferroalloy is an alloy of iron and one or more other elements, such as silicon, manganese or chromium. Ferroalloys are used as additives to impart unique properties to steel and cast iron. The iron and steel industry consumes approximately 95 percent of the ferroalloy produced in the United States. The remaining 5 percent is used in the production of nonferrous alloys, including cast aluminum, nickel/cobalt base alloys, titanium alloys, and in making other ferroalloys.

Three major groups, ferrosilicon, ferromanganese, and ferrochrome, constitute approximately 85 percent of domestic production. Subgroups of these alloys include siliconmanganese, silicon metal and ferrochromium. The variety of grades manufactured is distinguished primarily by carbon, silicon or aluminum content. The remaining 15 percent of ferroalloy production is specialty alloys, typically produced in small amounts and containing elements such as vanadium, columbium, molybdenum, nickel, boron, aluminum and tungsten.

Ferroalloy facilities in the United States vary greatly in size. Many facilities have only one furnace and require less than 25 megawatts. Others consist of 16 furnaces, produce six different types of ferroalloys, and require over 75 megawatts of electricity.

A typical ferroalloy plant is illustrated in Figure 7.4-1. A variety of furnace types produces ferroalloys, including submerged electric arc furnaces, induction furnaces, vacuum furnaces, exothermic reaction furnaces and electrolytic cells. Furnace descriptions and their ferroalloy products are given in Table 7.4-1. Ninety-five percent of all ferroalloys, including all bulk ferroalloys, are produced in submerged electric arc furnaces, and it is the furnace type principally discussed here.

The basic design of submerged electric arc furnaces is generally the same throughout the ferroalloy industry in the United States. The submerged electric arc furnace comprises a cylindrical steel shell with a flat bottom or hearth. The interior of the shell is lined with two or more layers of carbon blocks. Raw materials are charged through feed chutes from above the furnace. The molten metal and slag are removed through one or more tapholes extending through the furnace shell at the hearth level. Three carbon electrodes, arranged in a delta formation, extend downward through the charge material to a depth of 3 to 5 feet to melt the charge.

Submerged electric arc furnaces are of two basic types, open and covered. About 80 percent of submerged electric arc furnaces in the United States are of the open type. Open furnaces have a fume collection hood at least one meter above the top of the furnace. Moveable panels or screens sometimes are used to reduce the open area between the furnace and hood to improve emissions capture

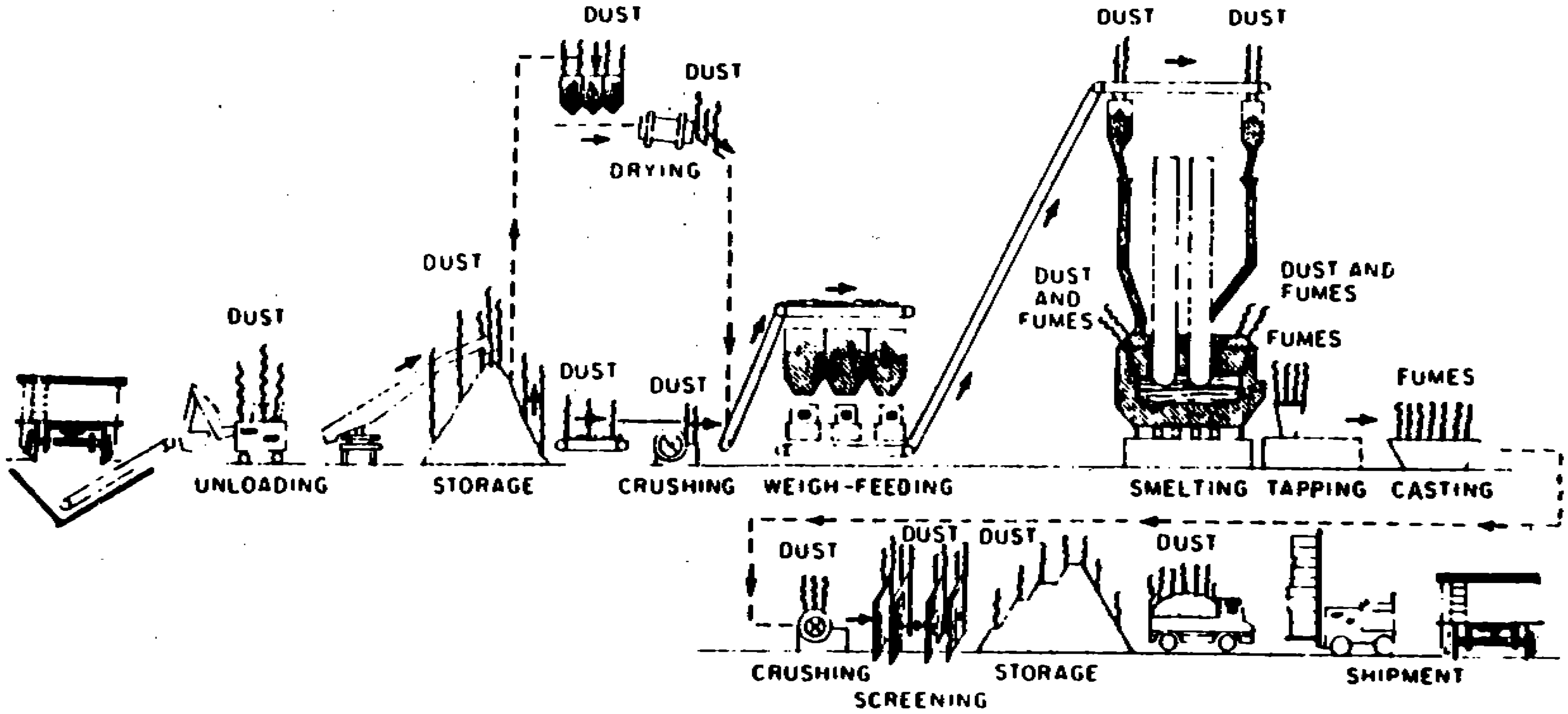


Figure 7.4-1. Typical ferroalloy production process, showing emission points.

TABLE 7.4-1. FERROALLOY PROCESSES AND RESPECTIVE PRODUCT GROUPS

Process	Product
Submerged arc furnace[a]	Silvery iron (15 - 22% Si) Ferrosilicon (50% Si) Ferrosilicon (65 - 75% Si) Silicon metal Silicon/manganese/zirconium (SMZ) High carbon (HC) ferromanganese Siliconmanganese HC ferrochrome Ferrochrome/silicon FeSi (90% Si)
Exothermic[b]	
Silicon reduction	Low carbon (LC) ferrochrome, LC ferromanganese, Medium carbon (MC) ferromanganese
Aluminum reduction	Chromium metal, Ferrotitanium, Ferrocolumbium, Ferrovanadium
Mixed aluminothermal/silicothermal	Ferromolybdenum, Ferrotungsten
Electrolytic[c]	Chromium metal, Manganese metal
Vacuum furnace[d]	LC ferrochrome
Induction furnace[e]	Ferrotitanium

[a] Process by which metal is smelted in a refractory lined cup shaped steel shell by three submerged graphite electrodes.

[b] Process by which molten charge material is reduced, in exthermic reaction, by addition of silicon, aluminum or combination of the two.

[c] Process by which simple ions of a metal, usually chromium or manganese in an electrolyte, are plated on cathodes by direct low voltage current.

[d] Process by which carbon is removed from solid state high carbon ferrochrome within vacuum furnaces maintained at temperature near melting point of alloy.

[e] Process which converts electrical energy without electrodes into heat, without electrodes, to melt metal charge in a cup or drum shaped vessel.

efficiency. Covered furnaces have a water cooled steel cover to seal the top, with holes through it for the electrodes. The degree of emission containment provided by the covers is quite variable. Air infiltration sometimes is reduced by placing charge material around the electrode holes. This type is called a mix seal or semienclosed furnace. Another type is a sealed or totally closed furnace having mechanical seals around the electrodes and a sealing compound packed around the cover edges.

The submerged arc process is a reduction smelting operation. The reactants consist of metallic ores and quartz (ferrous oxides, silicon oxides, manganese oxides, chrome oxides, etc.). Carbon, usually as coke, low volatility coal or wood chips, is charged to the furnace as a reducing agent. Limestone also may be added as a flux material. After crushing, sizing, and in some cases, drying, the raw materials are conveyed to a mix house for weighing and blending, thence by conveyors, buckets, skip hoists, or cars to hoppers above the furnace. The mix is then fed by gravity through a feed chute either continuously or intermittently, as needed. At high temperatures in the reaction zone the carbon sources react chemically with oxygen in the metal oxides to form carbon monoxide and to reduce the ores to base metal. A typical reaction, illustrating 50 percent ferrosilicon production, is:

$$Fe_2O_3 + 2\ SiO_2 + 7C \rightarrow 2\ FeSi + 7CO.$$

Smelting in an electric arc furnace is accomplished by conversion of electrical energy to heat. An alternating current applied to the electrodes causes a current flow through the charge between the electrode tips. This provides a reaction zone of temperatures up to 2000°C (3632°F). The tip of each electrode changes polarity continuously as the alternating current flows between the tips. To maintain a uniform electric load, electrode depth is continuously varied automatically by mechanical or hydraulic means, as required. Furnace power requirements vary from 7 megawatts to over 50 megawatts, depending upon the furnace size and the product being made. The average is 17.2 megawatts[6]. Electrical requirements for the most common ferroalloys are given in Table 7.4-2.

TABLE 7.4-2. FURNACE POWER REQUIREMENTS FOR DIFFERENT FERROALLOYS

Product	Furnace load (kw-hr/lb alloy produced)	
	Range	Approximate average
50% FeSi	2.4 - 2.5	2.5
Silicon metal	6.0 - 8.0	7.0
High carbon FeMn	1.0 - 1.2	1.2
High carbon FeCr	2.0 - 2.2	2.1
SiMn	2.0 - 2.3	2.2

The molten alloy and slag that accumulate on the furnce hearth are removed at 1 to 5 hour intervals through the taphole. Tapping typically lasts 10 to 15 minutes. Tapholes are opened with a pellet shot from a gun, by drilling or by oxygen lancing. The molten metal and slag flow from the taphole into a carbon lined trough, then into a carbon lined runner which directs the metal and slag into a reaction ladle, ingot molds, or chills. Chills are low flat iron or steel pans that provide rapid cooling of the molten metal. Tapping is terminated and the furnace resealed by inserting a carbon paste plug into the taphole.

When chemistry adjustments after furnace smelting are necessary to produce a specified product, a reaction ladle is used. Ladle treatment reactions are batch processes and may include chlorination, oxidation, gas mixing, and slag-metal reactions.

During tapping, and/or in the reaction ladle, slag is skimmed from the surface of the molten metal. It can be disposed of in landfills, sold as road ballast, or used as a raw material in a furnace or reaction ladle to produce a chemically related ferroalloy product.

After cooling and solidifying, the large ferroalloy castings are broken with drop weights or hammers. The broken ferroalloy pieces are then crushed, screened (sized) and stored in bins until shipment.

7.4.2 Emissions And Controls

Particulate is generated from several activities at a ferroalloy facility, including raw material handling, smelting and product handling. The furnaces are the largest potential sources of particulate emissions. The emission factors in Tables 7.4-3 and 7.4-4 and the particle size information in Figures 7.4-2 through 7.4-11 reflect controlled and uncontrolled emissions from ferroalloy smelting furnaces. Emission factors for sulfur dioxide, carbon monoxide and organic emissions are presented in Table 7.4-5.

Electric arc furnaces emit particulate in the form of fume, accounting for an estimated 94 percent of the particulate emissions in the ferroalloy industry. Large amounts of carbon monoxide and organic materials also are emitted by submerged electric arc furnaces. Carbon monoxide is formed as a byproduct of the chemical reaction between oxygen in the metal oxides of the charge and carbon contained in the reducing agent (coke, coal, etc.). Reduction gases containing organic compounds and carbon monoxide continuously rise from the high temperature reaction zone, entraining fine particles and fume precursors. The mass weight of carbon monoxide produced sometimes exceeds that of the metallic product (see Table 7.4-5). The chemical constituents of the heat induced fume consist of oxides of the products being produced, carbon from the reducing agent, and enrichment by SiO_2, CaO and MgO, if present in the charge.[20]

In an open electric arc furnace, all carbon monoxide burns with induced air at the furnace top. The remaining fume, captured by hooding about 1 meter above the furnace, is directed to a gas cleaning device. Baghouses are used to control emissions from 85 percent of the open furnaces in the United States.

TABLE 7.4-3. EMISSION FACTORS FOR PARTICULATE FROM SUBMERGED ARC FERROALLOY FURNACES^a

Product^b	Furnace type	Particulate emission factors Uncontrolled^c kg/Mg (lb/ton) alloy	Particulate emission factors Uncontrolled^c kg (lb)/Mw-hr	Size data	Notes	Emission Factor Rating	Control device^d	Particulate emission factors Controlled^c kg/Mg (lb/ton) alloy	Particulate emission factors Controlled^c kg (lb)/Mw-hr	Size data	Notes	Emission Factor Rating
FeSi (50%)	Open	35 (70)	7.4 (16.3)	Yes	e,f,g	B	Baghouse	0.9 (1.8)	0.2 (0.4)	Yes	e,f	B
	Covered	46 (92)	9.3 (20.5)		h	E	Scrubber					
							High energy	0.24 (0.48)	0.05 (0.1)		h,j	E
							Low energy	4.5 (9.0)	0.77 (1.7)		h,j	E
FeSi (75%)	Open	358 (316)	16 (35)		k	E						
	Covered	103 (206)	13 (29)		h,j	E	Scrubber					
							Low energy	4.0 (8.0)	0.5 (1.1)		h,j	E
FeSi (90%)	Open	282 (564)	24 (53)	Yes	m	E						
Si metal (98%)	Open	436 (872)	33 (73)	Yes	n,p	B	Baghouse	16 (32)	1.2 (2.6)	Yes	n,p	B
FeMn (80%)	Open	14 (28)	4.8 (11)	Yes	q,r	B	Baghouse	0.24 (0.48)	0.078 (0.2)	Yes	q,r	B
							Scrubber					
							High energy	0.8 (1.6)	0.34 (0.7)		h,s	E
FeMn (1% Si)	Covered	6 (12)	2.4 (5.3)		h,t	E	High energy	0.25 (0.5)	0.10 (0.2)		h,s,w	C
	Sealed	37 (74)	17 (37)		u,v	E						
FeCr (high carbon)	Open	78 (157)	15 (33)	Yes	x,y	C	ESP	1.2 (2.3)	0.23 (0.5)	Yes	x,y	C
SiMn	Open	96 (192)	20 (44)	Yes	z,aa	C	Scrubber	2.1 (4.2)	0.44 (1.0)	Yes	aa,bb	C
	Sealed	- (-)	- (-)				Scrubber					
							High energy	0.15 (0.30)	0.016 (0.04)		v,w	E

TABLE 7.4-3 (Cont.). NOTES

[a] Factors are for main furnace dust collection system before and after control device. Where other emissions, such as leaks or tapping, are included or quantified separately, such is noted. Particulate sources not included: raw material handling, storage, preparation; and product crushing, screening, handling, packaging.

[b] Percentages are of the main alloying element in product.

[c] In most source testing, fugitive emissions not measured or collected. Where tapping emissions are controlled by primary system, their contribution to total emissions could not be determined. Fugitive emissions may vary greatly among sources, with furnace and collection system design and operating practices.

[d] Low energy scrubbers are those with $\Delta P < 20$ in. H_2O; high energy, with $\Delta P > 20$ in. H_2O.

[e] Includes fumes captured by tapping hood (efficiency estimated near 100%).

[f] References 4, 10, 21.

[g] Factor is average of 3 sources, fugitive emissions not included. Fugitive emissions at one source measured an additional 10.5 kg/Mg alloy, or 2.7 kg/Mw hr.

[h] References 4, 10.

[j] Does not include emissions from tapping or mix seal leaks.

[k] References 25-26.

[m] Reference 23.

[n] Estimated 60% of tapping emissions captured by control system (escaped fugitive emissions not included in factor).

[p] References 10, 13.

[q] Estimated 50% of tapping emissions captured by control system (escaped fugitive emissions not included in factor).

[r] References 4, 10, 12.

[s] Includes fume only from primary control system.

[t] Includes tapping fumes and mix seal leak fugitive emissions. Fugitive emissions measured at 33% of total uncontrolled emissions.

[u] Assumes tapping fumes not included in emission factor.

[v] Reference 14. Dash = No data.

[w] Does not include tapping or fugitive emissions.

[x] Tapping emissions included. Factor developed from two test series performed on the same furnace 7 years apart. Measured emissions in latter test were 36% less than in former.

[y] References 2, 15-17.

[z] Factor is average of two test series. Tests at one source included fugitive emissions (3.4% of total uncontrolled emissions). Second test insufficient to determine if fugitive emissions were included in total.

[aa] References 2, 18-19.

[bb] Factors developed from two scrubber controlled sources, one operated at $\Delta P = 47-57"$ H_2O, the other at unspecified ΔP. Uncontrolled tapping operations emissions are 2.1 kg/Mg alloy.

TABLE 7.4-4. SIZE SPECIFIC EMISSION FACTORS FOR SUBMERGED ARC FERROALLOY FURNACES

Product	Control device	Particle size^a (μm)	Cumulative mass % ≤ stated size	Cumulative mass emission factor kg/Mg (lb/ton) alloy	Emission Factor Rating
50% FeSi Open furnace	None^{b,c}	0.63	45	16 (32)	B
		1.00	50	18 (35)	
		1.25	53	19 (37)	
		2.50	57	20 (40)	
		6.00	61	21 (43)	
		10.00	63	22 (44)	
		15.00	66	23 (46)	
		20.00	69	24 (48)	
		d	100	35 (70)	
	Baghouse	0.63	31	0.28 (0.56)	B
		1.00	39	0.35 (0.70)	
		1.25	44	0.40 (0.80)	
		2.50	54	0.49 (1.0)	
		6.00	63	0.57 (1.1)	
		10.00	72	0.65 (1.3)	
		15.00	80	0.72 (1.4)	
		20.00	85	0.77 (1.5)	
			100	0.90 (1.8)	
80% FeMn Open furnace	None^{e,f}	0.63	30	4 (8)	B
		1.00	46	7 (13)	
		1.25	52	8 (15)	
		2.50	62	9 (17)	
		6.00	72	10 (20)	
		10.00	86	12 (24)	
		15.00	96	13 (26)	
		20.00	97	14 (27)	
		d	100	14 (28)	

(continued)

TABLE 7.4-4 (cont.)

Product	Control device	Particle size[a] (μm)	Cumulative mass% ≤ stated size	Cumulative mass emission factor kg/Mg	(lb/ton) alloy	Emission Factor Rating
80% FeMn Open furnace	Baghouse[e]	0.63	20	0.048	(0.10)	B
		1.00	30	0.070	(0.14)	
		1.25	35	0.085	(0.17)	
		2.50	49	0.120	(0.24)	
		6.00	67	0.160	(0.32)	
		10.00	83	0.200	(0.40)	
		15.00	92	0.220	(0.44)	
		20.00	97	0.235	(0.47)	
		d	100	0.240	(0.48	
Si Metal[h] Open furnace	None[g]	0.63	57	249	(497)	B
		1.00	67	292	(584)	
		1.25	70	305	(610)	
		2.50	75	327	(654)	
		6.00	80	349	(698)	
		10.00	86	375	(750)	
		15.00	91	397	(794)	
		20.00	95	414	(828)	
		d	100	436	(872)	
	Baghouse	1.00	49	7.8	(15.7)	B
		1.25	53	8.5	(17.0)	
		2.50	64	10.2	(20.5)	
		6.00	76	12.2	(24.3)	
		10.00	87	13.9	(28.0)	
		15.00	96	15.4	(31.0)	
		20.00	99	15.8	(31.7)	
			100	16.0	(32.0)	

(continued)

TABLE 7.4-4 (cont.)

Product	Control device	Particle size[a] (µm)	Cumulative mass% ≤ stated size	Cumulative mass emission factor kg/Mg (lb/ton) alloy	Emission Factor Rating
FeCr (HC) Open furnace	None[b,j]	0.5	19	15 (30)	C
		1.0	36	28 (57)	
		2.0	60	47 (94)	
		2.5	63[k]	49 (99)	
		4.0	76	59 (119)	
		6.0	88[k]	67 (138)	
		10.0	91	71 (143)	
		d	100	78 (157)	
	ESP	0.5	33	0.40 (0.76)	C
		1.0	47	0.56 (1.08)	
		2.5	67	0.80 (1.54)	
		5.0	80	0.96 (1.84)	
		6.0	86	1.03 (1.98)	
		10.0	90	1.08 (2.07)	
		d	100	1.2 (2.3)	
SiMn Open furnace	None[b,m]	0.5	28	27 (54)	C
		1.0	44	42 (84)	
		2.0	60	58 (115)	
		2.5	65	62 (125)	
		4.0	76	73 (146)	
		6.0	85	82 (163)	
		10.0	96[k]	92[k] (177)[k]	
		d	100	96 (192)	

(continued)

TABLE 7.4-4 (cont.)

Product	Control device	Particle size[a] (µm)	Cumulative mass% ≤ stated size	Cumulative mass emission factor kg/Mg (lb/ton) alloy	Emission Factor Rating
SiMn Open furnace (cont.)	Scrub-ber[m,n]	0.5	56	1.18 (2.36)	C
		1.0	80	1.68 (3.44)	
		2.5	96	2.02 (4.13)	
		5.0	99	2.08 (4.26)	
		6.0	99.5	2.09 (4.28)	
		10.0	99.9[k]	2.10[k] (4.30)[k]	
			100	2.1 (4.3)	

[a] Aerodynamic diameter, based on Task Group On Lung Dynamics definition. Particle density = 1 g/cm^3.

[b] Includes tapping emissions.

[c] References 4, 10, 21.

[d] Total particulate, based on Method 5 total catch (see Table 7.4-3).

[e] Includes tapping fume (capture efficiency 50%).

[f] References 4, 10, 12.

[g] Includes tapping fume (estimated capture efficiency 60%).

[h] References 10, 13.

[j] References 1, 15-17.

[k] Interpolated data.

[m] References 2, 18-19.

[n] Primary emission control system only, without tapping emissions.

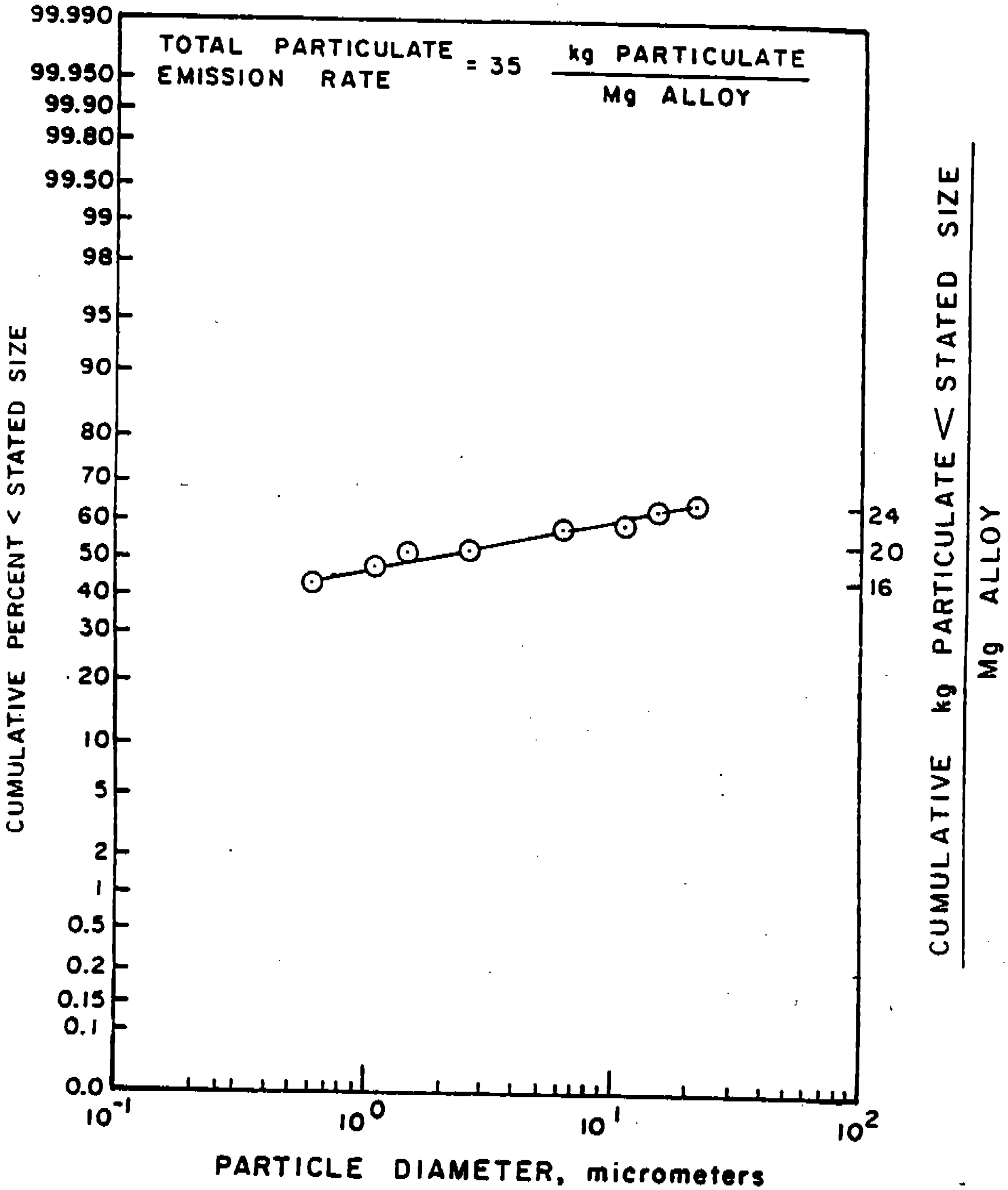


Figure 7.4-2. Uncontrolled, 50% FeSi producing, open furnace particle size distribution.

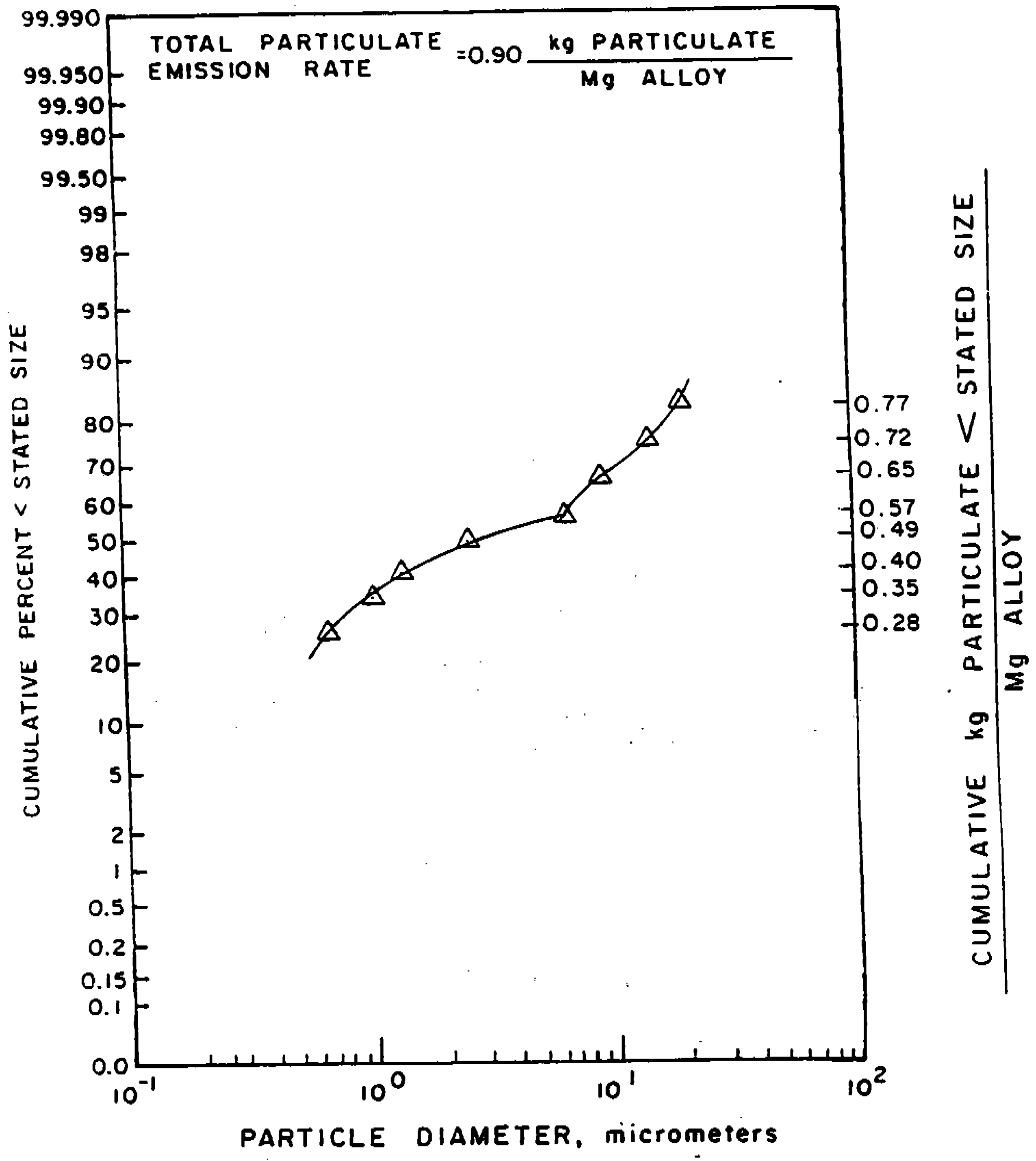


Figure 7.4-3 Controlled (baghouse), 50% FeSi, open furnace particle size distribution

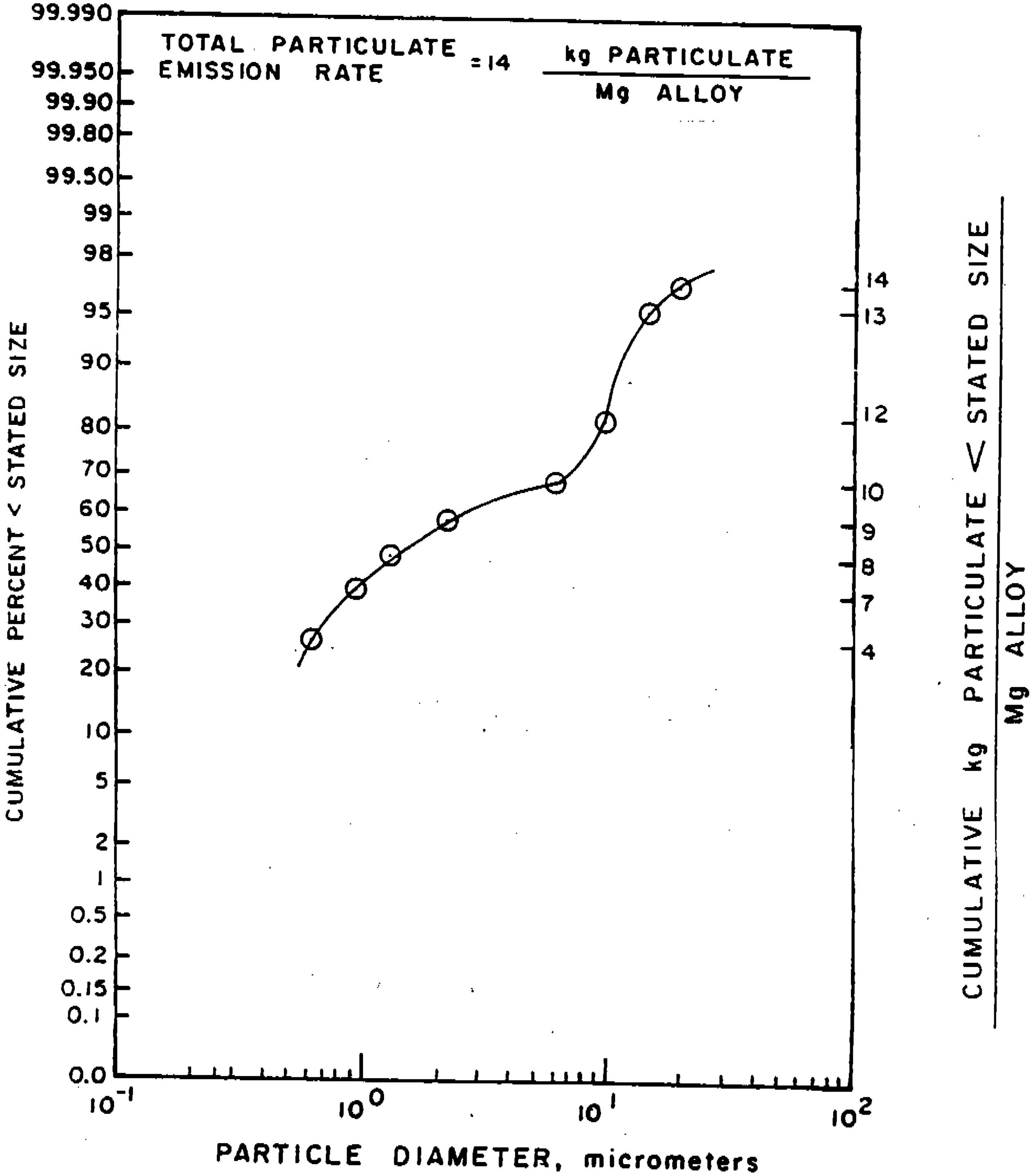


Figure 7.4-4. Uncontrolled, 80% FeMn producing, open furnace particle size distribution

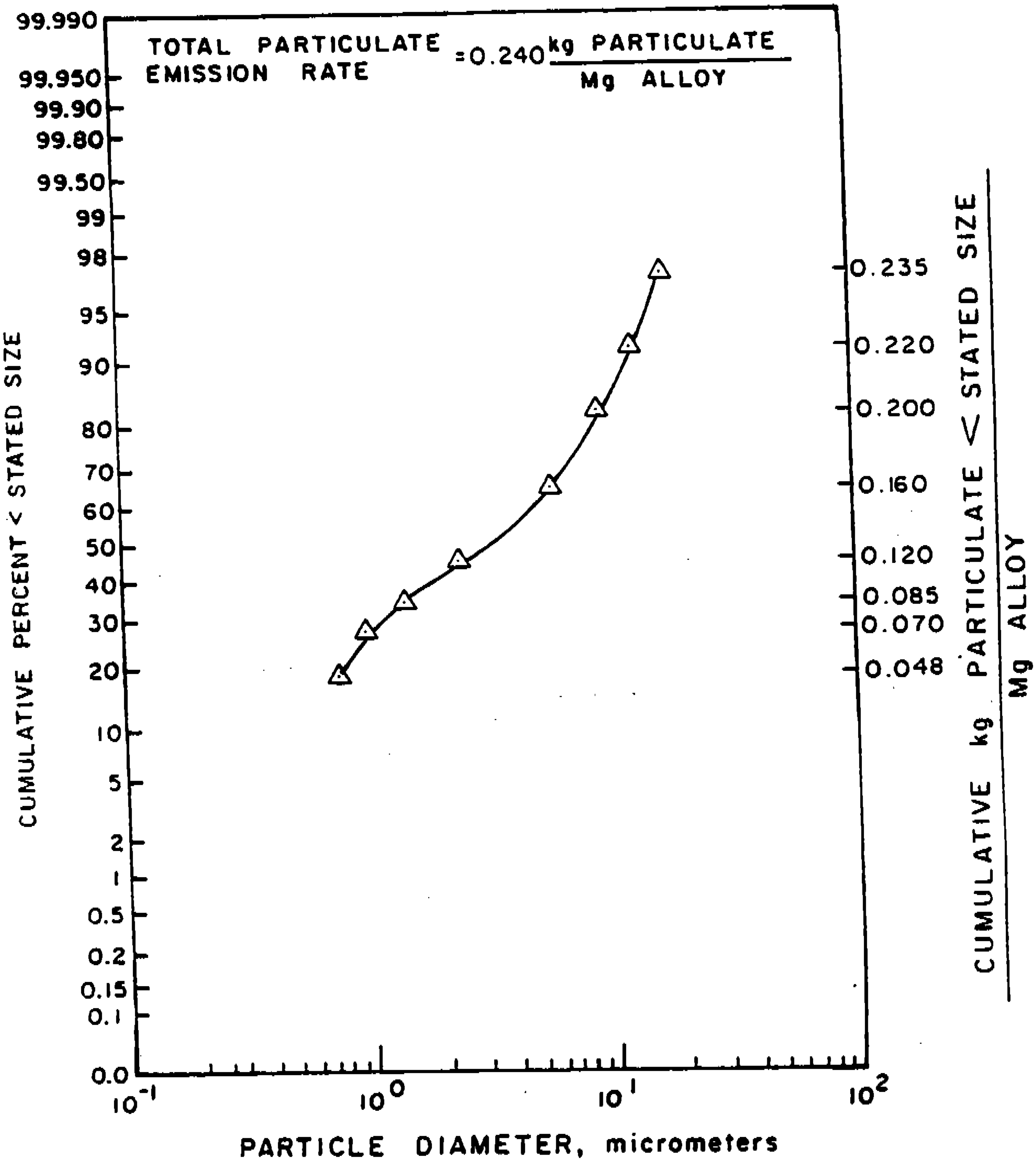


Figure 7.4-5. Controlled (baghouse), 80% FeMn producing, open furnace size distribution

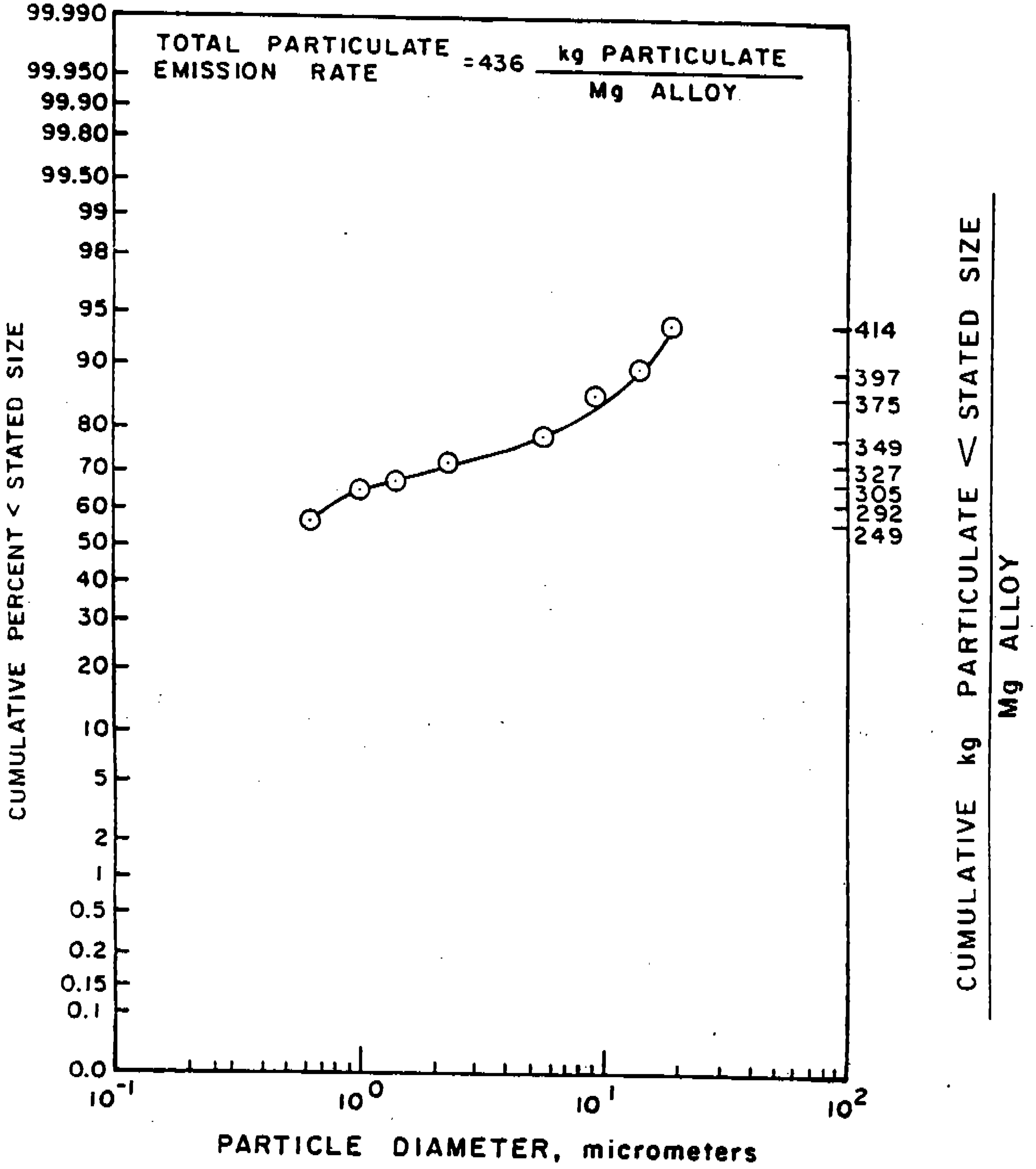


Figure 7.4-6. Uncontrolled, Si metal producing, open furnace particle size distribution

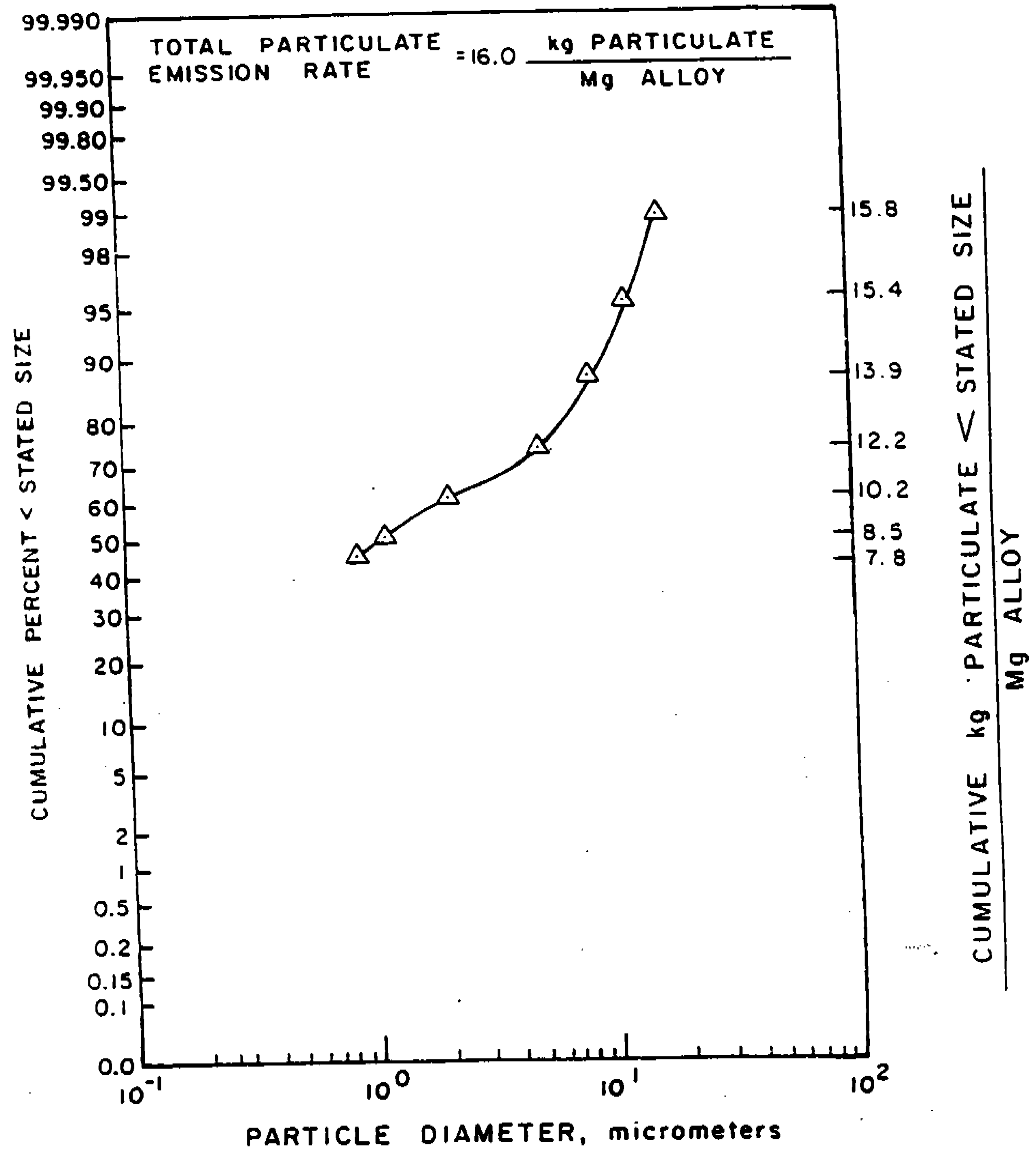


Figure 7.4-7. Controlled (baghouse), Si metal producing, open furnace particle size distribution

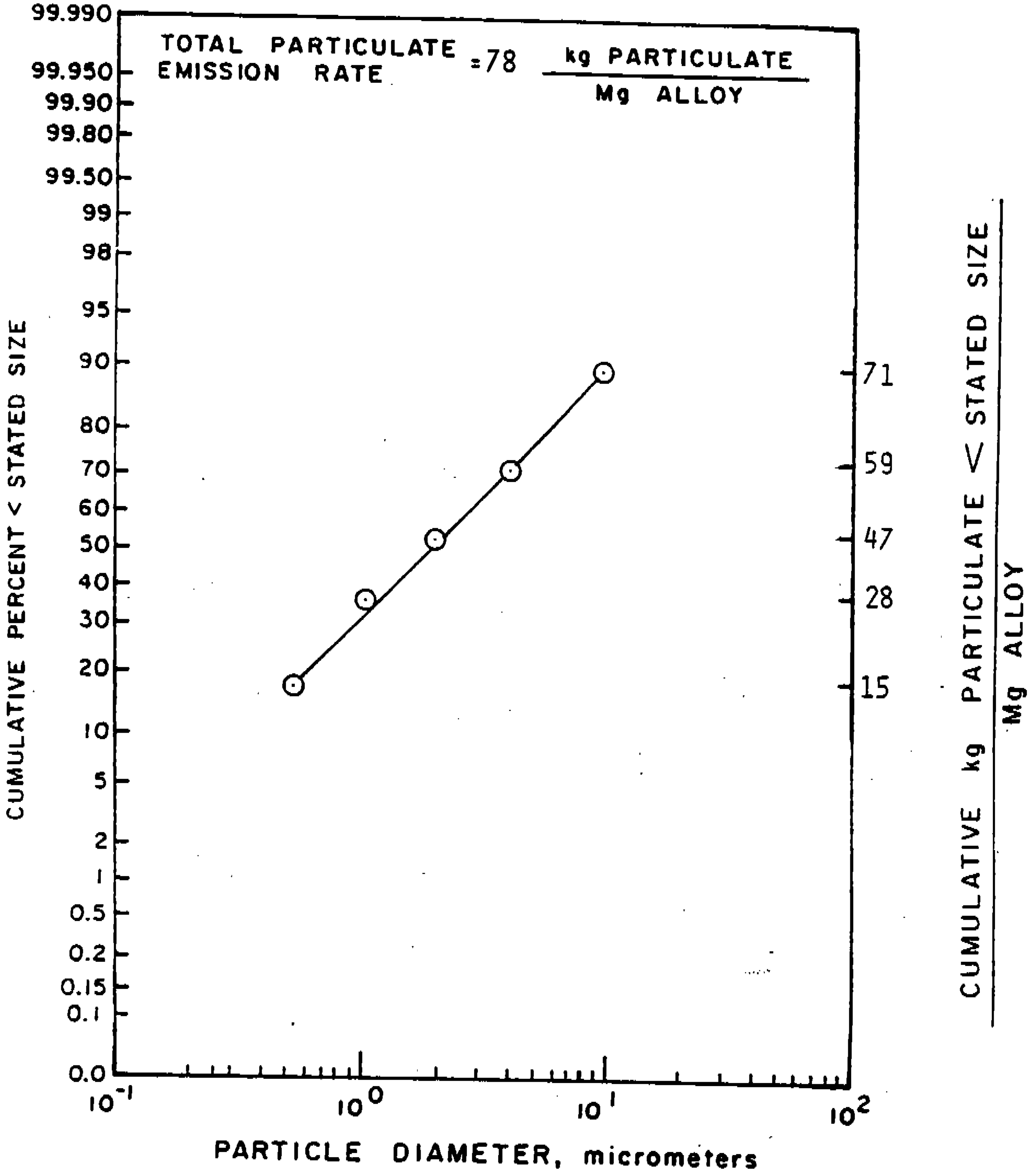


Figure 7.4-8. Uncontrolled, FeCr producing, open furnace particle size distribution

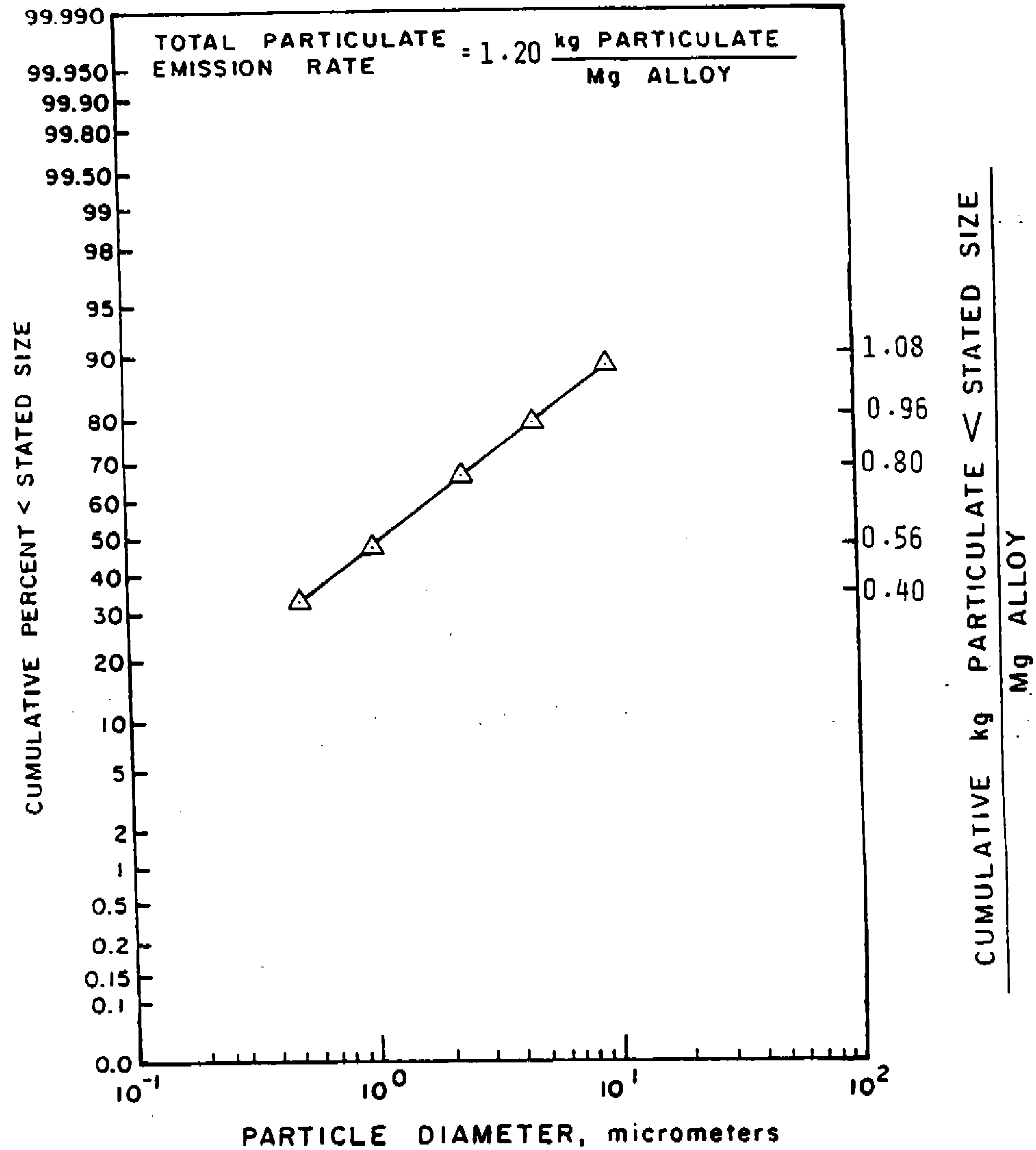


Figure 7.4-9. Controlled (ESP), FeCr (HC) producing, open furnace particle size distribution

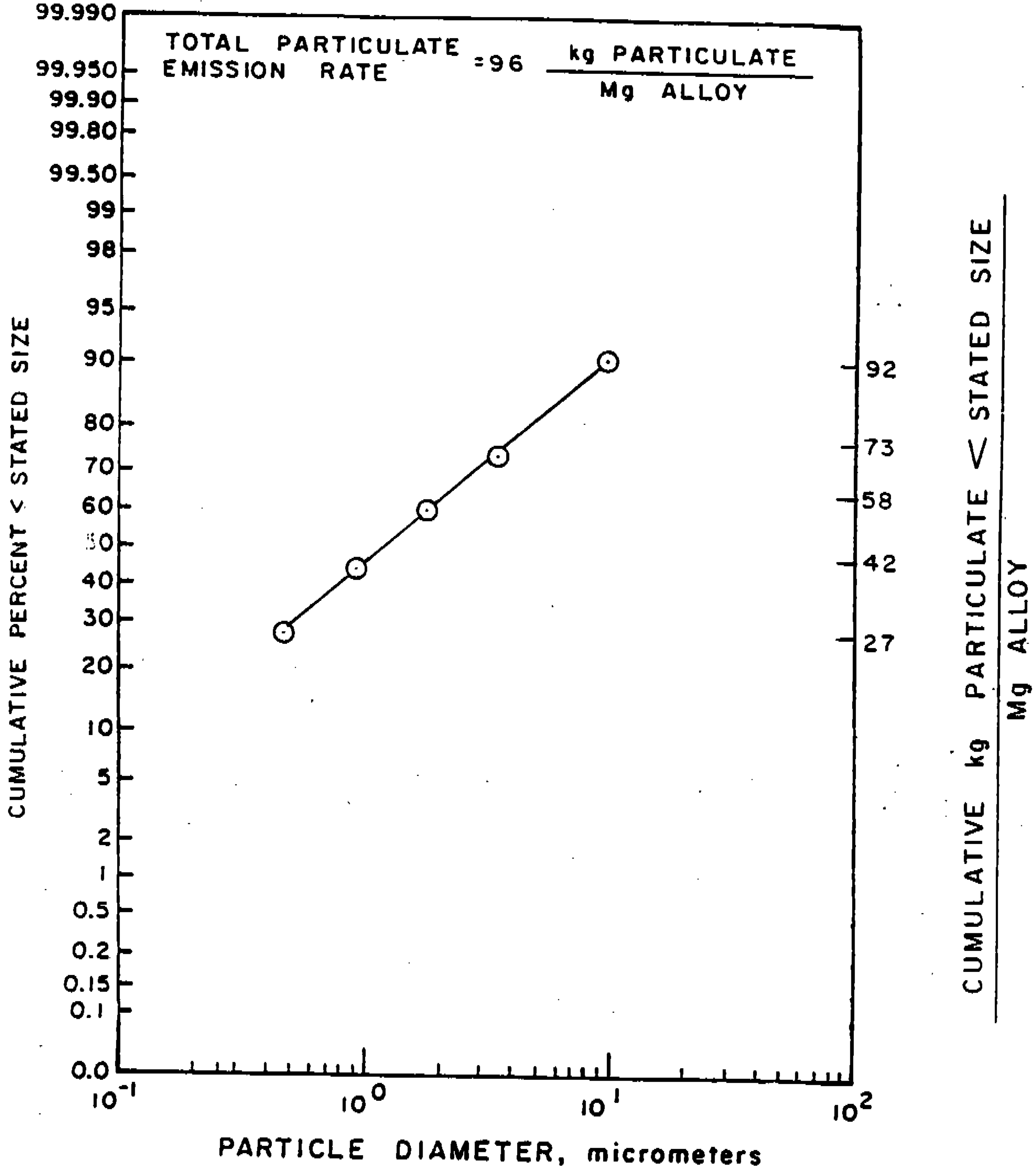


Figure 7.4-10. Uncontrolled, SiMn producing, open furnace particle size distribution

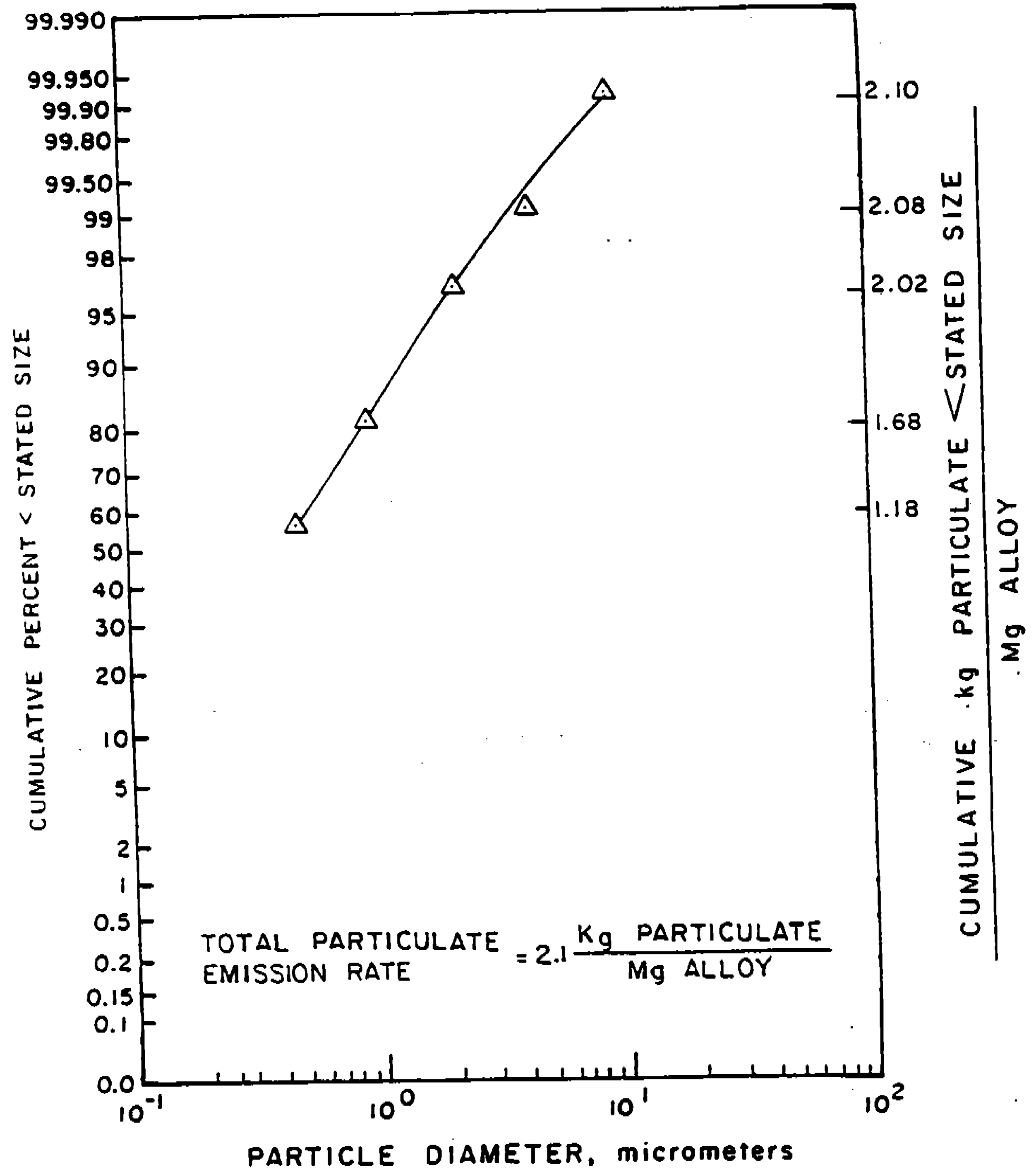


Figure 7.4-11. Controlled (scrubber), SiMn producing, open furnace particle size distribution

TABLE 7.4-5. EMISSION FACTORS FOR SULFUR DIOXIDE, CARBON MONOXIDE, LEAD AND VOLATILE ORGANICS FROM SUBMERGED ARC FERROALLOY FURNACES[a]

EMISSION FACTOR RATING: D

LEAD: C

Product	Furnace type	SO_2[b] (lb/ton)	CO[c,d,e] (lb/ton)	Lead[f] kg/Mg (lb/ton)	Volatile Organic Compounds Uncontrolled[d,e] kg/Mg (lb/ton)	Volatile Organic Compounds Controlled[g] kg/Mg (lb/ton)	Volatile Organic Compounds Control device
FeSi - 50%	Open	-	-	0.15 (0.29)	2.25 (4.5)	2.2 (4.4)	Baghouse
	Covered	-	2180	-	6.35 (12.7)		Scrubber
						0.28 (0.56)	High energy
						0.75 (1.5)	Low energy
FeSi - 75%	Open	-	-	0.0015 (0.0031)	-		
	Covered		3230	-	10.25 (20.5)	2.4 (4.8)	Scrubber
Si Metal - 98%	Open	-		0.0015 (0.0031)	35.90 (71.8)	25.9 (51.6)	Baghouse
FeMn - 80%	Open	-	-	-	3.05 (6.1)	1.85 (3.7)	Baghouse
						0.70 (1.4)	High energy scrubber
	Covered	-	-	-	0.70 (1.4)	0.40 (0.8)	Scrubber
	Sealed	0.010[h]	-	0.06 (0.11)	-	-	
FeCr (HC)	Open	5.4[h,j]	-	0.17 (0.34)	-	-	
FeCr-Si	Open	-	-	0.04 (0.08)	-	-	
SiMn	Open	0.070[e,k]	-	0.0029 (0.0057)	-	-	
	Sealed	0.021[e,k]	1690	-	-	0.05 (0.10)	High energy scrubber

[a] Expressed as weight/unit weight of specified product (alloy). Dash = No data.

[b] References 14-15, 17, 19, 30. Emissions depend on amount of sulfur in feed material.

[c] References 4, 14. Measured before control by flare. CO emissions from open furnaces are low. Quantity from covered furnaces will vary with volume of air drawn into cover. Increased air will reduce CO emissions.

[d] References 4, 10, 12-15, 17, 19, 21. May increase if furnace feed is dirty scrap iron or steel.

[e] Does not include seal leaks or tapping emissions. Open furnace hoods may capture some tapping emissions.

[f] References 2, 20, 27-29.

[g] Measured before any flare in the control system.

[h] Uncontrolled.

[j] Includes tapping emissions.

[k] Scrubber outlet.

Scrubbers are used on 13 percent of the furnaces, and electrostatic precipitators on 2 percent. Control efficiences for well designed and operated control systems [i. e., baghouses with air to cloth ratios of 1:1 to 2:1 ft^3/ft^2, and and scrubbers with a pressure drop from 14 to 24 kilopascals (kPa) (55 to 96 inches H_2O)], have been reported to be in excess of 99 percent.[4] Air to cloth ratio is the ratio of the volumetric air flow through the filter media to the media area.

Two emission capture systems, not usually connected to the same gas cleaning device, are necessary for covered furnaces. A primary capture system withdraws gases from beneath the furnace cover. A secondary system captures fume released around the electrode seals and during tapping. Scrubbers are used almost exclusively to control exhaust gases from sealed furnaces. The gas from sealed and mix sealed furnaces is usually flared at the exhaust of the scrubber. The carbon monoxide rich gas has an estimated heating value of 300 Btu per cubic foot and is sometimes used as a fuel in kilns and sintering machines. The efficiency of flares for the control of carbon monoxide and the reduction of organic emission has been estimated to be greater than 98 percent for steam assisted flares with a velocity of less than 60 feet per second and a gas heating value of 300 Btu per standard cubic foot[24]. For unassisted flares, the reduction of organic and carbon monoxide emissions is 98 percent efficient with a velocity of less than 60 feet per second and a gas heating value greater than 200 Btu per standard cubic foot.[24]

Tapping operations also generate fumes. Tapping is intermittent and is usually conducted during 10 to 20 percent of the furnace operating time. Some fumes originate from the carbon lip liner, but most are a result of induced heat transfer from the molten metal or slag as it contacts the runners, ladles, casting beds and ambient air. Some plants capture these emissions to varying degrees with a main canopy hood. Other plants employ separate tapping hoods ducted to either the furnace emission control device or a separate control device. Emission factors for tapping emissions are unavailable because of a lack of data.

A reaction ladle may be involved to adjust the metallurgy after furance tapping by chlorination, oxidation, gas mixing and slag metal reactions. Ladle reactions are an intermittent process, and emissions have not been quantified. Reaction ladle emissions often are captured by the tapping emissions control system.

Available data are insufficient to provide emission factors for raw material handling, pretreatment and product handling. Dust particulate is emitted from raw material handling, storage and preparation activities (see Figure 7.4-1), from such specific activities as unloading of raw materials from delivery vehicles (ship, railcar or truck), storage of raw materials in piles, loading of raw materials from storage piles into trucks or gondola cars and crushing and screening of raw materials. Raw materials may be dried before charging in rotary or other type dryers, and these dryers can generate significant particulate emissions. Dust may also be generated by heavy vehicles used for loading, unloading and transferring material. Crushing, screening and storage of the ferroalloy product emit particulate in the form of dust. The properties of particulate emitted as dust are similar to the natural properties of the ores or alloys from which they originated, ranging in size from 3 to 100 micrometers.

Approximately half of ferroalloy facilities have some type of control for dust emissions. Dust generated from raw material storage may be controlled in several ways, including sheltering storage piles from the wind with block walls, snow fences or plastic covers. Occasionally, piles are sprayed with water to prevent airborne dust. Emissions generated by heavy vehicle traffic may be reduced by using a wetting agent or paving the plant yard.[3] Moisture in the raw materials, which may be as high as 20 percent, helps to limit dust emissions from raw material unloading and loading. Dust generated by crushing, sizing, drying or other pretreatment activities is sometimes controlled by dust collection equipment such as scrubbers, cyclones or baghouses. Ferroalloy product crushing and sizing usually require a baghouse. The raw material emission collection equipment may be connected to the furnace emission control system. For fugitive emissions from open sources, see Section 11.2 of this document.

References for Section 7.4

1. F. J. Schottman, "Ferroalloys", <u>1980 Mineral Facts and Problems</u>, Bureau Of Mines, U. S. Department Of The Interior, Washington, DC, 1980.
2. J. O. Dealy, and A. M. Killin, Engineering and Cost Study of the Ferroalloy Industry, EPA-450/2-74-008, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1974.
3. Backgound Information on Standards of Performance: Electric Submerged Arc Furnaces for Production of Ferroalloys, Volume I: Proposed Standards, EPA-450/2-74-018a, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1974.
4. C. W. Westbrook, and D. P. Dougherty, Level I Environmental Assessment of Electric Submerged Arc Furnaces Producing Ferroalloys, EPA-600/2-81-038, U. S. Environmental Protection Agency, Washington, DC, March 1981.
5. F. J. Schottman, "Ferroalloys", Minerals Yearbook, Volume I: Metals and Minerals, Bureau Of Mines, Department Of The Interior, Washington, DC, 1980.
6. S. Beaton and H. Klemm, Inhalable Particulate Field Sampling Program for the Ferroalloy Industry, TR-80-115-G, GCA Corporation, Bedford, MA, November 1980.
7. G. W. Westbrook and D. P. Dougherty, Environmentall Impact of Ferroalloy Production Interim Report: Assessment of Current Data, Research Triangle Institute, Research Triangle Park, NC, November 1978.
8. K. Wark and C. F. Warner, Air Pollution: Its Origin and Control, Harper and Row Publisher, New York, 1981.

9. M. Szabo and R. Gerstle, Operations and Maintenance of Particulate Control Devices on Selected Steel and Ferroalloy Processes, EPA-600/2-78-037, U. S. Environmental Protection Agency, Washington, DC, March 1978.

10. C. W. Westbrook, Multimedia Environmental Assessment of Electric Submerged Arc Furnaces Producing Ferroalloys, EPA-600/2-83-092, U. S. Environmental Protection Agency, Washington, DC, September 1983.

11. S. Gronberg, et al., Ferroalloy Industry Particulate Emissions: Source Category Report, EPA-600/7-86-039, U. S. Environmental Protection Agency, Cincinnati, OH, November 1986.

12. T. Epstein, et al., Ferroalloy Furnace Emission Factor Development, Roane Limited, Rockwood, Tennessee, EPA-600/X-85-325, U. S. Environmental Protection Agency, Washington, DC, June 1981.

13. S. Beaton, et al., Ferroalloy Furnace Emission Factor Development, Interlake Inc., Alabama Metallurgical Corp., Selma, Alabama, EPA-600/X-85-324, U. S. Environmental Protection Agency, Washington, DC, May 1981.

14. J. L. Rudolph, et al., Ferroalloy Process Emissions Measurement, EPA-600/2-79-045, U. S. Environmental Protection Agency, Washington, DC, February 1979.

15. Written communication from Joseph F. Eyrich, Macalloy Corporation, Charleston, SC to GCA Corporation, Bedford, MA, February 10, 1982, citing Airco Alloys and Carbide test R-07-7774-000-1, Gilbert Commonwealth, Reading, PA, 1978.

16. Source test, Airco Alloys and Carbide, Charleston, SC, EMB-71-PC-16(FEA), U. S. Environmental Protection Agency, Research Triangle Park, NC, 1971.

17. Telephone communication between Joseph F. Eyrich, Macalloy Corporation, Charleston, SC and Evelyn J. Limberakis, GCA Corporation, Bedford, MA, February 23, 1982.

18. Source test, Chromium Mining and Smelting Corporation, Memphis, TN, EMB-72-PC-05 (FEA), U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1972.

19. Source test, Union Carbide Corporation, Ferroalloys Division, Marietta, Ohio, EMB-71-PC-12(FEA), U. S. Environmental Protection Agency, Research Triangle Park, NC, 1971.

20. R. A. Person, "Control of Emissions from Ferroalloy Furnace Processing", Journal Of Metals, 23(4):17-29, April 1971.

21. S. Gronberg, Ferroalloy Furnace Emission Factor Development Foote Minerals, Graham, W. Virginia, EPA-600/X-85-327, U. S. Environmental Protection Agency, Washington, DC, July 1981.

22. R. W. Gerstle, et al., Review of Standards of Performance for New Stationary Air Sources - Ferroalloy Production Facility, EPA-450/3-80-041, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1980.

23. Air Pollutant Emission Factors, Final Report, APTD-0923, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1970.

24. Telephone communication between Leslie B. Evans, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, and Richard Vacherot, GCA Corporation, Bedford, MA, October 18, 1984.

25. R. Ferrari, Experiences in Developing an Effective Pollution Control System for a Submerged Arc Ferroalloy Furnace Operation, J. Metals, p. 95-104, April 1968.

26. Fredriksen and Nestaas, Pollution Problems by Electric Furnace Ferroalloy Production, United Nations Economic Commission for Europe, September 1968.

27. A. E. Vandergrift, et al., Particulate Pollutant System Study - Mass Emissions, PB-203-128, PB-203-522 and P-203-521, National Technical Information Service, Springfield, VA, May 1971.

28. Control Techniques for Lead Air Emissions, EPA-450/2-77-012, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1977.

29. W. E. Davis, Emissions Study of Industrial Sources of Lead Air Pollutants, 1970, EPA-APTD-1543, W. E. Davis and Associates, Leawood, KS, April 1973.

30. Source test, Foote Mineral Company, Vancoram Operations, Steubenville, OH, EMB-71-PC-08(FEA), U. S. Environmental Protection Agency, Research Triangle Park, NC, August 1971.

7.5 IRON AND STEEL PRODUCTION

7.5.1 Process Description[1-3]

The production of steel at an integrated iron and steel plant is accomplished using several interrelated processes. The major operations are: (1) coke production, (2) sinter production, (3) iron production, (4) iron preparation, (5) steel production, (6) semifinished product preparation, (7) finished product preparation, (8) heat and electricity supply, and (9) handling and transport of raw, intermediate and waste materials. The interrelation of these operations is depicted in a general flow diagram of the iron and steel industry in Figure 7.5-1. Coke production is discussed in detail in Section 7.2 of this publication, and more information on the handling and transport of materials is found in Chapter 11.

7.5.1.1 Sinter Production - The sintering process converts fine sized raw materials, including iron ore, coke breeze, limestone, mill scale, and flue dust, into an agglomerated product, sinter, of suitable size for charging into the blast furnace. The raw materials are sometimes mixed with water to provide a cohesive matrix, and then placed on a continuous, travelling grate called the sinter strand. A burner hood, at the beginning of the sinter strand ignites the coke in the mixture, after which the combustion is self supporting and it provides sufficient heat, 1300 to 1480°C (2400 to 2700°F), to cause surface melting and agglomeration of the mix. On the underside of the sinter strand is a series of windboxes that draw combusted air down through the material bed into a common duct leading to a gas cleaning device. The fused sinter is discharged at the end of the sinter strand, where it is crushed and screened. Undersize sinter is recycled to the mixing mill and back to the strand. The remaining sinter product is cooled in open air or in a circular cooler with water sprays or mechanical fans. The cooled sinter is crushed and screened for a final time, then the fines are recycled, and the product is sent to be charged to the blast furnaces. Generally, 2.5 tons of raw materials, including water and fuel, are required to produce one ton of product sinter.

7.5.1.2 Iron Production - Iron is produced in blast funaces by the reduction of iron bearing materials with a hot gas. The large, refractory lined furnace is charged through its top with iron as ore, pellets, and/or sinter; flux as limestone, dolomite and sinter; and coke for fuel. Iron oxides, coke and fluxes react with the blast air to form molten reduced iron, carbon monoxide and slag. The molten iron and slag collect in the hearth at the base of the furnace. The byproduct gas is collected through offtakes located at the top of the furnace and is recovered for use as fuel.

The production of one ton of iron requires 1.4 tons of ore or other iron bearing material; 0.5 to 0.65 tons of coke; 0.25 tons of limestone or dolomite; and 1.8 to 2 tons of air. Byproducts consist of 0.2 to 0.4 tons of slag, and 2.5 to 3.5 tons of blast furnace gas containing up to 100 lbs of dust.

The molten iron and slag are removed, or cast, from the furnace periodically. The casting process begins with drilling a hole, called the taphole, into the clay filled iron notch at the base of the hearth. During casting, molten iron flows into runners that lead to transport ladles. Slag also flows

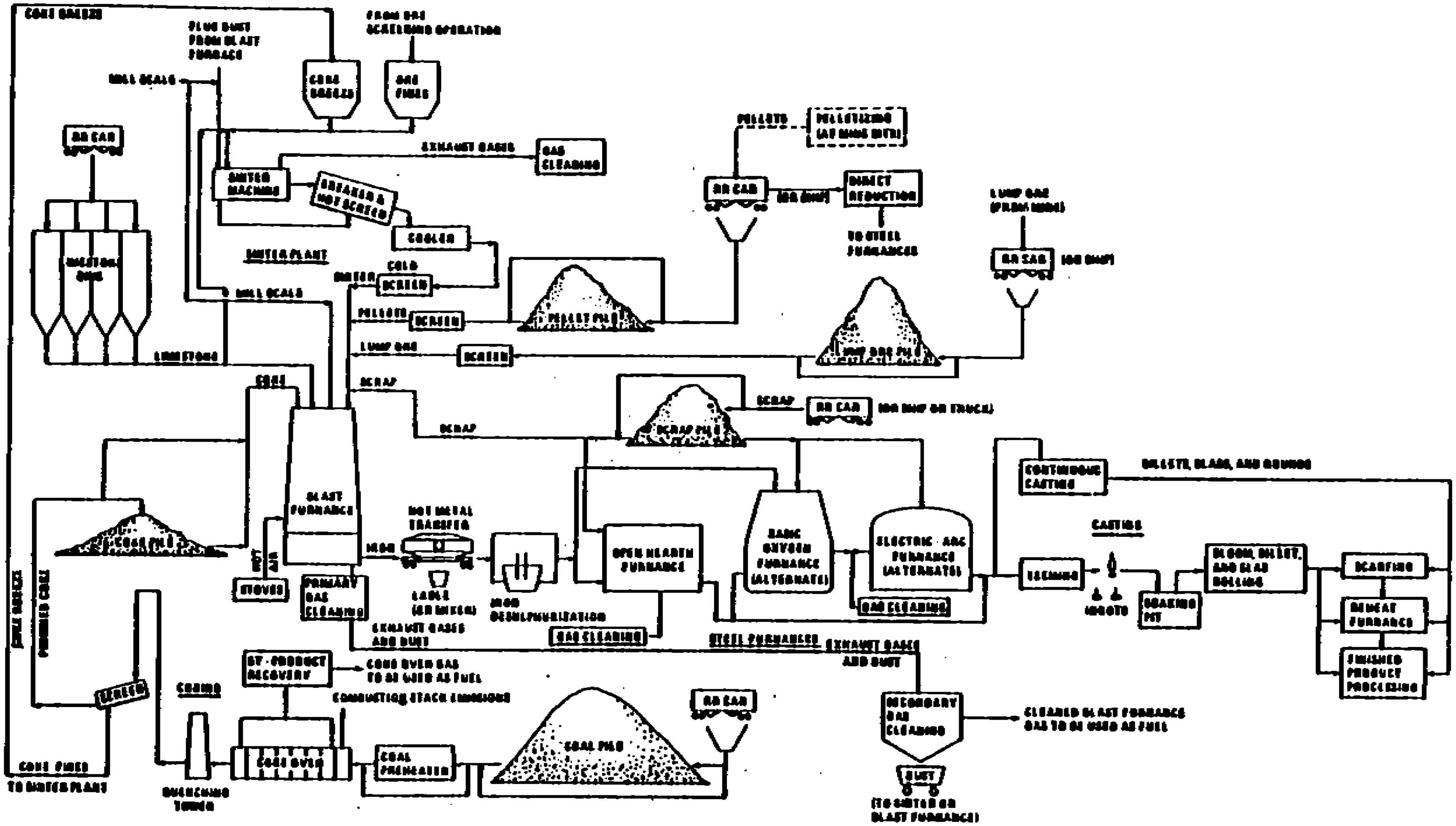


Figure 7.5-1. General flow diagram for the iron and steel industry.

into the clay filled iron notch at the base of the hearth. During casting, molten iron flows into runners that lead to transport ladles. Slag also flows from the furnace, and is directed through separate runners to a slag pit adjacent to the casthouse, or into slag pots for transport to a remote slag pit. At the conclusion of the cast, the taphole is replugged with clay. The area around the base of the furnace, including all iron and slag runners, is enclosed by a casthouse. The blast furnace byproduct gas, which is collected from the furnace top, contains carbon monoxide and particulate. Because of its high carbon monoxide content, this blast furnace gas has a low heating value, about 2790 to 3350 joules per liter (75 to 90 BTU/ft^3) and is used as a fuel within the steel plant. Before it can be efficiently oxidized, however, the gas must be cleaned of particulate. Initially, the gases pass through a settling chamber or dry cyclone to remove about 60 percent of the particulate. Next, the gases undergo a one or two stage cleaning operation. The primary cleaner is normally a wet scrubber, which removes about 90 percent of the remaining particulate. The secondary cleaner is a high energy wet scrubber (usually a venturi) or an electrostatic precipitator, either of which can remove up to 90 percent of the particulate that eludes the primary cleaner. Together these control devices provide a clean fuel of less than 0.05 grams per cubic meter (0.02 gr/ft^3). A portion of this gas is fired in the blast furnace stoves to preheat the blast air, and the rest is used in other plant operations.

7.5.1.3 Iron Preparation Hot Metal Desulfurization - Sulfur in the molten iron is sometimes reduced before charging into the steelmaking furnace by adding reagents. The reaction forms a floating slag which can be skimmed off. Desulfurization may be performed in the hot metal transfer (torpedo) car at a location between the blast furnace and basic oxygen furnace (BOF), or it may be done in the hot metal transfer (torpedo) ladle at a station inside the BOF shop.

The most common reagents are powdered calcium carbide (CaC_2) and calcium carbonate ($CaCO_3$) or salt coated magnesium granules. Powdered reagents are injected into the metal through a lance with high pressure nitrogen. The process duration varies with the injection rate, hot metal chemistry, and desired final sulfur content, and is in the range of 5 to 30 minutes.

7.5.1.4 Steelmaking Process - Basic Oxygen Furnaces - In the basic oxygen process (BOP), molten iron from a blast furance and iron scrap are refined in a furnace by lancing (or injecting) high purity oxygen. The input material is typically 70 percent molten metal and 30 percent scrap metal. The oxygen reacts with carbon and other impurities to remove them from the metal. The reactions are exothermic, i. e., no external heat source is necessary to melt the scrap and to raise the temperature of the metal to the desired range for tapping. The large quantities of carbon monoxide (CO) produced by the reactions in the BOF can be controlled by combustion at the mouth of the furnace and then vented to gas cleaning devices, as with open hoods, or combustion can be suppressed at the furnace mouth, as with closed hoods. BOP steelmaking is conducted in large (up to 400 ton capacity) refractory lined pear shaped furnaces. There are two major variations of the process. Conventional BOFs have oxygen blown into the top of the furnace through a water cooled lance. In the newer, Quelle Basic Oxygen process (Q-BOP), oxygen is injected through tuyeres located in the bottom of the furnace. A typical BOF cycle consists of the scrap charge, hot metal charge, oxygen blow (refining) period, testing for temperature and chemical composition of the steel, alloy additions and reblows (if necessary), tapping, and slagging. The full furnace cycle typically ranges from 25 to 45 minutes.

7.5.1.5 Steelmaking Process - Electric Arc Furnace - Electric arc furnaces (EAF) are used to produce carbon and alloy steels. The input material to an EAF is typically 100 percent scrap. Cylindrical, refractory lined EAFs are equipped with carbon electrodes to be raised or lowered through the furnace roof. With electrodes retracted, the furnace roof can be rotated aside to permit the charge of scrap steel by overhead crane. Alloying agents and fluxing materials usually are added through the doors on the side of the furnace. Electric current of the opposite polarity electrodes generates heat between the electrodes and through the scrap. After melting and refining periods, the slag and steel are poured from the furnace by tilting.

The production of steel in an EAF is a batch process. Cycles, or "heats", range from about 1 1/2 to 5 hours to produce carbon steel and from 5 to 10 hours or more to produce alloy steel. Scrap steel is charged to begin a cycle, and alloying agents and slag materials are added for refining. Stages of each cycle normally are charging and melting operations, refining (which usually includes oxygen blowing), and tapping.

7.5.1.6 Steelmaking Process-Open Hearth Furnaces - The open hearth furnace (OHF) is a shallow, refractory-lined basin in which scrap and molten iron are melted and refined into steel. Scrap is charged to the furnace through doors in the furnace front. Hot metal from the blast furnace is added by pouring from a ladle through a trough positioned in the door. The mixture of scrap and hot metal can vary from all scrap to all hot metal, but a half and half mixture is most common. Melting heat is provided by gas burners above and at the side of the furnace. Refining is accomplished by the oxidation of carbon in the metal and the formation of a limestone slag to remove impurities. Most furnaces are equipped with oxygen lances to speed up melting and refining. The steel product is tapped by opening a hole in the base of the furnace with an explosive charge. The open hearth steelmaking process with oxygen lancing normally requires from 4 to 10 hours for each heat.

7.5.1.7 Semifinished Product Preparation - After the steel has been tapped, the molten metal is teemed (poured) into ingots which are later heated and formed into other shapes, such as blooms, billets, or slabs. The molten steel may bypass this entire process and go directly to a continuous casting operation. Whatever the production technique, the blooms, billets, or slabs undergo a surface preparation step, scarfing, which removes surface defects before shaping or rolling. Scarfing can be performed by a machine applying jets of oxygen to the surface of hot semifinished steel, or by hand (with torches) on cold or slightly heated semifinished steel.

7.5.2 Emissions And Controls

7.5.2.1 Sinter - Emissions from sinter plants are generated from raw material handling, windbox exhaust, discharge end (associated sinter crushers and hot screens), cooler and cold screen. The windbox exhaust is the primary source of particulate emissions, mainly iron oxides, sulfur oxides, carbonaceous compounds, aliphatic hydrocarbons, and chlorides. At the discharge end, emissions are mainly iron and calcium oxides. Sinter strand windbox emissions commonly are controlled by cyclone cleaners followed by a dry or wet ESP, high pressure drop wet scrubber, or baghouse. Crusher and hot screen emissions, usually controlled by hooding and a baghouse or scrubber, are the next largest emissions source. Emissions are also generated from other material handling operations. At some sinter plants, these emissions are captured and vented to a baghouse.

7.5.2.2 Blast Furnace - The primary source of blast furnace emissions is the casting operation. Particulate emissions are generated when the molten iron and slag contact air above their surface. Casting emissions also are generated by drilling and plugging the taphole. The occasional use of an oxygen lance to open a clogged taphole can cause heavy emissions. During the casting operation, iron oxides, magnesium oxide and carbonaceous compounds are generated as particulate. Casting emissions at existing blast furnaces are controlled by evacuation through retrofitted capture hoods to a gas cleaner, or by suppression techniques. Emissions controlled by hoods and an evacuation system are usually vented to a baghouse. The basic concept of suppression techniques is to prevent the formation of pollutants by excluding ambient air contact with the molten surfaces. New furnaces have been constructed with evacuated runner cover systems and local hooding ducted to a baghouse.

Another potential source of emissions is the blast furnace top. Minor emissions may occur during charging from imperfect bell seals in the double bell system. Occasionally, a cavity may form in the blast fuernace charge, causing a collapse of part of the burden (charge) above it. The resulting pressure surge in the furnace opens a relief valve to the atmosphere to prevent damage to the furnace by the high pressure created and is referred to as a "slip".

7.5.2.3 Hot Metal Desulfurization - Emissions during the hot metal desulfurization process are created by both the reaction of the reagents injected into the metal and the turbulence during injection. The pollutants emitted are mostly iron oxides, calcium oxides and oxides of the compound injected. The sulfur reacts with the reagents and is skimmed off as slag. The emissions generated from desulfurization may be collected by a hood positioned over the ladle and vented to a baghouse.

7.5.2.4 Steelmaking - The most significant emissions from the BOF process occur during the oxygen blow period. The predominant compounds emitted are iron oxides, although heavy metals and fluorides are usually present. Charging emissions will vary with the quality and quantity of scrap metal charged to the furnace and with the pour rate. Tapping emissions include iron oxides, sulfur oxides, and other metallic oxides, depending on the grade of scrap used. Hot metal transfer emissions are mostly iron oxides.

BOFs are equipped with a primary hood capture system located directly over the open mouth of the furnaces to control emissions during oxygen blow periods. Two types of capture systems are used to collect exhaust gas as it leaves the furnace mouth: closed hood (also known as an off gas, or O. G., system) or open, combustion type hood. A closed hood fits snugly against the furnace mouth, ducting all particulate and carbon monoxide to a wet scrubber gas cleaner. Carbon monoxide is flared at the scrubber outlet stack. The open hood design allows dilution air to be drawn into the hood, thus combusting the carbon monoxide in the hood system. Charging and tapping emissions are controlled by a variety of evacuation systems and operating practices. Charging hoods, tapside enclosures, and full furnace enclosures are used in the industry to capture these emissions and send them to either the primary hood gas cleaner or a second gas cleaner.

7.5.2.5 Steelmaking - Electric Arc Furnace - The operations which generate emissions during the electric arc furnace steelmaking process are melting and refining, charging scrap, tapping steel, and dumping slag. Iron oxide is the predominant constituent of the particulate emitted during melting. During refining, the primary particulate compound emitted is calcium oxide from the slag. Emissions from charging scrap are difficult to quantify, because they depend on the grade of scrap utilized. Scrap emissions usually contain iron and other metallic oxides from alloys in the scrap metal. Iron oxides and oxides from the fluxes are the primary constituents of the slag emissions. During tapping, iron oxide is the major particulate compound emitted.

Emission control techniques involve an emission capture system and a gas cleaning system. Five emission capture systems used in the industry are fourth hold (direct shell) evacuation, side draft hood, combination hood, canopy hood, and furnace enclosures. Direct shell evacuation consists of ductwork attached to a separate or fourth hole in the furnace roof which draws emissions to a gas cleaner. The fourth hole system works only when the furnace is upright with the roof in place. Side draft hoods collect furnace off gases from around the electrode holes and the work doors after the gases leave the furnace. The combination hood incorporates elements from the side draft and fourth hole ventilation systems. Emissions are collected both from the fourth hole and around the electrodes. An air gap in the ducting introduces secondary air for combustion of CO in the exhaust gas. The combination hood requires careful regulation of furnace interval pressure. The canopy hood is the least efficient of the four ventilation systems, but it does capture emissions during charging and tapping. Many new electric arc furnaces incorporate the canopy hood with one of the other three systems. The full furnace enclosure completely surrounds the furnace and evacuates furnace emissions through hooding in the top of the enclosure.

7.5.2.6 Steelmaking - Open Hearth Furnace - Particulate emissions from an open hearth furnace vary considerably during the process. The use of oxygen lancing increases emissions of dust and fume. During the melting and refining cycle, exhaust gas drawn from the furnace passes through a slag pocket and a regenerative checker chamber, where some of the particulate settles out. The emissions, mostly iron oxides, are then ducted to either an ESP or a wet scrubber. Other furnace related process operations which produce fugitive emissions inside the shop include transfer and charging of hot metal, charging of scrap, tapping steel and slag dumping. These emissions are usually uncontrolled.

7.5.2.7 Semifinished Product Preparation - During this activity, emissions are produced when molten steel is poured (teemed) into ingot molds, and when semifinished steel is machine or manually scarfed to remove surface defects. Pollutants emitted are iron and other oxides (FeO, Fe_2O_3, SiO_2, CaO, MgO).

Teeming emissions are rarely controlled. Machine scarfing operations generally use as ESP or water spray chamber for control. Most hand scarfing operations are uncontrolled.

7.5.2.8 Miscellaneous Combustion - Every iron and steel plant operation requires energy in the form of heat or electricity. Combustion sources that produce emissions on plant property are blast furnace stoves, boilers, soaking pits, and reheat furnaces. These facilities burn combinations of coal, No. 2 fuel oil, natural gas, coke oven gas, and blast furnace gas. In blast furnace stoves, clean gas from the blast furnace is burned to heat the refractory checker work, and in turn, to heat the blast air. In soaking pits, ingots are heated until the temperature distribution over the cross section of the ingots is acceptable and the surface temperature is uniform for further rolling into semifinished products (blooms, billets and slabs). In slab furnaces, a slab is heated before being rolled into finished products (plates, sheets or strips). Emissions from the combustion of natural gas, fuel oil or coal in the soaking pits or slab furnaces are estimated to be the same as those for boilers. (See Chapter 1 of this document.) Emission factor data for blast furnace gas and coke oven gas are not available and must be estimated. There are three facts available for making the estimation. First, the gas exiting the blast furnace passes through primary and secondary cleaners and can be cleaned to less than 0.05 grams per cubic meter (0.02 gr/ft^3). Second, nearly one third of the coke oven gas is methane. Third, there are no blast furnace gas constituents that generate particulate when burned. The combustible constituent of blast furnace gas is CO, which burns clean. Based on facts one and three, the emission factor for combustion of blast furnace gas is equal to the particulate loading of that fuel, 0.05 grams per cubic meter (2.9 lb/10^6 ft^3) having an average heat value of 83 BTU/ft^3.

Emissions for combustion of coke oven gas can be estimated in the same fashion. Assume that cleaned coke oven gas has as much particulate as cleaned blast furnace gas. Since one third of the coke oven gas is methane, the main component of natural gas, it is assumed that the combustion of this methane in coke oven gas generates 0.06 grams per cubic meter (3.3 lb/10^6 ft^3) of particulate. Thus, the emission factor for the combustion of coke oven gas is the sum of the particulate loading and that generated by the methane combustion, or 0.1 grams per cubic meter (6.2 lb/10^6 ft^3) having an average heat value of 516 BTU/ft^3.

The particulate emission factors for processes in Table 7.5-1 are the result of an extensive investigation by EPA and the American Iron and Steel Institute.[3] Particle size distributions for controlled and uncontrolled emissions from specific iron and steel industry processes have been calculated and summarized from the best available data.[1] Size distributions have been used with particulate emission factors to calculate size specific factors for the sources listed in Table 7.5-1 for which data are available. Table 7.5-2 presents these size specific particulate emission factors. Particle size distributions are presented in Figures 7.5-2 to 7.5-4. Carbon monoxide emission factors are in Table 7.5-3.[6]

TABLE 7.5-1. PARTICULATE EMISSION FACTORS FOR IRON AND STEEL MILLS[a]

Source	Units	Emission Factor	Emission Factor Rating	Particle Size Data
Sintering				
Windbox	kg/Mg (lb/ton) finished sinter			
Uncontrolled				
Leaving grate		5.56 (11.1)	B	Yes
After coarse particulate removal		4.35 (8.7)	A	
Controlled by dry ESP		0.8 (1.6)	B	
Controlled by wet ESP		0.085 (0.17)	B	Yes
Controlled by venturi scrubber		0.235 (0.47)	B	Yes
Controlled by cyclone		0.5 (1.0)	B	Yes
Sinter discharge (breaker and hot screens)	kg/Mg (lb/ton) finished sinter			
Uncontrolled		3.4 (6.8)	B	
Controlled by baghouse		0.05 (0.1)	B	Yes
Controlled by venturi scrubber		0.295 (0.59)	A	
Windbox and discharge	kg/Mg (lb/ton) finished sinter			
Controlled by baghouse		0.15 (0.3)	A	
Blast furnace				
Slip	kg/Mg (lb/ton) slip	39.5 (87.0)	D	
Uncontrolled casthouse	kg/Mg (lb/ton) hot metal			
Roof Monitor[b]		0.3 (0.6)	B	Yes
Furnace with local evacuation[c]		0.65 (1.3)	B	Yes
Taphole and trough only (not runners)		0.15 (0.3)	B	
Hot metal desulfurization				
Uncontrolled[d]	kg/Mg (lb/ton) hot metal	0.55 (1.09)	D	Yes
Controlled by baghouse		0.0045 (0.009)	D	Yes
Basic oxygen furnace (BOF)				
Top blown furnace melting and refining	kg/Mg (lb/ton) steel			
Uncontrolled		14.25 (28.5)	B	
Controlled by open hood vented to:				
ESP		0.065 (0.13)	A	
Scrubber		0.045 (0.09)	B	
Controlled by closed hood vented to:				
Scrubber		0.0034 (0.0068)	A	Yes

TABLE 7.5-1 (cont.). PARTICULATE EMISSION FACTORS FOR IRON AND STEEL MILLS[a]

Source	Units	Emission Factor	Emission Factor Rating	Particle Size Data
BOF Charging	kg/Mg (lb/ton) hot metal			
At source		0.3 (0.6)	D	Yes
At building monitor		0.071 (0.142)	B	
Controlled by baghouse		0.0003 (0.0006)	B	Yes
BOF Tapping	kg/Mg (lb/ton) steel			
At source		0.46 (0.92)	D	Yes
At building monitor		0.145 (0.29)	B	
Controlled by baghouse		0.0013 (0.0026)	B	Yes
Hot metal transfer	kg/Mg (lb/ton) hot metal			
At source		0.095 (0.19)	A	
At building monitor		0.028 (0.056)	B	
BOF monitor (all sources)	kg/Mg (lb/ton) steel	0.25 (0.5)	B	
Q-BOP melting and refining	kg/Mg (lb/ton) steel			
Controlled by scrubber		0.028 (0.056)	B	Yes
Electric arc furnace				
Melting and refining	kg/Mg (lb/ton) steel			
Uncontrolled carbon steel		19.0 (38.0)	C	Yes
Charging, tapping and slagging	kg/Mg (lb/ton) steel			
Uncontrolled emissions escaping monitor		0.7 (1.4)	C	
Melting, refining, charging, tapping and slagging	kg/Mg (lb/ton) steel			
Uncontrolled				
Alloy steel		5.65 (11.3)	A	
Carbon steel		25.0 (50.0)	C	
Controlled by:[e]				
Building evacuation to baghouse for alloy steel		0.15 (0.3)	A	
Direct shell evacuation (plus charging hood) vented to common baghouse for carbon steel		0.0215 (0.043)	E	Yes

TABLE 7.5-1 (Cont.). PARTICULATE EMISSION FACTORS FOR IRON AND STEEL MILLS

Source	Units	Emission Factor	Emission Factor Rating	Particle Size Data
Open hearth furnace				
Melting and refining	kg/Mg (lb/ton) steel			
Uncontrolled		10.55 (21.1)	D	Yes
Controlled by ESP		0.14 (0.28)	D	Yes
Roof monitor		0.084 (0.168)	C	
Teeming				
Leaded steel	kg/Mg (lb/ton) steel			
Uncontrolled (measured at source)		0.405 (0.81)	A	
Controlled by side draft hood vented to baghouse		0.0019 (0.0038)	A	
Unleaded steel				
Uncontrolled (measured at source)		0.035 (0.07)	A	
Controlled by side draft hood vented to baghouse		0.0008 (0.0016)	A	
Machine scarfing				
Uncontrolled	kg/Mg (lb/ton) metal through scarfer	0.05 (0.1)	B	
Controlled by ESP		0.0115 (0.023)	A	
Miscellaneous combustion sources[f]		f f		
Boiler, soaking pit and slab reheat	kg/10^9 J (lb/10^6 Btu)			
Blast furnace gas[g]		0.015 (0.035)	D	
Coke oven gas[g]		0.0052 (0.012)	D	

[a] Reference 3, except as noted.

[b] Typical of older furnaces with no controls, or for canopy hoods or total casthouse evacuation.

[c] Typical of large, new furnaces with local hoods and covered evaucated runners. Emissions are higher than without capture systems because they are not diluted by outside environment.

[d] Emission factor of 0.55 kg/Mg (1.09 lb/ton) represents one torpedo car; 1.26 kg/Mg (2.53 lb/ton) for two torpedo cars, and 1.37 kg/Mg (2.74 lb/ton) for three torpedo cars.

[e] Building evacuation collects all process emissions, and direct shell evacuation collects only melting and refining emissions.

[f] For various fuels, use the emission factors in Chapter 1 of this document. The emission factor rating, for these fuels in boilers is A, and in soaking pits and slab reheat furnaces is D.

[g] Based on methane content and cleaned particulate loading.

TABLE 7.5-2. SIZE SPECIFIC EMISSION FACTORS

Source	Emission Factor Rating	Particle Size μm[a]	Cumulative Mass % ≤ Stated size	Cumulative mass emission factor kg/Mg (lb/ton)
Sintering Windbox Uncontrolled Leaving grate	D	0.5	4[b]	0.22 (0.44)
		1.0	4	0.22 (0.44)
		2.5	5	0.28 (0.56)
		5.0	9	0.50 (1.00)
		10	15	0.83 (1.67)
		15	20[c]	1.11 (2.22)
		d	100	5.56 (11.1)
Controlled by wet ESP	C	0.5	18[b]	0.015 (0.03)
		1.0	25	0.021 (0.04)
		2.5	33	0.028 (0.06)
		5.0	48	0.041 (0.08)
		10	59[b]	0.050 (0.10)
		15	69	0.059 (0.12)
		d	100	0.085 (0.17)
Controlled by venturi scrubber	C	0.5	55	0.129 (0.26)
		1.0	75	0.176 (0.35)
		2.5	89	0.209 (0.42)
		5.0	93	0.219 (0.44)
		10	96	0.226 (0.45)
		15	98	0.230 (0.46)
		d	100	0.235 (0.47)
Controlled by cyclone[e]	C	0.5	25[c]	0.13 (0.25)
		1.0	37[b]	0.19 (0.37)
		2.5	52	0.26 (0.52)
		5.0	64	0.32 (0.64)
		10	74	0.37 (0.74)
		15	80	0.40 (0.80)
		d	100	0.5 (1.0)
Controlled by baghouse	C	0.5	3.0	0.005 (0.009)
		1.0	9.0	0.014 (0.027)
		2.5	27.0	0.041 (0.081)
		5.0	47.0	0.071 (0.141)
		10.0	69.0	0.104 (0.207)
		15.0	79.0	0.119 (0.237)
		d	100.0	0.15 (0.3)

TABLE 7.5.2 (cont.) SIZE SPECIFIC EMISSION FACTORS

Source	Emission Factor Rating	Particle Size µm[a]	Cumulative Mass % ≤ Stated size	Cumulative mass emission factor kg/Mg (lb/ton)
Sinter discharge (breaker and hot screens) controlled by baghouse	C	0.5	2[b]	0.001 (0.002)
		1.0	4	0.002 (0.004)
		2.5	11	0.006 (0.011)
		5.0	20	0.010 (0.020)
		10	32[b]	0.016 (0.032)
		15	42[b]	0.021 (0.042)
		d	100	0.05 (0.1)
Blast furnace Uncontrolled cast-house emissions Roof monitor[f]	C	0.5	4	0.01 (0.02)
		1.0	15	0.05 (0.09)
		2.5	23	0.07 (0.14)
		5.0	35	0.11 (0.21)
		10	51	0.15 (0.31)
		15	61	0.18 (0.37)
		d	100	0.3 (0.6)
Furnace with local evacuation[g]	C	0.5	7[c]	0.04 (0.09)
		1.0	9	0.06 (0.12)
		2.5	15	0.10 (0.20)
		5.0	20	0.13 (0.26)
		10	24	0.16 (0.31)
		15	26	0.17 (0.34)
		d	100	0.65 (1.3)
Hot metal desulfurization[h] Uncontrolled	E	0.5	j	
		1.0	2[c]	0.01 (0.02)
		2.5	11	0.06 (0.12)
		5.0	19	0.10 (0.22)
		10	19	0.10 (0.22)
		15	21	0.12 (0.23)
		d	100	0.55 (1.09)
Hot metal desulfurization[h] Controlled baghouse	D	0.5	8	0.0004 (0.0007)
		1.0	18	0.0009 (0.0016)
		2.5	42	0.0019 (0.0038)
		5.0	62	0.0028 (0.0056)
		10	74	0.0033 (0.0067)
		15	78	0.0035 (0.0070)
		d	100	0.0045 (0.009)

TABLE 7.5-2 (cont.) SIZE SPECIFIC EMISSION FACTORS

Source	Emission Factor Rating	Particle Size µm[a]	Cumulative Mass % ≤ Stated size	Cumulative mass emission factor kg/Mg (lb/ton)
Basic oxygen furnace Top blown furnace melting and refining controlled by closed hood and vented to scrubber	C	0.5	34	0.0012 (0.0023)
		1.0	55	0.0019 (0.0037)
		2.5	65	0.0022 (0.0044)
		5.0	66	0.0022 (0.0045)
		10	67	0.0023 (0.0046)
		15	72[c]	0.0024 (0.0049)
		d	100	0.0034 (0.0068)
BOF Charging At source[k]	E	0.5	8[c]	0.02 (0.05)
		1.0	12	0.04 (0.07)
		2.5	22	0.07 (0.13)
		5.0	35	0.10 (0.21)
		10	46	0.14 (0.28)
		15	56	0.17 (0.34)
		d	100	0.3 (0.6)
Controlled by baghouse	D	0.5	3	9.0×10^{-6} 1.8×10^{-5}
		1.0	10	3.0×10^{-5} 6.0×10^{-5}
		2.5	22	6.6×10^{-5} (0.0001)
		5.0	31	9.3×10^{-5} (0.0002)
		10	45	0.0001 (0.0003)
		15	60	0.0002 (0.0004)
		d	100	0.0003 (0.0006)
BOF Tapping At source[k]	E	0.5	j	j j
		1.0	11	0.05 (0.10)
		2.5	37	0.17 (0.34)
		5.0	43	0.20 (0.40)
		10	45	0.21 (0.41)
		15	50	0.23 (0.46)
		d	100	0.46 (0.92)

TABLE 7.5-2 (cont.) SIZE SPECIFIC EMISSION FACTORS

Source	Emission Factor Rating	Particle Size m[a]	Cumulative Mass % < Stated size	Cumulative mass emission factor kg/Mg (lb/ton)
BOF Tapping Controlled by baghouse	D	0.5	4	5.2x10^{-5} (0.0001)
		1.0	7	0.0001 (0.0002)
		2.5	16	0.0002 (0.0004)
		5.0	22	0.0003 (0.0006)
		10	30	0.0004 (0.0008)
		15	40	0.0005 (0.0010)
		d	100	0.0013 (0.0026)
Q-BOP melting and refining controlled by scrubber	D	0.5	45	0.013 (0.025)
		1.0	52	0.015 (0.029)
		2.5	56	0.016 (0.031)
		5.0	58	0.016 (0.032)
		10	68	0.019 (0.038)
		15	85[c]	0.024 (0.048)
		d	100	0.028 (0.056)
Electric arc furnace melting and refining carbon steel uncontrolled[m]	D	0.5	8	1.52 (3.04)
		1.0	23	4.37 (8.74)
		2.5	43	8.17 (16.34)
		5.0	53	10.07 (20.14)
		10	58	11.02 (22.04)
		15	61	11.59 (23.18)
		d	100	19.0 (38.0)
Electric arc furnace Melting, refining, charging, tapping, slagging Controlled by direct shell evacuation (plus charging hood) vented to common baghouse for carbon steel[n]	E	0.5	74[b]	0.0159 (0.0318)
		1.0	74	0.0159 (0.0318)
		2.5	74	0.0159 (0.0318)
		5.0	74	0.0159 (0.0318)
		10	76	0.0163 (0.0327)
		15	80	0.0172 (0.0344)
		d	100	0.0215 (0.043)

TABLE 7.5-2 (cont.) SIZE SPECIFIC EMISSION FACTORS

Source	Emission Factor Rating	Particle Size μm[a]	Cumulative Mass, % ≤ Stated size	Cumulative mass emission factor kg/Mg (lb/ton)
Open hearth furnace Melting and refining Uncontrolled	E	0.5	1[b]	0.11 (0.21)
		1.0	21	2.22 (4.43)
		2.5	60	6.33 (12.66)
		5.0	79	8.33 (16.67)
		10	83	8.76 (17.51)
		15	85[c]	8.97 (17.94)
		d	100	10.55 (21.1)
Open Hearth Furnaces Controlled by ESP[p]	E	0.5	10[b]	0.01 (0.02)
		1.0	21	0.03 (0.06)
		2.5	39	0.05 (0.10)
		5.0	47	0.07 (0.13)
		10	53[b]	0.07 (0.15)
		15	56[b]	0.08 (0.16)
		d	100	0.14 (0.28)

[a] Particle aerodynamic diameter micrometers (μm) as defined by Task Group on Lung Dynamics. (Particle density = 1 gr/cm^3).

[b] Interpolated data used to develop size distribution.

[c] Extrapolated, using engineering estimates.

[d] Total particulate based on Method 5 total catch. See Table 7.5-1.

[e] Average of various cyclone efficiencies.

[f] Total casthouse evacuation control system.

[g] Evacuation runner covers and local hood over taphole, typical of new state of the art blast furnace technology.

[h] Torpedo ladle desulfurization with CaC_2 and $CaCO_3$.

[j] Unable to extrapolate because of insufficient data and/or curve exceeding limits.

[k] Doghouse type furnace enclosure using front and back sliding doors, totally enclosing the furnace, with emissions vented to hoods.

[m] Full cycle emissions captured by canopy and side draft hoods.

[n] Information on control system not available.

[p] May not be representative. Test outlet size distribution was larger than inlet and may indicate reentrainment problem.

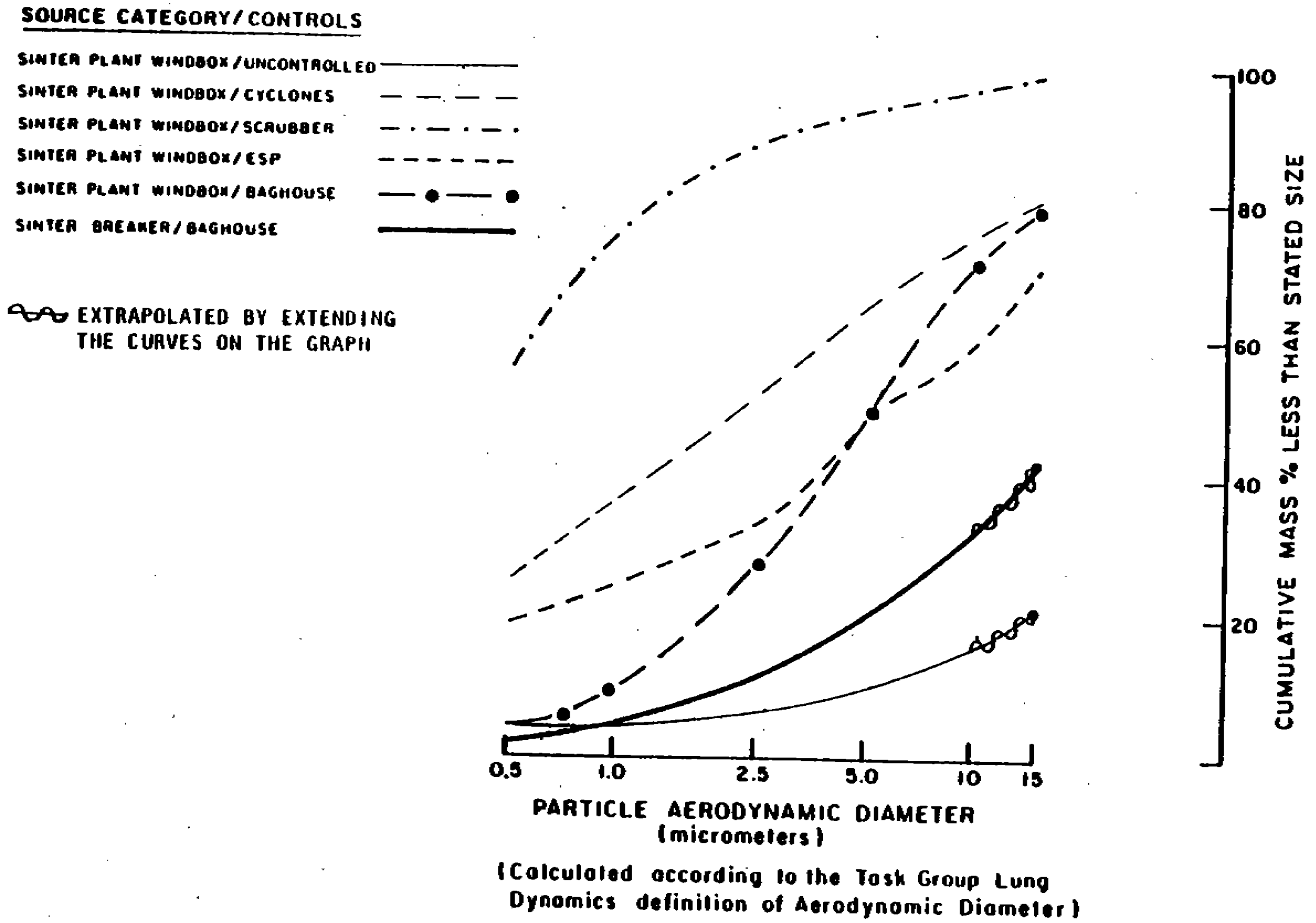


Figure 7.5-2. Particle size distribution of sinter plant emissions.

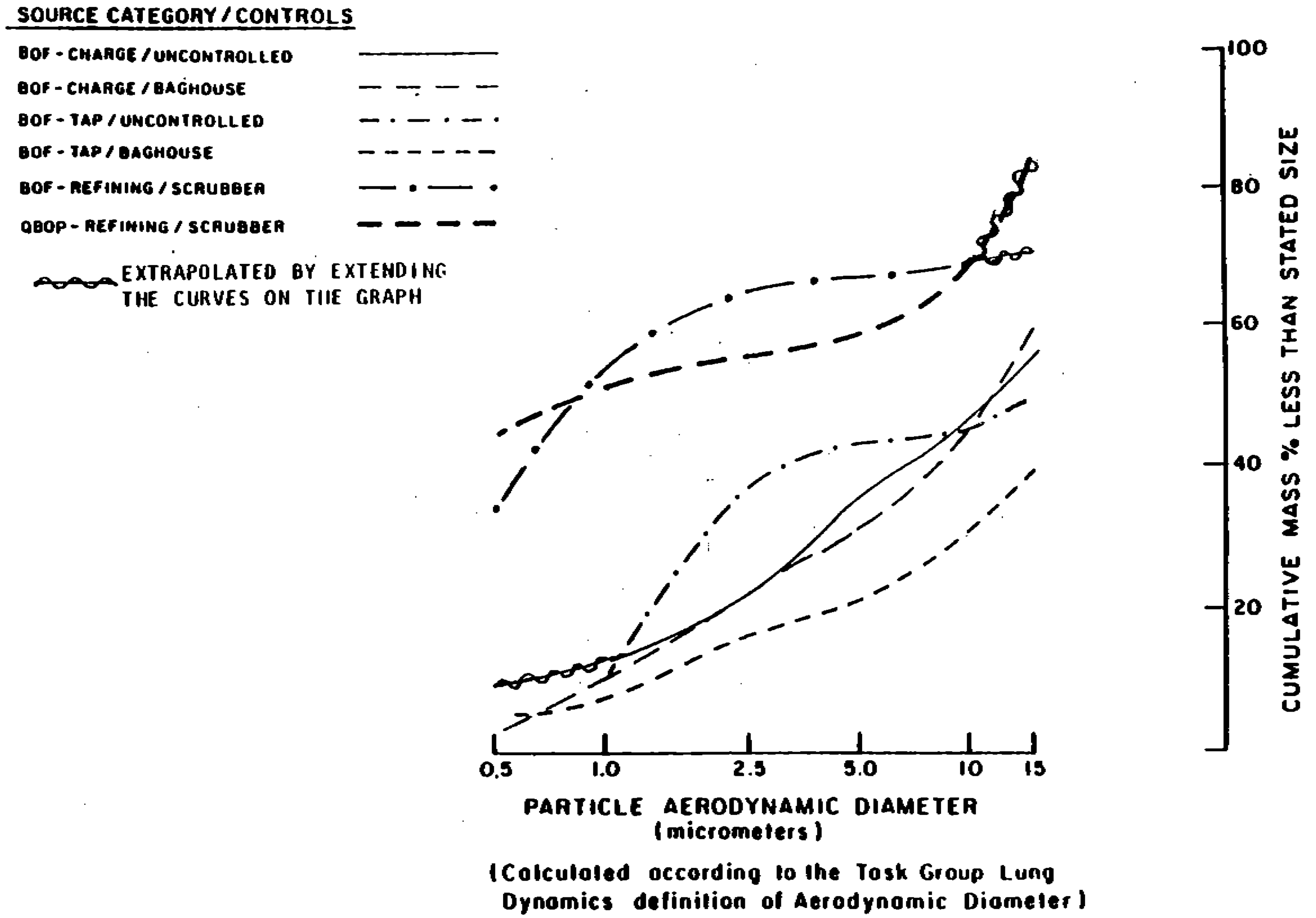
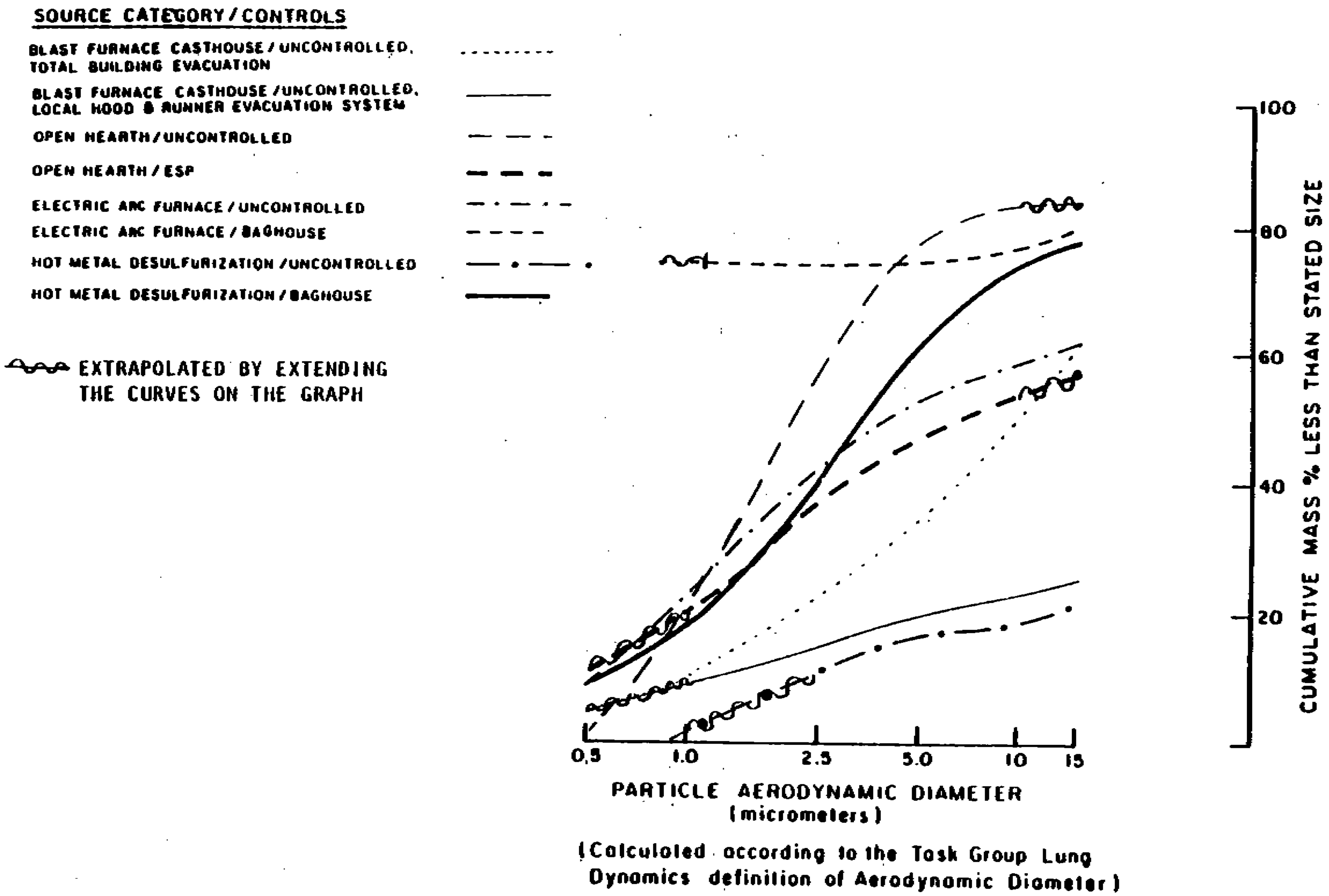


Figure 7.5-3. Particle size distribution of basic oxygen furnace emissions.



(Calculated according to the Task Group Lung Dynamics definition of Aerodynamic Diameter)

Figure 7.5-4. Particle size distribution of blast furnace, open hearth, electric arc furnace and hot metal desulfurization emissions.

TABLE 7.5-3. UNCONTROLLED CARBON MONOXIDE EMISSION FACTORS FOR IRON AND STEEL MILLS[a]

EMISSION FACTOR RATING: C

Source	kg/Mg	lb/ton
Sintering windbox[b]	22	44
Basic oxygen furnace[c]	69	138
Electric arc furnace[c]	9	18

[a] Reference 6.
[b] kg/Mg (lb/ton) of finished sinter.
[c] kg/Mg (lb/ton) of finished steel.

7.5.2.9 Open Dust Sources - Like process emission sources, open dust sources contribute to the atmospheric particulate burden. Open dust sources include vehicle traffic on paved and unpaved roads, raw material handling outside of buildings and wind erosion from storage piles and exposed terrain. Vehicle traffic consists of plant personnel and visitor vehicles, plant service vehicles, and trucks handling raw materials, plant deliverables, steel products and waste materials. Raw materials are handled by clamshell buckets, bucket/ladder conveyors, rotary railroad dumps, bottom railroad dumps, front end loaders, truck dumps, and conveyor transfer stations, all of which disturb the raw material and expose fines to the wind. Even fine materials resting on flat areas or in storage piles are exposed and are subject to wind erosion. It is not unusual to have several million tons of raw materials stored at a plant and to have in the range of 10 to 100 acres of exposed area there.

Open dust source emission factors for iron and steel production are presented in Table 7.5-4. These factors were determined through source testing at various integrated iron and steel plants.

As an alternative to the single valued open dust emission factors given in Table 7.5-4, empirically derived emission factor equations are presented in Section 11.2 of this document. Each equation was developed for a source operation defined on the basis of a single dust generating mechanism which crosses industry lines, such as vehicle traffic on unpaved roads. The predictive equation explains much of the observed variance in measured emission factors by relating emissions to parameters which characterize source conditions. These parameters may be grouped into three categories: (1) measures of source activity or energy expended (e. g., the speed and weight of a vehicle traveling on an unpaved road), (2) properties of the material being disturbed (e. g., the content of suspendible fines in the surface material on an unpaved road) and (3) climatic parameters (e. g., number of precipitation free days per year, when emissions tend to a maximum).[4]

TABLE 7.5-4. UNCONTROLLED PARTICULATE EMISSION FACTORS FOR OPEN DUST SOURCES AT IRON AND STEEL MILLS[a]

Operation	Emissions by particle size range (aerodynamic diameter)					Units[b]	Emission Factor Rating
	≤ 30 µm	≤ 15 µm	≤ 10 µm	≤ 5 µm	≤ 2.5 µm		
Continuous drop							
Conveyor transfer station sinter[c]	13 0.026	9.0 0.018	6.5 0.013	4.2 0.0084	2.3 0.0046	g/Mg lb/ton	D D
Pile formation stacker pellet ore[c]	1.2 0.0024	0.75 0.0015	0.55 0.0011	0.32 0.00064	0.17 0.00034	g/Mg lb/ton	B B
Lump ore[c]	0.15 0.00030	0.095 0.00019	0.075 0.00015	0.040 0.000081	0.022 0.000043	g/Mg lb/ton	C C
Coal[d]	0.055 0.00011	0.034 0.000068	0.026 0.000052	0.014 0.000028	0.0075 0.000015	g/Mg lb/ton	E E
Batch drop							
Front end loader/truck[c]							
High silt slag	13 0.026	8.5 0.017	6.5 0.013	4.0 0.0080	2.3 0.0046	g/Mg lb/ton	C C
Low silt slag	4.4 0.0088	2.9 0.0058	2.2 0.0043	1.4 0.0028	0.80 0.0016	g/Mg lb/ton	C C
Vehicle travel on unpaved roads							
Light duty vehicle[d]	0.51 1.8	0.37 1.3	0.28 1.0	0.18 0.64	0.10 0.36	Kg/VKT lb/VMT	C C
Medium duty vehicle[d]	2.1 7.3	1.5 5.2	1.2 4.1	0.70 2.5	0.42 1.5	Kg/VKT lb/VMT	C C
Heavy duty vehicle[d]	3.9 14	2.7 9.7	2.1 7.6	1.4 4.8	0.76 2.7	Kg/VKT lb/VMT	B B
Vehicle travel on paved roads							
Light/heavy vehicle mix[c]	0.22 0.78	0.16 0.58	0.12 0.44	0.079 0.28	0.042 0.15	Kg/VKT lb/VMT	C C

[a] Predictive emission factor equations are generally preferred over these single values emission factors. Predictive emission factors estimates are presented in Chapter 11, Section 11.2. VKT = Vehicle kilometer traveled. VMT = Vehicle mile traveled.

[b] Units/unit of material transferred or units/unit of distance traveled.

[c] Reference 4. Interpolation to other particle sizes will be approximate.

[d] Reference 5. Interpolation to other particle sizes will be approximate.

Because the predictive equations allow for emission factor adjustment to specific source conditions, the equations should be used in place of the factors in Table 7.5-4, if emission estimates for sources in a specific iron and steel facility are needed. However, the generally higher quality ratings assigned to the equations are applicable only if (1) reliable values of correction parameters have been determined for the specific sources of interest and (2) the correction parameter values lie within the ranges tested in developing the equations. Section 11.2 lists measured properties of aggregate process materials and road surface materials in the iron and steel industry, which can be used to estimate correction parameter values for the predictive emission factor equations, in the event that site specific values are not available.

Use of mean correction parameter values from Section 11.2 reduces the quality ratings of the emission factor equation by one level.

References for Section 7.5

1. J. Jeffery and J. Vay, Source Category Report for the Iron and Steel Industry, EPA-600/7-86-036, U.S. Environmental Protection Agency, Research Triangle Park, NC, October 1986.

2. H. E. McGannon, ed., The Making, and Shaping and Treating of Steel, U. S. Steel Corporation, Pittsburgh, PA, 1971.

3. T. A. Cuscino, Jr., Particulate Emission Factors Applicable to the Iron and Steel Industry, EPA-450/4-79-028, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1979.

4. R. Bohn, et al., Fugitive Emissions from Integrated Iron and Steel Plants, EPA-600/2-78-050, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1978.

5. C. Cowherd, Jr., et al., Iron and Steel Plant Open Source Fugitive Emission Evaluation, EPA-600/2-79-103, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1979.

6. Control Techniques for Carbon Monoxide Emissions from Stationary Sources, AP-65, U. S. Department of Health, Education and Welfare, Washington, DC, March 1970.

7.6 PRIMARY LEAD SMELTING

7.6.1 Process Description

Lead is usually found naturally as a sulfide ore containing small amounts of copper, iron, zinc and other trace elements. It is usually concentrated at the mine from an ore of 3 to 8 percent lead to a concentrate of 55 to 70 percent lead, containing from 13 to 19 weight percent free and uncombined sulfur. Processing involves three major steps, sintering, reduction and refining.

A typical diagram of the production of lead metal from ore concentrate, with particle and gaseous emission sources indicated, is shown in Figure 7.6-1.

Sintering - Sinter is produced by a sinter machine, a continuous steel pallet conveyor belt moved by gears and sprockets. Each pallet consists of perforated or slotted grates, beneath which are wind boxes connected to fans to provide a draft, either up or down, through the moving sinter charge. Except for draft direction, all machines are similar in design, construction and operation.

The primary reactions occurring during the sintering process are autogenous, occurring at approximately 1000°C (1800°F):

$$2PbS + 3O_2 > 2PbO + 2SO_2 \qquad (1)$$

$$PbS + 2O_2 > PbSO_4 \qquad (2)$$

Operating experience has shown that system operation and product quality are optimum when the sulfur content of the sinter charge is from 5 to 7 weight percent. To maintain this desired sulfur content, sulfide free fluxes such as silica and limestone, plus large amounts of recycled sinter and smelter residues, are added to the mix. The quality of the product sinter is usually determined by its Ritter Index hardness, which is inversely proportional to the sulfur content. Hard quality sinter (low sulfur content) is preferred, because it resists crushing during discharge from the sinter machine. Undersize sinter, usually from insufficient desulfurization, is recycled for further processing.

Of the two kinds of sintering machines, the updraft design is superior for many reasons. First, the sinter bed is more permeable (and hence can be larger), thereby permitting a higher production rate than with a downdraft machine of similar dimensions. Secondly, the small amounts of elemental lead that form during sintering will solidify at their point of formation in updraft machines, but, in downdraft operation, the metal flows down and collects on the grates or at the bottom of the sinter charge, thus causing increased pressure drop and attendant reduced blower capacity. The updraft system also can produce sinter

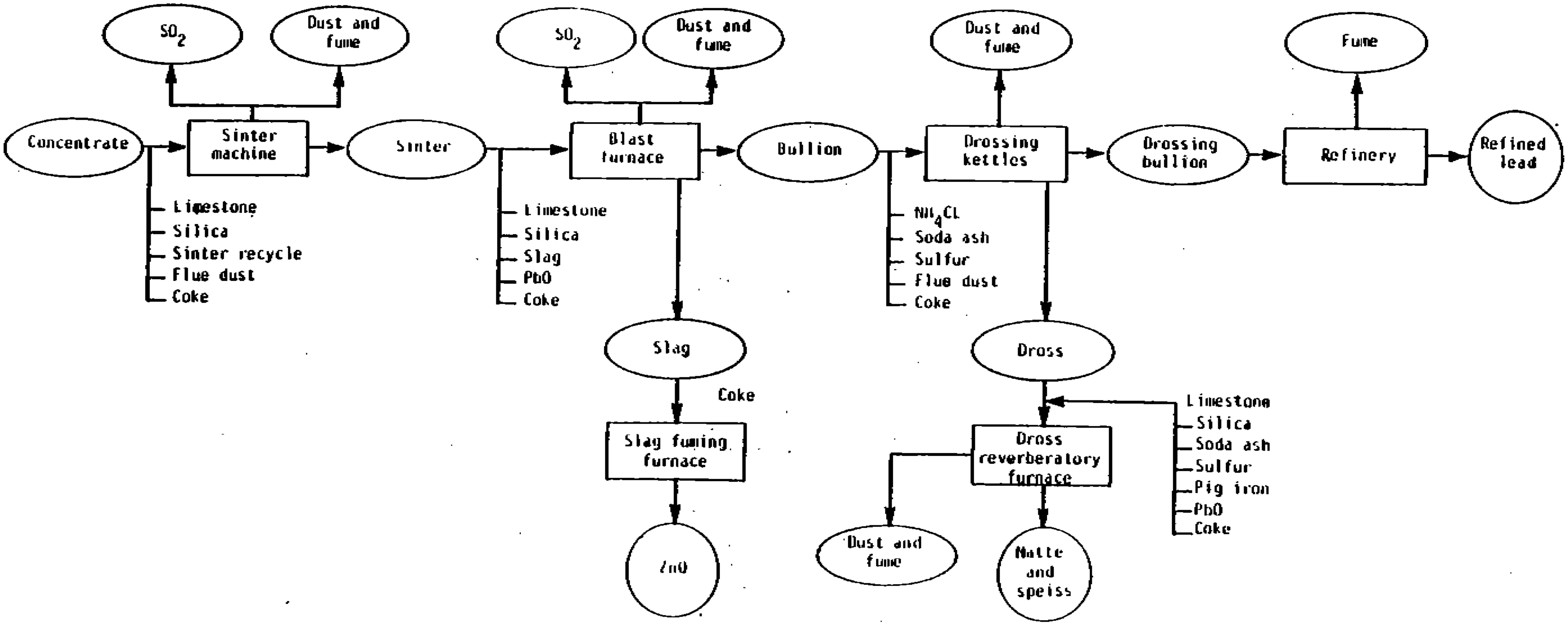


Figure 7.6-1. Typical primary lead processing scheme.

of higher lead content, and it requires less maintenance than the downdraft machine. Finally, and most important from an air pollution control standpoint, updraft sintering can produce a single strong sulfur dioxide (SO_2) effluent stream from the operation, by the use of weak gas recirculation. This permits more efficient and economical use of control methods such as sulfuric acid recovery devices.

Reduction - Lead reduction is carried out in a blast furnace, which basically is a water jacketed shaft furnace supported by a refractory base. Tuyeres, through which combustion air is admitted under pressure, are located near the bottom and are evenly spaced on either side of the furnace.

The furnace is charged with a mixture of sinter (80 to 90 percent of charge), metallurgical coke (8 to 14 percent of charge), and other materials such as limestone, silica, litharge, slag forming constituents, and various recycled and cleanup materials. In the furnace, the sinter is reduced to lead bullion by Reactions 3 through 7.

$$C + O_2 \rightarrow CO_2 \quad (3)$$

$$C + CO_2 \rightarrow 2CO \quad (4)$$

$$PbO + CO \rightarrow Pb + CO_2 \quad (5)$$

$$2PbO + PbS \rightarrow 3Pb + SO_2 \quad (6)$$

$$PbSO_4 + PbS \rightarrow 2Pb + 2SO_2 \quad (7)$$

Carbon monoxide and heat required for reduction are supplied by the combustion of coke. Most of the impurities are eliminated in the slag. Solid products from the blast furnace generally separate into four layers, speiss (the lightest material, basically arsenic and antimony), matte (copper sulfide and other metal sulfides), slag (primarily silicates), and lead bullion. The first three layers are called slag, which is continually collected from the furnace and is either processed at the smelter for its metal content or shipped to treatment facilities.

Sulfur oxides are also generated in blast furnaces from small quantities of residual lead sulfide and lead sulfates in the sinter feed. The quantity of these emissions is a function not only of the sinter's residual sulfur content, but also of the sulfur captured by copper and other impurities in the slag.

Rough lead bullion from the blast furnace usually requires preliminary treatment (drossing) in kettles before undergoing refining operations. First, the bullion is cooled to 370° to 430°C (700 to 800°F). Copper and small amounts of sulfur, arsenic, antimony and nickel collect on the surface as a dross and are removed from the solution. This dross, in turn, is treated in a reverberatory furnace to concentrate the copper and other metal impurities before being routed to copper smelters for their eventual recovery. To enhance copper removal, drossed lead bullion is treated by adding sulfur bearing material, zinc, and/or aluminum, lowering the copper content to approximately 0.01 percent.

Refining - The third and final phase in smelting, the refining of the bullion in cast iron kettles, occurs in five steps:

- Removal of antimony, tin and arsenic
- Removal of precious metals by Parke's Process, in which zinc combines with gold and silver to form an insoluble intermetallic at operating temperatures
- Vacuum removal of zinc
- Removal of bismuth by the Betterson Process, which is the addition of calcium and magnesium to form an insoluble compound with the bismuth that is skimmed from the kettle
- Removal of remaining traces of metal impurities by addition of NaOH and $NaNO_3$

The final refined lead, commonly from 99.990 to 99.999 percent pure, is then cast into 45 kilogram (100 pound) pigs for shipment.

7.6.2 Emissions And Controls[1-2]

Each of the three major lead smelting process steps generates substantial quantities of SO_2 and/or particulate.

Nearly 85 percent of the sulfur present in the lead ore concentrate is eliminated in the sintering operation. In handling process offgases, either a single weak stream is taken from the machine hood at less than 2 percent SO_2, or two streams are taken, a strong stream (5 to 7 percent SO_2) from the feed end of the machine and a weak stream (less than 0.5 percent SO_2) from the discharge end. Single stream operation has been used if there is little or no market for recovered sulfur, so that the uncontrolled, weak SO_2 stream is emitted to the atmosphere. When sulfur removal is required, however, dual stream operation is preferred. The strong stream is sent to a sulfuric acid plant, and the weak stream is vented to the atmosphere after removal of particulate.

When dual gas stream operation is used with updraft sinter machines, the weak gas stream can be recirculated through the bed to mix with the strong gas stream, resulting in a single stream with an SO_2 concentration of about 6 percent. This technique decreases machine production capacity, but it does permit a more convenient and economical recovery of the SO_2 by sulfuric acid plants and other control methods.

Without weak gas recirculation, the end portion of the sinter machine acts as a cooling zone for the sinter and, consequently, assists in the reduction of dust formation during product discharge and screening. However, when recirculation is used, sinter is usually discharged at 400° to 500°C (745° to 950°F), with an attendant increase in particulate. Methods to reduce these dust quantities include recirculatng offgases through the sinter bed (to use the bed as a filter) or ducting gases from the sinter machine discharge through a particulate collection device and then to the atmosphere. Because reaction activity has ceased in the discharge area, these gases contain little SO_2.

Particulate emissions from sinter machines range from 5 to 20 percent of the concentrated ore feed. In terms of product weight, a typical emission is estimated to be 106.5 kilograms per megagram (213 pounds per ton) of lead produced. This value, and other particulate and SO_2 factors, appears in Table 7.6-1.

Typical material balances from domestic lead smelters indicate that about 15 percent of the sulfur in the ore concentrate fed to the sinter machine is eliminated in the blast furnace. However, only half of this amount, about 7 percent of the total sulfur in the ore, is emitted as SO_2.

The remainder is captured by the slag. The concentration of this SO_2 stream can vary from 1.4 to 7.2 grams per cubic meter (500 to 2500 parts per million) by volume , depending on the amount of dilution air injected to oxidize the carbon monoxide and to cool the stream before baghouse particulate removal.

Particulate emissions from blast furnaces contain many different kinds of material, including a range of lead oxides, quartz, limestone, iron pyrites, iron-lime-silicate slag, arsenic, and other metallic compounds associated with lead ores. These particles readily agglomerate and are primarily submicron in size, difficult to wet, and cohesive. They will bridge and arch in hoppers. On average, this dust loading is quite substantial, as is shown in Table 7.6-1.

Minor quantities of particulates are generated by ore crushing and materials handling operations, and these emission factors are also presented in Table 7.6-1.

TABLE 7.6-1. UNCONTROLLED EMISSION FACTORS FOR PRIMARY LEAD SMELTING[a]

EMISSION FACTOR RATING: B

Process	Particulate		Sulfur dioxide	
	kg/Mg	lb/ton	kg/Mg	lb/ton
Ore crushing[b]	1.0	2.0	-	-
Sintering (updraft)[c]	106.5	213.0	275.0	550.0
Blast furnace[d]	180.5	361.0	22.5	45.0
Dross reverberatory furnace[e]	10.0	20.0	Neg	Neg
Materials handling[f]	2.5	5.0	-	-

[a] Based on quantity of lead produced. Dash = no data. Neg = negligible.
[b] Reference 2. Based on quantity of ore crushed. Estimated from similar nonferrous metals processing.
[c] References 1, 5-7.
[d] References 1-2, 8.
[e] Reference 2.
[f] Reference 2. Based on quantity of materials handled.

Table 7.6-2 and Figure 7.6-2 present size specific emission factors for the controlled emissions from a primary lead blast furnace. No other size distribution data can be located for point sources within a primary lead processing plant. Lacking definitive data, size distributions for uncontrolled assuming that the uncontrolled size distributions for the sinter machine and blast furnace are the same as for fugitive emissions from these sources.

Tables 7.6-3 through 7.6-7 and Figures 7.6-3 through 7.6-7 present size specific emission factors for the fugitive emissions generated at a primary lead processing plant. The size distribution of fugitive emissions at a primary lead processing plant is fairly uniform, with approximately 79 percent of these emissions at less than 2.5 micrometers. Fugitive emissions less than 0.625 micrometers in size make up approximately half of all fugitive emissions, except from the sinter machine, where they constitute about 73 percent.

Emission factors for total fugitive particulate from primary lead smelting processes are presented in Table 7.6-8. The factors are based on a combination of engineering estimates, test data from plants currently operating, and test data from plants no longer operating. The values should be used with caution, because of the reported difficulty in accurately measuring the source emission rates.

Emission controls on lead smelter operations are for particulate and sulfur dioxide. The most commonly employed high efficiency particulate control devices are fabric filters and electrostatic precipitators (ESP), which often follow centrifugal collectors and tubular coolers (pseudogravity collectors).

Three of the six lead smelters presently operating in the United States use single absorption sulfuric acid plants to control SO_2 emissions from sinter machines and, occasionally, from blast furnaces. Single stage plants can attain sulfur oxide levels of 5.7 grams per cubic meter (2000 parts per million), and dual stage plants can attain levels of 1.6 grams per cubic meter (550 parts per million). Typical efficiencies of dual stage sulfuric acid plants in removing sulfur oxides can exceed 99 percent. Other technically feasible SO_2 control methods are elemental sulfur recovery plants and dimethylaniline (DMA) and ammonia absorption processes. These methods and their representative control efficiencies are given in Table 7.6-9.

TABLE 7.6-2. LEAD EMISSION FACTORS AND PARTICLE SIZE DISTRIBUTION FOR BAGHOUSE CONTROLLED BLAST FURNACE FLUE GASES[a]

EMISSION FACTOR RATING: C

Particle size[b] (um)	Cumulative mass % ≤ stated size	Cumulative emission factors	
		kg/Mg	lb/ton
15	98	1.17	2.34
10	86.3	1.03	2.06
6	71.8	0.86	1.72
2.5	56.7	0.68	1.36
1.25	54.1	0.65	1.29
1.00	53.6	0.64	1.28
0.625	52.9	0.63	1.27
Total	100.0	1.20	2.39

[a] Reference 9.

[b] Expressed as aerodynamic equivalent diameter.

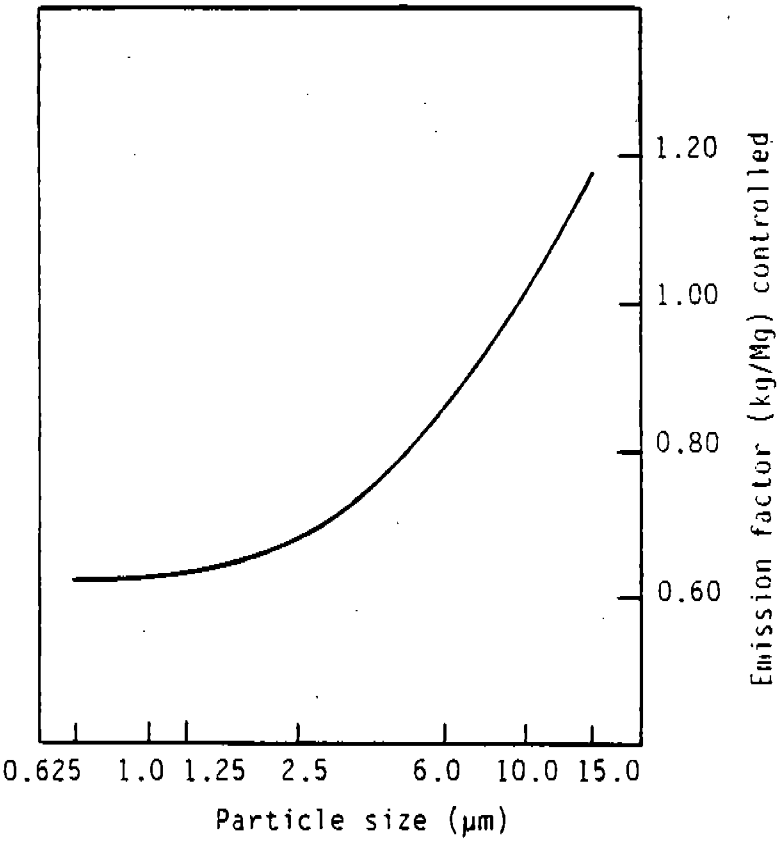


Figure 7.6-2. Size specific emission factors for baghouse controlled blast furnace.

TABLE 7.6-3 UNCONTROLLED FUGITIVE EMISSION FACTORS AND PARTICLE SIZE DISTRIBUTION FOR LEAD ORE STORAGE[a]

EMISSION FACTOR RATING: D

Particle size[b] (um)	Cumulative mass % ≤ stated size	Cumulative emission factors	
		kg/Mg	lb/ton
15	91	0.011	0.023
10	86	0.010	0.021
6	80.5	0.010	0.020
2.5	69.0	0.009	0.017
1.25	61.0	0.008	0.015
1.00	59.0	0.007	0.015
0.625	54.5	0.007	0.013
Total	100.0	0.012	0.025

[a] Reference 10.

[b] Expressed as aerodynamic equivalent diameter.

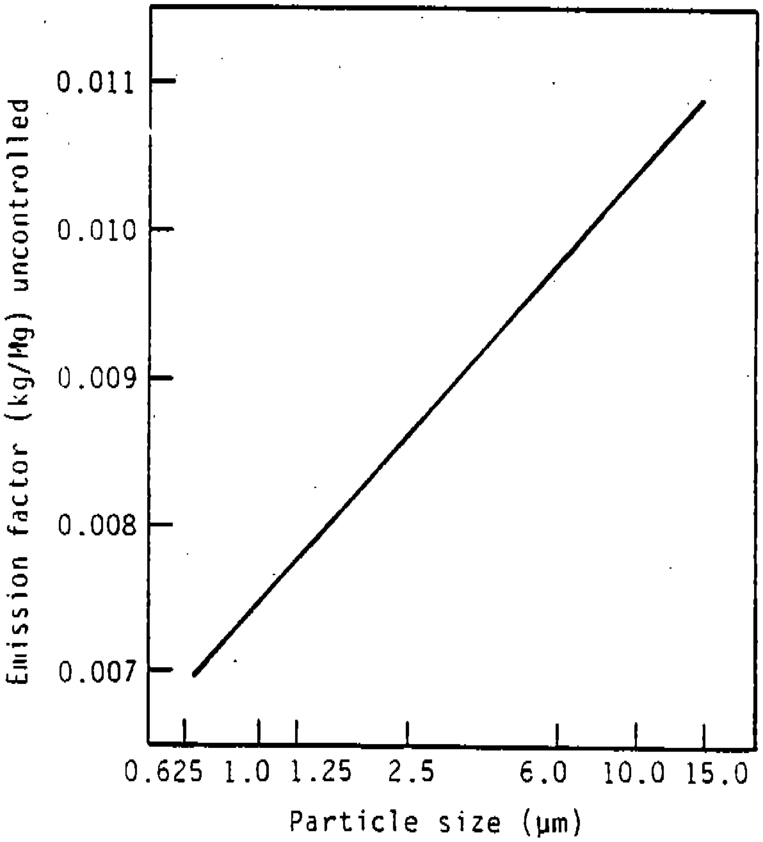


Figure 7.6-3. Size specific uncontrolled fugitive emission factors for lead ore storage.

TABLE 7.6-4. UNCONTROLLED LEAD FUGITIVE EMISSION FACTORS AND PARTICLE SIZE DISTRIBUTION FOR SINTER MACHINE[a]

EMISSION FACTOR RATING: D

Particle size[b] (um)	Cumulative mass % ≤ stated size	Cumulative emission factors	
		kg/Mg	lb/ton
15	99	0.10	0.19
10	98	0.10	0.19
6	94.1	0.09	0.17
2.5	87.3	0.08	0.16
1.25	81.1	0.07	0.15
1.00	78.4	0.07	0.15
0.625	73.2	0.07	0.14
Total	100.0	0.10	0.19

[a] Reference 10.

[b] Expressed as aerodynamic equivalent diameter.

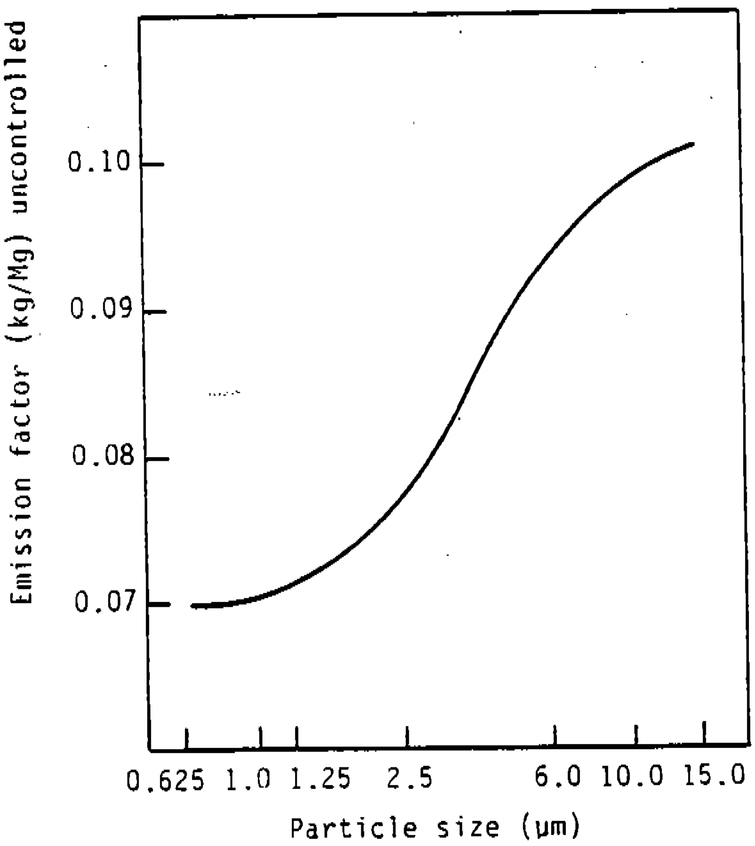


Figure 7.6-4. Size specific fugitive emission factors for uncontrolled sinter machine.

TABLE 7.6-5. UNCONTROLLED LEAD FUGITIVE EMISSION FACTORS AND PARTICLE SIZE DISTRIBUTION FOR BLAST FURNACE[a]

EMISSION FACTOR RATING: D

Particle size[b] (um)	Cumulative mass % ≤ stated size	Cumulative emission factors	
		kg/Mg	lb/ton
15	94	0.11	0.23
10	89	0.11	0.21
6	83.5	0.10	0.20
2.5	73.8	0.09	0.17
1.25	65.0	0.08	0.15
1.00	61.8	0.07	0.15
0.625	54.4	0.06	0.13
Total	100.0	0.12	0.24

[a] Reference 10.

[b] Expressed as aerodynamic equivalent diameter.

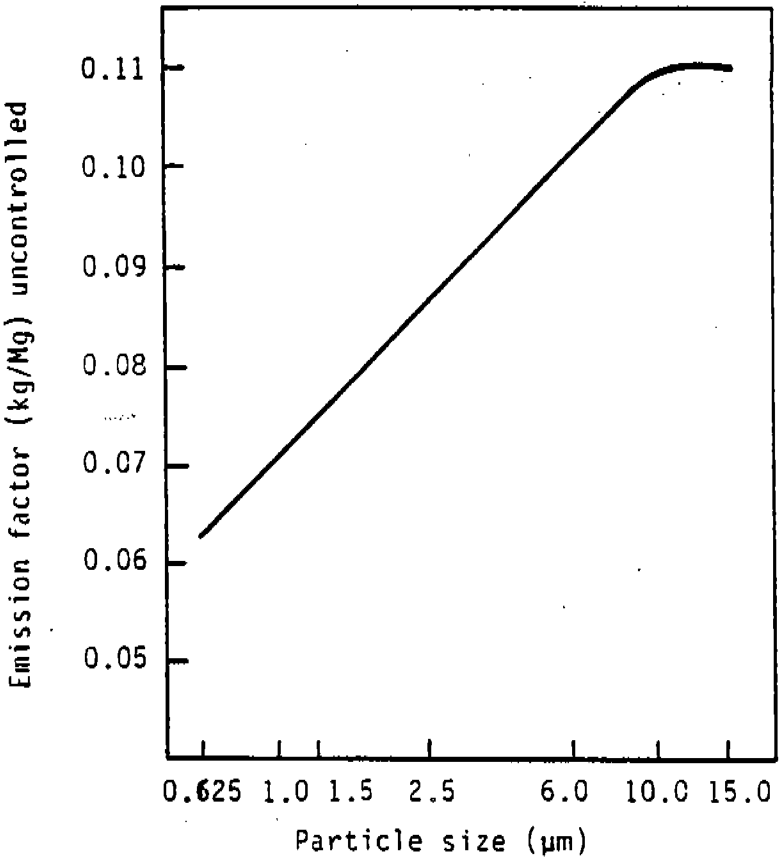


Figure 7.6-5. Size specific lead fugitive emission factors for uncontrolled blast furnace.

TABLE 7.6-6. UNCONTROLLED LEAD FUGITIVE EMISSION FACTORS AND PARTICLE SIZE DISTRIBUTION FOR DROSS KETTLE[a]

EMISSION FACTOR RATING: D

Particle size[b] (um)	Cumulative mass % ≤ stated size	Cumulative emission factors	
		kg/Mg	lb/ton
15	99	0.18	0.36
10	98	0.18	0.35
6	92.5	0.17	0.33
2.5	83.3	0.15	0.30
1.25	71.3	0.13	0.26
1.00	66.0	0.12	0.24
0.625	51.0	0.09	0.18
Total	100.0	0.18	0.36

[a] Reference 10.

[b] Expressed as aerodynamic equivalent diameter.

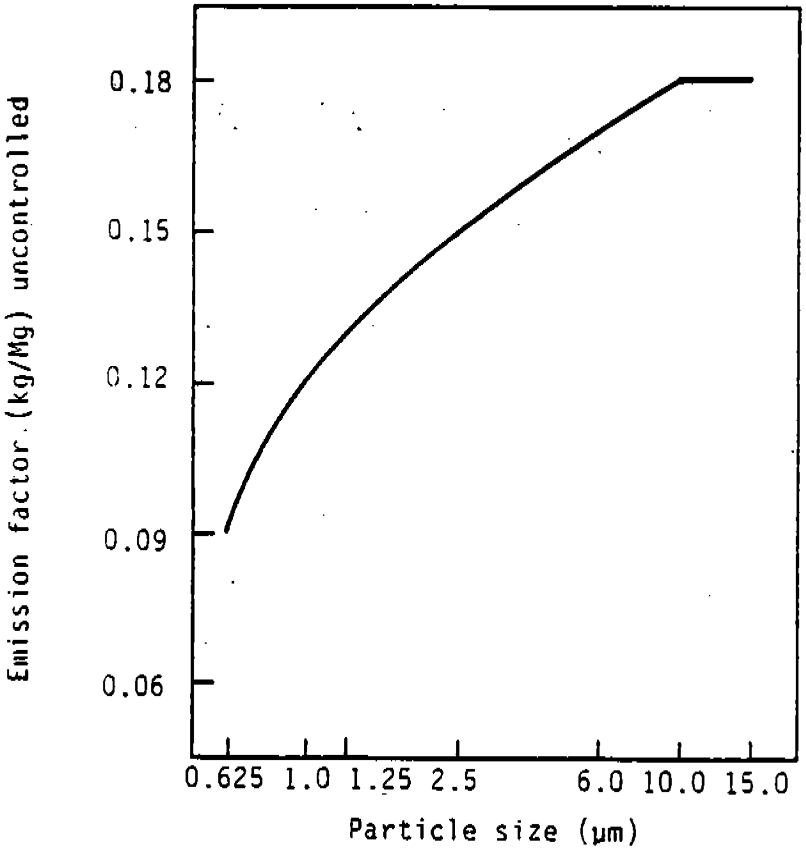


Figure 7.6-6. Size specific lead fugitive emission factors for uncontrolled dross kettle.

TABLE 7.6-7. UNCONTROLLED LEAD FUGITIVE EMISSION FACTORS AND PARTICLE SIZE DISTRIBUTION FOR REVERBERATING FURNACE[a]

EMISSION FACTOR RATING: D

Particle size[b] (um)	Cumulative mass % ≤ stated size	Cumulative emission factors kg/Mg	Cumulative emission factors lb/ton
15	99	0.24	0.49
10	98	0.24	0.48
6	92.3	0.22	0.45
2.5	80.8	0.20	0.39
1.25	67.5	0.16	0.33
1.00	61.8	0.15	0.30
0.625	49.3	0.12	0.24
Total	100.0	0.24	0.49

[a] Reference 10.

[b] Expressed as aerodynamic equivalent diameter.

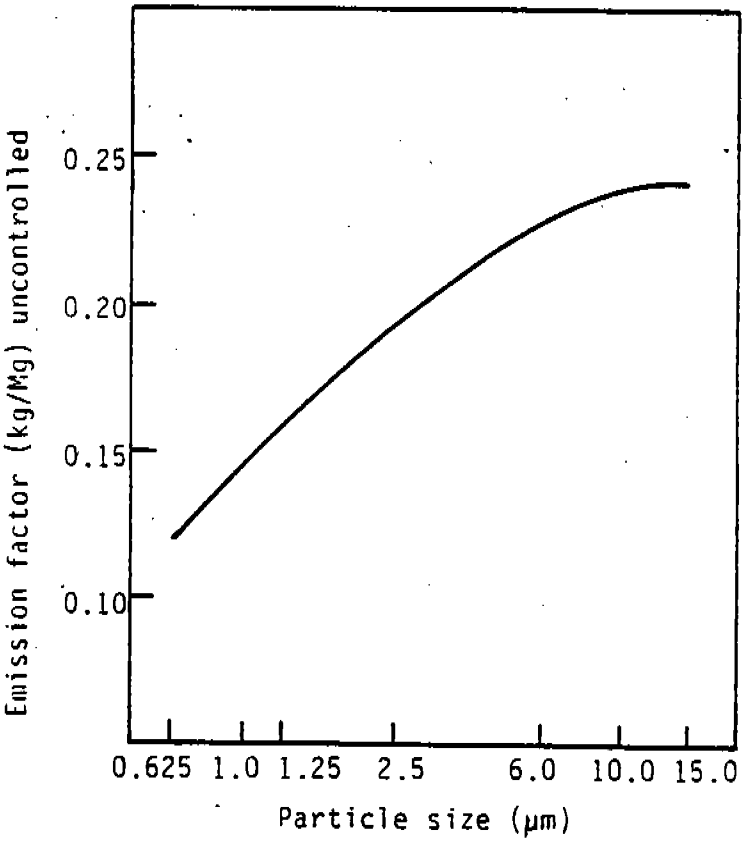


Figure 7.6-7. Size specific lead fugitive emission factors for uncontrolled reverberating furnace.

TABLE 7.6-8. UNCONTROLLED FUGITIVE EMISSION FACTORS FOR PRIMARY LEAD SMELTING PROCESSESS[a,b]

Emission points	Particulate		Emission Factor Rating
	kg/Mg	lb/ton	
Ore storage[b]	0.012	0.025	D
Ore mixing and pelletizing (crushing)	1.13	2.26	E
Car charging (conveyor loading, transfer) of sinter	0.25	0.50	E
Sinter machine			
Machine leakage[c]	0.34	0.68	E
Sinter return handling	4.50	9.00	E
Machine discharge, sinter crushing, screening[c]	0.75	1.50	E
Sinter transfer to dump area	0.10	0.20	E
Sinter product dump area	0.005	0.01	E
Total building[b]	0.10	0.19	D
Blast furnace			
Lead pouring to ladle, transferring, slag pouring[c]	0.47	0.93	D
Slag cooling[d]	0.24	0.47	E
Zinc fuming furnace vents	2.30	4.60	E
Dross kettle[b]	0.24	0.48	D
Reverberatory furnace leakage[b]	1.50	3.00	D
Silver retort building	0.90	1.80	E
Lead casting	0.44	0.87	E

[a] Expressed in units/end product lead produced, except sinter operations, which are units/sinter handled, transferred, charged.

[b] Reference 10.

[c] References 12-13. Engineering judgment, using steel sinter machine leakage emission factor.

[d] Reference 2. Engineering judgment, estimated to be half the magnitude of lead pouring and ladling operations.

TABLE 7.6-9. TYPICAL CONTROL DEVICE EFFICIENCIES IN PRIMARY LEAD SMELTING OPERATIONS

Control method	Efficiency range (%)	
	Particulate	Sulfur dioxide
Centrifugal collector[a]	80 - 90	NA
Electrostatic precipitator[a]	95 - 99	NA
Fabric filter[a]	95 - 99	NA
Tubular cooler (associated with waste heat boiler)[a]	70 - 80	NA
Sulfuric acid plant (single contact)[b,c]	99.5 - 99.9	96 - 97
Sulfuric acid plant (dual contact)[b,d]	99.5 - 99.9	96 - 99.9
Elemental sulfur recovery plant[b,e]	NA	90
Dimethylaniline (DMA) absorption process[b,c]	NA	95 - 99
Ammonia absorption process[b,f]	NA	92 - 95

[a] Reference 2. NA = not available.

[b] Reference 1.

[c] High particulate control efficiency from action of acid plant gas cleaning systems. With SO_2 inlet concentrations 5-7%, typical outlet emission levels are 5.7 g/m^3 (2000 ppm) for single contact, 1.4 g/m^3 (500 ppm) for dual contact.

[d] Collection efficiency for a two stage uncontrolled Claus type plant. See Section 5.18, Sulfur Recovery.

[e] With SO_2 inlet concentrations 4-6 %, typical outlet emission levels are from 1.4-8.6 g/m^3 (500-3000 ppm).

[f] With SO_2 inlet concentrations of 1.5-2.5 %, typical outlet emission level is 3.4 g/m^3 (1200 ppm).

References for Section 7.6

1. C. Darvin and F. Porter, Background Information for New Source Performance Standards: Primary Copper, Zinc and Lead Smelters, Volume I, EPA-450/2-74-002a, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1974.

2. A. E. Vandergrift, et al., Particulate Pollutant System Study, Volume I: Mass Emissions, APTD-0743, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1971.

3. A. Worcester and D. H. Beilstein, "The State of the Art: Lead Recovery", presented at the 10th Annual Meeting of the Metallurgical Society, AIME, New York, NY, March 1971.

4. Environmental Assessment of the Domestic Primary Copper, Lead and Zinc Industries (Prepublication), EPA Contract No. 68-03-2537, Pedco Environmental, Cincinnati, OH, October 1978.

5. T. J. Jacobs, Visit to St. Joe Minerals Corporation Lead Smelter, Herculaneum, MO, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 21, 1971.

6. T. J. Jacobs, Visit to Amax Lead Company, Boss, MO, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 28, 1971.

7. Written communication from R. B. Paul, American Smelting and Refining Co., Glover, MO, to Regional Administrator, U. S. Environmental Protection Agency, Kansas City, MO, April 3, 1973.

8. Emission Test No. 72-MM-14, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1972.

9. Source Sampling Report: Emissions from Lead Smelter at American Smelting and Refining Company, Glover, MO, July 1973 to July 23, 1973, EMB-73-PLD-1, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, August 1974.

10. Sample Fugitive Lead Emissions From Two Primary Lead Smelters, EPA-450/3-77-031, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1977.

11. Silver Valley/Bunker Hill Smelter Environmental Investigation (Interim Report), Contract No. 68-02-1343, Pedco Environmental, Durham, NC, February 1975.

12. R. E. Iversen, Meeting with U. S. Environmental Protection Agency and AISI on Steel Facility Emission Factors, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1976.

13. G. E. Spreight, "Best Practicable Means in the Iron and Steel Industry", The Chemical Engineer, London, England, 271:132-139, March 1973.

14. Control Techniques for Lead Air Emissions, EPA-450/2-77-012, U. S. Environmental Protection Agency, Research Triangle Park, NC, January 1978.

7.7 PRIMARY ZINC SMELTING

7.7.1 Process Description[1-2]

Zinc is found primarily as the sulfide ore sphalerite (ZnS). Its common coproduct ores are lead and copper. Metal impurities commonly associated with ZnS are cadmium (up to 2 percent) and minor quantities of germanium, gallium, indium and thalium. Zinc ores typically contain from 3 to 11 percent zinc. Some ores containing as little as 2 percent are recovered. Concentration at the mine brings this to 49 to 54 percent zinc, with approximately 31 percent free and uncombined sulfur.

Zinc ores are processed into metallic slab zinc by two basic processes. Four of the five domestic U. S. zinc smelting facilities use the electrolytic process, and one plant uses a pyrometallurgical smelting process typical of the primary nonferrous smelting industry. A general diagram of the industry is presented in Figure 7.7-1.

Electrolytic processing involves four major steps, roasting, leaching, purification and electrolysis, details of which follow.

Pyrometalluirgical processing involves three major steps, roasting (as above), sintering and retorting.

Roasting is a process common to both electrolytic and pyrometallurgical processing. Calcine is produced by the roasting reactions in any one of three different types of roasters, multiple hearth, suspension, or fluidized bed. Multiple hearth roasters are the oldest type used in the United States, while fluidized bed roasters are the most modern. The primary zinc roasting reaction occurs between 640° and 1000°C (1300° and 1800°F), depending on the type of roaster used, and is as follows:

$$2ZnS + 3O_2 \longrightarrow 2ZnO + 2SO_2 \qquad (1)$$

In a multiple hearth roaster, the concentrate is blown through a series of nine or more hearths stacked inside a brick lined cylindrical column. As the feed concentrate drops through the furnace, it is first dried by the hot gases passing through the hearths and then oxidized to produce calcine. The reactions are slow and can only be sustained by the addition of fuel.

In a suspension roaster, the feed is blown into a combustion chamber very similar to that of a pulverized coal furnace. Additional grinding, beyond that required for a multiple hearth furnace, is normally required to assure that heat transfer to the material is sufficiently rapid for the desulfurization and oxidation reactions to occur in the furnace chamber. Hearths at the bottom of the roaster capture the larger particles, which require additional time within the furnace to complete the desulfurization reaction.

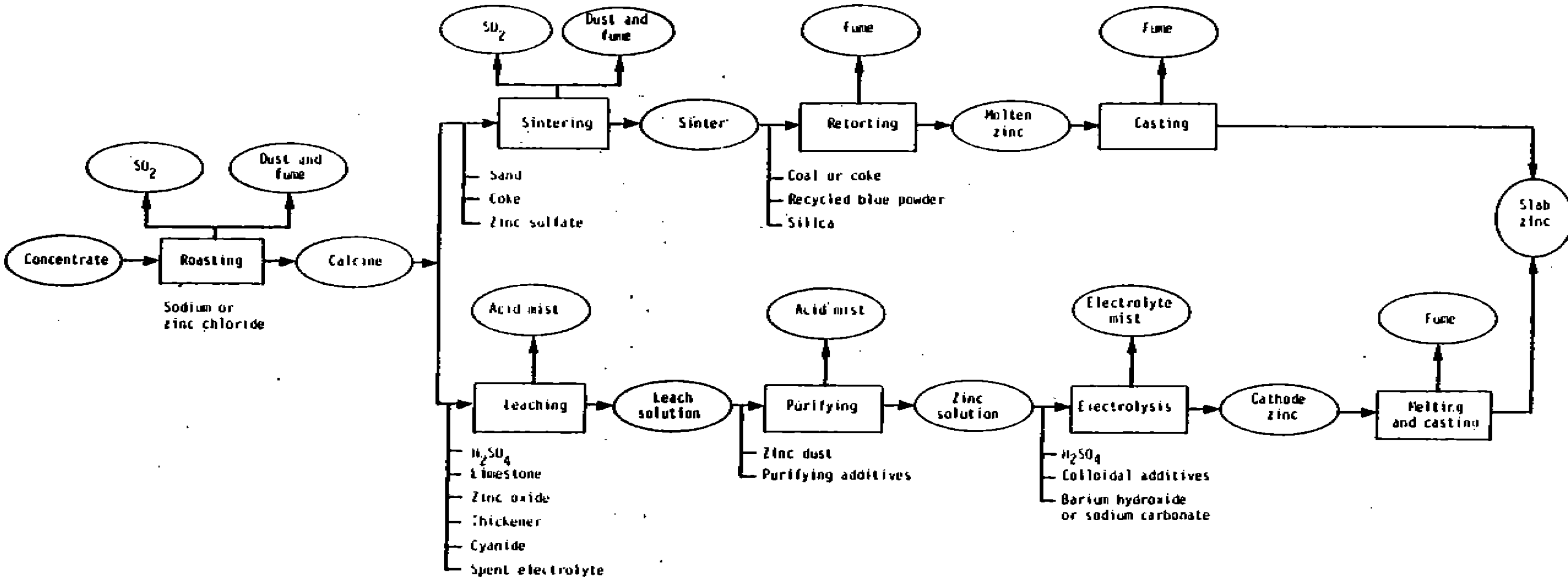


Figure 7.7-1. Typical primary zinc smelting process.

In a fluidized bed roaster, finely ground sulfide concentrates are suspended and oxidized within a pneumatically supported feedstock bed. This achieves the lowest sulfur content calcine of the three roaster designs.

Suspension and fluidized bed roasters are superior to the multiple hearth for several reasons. Although they emit more uncontrolled particulate, their reaction rates are much faster, allowing greater process rates. Also, the sulfur dioxide (SO_2) content of the effluent streams of these two types of roasters is significantly higher, thus permitting more efficient and economical use of acid plants to control SO_2 emissions.

Leaching is the first step of electrolytic reduction, in which the zinc oxide reacts to form aqueous zinc sulfate in an electrolyte solution containing sulfuric acid.

$$ZnO + H_2SO_4 \rightarrow Zn^{+2}(aq) + SO_4^{-2}(aq) + H_2O \qquad (2)$$

Single and double leach methods can be used, although the former exhibits excessive sulfuric acid losses and poor zinc recovery. In double leaching, the calcine is first leached in a neutral or slightly alkaline solution. The readily soluble sulfates from the calcine dissolve, but only a portion of the zinc oxide enters the solution. The calcine is then leached in the acidic electrolysis recycle electrolyte. The zinc oxide is dissolved through Reaction 2, as are many of the impurities, especially iron. The electrolyte is neutralized by this process, and it serves as the leach solution for the first stage of the calcine leaching. This recycling also serves as the first stage of refining, since much of the dissolved iron precipitates out of the solution. Variations on this basic procedure include the use of progressively stronger and hotter acid baths to bring as much of the zinc as possible into solution.

Purification is a process in which a variety of reagents are added to the zinc laden electrolyte to force impurities to precipitate. The solid precipitates are separated from the solution by filtration. The techniques used are among the most advanced industrial applications of inorganic solution chemistry. Processes vary from smelter to smelter, and the details are proprietary and often patented. Metallic impurities, such as arsenic, antimony, cobalt, germanium, nickel and thallium, interfere severely with the electrolyte deposition of zinc, and their final concentrations are limited to less than 0.05 milligrams per liter (4×10^{-7} pounds per gallon).

Electrolysis takes place in tanks, or cells, containing a number of closely spaced rectangular metal plates acting as anodes (made of lead with 0.75 to 1.0 percent silver) and as cathodes (made of aluminum). A series of three major reactions occurs within the electrolysis cells:

$$2H_2O \xrightarrow[\text{anode}]{H_2SO_4} 4H^+(aq) + 4e^- + O_2 \quad (3)$$

$$2Zn^{+2} + 4e^- \xrightarrow{\text{cathode}} 2Zn \quad (4)$$

$$4H^+(aq) + 2SO_4^{-2}(aq) \longrightarrow 2H_2SO_4 \quad (5)$$

Oxygen gas is released at the anode, metallic zinc is deposited at the cathode, and sulfuric acid is regenerated within the electrolyte.

Electrolytic zinc smelters contain a large number of cells, often several hundred. A portion of the electrical energy released in these cells dissipates as heat. The electrolyte is continuously circulated through cooling towers, both to lower its temperature and to concentrate the electrolyte through the evaporation of water. Periodically, each cell is shut down and the zinc is removed from the plates.

The final stage of electrolytic zinc smelting is the melting and casting of the cathode zinc into small slabs, 27 kilograms (60 pounds), or large slabs, 640 to 1100 kilograms (1400 to 2400 pounds).

Sintering is the first stage of the pyrometallurgical reduction of zinc oxide to slab zinc. Sintering removes lead and cadmium impurities by volatilization and produces an agglomerated permeable mass suitable for feed to retorting furnaces. Downdraft sintering machines of the Dwight-Lloyd type are used in the industry. Grate pallets are joined to form a continuous conveyor system. Combustion air is drawn down through the grate pallets and is exhausted to a particulate control system. The feed is a mixture of calcine, recycled sinter and coke or coal fuel. The low boiling point oxides of lead and cadmium are volatilized from the sinter bed and are recovered in the particulate control system.

In retorting, because of the low boiling point of metallic zinc, 906°C (1663°F), reduction and purification of zinc bearing minerals can be accomplished to a greater extent than with most minerals. The sintered zinc oxide feed is brought into high temperature reducing atmosphere of 900° to 1499°C (1650° to 2600°F). Under these conditions, the zinc oxide is simultaneously reduced and volatilized to gaseous zinc:

$$ZnO + CO \rightarrow Zn(vapor) + CO_2 \quad (6)$$

Carbon monoxide regeneration also occurs:

$$CO_2 + C \rightarrow 2CO \quad (7)$$

The zinc vapor and carbon monoxide produced pass from the main furnace to a condenser, for zinc recovery by bubbling through a molten zinc bath.

Retorting furnaces can be heated either externally by combustion flames or internally by electric resistance heating. The latter approach, electrothermic reduction, is the only method currently practiced in the United States, and it has greater thermal efficiency than do external heating methods. In a retort furnace, preheated coke and sinter, silica and miscellaneous zinc bearing materials are fed continuously into the top of the furnace. Feed coke serves as the principle electrical conductor, producing heat, and it also provides the carbon monoxide required for zinc oxide reduction. Further purification steps can be performed on the molten metal collected in the condenser. The molten zinc finally is cast into small slabs 27 kilograms (60 pounds), or the large slabs, 640 to 1000 kilograms (1400 to 2400 pounds).

Each of the two zinc smelting processes generates emissions along the various process steps. Although the electrolytic reduction process emits less particulate than does pyrometallurgical reduction, significant quantities of acid mists are generated by electrolytic production steps. No data are currently available to quantify the significance of these emissions.

Nearly 90 percent of the potential SO_2 emissions from zinc ores is released in roasters. Concentrations of SO_2 in the exhaust gases vary with the roaster type, but they are sufficiently high to allow recovery in an acid plant. Typical SO_2 concentrations for multiple hearth, suspension, and fluidized bed roasters are 4.5 to 6.5 percent, 10 to 13 percent, and 7 to 12 percent, respectively. Additional SO_2 is emitted from the sinter plant, the quantity depending on the sulfur content of the calcine feedstock. The SO_2 concentration of sinter plant exhaust gases ranges from 0.1 to 2.4 percent. No sulfur controls are used on this exhaust stream. Extensive desulfurization before electrothermic retorting results in practically no SO_2 emissions from these devices.

The majority of particulate emissions in the primary zinc smelting industry is generated in the ore concentrate roasters. Depending on the type of roaster used, emissions range from 3.6 to 70 percent of the concentrate feed. When expressed in terms of zinc production, emissions are estimated to be 133 kilograms per megagram (266 pounds per ton) for a multiple hearth roaster, 1000 kilograms per megagram (2000 pounds per ton) for a fluidized bed roaster, expressed in terms of zinc production. Particulate emission controls are generally required for the economical operation of a roaster, with cyclones and electrostatic precipitators (ESP) the primary methods used. No data are available for controlled particulate emissions from a roasting plant.

Controlled and uncontrolled emission factors for point sources within a zinc smelting plant appear in Table 7.7-1. Sinter plant emission factors should be applied carefully, because the data source is different from the only plant currently in operation in the United States, although the technology is identical. Additional data have been obtained for a vertical retort, although no examples of this type of plant are operating in the United States. Particulate factors also have been developed for uncontrolled emissions from an electric retort and the electrolytic process.

Fugitive emission factors have been estimated for the zinc smelting industry and are presented in Table 7.7-2. These emission factors are based on similar operations in the steel, lead and copper industries.

TABLE 7.7-1. PARTICULATE EMISSION FACTORS FOR PRIMARY SLAB ZINC PROCESSING[a]

Process	Uncontrolled		Emission Factor Rating	Controlled		Emission Factor Rating
	kg/Mg	lb/ton		kg/Mg	lb/ton	
Roasting						
Multiple hearth[b]	113	227	E	-	-	
Suspension[c]	1000	2000	E	4	8	E
Fluidized bed[d]	1083	2167	E	-	-	
Sinter plant						
Uncontrolled[e]	62.5	125	E	-	-	
With cyclone[f]	NA	NA		24.1	48.2	D
With cyclone and ESP[f]	NA	NA		8.25	16.5	D
Vertical retort[g]	7.15	14.3	D	-	-	
Electric retort[h]	10.0	20.0	E	-	-	
Electrolytic process[j]	3.3	6.6	E	-	-	

[a] Based on quantity of slab zinc produced. NA = not applicable. Dash = no data.

[b] References 3-5. Averaged from an estimated 10% of feed released as particulate emissions, zinc production rate at 60% of roaster feed rate, and other estimates.

[c] References 3-5. Based on an average 60% of feed released as particulate emission and a zinc production rate at 60% of roaster feed rate. Controlled emissions based on 20% drop out in waste heat boiler and 99.5% drop out in cyclone and ESP.

[d] References 3,6. Based on an average 65% of feed released as particulate emissions and a zinc production rate of 60% of roaster feed rate.

[e] Reference 3. Based on unspecified industrial source data.

[f] Reference 7. Data not necessarily compatible with uncontrolled emissions.

[g] Reference 7.

[h] Reference 2. Based on unspecified industrial source data.

[j] Reference 13.

TABLE 7.7-2. UNCONTROLLED FUGITIVE PARTICULATE EMISSION FACTORS FOR PRIMARY SLAB ZINC PROCESSING[a]

EMISSION FACTOR RATING: E

Process	Emission factor[b]	
	(kg/Mg)	(lb/ton)
Roasting	Negligible	Negligible
Sinter plant[c]		
Wind box	0.12 - 0.55	0.24 - 1.10
Discharge and screens	0.28 - 1.22	0.56 - 2.44
Retort building[d]	1.0 - 2.0	2.0 - 4.0
Casting[e]	1.26	2.52

[a] Based on quantity of slab zinc produced, except as noted.
[b] Reference 8.
[c] From steel industry operations for which there are emission factors. Based on quantity of sinter produced.
[d] From lead industry operations.
[e] From copper industry operations.

References for Section 7.7

1. V. Anthony Cammerota, Jr., "Mineral Facts and Problems: 1980", Zinc, Bureau Of Mines, U. S. Department Of Interior, Washington, DC, 1980.

2. Environmental Assessment of the Domestic Primary Copper, Lead and Zinc Industries, EPA-600/2-82-066, U. S. Environmental Protection Agency, Cincinnati, OH, October 1978.

3. Particulate Pollutant System Study, Volume I: Mass Emissions, APTD-0743, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1971.

4. G. Sallee, personal communication anent Reference 3, Midwest Research Institute, Kansas City, MO, June 1970.

5. Systems Study for Control of Emissions in the Primary Nonferrous Smelting Industry, Volume I, APTD-1280, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1969.

6. Encyclopedia of Chemical Technology, John Wiley and Sons, Inc., New York, NY, 1967.

7. Robert B. Jacko and David W. Nevendorf, "Trace Metal Emission Test Results from a Number of Industrial and Municipal Point Sources", Journal of the Air Pollution Control Association, 27(10):989-994, October 1977.

8. Technical Guidance for Control of Industrial Process Fugitive Particulate Emissions, EPA-450/3-77-010, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1977.

9. Linda J. Duncan and Edwin L. Keitz, "Hazardous Particulate Pollution from Typical Operations in the Primary Non-ferrous Smelting Industry", presented at the 67th Annual Meeting of the Air Pollution Control Association, Denver, CO, June 9-13, 1974.

10. Environmental Assessment Data Systems, FPEIS Test Series No. 3, U. S. Environmental Protection Agency, Research Triangle Park, NC.

11. Environmental Assessment Data Systems, FPEIS Test Series No. 44, U. S. Environmental Protection Agency, Research Triangle Park, NC.

12. R. E. Lund, et al., "Josephtown Electrothermic Zinc Smelter of St. Joe Minerals Corporation", AIME Symposium on Lead and Zinc, Volume II, 1970.

13. Background Information For New Source Performance Standards: Primary Copper, Lead and Zinc Smelters, EPA-450/2-74-002a, U. S. Environmental Protection Agency, Research Triangle Park, NC October 1974.

7.8 SECONDARY ALUMINUM OPERATIONS

7.8.1 General

Secondary aluminum operations involve the cleaning, melting, refining, alloying and pouring of aluminum recovered from scrap, foundry returns and dross. The processes used to convert scrap aluminum to secondary aluminum products such as lightweight metal alloys for industrial castings and ingots are presented in Figure 7.8-1. Production involves two general classes of operations, scrap treatment and smelting/refining.

Scrap treatment involves receiving, sorting and processing scrap to remove contaminants and to prepare the material for smelting. Processes based on mechanical, pyrometallurgical and hydrometallurgical techniques are used, and those employed are selected to suit the type of scrap processed.

The smelting/refining operation generally involves the following steps:

- charging
- melting
- fluxing
- alloying
- mixing
- demagging
- degassing
- skimming
- pouring

All of these steps may be involved at each facility, with process distinctions being in the furnace type used and in emission characteristics. However, as with scrap treatment, not all of these steps are necessarily incorporated into the operations at a particular plant. Some steps may be combined or reordered, depending on furnace design, scrap quality, process inputs and product specifications.

Scrap treatment - Purchased aluminum scrap undergoes inspection upon delivery. Clean scrap requiring no treatment is transported to storage or is charged directly into the smelting furnace. The bulk of the scrap, however, must be manually sorted as it passes along a steel belt conveyor. Free iron, stainless steel, zinc, brass and oversized materials are removed. The sorted scrap then goes to appropriate scrap treating processes or is charged directly to the smelting furnace.

Sorted scrap is conveyed to a ring crusher or hammer mill, where the material is shredded and crushed, with the iron torn away from the aluminum. The crushed material is passed over vibrating screens to remove dirt and fines, and tramp iron is removed by magnetic drums and/or belt separators. Baling equipment compacts bulky aluminum scrap into 1 x 2 meter (3 x 6 foot) bales.

Pure aluminum cable with steel reinforcement or insulation is cut by alligator type shears and granulated or further reduced in hammer mills, to separate the iron core and the plastic coating from the aluminum. Magnetic processing accomplishes iron removal, and air classification separates the insulation.

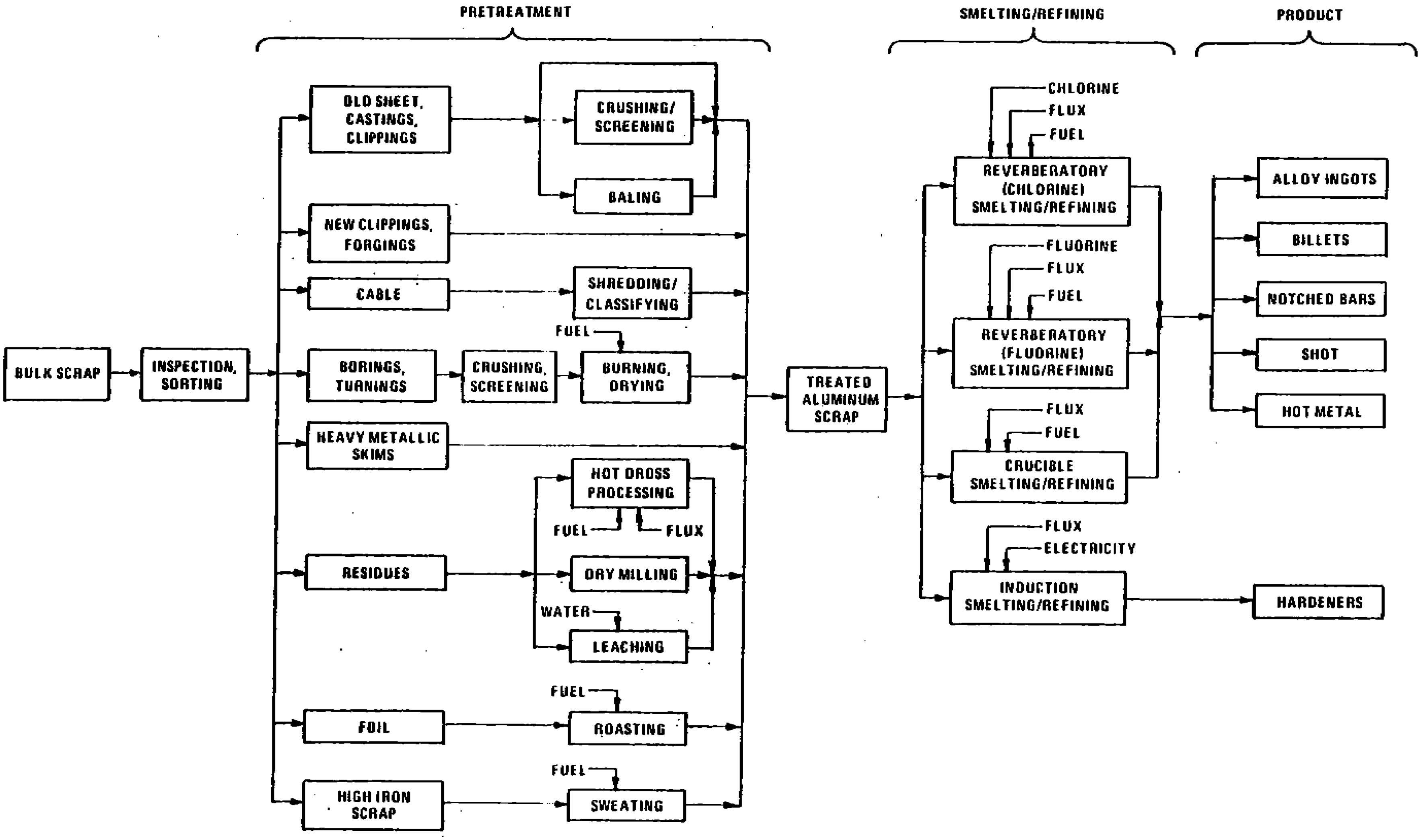


Figure 7.8-1 Typical process diagram for secondary aluminum processing industry.

Borings and turnings, in most cases, are treated to remove cutting oils, greases, moisture and free iron. The processing steps involved are (a) crushing in hammer mills or ring crushers, (b) volatilizing the moisture and organics in a gas or oil fired rotary dryer, (c) screening the dried chips to remove aluminum fines, (d) removing iron magnetically and (e) storing the clean dried borings in tote boxes.

Aluminum can be recovered from the hot dross discharged from a refining furnace by batch fluxing with a salt/cryolite mixture in a mechanically rotated, refractory lined barrel furnace. The metal is tapped periodically through a hole in its base. Secondary aluminum recovery from cold dross and other residues from primary aluminum plants is carried out by means of this batch fluxing in a rotary furnace. In the dry milling process, cold aluminum laden dross and other residues are processed by milling, screening and concentrating to obtain a product containing at least 60-70 percent aluminum. Ball, rod or hammer mills can be used to reduce oxides and nonmetallics to fine powders. Separation of dirt and other unrecoverables from the metal is achieved by screening, air classification and/or magnetic separation.

Leaching involves (a) wet milling, (b) screening, (c) drying and (d) magnetic separation to remove fluxing salts and other non-recoverables from drosses, skimmings and slags. First, the raw material is fed into a long rotating drum or an attrition or ball mill where soluble contaminants are leached. The washed material is then screened to remove fines and dissolved salts and is dried and passed through a magnetic separator to remove ferrous materials. The nonmagnetics then are stored or charged directly to the smelting furnace.

In the roasting process, carbonaceous materials associated with aluminum foil are charred and then separated from the metal product.

Sweating is a pyrometallurgical process used to recover aluminum from high iron content scrap. Open flame reverberatory furnaces may be used. Separation is accomplished as aluminum and other low melting constituents melt and trickle down the hearth, through a grate and into air cooled molds or collecting pots. This product is termed "sweated pig". The higher melting materials, including iron, brass and oxidation products formed during the sweating process, are periodically removed from the furnace.

Smelting/refining - In reverberatory (chlorine) operations, reverberatory furnaces are commonly used to convert clean sorted scrap, sweated pigs or some untreated scrap to specification ingots, shot or hot metal. The scrap is first charged to the furnace by some mechancial means, often through charging wells designed to permit introduction of chips and light scrap below the surface of a previously melted charge ("heel"). Batch processing is generally practiced for alloy ingot production, and continuous feeding and pouring are generally used for products having less strict specifications.

Cover fluxes are used to prevent air contact with and consequent oxidation of the melt. Solvent fluxes react with nonmetallics such as burned coating residues and dirt to form insolubles which float to the surface as part of the slag.

Alloying agents are charged through the forewell in amounts determined by product specifications. Injection of nitrogen or other inert gases into the molten metal can be used to aid in raising dissolved gases (typically hydrogen) and intermixed solids to the surface.

Demagging reduces the magnesium content of the molten charge from approximately 0.3 to 0.5 percent (typical scrap value) to about 0.1 percent (typical product line alloy specification). When demagging with chlorine gas, chlorine is injected under pressure through carbon lances to react with magnesium and aluminum as it bubbles to the surface. Other chlorinating agents, or fluxes, are sometimes used such as anhydrous aluminum chloride or chlorinated organics.

In the skimming step, contaminated semisolid fluxes (dross, slag or skimmings) are ladled from the surface of the melt and removed through the forewell. The melt is then cooled before pouring.

The reverberatory (fluorine) process is similar to the reverberatory (chlorine) smelting/refining process, except that aluminum fluoride (AlF_3) is employed in the demagging step instead of chlorine. The AlF_3 reacts with magnesium to produce molten metallic aluminum and solid magnesium fluoride salt which floats to the surface of the molten aluminum and is skimmed off.

The crucible smelting/refining process is used to melt small batches of aluminum scrap, generally limited to 500 kg (1000 lb) or less. The metal treating process steps are essentially the same as those of reverberatory furnaces.

The induction smelting/refining process is designed to produce hardeners by blending pure aluminum and hardening agents in an electric induction furnace. The process steps include charging scrap to the furnace, melting, adding and blending the hardening agent, skimming, pouring and casting into notched bars.

7.8.2 Emissions and Controls[1]

Table 7.8-1 presents emission factors for the principal emission sources in secondary aluminum operations. Although each step in scrap treatment and smelting/refining is a potential source of emissions, emissions from most of the scrap treatment operations are either not characterized here or represent small amounts of pollutants. Table 7.8-2 presents particle size distributions and corresponding emission factors for uncontrolled chlorine demagging and metal refining in secondary aluminum reverberatory furnaces.

Crushing/screening and shredding/classifying produce small amounts of metallic and nonmetallic particulate. Baling operations produce particulate emissions, primarily dirt and alumina dust resulting from aluminum oxidation. These processing steps are normally uncontrolled.

Burning/drying operations emit a wide range of pollutants, particulate matter as well as VOCs. Afterburners are used generally to convert unburned VOCs to CO_2 and H_2O. Other gases potentially present, depending on the composition of the organic contaminants, include chlorides, fluorides and sulfur oxides. Oxidized aluminum fines blown out of the dryer by the combustion

TABLE 7.8-1. PARTICULATE EMISSION FACTORS FOR SECONDARY ALUMINUM OPERATIONS[a]

	Uncontrolled		Baghouse		Electrostatic precipitator		Emission factor rating
Operation	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	
Sweating furnace[b]	7.25	14.5	1.65	3.3	-	-	C
Smelting							
Crucible furnace[b]	0.95	1.9	-	-	-	-	C
Reverberatory furnace[c]	2.15	4.3	0.65[e]	1.3[e]	0.65	1.3	B
Chlorine demagging[d]	500	1000	25	50	-	-	B

[a] Reference 2. Emission factors for sweating and smelting furnaces expressed as units per unit weight of metal processed. For chlorine demagging, emission factor is kg/Mg (lb/ton) of chlorine used.

[b] Based on averages of two source tests.

[c] Uncontrolled, based on averages of ten source tests. Standard deviation of uncontrolled emission factor is 1.75 kg/Mg (3.5 lb/ton), that of controlled factor is 0.15 kg/Mg (0.3 lb/ton).

[d] Based on average of ten source tests. Standard deviation of uncontrolled emission factor is 215 kg/Mg (430 lb/ton); of controlled factor, 18 kg/Mg (36 lb/ton).

[e] This factor may be lower if a coated baghouse is used.

gases comprise particulate emissions. Wet scrubbers are sometimes used in place of afterburners.

Mechanically generated dust from the rotating barrel dross furnace constitutes the main air emission of hot dross processing. Some fumes are produced from the fluxing reactions. Fugitive emissions are controlled by enclosing the barrel in a hood system and by ducting the stream to a baghouse. Furnace offgas emissions, mainly fluxing salt fume, are controlled by a venturi scrubber.

In dry milling, large amounts of dust are generated from the crushing, milling, screening, air classification and materials transfer steps. Leaching operations may produce particulate emissions during drying. Emissions from roasting are particulates from the charring of carbonaceous materials.

Emissions from sweating furnaces vary with the feed scrap composition. Smoke may result from incomplete combustion of organic contaminants (e.g., rubber, oil and grease, plastics, paint, cardboard, paper) which may be present. Fumes can result from oxidation of magnesium and zinc contaminants and from fluxes in recovered drosses and skims.

Atmospheric emissions from reverberatory (chlorine) smelting/refining represent a significant fraction of the total particulate and gaseous effluents generated in the secondary aluminum industry. Typical furnace effluent gases contain combustion products, chlorine, hydrogen chloride and metal chlorides of zinc, magnesium and aluminum, aluminum oxide and various metals and metal compounds, depending on the quality of scrap charged.

Emissions from reverberatory (fluorine) smelting/refining are similar to those from reverberatory (chlorine) smelting/refining. The use of AlF_3

Particle Size Distributions and Size Specific Emission Factors for Uncontrolled Reverberatory Furnaces

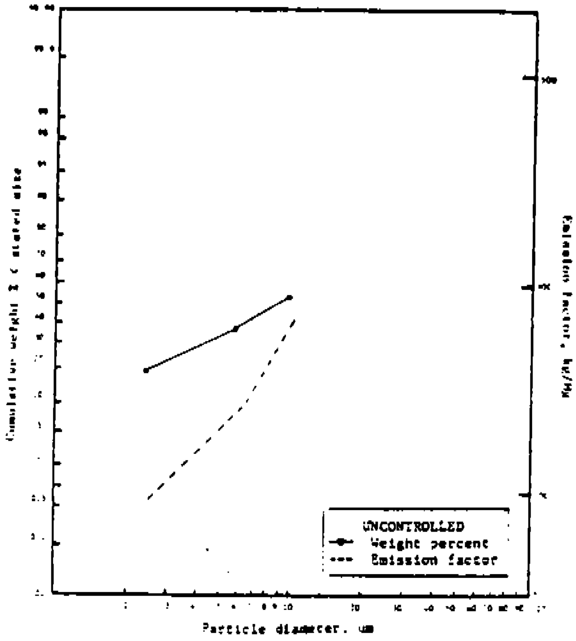


Figure 7.8-2. Chlorine demagging.

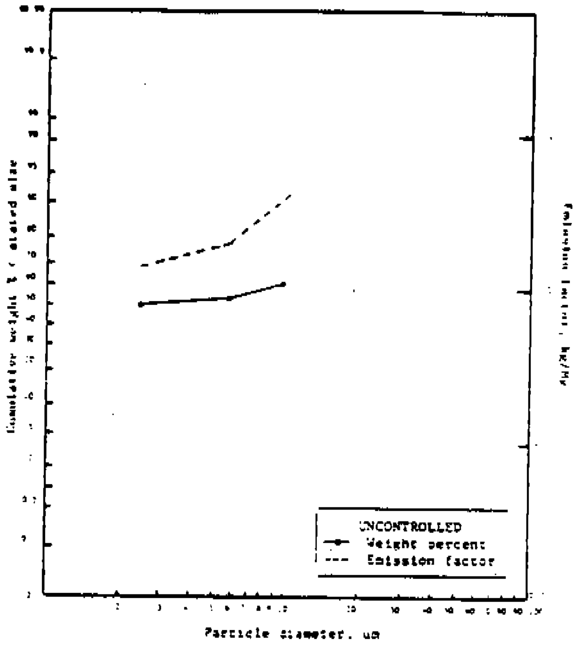


Figure 7.8-3. Refining.

TABLE 7.8-2. PARTICLE SIZE DISTRIBUTIONS AND SIZE SPECIFIC EMISSION FACTORS FOR UNCONTROLLED REVERBERATORY FURNACES IN SECONDARY ALUMINUM OPERATIONS[a]

SIZE-SPECIFIC EMISSION FACTOR RATING: D

Aerodynamic particle diameter, um	Particle size distribution[b]		Size specific emission factor[c], kg/Mg	
	Chlorine demagging	Refining	Chlorine demagging	Refining
2.5	19.8	50.0	99.5	1.08
6.0	36.9	53.4	184.5	1.15
10.0	53.2	60.0	266.0	1.30

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[a] References 4-5.

[b] Cumulative weight % < aerodynamic particle diameter, um.

[c] Size specific emission factor = total particulate emission factor x particle size distribution, %/100. From Table 7.8-1, total particulate emission factor for chlorine demagging is 500 kg/Mg chlorine used, and for refining, 2.15 kg/Mg aluminum processed.

rather than chlorine in the demagging step reduces demagging emissions. Fluorides are emitted as gaseous fluorides (hydrogen fluoride, aluminum and magnesium fluoride vapors, and silicon tetrafluoride) or as dusts. Venturi scrubbers are usually used for fluoride emission control.

References for Section 7.8

1. W. M. Coltharp, et al., Multimedia Environmental Assessment of the Secondary Nonferrous Metal Industry, Draft Final Report, 2 vols., EPA Contract No. 68-02-1319, Radian Corporation, Austin, TX, June 1976.
2. W. F. Hammond and S. M. Weiss, Unpublished report on air contaminant emissions from metallurgical operations in Los Angeles County, Los Angeles County Air Pollution Control District, July 1964.
3. R. A. Baker, et al., Evaluation of a Coated Baghouse at a Secondary Aluminum Smelter, EPA Contract No. 68-02-1402, Environmental Science and Engineering, Inc., Gainesville, FL, October 1976.
4. Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System (FPEIS), Series Report No. 231, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.
5. Environmental Assessment Data Systems, op. cit., Series Report No. 331.
6. J. A. Danielson, (ed.), Air Pollution Engineering Manual, 2nd Ed., AP-40, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1973. Out of Print.
7. E. J. Petkus, Precoated Baghouse Control for Secondary Aluminum Smelting, presented at the 71st Annual Meeting of the Air Pollution Control Association, Houston, TX, June 1978.

7.10 GRAY IRON FOUNDRIES

7.10.1 General[1-5]

Gray iron foundries produce gray iron castings from scrap iron, pig iron and foundry returns by melting, alloying and molding. The production of gray iron castings involves a number of integrated steps, which are outlined in Figures 7.10-1 and 7.10-2. The four major production steps are raw materials handling and preparation, metal melting, mold and core production, and casting and finishing.

Raw Materials Handling And Preparation - Handling operations include receiving, unloading, storing and conveying of all raw materials for both furnace charging and mold and core preparation. The major groups of raw materials required for furnace charging are metallics, fluxes and fuels. Metallic raw materials include pig iron, iron and steel scrap, foundry returns and metal turnings. Fluxes include carbonates (limestone, dolomite), fluoride (fluorspar), and carbide compounds (calcium carbide).[4] Fuels include coal, oil, natural gas and coke. Coal, oil and natural gas are used to fire reverberatory furnaces. Coke, a derivative of coal, is used as a fuel in cupola furnaces. Carbon electrodes are required for electric arc furnaces.

As shown in Figures 7.10-1 and 7.10-2, the raw materials, metallics and fluxes are added to the melting furnaces directly. For electric induction furnaces, however, the scrap metal added to the furnace charge must first be pretreated to remove any grease and/or oil, which can cause explosions. Scrap metals may be degreased with solvents, by centrifugation, or by preheating to combust the organics.

In addition to the raw materials used to produce the molten metal, a variety of materials is needed to prepare the sand cores and molds that form the iron castings. Virgin sand, recycled sand and chemical additives are combined in a sand handling system typically comprising receiving areas, conveyors, storage silos and bins, mixers (sand mullers), core and mold making machines, shakeout grates, sand cleaners, and sand screening.

Raw materials are received in ships, railroad cars, trucks and containers, then transferred by truck, loaders and conveyors to both open piles and enclosed storage areas. When needed, the raw materials are transferred from storage to process areas by similar means.

Metal Melting - The furnace charge includes metallics, fluxes and fuels. The composition of the charge depends upon the specific metal characteristics required. Table 7.10-1 lists the different chemical compositions of typical irons produced. The three most common furnaces used in the gray iron foundry industry are cupolas, electric arc, and electric induction furnaces.

The cupola, which is the major type of furnace used in industry today, is typically a vertical cylindrical steel shell with either a refractory lined or water cooled inner wall. Refractory linings usually consist of silica brick, or dolomite or magnesium brick. Water cooled linings, which involve circulating

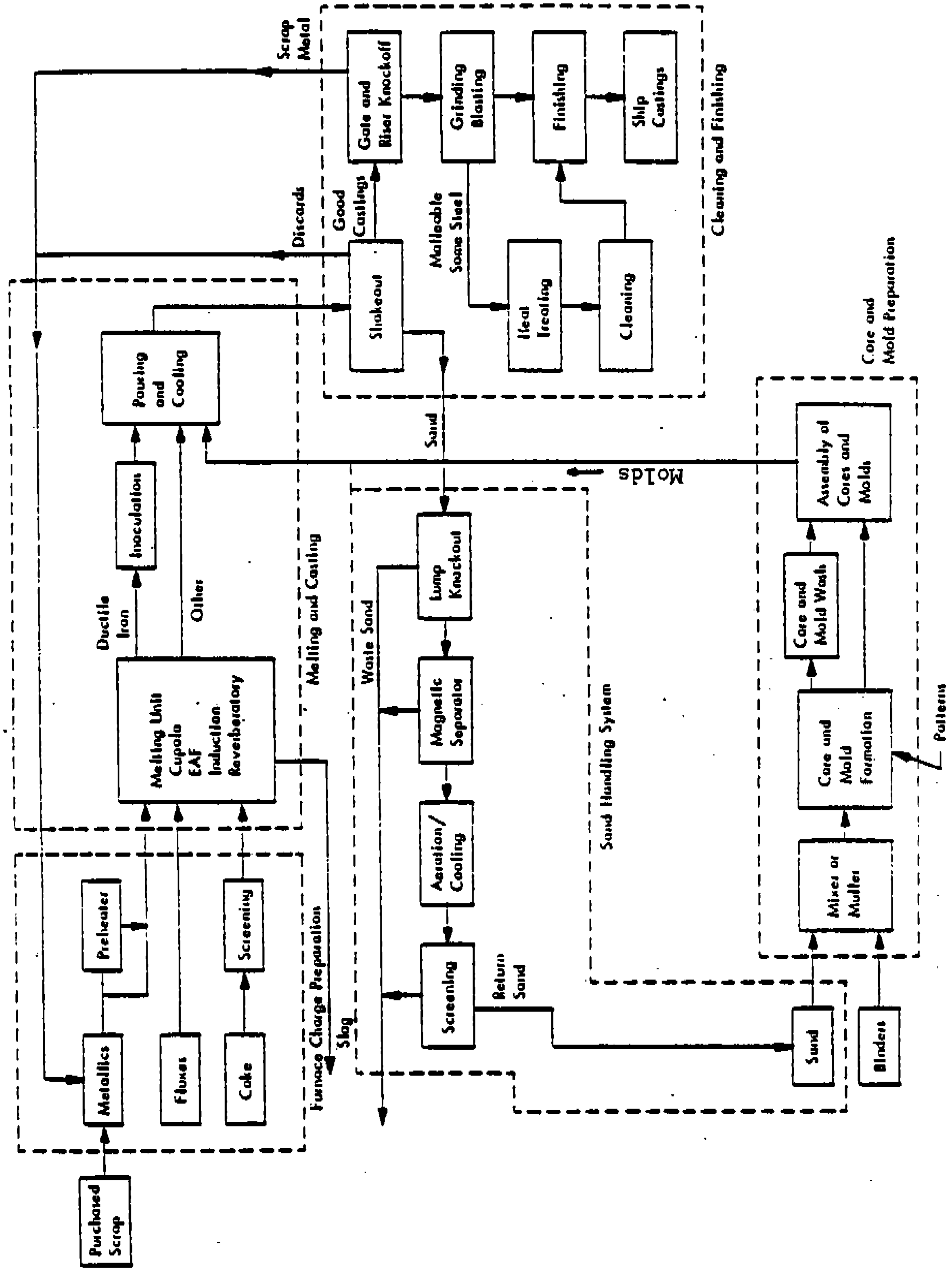

Figure 7.10-1. Typical iron foundry diagram.[1]

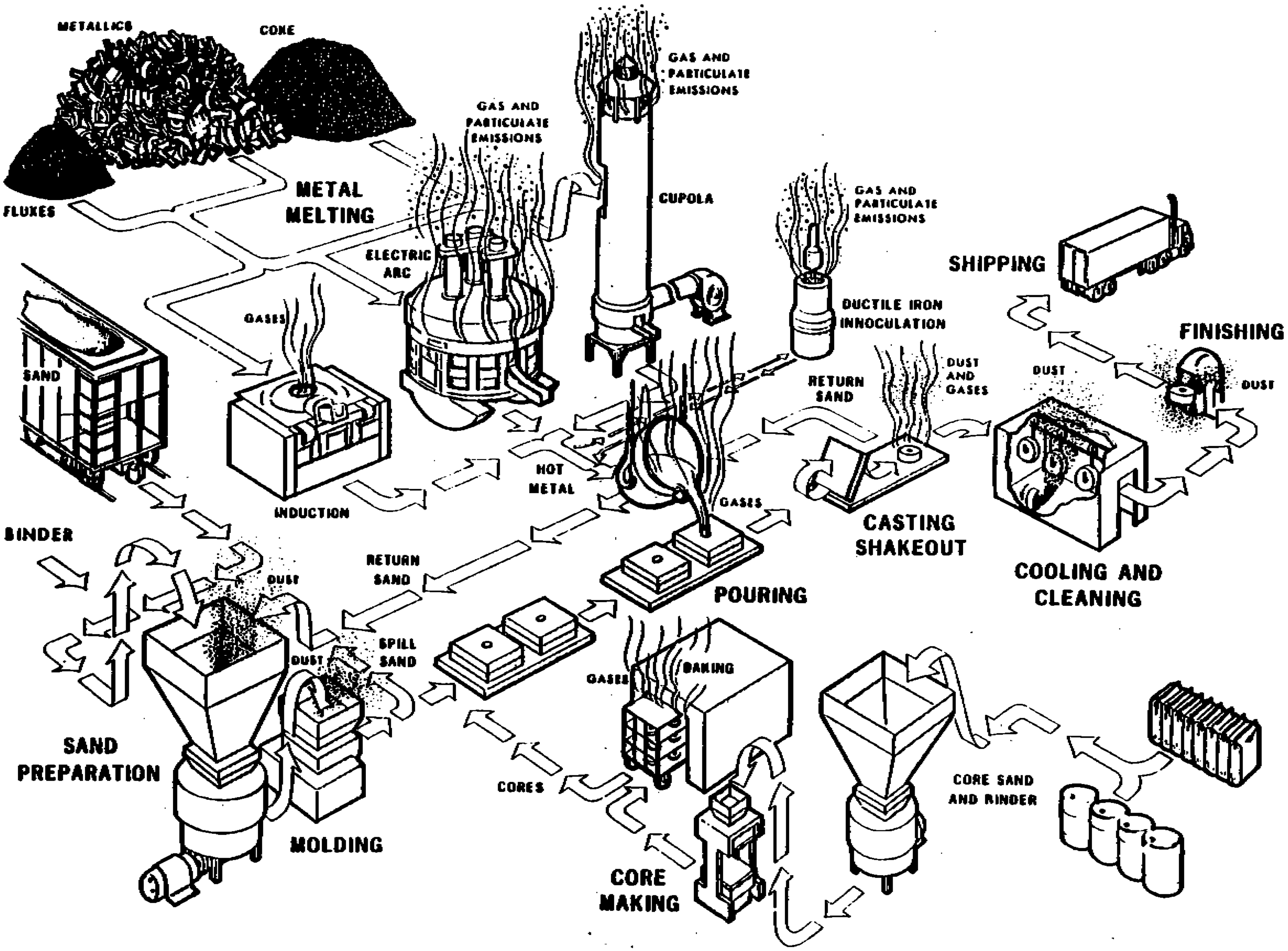

Figure 7.10-2. Emission points in a typical iron foundry.[2-3]

TABLE 7.10-1. CHEMICAL COMPOSITION OF FERROUS CASTINGS BY PERCENTAGE

Element	Gray iron	Malleable iron (as white iron)	Ductile iron[a]	Steel
Carbon	2.5 - 4.0	1.8 - 3.6	3.0 - 4.0	<2.0[b]
Silicon	1.0 - 3.0	0.5 - 1.9	1.4 - 2.0	0.2 - 0.8
Manganese	0.40 - 1.0	0.25 - 0.80	0.5 - 0.8	0.5 - 1.0
Sulfur	0.05 - 0.25	0.06 - 0.20	<0.12	<0.06
Phosphorus	0.05 - 1.0	0.06 - 0.18	<0.15	<0.05

[a] Necessary chemistry also includes 0.01 - 1.0% Mg.

[b] Steels are further classified by carbon content: low carbon, <0.20%; medium carbon, 0.20 - 0.50%; high carbon, >0.50%.

water around the outer steel shell, are used to protect the furnace wall from interior temperatures. The cupola is charged at the top with alternate layers of coke, metallics and fluxes.[2] The cupola is the only furnace type to use coke as a fuel; combustion air used to burn the coke is introduced through tuyeres located at the base of the cupola.[2] Cupolas use either cold blast air, air introduced at ambient temperature, or hot blast air with a regenerative system which utilizes heat from the cupola exhaust gases to preheat the combustion air.[2] Iron is melted by the burning coke and flows down the cupola. As the melt proceeds, new charges are added at the top. The flux removes nonmetallic impurities in the iron to form slag. Both the molten iron and the slag are removed through tap holes at the bottom of the cupola. Periodically, the heat period is completed, and the bottom of the cupola is opened to remove the remaining unburned material. Cupola capacities range from 1.0 to 27 megagrams per hour (1 to 30 tons per hour), with a few larger units approaching 90 megagrams per hour (100 tons per hour). Larger furnaces operate continuously and are inspected and cleaned at the end of each week or melting cycle.

Electric arc furnaces (EAF) are large, welded steel cylindrical vessels equipped with a removable roof through which three retractable carbon electrodes are inserted. The electrodes are lowered through the roof of the furnace and are energized by three phase alternating current, creating arcs that melt the metallic charge with their heat. Additional heat is produced by the resistance of the metal between the arc paths. The most common method of charging an electric arc furnace is by removing the roof and introducing the raw materials directly. Alternative methods include introducing the charge through a chute cut in the roof or through a side charging door in the furnace shell . Once the melting cycle is complete, the carbon electrodes are raised, and the roof is removed. The vessel is tilted, and the molten iron is poured into a ladle. Electric arc furnace capacities range from 0.23 to 59 megagrams (0.25 to 65 tons). Nine to 11 pounds of electrode are consumed per ton of metal melted.

Electric induction furnaces are either cylindrical or cup shaped refractory lined vessels that are surrounded by electrical coils which, when energized with high frequency alternating current, produce a fluctuating electromagnetic field to heat the metal charge. For safety reasons, the scrap metal added to the furnace charge is cleaned and heated before being introduced into the furnace. Any oil or moisture on the scrap could cause an explosion in the furnace. Induction furnaces are kept closed except when charging, skimming and tapping. The molten metal is tapped by tilting and pouring through a hole in the side of the vessel. Induction furnaces also may be used for metal refining in conjunction with melting in other furnaces and for holding and superheating the molten metal before pouring (casting).

The basic melting process operations are 1) furnace charging, in which metal, scrap, alloys, carbon, and flux are added to the furnace; 2) melting, during which the furnace remains closed; 3) backcharging, which involves the addition of more metal and alloys, as needed; 4) refining and treating, during which the chemical composition is adjusted to meet product specifications; 5) slag removing; and 6) tapping molten metal into a ladle or directly into molds.

Mold And Core Production - Molds are forms used to shape the exterior of castings. Cores are molded sand shapes used to make the internal voids in castings. Cores are made by mixing sand with organic binders, molding the sand into a core, and baking the core in an oven. Molds are prepared of a mixture of wet sand, clay and organic additives to make the mold shapes, which are usually dried with hot air. Cold setting binders are being used more frequently in both core and mold production. The green sand mold, the most common type, uses moist sand mixed with 4 to 6 percent clay (bentonite) for bonding. The mixture is 4 to 5 percent water content. Added to the mixture, to prevent casting defects from sand expansion when the hot metal is poured, is about 5 percent organic material, such as sea coal (a pulverized high volatility bituminous coal), wood flour, oat hulls, pitch or similar organic matter.

Common types of gray iron cores are:

- Oil core, with typical sand binder percents of 1.0 core oil, 1.0 cereal, and 0 to 1 pitch or resin. Cured by oven baking at 205 to 315°C (400 to 600°F), for 1 to 2 hours.

- Shell core, with sand binder typically 3 to 5 percent phenolic and/or urea formaldehyde, with hexamine activator. Cured as a thin layer on a heated metal pattern at 205 to 315°C (400 to 600°F), for 1 to 3 minutes.

- Hot box core, with sand binder typically 3 to 5 percent furan resin, with phosphoric acid activator. Cured as a solid core in a heated metal pattern at 205 to 315°C (400 to 600°F), for 0.5 to 1.5 minutes.

- Cold set core, with typical sand binder percents of 3 to 5 furan resin, with phosphoric acid activator; or 1 to 2 core oil, with phosphoric acid activator. Hardens in the core box. Cured for 0.5 to 3 hours.

- Cold box core, with sand binder typically 1 to 3 percent of each of two resins, activated by a nitrogen diluted gas. Hardens when the green core is gassed in the box with polyisocyanate in air. Cured for 10 to 30 seconds.

Used sand from castings shakeout is recycled to the sand preparation area and cleaned to remove any clay or carbonaceous buildup. The sand is then screened and reused to make new molds. Because of process losses and discard of a certain amount of sand because of contamination, makeup sand is added.

Casting And Finishing - After the melting process, molten metal is tapped from the furnace. Molten iron produced in cupolas is tapped from the bottom of the furnace into a trough, thence into a ladle. Iron produced in electric arc and induction furnaces is poured directly into a ladle by tilting the furnace. At this point, the molten iron may be treated with magnesium to produce ductile iron. The magnesium reacts with the molten iron to nodularize the carbon in the molten metal, giving the iron less brittleness. At times, the molten metal may be inoculated with graphite to adjust carbon content. The treated molten iron is then ladled into molds and transported to a cooling area, where it solidifies in the mold and is allowed to cool further before separation (shakeout) from the mold and core sand. In larger, more mechanized foundries, the molds are conveyed automatically through a cooling tunnel. In simpler foundries, molds are placed on an open floor space, and the molten iron is poured into the molds and allowed to cool partially. Then the molds are placed on a vibrating grid to shake the mold and core sand loose from the casting. In the simpler foundries, molds, core sand and castings are separated manually, and the sand from the mold and core is then returned to the sand handling area.

When castings have cooled, any unwanted appendages, such as spurs, gates, and risers, are removed. These appendages are removed with oxygen torch, abrasive band saw, or friction cutting tools. Hand hammers may be used, in less mechanized foundries. to knock the appendages off. After this, the castings are subjected to abrasive blast cleaning and/or tumbling to remove any remaining mold sand or scale.

Another step in the metal melting process involves removing the slag in the furnace through a tapping hole or door. Since the slag is lighter than molten iron, it remains atop the molten iron and can be raked or poured out of cupola furnaces through the slag hole located above the level of the molten iron. Electric arc and induction furnaces are tilted backwards, and their slag is removed through a slag door.

7.10.2 Emissions And Controls

Emissions from the raw materials handling operations are fugitive particulate generated from the receiving, unloading, storage and conveying of raw materials. These emissions are controlled by enclosing the major emission points (e. g., conveyor belt transfer points) and routing air from the enclosures through fabric filters or wet collectors. Figure 7.10-2 shows emission points and types of emissions from a typical foundry.

Scrap preparation with heat will emit smoke, organic compounds and carbon monoxide, and scrap preparation with solvent degreasers will emit organics. Catalytic incinerators and afterburners can control about 95 percent of organic and carbon monoxide emissions. (See Section 4.6, Solvent Degreasing.)

Emissions released from the melting furnaces include particulate matter, carbon monoxide, organic compounds, sulfur dioxide, nitrogen oxides and small quantities of chloride and fluoride compounds. The particulates, chlorides and fluorides are generated from incomplete combustion of coke, carbon additives, flux additions, and dirt and scale on the scrap charge. Organic material on the scrap, the consumption of coke in the furnace, and the furnace temperature all affect the amount of carbon monoxide generated. Sulfur dioxide emissions, characteristic of cupola furnaces, are attributable to sulfur in the coke. Fine particulate fumes emitted from the melting furnaces come from the condensation of volatilized metal and metal oxides.

During melting in an electric arc furnace, particulate emissions are generated by the vaporization of iron and the transformation of mineral additives. These emissions occur as metallic and mineral oxides. Carbon monoxide emissions come from the combustion of the graphite lost from the electrodes and the carbon added to the charge. Hydrocarbons may come from vaporization and partial combustion of any oil remaining on the scrap iron added to the furnace charge.

The highest concentrations of furnace emissions occur during charging, backcharging, alloying, slag removal, and tapping operations, because furnace lids and doors are opened. Generally, these emissions escape into the furnace building or are collected and vented through roof openings. Emission controls for melting and refining operations usually involve venting the furnace gases and fumes directly to a control device. Controls for fugitive furnace emissions include canopy hoods or special hoods near the furnace doors and tapping hoods to capture emissions and route them to emission control systems.

High energy scrubbers and baghouses (fabric filters) are used to control particulate emissions from cupolas and electric arc furnaces in this country. When properly designed and maintained, these control devices can achieve respective efficiencies of 95 and 98 percent. A cupola with such controls typically has an afterburner with up to 95 percent efficiency, located in the furnace stack, to oxidize carbon monoxide and to burn organic fumes, tars and oils. Reducing these contaminants protects the particulate control device from possible plugging and explosion. Because induction furnaces emit negligible amounts of hydrocarbon and carbon monoxide emissions, and relatively little particulate, they are usually uncontrolled.[2]

The major pollutant emitted in mold and core production operations is particulate from sand reclaiming, sand preparation, sand mixing with binders and additives, and mold and core forming. Organics, carbon monoxide and particulate are emitted from core baking, and organic emissions from mold drying. Baghouses and high energy scrubbers generally are used to control particulate from mold and core production. Afterburners and catalytic incinerators can be used to control organics and carbon monoxide emissions.

Particulate emissions are generated during the treatment and inoculation of molten iron before pouring. For example, during the addition of magnesium to molten metal to produce ductile iron, the reaction between the magnesium and molten iron is very violent, accompanied by emissions of magnesium oxides and metallic fumes. Emissions from pouring consist of hot metal fumes, and carbon monoxide, organic compounds and particulate evolved from the mold and core materials contacting the molten iron. Emissions from pouring normally are captured by a collection system and vented, either controlled or uncontrolled, to the atmosphere. Emissions continue as the molds cool. A significant quantity of particulate is also generated during the casting shakeout operation. These fugitive emissions must be captured, and they usually are controlled by either high energy scrubbers or bag filters.

Finishing operations emit large, coarse particles during the removal of burrs, risers and gates, and during shot blast cleaning. These emissions are easily controlled by cyclones and baghouses.

Emission factors for total particulate from gray iron furnaces are presented in Table 7.10-2, and emission factors for gaseous and lead pollutants are given in Table 7.10-3. Tables 7.10-4 and 7.10-5, respectively, give factors for ancillary process operations and fugitive sources and for specific particle sizes. Particle size factors and distributions are presented also in Figures 7.10-3 through 7.10-8.

TABLE 7.10-2. EMISSION FACTORS FOR GRAY IRON FURNACES[a]

Process	Control device	Total particulate kg/Mg	Total particulate lb/ton	Emission Factor Rating
Cupola	Uncontrolled[b]	6.9	13.8	C
	Scrubber[c]	1.6	3.1	C
	Venturi scrubber[d]	1.5	3.0	C
	Electrostatic precipitator[e]	0.7	1.4	E
	Baghouse[f]	0.3	0.7	C
	Single wet cap[g]	4.0	8.0	B
	Impingement scrubber[g]	2.5	5.0	B
	High energy scrubber[g]	0.4	0.8	B
Electric arc furnace	Uncontrolled[h]	6.3	12.7	C
	Baghouse[j]	0.2	0.4	C
Electric induction furnace	Uncontrolled[k]	0.5	0.9	D
	Baghouse[m]	0.1	0.2	E
Reverberatory	Uncontrolled[n]	1.1	2.1	D
	Baghouse[m]	0.1	0.2	E

[a] Expressed as weight of pollutant/weight of gray iron produced.
[b] References 1,7,9-10.
[c] References 12,15. Includes averages for wet cap and other scrubber types not already listed.
[d] References 12,17,19.
[e] References 8,11.
[f] References 12-14.
[g] References 8,11,29-30.
[h] References 1,6,23.
[j] References 6,23-24.
[k] References 1,12. For metal melting only.
[m] Reference 4.
[n] Reference 1.

TABLE 7.10-3. GASEOUS AND LEAD EMISSION FACTORS FOR GRAY IRON FOUNDRIES[a]

EMISSION FACTOR RATING: B

Furnace type	Carbon monoxide		Sulfur dioxide		Nitrogen oxides		Volatile organic compounds		Lead[b]	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Cupola										
Uncontrolled	73[c]	145[c]	$0.6S$[d]	$1.2S$[d]	-	-	-	-	0.05-0.6	0.1-1.1
High energy scrubber	-	-	$0.3S$[d]	$0.6S$[d]	-	-	-	-	-	-
Electric arc[e]	0.5-19	1-37	Neg	Neg	0.02-0.3	0.04-0.6	0.03-0.15	0.06-0.3	-	-
Electric induction[f]	Neg	Neg	Neg	Neg	-	-	-	-	0.005-0.05	0.009-0.1
Reverberatory	-	-	-	-	-	-	-	-	0.006-0.07	0.012-0.14

[a] Expressed as weight of pollutant/weight of gray iron produced. Dash = no data. Neg = negligible.
[b] References 11,31,34.
[c] Reference 2.
[d] Reference 4. S = % sulfur in the coke. Assumes 30% of sulfur is converted to SO_2.
[e] Reference 4,6.
[f] References 8,11,29-30.

TABLE 7.10-4. PARTICULATE EMISSION FACTORS FOR ANCILLARY PROCESS OPERATIONS AND FUGITIVE SOURCES AT GRAY IRON FOUNDRIES

Process	Control device	Total emission factor		Emitted to work environment		Emitted to atmosphere		Emission Factor Rating
		kg/Mg metal	lb/ton metal	kg/Mg metal	lb/ton metal	kg/Mg metal	lb/ton metal	
Scrap and charge handling, heating[b]	Uncontrolled	0.3	0.6	0.25	0.5	0.1	0.2	D
Magnesium treatment[c]	Uncontrolled	0.9	1.8	0.9	1.8	0.2	0.4	E
Inoculation[d]	Uncontrolled	1.5 - 2.5	3 - 5	-	-	-	-	D
Pouring, cooling[e]	Uncontrolled	2.1	4.2					D
Shakeout[f]	Uncontrolled[c]	1.6	3.2					D
Cleaning, finishing[b]	Uncontrolled	8.5	17	0.15	0.3	0.05	0.1	D
Sand handling[g]	Uncontrolled[c]	1.8	3.6	-	-	-	-	E
	Scrubber[h]	0.023	0.046	-	-	-	-	D
	Baghouse[j]	0.10	0.20	-	-	-	-	D
Core making, baking[b]	Uncontrolled	0.6	1.1	0.6	1.1	0.6	1.1	D

[a] Expressed as weight of pollutant/weight of gray iron produced, except as noted. Dash = no data.
[b] Reference 4.
[c] References 1,4.
[d] Reference 35.
[e] References 1,3,25.
[f] Reference 1.
[g] Kg of sand/Mg of sand handled.
[h] References 12,27.
[j] Reference 12.

TABLE 7.10-5. PARTICLE SIZE DISTRIBUTION DATA AND EMISSION FACTORS FOR GRAY IRON FOUNDRIES[a]

Source	Emission Factor Rating	Particle size (um)	Cumulative mass % $\leq$ stated size[b]	Cumulative mass emission factor	
				kg/Mg metal	lb/ton metal
Cupola Furnace[b] Uncontrolled	C	0.5	44.3	3.1	6.1
		1.0	69.1	4.8	9.5
		2.0	79.6	5.5	11.0
		2.5	84.0	5.8	11.6
		5.0	90.1	6.2	12.4
		10.0	90.1	6.2	12.4
		15.0	90.6	6.3	12.5
			100.0	6.9	13.8
Controlled by baghouse	E	0.5	83.4	0.33	0.58
		1.0	91.5	0.37	0.64
		2.0	94.2	0.38	0.66
		2.5	94.9	0.38	0.66
		5.0	94.9	0.38	0.66
		10.0	94.9	0.38	0.66
		15.0	95.0	0.38	0.67
			100.0	0.4	0.7
Controlled by venturi scrubber[c]	C	0.5	56.0	0.84	1.7
		1.0	70.2	1.05	2.1
		2.0	77.4	1.16	2.3
		2.5	77.7	1.17	2.3
		5.0	77.7	1.17	2.3
		10.0	77.7	1.17	2.3
		15.0	77.7	1.17	2.3
			100.0	1.5	3.0

TABLE 7.10-5 (cont.).

Process	Particle size (um)	Cumulative mass % $\leq$ stated size[b]	Cumulative mass emission factor kg/Mg metal	Cumulative mass emission factor lb/ton metal	Emission Factor Rating
Electric arc furnace[d]					
Uncontrolled	1.0	13.0	0.8	1.6	E
	2.0	57.5	3.7	7.3	
	5.0	82.0	5.2	10.4	
	10.0	90.0	5.8	11.4	
	15.0	93.5	6.0	11.9	
		100.0	6.4	12.7	
Pouring, cooling[b]					
Uncontrolled	0.5	d	-	-	D
	1.0	19.0	0.40	0.80	
	2.0	20.0	0.42	0.84	
	2.5	24.0	0.50	1.00	
	5.0	34.0	0.71	1.43	
	10.0	49.0	1.03	2.06	
	15.0	72.0	1.51	3.02	
		100.0	2.1	4.2	
Shakeout[b]					
Uncontrolled	0.5	23.0	0.37	0.74	E
	1.0	37.0	0.59	1.18	
	2.0	41.0	0.66	1.31	
	2.5	42.0	0.67	1.34	
	5.0	44.0	0.70	1.41	
	10.0	70.0	1.12	2.24	
	15.0	99.9	1.60	3.20	
		100.0	1.60	3.20	

[a] Expressed as weight of pollutant/weight of metal melted (produced). Dash = no data. Mass emission rate data available in Tables 7.10-2 and 7.10-4 to calculate size specific emission factors.

[b] References 13,21-22,25-26. See Figures 7.10-3 through 7.10-8.

[c] Pressure drop across venturi: approx. 102 inches of water.

[d] Reference 3, Exhibit VI-15. Averaged from data on two foundries. Because original test data could not be obtained, Emission Factor Rating is E.

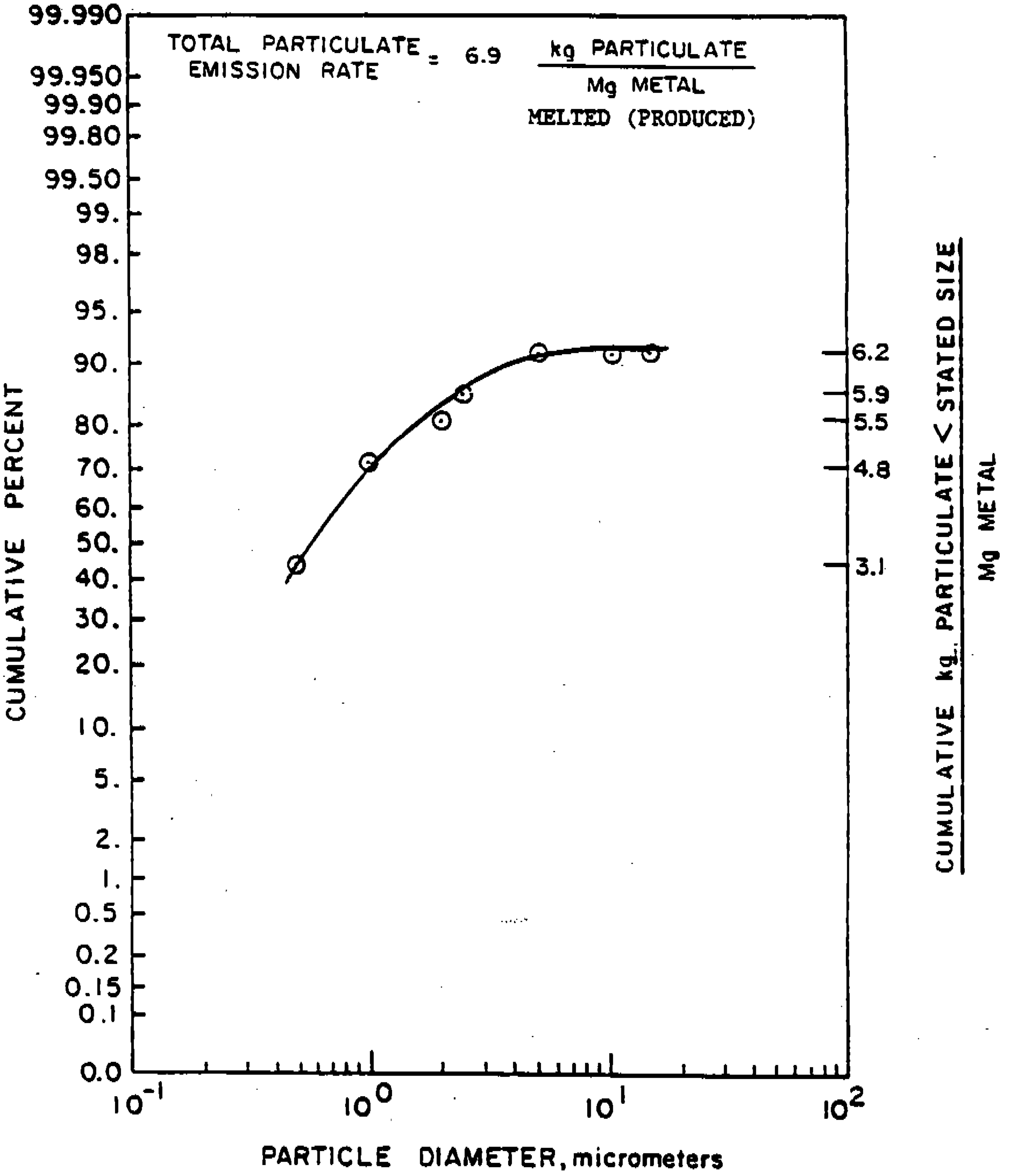

Figure 7.10-3. Particle size distribution for uncontrolled cupola.21-22

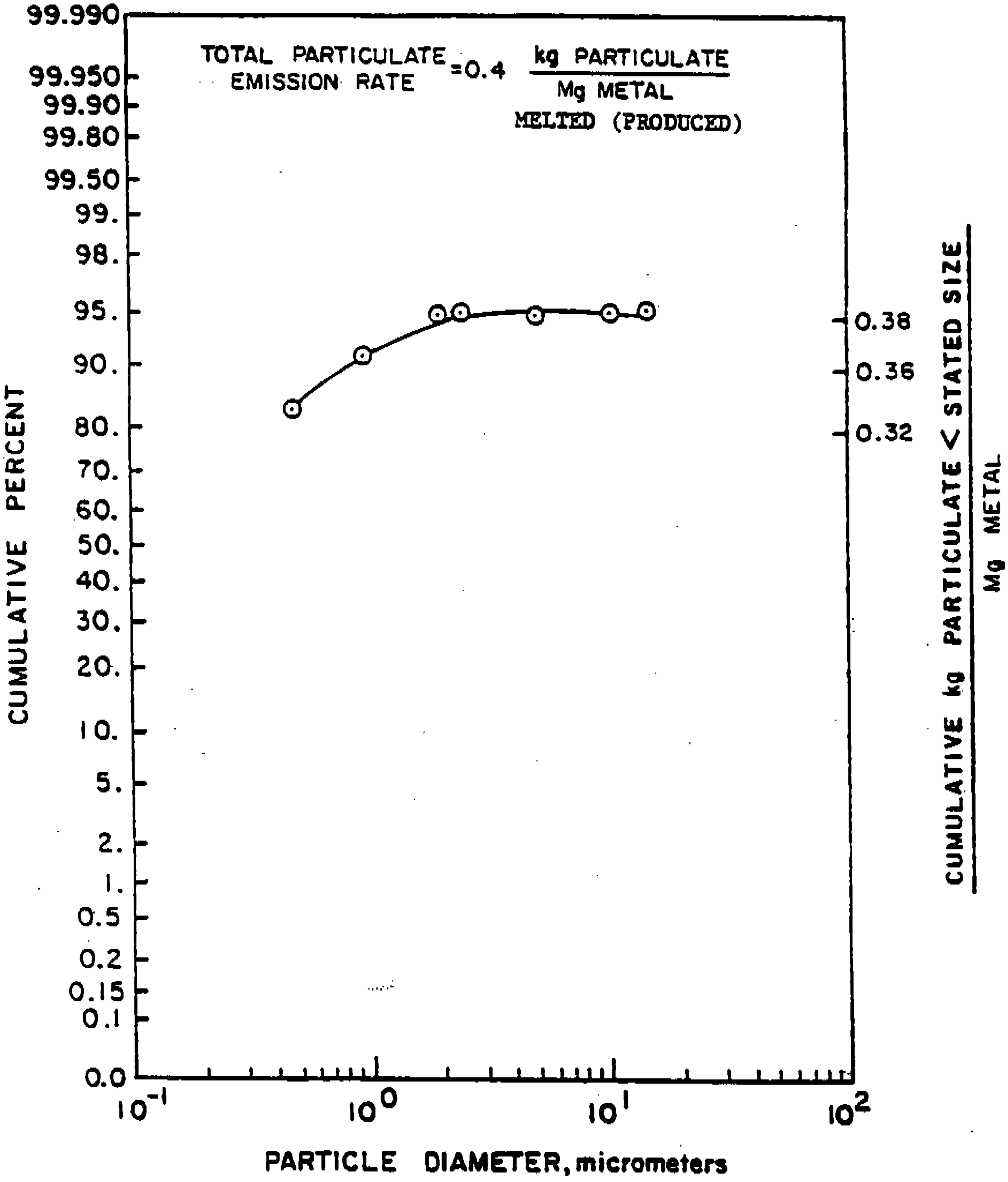

Figure 7.10-4. Particle size distribution for baghouse controlled cupola.[13]

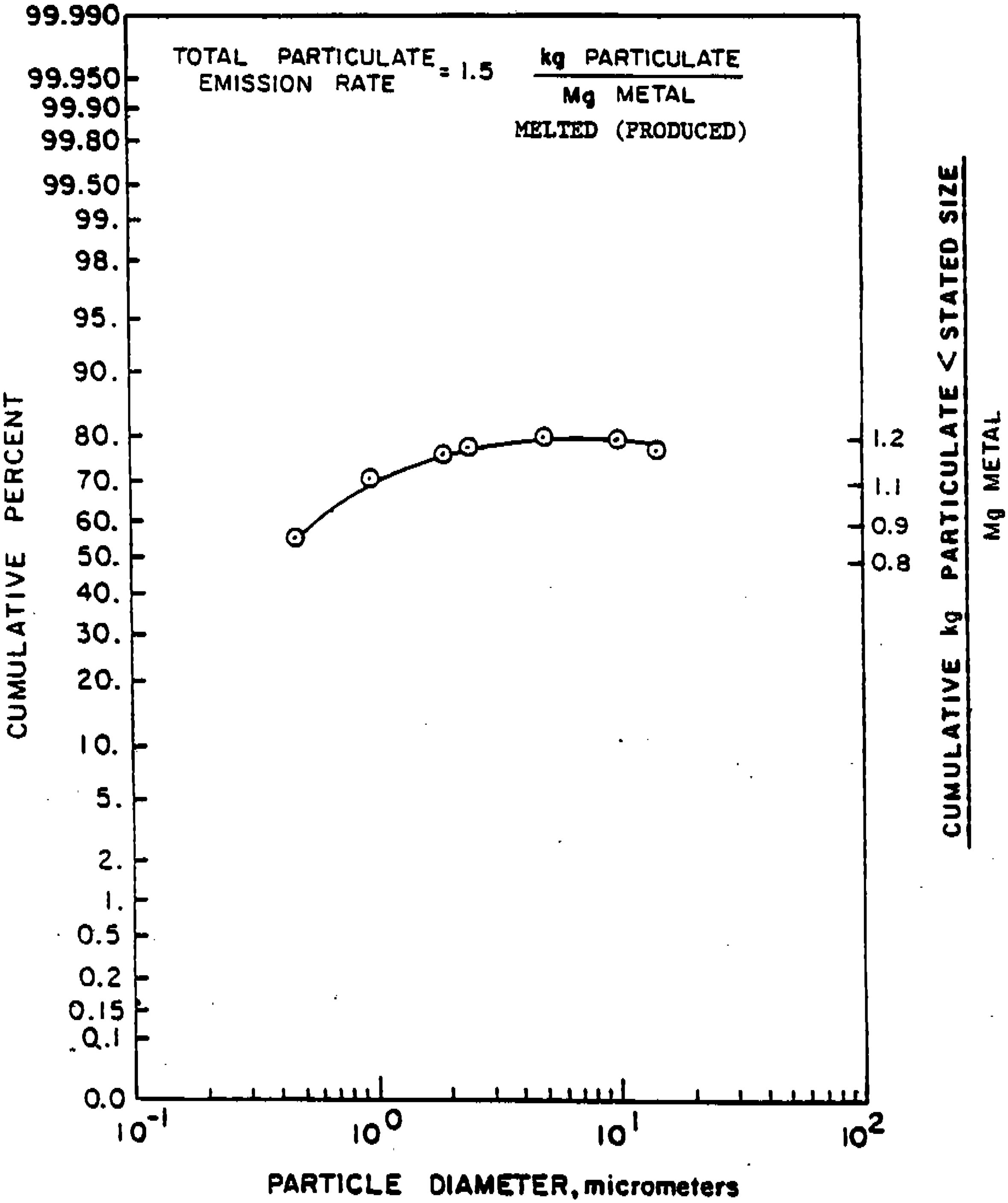

Figure 7.10-5. Particle size distribution for venturi scrubber controlled cupola.[21-22]

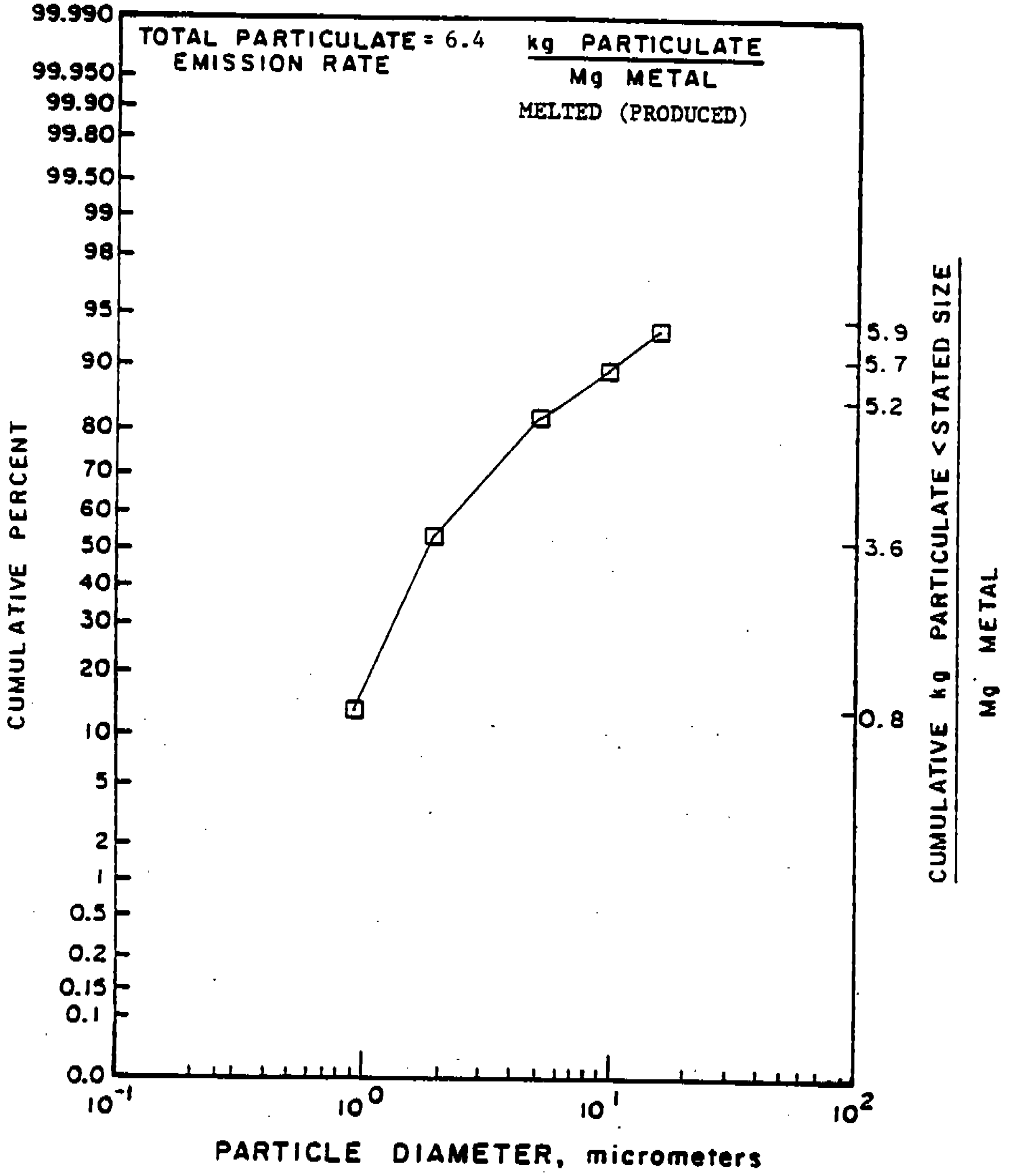

Figure 7.10-6. Particle size distribution for uncontrolled electric arc furnace.[3]

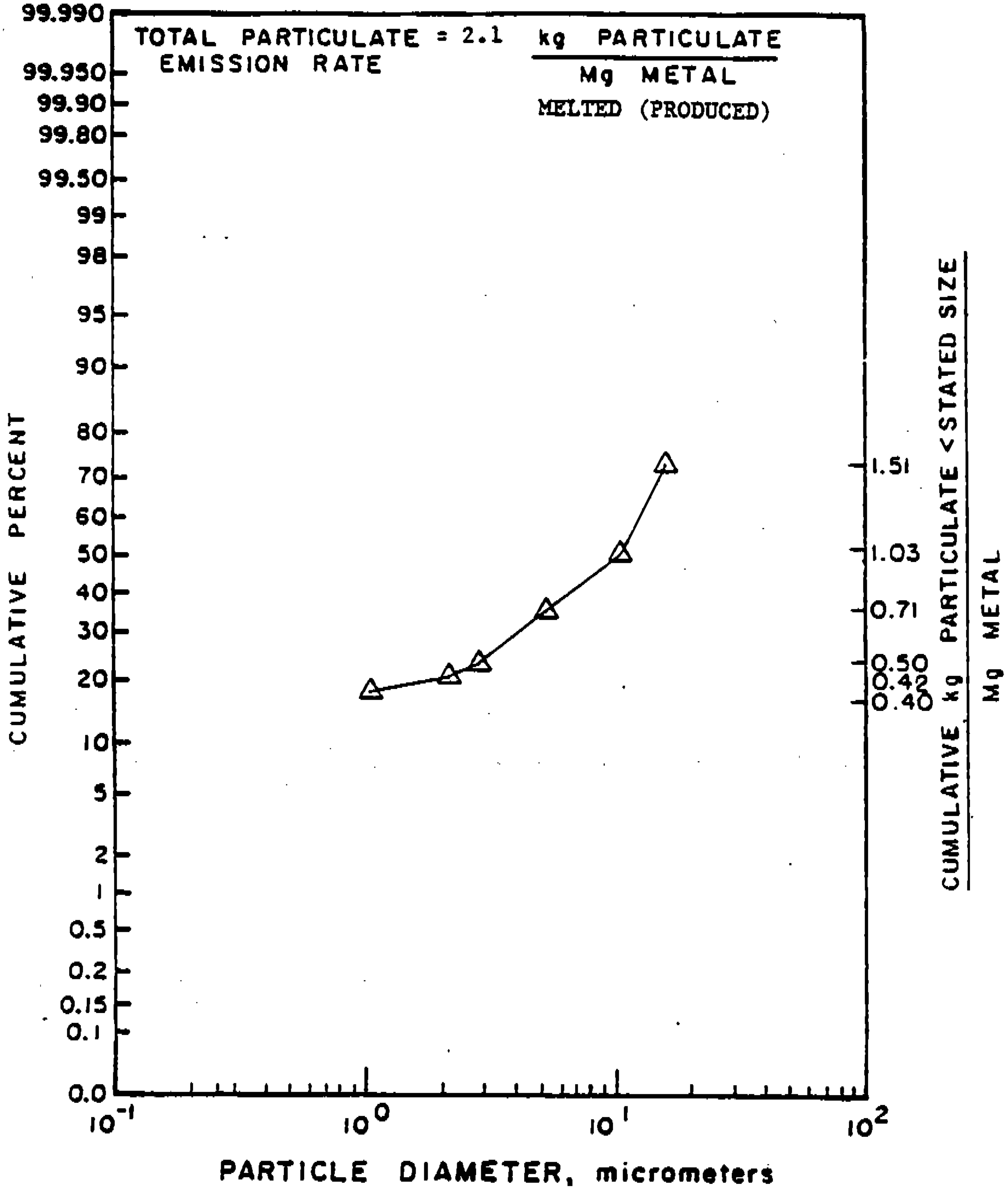

Figure 7.10-7. Particle size distribution for uncontrolled pouring and cooling.[25]

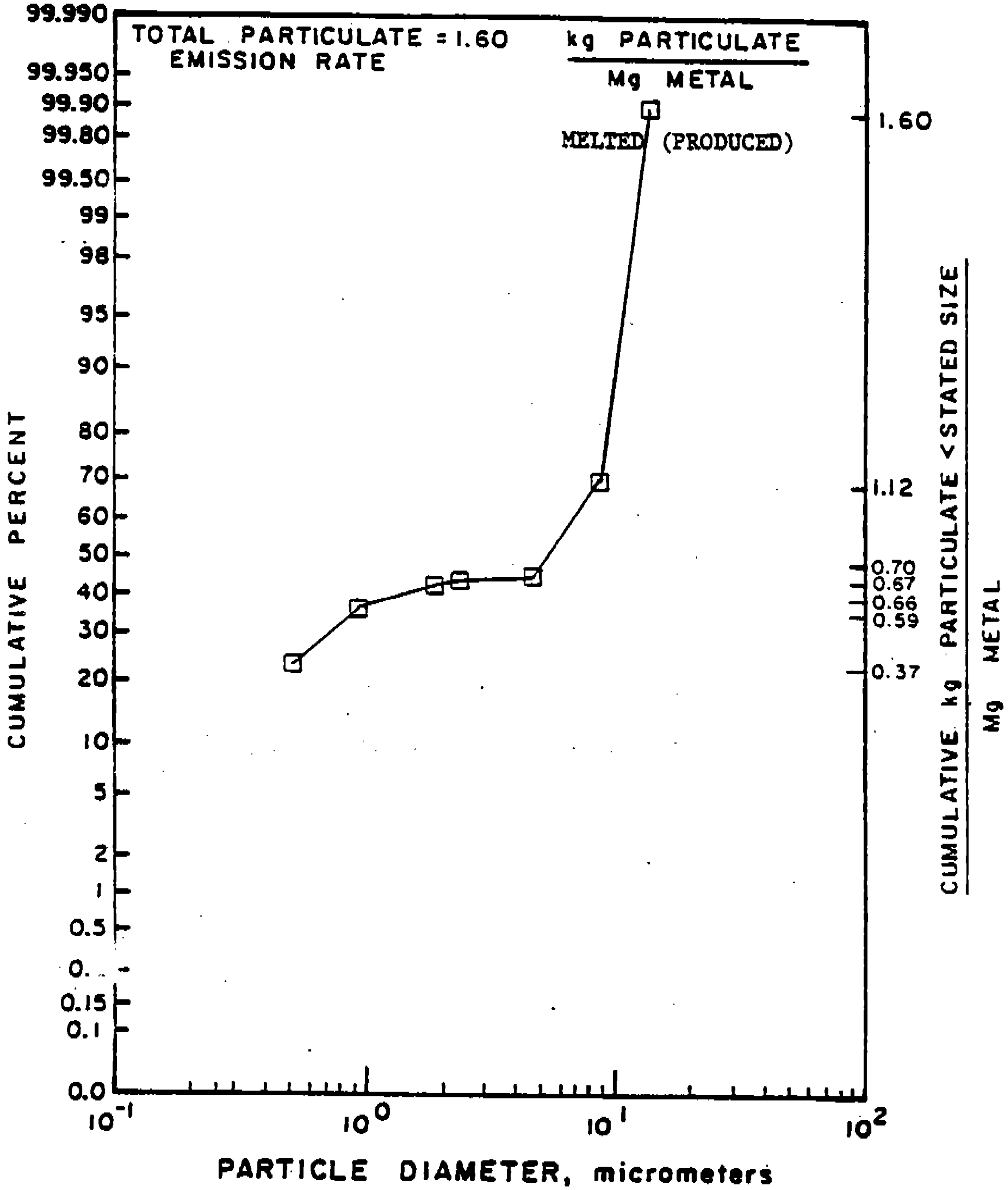

Figure 7.10-8. Particle size distribution for uncontrolled shakeout.[26]

REFERENCES FOR SECTION 7.10

1. Summary of Factors Affecting Compliance by Ferrous Foundries, Volume I: Text, EPA-340/1-80-020, U. S. Environmental Protection Agency, Washington, DC, January 1981.

2. Air Pollution Aspects of the Iron Foundry Industry, APTD-0806, U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1971.

3. Systems Analysis of Emissions and Emission Control in the Iron Foundry Industry, Volume II: Exhibits, APTD-0645, U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1971.

4. J. A. Davis, et al., Screening Study on Cupolas and Electric Furnaces in Gray Iron Foundries, EPA Contract No. 68-01-0611, Battelle Laboratories, Columbus, OH, August 1975.

5. R. W. Hein, et al., Principles of Metal Casting, McGraw-Hill, New York, 1967.

6. P. Fennelly and P. Spawn, Air Pollution Control Techniques for Electric Arc Furnaces in the Iron and Steel Foundry Industry, EPA-450/2-78-024, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1978.

7. R. D. Chmielewski and S. Calvert, Flux Force/Condensation Scrubbing for Collecting Fine Particulate from Iron Melting Cupola, EPA-600/7-81-148, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1981.

8. W. F. Hammond and S. M. Weiss, "Air Contaminant Emissions From Metallurgical Operations In Los Angeles County", Presented at the Air Pollution Control Institute, Los Angeles, CA, July 1964.

9. Particulate Emission Test Report On A Gray Iron Cupola at Cherryville Foundry Works, Cherryville, NC, Department Of Natural And Economic Resources, Raleigh, NC, December 18, 1975.

10. J. N. Davis, "A Statistical Analysis of the Operating Parameters Which Affect Air Pollution Emissions From Cupolas", November 1977. Further information unavailable.

11. Air Pollution Engineering Manual, Second Edition, AP-40, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1973. Out of Print.

12. Written communication from Dean Packard, Department Of Natural Resources, Madison, WI, to Douglas Seeley, Alliance Technology, Bedford, MA, April 15, 1982.

13. Particulate Emissions Testing At Opelika Foundry, Birmingham, AL, Air Pollution Control Commission, Montgomery, AL, November 1977 - January 1978.

14. Written communication from Minnesota Pollution Control Agency, St. Paul, MN, to Mike Jasinski, Alliance Technology, Bedford, MA, July 12, 1982.

15. Stack Test Report, Dunkirk Radiator Corporation Cupola Scrubber, State Department Of Environmental Conservation, Region IX, Albany, NY, November 1975.

16. Particulate Emission Test Report For A Scrubber Stack For A Gray Iron Cupola At Dewey Brothers, Goldsboro, NC, Department Of Natural Resources, Raleigh, NC, April 7, 1978.

17. Stack Test Report, Worthington Corp. Cupola, State Department Of Environmental Conservation, Region IX, Albany, NY, November 4-5, 1976.

18. Stack Test Report, Dresser Clark Cupola Wet Scrubber, Orlean, NY, State Department Of Environmental Conservation, Albany, NY, July 14 & 18, 1977.

19. Stack Test Report, Chevrolet Tonawanda Metal Casting, Plant Cupola #3 And Cupola #4, Tonawanda, NY, State Department Of Environmental Conservation, Albany, NY, August 1977.

20. Stack Analysis For Particulate Emission, Atlantic States Cast Iron Foundry/Scrubber, State Department Of Environmental Protection, Trenton, NJ, September 1980.

21. S. Calvert, et al., Fine Particle Scrubber Performance, EPA-650/2-74-093, U. S. Environmental Protection Agency, Cincinnati, OH, October 1974.

22. S. Calvert, et al., National Dust Collector Model 850 Variable Rod Module Venturi Scrubber Evaluation, EPA-600/2-76-282, U. S. Environmental Protection Agency, Cincinnati, OH, December 1976.

23. Source Test, Electric Arc Furnace At Paxton-Mitchell Foundry, Omaha, NB, Midwest Research Institute, Kansas City, MO, October 1974.

24. Source Test, John Deere Tractor Works, East Moline, IL, Gray Iron Electric Arc Furnace, Walden Research, Wilmington, MA, July 1974

25. S. Gronberg, Characterization Of Inhalable Particulate Matter Emissions From An Iron Foundry, Lynchburg Foundry, Archer Creek Plant, EPA-600/X-85-328, U. S. Environmental Protection Agency, Cincinnati, OH, August 1984.

26. Particulate Emissions Measurements From The Rotoclone And General Casting Shakeout Operations Of United States Pipe & Foundry, Inc, Anniston, AL, State Air Pollution Control Commission, Montgomery, AL. Further information unavailable.

27. Report Of Source Emissions Testing At Newbury Manufacturing, Talladega, AL, State Air Pollution Control Commission, Montgomery, AL, May 15-16, 1979.

28. Particulate Emission Test Report For A Gray Iron Cupola At Hardy And Newson, La Grange, NC, State Department Of Natural Resources And Community Development, Raleigh, NC, August 2-3, 1977.

29. H. R. Crabaugh, et al., "Dust And Fumes From Gray Iron Cupolas: How Are They Controlled In Los Angeles County", Air Repair, 4(3):125-130, November 1954.

30. J. M. Kane, "Equipment For Cupola Control", American Foundryman's Society Transactions, 64:525-531, 1956.

31. Control Techniques For Lead Air Emissions, 2 Volumes, EPA-450/2-77-012, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1977.

32. W. E. Davis, Emissions Study Of Industrial Sources Of Lead Air Pollutants, 1970, APTD-1543, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1973.

33. Emission Test No. EMB-71-CI-27, Office Of Air Quality Planning and Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1972.

34. Emission Test No. EMB-71-CI-30, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1972.

35. John Zoller, et al., Assessment Of Fugitive Particulate Emission Factors For Industrial Processes, EPA-450/3-78-107, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1978.

36. J. Jeffery, et al., Inhalable Particulate Source Category Report For The Gray Iron Foundry Industry, TR-83-15-G, EPA Contract No. 68-02-3157, GCA Corporation, Bedford, MA, July 1986.

7.11 SECONDARY LEAD PROCESSING

7.11.1 Process Description[1-7]

The secondary lead industry processes a variety of lead bearing scrap and residue to produce lead and lead alloy ingots, battery lead oxide, and lead pigments (Pb_3O_4 and PbO). Processing may involve scrap pretreatment, smelting, and refining/casting. Processes typically used in each operation are shown in Figure 7.11-1.

Scrap pretreatment is the partial removal of metal and nonmetal contaminants from leadbearing scrap and residue. Processes used for scrap pretreatment include battery breaking, crushing and sweating. Battery breaking is the draining and crushing of batteries, followed by manual separation of the lead from nonmetallic materials. Oversize pieces of scrap and residues are usually put through jaw crushers. This separated lead scrap is then mixed with other scraps and is smelted in reverberatory or blast furnaces to separate lead from metals with higher melting points. Rotary gas or oil furnaces usually are used to process low lead content scrap and residue, while reverberatory furnaces are used to process high lead content scrap. The partially purified lead is periodically tapped from these furnaces for further processing in smelting furnaces or pot furnaces.

Smelting is the production of purified lead by melting and separating lead from metal and nonmetallic contaminants and by reducing oxides to elemental lead. Reverberatory smelting furnaces are used to produce a semisoft lead product that contains typically 3 to 4 percent antimony. Blast furnaces produce hard or antimonial lead containing about 10 percent antimony.

A reverberatory furnace,to produce semisoft lead, is charged with lead scrap, metallic battery parts, oxides, drosses, and other residues. The reverberatory furnace is a rectangular shell lined with refractory brick, and it is fired directly with oil or gas to a temperature of 1260°C (2300°F). The material to be melted is heated by direct contact with combustion gases. The average furnace can process about 45 megagrams per day (50 tons per day). About 47 percent of the charge is recovered as lead product and is periodically tapped into molds or holding pots. Forty-six percent of the charge is removed as slag and later processed in blast furnaces. The remaining 7 percent of the furnace charge escapes as dust or fume.

Blast furnaces produce hard lead from charges containing siliceous slag from previous runs (about 4.5 percent of the charge), scrap iron (about 4.5 percent), limestone (about 3 percent), and coke (about 5.5 percent). The reqaining 82.5 percent of the charge is comprised of oxides, pot furnace refining drosses, and reverberatory slag. The proportions of rerun slags, limestone, and coke, respectively vary to as high as 8 percent, 10 percent, and 8 percent of the charge. Processing capacity of the blast furnace ranges from 18 to 73 megagrams per day (20 to 80 tons per day). Similar to iron cupolas, the blast furnace is a vertical steel cylinder lined with refractory brick. Combustion

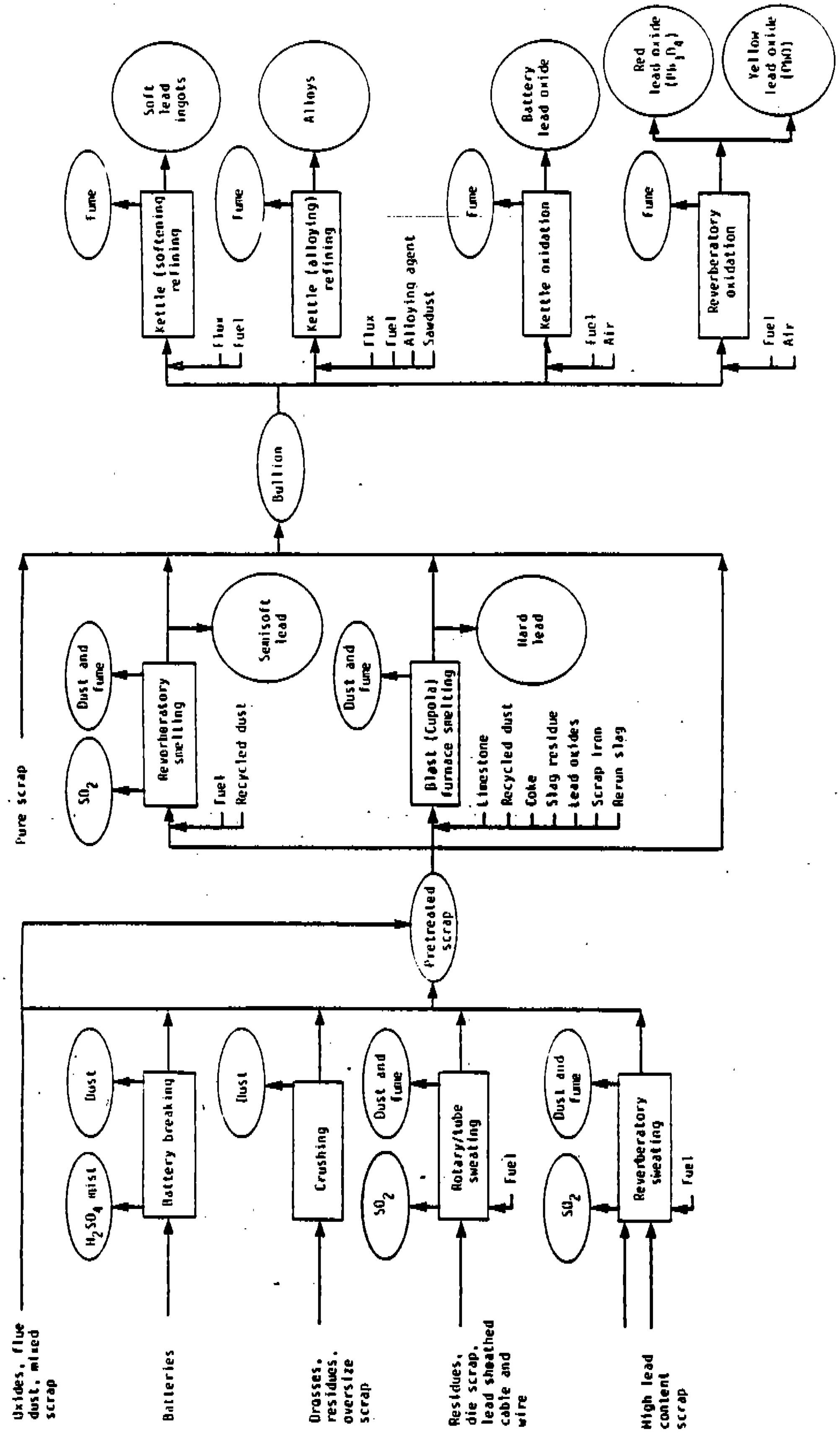

Figure 7.11-1. Typical secondary lead smelting and refining scheme.

air at 3.4 to 5.2 kilopascals (0.5 to 0.75 pounds per square inch) is introduced through tuyeres at the bottom of the furnace. Some of the coke combusts to melt the charge, while the remainder reduces lead oxides to elemental lead. The furnace exhaust is from 650° to 730°C (1200° to 1350°F).

As the lead charge melts, limestone and iron float to the top of the molte molten bath and form a flux that retards oxidation of the product lead. The molten lead flows from the furnace into a holding pot at a nearly continuous rate. The product lead constitutes roughly 70 percent of the charge. From the holding pot, the lead is usually cast into large ingots, called pigs, or sows.

About 18 percent of the charge is recovered as slag, with about 60 percent of this being a sulfurous slag called matte. Roughly 5 percent of the charge is retained for reuse, and the remaining 7 percent of the charge escapes as dust or fume.

Refining/casting is the use of kettle type furnaces for remelting, alloying, refining, and oxidizing processes. Materials charged for remelting are usually lead alloy ingots that require no further processing before casting. The furnaces used for alloying, refining and oxidizing are usually gas fired, and operating temperatures range from 370° to 480°C (700° to 900°F). Alloying furnaces simply melt and mix ingots of lead and alloy materials. Antimony, tin, arsenic, copper, and nickel are the most common alloying materials.

Refining furnaces are used either to remove copper and antimony for soft lead production, or to remove arsenic, copper and nickel for hard lead production. Sulfur may be added to the molten lead bath to remove copper. Copper sulfide skimmed off as dross may subsequently be processed in a blast furnace to recover residual lead. Aluminum chloride flux may be used to remove copper, antimony and nickel. The antimony content can be reduced to about 0.02 percent by bubbling air through the molten lead. Residual antimony can be removed by adding sodium nitrate and sodium hydroxide to the bath and skimming off the resulting dross. Dry drossing consists of adding sawdust to the agitated mass of molten metal. The sawdust supplies carbon to help separate globules of lead suspended in the dross and to reduce some of the lead oxide to elemental lead.

Oxidizing furnaces, either kettle or reverberatory units, are used to oxidize lead and to entrain the product lead oxides in the combustion air stream, with subsequent recovery in high efficiency baghouses.

7.11.2 Emissions And Controls[1,4-5]

Emission factors for controlled and uncontrolled processes and fugitive particulate are given in Tables 7.11-1 and 7.11-2. Particulate emissions from most processes are based on accumulated test data, whereas fugitive particulate emission factors are based on the assumption that 5 percent of uncontrolled stack emissions is released as fugitive emissions.

Reverberatory and blast furnaces account for the vast majority of the total lead emissions from the secondary lead industry. The relative quantities emitted from these two smelting processes can not be specified, because of a lack of complete information. Most of the remaining processes are small emission sources with undefined emission characteristics.

TABLE 7.11-1. EMISSION FACTORS FOR SECONDARY LEAD PROCESSING[a]

Pollutant		Sweating[b]	Leaching[c]	Smelting		Kettle refining	Kettle oxidation	Casting
				Reverberatory	Blast (cupola)[d]			
Particulate[e]								
Uncontrolled	(kg/Mg)	16-35	Neg[f]	162 (87-242)[g]	153 (92-207)[h]	0.02[j]	≤20[k]	0.02[j]
	(lb/ton)	32-70	Neg[f]	323 (173-483)[a,g]	307 (184-413)[h]	0.03[j]	≤40[k]	0.04[j]
Controlled	(kg/Mg)	-	Neg	0.50 (0.26-0.77)[m]	1.12 (0.11-2.44)[n]	Neg	-	Neg
	(lb/ton)	-	Neg	1.01 (0.53-1.55)[m]	2.24 (0.22-4.88)[n]	Neg	-	Neg
Lead[e]								
Uncontrolled	(kg/Mg)	4-8[p]	Neg	32 (17-48)[q]	52 (31-70)[r]	0.006[j]	-	0.007[j]
	(lb/ton)	7-16[p]	Neg	65 (35-97)[q]	104 (64-140)[r]	0.01[j]	-	0.01[j]
Controlled	(kg/Mg)	-	Neg	-	0.15 (0.02-0.32)[s]	Neg	-	Neg
	(lb/ton)	-	Neg	-	0.29 (0.03-0.64)[s]	Neg	-	Neg
Sulfur dioxide[s]								
Uncontrolled	(kg/Mg)	-	Neg	40 (36-44)[m]	27 (9-55)[g]	-	-	-
	(lb/ton)	-	Neg	80 (71-88)[m]	53 (18-110)[g]	-	-	-
Emission Factor Rating		E		C	C	C	E	C

[a] Neg = negligible. Dash = not available. Ranges in parentheses.

[b] Reference 1. Estimated from sweating furnace emissions from nonlead secondary nonferrous processing industries. Based on quantity of material charged to furnace.

[c] Reference 1.

[d] Blast furnace emissions are combined flue gases and associated ventilation hood streams (charging and tapping).

[e] Particulate and lead factors based on quantity of lead product produced, except as noted.

[f] Determined negligible, based on average baghouse control efficiency >99%.

[g] References 8-11.

[h] References 8,11-12.

[j] Reference 13. Lead content of kettle refining emissions is 40% and of casting emissions is 36%.

[k] References 1-2. Essentially all product lead oxide is entrained in an air stream and subsequently recovered by baghouse with average collection efficiency >99%. Factor represents emissions of lead oxide that escape a baghouse used to collect the lead oxide product. Based on the amount of lead produced and represents approximate upper limit for emissions.

[m] References 6,8-11.

[n] References 6,8,11-12,14-15.

[p] References 3,5. Based on assumption that uncontrolled reverberatory furnace flue emissions are 23% lead.

[q] Reference 13. Uncontrolled reverberatory furnace flue emissions assumed to be 23% lead. Blast furnace emissions have lead content of 34%, based on single uncontrolled plant test.

[r] Reference 13. Blast furnace emissions have lead content of 26%, based on single controlled plant test.

[s] Based on quantity of material charged to furnaces.

TABLE 7.11-2. FUGITIVE EMISSION FACTORS FOR SECONDARY LEAD PROCESSING[a]

EMISSION FACTOR RATING: E

Operation	Particulate		Lead	
	kg/Mg	lb/ton	kg/Mg	lb/ton
Sweating	0.8 - 1.8	1.6 - 3.5[b]	0.2 - 0.9	0.4 - 1.8[c]
Smelting	4.3 - 12.1	8.7 - 24.2	0.88 - 3.5[d]	1.75 - 7.0[d]
Kettle refining	0.001	0.002	0.0003[d]	0.0006[d]
Casting	0.001	0.002	0.0004[d]	0.0007[d]

[a] Reference 16. Based on amount of lead product, except for sweating, which is based on quantity of material charged to furnace. Fugitive emissions estimated to be 5% of uncontrolled stack emissions.

[b] Reference 1. Sweating furnace emissions estimated from nonlead secondary nonferrous processing industries.

[c] References 3,5. Assumes 23% lead content of uncontrolled blast furnace flue emissions.

[d] Reference 13.

Emissions from battery breaking are mainly of sulfuric acid mist and dusts containing dirt, battery case material and lead compounds. Emissions from crushing are also mainly dusts.

Emissions from sweating operations are fume, dust, soot particles and combustion products, including sulfur dioxide (SO_2). The SO_2 emissions come from combustion of sulfur compounds in the scrap and fuel. Dusts range in particle size from 5 to 20 micrometers, and unagglomerated lead fumes range from 0.07 to 0.4 micrometers, with an average diameter of 0.3. Particulate loadings in the stack gas from reverberatory sweating range from 3.2 to 10.3 grams per cubic meter (1.4 to 4.5 grains per cubic foot). Baghouses are usually used to control sweating emissions, with removal efficiencies exceeding 99 percent. The emission factors for lead sweating in Table 7.11-1 are based on measurements at similar sweating furnaces in other secondary metal processing industries, not on measurements at lead sweating furnaces.

Reverberatory smelting furnaces emit particulate and oxides of sulfur and nitrogen. Particulate consists of oxides, sulfides and sulfates of lead, antimony, arsenic, copper and tin, as well as unagglomerated lead fume. Particulate loadings range from to 16 to 50 grams per cubic meter (7 to 22 grains per cubic foot. Emissions are generally controlled with settling and cooling chambers, followed by a baghouse. Control efficiencies generally exceed 99 percent. Wet scrubbers are sometimes used to reduce SO_2 emissions. However, because of the small particles emitted from reverberatory furnaces, baghouses are more often used than scrubbers for particulate control.

Two chemical analyses by electron spectroscopy have shown the particulate to consist of 38 to 42 percent lead, 20 to 30 percent tin, and about 1 percent zinc.[17] Particulate emissions from reverberatory smelting furnaces are estimated to contain 20 percent lead.

TABLE 7.11-3. EMISSION FACTORS AND PARTICLE SIZE DISTRIBUTION FOR BAGHOUSE CONTROLLED BLAST FURNACE FLUE GASES[a]

EMISSION FACTOR RATING: D

Particle size[b] (um)	Cumulative mass % ≤stated size	Cumulative emission factors	
		kg/Mg	lb/ton
15	93.0	0.22	0.45
10	89.0	0.21	0.43
6	83.5	0.20	0.40
2.5	71.0	0.17	0.34
1.25	44.5	0.11	0.21
1.00	33.0	0.08	0.16
0.625	14.5	0.03	0.07
Total	100.0	0.24	0.48

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[a] Units are for lead, as produced.

[b] Expressed as equivalent aerodynamic particle diameter.

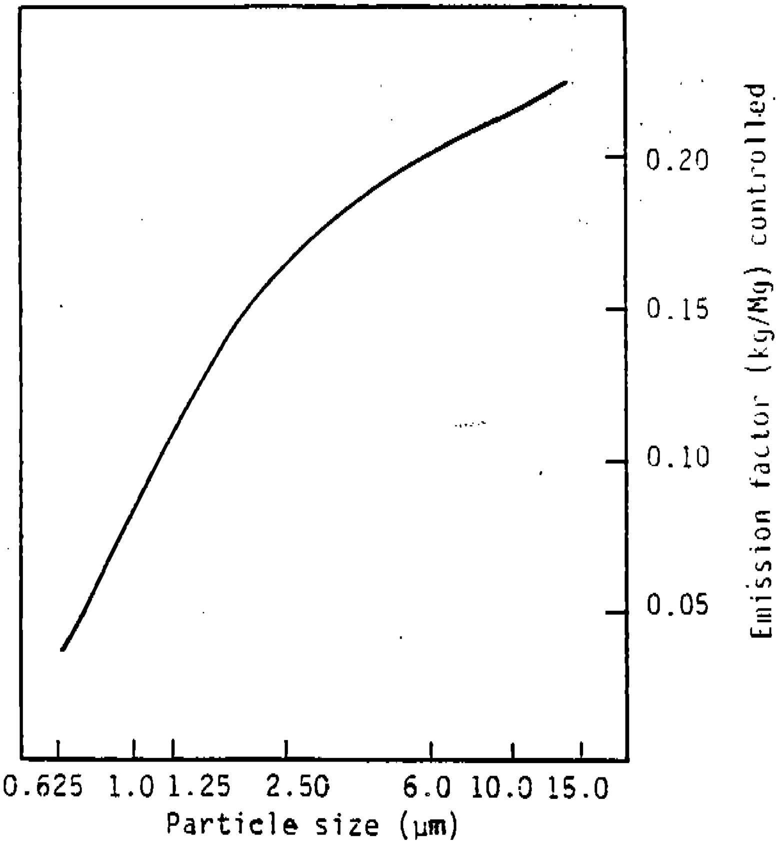

Figure 7.11-2. Emission factors less than stated particle size for baghouse controlled blast furnace flue gases.

TABLE 7.11-4. EMISSION FACTORS AND PARTICLE SIZE DISTRIBUTION FOR UNCONTROLLED AND BAGHOUSE CONTROLLED BLAST FURNACE VENTILATION[a]

EMISSION FACTOR RATING: D

Particle size[b] (um)	Cumulative mass % ≤ stated size		Cumulative emission factors			
			Uncontrolled		Controlled	
	Uncontrolled	Controlled	kg/Mg	lb/ton	kg/Mg	lb/ton
15	40.5	88.5	25.7	51.4	0.41	0.83
10	39.5	83.5	25.1	50.2	0.39	0.78
6	39.0	78.0	24.8	49.5	0.36	0.73
2.5	35.0	65.0	22.2	44.5	0.30	0.61
1.25	23.5	43.5	14.9	29.8	0.20	0.41
1.00	16.5	32.5	10.5	21.0	0.15	0.30
0.625	4.5	13.0	2.9	5.7	0.06	0.12
Total	100.0	100.0	63.5	127.0	0.47	0.94

[a] Based on lead, as produced. Includes emissions from charging, metal and slag tapping.

[c] Expressed as equivalent aerodynamic particle diameter.

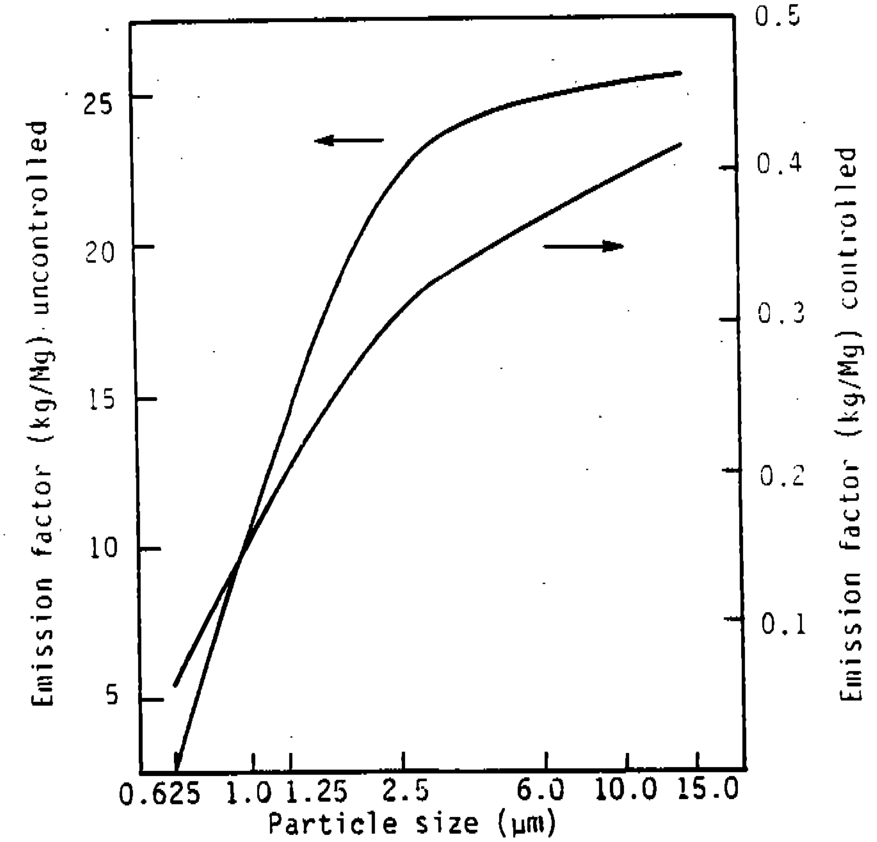

Figure 7.11-3. Emission factors less than stated particle size for uncontrolled and baghouse controlled blast furnace ventilation.

TABLE 7.11-5. EFFICIENCIES OF PARTICULATE CONTROL EQUIPMENT ASSOCIATED WITH SECONDARY LEAD SMELTING FURNACES

Control equipment	Furnace type	Control efficiency (%)
Fabric filter[a]	Blast	98.4
	Reverberatory	99.2
Dry cyclone plus fabric filter[a]	Blast	99.0
Wet cyclone plus fabric filter[b]	Reverberatory	99.7
Settling chamber plus dry cyclone plus fabric filter[c]	Reverberatory	99.8
Venturi scrubber plus demister[d]	Blast	99.3

[a] Reference 8.
[b] Reference 9.
[c] Reference 10.
[d] Reference 14.

Particle size distributions and size specific emission factors for blast furnace flue gases and for charging and tapping operations, respectively, are presented in Tables 7.11-3 and 7.11-4, and Figures 7.11-2 and 7.11-3.

Emissions from blast furnaces occur at charging doors, the slag tap, the lead well, and the furnace stack. The emissions are combustion gases (including carbon monoxide, hydrocarbons, and oxides of sulfur and nitrogen) and particulate. Emissions from the charging doors and the slag tap are hooded and routed to the devices treating the furnace stack emissions. Blast furnace particulate is smaller than that emitted from reverberatory furnaces and is suitable for control by scrubbers or fabric filters downstream of coolers. Efficiencies for various control devices are shown in Table 7.11-5. In one application, fabric filters alone captured over 99 percent of the blast furnace particulate emissions.

Particulate recovered from the uncontrolled flue emissions at six blast furnaces had an average lead content of 23 percent.[3,5] Particulate recovered from the uncontrolled charging and tapping hoods at one blast furnace had an average lead content of 61 percent.[13] Based on relative emission rates, lead is 34 percent of uncontrolled blast furnace emissions. Controlled emissions from the same blast furnace had lead content of 26 percent, with 33 percent from flues, and 22 percent from charging and tapping operations.[13] Particulate recovered from another blast furnace contained 80 to 85 percent lead sulfate and lead chloride, 4 percent tin, 1 percent cadmium, 1 percent zinc, 0.5 percent antimony, 0.5 percent arsenic, and less than 1 percent organic matter.[18]

Kettle furnaces for melting, refining and alloying are relatively minor emission sources. The kettles are hooded, with fumes and dusts typically vented to baghouses and recovered at efficiencies exceeding 99 percent. Twenty measurements of the uncontrolled particulates from kettle furnaces showed a mass median aerodynamic particle diameter of 18.9 micrometers, with particle size ranging from 0.05 to 150 micrometers. Three chemical analyses by electron spectroscopy showed the composition of particulate to vary from 12 to 17 percent lead, 5 to 17 percent tin, and 0.9 to 5.7 percent zinc.[16]

Emissions from oxidizing furnaces are economically recovered with baghouses. The particulates are mostly lead oxide, but they also contain amounts of lead and other metals. The oxides range in size from 0.2 to 0.5 micrometers. Controlled emissions have been estimated to be 0.1 kilograms per megagram (0.2 pounds per ton) of lead product, based on a 99 percent efficient baghouse.

References for Section 7.11

1. William M. Coltharp, et al., Multimedia Environmental Assessment of the Secondary Nonferrous Metal Industry (Draft), Contract No. 68-02-1319, Radian Corporation, Austin, TX, June 1976.

2. H. Nack, et al., Development of an Approach to Identification of Emerging Technology and Demonstration Opportunities, EPA-650/2-74-048, U. S. Environmental Protection Agency, Cincinnati, OH, May 1974.

3. J. M. Zoller, et al., A Method of Characterization and Quantification of Fugitive Lead Emissions from Secondary Lead Smelters, Ferroalloy Plants and Gray Iron Foundries (Revised), EPA-450/3-78-003 (Revised), U. S. Environmental Protection Agency, Research Triangle Park, NC, August 1978.

4. Air Pollution Engineering Manual, Second Edition, AP-40, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1973. Out of Print.

5. Control Techniques for Lead Air Emissions, EPA-450/2-77-012, U. S. Environmental Protection Agency, Research Triangle Park, NC, January 1978.

6. Background Information for Proposed New Source Performance Standards, Volumes I and II: Secondary Lead Smelters and Refineries, APTD-1352a and b, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1973.

7. J. W. Watson and K. J. Brooks, A Review of Standards of Performance for New Stationary Sources - Secondary Lead Smelters, Contract No. 68-02-2526, Mitre Corporation, McLean, VA, January 1979.

8. John E. Williamson, et al., A Study of Five Source Tests on Emissions from Secondary Lead Smelters, County of Los Angeles Air Pollution Control District, Los Angeles, CA, February 1972.

9. Emission Test No. 72-CI-8, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, July 1972.

10. Emission Test No. 72-CI-7, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, August 1972.

11. A. E. Vandergrift, et al., Particulate Pollutant Systems Study, Volume I: Mass Emissions, APTD-0743, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1971.

12. Emission Test No. 71-CI-34, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, July 1972.

13. Emissions and Emission Controls at a Secondary Lead Smelter (Draft), Contract No. 68-03-2807, Radian Corporation, Durham, NC, January 1981.

14. Emission Test No. 71-CI-33, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, August 1972.

15. Secondary Lead Plant Stack Emission Sampling At General Battery Corporation, Reading, Pennsylvania, Contract No. 68-02-0230, Battelle Institute, Columbus, OH, July 1972.

16. Technical Guidance for Control of Industrial Process Fugitive Particulate Emissions, EPA-450/3-77-010, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1977.

17. E. I. Hartt, An Evaluation of Continuous Particulate Monitors at A Secondary Lead Smelter, M. S. Report No. O. R.-16, Environment Canada, Ottawa, Canada. Date unknown.

18. J. E. Howes, et al., Evaluation of Stationary Source Particulate Measurement Methods, Volume V: Secondary Lead Smelters, Contract No. 68-02-0609, Battelle Laboratories, Columbus, OH, January 1979.

19. Silver Valley/Bunker Hill Smelter Environmental Investigation (Interim Report), Contract No. 68-02-1343, Pedco, Inc., Cincinnati, OH, February 1975.

8.1 ASPHALTIC CONCRETE PLANTS

8.1.1 General[1-2]

Asphaltic concrete paving is a mixture of well graded, high quality aggregate and liquid asphaltic cement which is heated and mixed in measured quantities to produce bituminous pavement material. Aggregate constitutes over 92 weight percent of the total mixture. Aside from the amount and grade of asphalt used, mix characteristics are determined by the relative amounts and types of aggregate used. A certain percentage of fine aggregate (% less than 74 micrometers in physical diameter) is required for the production of good quality asphaltic concrete.

Hot mix asphalt paving can be manufactured by batch mix, continuous mix or drum mix process. Of these various processes, batch mix plants are currently predominant. However, most new installations or replacements to existing equipment are of the drum mix type. In 1980, 78 percent of the total plants were of the conventional batch type, with 7 percent being continuous mix facilities and 15 percent drum mix plants. Any of these plants can be either permanent installations or portable.

Conventional Plants - Conventional plants produce finished asphaltic concrete through either batch (Figure 8.1-1) or continuous (Figure 8.1-2) mixing operations. Raw aggregate normally is stockpiled near the plant at a location where the bulk moisture content will stabilize to between 3 and 5 weight percent.

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

As it leaves the dryer, the hot material drops into a bucket elevator and is transferred to a set of vibrating screens and classified into as many as four different grades (sizes). The classified material then enters the mixing operation.

In a batch plant, the classified aggregate drops into four large bins according to size. The operator controls the aggregate size distribution by opening various bins over a weigh hopper until the desired mix and weight are obtained. This material is dropped into a pug mill (mixer) and is mixed dry for about 15 seconds. The asphalt, a solid at ambient temperature, is pumped from a heated storage tank, weighed and injected into the mixer. Then the hot mix is dropped into a truck and is hauled to the job site.

In a continuous plant, the dried and classified aggregate drops into a set of small bins which collects the aggregate and meters it through a set of feeder conveyors to another bucket elevator and into the mixer. Asphalt is metered through the inlet end of the mixer, and retention time is

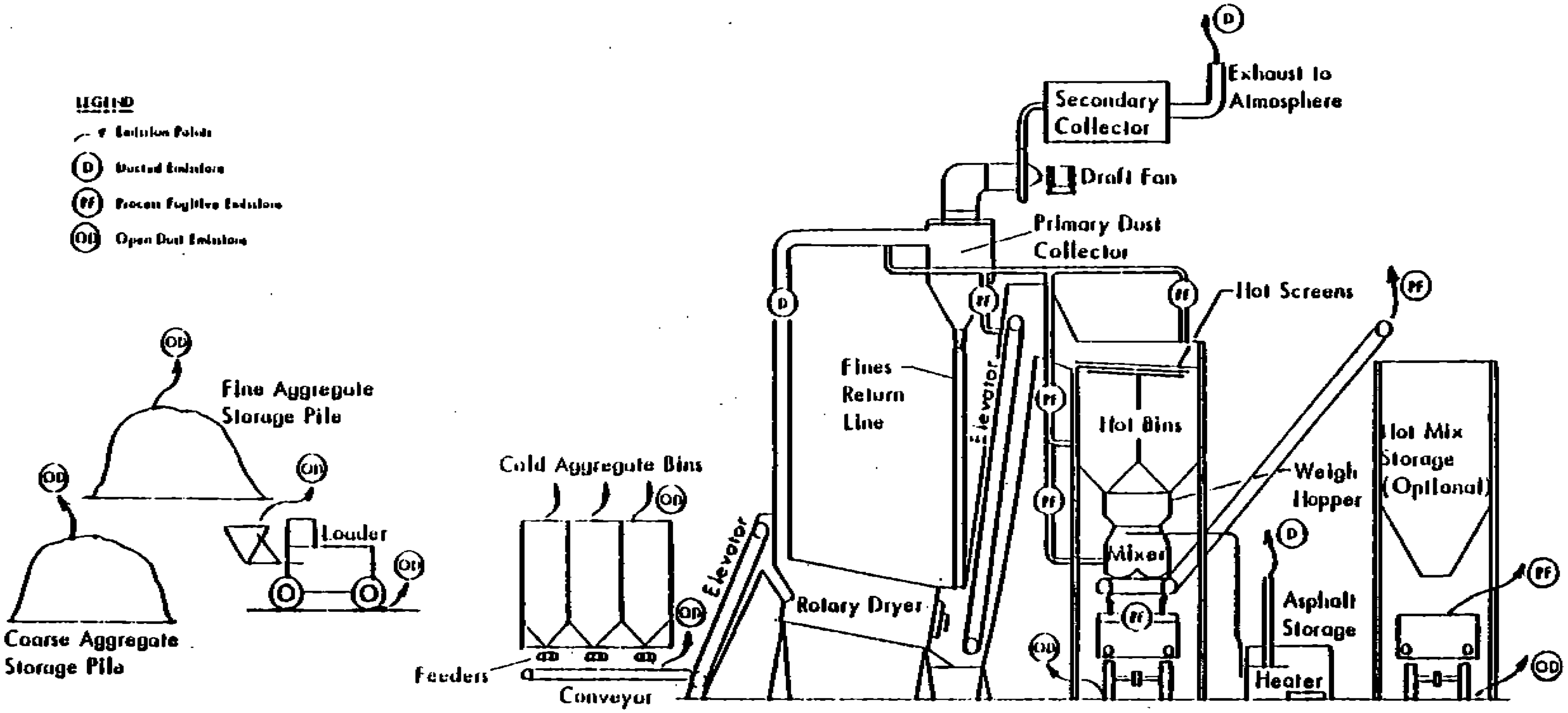

Figure 8.1-1. General process flow diagram for batch mix asphalt paving plants.

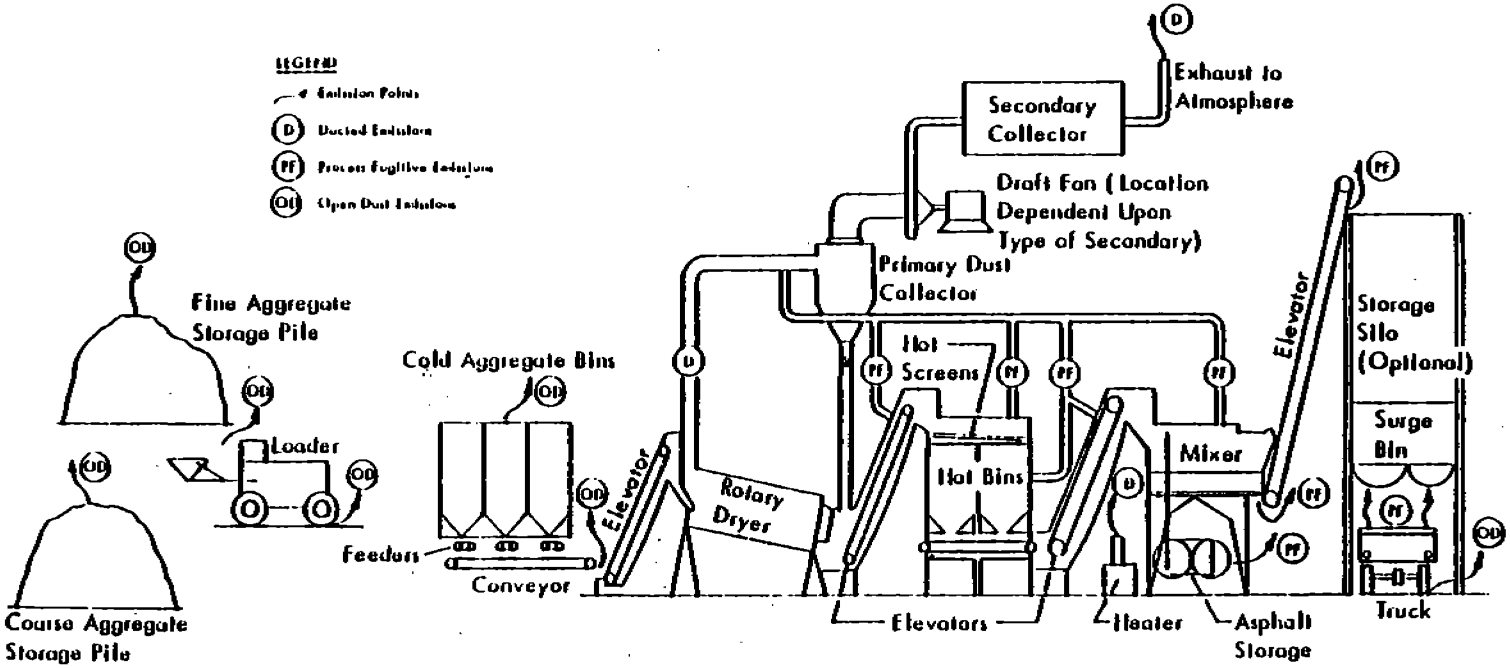

Figure 8.1-2. General process flow diagram for continuous mix asphalt paving plants.

controlled by an adjustable dam at the opposite end. The hot mix flows out of the mixer into a surge hopper, from which trucks are loaded.

Drum Mix Plants - The drum mix process simplifies the conventional process by using proportioning feed controls in place of hot aggregate storage bins, vibrating screens and the mixer. Aggregate is introduced near the burner end of the revolving drum mixer, and the asphalt is injected midway along the drum. A variable flow asphalt pump is linked electronically to the aggregate belt scales to control mix specifications. The hot mix is discharged from the revolving drum mixer into surge bins or storage silos. Figure 8.1-3 is a diagram of the drum mix process.

Drum mix plants generally use parallel flow design for hot burner gases and aggregate flow. Parallel flow has the advantage of giving the mixture a longer time to coat and to collect dust in the mix, thereby reducing particulate emissions. The amount of particulate generated within the dryer in this process is usually lower than that generated within conventional dryers, but because asphalt is heated to high temperatures for a long period of time, organic emissions (gaseous and liquid aerosol) are greater than in conventional plants.

Recycle Processes - In recent years, recycling of old asphalt paving has been initiated in the asphaltic concrete industry. Recycling significantly reduces the amount of new (virgin) rock and asphaltic cement needed to repave an existing road. The various recycling techniques include both cold and hot methods, with the hot processing conducted at a central plant.

In recycling, old asphalt pavement is broken up at a job site and is removed from the road base. This material is then transported to the plant, crushed and screened to the appropriate size for further processing. The paving material is then heated and mixed with new aggregate (if applicable), to which the proper amount of new asphaltic cement is added to produce a grade of hot asphalt paving suitable for laying.

There are three methods which can be used to heat recycled asphalt paving before the addition of the asphaltic cement: direct flame heating, indirect flame heating, and superheated aggregate.

Direct flame heating is typically performed with a drum mixer, wherein all materials are simultaneously mixed in the revolving drum. The first experimental attempts at recycling used a standard drum mix plant and introduced the recycled paving and virgin aggregate concurrently at the burner end of the drum. Continuing problems with excessive blue smoke emissions led to several process modifications, such as the addition of heat shields and the use of split feeds.

One method of recycling involves a drum mixer with a heat dispersion shield. The heat shield is installed around the burner, and additional cooling air is provided to reduce the hot gases to a temperature below 430 to 650°C (800 to 1200°F), thus decreasing the amount of blue smoke. Although now considered obsolete, a drum within a drum design has also been successfully

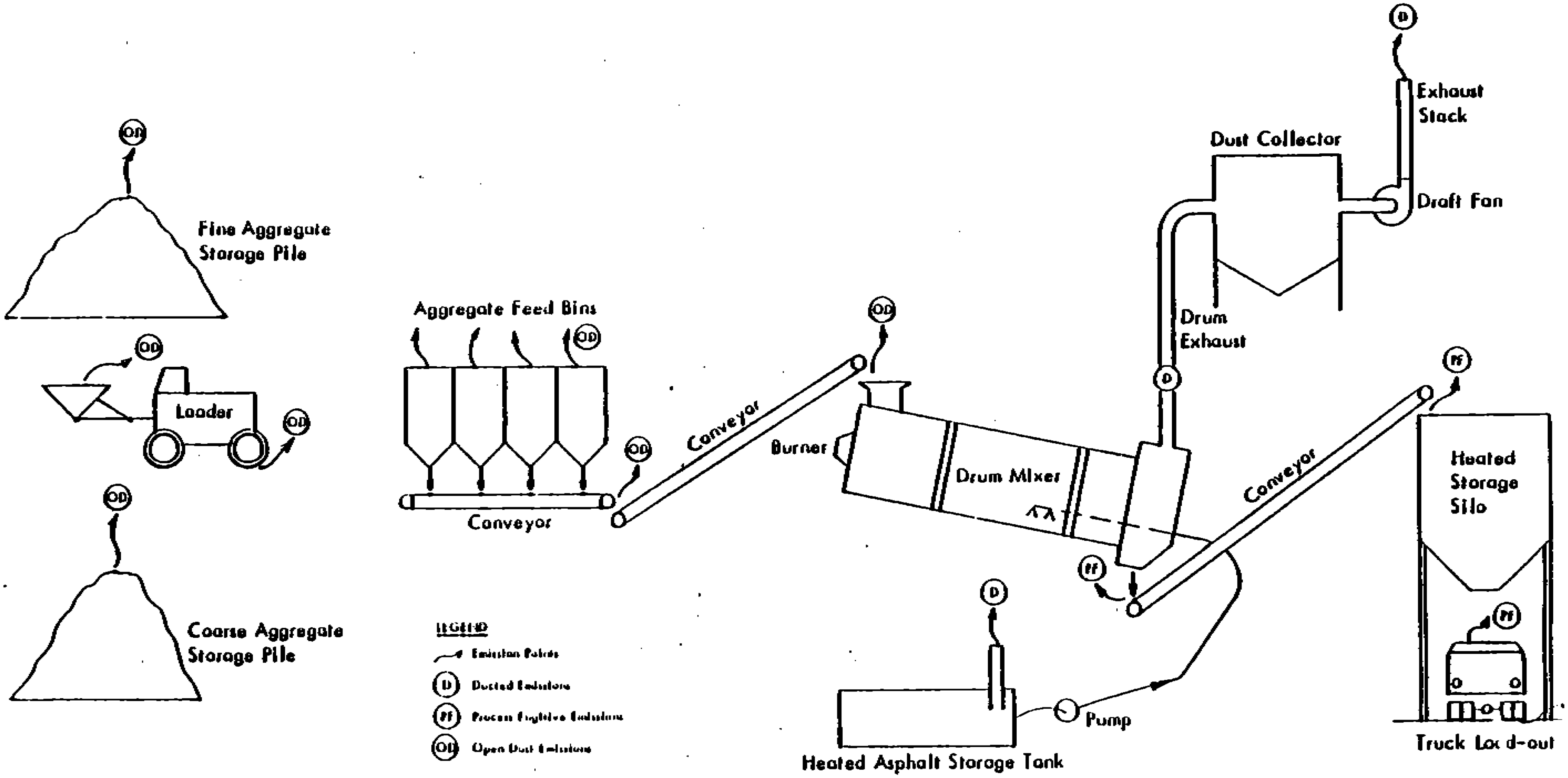

Figure 8.1-3. General process flow diagram for drum mix asphalt paving plants.

used for recycling. Reclaimed material is introduced into the outer drum through a separate charging chute while virgin material is introduced into the inner drum.

Split feed drum mixers were first used for recycling in 1976 and are now the most popular design. At about the midpoint of the drum, the recycled bituminous material is introduced by a split feed arrangement and is heated by both the hot gases and heat transfer from the superheated virgin aggregate. Another type of direct flame method involves the use of a slinger conveyor to throw recycled material into the center of the drum mixer from the discharge end. In this process, the recycled material enters the drum along an arc, landing approximately at the asphalt injection point.

Indirect flame heating has been performed with special drum mixers equipped with heat exchanger tubes. These tubes prevent the mixture of virgin aggregate and recycled paving from coming into direct contact with the flame and the associated high temperatures. Superheated aggregate can also be used to heat recycled bituminous material.

In conventional plants, recycled paving can be introduced either into the pug mill or at the discharge end of the dryer, after which the temperature of the material is raised by heat from the virgin aggregate. The proper amount of new asphaltic cement is then added to the virgin aggregate/recycle paving mixture to produce high grade asphaltic concrete.

Tandem drum mixers can also be used to heat the recycle material. The first drum or aggregate dryer is used to superheat the virgin aggregate, and a second drum or dryer either heats recycled paving only or mixes and heats a combination of virgin and recycled material. Sufficient heat remains in the exhaust gas from the first dryer to heat the second unit also.

8.1.2 Emissions and Controls

Emission points at batch, continuous and drum mix asphalt plants discussed below refer to Figures 8.1-1, 8.1-2 and 8.1-3, respectively.

Conventional Plants - As with most facilities in the mineral products industry, conventional asphaltic concrete plants have two major categories of emissions, those which are vented to the atmosphere through some type of stack, vent or pipe (ducted sources), and those which are not confined to ducts and vents but are emitted directly from the source to the ambient air (fugitive sources). Ducted emissions are usually collected and transported by an industrial ventilation system with one or more fans or air movers, eventually to be emitted to the atmosphere through some type of stack. Fugitive emissions result from process sources, which consist of a combination of gaseous pollutants and particulate matter, or open dust sources.

The most significant source of ducted emissions from conventional asphaltic concrete plants is the rotary dryer. The amount of aggregate dust carried out of the dryer by the moving gas stream depends upon a number of factors, including the gas velocity in the drum, the particle size distribution of the aggregate, and the specific gravity and aerodynamic characteristics of the particles. Dryer emissions also contain the fuel combustion products of the burner.

There may also be some ducted emissions from the heated asphalt storage tanks. These may consist of combustion products from the tank heater.

The major source of process fugitives in asphalt plants is enclosures over the hot side conveying, classifying and mixing equipment which are vented into the primary dust collector along with the dryer gas. These vents and enclosures are commonly called a "fugitive air" or "scavenger" system. The scavenger system may or may not have its own separate air mover device, depending on the particular facility. The emissions captured and transported by the scavenger system are mostly aggregate dust, but they may also contain gaseous volatile organic compounds (VOC) and a fine aerosol of condensed liquid particles. This liquid aerosol is created by the condensation of gas into particles during cooling of organic vapors volatilized from the asphaltic cement in the pug mill. The amount of liquid aerosol produced depends to a large extent on the temperature of the asphaltic cement and aggregate entering the pug mill. Organic vapor and its associated aerosol are also emitted directly to the atmosphere as process fugitives during truck loadout, from the bed of the truck itself during transport to the job site, and from the asphalt storage tank, which also may contain small amounts of polycyclic compounds.

The choice of applicable control equipment for the drier exhaust and vent line ranges from dry mechanical collectors to scrubbers and fabric collectors. Attempts to apply electrostatic precipitators have met with little success. Practically all plants use primary dust collection equipment like large diameter cyclones, skimmers or settling chambers. These chambers are often used as classifiers to return collected material to the hot elevator and to combine it with the drier aggregate. Because of high pollutant levels, the primary collector effluent is ducted to a secondary collection device. Table 8.1-1 presents total particulate emission factors for conventional asphaltic concrete plants, with the factors based on the type of control technology employed. Size specific emission factors for conventional asphalt plants, also based on the control of technology used, are shown in Table 8.1-2 and Figure 8.1-4. Interpolations of size data other than those shown in Figure 8.1-4 can be made from the curves provided.

There are also a number of open dust sources associated with conventional asphalt plants. These include vehicle traffic generating fugitive dust on paved and unpaved roads, handling aggregate material, and similar operations. The number and type of fugitive emission sources associated with a particular plant depend on whether the equipment is portable or stationary and whether it is located adjacent to a gravel pit or quarry. Fugitive dust may range from 0.1 micrometers to more than 300 micrometers in diameter. On the average, 5 percent of cold aggregate feed is less than 74 micrometers (minus 200 mesh). Dust that may escape collection before primary control generally consists of particulate having 50 to 70 percent of the total mass being less than 74 micrometers. Uncontrolled particulate emission factors for various types of fugitive sources in conventional asphaltic concrete plants can be found in Section 11.2.3 of this document.

TABLE 8.1-1. EMISSION FACTORS FOR TOTAL PARTICULATE FROM CONVENTIONAL ASPHALTIC CONCRETE PLANTS[a]

Type of control	Emission factor	
	kg/Mg	lb/ton
Uncontrolled[b,c]	22.5	45.0
Precleaner[c]	7.5	15.0
High efficiency cyclone	0.85	1.7
Spray tower	0.20	0.4
Baffle spray tower	0.15	0.3
Multiple centrifugal scrubber[d]	0.035	0.07
Orifice scrubber	0.02	0.04
Venturi scrubber[e]	0.02	0.04
Baghouse[f]	0.01	0.02

[a] References 1-2, 5-10, 14-16. Expressed in terms of emissions per unit weight of asphaltic concrete produced. Includes both batch mix and continuous mix processes.

[b] Almost all plants have at least a precleaner following the rotary drier.

[c] Reference 16. These factors differ from those given in Table 8.1-6 because they are for uncontrolled emissions and are from an earlier survey.

[d] Reference 15. Range of values = 0.004 - 0.0690 kg/Mg. Average from a properly designed, installed, operated and maintained scrubber, based on a study to develop New Source Performance Standards.

[e] References 14-15. Range of values = 0.013 - 0.0690 kg/Mg.

[f] References 14-15. Emissions from a properly designed, installed, operated and maintained baghouse, based on a study to develop New Source Performance Standards. Range of values = 0.008 - 0.018 kg/Mg.

TABLE 8.1-2. SUMMARY OF SIZE SPECIFIC EMISSION FACTORS FOR CONVENTIONAL ASPHALT PLANTS[a]

EMISSION FACTOR RATING: D

Particle size (µmA)[b]	Cumulative mass ≤ stated size (%)					Cumulative particulate emission factor ≤ stated size[c]									
	Uncontrolled	Cyclone collectors	Multiple centrifugal scrubbers	Gravity spray towers	Baghouse collector	Uncontrolled		Cyclone collectors		Multiple centrifugal scrubbers		Gravity spray towers		Baghouse collector[d]	
						kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
2.5 µmA	0.83	5.0	67	21	33	0.19	0.37	0.05[d]	0.10[d]	0.023	0.046	0.041	0.082	0.003	0.006
5.0 µmA	3.5	11	74	27	36	0.78	1.6	0.13	0.26	0.026	0.052	0.053	0.11	0.004	0.008
10.0 µmA	14	21	80	37	40	3.1	6.1	0.18	0.36	0.028	0.056	0.073	0.15	0.004	0.008
15.0 µmA	23	29	83	39	47	5.3	11	0.25	0.50	0.029	0.058	0.078	0.16	0.005	0.010
20.0 µmA	30	36	84	41	54	6.8	14	0.30	0.60	0.030	0.060	0.081	0.16	0.005	0.010
Total mass emission factor						23	45	0.85	1.7	0.035	0.070	0.20	0.40	0.01	0.02

[a] Reference 23, Table 3-36. Rounded to two significant figures.
[b] Aerodynamic diameter.
[c] Based on emission factors for total particulate shown in Table 8.1-1. Expressed in terms of emissions per unit weight of asphaltic concrete produced. Mg = 10^6 g; ton = 2,000 lb.
[d] Rounded to one significant figure.

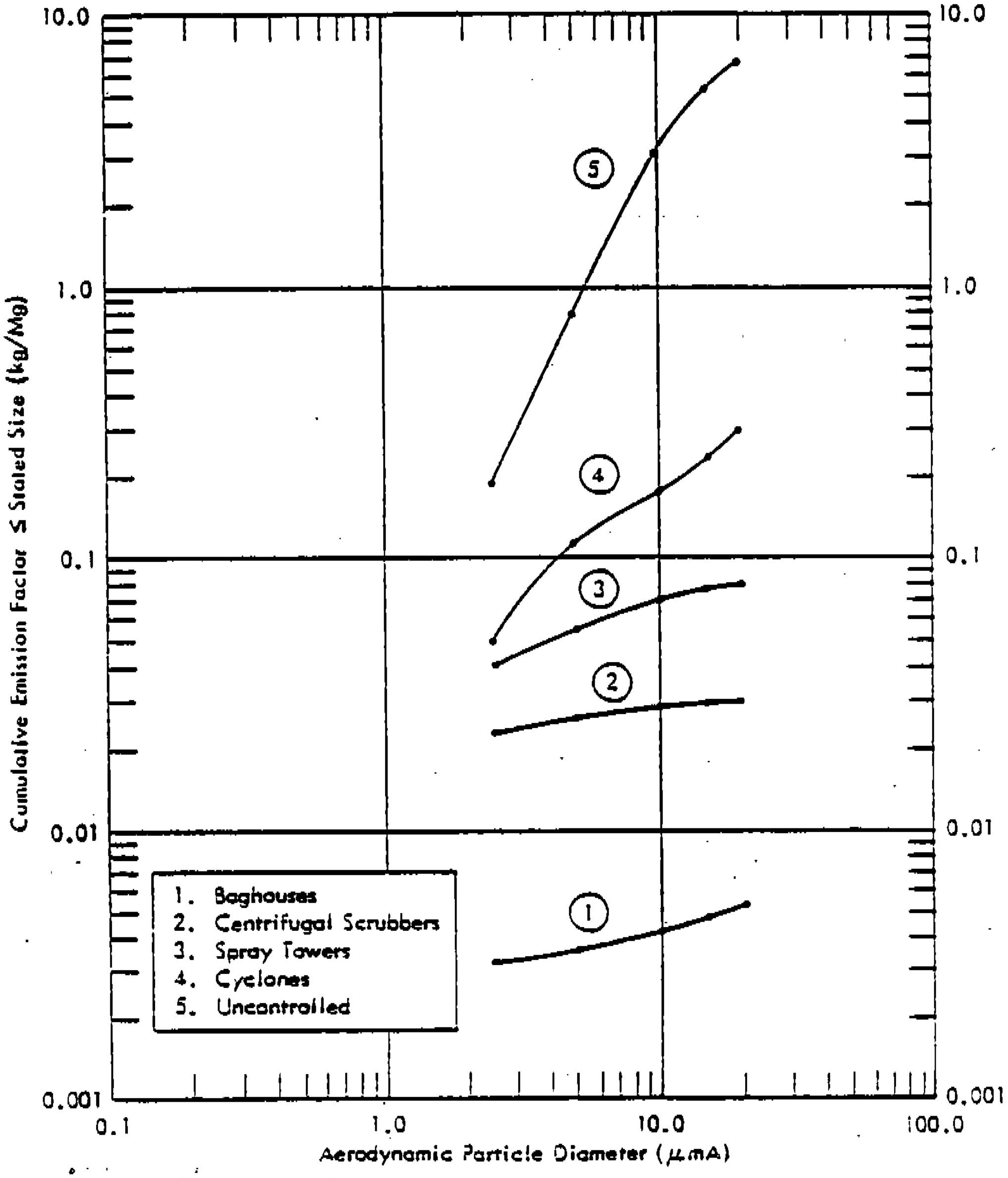

Figure 8.1-4. Size specific emission factors for conventional asphalt plants.

Drum Mix Plants - As with the other two asphaltic concrete production processes, the most significant ducted source of particulate emissions is the drum mixer itself. Emissions from the drum mixer consist of a gas stream with a substantial amount of particulate matter and lesser amounts of gaseous VOC of various species. The solid particulate generally consists of fine aggregate particles entrained in the flowing gas stream during the drying process. The organic compounds, on the other hand, result from heating and mixing of asphalt cement inside the drum, which volatilizes certain components of the asphalt. Once the VOC have sufficiently cooled, some condense to form the fine liquid aerosol (particulate) or "blue smoke" plume typical of drum mix asphalt plants.

A number of process modifications have been introduced in the newer plants to reduce or eliminate the blue smoke problem, including installation of flame shields, rearrangement of the flights inside the drum, adjustments in the asphalt injection point, and other design changes. Such modifications result in significant improvements in the elimination of blue smoke.

Emissions from the drum mix recycle process are similar to emissions from regular drum mix plants, except that there are more volatile organics because of the direct flame volatilization of petroleum derivatives contained in the old asphalt paving. Control of liquid organic emissions in the drum mix recycle process is through some type of process modification, as described above.

Table 8.1-3 provides total particulate emission factors for ducted emissions in drum mix asphaltic concrete plants, with available size specific emission factors shown in Table 8.1-4 and Figure 8.1-5.

TABLE 8.1-3. TOTAL PARTICULATE EMISSION FACTORS FOR DRUM MIX ASPHALTIC CONCRETE PLANTS[a]

EMISSION FACTOR RATING: B

Type of control	Emission factor	
	kg/Mg	lb/ton
Uncontrolled	2.45	4.9
Cyclone or multiclone	0.34	0.67
Low energy wet scrubber[b]	0.04	0.07
Venturi scrubber	0.02	0.04

[a] Reference 11. Expressed in terms of emissions per unit weight of asphaltic concrete produced. These factors differ from those for conventional asphaltic concrete plants because the aggregate contacts and is coated with asphalt early in the drum mix process.

[b] Either stack sprays, with water droplets injected into the exit stack, or a dynamic scrubber with a wet fan.

TABLE 8.1-4. PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR DRUM MIX ASPHALT PLANTS CONTROLLED BY A BAGHOUSE COLLECTOR[a]

EMISSION FACTOR RATING: D

Particle size (μmA)[b]	Cumulative mass ≤ stated size (%)		Cumulative particulate emission factors ≤ stated size[c]			
	Uncontrolled	Controlled[f]	Uncontrolled[d]		Controlled[e]	
			kg/Mg	lb/ton	10^{-3} kg/Mg	10^{-3} lb/ton
2.5	5.5	11	0.14	0.27	0.53	1.1
10.0	23	32	0.57	1.1	1.6	3.2
15.0	27	35	0.65	1.3	1.7	3.5
Total mass emission factor			2.5	4.9	4.9	9.8
Condensable organics[g]					3.9	7.7

---

[a] Reference 23, Table 3-35. Rounded to two significant figures.

[b] Aerodynamic diameter.

[c] Expressed in terms of emissions per unit weight of asphaltic concrete produced. Not generally applicable to recycle processes.

[d] Based on an uncontrolled emission factor of 2.45 kg/Mg (see Table 8.1-3).

[e] Reference 23. Calculated using an overall collection efficiency of 99.8% for a baghouse applied to an uncontrolled emission factor of 2.45 kg/Mg.

[f] Includes data from two out of eight tests where ~ 30% recycled asphalt paving was processed using a split feed process.

[g] Determined at outlet of a baghouse collector while plant was operating with ~ 30% recycled asphalt paving. Factors are applicable only to a direct flame heating process with a split feed.

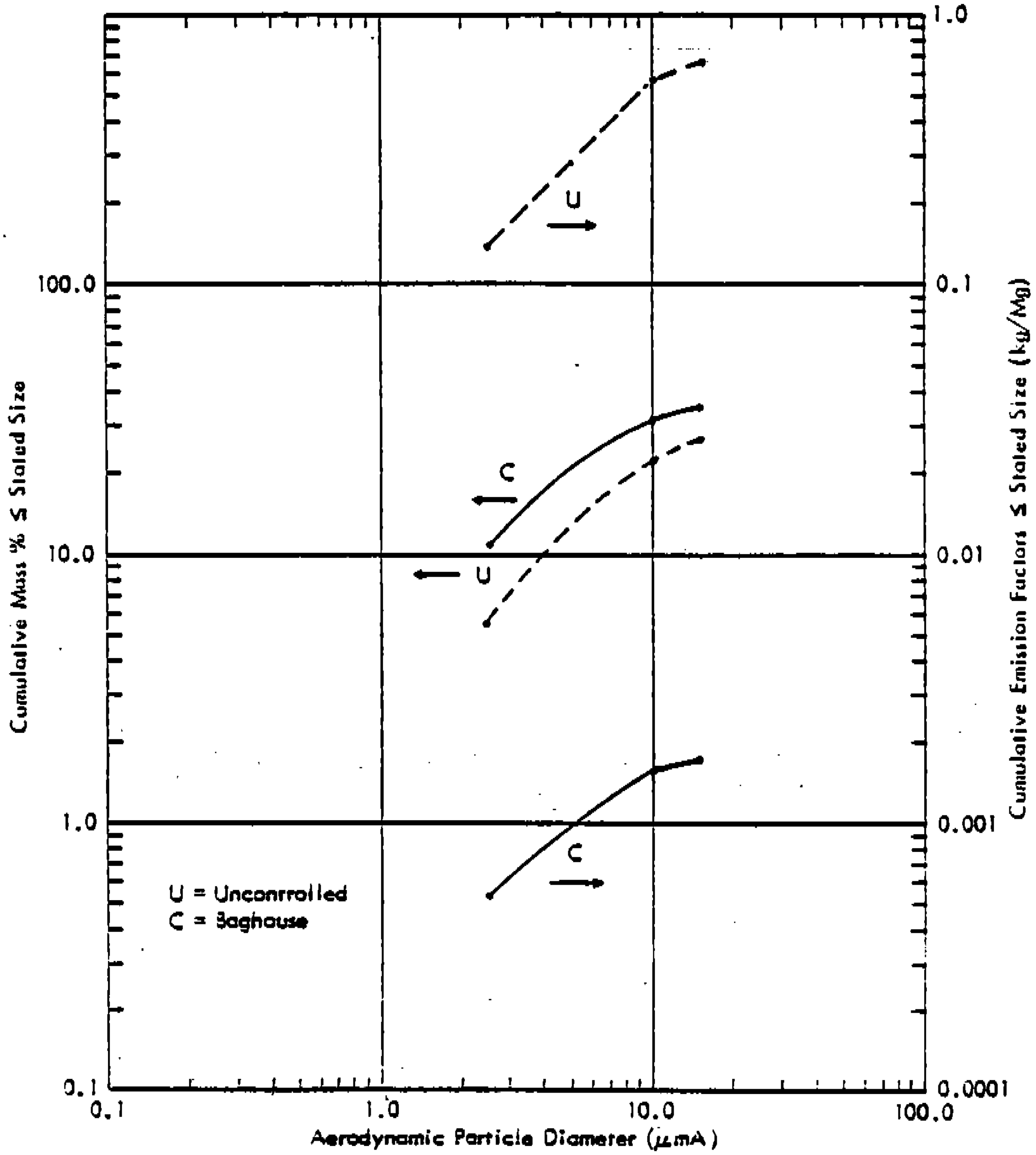

Figure 8.1-5. Particle size distribution and size specific emission factors for drum mix asphaltic concrete plants.

Interpolations of the data shown in Figure 8.1-5 to particle sizes other than those indicated can be made from the curves provided.

Process fugitive emissions normally associated with batch and continuous plants from the hot side screens, bins, elevators and pug mill have been eliminated in the drum mix process. There may be, however, a certain amount of fugitive VOC and liquid aerosol produced from transport and handling of hot mix from the drum mixer to the storage silo, if an open conveyor is used, and also from the beds of trucks. The open dust sources associated with drum mix plants are similar to those of batch or continuous plants, with regard to truck traffic and aggregate handling operations.

8.1.3 Representative Facility

Factors for various materials emitted from the stack of a typical asphaltic concrete plant are given in Table 8.1-5, and the characteristics of such a plant are shown in Table 8.1-6. With the exception of aldehydes, the materials listed in Table 8.1-6 are also emitted from the mixer, but in concentrations 5 to 100 fold smaller than stack gas concentrations, and they last only during the discharge of the mixer.

Reference 16 reports mixer emissions of SO_x, NO_x, and VOC as "less than" values, so it is possible they may not be present at all. Particulates, carbon monoxide, polycyclics, trace metals and hydrogen sulfide were observed at concentrations that were small relative to stack amounts. Emissions from the mixer are thus best treated as fugitive.

All emission factors for the typical facility are for controlled operation and are based either on average industry practice shown by survey or on results of actual testing in a selected typical plant.

An industrial survey[16] showed that over 66 percent of operating hot mix asphalt plants use fuel oil for combustion. Possible sulfur oxide emissions from the stack were calculated, assuming that all sulfur in the fuel oil is oxidized to SO_x. The amount of sulfur oxides actually released through the stack may be attenuated by water scrubbers, or even by the aggregate itself, if limestone is being dried. Number 2 fuel oil has an average sulfur content of 0.22 weight percent.

Emission factors for nitrogen oxides, nonmethane volatile organics, carbon monoxide, polycyclic organic material, and aldehydes were determined by sampling stack gas at the representative asphalt hot mix plant.

TABLE 8.1-5. EMISSION FACTORS FOR SELECTED GASEOUS POLLUTANTS FROM A CONVENTIONAL ASPHALTIC CONCRETE PLANT STACK[a]

Material emitted[b]	Emission Factor Rating	Emission factor[c] g/Mg	Emission factor[c] lb/ton
Sulfur oxides (as SO_2)[d,e]	C	146S	0.292S
Nitrogen oxides (as NO_2)[f]	D	18	0.036
Volatile organic compounds[f]	D	14	0.028
Carbon monoxide[f]	D	19	0.038
Polycyclic organic material[f]	D	0.013	0.000026
Aldehydes[f]	D	10	0.02
Formaldehyde	D	0.075	0.00015
2-Methylpropanal (isobutyraldehyde)	D	0.65	0.0013
1-Butanal (n-butyraldehyde)	D	1.2	0.0024
3-Methylbutanal (isovaleraldehyde)	D	8.0	0.016

[a] Reference 16.

[b] Particulates, carbon monoxide, polycyclics, trace metals and hydrogen sulfide were observed in the mixer emissions at concentrations that were small relative to stack concentrations.

[c] Expressed as g/Mg and lb/ton of asphaltic concrete produced.

[d] Mean source test results of a 400 plant survey.

[e] Reference 21. S = % sulfur in fuel. SO_2 may be attenuated 50% by adsorption on alkaline aggregate.

[f] Based on limited test data from the single asphaltic concrete plant described in Table 8.1-6.

TABLE 8.1-6. CHARACTERISTICS OF A REPRESENTATIVE ASPHALTIC CONCRETE PLANT SELECTED FOR SAMPLING[a]

Parameter	Plant sampled
Plant type	Conventional, permanent, batch plant
Production rate, Mg/hr (tons/hr)	160.3 ± 16% (177 ± 16%)
Mixer capacity, Mg (tons)	3.6 (4.0)
Primary collector	Cyclone
Secondary collector	Wet scrubber (venturi)
Fuel	Oil
Release agent	Fuel oil
Stack height, m (ft)	15.85 (52)

[a] Reference 16, Table 16.

References for Section 8.1

1. <u>Asphaltic Concrete Plants Atmospheric Emissions Study</u>, EPA Contract No. 68-02-0076, Valentine, Fisher, and Tomlinson, Seattle, WA, November 1971.

2. <u>Guide for Air Pollution Control of Hot Mix Asphalt Plants</u>, Information Series 17, National Asphalt Pavement Association, Riverdale, MD, 1965.

3. R. M. Ingels, et al., "Control of Asphaltic Concrete Batching Plants in Los Angeles County", Journal of the Air Pollution Control Association, 10(1):29-33, January 1960.

4. H. E. Friedrich, "Air Pollution Control Practices and Criteria for Hot Mix Asphalt Paving Batch Plants", Journal of the Air Pollution Control Association, 19(12):924-928, December 1969.

5. Air Pollution Engineering Manual, AP-40, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1973. Out of Print.

6. G. L. Allen, et al., "Control of Metallurgical and Mineral Dust and Fumes in Los Angeles County, California", Information Circular 7627, U. S. Department of Interior, Washington, DC, April 1952.

7. P. A. Kenline, Unpublished report on control of air pollutants from chemical process industries, U. S. Environmental Protection Agency, Cincinnati, OH, May 1959.

8. Private communication on particulate pollutant study between G. Sallee, Midwest Research Institute, Kansas City, MO, and U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1970.

9. J. A. Danielson, Unpublished test data from asphalt batching plants, Los Angeles County Air Pollution Control District, Presented at Air Pollution Control Institute, University of Southern California, Los Angeles, CA, November 1966.

10. M. E. Fogel, et al., Comprehensive Economic Study of Air Pollution Control Costs for Selected Industries and Selected Regions, R-OU-455, U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1970.

11. Preliminary Evaluation of Air Pollution Aspects of the Drum Mix Process, EPA-340/1-77-004, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1976.

12. R. W. Beaty and B. M. Bunnell, "The Manufacture of Asphalt Concrete Mixtures in the Dryer Drum", Presented at the Annual Meeting of the Canadian Technical Asphalt Association, Quebec City, Quebec, November 19-21, 1973.

13. J. S. Kinsey, "An Evaluation of Control Systems and Mass Emission Rates from Dryer Drum Hot Asphalt Plants", Journal of the Air Pollution Control Association, 26(12):1163-1165, December 1976.

14. Background Information for Proposed New Source Performance Standards, APTD-1352A and B, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1973.

15. Background Information for New Source Performance Standards, EPA 450/2-74-003, U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1974.

16. Z. S. Kahn and T. W. Hughes, Source Assessment: Asphalt Paving Hot Mix, EPA-600/2-77-107n, U. S. Environmental Protection Agency, Cincinnati, OH, December 1977.

17. V. P. Puzinauskas and L. W. Corbett, Report on Emissions from Asphalt Hot Mixes, RR-75-1A, The Asphalt Institute, College Park, MD, May 1975.

18. Evaluation of Fugitive Dust from Mining, EPA Contract No. 68-02-1321, PEDCo Environmental, Inc., Cincinnati, OH, June 1976.

19. J. A. Peters and P. K. Chalekode, "Assessment of Open Sources", Presented at the Third National Conference on Energy and the Environment, College Corner, OH, October 1, 1975.

20. Illustration of Dryer Drum Hot Mix Asphalt Plant, Pacific Environmental Services, Inc., Santa Monica, CA, 1978.

21. Herman H. Forsten, "Applications of Fabric Filters to Asphalt Plants", Presented at the 71st Annual Meeting of the Air Pollution Control Association, Houston, TX, June 1978.

22. Emission Of Volatile Organic Compounds From Drum Mix Asphalt Plants, EPA-600/2-81-026, U. S. Environmental Protection Agency, Washington, DC, February 1981.

23. J. S. Kinsey, Asphaltic Concrete Industry - Source Category Report, EPA-600/7-86-038, U. S. Environmental Protection Agency, Cincinnati, OH, October 1986.

8.3 BRICKS AND RELATED CLAY PRODUCTS

8.3.1 Process Description

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

Surface clays and shales are mined in open pits. Most fine clays are found underground. After mining, the material is crushed to remove stones and is stirred before it passes onto screens for segregation by particle size.

To start the forming process, clay is mixed with water, usually in a pug mill. The three principal processes for forming brick are stiff mud, soft mud and dry press. In the stiff mud process, sufficient water is added to give the clay plasticity, and bricks are formed by forcing the clay through a die. Wire is used in separating bricks. All structural tile and most brick are formed by this process. The soft mud process is usually used with clay too wet for the stiff mud process. The clay is mixed with water to a moisture content of 20 to 30 percent, and the bricks are formed in molds. In the dry press process, clay is mixed with a small amount of water and formed in steel molds by applying pressure of 3.43 to 10.28 megapascals (500 to 1500 pounds per square inch). A typical brick manufacturing process is shown in Figure 8.3-1.

Wet clay units that have been formed are almost completely dried before firing, usually with waste heat from kilns. Many types of kilns are used for firing brick, but the most common are the downdraft periodic kiln and the tunnel kiln. The periodic kiln is a permanent brick structure with a number of fireholes where fuel enters the furnace. Hot gases from the fuel are drawn up over the bricks, down through them by underground flues, and out of the oven to the chimney. Although lower heat recovery makes this type less efficient than the tunnel kiln, the uniform temperature distribution leads to a good quality product. In most tunnel kilns, cars carrying about 1200 bricks travel on rails through the kiln at the rate of one 1.83 meter (6 foot) car per hour. The fire zone is located near the middle of the kiln and is stationary.

In all kilns, firing takes place in six steps: evaporation of free water, dehydration, oxidation, vitrification, flashing, and cooling. Normally, gas or residual oil is used for heating, but coal may be used. Total heating time varies with the type of product, for example, 22.9 centimeter (9 inch) refractory bricks usually require 50 to 100 hours of firing. Maximum temperatures of about 1090°C (2000°F) are used in firing common brick.

8.3.2 Emissions And Controls[1,3]

Particulate matter is the primary emission in the manufacture of bricks. The main source of dust is the materials handling procedure, which includes drying, grinding, screening and storing the raw material. Combustion products are emitted from the fuel consumed in the dryer and the kiln. Fluorides, largely in gaseous form, are also emitted from brick manufacturing operations. Sulfur dioxide may be emitted from the bricks when temperatures reach or exceed 1370°C (2500°F), but no data on such emissions are available.[4]

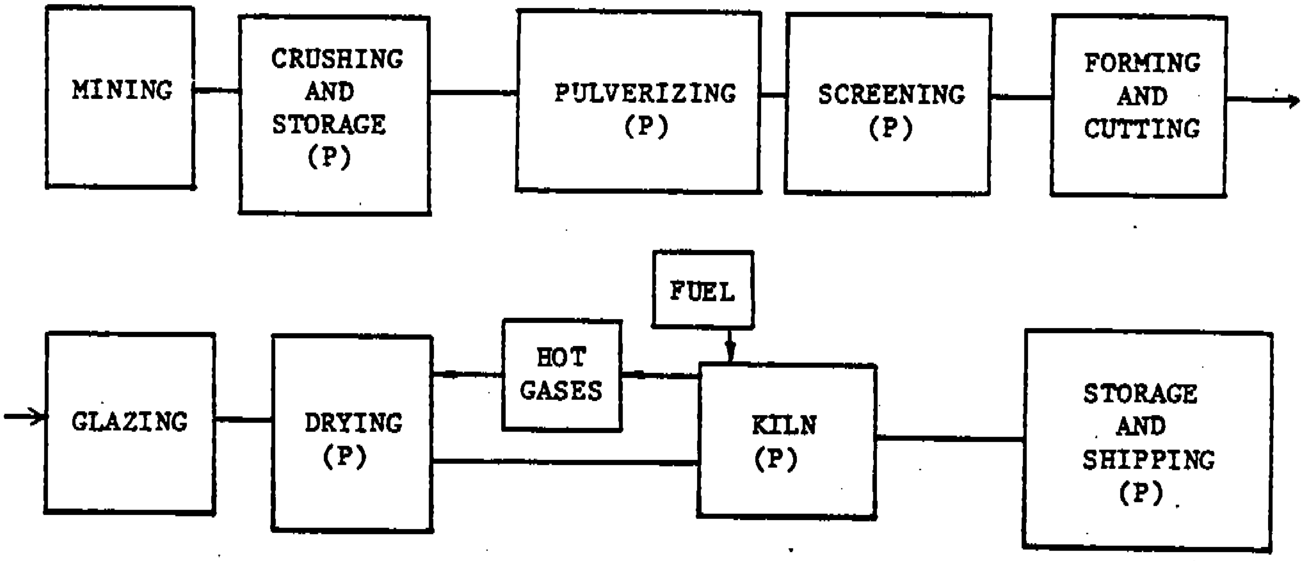

Figure 8.3-1. Basic flow diagram of brick manufacturing process. (P = a major source of particulate emissions)

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 material handling process, but good plant design and hooding are also required to keep emissions to an acceptable level.

The emissions of fluorides can be reduced by operating the kiln at temperatures below 1090°C (2000°F) and by choosing clays with low fluoride content. Satisfactory control can be achieved by scrubbing kiln gases with water, since wet cyclonic scrubbers can remove fluorides with an efficiency of 95 percent or higher.

Table 8.3-1 presents emission factors for brick manufacturing without controls. Table 8.3-2 presents data on particle size distribution and emission factors for uncontrolled sawdust fired brick kilns. Table 8.3-3 presents data on particle size distribution and emission factors for uncontrolled coal fired tunnel brick kilns.

TABLE 8.3-1. EMISSION FACTORS FOR BRICK MANUFACTURING WITHOUT CONTROLS[a]

EMISSION FACTOR RATING: C

							Volatile Organic Compounds							
	Particulates		Sulfur oxides		Carbon monoxide		Nonmethane		Methane		Nitrogen oxides		Fluorides[b]	
Process	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Raw material handling[c]														
Drying	35	70	-	-	-	-	-	-	-	-	-	-	-	-
Grinding	38	76	-	-	-	-	-	-	-	-	-	-	-	-
Storage	17	34	-	-	-	-	-	-	-	-	-	-	-	-
Brick dryer[d]														
Coal/gas fired	0.006A	0.012A	0.55S	1.10S	-	-	-	-	-	-	0.33	0.66	-	-
Curing and firing[e]														
Tunnel kiln														
Gas fired	0.012	0.023	Neg	Neg	0.03	0.06	0.0015	0.003	0.003	0.006	0.09	0.18	0.5	1.0
Oil fired	0.29	0.59	1.98S	3.95S	0.06	0.12	0.0035	0.007	0.013	0.025	0.525	1.05	0.5	1.0
Coal fired	0.34A	0.67A	3.65S	7.31S	0.71	1.43	0.005	0.01	0.003	0.006	0.73	1.45	0.5	1.0
Coal/gas fired	0.16A	0.31A	0.31S	0.62S	-	-	-	-	-	-	0.81	1.61	-	-
Sawdust fired	0.12	0.24	-	-	-	-	-	-	-	-	-	-	-	-
Periodic kiln														
Gas fired	0.033	0.065	Neg	Neg	0.075	0.15	0.005	0.01	0.01	0.02	0.25	0.50	0.5	1.0
Oil fired	0.44	0.88	2.93S	5.86S	0.095	0.19	0.005	0.01	0.02	0.04	0.81	1.62	0.5	1.0
Coal fired	9.42	18.84	6.06S	12.13S	1.19	2.39	0.01	0.02	0.005	0.01	1.18	2.35	0.5	1.0

[a] Expressed as units per unit weight of brick produced. One brick weighs about 2.95 kg (6.5 pounds). Dash = No data. A = % ash in coal. S = % sulfur in fuel. Neg = negligible.

[b] References 3, 6-10.

[c] Based on data from Section 8.7 on Ceramic Clay Manufacturing in this publication. Because of process variation some steps may be omitted. Storage losses apply only to that quantity of material stored.

[d] Reference 12.

[e] References 1, 5, 12-16.

TABLE 8.3-2. PARTICLE SIZE DISTRIBUTION AND EMISSION FACTORS FOR UNCONTROLLED SAWDUST FIRED BRICK KILNS[a]

EMISSION FACTOR RATING: E

Aerodynamic particle diameter (μm)	Cumulative weight % ≤ stated size	Emission factor[b] (kg/Mg)
2.5	36.5	0.044
6.0	63.0	0.076
10.0	82.5	0.099
	Total particulate emission factor	0.12[c]

[a] Reference 13.

[b] Expressed as cumulative weight of particulate ≤ corresponding particle size/unit weight of brick produced.

[c] Total mass emission factor from Table 8.3-1.

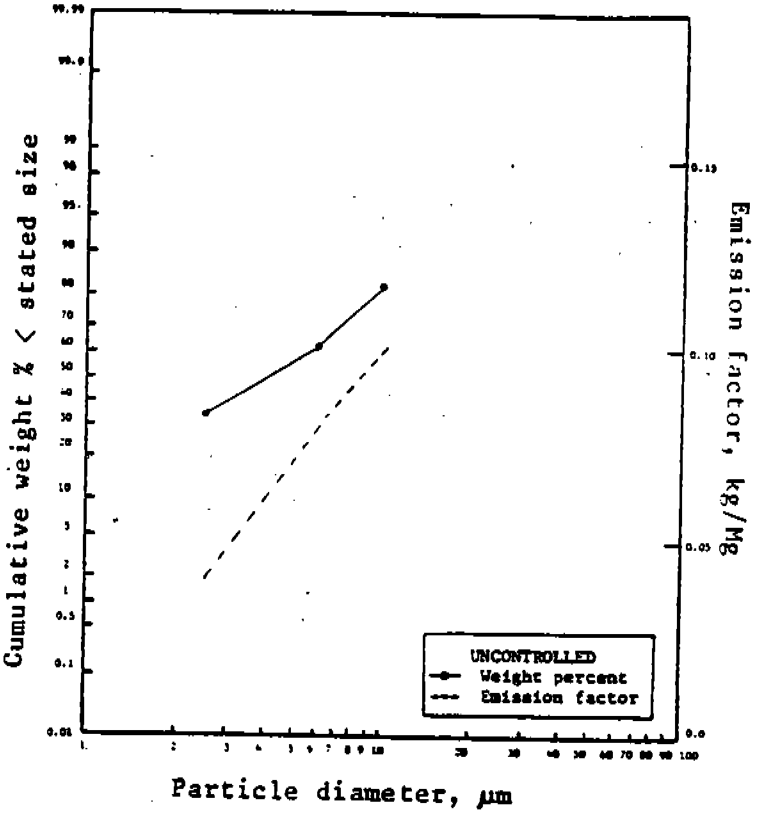

Figure 8.3-2. Cumulative weight percent of particles less than stated particle diameters for uncontrolled sawdust fired brick kilns.

TABLE 8.3-3. PARTICLE SIZE DISTRIBUTION AND EMISSION FACTORS FOR UNCONTROLLED COAL FIRED TUNNEL BRICK KILNS[a]

EMISSION FACTOR RATING: E

Aerodynamic particle diameter (μm)	Cumulative weight % $\leq$ stated size	Emission factor[b] (kg/Mg)
2.5	24.7	0.08A
6.0	50.4	0.17A
10.0	71.0	0.24A
	Total particulate emission factor	0.34A[c]

[a] References 12, 17.

[b] Expressed as cumulative weight of particulate $\leq$ corresponding particle size/unit weight of brick produced. A = % ash in coal. (Use 10% if ash content is not known).

[c] Total mass emission factor from Table 8.3-1.

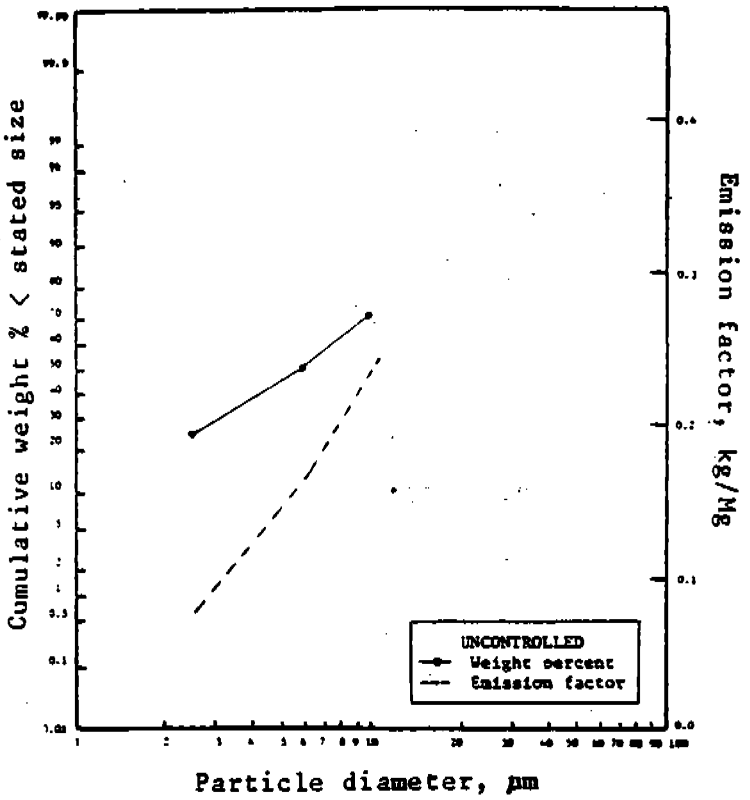

Figure 8.3-3. Cumulative weight percent of particles less than stated particle diameters for uncontrolled coal fired tunnel brick kilns

TABLE 8.3-4. PARTICLE SIZE DISTRIBUTION AND EMISSION FACTORS FOR UNCONTROLLED SCREENING AND GRINDING OF RAW MATERIALS FOR BRICKS AND RELATED CLAY PRODUCTS[A]

EMISSION FACTOR RATING: E

Aerodynamic particle diameter (μm)	Cumulative weight % ≤ stated size	Emission factor[b] (kg/Mg)
2.5	0.2	0.08
6.0	0.4	0.15
10.0	7.0	2.66
	Total particulate emission factor 38[c]	

[a] References 11, 18.

[b] Expressed as cumulative weight of particulate ≤ corresponding particle size/unit weight of raw material processed.

[c] Total mass emission factor from Table 8.3-1.

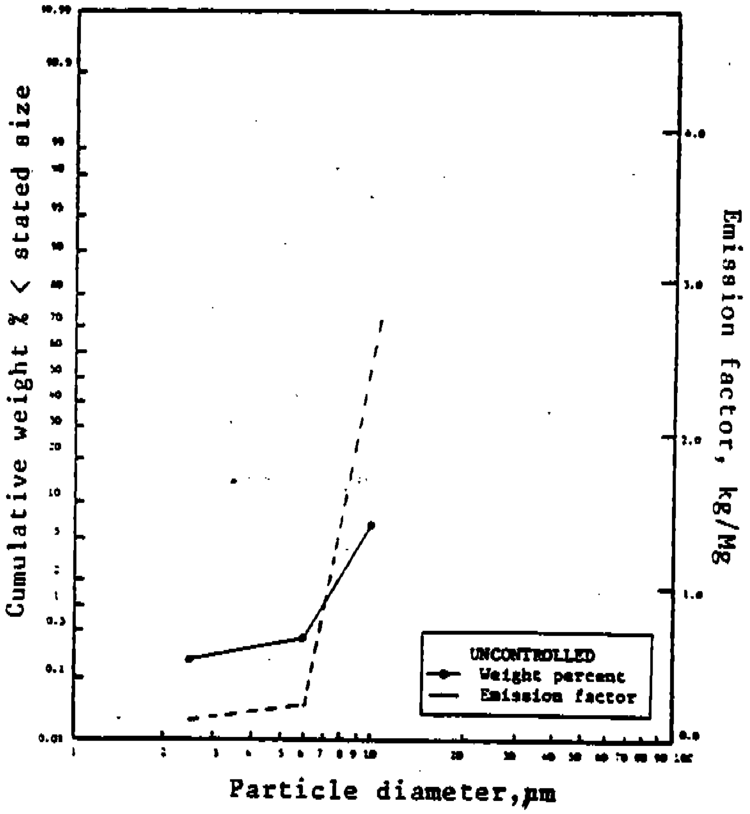

Figure 8.3-4. Cumulative weight percent of particles less than stated particle diameters for uncontrolled screening and grinding of raw materials for bricks and related clay products.

References for Section 8.3

1. Air Pollutant Emission Factors, APTD-0923, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1970.
2. "Technical Notes on Brick and Tile Construction", Pamphlet No. 9, Structural Clay Products Institute, Washington, DC, September 1961.
3. Unpublished control techniques for fluoride emissions, U. S. Department Of Health And Welfare, Washington, DC, May 1970.
4. M. H. Allen, "Report on Air Pollution, Air Quality Act of 1967 and Methods of Controlling the Emission of Particulate and Sulfur Oxide Air Pollutants", Structural Clay Products Institute, Washington, DC, September 1969.
5. F. H. Norton, Refractories, 3rd Ed, McGraw-Hill, New York, 1949.
6. K. T. Semrau, "Emissions of Fluorides from Industrial Processes: A Review", Journal Of The Air Pollution Control Association, 7(2):92-108, August 1957.
7. Kirk-Othmer Encyclopedia of Chemical Technology, Vol 5, 2nd Edition, John Wiley and Sons, New York, 1964.
8. K. F. Wentzel, "Fluoride Emissions in the Vicinity of Brickworks", Staub, 25(3):45-50, March 1965.
9. "Control of Metallurgical and Mineral Dusts and Fumes in Los Angeles County", Information Circular No. 7627, Bureau Of Mines, U. S. Department Of Interior, Washington, DC, April 1952.
10. Notes on oral communication between Resources Research, Inc., Reston, VA and New Jersey Air Pollution Control Agency, Trenton, NJ, July 20, 1969.
11. H. J. Taback, Fine Particle Emissions from Stationary and Miscellaneous Sources in the South Coast Air Basin, PB 293 923/AS, National Technical Information Service, Springfield, VA, February 1979.
12. Building Brick and Structural Clay Industry - Lee Brick and Tile Co., Sanford, NC, EMB 80-BRK-1, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1980.
13. Building Brick and Structural Clay Wood Fired Brick Kiln - Emission Test Report - Chatham Brick and Tile Company, Gulf, North Carolina, EMB-80-BRK-5, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1980.
14. R. N. Doster and D. J. Grove, Stationary Source Sampling Report: Lee Brick and Tile Co., Sanford, NC, Compliance Testing, Entropy Environmentalists, Inc., Research Triangle Park, NC, February 1978.
15. R. N. Doster and D. J. Grove, Stationary Source Sampling Report: Lee Brick and Tile Co., Sanford, NC, Compliance Testing, Entropy Environmentalists, Inc., Research Triangle Park, NC, June 1978.

16. F. J. Phoenix and D. J. Grove, Stationary Source Sampling Report - Chatham Brick and Tile Co., Sanford, NC, Particulate Emissions Compliance Testing, Entropy Environmentalists, Inc., Research Triangle Park, NC, July 1979.

17. Fine Particle Emissions Information System, Series Report No. 354, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.

8.6 PORTLAND CEMENT MANUFACTURING

8.6.1 Process Description[1-3]

Portland cement manufacture accounts for about 95 percent of the cement production in the United States. The more than 30 raw materials used to make cement may be divided into four basic components: line (calcareous), silica (siliceous), alumina (argillaceous), and iron (ferriferous). Approximately 1575 kilograms (3500 pounds) of dry raw materials are required to produce 1 metric ton (2200 pounds of cement). Between 45 and 65 percent of raw material weight is removed as carbon dioxide and water vapor. As shown in Figure 8.6-1, the raw materials undergo separate crushing after the quarrying operation, and, when needed for processing, are proportioned, ground and blended by either a dry or wet process. One barrel of cement weighs 171 kilograms (376 pounds).

In the dry process, moisture content of the raw material is reduced to less than 1 percent, either before or during grinding. The dried materials are then pulverized and fed directly into a rotary kiln. The kiln is a long steel cylinder with a refractory brick lining. It is slightly inclined, rotating about the longitudinal axis. The pulverized raw materials are fed into the upper end, traveling slowly to the lower end. Kilns are fired from the lower end, so that the rising hot gases pass through the raw material. Drying, decarbonating and calcining are accomplished as the material travels through the heated kiln and finally burns to incipient fusion and forms the clinker. The clinker is cooled, mixed with about 5 weight percent gypsum and ground to the desired fineness. The product, cement, is then stored for later packaging and shipment.

With the wet process, a slurry is made by adding water to the initial grinding operation. Proportioning may take place before or after the grinding step. After the materials are mixed, excess water is removed and final adjustments are made to obtain a desired composition. This final homogeneous mixture is fed to the kilns as a slurry of 30 to 40 percent moisture or as a wet filtrate of about 20 percent moisture. The burning, cooling, addition of gypsum, and storage are then carried out, as in the dry process.

The trend in the Portland cement industry is toward the use of the dry process of clinker production. Eighty percent of the kilns built since 1971 use the dry process, compared to 46 percent of earlier kilns. Dry process kilns that have become subject to new source performance standards (NSPS) since 1979 commonly are either preheater or preheater/precalciner systems. Both systems allow the sensible heat in kiln exhast gases to heat, and partially to calcine, the raw feed before it enters the kiln.

Addition of a preheater to a dry process kiln permits use of a kiln one half to two thirds shorter than those without a preheater, because heat transfer to the dry feed is more efficient in a preheater than in the preheating zone of the kiln.[4] Also, because of the increased heat transfer efficiency, a preheater kiln system requires less energy than either a wet kiln or a dry kiln without a preheater to achieve the same amount of calcination. Wet raw feed (of 20 to 40 percent moisture) requires a longer residence time for preheating, which is best provided in the kiln itself. Therefore, wet process plants do not use

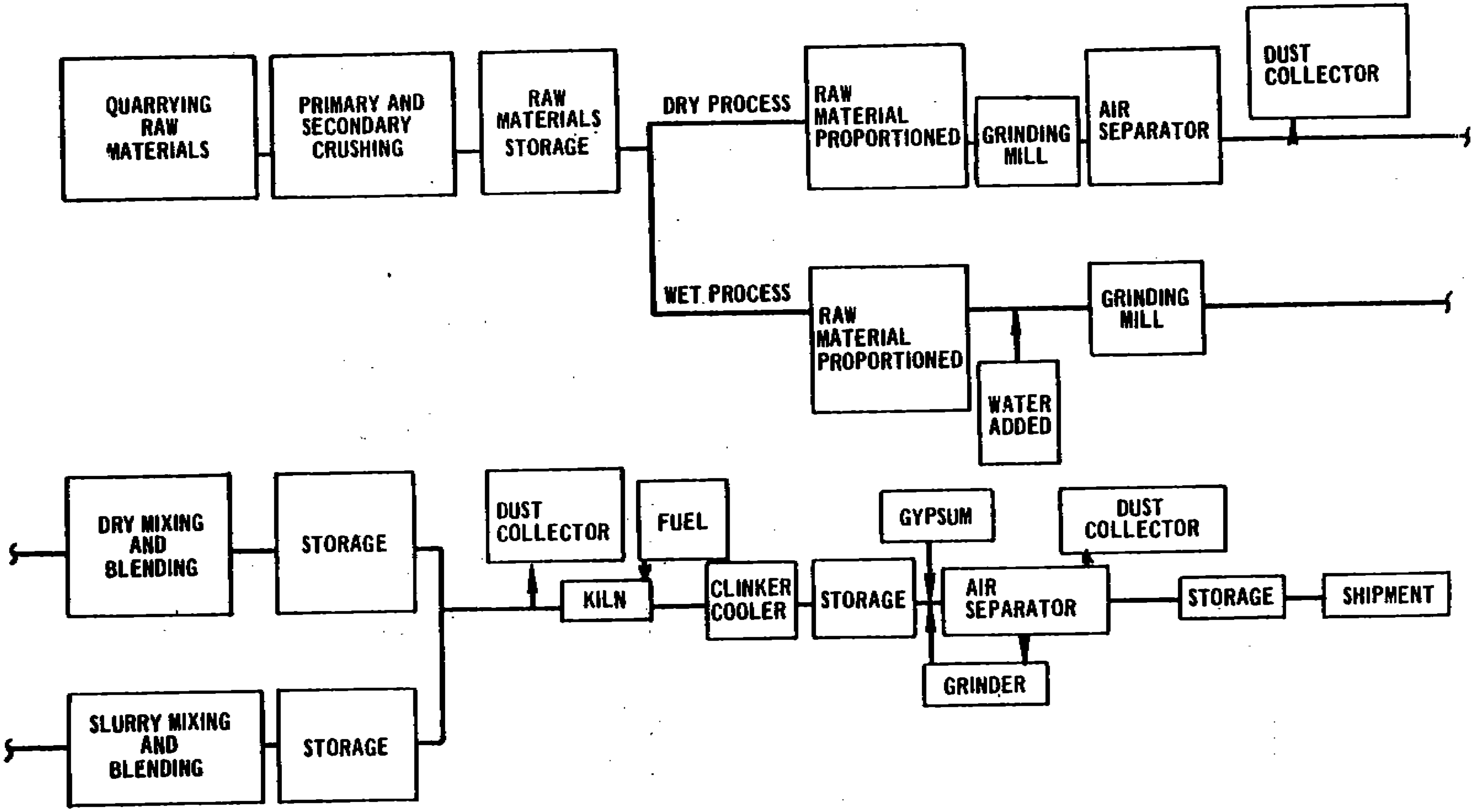

Figure 8.6-1. Basic flow diagram of portland cement manufacturing process.

preheater systems. A dry process kiln with a preheater system can use 50 percent less fuel than a wet process kiln.

8.6.2 Emissions And Controls[1-2,5]

Particulate matter is the primary emission in the manufacture of Portland cement. Emissions also include the normal combustion products of the fuel used for heat in the kiln and in drying operations, including oxides of nitrogen and small amounts of oxides of sulfur.

Sources of dust at cement plants are 1) quarrying and crushing, 2) raw material storage, 3) grinding and blending (dry process only), 4) clinker production and cooling, 5) finish grinding, and 6) packaging. The largest single point of emissions is the kiln, which may be considered to have three units, the feed system, the fuel firing system, and the clinker cooling and handling system. The most desirable method of disposing of the dust collected by an emissions control system is injection into the kiln burning zone for inclusion in the clinker. If the alkali content of the raw materials is too high, however, some of the dust is discarded or treated before its return to the kiln. The maximum alkali content of dust that can be recycled is 0.6 percent (calculated as sodium oxide). Additional sources of dust emissions are quarrying, raw material and clinker storage piles, conveyors, storage silos, loading/unloading facilities, and paved/unpaved roads.

The complications of kiln burning and the large volumes of material handled have led to the use of many control systems for dust collection. The cement industry generally uses mechanical collectors, electric precipitators, fabric filter (baghouse) collectors, or combinations of these to control emissions.

To avoid excessive alkali and sulfur buildup in the raw feed, some systems have an alkali bypass exhaust gas system added between the kiln and the preheater. Some of the kiln exhaust gases are ducted to the alkali bypass before the preheater, thus reducing the alkali fraction passing through the feed. Particulate emissions from the bypass are collected by a separate control device.

Tables 8.6-1 through 8.6-4 give emission factors for cement manufacturing, including factors based on particle size. Size distributions for particulate emissions from controlled and uncontrolled kilns and clinker coolers are also shown in Figures 8.6-2 and 8.6-3.

Sulfur dioxide (SO_2) may come from sulfur compounds in the ores and in the fuel combusted. The sulfur content of both will vary from plant to plant and from region to region. Information on the efficacy of particulate control devices on SO_2 emissions from cement kilns is inconclusive. This is because of variability of factors such as feed sulfur content, temperature, moisture, and feed chemical composition. Control extent will vary, of course, according to the alkali and sulfur content of the raw materials and fuel.[6]

Nitrogen oxides (NO_x) are also formed during fuel combustion in rotary cement kilns. The NO_x emissions result from the oxidation of nitrogen in the fuel (fuel NO_x) as well as in incoming combustion air (thermal NO_x). The quantity of NO_x formed depends on the type of fuel, its nitrogen content, combustion temperature, etc. Like SO_2, a certain portion of the NO_x reacts with the alkaline cement and thus is removed from the gas stream.

TABLE 8.6-1. UNCONTROLLED EMISSION FACTORS FOR CEMENT MANUFACTURING[a]

EMISSION FACTOR RATING: E

Process	Particulate[b]		Sulfur dioxide[c]								Nitrogen oxides		Lead	
			Mineral source[d]		Gas combustion		Oil combustion		Coal combustion					
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Dry process kiln	128	256	5.4	10.8	Neg	Neg	2.2S	4.4S	3.6S	7.2S	1.4	2.8	0.06	0.12
Wet process kiln	120	240	5.4	10.8	Neg	Neg	2.2S	4.4S	3.6S	7.2S	1.4	2.8	0.05	0.10
Clinker cooler[e]	4.6	9.2	-	-	-	-	-	-	-	-	-	-	-	-
Dryers, grinders, etc.[f]														
Wet process	16.0	32.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.01	0.02
Dry process	48.0	96.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.02	0.04

[a] References 1-2. Expressed in terms of units of clinker produced, assuming 5% gypsum in finished cement. Includes fuel combustion emissions, which should not be calculated separately. Neg = negligible. S = % sulfur in fuel. Dash = no data. NA = not applicable.

[b] Emission Factor Rating: B

[c] Factors account for reactions with alkaline dust, with no controls. One test series for gas and oil fired wet process kilns, with limited data, suggests that 21-45% of SO_2 can be removed by reactions with the alkaline filter cake, if baghouses are used.

[d] From sulfur in raw materials, which varies with their sources. Factors account for some residual sulfur, because of its alkalinity and affinity for SO_2.

[e] Reference 8. Emission Factor Rating: D.

[f] Expressed in terms of units of cement produced.

TABLE 8.6-2. CONTROLLED PARTICULATE EMISSION FACTORS FOR CEMENT MANUFACTURING[a]

Type of source	Control technology	Particulate kg/Mg clinker	Particulate lb/ton clinker	Emission Factor Rating
Wet process kiln	Baghouse	0.57	1.1	C
	ESP	0.39	0.78	C
Dry process kiln	Multiclone	130[b]	260[b]	D
	Multicyclone + ESP	0.34	0.68	C
	Baghouse	0.16	0.32	B
Clinker cooler	Gravel bed filter	0.16	0.32	C
	ESP	0.048	0.096	D
	Baghouse	0.010	0.020	C
Primary limestone crusher[c]	Baghouse	0.00051	0.0010	D
Primary limestone screen[c]	Baghouse	0.00011	0.00022	D
Secondary limestone screen and crusher[c]	Baghouse	0.00016	0.00032	D
Conveyor transfer[c]	Baghouse	0.000020	0.000040	D
Raw mill system[c,d]	Baghouse	0.034	0.068	D
Finish mill system[e]	Baghouse	0.017	0.034	C

[a] Reference 8. Expressed as kg particulate/Mg (lb particulate/ton) of clinker produced, except as noted. ESP = electrostatic precipitator.

[b] Based on a single test of a dry process kiln fired with a combination of coke and natural gas. Not generally applicable to a broad cross section of the cement industry.

[c] Expressed as mass of pollutant/mass of raw material processed.

[d] Includes mill, air separator and weigh feeder.

[e] Includes mill, air separator(s) and one or more material transfer operations. Expressed in terms of units of cement produced.

TABLE 8.6-3. SIZE SPECIFIC PARTICULATE EMISSION FACTORS FOR CEMENT KILNS[a]

EMISSION FACTOR RATING: D

Particle size (um)	Cumulative mass % < stated size[b]						Cumulative emission factor < stated size[c]													
	Uncontrolled		Dry process kiln with multiclone[d]	Wet process kiln with ESP	Baghouse		Uncontrolled				Dry process with multiclone[d]		Wet process with ESP		Baghouse					
	Wet process kiln	Dry process kiln			Wet process kiln	Dry process kiln	Wet Process		Dry Process						Wet process		Dry process			
							kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton		
2.5	7.0	18	3.8	64	NA	45	8.4	17	23	46	5.0	10	0.25	0.50	NA	NA	0.073	0.15		
5.0	20	NA	14	83	NA	77	24	48	-	-	19	38	0.32	0.64	NA	NA	0.13	0.26		
10.0	24	42	24	85	NA	84	29	58	54	108	32	64	0.33	0.66	NA	NA	0.14	0.28		
15.0	35	44	31	91	NA	89	43	86	57	114	41	82	0.36	0.72	NA	NA	0.15	0.30		
20.0	57	NA	38	98	NA	100	68	136	-	-	49	98	0.39	0.78	NA	NA	0.16	0.32		
Total mass emission factor							120[e]	240[e]	128[e]	256[e]	130[f]	260[f]	0.39[f]	0.78[f]	0.57[f]	1.1[f]	0.16[f]	0.32[f]		

[a] Reference 8. ESP = electrostatic precipitator. NA = not available. Dash = no data.

[b] Aerodynamic diameter. Percentages rounded to two significant figures.

[c] Expressed as unit weight of particulate/unit weight of clinker produced, assuming 5% gypsum in finished cement. Rounded to two significant figures.

[d] Based on a single test, and should be used with caution.

[e] From Table 8.6-1.

[f] From Table 8.6-2.

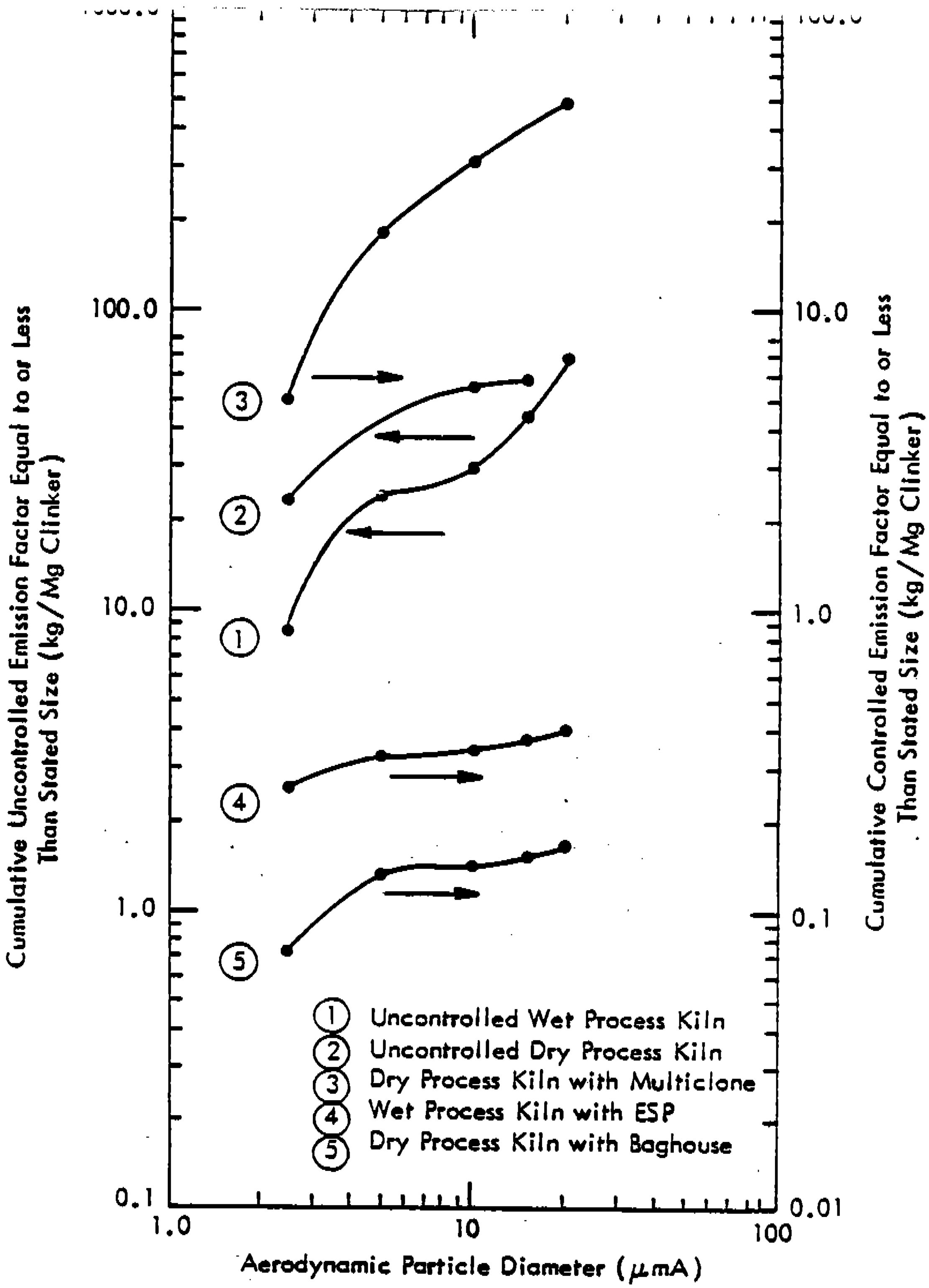

Figure 8.6-2. Size specific emission factors for cement kilns.

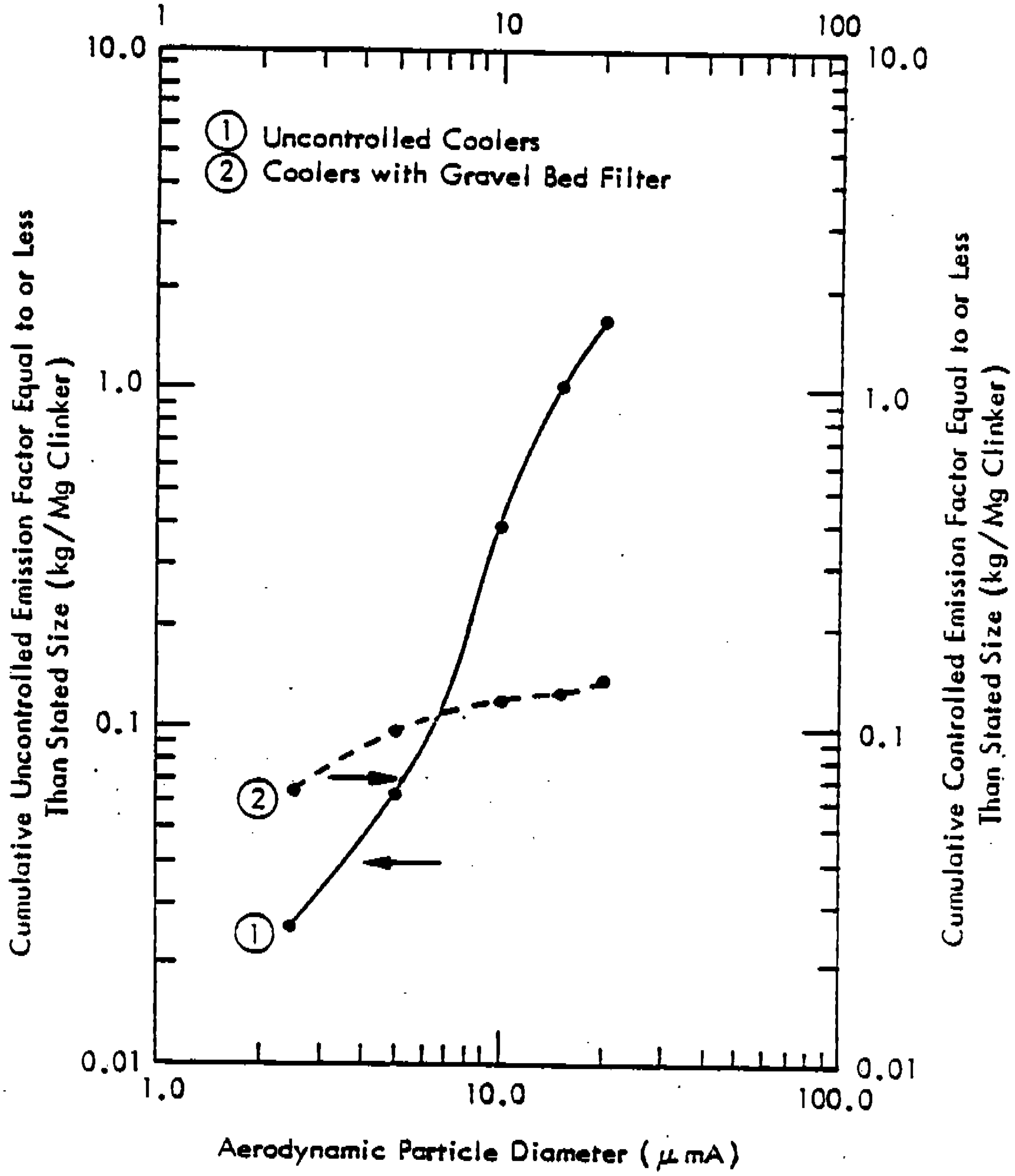

Figure 8.6-3. Size specific emission factors for clinker coolers.

TABLE 8.6-4. SIZE SPECIFIC EMISSION FACTORS FOR CLINKER COOLERS[a]

EMISSION FACTOR RATING: E

Particle size[b] (um)	Cumulative mass % < stated size[c]		Cumulative emission factor < stated size[d]			
	Uncontrolled	Gravel bed filter	Uncontrolled		Gravel bed filter	
			kg/Mg	lb/ton	kg/Mg	lb/ton
2.5	0.54	40	0.025	0.050	0.064	0.13
5.0	1.5	64	0.067	0.13	0.10	0.20
10.0	8.6	76	0.40	0.80	0.12	0.24
15.0	21	84	0.99	2.0	0.13	0.26
20.0	34	89	1.6	3.2	0.14	0.28
Total mass emission factor			4.6[e]	9.2[e]	0.16[f]	0.32[f]

[a] Reference 8.
[b] Aerodynamic diameter
[c] Rounded to two significant figures.
[d] Unit weight of pollutant/unit weight of clinker produced. Rounded to two significant figures.
[e] From Table 8.6-1.
[f] From Table 8.6-2.

References for Section 8.6

1. T. E. Kreichelt, *et al.*, *Atmospheric Emissions from the Manufacture of Portland Cement*, 999-AP-17, U. S. Environmental Protection Agency, Cincinnati, OH, 1967.

2. Background Information For Proposed New Source Performance Standards: Portland Cement Plants, APTD-0711, U. S. Environmental Protection Agency, Research Triangle Park, NC, August 1971.

3. *A Study of the Cement Industry in the State of Missouri*, Resources Research, Inc., Reston, VA, December 1967.

4. *Portland Cement Plants - Background Information for Proposed Revisions to Standards*, EPA-450/3-85-003a, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1985.

5. *Standards of Performance for New Stationary Sources*, 36 FR 28476, December 23, 1971.

6. *Particulate Pollutant System Study*, EPA Contract No. CPA-22-69-104, Midwest Research Institute, Kansas City, MO, May 1971.

7. Restriction of Emissions from Portland Cement Works, VDI Richtlinien, Duesseldorf, West Germany, February 1967.

8. J. S. Kinsey, Lime and Cement Industry - Source Category Report, Vol. II, EPA Contract No. 68-02-3891, Midwest Research Institute, Kansas City, MO, August 14, 1986.

8.10 CONCRETE BATCHING

8.10.1 Process Description[1-4]

Concrete is composed essentially of water, cement, sand (fine aggregate) and coarse aggregate. Coarse aggregate may consist of gravel, crushed stone or iron blast furnace slag. Some specialty aggregate products could be either heavyweight aggregate (of barite, magnetite, limonite, ilmenite, iron or steel) or lightweight aggregate (with sintered clay, shale, slate, diatomaceous shale, perlite, vermiculite, slag, pumice, cinders, or sintered fly ash). Concrete batching plants store, convey, measure and discharge these constituents into trucks for transport to a job site. In some cases, concrete is prepared at a building construction site or for the manufacture of concrete products such as pipes and prefabricated construction parts. Figure 8.10-1 is a generalized process diagram for concrete batching.

The raw materials can be delivered to a plant by rail, truck or barge. The cement is transferred to elevated storage silos pneumatically or by bucket elevator. The sand and coarse aggregate are transferred to elevated bins by front end loader, clam shell crane, belt conveyor, or bucket elevator. From these elevated bins, the constituents are fed by gravity or screw conveyor to weigh hoppers, which combine the proper amounts of each material.

Truck mixed (transit mixed) concrete involves approximately 75 percent of U. S. concrete batching plants. At these plants, sand, aggregate, cement and water are all gravity fed from the weigh hopper into the mixer trucks. The concrete is mixed on the way to the site where the concrete is to be poured. Central mix facilities (including shrink mixed) constitute the other one fourth of the industry. With these, concrete is mixed and then transferred to either an open bed dump truck or an agitator truck for transport to the job site. Shrink mixed concrete is concrete that is partially mixed at the central mix plant and then completely mixed in a truck mixer on the way to the job site. Dry batching, with concrete is mixed and hauled to the construction site in dry form, is seldom, if ever, used.

8.10-2 Emissions and Controls[5-7]

Emission factors for concrete batching are given in Table 8.10-1, with potential air pollutant emission points shown. Particulate matter, consisting primarily of cement dust but including some aggregate and sand dust emissions, is the only pollutant of concern. All but one of the emission points are fugitive in nature. The only point source is the transfer of cement to the silo, and this is usually vented to a fabric filter or "sock". Fugitive sources include the transfer of sand and aggregate, truck loading, mixer loading, vehicle traffic, and wind erosion from sand and aggregate storage piles. The amount of fugitive emissions generated during the transfer of sand and aggregate depends primarily on the surface moisture content of these materials. The extent of fugitive emission control varies widely from plant to plant.

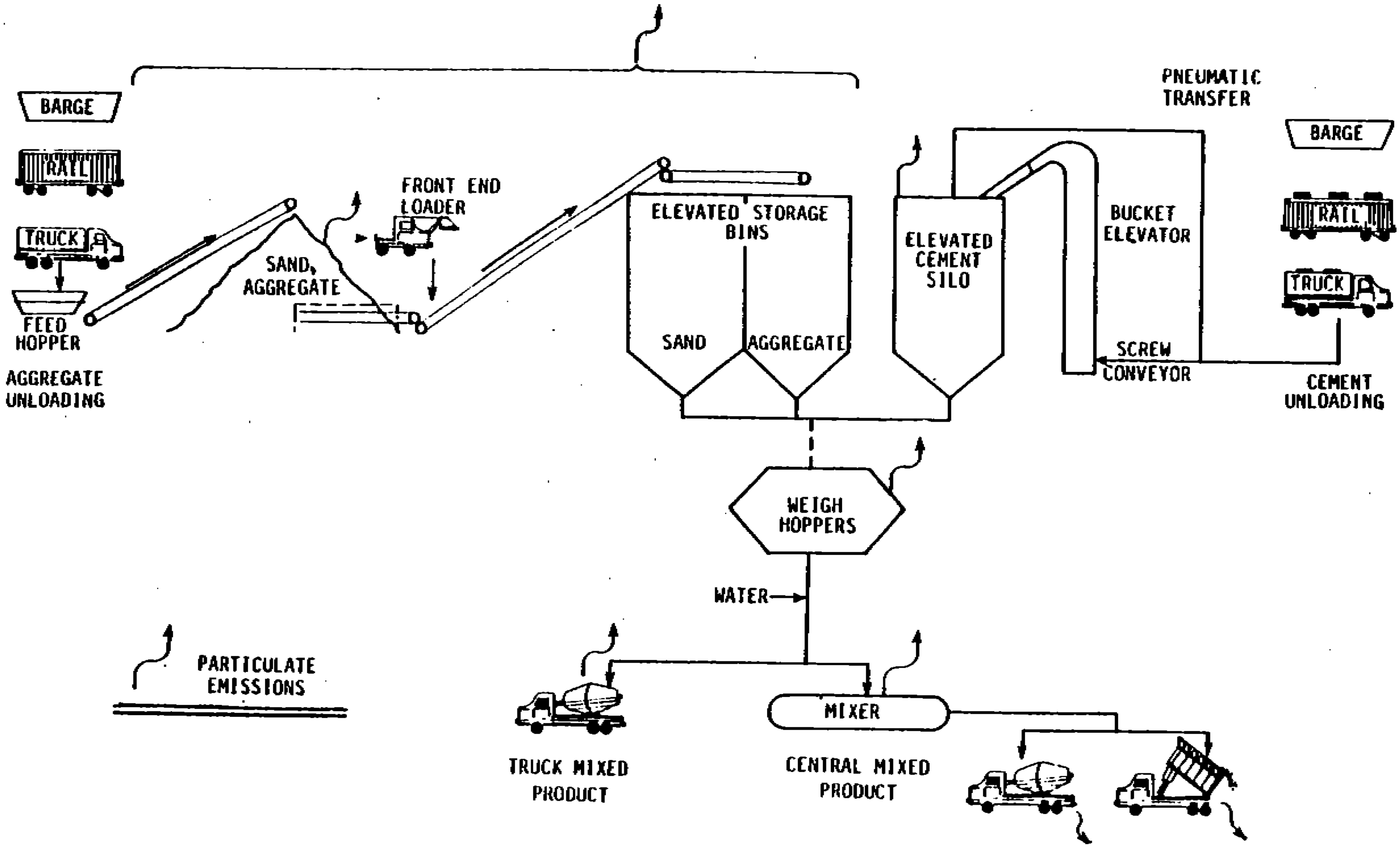

Figure 8.1-1. Typical concrete batching process.

TABLE 8.10-1. UNCONTROLLED PARTICULATE EMISSION FACTORS FOR CONCRETE BATCHING

Source	kg/Mg of material	lb/ton of material	lb/yd^3 of concrete[a]	Emission Factor Rating
Sand and aggregate transfer to elevated bin[b]	0.014	0.029	0.05	E
Cement unloading to elevated storage silo				
Pneumatic[c]	0.13	0.27	0.07	D
Bucket elevator[d]	0.12	0.24	0.06	E
Weigh hopper loading[e]	0.01	0.02	0.04	E
Truck loading (truck mix)[e]	0.01	0.02	0.04	E
Mixer loading (central mix)[e]	0.02	0.04	0.07	E
Vehicle traffic (unpaved road)[f]	4.5 kg/VKT	16 lb/VMT	0.28[g]	C
Wind erosion from sand and aggregate storage piles[h]	3.9 kg/ hectare/day	3.5 lb/ acre/day	0.1[i]	D
Total process emissions (truck mix)[j]	0.05	0.10	0.20	E

[a] Based on a typical yd^3 weighing 1,818 kg (4,000 lb) and containing 227 kg (500 lb) cement, 564 kg (1,240 lb) sand, 864 kg (1,900 lb) coarse aggregate and 164 kg (360 lb) water.

[b] Reference 6.

[c] For uncontrolled emissions measured before filter. Based on two tests on pneumatic conveying controlled by a fabric filter.

[d] Reference 7. From test of mechanical unloading to hopper and subsequent transport of cement by enclosed bucket elevator to elevated bins with fabric socks over bin vent.

[e] Reference 5. Engineering judgement, based on observations and emission tests of similar controlled sources.

[f] From Section 11.2.1, with $k = 0.8$, $s = 12$, $S = 20$, $W = 20$, $w = 14$, and $p = 100$. VKT = vehicle kilometers traveled. VMT = vehicle miles traveled.

[g] Based on facility producing 23,100 m^3/yr (30,000 yd^3/yr), with average truck load of 6.2m^3 (8 yd^3) and plant road length of 161 meters (1/10 mile).

[h] From Section 8.19.1, for emissions <30 um for inactive storage piles.

[i] Assumes 1,011 m^2 (1/4 acre) of sand and aggregate storage at plant with production of 23,100 m^3/yr (30,000 yd^3/yr).

[j] Based on pneumatic conveying of cement at a truck mix facility. Does not include vehicle traffic or wind erosion from storage piles.

Types of controls used may include water sprays, enclosures, hoods, curtains, shrouds, movable and telescoping chutes, and the like. A major source of potential emissions, the movement of heavy trucks over unpaved or dusty surfaces in and around the plant, can be controlled by good maintenance and wetting of the road surface.

Predictive equations which allow for emission factor adjustment based on plant specific conditions are given in Chapter 11. Whenever plant specific data are available, they should be used in lieu of the fugitive emission factors presented in Table 8.10-1.

References for Section 8.10

1. Air Pollutant Emission Factors, APTD-0923, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1970.

2. Air Pollution Engineering Manual, 2nd Edition, AP-40, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1974. Out of Print.

3. Telephone and written communication between Edwin A. Pfetzing, Pedco Environmental, Inc., Cincinnati, OH, and Richard Morris and Richard Meininger, National Ready Mix Concrete Association, Silver Spring, MD, May 1984.

4. Development Document for Effluent Limitations Guidelines and Standards of Performance, The Concrete Products Industries, Draft, U. S. Environmental Protection Agency, Washington, DC, August 1975.

5. Technical Guidance for Control of Industrial Process Fugitive Particulate Emissions, EPA-450/3-77-010, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1977.

6. Fugitive Dust Assessment at Rock and Sand Facilities in the South Coast Air Basin, Southern California Rock Products Association and Southern California Ready Mix Concrete Association, Santa Monica, CA, November 1979.

7. Telephone communication between T. R. Blackwood, Monsanto Research Corp., Dayton, OH, and John Zoller, Pedco Environmental, Inc., Cincinnati, OH, October 18, 1976.

8.13 GLASS MANUFACTURING

8.13.1 General[1-5]

Commercially produced glass can be classified as soda-lime, lead, fused silica, borosilicate, or 96 percent silica. Soda-lime glass, since it constitutes 77 percent of total glass production, is discussed here. Soda-lime glass consists of sand, limestone, soda ash, and cullet (broken glass). The manufacture of such glass is in four phases: (1) preparation of raw material, (2) melting in a furnace, (3) forming and (4) finishing. Figure 8.13-1 is a diagram for typical glass manufacturing.

The products of this industry are flat glass, container glass, and pressed and blown glass. The procedures for manufacturing glass are the same for all products except forming and finishing. Container glass and pressed and blown glass, 51 and 25 percent respectively of total soda-lime glass production, use pressing, blowing or pressing and blowing to form the desired product. Flat glass, which is the remainder, is formed by float, drawing or rolling processes.

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

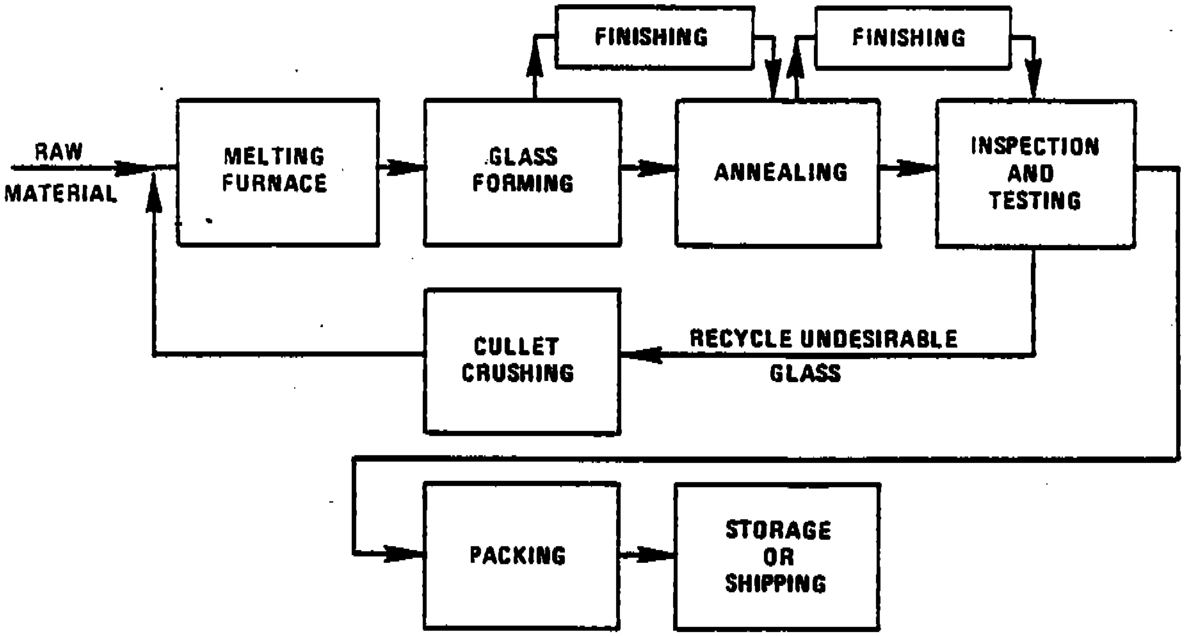

Figure 8.13-1. Typical glass manufacturing process.

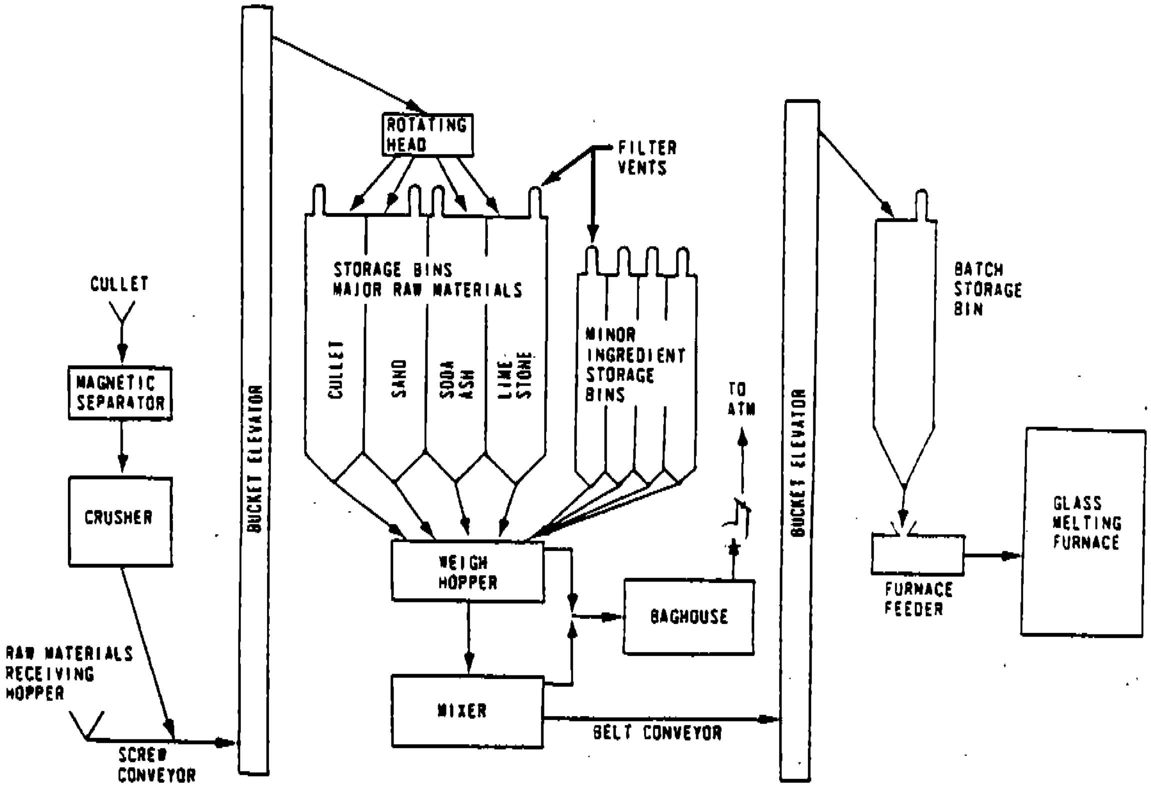

Figure 8.13-2. General diagram of a batch plant.

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

After refining, the molten glass leaves the furnace through forehearths (except in the float process, with molten glass moving directly to the tin bath) and goes to be shaped by pressing, blowing, pressing and blowing, drawing, rolling, or floating to produce the desired product. Pressing and blowing are performed mechanically, using blank molds and glass cut into sections (gobs) by a set of shears. In the drawing process, molten glass is drawn upward in a sheet through rollers, with thickness of the sheet determined by the speed of the draw and the configuration of the draw bar. The rolling process is similar to the drawing process except that the glass is drawn horizontally

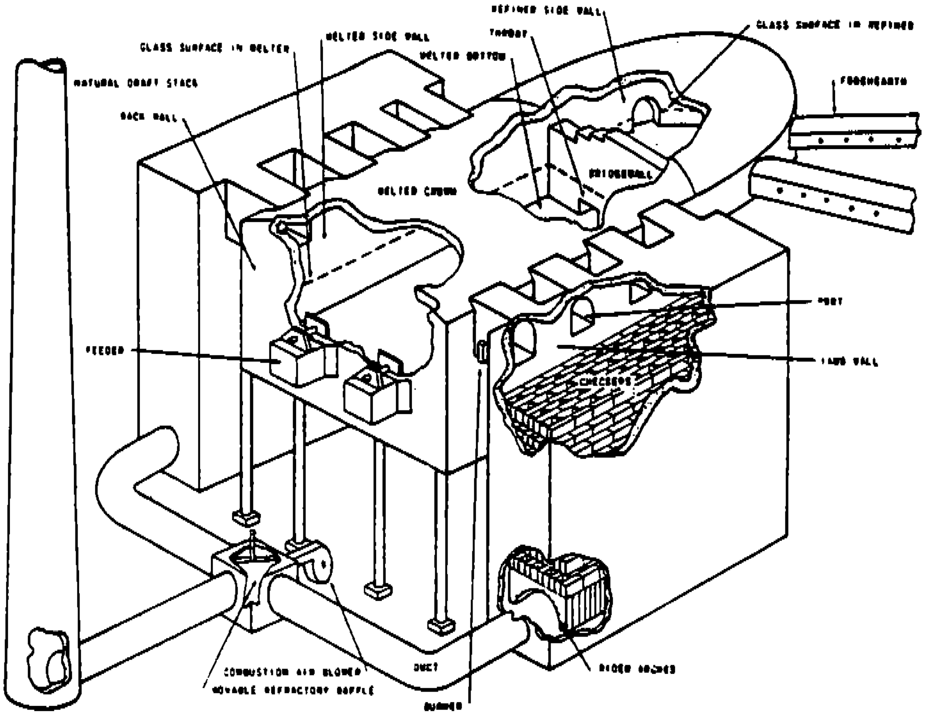

Figure 8.13-3. Side port continuous regenerative furnace.

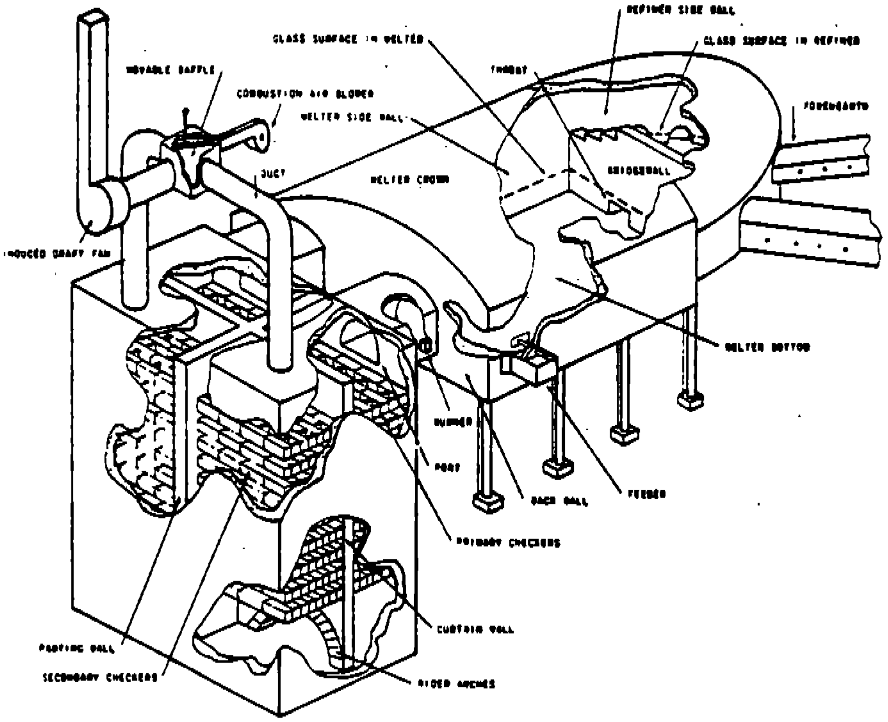

Figure 8.13-4. End port continuous regenerative furnace.

on plain or patterned rollers and, for plate glass, requires grinding and polishing. The float process is different, having a molten tin bath over which the glass is drawn and formed into a finely finished surface requiring no grinding or polishing. The end product undergoes finishing (decorating or coating) and annealing (removing unwanted stress areas in the glass) as required, and is then inspected and prepared for shipment to market. Any damaged or undesirable glass is transferred back to the batch plant to be used as cullet.

8.13.2 Emissions and Controls[1-5]

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

The melting furnace contributes over 99 percent of the total emissions from a glass plant, both particulates and gaseous pollutants. Particulates result from volatilization of materials in the melt that combine with gases and form condensates. These either are collected in the checker work and gas passages or are emitted to the atmosphere. Serious problems arise when the checkers are not properly cleaned, in that slag can form, clog the passages and eventually deteriorate the condition and efficiency of the furnace. Nitrogen oxides form when nitrogen and oxygen react in the high temperatures of the furnace. Sulfur oxides result from the decomposition of the sulfates in the batch and sulfur in the fuel. Proper maintenance and firing of the furnace can control emissions and also add to the efficiency of the furnace and reduce operational costs. Low pressure wet centrifugal scrubbers have been used to control particulate and sulfur oxides, but their inefficiency (approximately 50 percent) indicates their inability to collect particulates of submicron size. High energy venturi scrubbers are approximately 95 percent effective in reducing particulate and sulfur oxide emissions. Their effect on nitrogen oxide emissions is unknown. Baghouses, with up to 99 percent particulate collection efficiency, have been used on small regenerative furnaces, but fabric corrosion requires careful temperature control. Electrostatic precipitators have an efficiency of up to 99 percent in the collection of particulates. Table 8.13-1 lists controlled and uncontrolled emission factors for glass manufacturing. Table 8.13-2 presents particle size distributions and corresponding emission factors for uncontrolled and controlled glass melting furnaces.

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

TABLE 8.13-1. EMISSION FACTORS FOR GLASS MANUFACTURING[a]

EMISSION FACTOR RATING: B

Process	Particulate kg/Mg	Particulate lb/ton	Sulfur oxides kg/Mg	Sulfur oxides lb/ton	Nitrogen oxides kg/Mg	Nitrogen oxides lb/ton	VOC kg/Mg	VOC lb/ton	Carbon monoxide kg/Mg	Carbon monoxide lb/ton	Lead kg/Mg	Lead lb/ton
Raw materials handling[b] (all types of glass)	Neg	Neg	0	0	0	0	0	0	0	0	-	-
Melting furnace[c]												
Container												
Uncontrolled	0.7 (0.4-0.9)	1.4 (0.9-1.9)	1.7 (1.0-2.4)	3.4 (2.0-4.8)	3.1 (1.6-4.5)	6.2 (3.3-9.1)	0.1 (0-0.2)	0.2 (0-0.4)	0.1 (0-0.2)	0.2 (0-0.5)	-	-
W/low energy scrubber[d]	0.4	0.7	0.9	1.7	3.1	6.2	0.1	0.2	0.1	0.2	-	-
W/venturi scrubber[e]	<0.1	0.1	0.1	0.2	3.1	6.2	0.1	0.2	0.1	0.2	-	-
W/baghouse[f]	Neg	Neg	1.7	3.4	3.1	6.2	0.1	0.2	0.1	0.2	-	-
W/electrostatic precipitator[g]	Neg	Neg	1.7	3.4	3.1	6.2	0.1	0.2	0.1	0.2	-	-
Flat												
Uncontrolled	1.0 (0.4-1.6)	2.0 (0.8-3.2)	1.5 (1.1-1.9)	3.0 (2.2-3.8)	4.0 (2.8-5.2)	8.0 (5.6-10.4)	<0.1	<0.1	<0.1	<0.1	-	-
W/low-energy scrubber[d]	0.5	1.0	0.8	1.5	4.0	8.0	<0.1	<0.1	<0.1	<0.1	-	-
W/venturi scrubber[e]	Neg	Neg	0.1	0.2	4.0	8.0	<0.1	<0.1	<0.1	<0.1	-	-
W/baghouse[f]	Neg	Neg	1.5	3.0	4.0	8.0	<0.1	<0.1	<0.1	<0.1	-	-
W/electrostatic precipitator[g]	Neg	Neg	1.5	3.0	4.0	8.0	<0.1	<0.1	<0.1	<0.1	-	-
Pressed and blown												
Uncontrolled	8.7 (0.5-12.6)	17.4 (1.0-25.1)	2.8 (0.5-5.4)	5.6 (1.1-10.9)	4.3 (0.4-10.0)	8.5 (0.8-20.0)	0.2 (0.1-0.3)	0.3 (0.1-1.0)	0.1 (0.1-0.2)	0.2 (0.1-0.3)	-	-
W/low energy scrubber[d]	4.2	8.4	1.3	2.7	4.3	8.5	0.2	0.3	0.1	0.2	-	-
W/venturi scrubber[e]	0.5	0.9	0.1	0.3	4.3	8.5	0.2	0.3	0.1	0.2	-	-
W/baghouse[f]	0.1	0.2	2.8	5.6	4.3	8.5	0.2	0.3	0.1	0.2	-	-
W/electrostatic precipitator[g]	0.1	0.2	2.8	5.6	4.3	8.5	0.2	0.3	0.1	0.2	-	-
Forming and finishing												
Container[h,j]	Neg	Neg	Neg	Neg	Neg	Neg	4.4	8.7	Neg	Neg	-	-
Flat	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	Neg	-	-
Pressed and blown[h,j]	Neg	Neg	Neg	Neg	Neg	Neg	4.5	9.0	Neg	Neg	-	-
Lead glass manufacturing, all processes[k]	-	-	-	-	-	-	-	-	-	-	2.5	5

[a] References 2-3, 5. Dash = no available data. Neg = negligible. Ranges in parentheses, where available. Expressed as kg/Mg (lb/ton) of glass produced.

[b] Not separated into types of glass produced, since batch preparation is the same for all types. Particulate emissions are negligible because almost all plants utilize some form of control (i.e., baghouses, scrubbers, centrifugal collectors).

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

[d] Approximately 53% efficiency in reducing particulate and sulfur oxides emissions. Effect on nitrogen oxides is unknown.

[e] Approximately 95% efficiency in reducing particulate and sulfur oxide emissions. Effect on nitrogen oxides is unknown.

[f] Approximately 99% efficiency in reducing particulate emissions.

[g] Calculated using data for furnaces melting soda lime and lead glasses. No data available for borosilicate or opal glasses.

[h] Organic emissions are from decorating process. Can be controlled by incineration, absorption or condensation, but efficiencies are not known.

[j] For container and pressed and blown glass, tin chloride, hydrated tin chloride and hydrogen chloride are also emitted during surface treatment process at a rate of <0.1 kg/Mg (0.2 lb/ton) each.

[k] References 6-7. Particulate containing 23% lead.

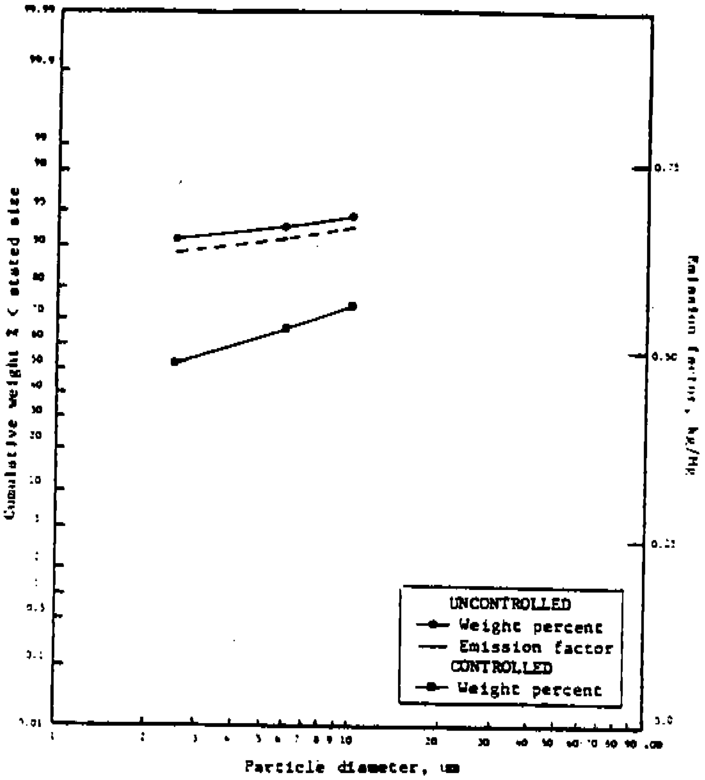

Figure 8.13-5. Particle size distributions and emission factors for glass melting furnace exhaust.

TABLE 8.13-2. PARTICLE SIZE DISTRIBUTIONS AND EMISSION FACTORS FOR UNCONTROLLED AND CONTROLLED MELTING FURNACES IN GLASS MANUFACTURING[a]

Emission Factor Rating: E

Aerodynamic particle diameter, um	Particle size distribution[b]		Size specific emission factor, kg/Mg[c]
	Uncontrolled	ESP Controlled[d]	Uncontrolled
2.5	91	53	0.64
6.0	93	66	0.65
10	95	75	0.66

[a] References 8-11.

[b] Cumulative weight % of particles < corresponding particle size.

[c] Based on mass particulate emission factor of 0.7 kg/Mg glass produced, from Table 8.13-1. Size specific emission factor = mass particulate emission factor x particle size distribution, %/100. After ESP control, size specific emission factors are negligible.

[d] Reference 8-9. Based on a single test.

References for Section 8.13

1. J. A. Danielson, (ed.), Air Pollution Engineering Manual, 2nd Ed., AP-40, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1973. Out of Print.

2. Richard B. Reznik, Source Assessment: Flat Glass Manufacturing Plants, EPA-600/20-76-032b, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1976.

3. J. R. Schoor, et al., Source Assessment: Glass Container Manufacturing Plants, EPA-600/2-76-269, U. S. Environmental Protection Agency, Washington, DC, October 1976.

4. A. B. Tripler, Jr. and G. R. Smithson, Jr., A Review of Air Pollution Problems and Control in the Ceramic Industries, Battelle Memorial Institute, Columbus, OH, presented at the 72nd Annual Meeting of the American Ceramic Society, May 1970.

5. J. R. Schorr, et al., Source Assessment: Pressed and Blown Glass Manufacturing Plants, EPA-600/77-005, U. S. Environmental Protection Agency, Washington, DC, January 1977.

6. Control Techniques for Lead Air Emissions, EPA-450/2-77-012, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1977.

7. Confidential test data, Pedco-Environmental Specialists, Inc., Cincinnati, OH.

8. H. J. Taback, Fine Particle Emissions from Stationary and Miscellaneous Sources in the South Coast Air Basin, PB-293-923, National Technical Information Service, Springfield, VA, February 1979.

9. Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System (FPEIS), Series Report No. 219, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.

10. Environmental Assessment Data Systems, op. cit., Series No. 223.

11. Environmental Assessment Data Systems, op. cit., Series No. 225.

8.15 LIME MANUFACTURING

8.15.1 General[1-4]

Lime is the high temperature product of the calcination of limestone. There are two kinds, high calcium lime (CaO) and dolomitic lime ($CaO \cdot MgO$). Lime is manufactured in various kinds of kilns by one of the following reactions:

$$CaCO_3 + \text{heat} \rightarrow CO_2 + CaO \text{ (high calcium lime)}$$
$$CaCO_3 \cdot MgCO_3 + \text{heat} \rightarrow CO_2 + CaO \cdot MgO \text{ (dolomitic lime)}$$

In some lime plants, the resulting lime is reacted (slaked) with water to form hydrated lime.

The basic processes in the production of lime are 1) quarrying raw limestone; 2) preparing limestone for the kilns by crushing and sizing; 3) calcining limestone; 4) processing the lime further by hydrating; and 5) miscellaneous transfer, storage and handling operations. A generalized material flow diagram for a lime manufacturing plant is given in Figure 8.15-1. Note that some operations shown may not be performed in all plants.

The heart of a lime plant is the kiln. The prevalent type of kiln is the rotary kiln, accounting for about 90 percent of all lime production in the United States. This kiln is a long, cylindrical, slightly inclined, refractory lined furnace, through which the limestone and hot combustion gases pass countercurrently. Coal, oil and natural gas may all be fired in rotary kilns. Product coolers and kiln feed preheaters of various types are commonly used to recover heat from the hot lime product and hot exhaust gases, respectively.

The next most common type of kiln in the United States is the vertical, or shaft, kiln. This kiln can be described as an upright heavy steel cylinder lined with refractory material. The limestone is charged at the top and is calcined as it descends slowly to discharge at the bottom of the kiln. A primary advantage of vertical kilns over rotary kilns is higher average fuel efficiency. The primary disadvantages of vertical kilns are their relatively low production rates and the fact that coal cannot be used without degrading the quality of the lime produced. There have been few recent vertical kiln installations in the United States because of high product quality requirements.

Other, much less common, kiln types include rotary hearth and fluidized bed kilns. Both kiln types can achieve high production rates, and neither can operate with coal. The "calcimatic" kiln, or rotary hearth kiln, is a circular shaped kiln with a slowly revolving donut shaped hearth. In fluidized bed kilns, finely divided limestone is brought into contact with hot combustion air in a turbulent zone, usually above a perforated grate. Because of the amount of lime carryover into the exhaust gases, dust collection equipment must be installed on fluidized bed kilns for process economy.

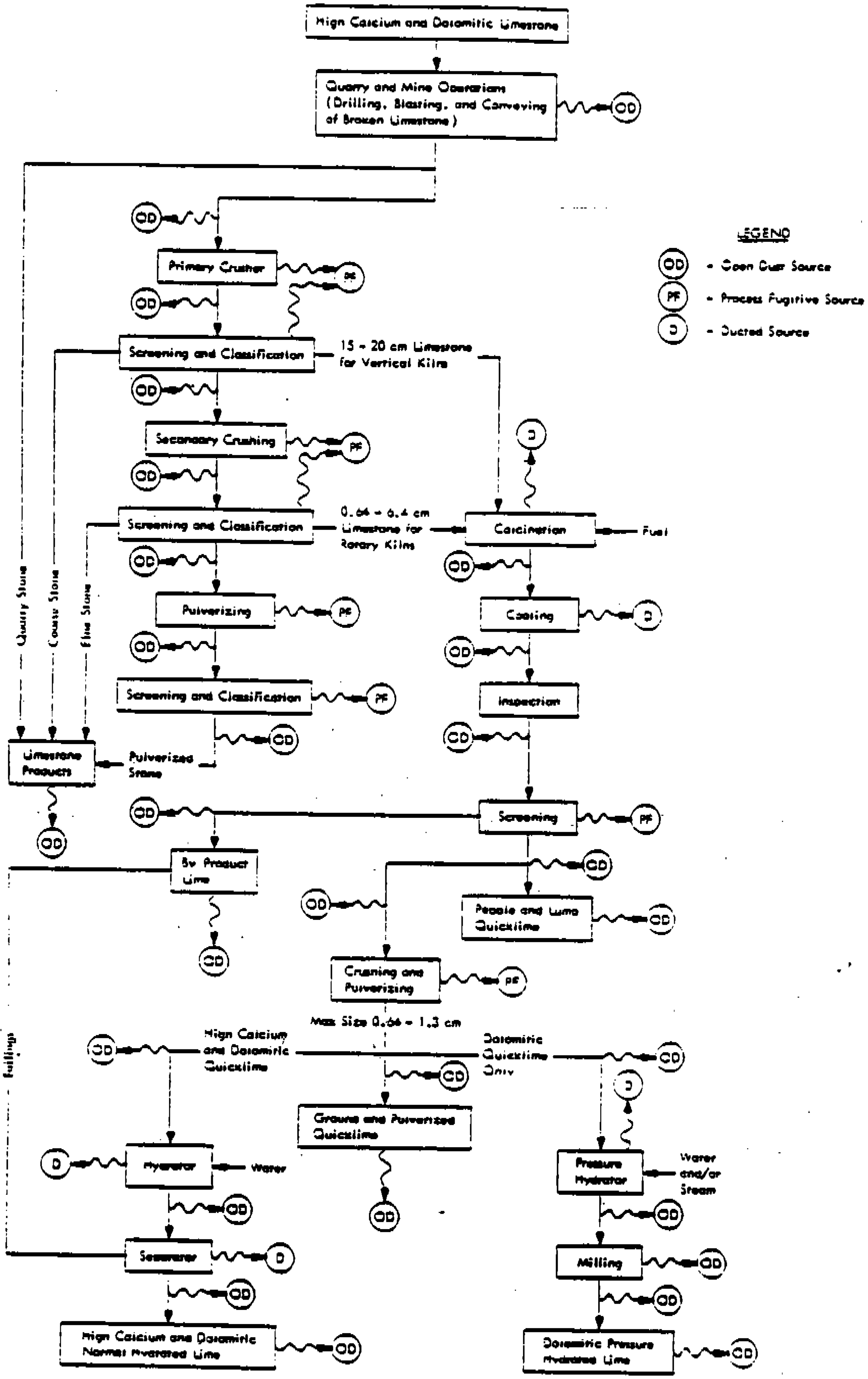

Figure 8.15-1. Simplified flow diagram for lime and limestone products.

About 10 percent of all lime produced is converted to hydrated (slaked) lime. There are two kinds of hydrators, atmospheric and pressure. Atmospheric hydrators, the more prevalent type, are used in continuous mode to produce high calcium and normal dolomitic hydrates. Pressure hydrators, on the other hand, produce only a completely hydrated dolomitic lime and operate only in batch mode. Generally, water sprays or wet scrubbers perform the hydrating process, to prevent product loss. Following hydration, the product may be milled and then conveyed to air separators for further drying and removal of coarse fractions.

In the United States, lime plays a major role in chemical and metallurgical operations. Two of the largest uses are as steel flux and in alkali production. Lesser uses include construction, refractory and agricultural applications.

8.15.2 Emissions And Controls[3-5]

Potential air pollutant emission points in lime manufacturing plants are shown in Figure 8.15-1. Except for gaseous pollutants emitted from kilns, particulate is the only pollutant of concern from most of the operations.

The largest ducted source of particulate is the kiln. Of the various kiln types, fluidized beds have the most uncontrolled particulate emissions, because of the very small feed size combined with high air flow through these kilns. Fluidized bed kilns are well controlled for maximum product recovery. The rotary kiln is second worst in uncontrolled particulate emissions, also because of the small feed size and relatively high air velocities and dust entrainment caused by the rotating chamber. The calcimatic (rotary hearth) kiln ranks third in dust production, primarily because of the larger feed size and the fact that, during calcination, the limestone remains stationary relative to the hearth. The vertical kiln has the lowest uncontrolled dust emissions, due to the large lump feed and the relatively low air velocities and slow movement of material through the kiln.

Some sort of particulate control is generally applied to most kilns. Rudimentary fallout chambers and cyclone separators are commonly used for control of the larger particles. Fabric and gravel bed filters, wet (commonly venturi) scrubbers, and electrostatic precipitators are used for secondary control.

Nitrogen oxides, carbon monoxide and sulfur oxides are all produced in kilns, although the last are the only gaseous pollutant emitted in significant quantities. Not all of the sulfur in the kiln fuel is emitted as sulfur oxides, since some fraction reacts with the materials in the kiln. Some sulfur oxide reduction is also effected by the various equipment used for secondary particulate control.

Product coolers are emission sources only when some of their exhaust gases are not recycled through the kiln for use as combustion air. The trend is away from the venting of product cooler exhaust, however, to maximize fuel use efficiencies. Cyclones, baghouses and wet scrubbers have been employed on coolers for particulate control.

Hydrator emissions are low, because water sprays or wet scrubbers are usually installed to prevent product loss in the exhaust gases. Emissions from pressure hydrators may be higher than from the more common atmospheric hydrators, because the exhaust gases are released intermittently, making control more difficult.

Other particulate sources in lime plants include primary and secondary crushers, mills, screens, mechanical and pneumatic transfer operations, storage piles, and roads. If quarrying is a part of the lime plant operation, particulate may also result from drilling and blasting. Emission factors for some of these operations are presented in Sections 8.20 and 11.2 of this document.

Controlled and uncontrolled emission factors and particle size data for lime manufacturing are given in Tables 8.15-1 through 8.15-3. The size distributions of particulate emissions from controlled and uncontrolled rotary kilns and uncontrolled product loading operations are shown in Figures 8.15-2 and 8.15-3.

TABLE 8.15-1. EMISSION FACTORS FOR LIME MANUFACTURING[a]

EMISSION FACTOR RATING: B

Source	Particulate[b]		Nitrogen oxides		Carbon monoxide		Sulfur dioxide	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Crushers, screens, conveyors, storage piles, unpaved roads, etc.	c	c	Neg	Neg	Neg	Neg	Neg	Neg
Rotary kilns[d]								
Uncontrolled[e]	180	350	1.4	2.8	1	2	f	f
Large diameter cyclone	81	160	1.4	2.8	1	2	f	f
Multiple cyclone	42	83	1.4	2.8	1	2	f	f
Electrostatic precipitator[g]	2.4	4.8	1.4	2.8	1	2	h	h
Venturi scrubber	2.4	4.8	1.4	2.8	1	2	h	h
Gravel bed filter[g]	0.53[i]	1.1[i]	1.4	2.8	1	2	h	h
Multiclone and venturi scrubber[g]	0.44	0.87	1.4	2.8	1	2	h	h
Baghouse	0.45[j]	0.89[j]	1.4	2.8	1	2	h	h
Cyclone and baghouse	0.055	0.11	1.4	2.8	1	2	h	h
Vertical kilns								
Uncontrolled	4	8	NA	NA	NA	NA	NA	NA
Calcimatic kilns[k]								
Uncontrolled	25	50	0.1	0.2	NA	NA	NA	NA
Multiple cyclone	3	6	0.1	0.2	NA	NA	NA	NA
Secondary dust collection[g]	NA	NA	0.1	0.2	NA	NA	NA	NA
Fluidized bed kilns	m	m	NA	NA	NA	NA	NA	NA
Product coolers								
Uncontrolled	20[n]	40[n]	Neg	Neg	Neg	Neg	Neg	Neg
Hydrators (atmospheric)[p]								
Wet scrubber	0.05	0.1	Neg	Neg	Neg	Neg	Neg	Neg
Crusher, screen, hammermill								
Baghouse	0.0005	0.001	Neg	Neg	Neg	Neg	Neg	Neg
Final screen								
Baghouse	0.0004	0.0008	Neg	Neg	Neg	Neg	Neg	Neg
Uncontrolled truck loading								
Limestone								
Open truck	0.75	1.5	Neg	Neg	Neg	Neg	Neg	Neg
Closed truck	0.38	0.76	Neg	Neg	Neg	Neg	Neg	Neg
Lime - closed truck	0.15[i]	0.30[i]	Neg	Neg	Neg	Neg	Neg	Neg

TABLE 8.15-1 (cont.).

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[a] References 4-7. Factors for kilns and coolers are per unit of lime produced. Divide by two to obtain factors per unit of limestone feed to the kiln. Factors for hydrators are per unit of hydrated lime produced. Multiply by 1.25 to obtain factors per unit of lime feed to the hydrator. Neg = negligible. NA = not available.

[b] Emission Factor Rating = D.

[c] Factors for these operations are presented in Sections 8.20 and 11.2 of this document.

[d] For coal fired rotary kilns only.

[e] No particulate control except for settling that may occur in stack breeching and chimney base.

[f] Sulfur dioxide may be estimated by a material balance using fuel sulfur content.

[g] Combination coal/gas fired rotary kilns only.

[h] When scrubbers are used, < 5% of the fuel sulfur will be emitted as SO_2 even with high sulfur coal. When other secondary collection devices are used, about 20% of the fuel sulfur will be emitted as SO_2 with high sulfur fuels, and < 10% with low sulfur fuels.

[i] Emission Factor Rating = E.

[j] Emission Factor Rating = C.

[k] Calcimatic kilns generally have stone preheaters. Factors are for emissions after the kiln exhaust passes through a preheater.

[l] Fabric filters and venturi scrubbers have been used on calcimatic kilns. No data are available on particulate emissions after secondary control.

[m] Fluidized bed kilns must have sophisticated dust collection equipment for process economics, hence particulate emissions will depend on efficiency of the control equipment installed.

[n] Some or all cooler exhaust typically is used in kiln as combustion air. Emissions will result only from that fraction not recycled to kiln.

[p] Typical particulate loading for atmospheric hydrators following water sprays or wet scrubbers. Limited data suggest particulate emissions from pressure hydrators may be approximately 1 kg/Mg (2 lb/ton) of hydrate produced, after wet collectors.

TABLE 8.15-2. SUMMARY OF SIZE SPECIFIC EMISSION FACTORS FOR ROTARY LIME KILNS[a]

EMISSION FACTOR RATING: D

Particle size (μmA)	Cumulative mass % ≤ stated particle size[b]				Cumulative particulate emission factor ≤ stated size[c]							
	Uncontrolled rotary kiln	Rotary kiln with multiclone[d]	Rotary kiln with ESP[e]	Rotary kiln with cyclone and baghouse[f]	Uncontrolled rotary kilns		Rotary kiln with multiclone[d]		Rotary kiln with ESP[e]		Rotary kiln with cyclone and baghouse[f]	
					kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
2.5	1.4	6.1	14	27	2.6	5.2	2.6	5.2	0.34	0.68	0.02	0.03
5.0	2.9	9.8	NA	NA	5.2	10	4.1	8.2	NA	NA	NA	NA
10.0	12	16	50	55	21	42	6.9	14	1.2	2.4	0.03	0.06
15.0	31	23	62	73	56	110	9.7	19	1.5	3.0	0.04	0.08
Total mass emission factor[g]					180	350	42	83	2.4	4.8	0.055	0.11

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[a] Reference 7. Coal fired rotary kilns. Numbers rounded to two significant figures. ESP = electrostatic precipitator. NA = not available.

[b] Aerodynamic diameter.

[c] Unit weight of particulate matter/unit weight of lime produced.

[d] Emission Factor Rating = E.

[e] For combination coal/natural gas fired rotary kilns.

[f] For rotary kiln with cyclone collector followed by baghouse.

[g] PM_{10} emission factor data is not available for baghouse, venturi scrubber, simple cyclone and other control technologies used for rotary lime kilns.

TABLE 8.15-3. UNCONTROLLED FUGITIVE PARTICULATE EMISSION FACTORS FOR PRODUCT LOADING[a]

Type of loading operation	Total particulate[b]		Inhalable particulate[c]		Fine particulate[d]		Emission factor rating
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	
Pulverized limestone into open bed trucks	0.75	1.5	0.51	1.0	0.13	0.26	D
Pulverized limestone into tank trucks	0.38	0.76	0.29	0.58	0.043	0.086	D
Glass lime into tank trucks	0.15	0.30	0.062	0.12	0.0080	0.016	E

[a] Reference 7. Factors are for mass of pollutant/mass of product loaded. Numbers rounded to two significant figures.
[b] Particles < ~ 300 µmA (aerodynamic diameter).
[c] Particles < 15 µmA (aerodynamic diameter).
[d] Particles < 2.5 µmA (aerodynamic diameter).

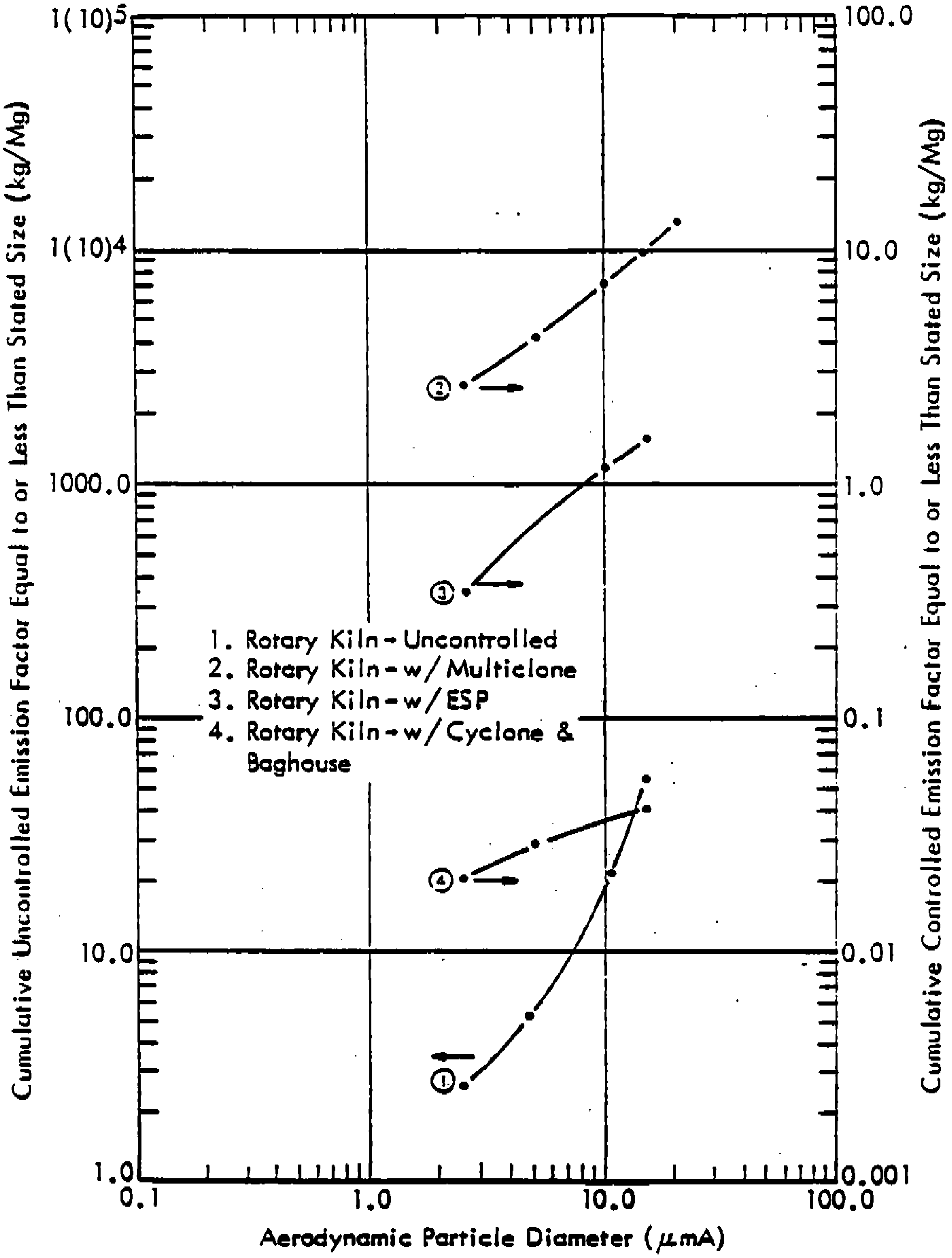

Figure 8.15-2. Size specific emission factors for lime kilns.

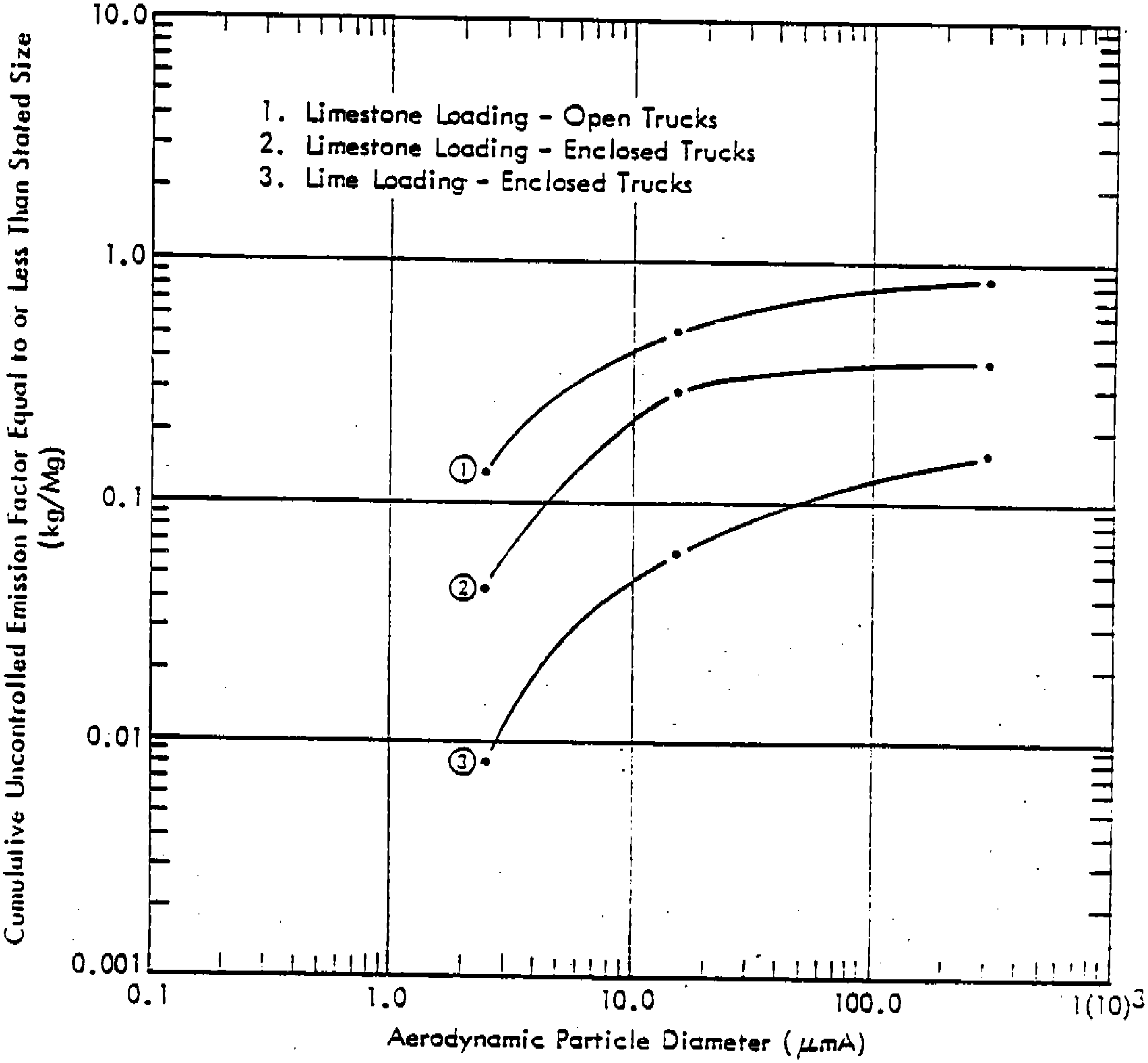

Figure 8.15-3. Size specific emission factors for product loading.

References for Section 8.15

1. C. J. Lewis and B. B. Crocker, "The Lime Industry's Problem Of Airborne Dust", Journal Of The Air Pollution Control Association, 19(1):31-39, January 1969.

2. Kirk-Othmer Encyclopedia Of Chemical Technology, 2d Edition, John Wiley And Sons, New York, 1967.

3. Screening Study For Emissions Characterization From Lime Manufacture, EPA Contract No. 68-02-0299, Vulcan-Cincinnati, Inc., Cincinnati, OH, August 1974.

4. Standards Support And Environmental Impact Statement, Volume I: Proposed Standards Of Performance For Lime Manufacturing Plants, EPA-450/2-77-007a, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1977.

5. Source test data on lime plants, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1976.

6. Air Pollutant Emission Factors, APTD-0923, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1970.

7. J. S. Kinsey, Lime And Cement Industry - Source Category Report, Volume I: Lime Industry, EPA-600/7-86-031, U. S. Environmental Protection Agency, Cincinnati, OH, September 1986.

TABLE 8.19.2-2. UNCONTROLLED PARTICULATE EMISSION FACTORS FOR OPEN DUST SOURCES AT CRUSHED STONE PLANTS

Operation	Material	Emissions by particle size range (aerodynamic diameter)^a			Emission Factor Rating
		TSP $\leq$ 30 um	PM^{10} $\leq$ 10 um	Units^b	
Wet quarry drilling	Unfractured stone^c	0.4 (0.0008)	0.04 (0.0001)	g/Mg (lb/ton)	E
Batch drop					
Truck unloading	Fractured stone^c	0.17 (0.0003)	0.008 (0.00002)	g/Mg (lb/ton)	D
Truck loading					
Conveyor	Crushed stone^d	0.17 (0.0003)	0.05 (0.0001)	g/Mg (lb/ton)	E
Front end loader	Crushed stone^e	29.0 (0.06)	NA	g/Mg (lb/ton)	E
Conveying					
Tunnel belt	Crushed stone^c	1.7 (0.0034)	0.11 (0.0002)	g/Mg (lb/ton)	E
Unpaved haul roads		f	f		

[a] Total suspended particulate (TSP) is that measured by a standard high volume sampler (See Section 11.2). Use of empirical equations in Chapter 11 is preferred to single value factors in this Table. Factors in this Table are provided for convenience in quick approximations and/or for occasions when equation variables can not be reasonably estimated. NA = not available.

[b] Expressed as g/Mg (lb/ton) of material through primary crusher, except for front end loading which is g/Mg (lb/ton) of material transferred.

[c] Reference 2.

[d] Reference 3.

[e] Reference 6.

[f] See Section 11.2 for empirical equations.

specific source conditions, these equations should be used instead of those in Table 8.19.2-2, whenever emission estimates applicable to specific stone quarrying and processing facility sources are needed. Chapter 11.2 provides measured properties of crushed limestone, as required for use in the predictive emission factor equations.

References for Section 8.19.2

1. Air Pollution Control Techniques for Nonmetallic Minerals Industry, EPA-450/3-82-014, U. S. Environmental Protection Agency, Research Triangle Park, NC, August 1982.

2. P. K. Chalekode, et al., Emissions from the Crushed Granite Industry: State of the Art, EPA-600/2-78-021, U. S. Environmental Protection Agency, Washington, DC, February 1978.

3. T. R. Blackwood, et al., Source Assessment: Crushed Stone, EPA-600/2-78-004L, U. S. Environmental Protection Agency, Washington, DC, May 1978.

4. F. Record and W. T. Harnett, Particulate Emission Factors for the Construction Aggregate Industry, Draft Report, GCA-TR-CH-83-02, EPA Contract No. 68-02-3510, GCA Corporation, Chapel Hill, NC, February 1983.

5. Review Emission Data Base and Develop Emission Factors for the Construction Aggregate Industry, Engineering-Science, Inc., Arcadia, CA, September 1984.

6. C. Cowherd, Jr., et al., Development of Emission Factors for Fugitive Dust Sources, EPA-450/3-74-037, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1974.

7. R. Bohn, et al., Fugitive Emissions from Integrated Iron and Steel Plants, EPA-600/2-78-050, U. S. Environmental Protection Agency, Washington, DC, March 1978.

8.22 TACONITE ORE PROCESSING

8.22.1 General [1-2]

More than two thirds of the iron ore produced in the United States consists of taconite, a low grade iron ore largely from deposits in Minnesota and Michigan, but from other areas as well. Processing of taconite consists of crushing and grinding the ore to liberate ironbearing particles, concentrating the ore by separating the particles from the waste material (gangue), and pelletizing the iron ore concentrate. A simplified flow diagram of these processing steps is shown in Figure 8.22-1.

Liberation - The first step in processing crude taconite ore is crushing and grinding. The ore must be ground to a particle size sufficiently close to the grain size of the ironbearing mineral to allow for a high degree of mineral liberation. Most of the taconite used today requires very fine grinding. The grinding is normally performed in three or four stages of dry crushing, followed by wet grinding in rod mills and ball mills. Gyratory crushers are generally used for primary crushing, and cone crushers are used for secondary and tertiary fine crushing. Intermediate vibrating screens remove undersize material from the feed to the next crusher and allow for closed circuit operation of the fine crushers. The rod and ball mills are also in closed circuit with classification systems such as cyclones. An alternative is to feed some coarse ores directly to wet or dry semiautogenous or autogenous (using larger pieces of the ore to grind/mill the smaller pieces) grinding mills, then to pebble or ball mills. Ideally, the liberated particles of iron minerals and barren gangue should be removed from the grinding circuits as soon as they are formed, with larger particles returned for further grinding.

Concentration - As the iron ore minerals are liberated by the crushing steps, the ironbearing particles must be concentrated. Since only about 33 percent of the crude taconite becomes a shippable product for iron making, a large amount of gangue is generated. Magnetic separation and flotation are most commonly used for concentration of the taconite ore.

Crude ores in which most of the recoverable iron is magnetite (or, in rare cases, maghemite) are normally concentrated by magnetic separation. The crude ore may contain 30 to 35 percent total iron by assay, but theoretically only about 75 percent of this is recoverable magnetite. The remaining iron is discarded with the gangue.

Nonmagnetic taconite ores are concentrated by froth flotation or by a combination of selective flocculation and flotation. The method is determined by the differences in surface activity between the iron and gangue particles. Sharp separation is often difficult.

Various combinations of magnetic separation and flotation may be used to concentrate ores containing various iron minerals (magnetite and hematite, or maghemite) and wide ranges of mineral grain sizes. Flotation is also often used as a final polishing operation on magnetic concentrates.

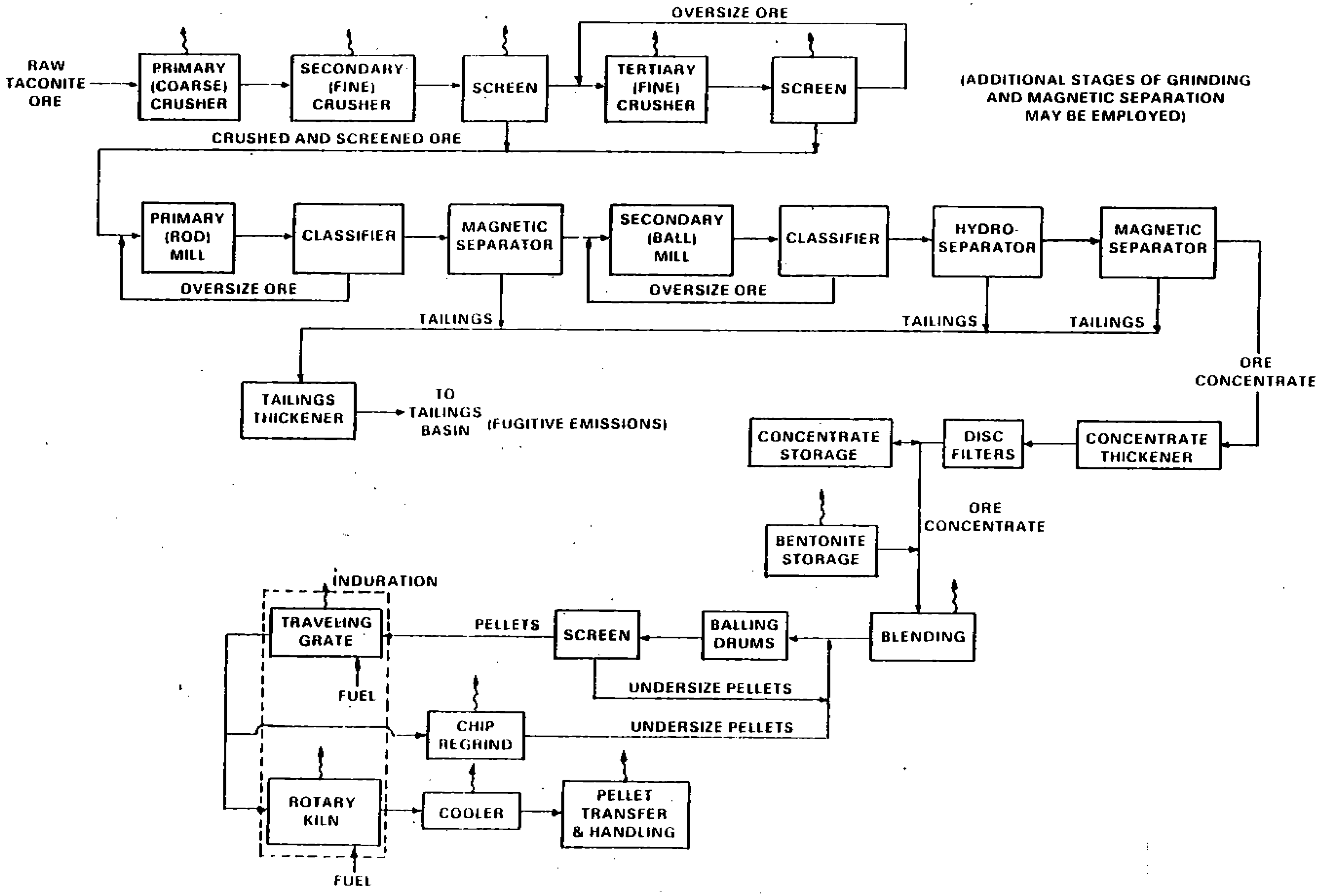

Figure 8.22-1. Taconite ore processing plant. (Process emissions are indicated by ⌇ .)

Pelletization - Iron ore concentrates must be coarser than about No. 10 mesh to be acceptable as blast furnace feed without further treatment. The finer concentrates are agglomerated into small "green" pellets. This is normally accomplished by tumbling moistened concentrate with a balling drum or balling disc. A binder, usually powdered bentonite, may be added to the concentrate to improve ball formation and the physical qualities of the "green" balls. The bentonite is lightly mixed with the carefully moistened feed at 5 to 10 kilograms per megagram (10 to 20 lb/ton).

The pellets are hardened by a procedure called induration, the drying and heating of the green balls in an oxidizing atmosphere at incipient fusion temperature of 1290 to 1400°C (2350 to 2550°F), depending on the composition of the balls, for several minutes and then cooling. Four general types of indurating apparatus are currently used. These are the vertical shaft furnace, the straight grate, the circular grate and grate/kiln. Most of the large plants and new plants use the grate/kiln. Natural gas is most commonly used for pellet induration now, but probably not in the future. Heavy oil is being used at a few plants, and coal may be used at future plants.

In the vertical shaft furnace, the wet green balls are distributed evenly over the top of the slowly descending bed of pellets. A rising stream of hot gas of controlled temperature and composition flows counter to the descending bed of pellets. Auxiliary fuel combustion chambers supply hot gases midway between the top and bottom of the furnace. In the straight grate apparatus, a continuous bed of agglomerated green pellets is carried through various up and down flows of gases at different temperatures. The grate/kiln apparatus consists of a continuous traveling grate followed by a rotary kiln. Pellets indurated by the straight grate apparatus are cooled on an extension of the grate or in a separate cooler. The grate/kiln product must be cooled in a separate cooler, usually an annular cooler with countercurrent airflow.

8.22.2 Emissions and Controls[1-4]

Emission sources in taconite ore processing plants are indicated in Figure 8.22-1. Particulate emissions also arise from ore mining operations. Emission factors for the major processing sources without controls are presented in Table 8.22-1, and control efficiencies in Table 8.22-2. Table 8.22-3 presents data on particle size distributions and corresponding size-specific emission factors for the controlled main waste gas stream from taconite ore pelletizing operations.

The taconite ore is handled dry through the crushing stages. All crushers, size classification screens and conveyor transfer points are major points of particulate emissions. Crushed ore is normally wet ground in rod and ball mills. A few plants, however, use dry autogenous or semi-autogenous grinding and have higher emissions than do conventional plants. The ore remains wet through the rest of the beneficiation process (through concentrate storage, Figure 8.22-1) so particulate emissions after crushing are generally insignificant.

The first source of emissions in the pelletizing process is the transfer and blending of bentonite. There are no other significant emissions in

TABLE 8.22-1. PARTICULATE EMISSION FACTORS FOR TACONITE ORE PROCESSING, WITHOUT CONTROLS[a]

EMISSION FACTOR RATING: D

Source	Emissions[b]	
	kg/Mg	lb/ton
Ore transfer	0.05	0.10
Coarse crushing and screening	0.10	0.20
Fine crushing	39.9	79.8
Bentonite transfer	0.02	0.04
Bentonite blending	0.11	0.22
Grate feed	0.32	0.64
Indurating furnace waste gas	14.6	29.2
Grate discharge	0.66	1.32
Pellet handling	1.7	3.4

[a] Reference 1. Median values.

[b] Expressed as units per unit weight of pellets produced.

the balling section, since the iron ore concentrate is normally too wet to cause appreciable dusting. Additional emission points in the pelletizing process include the main waste gas stream from the indurating furnace, pellet handling, furnace transfer points (grate feed and discharge), and for plants using the grate/kiln furnace, annular coolers. In addition, tailings basins and unpaved roadways can be sources of fugitive emissions.

Fuel used to fire the indurating furnace generates low levels of sulfur dioxide emissions. For a natural gas fired furnace, these emissions are about 0.03 kilograms of SO_2 per megagram of pellets produced (0.06 lb/ton). Higher SO_2 emissions (about 0.06 to 0.07 kg/Mg, or 0.12 to 0.14 lb/ton) would result from an oil or coal fired furnace.

Particulate emissions from taconite ore processing plants are controlled by a variety of devices, including cyclones, multiclones, rotoclones, scrubbers, baghouses and electrostatic precipitators. Water sprays are also used to suppress dusting. Annular coolers are generally left uncontrolled because their mass loadings of particulates are small, typically less than 0.11 grams per normal cubic meter (0.05 gr/scf).

The largest source of particulate emissions in taconite ore mines is traffic on unpaved haul roads.[4] Table 8.22-4 presents size specific emission factors for this source determined through source testing at one taconite mine. Other significant particulate emission sources at taconite mines are wind erosion and blasting.[4]

As an alternative to the single valued emission factors for open dust sources given in Tables 8.22-1 and 8.22-4, empirically derived emission

TABLE 8.22-2. CONTROL EFFICIENCIES FOR COMBINATIONS OF CONTROL DEVICES AND SOURCES[a]

Control	Coarse crushing	Ore transfer	Fine crushing	Bentonite transfer	Bentonite blending	Grate feed	Grate discharge	Waste gas	Pellet handling
Scrubber	95(10)f 91.6(4)f 99(2)m	99.5(18)f 99(5)f 97(4)m 99(1)m	99.5(5)f 99.6(6)f 97(10)m 97(19)e	98(1)f	98.7(1)f 99.3(1)f	98.7(2)f 98(1)m 99(5)e	99.3(2)f 99(5)e 98(1)e	98.5(1)e 89(1)e	99.3(2)f 99.7(1)f 99(2)f 97.5(1)e
Cyclone	85(1)f	95(2)e						95-98(56)f	
Multiclone	92(2)f 88(2)f							95-98(2)f	
Rotoclone	91.6(4)f	98(1)f	99.7(7)f 98.3(4)f						98(1)e
Bag collector	99(2)m 99.9(2)m 99(4)e 99.9(2)e			99(8)e	99(2)f 99.7(1)f				
Electrostatic precipitator								98.9(2)f 96.8(1)e	
Dry mechanical collector	85(1)f	85(1)f							
Centrifugal collector						88(1)f 98(1)e 99.4(1)e	88(1)f 99.4(1)e		

[a] Reference 1. Control efficiencies are expressed as percent reduction. Numbers in parentheses are the number of indicated combinations with the stated efficiency. The letters m, f, e denote whether the stated efficiencies were based upon manufacturer's rating (m), field testing (f), or estimations (e). Blanks indicate that no such combinations of source and control technology are known to exist, or that no data on the efficiency of the combination are available.

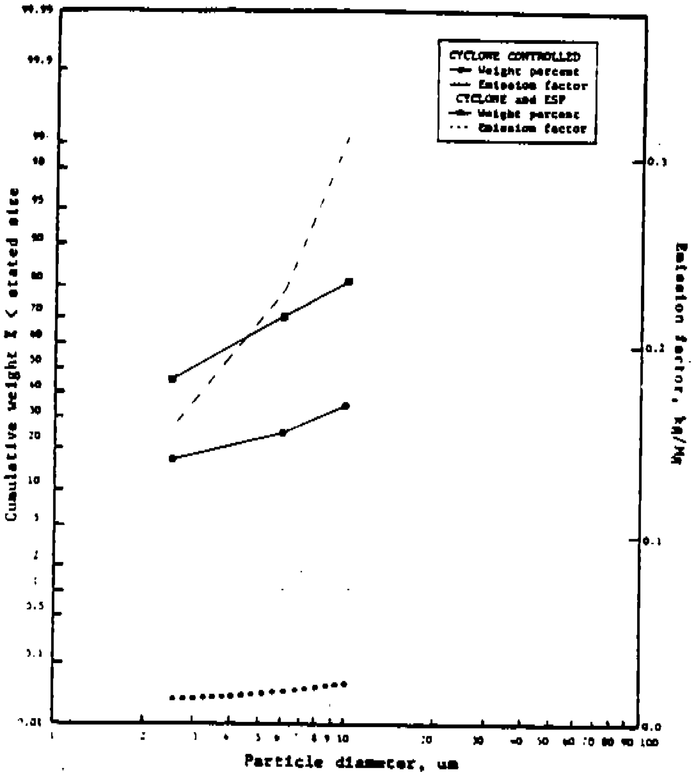

Figure 8.22-3. Particle size distributions and size specific emission factors for indurating furnace waste gas stream from taconite ore pelletizing.

TABLE 8.22-3. PARTICLE SIZE DISTRIBUTIONS AND SIZE SPECIFIC EMISSION FACTORS FOR CONTROLLED INDURATING FURNACE WASTE GAS STREAM FROM TACONITE ORE PELLETIZING[a]

SIZE-SPECIFIC EMISSION FACTOR RATING: D

	Particle size distribution[b]		Size specific emission factor, kg/Mg[c]	
Aerodynamic particle diameter, um	Cyclone controlled	Cyclone/ESP controlled	Cyclone controlled	Cyclone/ESP controlled
2.5	17.4	48.0	0.16	0.012
6.0	25.6	71.0	0.23	0.018
10.0	35.2	81.5	0.31	0.021

[a] Reference 3. ESP = electrostatic precipitator. After cyclone control, mass emission factor is 0.89 kg/Mg, and after cyclone/ESP control, 0.025 kg/Mg. Mass and size specific emission factors are calculated from data in Reference 3, and are expressed as kg particulate/Mg of pellets produced.

[b] Cumulative weight % < particle diameter.

[c] Size specific emission factor = mass emission factor x particle size distribution, %/100.

TABLE 8.22-4. UNCONTROLLED EMISSION FACTORS FOR HEAVY DUTY VEHICLE TRAFFIC ON HAUL ROADS AT TACONITE MINES[a]

Surface material	Emission factor by aerodynamic diameter (um)					Units	Emission Factor Rating
	≤30	≤15	≤10	≤5	≤2.5		
Crushed rock and glacial till	3.1	2.2	1.7	1.1	0.62	kg/VKT	C
	11.0	7.9	6.2	3.9	2.2	lb/VMT	C
Crushed taconite and waste	2.6	1.9	1.5	0.9	0.54	kg/VKT	D
	9.3	6.6	5.2	3.2	1.9	lb/VMT	D

[a] Reference 4. Predictive emission factor equations, which provide generally more accurate estimates, are in Chapter 11. VKT = vehicle kilometers travelled. VMT = vehicle miles travelled.

factor equations are presented in Chapter 11 of this document. Each equation has been developed for a source operation defined by a single dust generating mechanism, common to many industries, such as vehicle activity on unpaved roads. The predictive equation explains much of the observed variance in measured emission factors by relating emissions to parameters which characterize source conditions. These parameters may be grouped into three categories, 1) measures of source activity or energy expended, i. e., the speed and weight of a vehicle on an unpaved road; 2) properties of the material being disturbed, i. e., the content of suspendable fines in the surface material of an unpaved road; and 3) climatic parameters, such as the number of precipitation free days per year, when emissions tend to a maximum.

Because the predictive equations allow for emission factor adjustment to specific source conditions, such equations should be used in place of the single valued factors for open dust sources in Tables 8.22-1 and 8.22-4, whenever emission estimates are needed for sources in a specific taconite ore mine or processing facility. One should remember that the generally higher quality ratings assigned to these equations apply only if 1) reliable values of correction parameters have been determined for the specific sources of interest, and 2) the correction parameter values lie within the ranges tested in developing the equations. In the event that site specific values are not available, Chapter 11 lists measured properties of road surface and aggregate process materials found in taconite mining and processing facilities, and these can be used to estimate correction parameter values for the predictive emission factor equations. The use of mean correction parameter values from Chapter 11 reduces the quality ratings of the factor equations by one level.

References for Section 8.22

1. J. P. Pilney and G. V. Jorgensen, Emissions from Iron Ore Mining, Beneficiation and Pelletization, Volume 1, EPA Contract No. 68-02-2113, Midwest Research Institute, Minnetonka, MN, June 1983.

2. A. K. Reed, Standard Support and Environmental Impact Statement for the Iron Ore Beneficiation Industry (Draft), EPA Contract No. 68-02-1323, Battelle Columbus Laboratories, Columbus, OH, December 1976.

3. Air Pollution Emission Test, Empire Mining Company, Palmer, MI, EMB-76-IOB-2, U. S. Environmental Protection Agency, Research Triangle Park, NC, November 1975.

4. T. A. Cuscino, et al., Taconite Mining Fugitive Emissions Study, Minnesota Pollution Control Agency, Roseville, MN, June 1979.

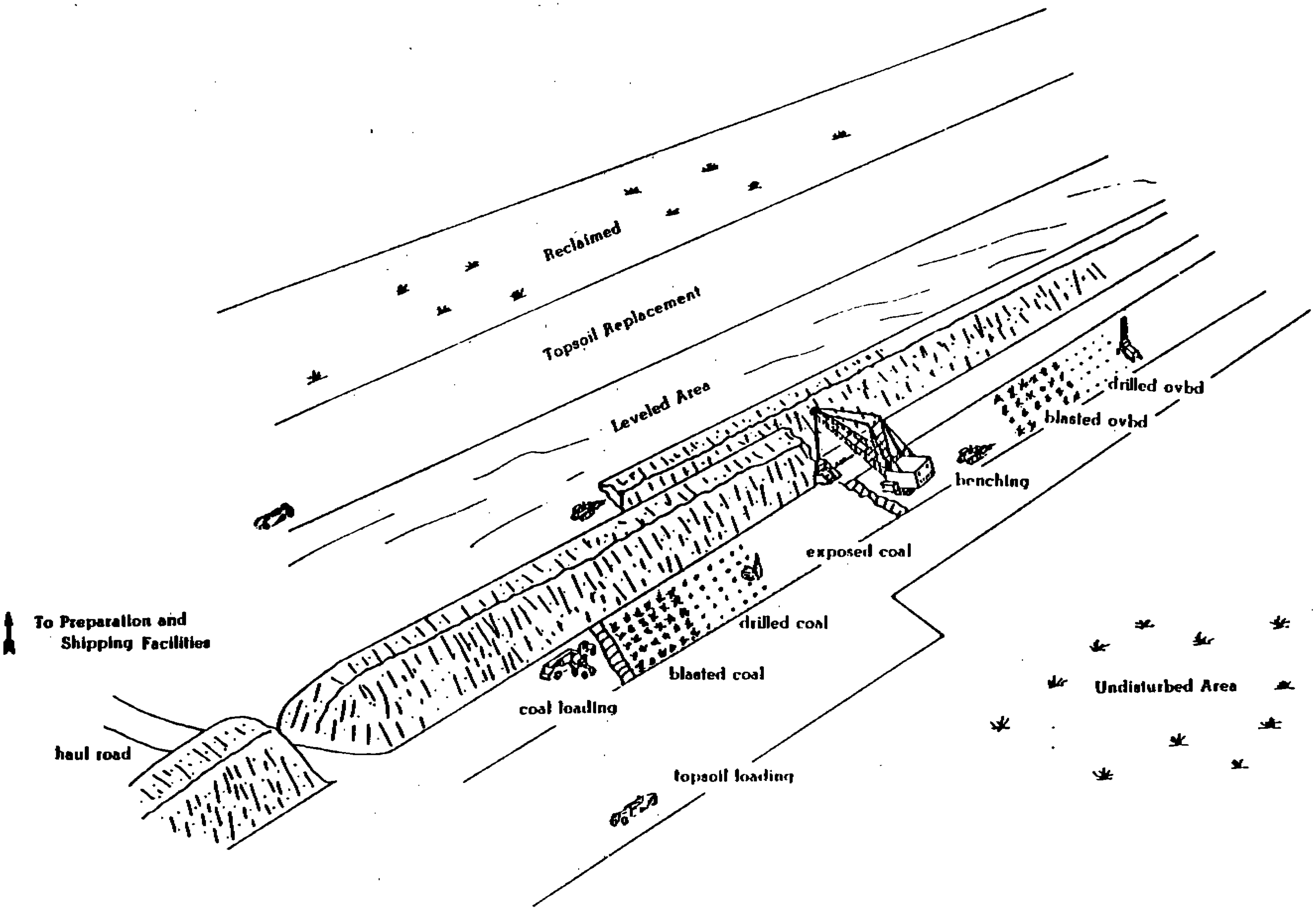

Figure 8.24-2. Operations at typical western surface coal mines.

TABLE 8.24-1. EMISSION FACTOR EQUATIONS FOR UNCONTROLLED OPEN DUST SOURCES AT WESTERN SURFACE COAL MINES (METRIC UNITS)[a]

Operation	Material	Emissions by particle size range (aerodynamic diameter)[b,c]			Units	Emission Factor Rating
		TSP < 30um	< 15um	< 2.5 um/TSP[d]		
Truck loading	Coal	$\frac{0.580}{(M)^{1.2}}$	$\frac{0.0596}{(M)^{0.9}}$	0.019	kg/Mg	B
Bulldozing	Coal	$\frac{35.6\ (s)^{1.2}}{(M)^{1.3}}$	$\frac{8.44\ (s)^{1.5}}{(M)^{1.4}}$	0.022	kg/hr	B
	Overburden	$\frac{2.6\ (s)^{1.2}}{(M)^{1.3}}$	$\frac{0.45\ (s)^{1.5}}{(M)^{1.4}}$	0.105	kg/hr	B
Dragline	Overburden	$\frac{0.0046\ (d)^{1.1}}{(M)^{0.3}}$	$\frac{0.0029\ (d)^{0.7}}{(M)^{0.3}}$	0.017	kg/m^3	B
Scraper (travel mode)		$9.6 \times 10^{-6}\ (s)^{1.3}\ (W)^{2.4}$	$2.2 \times 10^{-6}\ (s)^{1.4}\ (W)^{2.5}$	0.026	kg/VKT	A
Grading		$0.0034\ (S)^{2.5}$	$0.0056\ (S)^{2.0}$	0.031	kg/VKT	B
Vehicle traffic (light/medium duty)		$\frac{1.63}{(M)^{4.0}}$	$\frac{1.05}{(M)^{4.3}}$	0.040	kg/VKT	B
Haul truck		$0.0019\ (w)^{3.4}\ (L)^{0.2}$	$0.0014\ (w)^{3.5}$	0.017	kg/VKT	A
Active storage pile (wind erosion and maintenance)	Coal	1.8 u	NA	NA	$\frac{kg}{(hectare)(hr)}$	C[e]

[a] All equations are from Reference 1, except for coal storage pile equation from Reference 4. TSP = total suspended particulate. VKT = vehicle kilometers traveled. NA = not available.

[b] TSP denotes what is measured by a standard high volume sampler (see Section 11.2).

[c] Symbols for equations:

M = material moisture content (%)
s = material silt content (%)
u = wind speed (m/sec)
d = drop height (m)
W = mean vehicle weight (Mg)
S = mean vehicle speed (kph)
w = mean number of wheels
L = road surface silt loading (g/m^2)

[d] Multiply the TSP predictive equation by this fraction to determine emissions in the <2.5 m size range.

[e] Rating applicable to Mine Types I, II and IV (see Tables 8.24-5 and 8.24-6).

TABLE 8.24-2. EMISSION FACTOR EQUATIONS FOR UNCONTROLLED OPEN DUST SOURCES AT WESTERN SURFACE COAL MINES (ENGLISH UNITS)[a]

Operation	Material	Emissions by particle size range (aerodynamic diameter)[b,c]			Units	Emission Factor Rating
		TSP < 30um	< 15um	< 2.5um/TSP[d]		
Truck loading	Coal	$\frac{1.16}{(M)^{1.2}}$	$\frac{0.119}{(M)^{0.9}}$	0.019	lb/ton	B
Bulldozing	Coal	$\frac{78.4\ (s)^{1.2}}{(M)^{1.3}}$	$\frac{18.6\ (s)^{1.5}}{(M)^{1.4}}$	0.022	lb/hr	B
	Overburden	$\frac{5.7\ (s)^{1.2}}{(M)^{1.3}}$	$\frac{1.0\ (s)^{1.5}}{(M)^{1.4}}$	0.105	lb/hr	B
Dragline	Overburden	$\frac{0.0021\ (d)^{1.1}}{(M)^{0.3}}$	$\frac{0.0021\ (d)^{0.7}}{(M)^{0.3}}$	0.017	lb/yd^3	B
Scraper (travel model)		$2.7 \times 10^{-5}\ (s)^{1.3}\ (W)^{2.4}$	$6.2 \times 10^{-6}\ (s)^{1.4}\ (W)^{2.5}$	0.026	lb/VMT	A
Grading		$0.040\ (S)^{2.5}$	$0.051\ (S)^{2.0}$	0.031	lb/VMT	B
Vehicle traffic (light/medium duty)		$\frac{5.79}{(M)^{4.0}}$	$\frac{3.72}{(M)^{4.3}}$	0.040	lb/VMT	B
Haul truck		$0.0067\ (w)^{3.4}\ (L)^{0.2}$	$0.0051\ (w)^{3.5}$	0.017	lb/VMT	A
Active storage pile (wind erosion and maintenance)	Coal	1.6 u	NA	NA	$\frac{lb}{(acre)(hr)}$	C[e]

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[a] All equations are from Reference 1, except for coal storage pile equation from Reference 4. TSP = total suspended particulate. VMT = vehicle miles traveled. NA = not available.

[b] TSP denotes what is measured by a standard high volume sampler (see Section 11.2).

[c] Symbols for equations:

M = material moisture content (%)
s = material silt content (%)
u = wind speed (m/sec)
d = drop height (ft)
W = mean vehicle weight (tons)
S = mean vehicle speed (mph)
w = mean number of wheels
L = road surface silt loading (g/m^2)

[d] Multiply the TSP predictive equation by this fraction to determine emissions in the < 2.5um size range.

[e] Rating applicable to Mine Types I, II and IV (see Tables 8.24-5 and 8.24-6).

The equations were developed through field sampling of various western surface mine types and are thus applicable to any of the surface coal mines located in the western United States.

In Tables 8.24-1 and 8.24-2, the assigned quality ratings apply within the ranges of source conditions that were tested in developing the equations, given in Table 8.24-3. However, the equations are derated one letter value (e. g., A to B) if applied to eastern surface coal mines.

TABLE 8.24-3. TYPICAL VALUES FOR CORRECTION FACTORS APPLICABLE TO THE PREDICTIVE EMISSION FACTOR EQUATIONS[a]

Source	Correction factor	Number of test samples	Range	Geometric mean	Units
Coal loading	Moisture	7	6.6 - 38	17.8	%
Bulldozers					
Coal	Moisture	3	4.0 - 22.0	10.4	%
	Silt	3	6.0 - 11.3	8.6	%
Overburden	Moisture	8	2.2 - 16.8	7.9	%
	Silt	8	3.8 - 15.1	6.9	%
Dragline	Drop distance	19	1.5 - 30	8.6	m
	" "		5 - 100	28.1	ft
	Moisture	7	0.2 - 16.3	3.2	%
Scraper	Silt	10	7.2 - 25.2	16.4	%
	Weight	15	33 - 64	48.8	Mg
	"		36 - 70	53.8	ton
Grader	Speed	7	8.0 - 19.0	11.4	kph
	"		5.0 - 11.8	7.1	mph
Light/medium duty vehicle	Moisture	7	0.9 - 1.7	1.2	%
Haul truck	Wheels	29	6.1 - 10.0	8.1	number
	Silt loading	26	3.8 - 254	40.8	g/m^2
	" "		34 - 2270	364	lb/ac

[a] Reference 1.

In using the equations to estimate emissions from sources found in a specific western surface mine, it is necessary that reliable values for correction parameters be determined for the specific sources of interest, if the assigned quality ranges of the equations are to be applicable. For example, actual silt content of coal or overburden measured at a facility

10.0 WOOD PRODUCTS INDUSTRY

Wood processing involves the conversion of raw wood to pulp, pulpboard or types of wallboard such as plywood, particle board or hardboard. This chapter presents emissions data on chemical wood pulping, on pulpboard and plywood manufacturing, and on woodworking operations. The burning of wood waste in boilers and conical burners is discussed in Chapters 1 and 2 of this publication.

10.1 CHEMICAL WOOD PULPING

10.1.1 General

Chemical wood pulping involves the extraction of cellulose from wood by dissolving the lignin that binds the cellulose fibers together. The four processes principally used in chemical pulping are kraft, sulfite, neutral sulfite semichemical (NSSC), and soda. The first three display the greatest potential for causing air pollution. The kraft process alone accounts for over 80 percent of the chemical pulp produced in the United States. The choice of pulping process is determined by the desired product, by the wood species available, and by economic considerations.

10.1.2 Kraft Pulping

Process Description[1] - The kraft pulping process (See Figure 10.1-1) involves the digesting of wood chips at elevated temperature and pressure in "white liquor", which is a water solution of sodium sulfide and sodium hydroxide. The white liquor chemically dissolves the lignin that binds the cellulose fibers together.

There are two types of digester systems, batch and continuous. Most kraft pulping is done in batch digesters, although the more recent installations are of continuous digesters. In a batch digester, when cooking is complete, the contents of the digester are transferred to an atmospheric tank usually referred to as a blow tank. The entire contents of the blow tank are sent to pulp washers, where the spent cooking liquor is separated from the pulp. The pulp then proceeds through various stages of washing, and possibly bleaching, after which it is pressed and dried into the finished product. The "blow" of the digester does not apply to continuous digester systems.

The balance of the kraft process is designed to recover the cooking chemicals and heat. Spent cooking liquor and the pulp wash water are combined to form a weak black liquor which is concentrated in a multiple effect evaporator system to about 55 percent solids. The black liquor is then further concentrated to 65 percent solids in a direct contact evaporator, by bringing the liquor into contact with the flue gases from the recovery furnace, or in an indirect contact concentrator. The strong black liquor is then fired in a recovery furnace. Combustion of the organics dissolved in the black liquor provides heat for generating process steam and for converting sodium sulfate to sodium sulfide. Inorganic chemicals present in the black liquor collect as a molten smelt at the bottom of the furnace.

The smelt is dissolved in water to form green liquor, which is transferred to a causticizing tank where quicklime (calcium oxide) is added to convert the solution back to white liquor for return to the digester system. A lime mud precipitates from the causticizing tank, after which it is calcined in a lime kiln to regenerate quicklime.

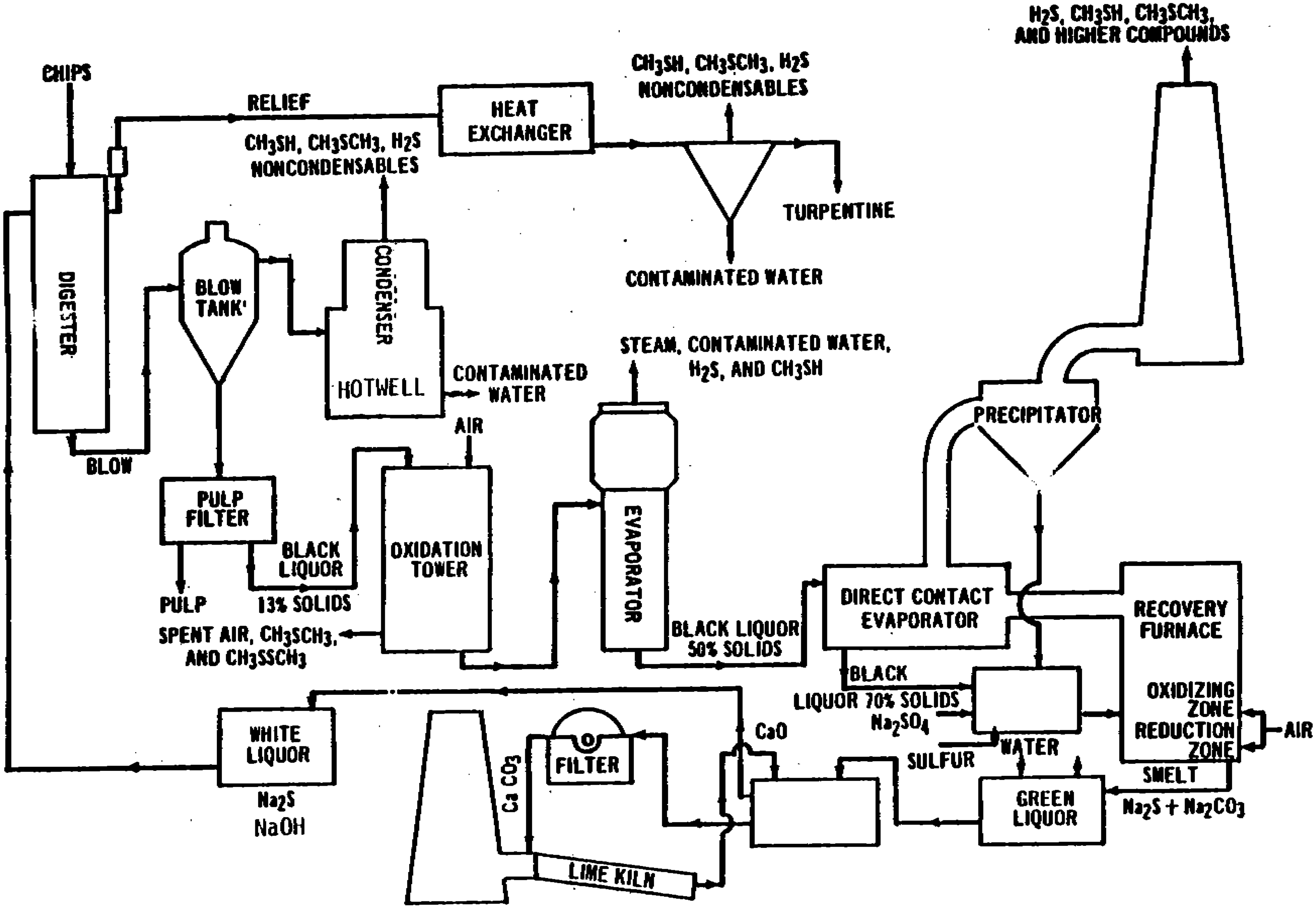


Figure 10.1-1. Typical kraft sulfate pulping and recovery process.

For process heating, for driving equipment, for providing electric power, etc., many mills need more steam than can be provided by the recovery furnace alone. Thus, conventional industrial boilers that burn coal, oil, natural gas, or bark and wood are commonly used.

Emissions And Controls[1-7] - Particulate emissions from the kraft process occur largely from the recovery furnace, the lime kiln and the smelt dissolving tank. These emissions are mainly sodium salts, with some calcium salts from the lime kiln. They are caused mostly by carryover of solids and sublimation and condensation of the inorganic chemicals.

Particulate control is provided on recovery furnaces in a variety of ways. In mills with either a cyclonic scrubber or cascade evaporator as the direct contact evaporator, further control is necessary, as these devices are generally only 20 to 50 percent efficient for particulates. Most often in these cases, an electrostatic precipitator is employed after the direct contact evaporator, for an overall particulate control efficiency of from 85 to more than 99 percent. Auxiliary scrubbers may be added at existing mills after a precipitator or a venturi scrubber to supplement older and less efficient primary particulate control devices.

Particulate control on lime kilns is generally accomplished by scrubbers. Electrostatic precipitators have been used in a few mills. Smelt dissolving tanks usually are controlled by mesh pads, but scrubbers can provide further control.

The characteristic odor of the kraft mill is caused by the emission of reduced sulfur compounds, the most common of which are hydrogen sulfide, methyl mercaptan, dimethyl sulfide and dimethyl disulfide, all with extremely low odor thresholds. The major source of hydrogen sulfide is the direct contact evaporator, in which the sodium sulfide in the black liquor reacts with the carbon dioxide in the furnace exhaust. Indirect contact evaporators can significantly reduce the emission of hydrogen sulfide. The lime kiln can also be a potential source of odor, as a similar reaction occurs with residual sodium sulfide in the lime mud. Lesser amounts of hydrogen sulfide are emitted with the noncondensible offgasses from the digesters and multiple effect evaporators.

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 lignin. These compounds are emitted from many points within a mill, but the main sources are the digester/blow tank systems and the direct contact evaporator.

Although odor control devices, per se, are not generally found in kraft mills, emitted sulfur compounds can be reduced by process modifications and improved operating conditions. For example, black liquor oxidation systems, which oxidize sulfides into less reactive thiosulfates, can considerably reduce odorous sulfur emissions from the direct contact evaporator, although the vent gases from such systems become minor odor sources themselves. Also, noncondensible odorous gases vented from the digester/blow tank system and multiple effect evaporators can be destroyed by thermal oxidation, usually by passing them through the lime kiln. Efficient operation of the recovery furnace, by avoiding overloading and by maintaining sufficient oxygen, residence time and turbulence, significantly reduces emissions of reduced sulfur compounds from this source as well. The use of fresh water instead of contaminated condensates in the scrubbers and pulp washers further reduces odorous emissions.

Several new mills have incorporated recovery systems that eliminate the conventional direct contact evaporators. In one system, heated combustion air, rather than fuel gas, provides direct contact evaporation. In another, the multiple effect evaporator system is extended to replace the direct contact evaporator altogether. In both systems, sulfur emissions from the recovery furnace/direct contact evaporator can be reduced by more than 99 percent.

Sulfur dioxide is emitted mainly from oxidation of reduced sulfur compounds in the recovery furnace. It is reported that the direct contact evaporator absorbs about 75 percent of these emissions, and further scrubbing can provide additional control.

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.

Some nitrogen oxides also are emitted from the recovery furnace and lime kilns, although amounts are relatively small. Indications are that nitrogen oxide emissions are on the order of 0.5 and 1.0 kilograms per air dried megagrams (1 and 2 lb/air dried ton) of pulp produced from the lime kiln and recovery furnace, respectively.[5-6]

A major source of emissions in a kraft mill is the boiler for generating auxiliary steam and power. The fuels used are coal, oil, natural gas or bark/wood waste. See Chapter 1 for emission factors for boilers.

Table 10.1-1 presents emission factors for a conventional kraft mill. The most widely used particulate control devices are shown, along with the odor reductions through black liquor oxidation and incineration of noncondensible offgases. Tables 10.1-2 through 10.1-7 present cumulative size distribution data and size specific emission factors for particulate emissions from sources within a conventional kraft mill. Uncontrolled and controlled size specific emission factors[7] are presented in Figures 10.1-2 through 10.1-7. The particle sizes presented are expressed in terms of the aerodynamic diameter.

10.1.3 Acid Sulfite Pulping

Process Description - The production of acid sulfite pulp proceeds similarly to kraft pulping, except that different chemicals are used in the cooking liquor. In place of the caustic solution used to dissolve the lignin in the wood, sulfurous acid is employed. To buffer the cooking solution, a bisulfite of sodium, magnesium, calcium or ammonium is used. A diagram of a typical magnesium base process is shown in Figure 10.1-8.

Digestion is carried out under high pressure and high temperature, in either batch mode or continuous digesters, and in the presence of a sulfurous acid/bisulfite cooking liquid. When cooking is completed, either the digester is discharged at high pressure into a blow pit, or its contents are pumped into a dump tank at a lower pressure. The spent sulfite liquor (also called red liquor) then drains through the bottom of the tank and is treated and discarded,

TABLE 10.1-1. EMISSION FACTORS FOR SULFITE PULPING[a]

EMISSION FACTOR RATING: A

Source	Type of control	Particulate		Sulfur dioxide (SO_2)		Carbon monoxide (CO)		Hydrogen sulfide ($S^=$)		RSH, RSR, RSSR ($S^=$)	
		kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Digester relief and blow tank	Untreated[b]	-	-	-	-	-	-	0.02	0.03	0.6	1.2
Brown stock washer	Untreated[b]	-	-	-	-	-	-	0.01	0.02	0.2[c]	0.4[c]
Multiple effect evaporator	Untreated[b]	-	-	-	-	-	-	0.55	1.1	0.05	0.1
Recovery boiler and direct evaporator	Untreated[d]	90	180	3.5	7	5.5	11	6[e]	12[e]	1.5[e]	3[e]
	Venturi scrubber[f]	24	48	3.5	7	5.5	11	6[e]	12[e]	1.5[e]	3[e]
	ESP	1	2	3.5	7	5.5	11	6[e]	12[e]	1.5[e]	3[e]
	Auxiliary scrubber	1.5-7.5[g]	3-15[g]					6[e]	12[e]	1.5[e]	3[e]
Noncontact recovery boiler without direct contact evaporator	Untreated	115	230	-	-	5.5	11	0.05[h]	0.1[h]	-	-
	ESP	1	2	-	-	5.5	11	0.05[h]	0.1[h]	-	-
Smelt dissolving tank	Untreated	3.5	7	0.1	0.2	-	-	0.1[j]	0.2[j]	0.15[j]	0.3[j]
	Mesh pad	0.5	1	0.1	0.2	-	-	0.1[j]	0.2[j]	0.15[j]	0.3[j]
	Scrubber	0.1	0.2	-	-	-	-	0.1[j]	0.2[j]	0.15[j]	0.3[j]
Lime kiln	Untreated	28	56	0.15	0.3	0.05	0.1	0.25[m]	0.5[m]	0.1[m]	0.2[m]
	Scrubber or ESP	0.25	0.5	-	-	0.05	0.1	0.25[m]	0.5[m]	0.1[m]	0.2[m]
Turpentine condenser	Untreated	-	-	-	-	-	-	0.005	.01	0.25	0.5
Miscellaneous[n]	Untreated	-	-	-	-	-	-	-	-	0.25	0.5

[a] References 8-10. Factors expressed in unit weight of air dried unbleached pulp (ADP). RSH = Methyl mercaptan. RSR = Dimethyl sulfide. RSSR = Dimethyl disulfide. ESP = Electrostatic precipitator. Dash = No data.

[b] If noncondensible gases from these sources are vented to lime kiln, recovery furnace or equivalent, the reduced sulfur compounds are destroyed.

[c] Apply with system using condensate as washing medium. When using fresh water, emissions are 0.05 (0.1).

[d] Apply when cyclonic scrubber or cascade evaporator is used for direct contact evaporation, with no further controls.

[e] Usually reduced by 50% with black liquor oxidation and can be cut 95 - 99% when oxidation is complete and recovery furnace is operated optimally.

[f] Apply when venturi scrubber is used for direct contact evaporation, with no further controls.

[g] Use 7.5 (15) when auxiliary scrubber follows venturi scrubber, and 1.5 (3) when it follows ESP.

[h] Apply when recovery furnace is operated optimally to control total reduced sulfur (TRS) compounds.

[j] Usually reduced to 0.01 g/kg (0.02 lb/ton) ADP when water low in sulfides is used in smelt dissolving tank and associated scrubber.

[m] Usually reduced to 0.015 g/kg (0.03 lb/ton) ADP with efficient mud washing, optimal kiln operation and added caustic in scrubbing water. With only efficient mud washing and optimal process control, TRS compounds reduced to 0.04 g/kg (0.08 lb/ton) ADP.

[n] Includes knotter vents, brownstock seal tanks, etc. When black liquor oxidation is included, emissions are 0.3 (0.6).

TABLE 10.1-2. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR A RECOVERY BOILER WITH A DIRECT CONTACT EVAPORATOR AND AN ESP[a]

EMISSION FACTOR RATING: C

Particle size (um)	Cumulative mass % ≤ stated size		Cumulative emission factor (kg/Mg of air dried pulp)	
	Uncontrolled	Controlled	Uncontrolled	Controlled
15	95.0	-	86	-
10	93.5	-	84	-
6	92.2	68.2	83	0.7
2.5	83.5	53.8	75	0.5
1.25	56.5	40.5	51	0.4
1.00	45.3	34.2	41	0.3
0.625	26.5	22.2	24	0.2
Total	100	100	90	1.0

[a] Reference 7. Dash = no data.

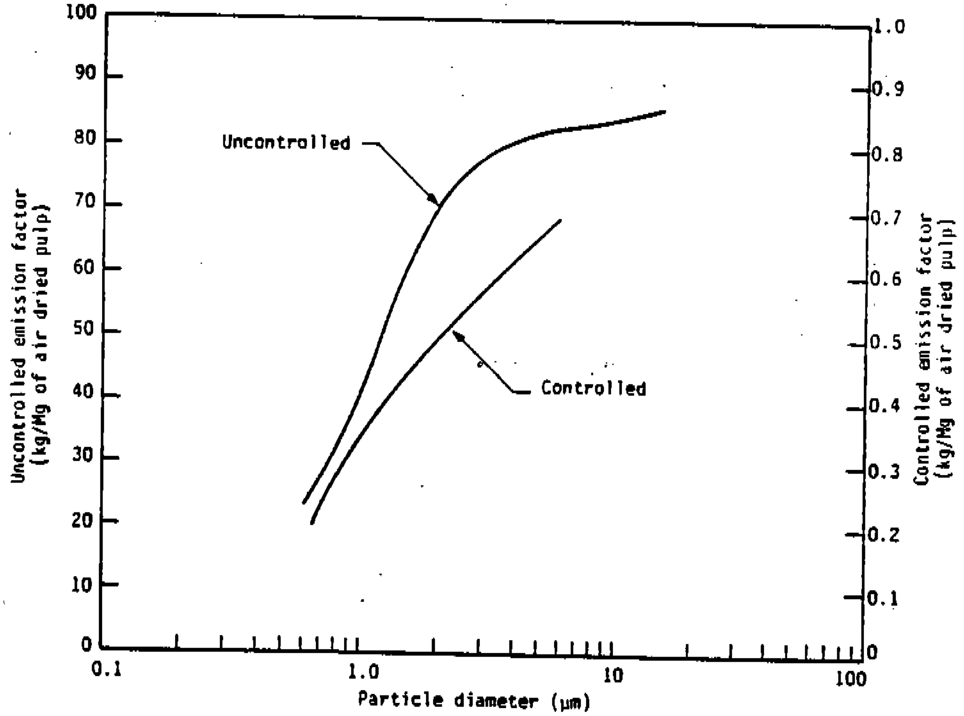


Figure 10.1-2. Cumulative particle size distribution and size specific emission factors for recovery boiler with direct contact evaporator and ESP.

TABLE 10.1-3. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR A RECOVERY BOILER WITHOUT A DIRECT CONTACT EVAPORATOR BUT WITH AN ESP[a]

EMISSION FACTOR RATING: C

Particle size (um)	Cumulative mass % ≤ stated size		Cumulative emission factor (kg/Mg of air dried pulp)	
	Uncontrolled	Controlled	Uncontrolled	Controlled
15	-	78.8	-	0.8
10	-	74.8	-	0.7
6	-	71.9	-	0.7
2.5	78.0	67.3	90	0.6
1.25	40.0	51.3	46	0.5
1.00	30.0	42.4	35	0.4
0.625	17.0	29.6	20	0.3
Total	100	100	115	1.0

[a] Reference 7. Dash = no data.

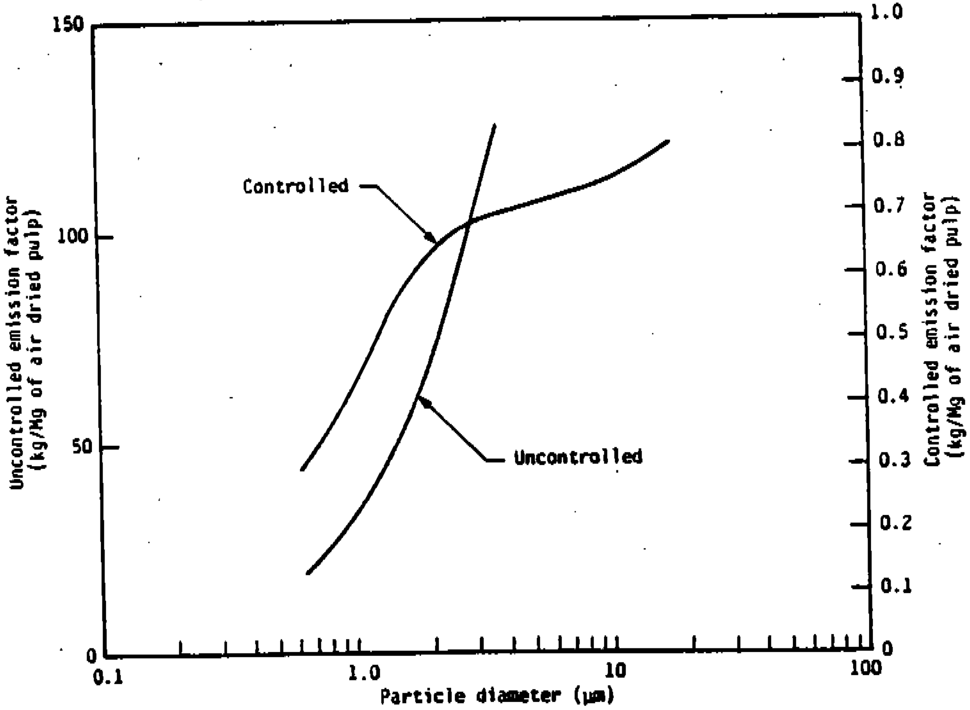


Figure 10.1-3. Cumulative particle size distribution and size specific emission factors for recovery boiler without direct contact evaporator but with ESP.

TABLE 10.1-4. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR A LIME KILN WITH A VENTURI SCRUBBER[a]

EMISSION FACTOR RATING: C

Particle size (um)	Cumulative mass % ≤ stated size		Cumulative emission factor (kg/Mg of air dried pulp)	
	Uncontrolled	Controlled	Uncontrolled	Controlled
15	27.7	98.9	7.8	0.24
10	16.8	98.3	4.7	0.24
6	13.4	98.2	3.8	0.24
2.5	10.5	96.0	2.9	0.24
1.25	8.2	85.0	2.3	0.21
1.00	7.1	78.9	2.0	0.20
0.625	3.9	54.3	1.1	0.14
Total	100	100	28.0	0.25

[a] Reference 7.

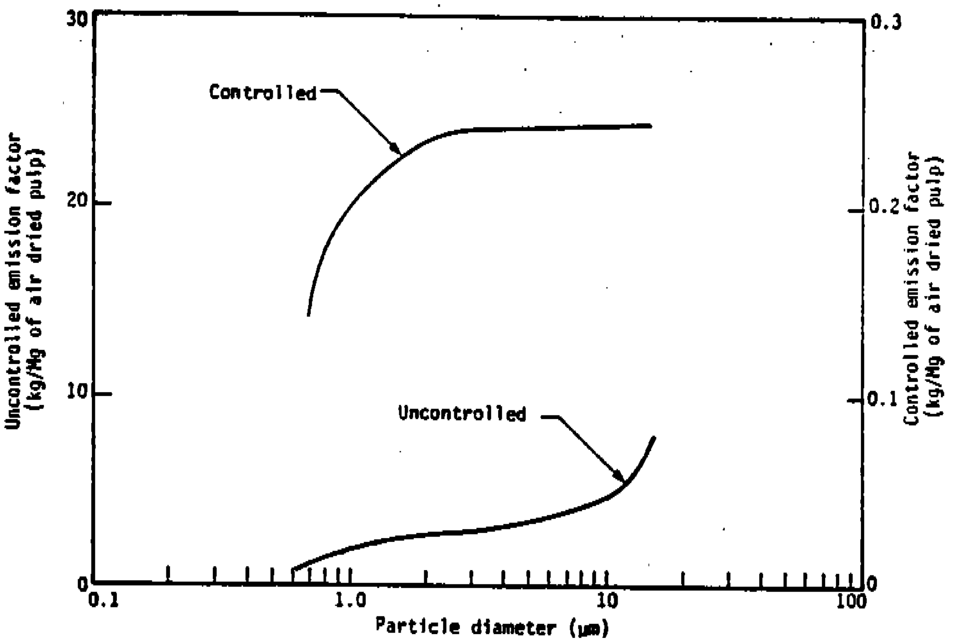


Figure 10.1-4. Cumulative particle size distribution and size specific emission factors for lime kiln with venturi scrubber.

TABLE 10.1-5. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR A LIME KILN WITH AN ESP[a]

EMISSION FACTOR RATING: C

Particle size (um)	Cumulative mass % ≤ stated size		Cumulative emission factor (kg/Mg of air dried pulp)	
	Uncontrolled	Controlled	Uncontrolled	Controlled
15	27.7	91.2	7.8	0.23
10	16.8	88.5	4.7	0.22
6	13.4	86.5	3.8	0.22
2.5	10.5	83.0	2.9	0.21
1.25	8.2	70.2	2.3	0.18
1.00	7.1	62.9	2.0	0.16
0.625	3.9	46.9	1.1	0.12
Total	100	100	28.0	0.25

[a] Reference 7.

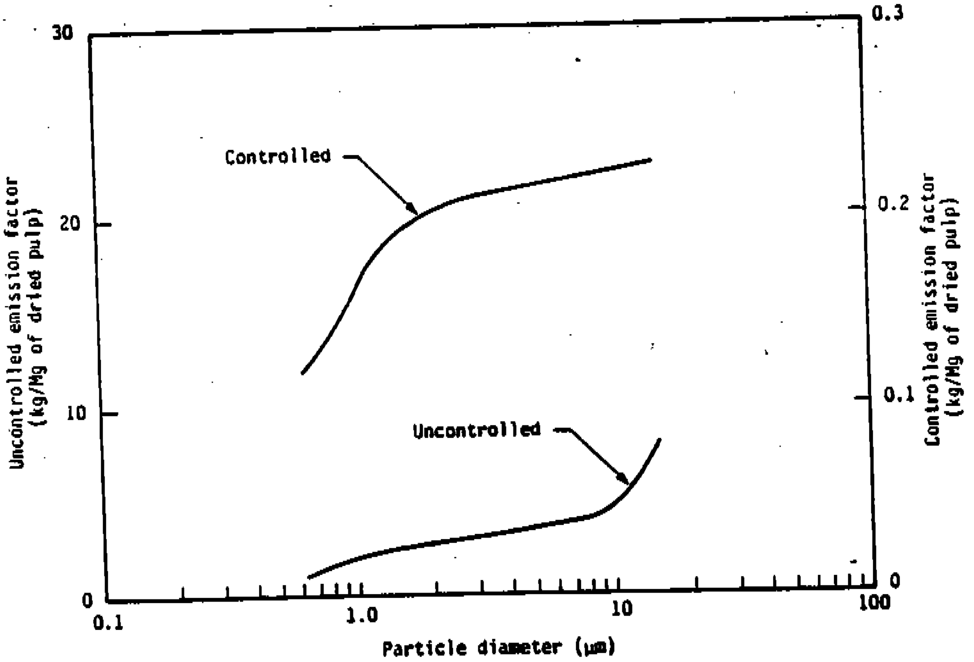


Figure 10.1-5. Cumulative particle size distribution and size specific emission factors for lime kiln with ESP.

TABLE 10.1-6. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR A SMELT DISSOLVING TANK WITH A PACKED TOWER[a]

EMISSION FACTOR RATING: C

Particle size (um)	Cumulative mass % ≤ stated size		Cumulative emission factor (kg/Mg of air dried pulp)	
	Uncontrolled	Controlled	Uncontrolled	Controlled
15	90.0	95.3	3.2	0.48
10	88.5	95.3	3.1	0.48
6	87.0	94.3	3.0	0.47
2.5	73.0	85.2	2.6	0.43
1.25	47.5	63.8	1.7	0.32
1.00	40.0	54.2	1.4	0.27
0.625	25.5	34.2	0.9	0.17
Total	100	100	3.5	0.50

[a] Reference 7.

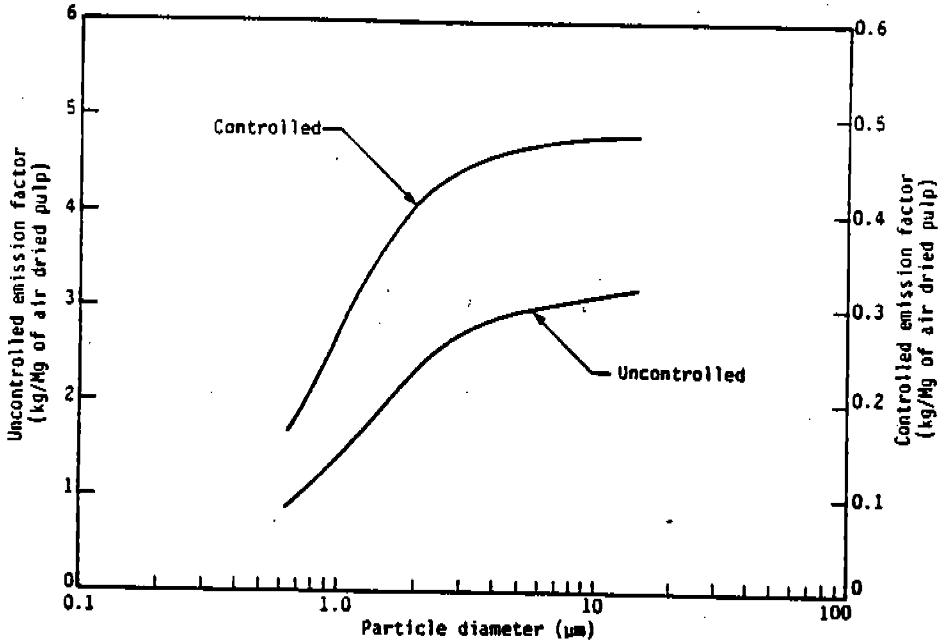


Figure 10.1-6. Cumulative particle size distribution and size specific emission factors for smelt dissolving tank with packed tower.

TABLE 10.1-7. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR A SMELT DISSOLVING TANK WITH A VENTURI SCRUBBER[a]

EMISSION FACTOR RATING: C

Particle size (um)	Cumulative mass % ≤ stated size		Cumulative emission factor (kg/Mg of air dried pulp)	
	Uncontrolled	Controlled	Uncontrolled	Controlled
15	90.0	89.9	3.2	0.09
10	88.5	89.5	3.1	0.09
6	87.0	88.4	3.0	0.09
2.5	73.0	81.3	2.6	0.08
1.25	47.5	63.5	1.7	0.06
1.00	54.0	54.7	1.4	0.06
0.625	25.5	38.7	0.9	0.04
Total	100	100	3.5	0.09

[a] Reference 7.

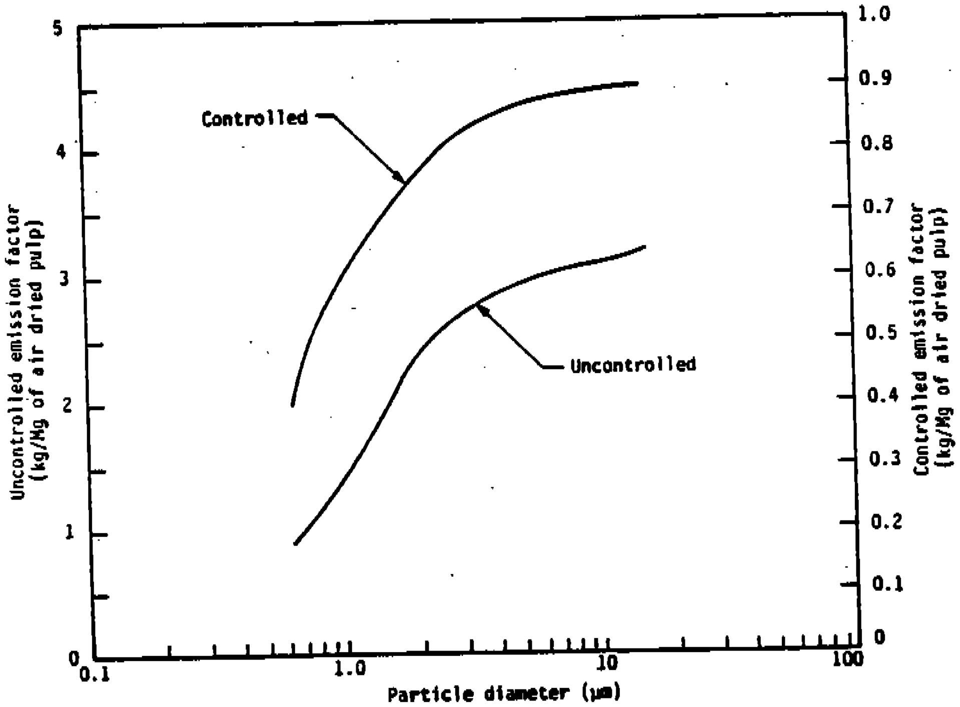


Figure 10.1-7. Cumulative particle size distribution and size specific emission factors for smelt dissolving tank with venturi scrubber.

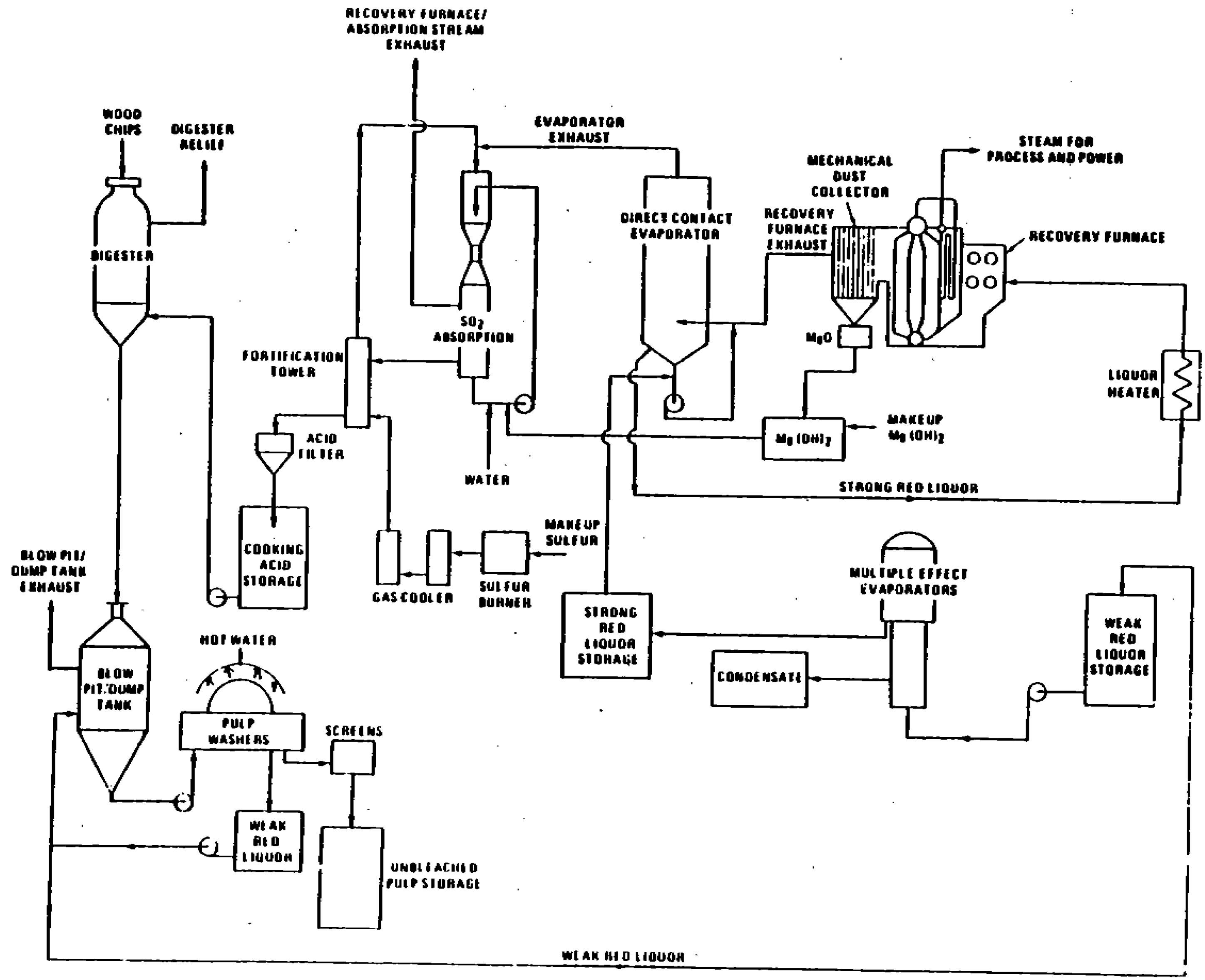


Figure 10.1-8. Simplified process flow diagram of magnesium-base process employing chemical and heat recovery.

incinerated, or sent to a plant for recovery of heat and chemicals. The pulp is then washed and processed through screens and centrifuges to remove knots, bundles of fibers and other material. It subsequently may be bleached, pressed and dried in papermaking operations.

Because of the variety of cooking liquor bases used, numerous schemes have evolved for heat and/or chemical recovery. In calcium base systems, found mostly in older mills, chemical recovery is not practical, and the spent liquor is usually discharged or incinerated. In ammonium base operations, heat can be recovered by combusting the spent liquor, but the ammonium base is thereby consumed. In sodium or magnesium base operations, the heat, sulfur and base all may be feasibly recovered.

If recovery is practiced, the spent (weak) red liquor (which contains more than half of the raw materials as dissolved organic solids) is concentrated in a multiple effect evaporator and a direct contact evaporator to 55 to 60 percent solids. This strong liquor is sprayed into a furnace and burned, producing steam to operate the digesters, evaporators, etc. and to meet other power requirements.

When magnesium base liquor is burned, a flue gas is produced from which magnesium oxide is recovered in a multiple cyclone as fine white power. The magnesium oxide is then water slaked and is used as circulating liquor in a series of venturi scrubbers, which are designed to absorb sulfur dioxide from the flue gas and to form a bisulfite solution for use in the cook cycle. When sodium base liquor is burned, the inorganic compounds are recovered as a molten smelt containing sodium sulfide and sodium carbonate. This smelt may be processed further and used to absorb sulfur dioxide from the flue gas and sulfur burner. In some sodium base mills, however, the smelt may be sold to a nearby kraft mill as raw material for producing green liquor.

If liquor recovery is not practiced, an acid plant is necessary of sufficient capacity to fulfill the mill's total sulfite requirement. Normally, sulfur is burned in a rotary or spray burner. The gas produced is then cooled by heat exhangers and a water spray and is then absorbed in a variety of different scrubbers containing either limestone or a solution of the base chemical. Where recovery is practiced, fortification is accomplished similarly, although a much smaller amount of sulfur dioxide must be produced to make up for that lost in the process.

Emissions And Controls[11] - Sulfur dioxide is generally considered the major pollutant of concern from sulfite pulp mills. The characteristic "kraft" odor is not emitted because volatile reduced sulfur compounds are not products of the lignin/bisulfite reaction.

A major SO_2 source is the digester and blow pit (dump tank) system. Sulfur dioxide is present in the intermittent digester relief gases, as well as in the gases given off at the end of the cook when the digester contents are discharged into the blow pit. The quantity of sulfur dioxide evolved and emitted to the atmosphere in these gas streams depends on the pH of the cooking liquor, the pressure at which the digester contents are discharged, and the effectiveness of the absorption systems employed for SO_2 recovery. Scrubbers can be installed that reduce SO_2 from this source by as much as 99 percent.

Another source of sulfur dioxide emissions is the recovery system. Since magnesium, sodium, and ammonium base recovery systems all use absorption systems to recover SO_2 generated in recovery furnaces, acid fortification towers, multiple effect evaporators, etc., the magnitude of SO_2 emissions depends on the desired efficiency of these systems. Generally, such absorption systems recover better than 95 percent of the sulfur so it can be reused.

The various pulp washing, screening, and cleaning operations are also potential sources of SO_2. These operations are numerous and may account for a significant fraction of a mill's SO_2 emissions if not controlled.

The only significant particulate source in the pulping and recovery process is the absorption system handling the recovery furnace exhaust. Ammonium base systems generate less particulate than do magnesium or sodium base systems. The combustion productions are mostly nitrogen, water vapor and sulfur dioxide.

Auxiliary power boilers also produce emissions in the sulfite pulp mill, and emission factors for these boilers are presented in Chapter 1.

Table 10.1-8 contains emission factors for the various sulfite pulping operations.

10.1.4 Neutral Sulfite Semichemical (NSSC) Pulping

Process Description[9, 12-14] - In this method, wood chips are cooked in a neutral solution of sodium sulfite and sodium carbonate. Sulfite ions react with the lignin in wood, and the sodium bicarbonate acts as a buffer to maintain a neutral solution. The major difference between all semichemical techniques and those of kraft and acid sulfite processes is that only a portion of the lignin is removed during the cook, after which the pulp is further reduced by mechanical disintegration. This method achieves yields as high as 60 to 80 percent, as opposed to 50 to 55 percent for other chemical processes.

The NSSC process varies from mill to mill. Some mills dispose of their spent liquor, some mills recover the cooking chemicals, and some, when operated in conjunction with kraft mills, mix their spent liquor with the kraft liquor as a source of makeup chemcials. When recovery is practiced, the involved steps parallel those of the sulfite process.

Emissions And Controls[9,12-14] - Particulate emissions are a potential problem only when recovery systems are involved. Mills that do practice recovery but are not operated in conjunction with kraft operations often utilize fluidized bed reactors to burn their spent liquor. Because the flue gas contains sodium sulfate and sodium carbonate dust, efficient particulate collection may be included for chemical recovery.

A potential gaseous pollutant is sulfur dioxide. Absorbing towers, digester/blower tank system, and recovery furnace are the main sources of SO_2, with amounts emitted dependent upon the capability of the scrubbing devices installed for control and recovery.

Hydrogen sulfide can also be emitted from NSSC mills which use kraft type recovery furnaces. The main potential source is the absorbing tower, where a

TABLE 10.1-8. EMISSION FACTORS FOR SULFITE PULPING[a]

Source	Base	Control	Emission factor[b]				Emission Factor Rating
			Particulate		Sulfur dioxide		
			kg/ADUMg	lb/ADUT	kg/ADUMg	lb/ADUT	
Digester/blow pit or dump tank[c]	All	None	Neg	Neg	5 to 35	10 to 70	C
	MgO	Process change[d]	Neg	Neg	1 to 3	2 to 6	C
	MgO	Scrubber	Neg	Neg	0.5	1	B
	MgO	Process change and scrubber	Neg	Neg	0.1	0.2	B
	MgO	All exhaust vented through recovery system	Neg	Neg	0	0	A
	NH_3	Process change	Neg	Neg	12.5	25	D
	NH_3	Process change and scrubber	Neg	Neg	0.2	0.4	B
	Na	Process change and scrubber	Neg	Neg	1	2	C
	Ca	Unknown	Neg	Neg	33.5	67	C
Recovery system[e]	MgO	Multicyclone and venturi scrubbers	1	2	4.5	9	A
	NH_3	Ammonia absorption and mist eliminator	0.35	0.7	3.5	7	B
	Na	Sodium carbonate scrubber	2	4	1	2	C
Acid plant[f]	NH_3	Scrubber	Neg	Neg	0.2	0.3	C
	Na	Unknown[g]	Neg	Neg	0.1	0.2	D
	Ca	Jenssen scrubber	Neg	Neg	4	8	C
Other[h]	All	None	Neg	Neg	6	12	D

[a] Reference 11. All factors represent long term average emissions. ADUMg = Air dried unbleached megagram. ADUT = Air dried unbleached ton. Neg = negligible.

[b] Expressed as kg (lb) of pollutant/air dried unbleached ton (mg) of pulp.

[c] Factors represent emissions after cook is completed and when digester contents are discharged into blow pit or dump tank. Some relief gases are vented from digester during cook cycle, but these are usually transferred to pressure accumulators and SO_2 therein reabsorbed for use in cooking liquor. In some mills, actual emissions will be intermittent and for short periods.

[d] May include such measures as raising cooking liquor pH (thereby lowering free SO_2), relieving digester pressure before contents discharge, and pumping out digester contents instead of blowing out.

[e] Recovery system at most mills is closed and includes recovery furnace, direct contact evaporator, multiple effect evaporator, acid fortification tower, and SO_2 absorption scrubbers. Generally only one emission point for entire system. Factors include high SO_2 emissions during periodic purging of recovery systems.

[f] Necessary in mills with insufficient or nonexistent recovery systems.

[g] Control is practiced, but type of system is unknown.

[h] Includes miscellaneous pulping operations such as knotters, washers, screens, etc.

significant quantity of hydrogen sulfite is liberated as the cooking liquor is made. Other possible sources, depending on the operating conditions, include the recovery furnace, and in mills where some green liquor is used in the cooking process, the digester/blow tank system. Where green liquor is used, it is also possible that significant quantities of mercaptans will be produced. Hydrogen sulfide emissions can be eliminated if burned to sulfur dioxide before the absorbing system.

Because the NSSC process differs greatly from mill to mill, and because of the scarcity of adequate data, no emission factors are presented for this process.

References for Section 10.1

1. Review of New Source Performance Standards for Kraft Pulp Mills, EPA-450/3-83-017, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1983.
2. Standards Support and Environmental Impact Statement, Volume I: Proposed Standards of Performance for Kraft Pulp Mills, EPA-450/2-76-014a, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1976.
3. Kraft Pulping - Control of TRS Emissions from Existing Mills, EPA-450/78-003b, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1979.
4. Environmental Pollution Control, Pulp and Paper Industry, Part I: Air, EPA-625/7-76-001, U. S. Environmental Protection Agency, Washington, DC, October 1976.
5. A Study of Nitrogen Oxides Emissions from Lime Kilns, Technical Bulletin Number 107, National Council of the Paper Industry for Air and Stream Improvement, New York, NY, April 1980.
6. A Study of Nitrogen Oxides Emissions from Large Kraft Recovery Furnaces, Technical Bulletin Number 111, National Council of the Paper Industry for Air and Stream Improvement, New York, NY, January 1981.
7. Source Category Report for the Kraft Pulp Industry, EPA Contract Number 68-02-3156, Acurex Corporation, Mountain View, CA, January 1983.
8. Source test data, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1972.
9. Atmospheric Emissions from the Pulp and Paper Manufacturing Industry, EPA-450/1-73-002, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1973.
10. Carbon Monoxide Emissions from Selected Combustion Sources Based on Short-Term Monitoring Records, Technical Bulleting Number 416, National Council of the Paper Industry for Air and Stream Improvement, New York, NY, January 1984.

11. Backgound Document: Acid Sulfite Pulping, EPA-450/3-77-005, U. S. Environmental Protection Agency, Research Triangle Park, NC, January 1977.

12. E. R. Hendrickson, et al., Control of Atmospheric Emissions in the Wood Pulping Industry, Volume I, HEW Contract Number CPA-22-69-18, U. S. Environmental Protection Agency, Washington, DC, March 15, 1970.

13. M. Benjamin, et al., "A General Description of Commercial Wood Pulping and Bleaching Processes", Journal of the Air Pollution Control Association, 19 (3):155-161, March 1969.

14. S. F. Galeano and B. M. Dillard, "Process Modifications for Air Pollution Control in Neutral Sulfite Semi-chemical Mills", Journal of the Air Pollution Control Association, 22(3):195-199, March 1972.

11.2.6 INDUSTRIAL PAVED ROADS

11.2.6.1 General

Various field studies have indicated that dust emissions from industrial paved roads are a major component of atmospheric particulate matter in the vicinity of industrial operations. Industrial traffic dust has been found to consist primarily of mineral matter, mostly tracked or deposited onto the roadway by vehicle traffic itself when vehicles enter from an unpaved area or travel on the shoulder of the road, or when material is spilled onto the paved surface from haul truck traffic.

11.2.6.2 Emissions And Correction Parameters

The quantity of dust emissions from a given segment of paved road varies linearly with the volume of traffic. In addition, field investigations have shown that emissions depend on correction parameters (road surface silt content, surface dust loading and average vehicle weight) of a particular road and associated vehicle traffic.[1-2]

Dust emissions from industrial paved roads have been found to vary in direct proportion to the fraction of silt (particles $\leq$75 microns in diameter) in the road surface material.[1-2] The silt fraction is determined by measuring the proportion of loose dry surface dust that passes a 200 mesh screen, using the ASTM-C-136 method. In addition, it has also been found that emissions vary in direct proportion to the surface dust loading.[1-2] The road surface dust loading is that loose material which can be collected by broom sweeping and vacuuming of the traveled portion of the paved road. Table 11.2.6-1 summarizes measured silt and loading values for industrial paved roads.

11.2.6.3 Predictive Emission Factor Equations

The quantity of total suspended particulate emissions generated by vehicle traffic on dry industrial paved roads, per vehicle kilometer traveled (VKT) or vehicle mile traveled (VMT) may be estimated, with a rating of B or D (see below), using the following empirical expression[2]:

$$E = 0.022\ I \left(\frac{4}{n}\right) \left(\frac{s}{10}\right) \left(\frac{L}{280}\right) \left(\frac{W}{2.7}\right)^{0.7} \quad \text{(kg/VKT)} \qquad (1)$$

$$E = 0.077\ I \left(\frac{4}{n}\right) \left(\frac{s}{10}\right) \left(\frac{L}{1000}\right) \left(\frac{W}{3}\right)^{0.7} \quad \text{(lb/VMT)}$$

where:
E = emission factor
I = industrial augmentation factor (dimensionless) (see below)
n = number of traffic lanes
s = surface material silt content (%)
L = surface dust loading, kg/km (lb/mile) (see below)
W = average vehicle weight, Mg (ton)

TABLE 11.2.6-1. TYPICAL SILT CONTENT AND LOADING VALUES FOR PAVED ROADS AT INDUSTRIAL FACILITIES[a]

Industry	No. of Sites	No. of Samples	Silt (%, w/w)		No. of Travel lanes	Total loading x 10^{-3}			Silt loading (g/m^2)	
			Range	Mean		Range	Mean	Units[b]	Range	Mean
Copper smelting	1	3	[15.4-21.7]	[19.0]	2	[12.9-19.5] [45.8-69.2]	[15.9] [55.4]	kg/km lb/mi	[188-400]	[292]
Iron and steel production	6	20	1.1-35.7	12.5	2	0.006-4.77 0.020-16.9	0.495 1.75	kg/km lb/mi	0.09-79	12
Asphalt batching	1	3	[2.6-4.6]	[3.3]	1	[12.1-18.0] [43.0-64.0]	[14.9] [52.8]	kg/km lb/mi	[76-193]	[120]
Concrete batching	1	3	[5.2-6.0]	[5.5]	2	[1.4-1.8] [5.0-6.4]	[1.7] [5.9]	kg/km lb/mi	[11-12]	[12]
Sand and gravel processing	1	3	[6.4-7.9]	[7.1]	1	[2.8-5.5] [9.9-19.4]	[3.8] [13.3]	kg/km lb/mi	[53-95]	[70]

[a] References 1-5. Brackets indicate values based on only one plant test.
[b] Multiply entries by 1,000 to obtain stated units.

The industrial road augmentation factor (I) in the Equation 1 takes into account higher emissions from industrial roads than from urban roads. I = 7.0 for an industrial roadway which traffic enters from unpaved areas. I = 3.5 for an industrial roadway with unpaved shoulders where 20 percent of the vehicles are forced to travel temporarily with one set of wheels on the shoulder. I = 1.0 for cases in which traffic does not travel on unpaved areas. A value between 1.0 and 7.0 which best represents conditions for paved roads at a certain industrial facility should be used for I in the equation.

The equation retains the quality rating of B if applied to vehicles traveling entirely on paved surfaces (I = 1.0) and if applied within the range of source conditions that were tested in developing the equation as follows:

Silt content (%)	Surface loading		No. of lanes	Vehicle weight	
	kg/km	lb/mile		Mg	tons
5.1 - 92	42.0 - 2000	149 - 7100	2 - 4	2.7 - 12	3 - 13

If I is >1.0, the rating of the equation drops to D because of the subjectivity in the guidelines for estimating I.

The quantity of fine particle emissions generated by traffic consisting predominately of medium and heavy duty vehicles on dry industrial paved roads, per vehicle unit of travel, may be estimated, with a rating of A, using the

APPENDIX B

(Reserved for future use.)

APPENDIX C.1

PARTICLE SIZE DISTRIBUTION DATA AND SIZED EMISSION FACTORS FOR SELECTED SOURCES

CONTENTS

AP-42
Section | Page

CONTENTS (cont.)

AP-42
Section

Page

8.9 Coal Cleaning

8.18 Phosphate Rock Processing

8.xx Lightweight Aggregate

10.4 Woodworking Waste Collection Operations

APPENDIX C.1

PARTICLE SIZE DISTRIBUTION DATA
AND
SIZED EMISSION FACTORS FOR SELECTED SOURCES

Introduction

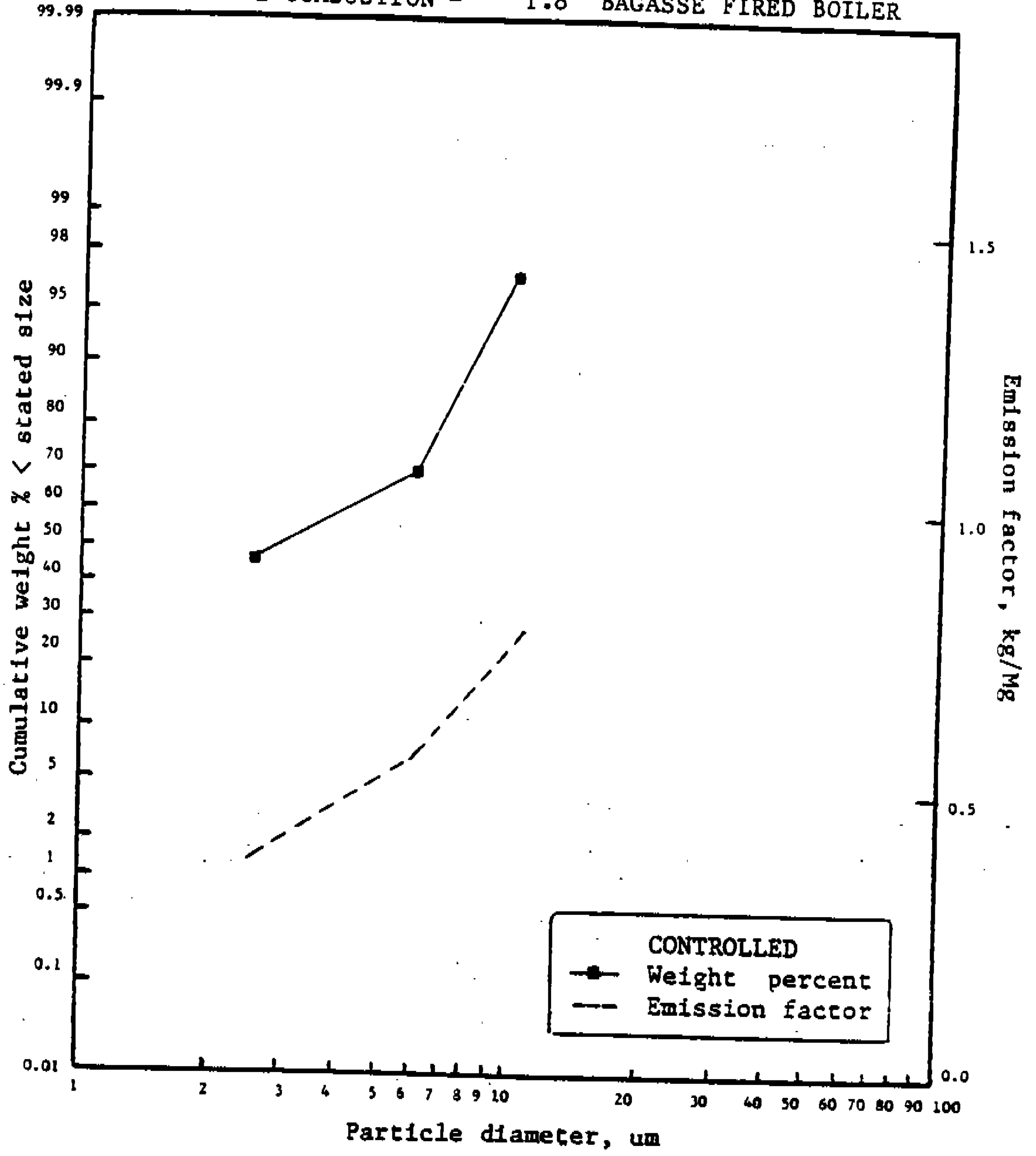
This Appendix presents particle size distributions and emission factors for miscellaneous sources or processes for which documented emission data were available. Generally, the sources of data used to develop particle size distributions and emission factors for this Appendix were:

1) Source test reports in the files of the Emission Measurement Branch (EMB) of EPA's Emission Standards And Engineering Division, Office Of Air Quality Planning And Standards.
2) Source test reports in the Fine Particle Emission Information System (FPEIS), a computerized data base maintained by EPA's Air And Energy Engineering Research Laboratory, Office Of Research And Development.
3) A series of source tests titled Fine Particle Emissions From Stationary And Miscellaneous Sources In The South Coast Air Basin, by H. J. Taback.[3]
4) Particle size distribution data reported in the literature by various individuals and companies.

Particle size data from FPEIS were mathematically normalized into more uniform and consistent data. Where EMB tests and Taback report data were filed in FPEIS, the normalized data were used in developing this Appendix.

Information on each source category in Appendix C.1 is presented in a two page format. For a source category, a graph provided on the first page presents a particle size distribution expressed as the cumulative weight percent of particles less than a specified aerodynamic diameter (cut point), in micrometers. A sized emission factor can be derived from the mathematical product of a mass emission factor and the cumulative weight percent of particles smaller than a specific cut point in the graph. At the bottom of the page is a table of numerical values for particle size distributions and sized emission factors, in micrometers, at selected values of aerodynamic particle diameter. The second page gives some information on the data used to derive the particle size distributions.

Portions of the Appendix denoted TBA in the table of contents refer to information which will be added at a later date.



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg
	Wet scrubber controlled	Wet scrubber controlled
2.5	46.3	0.37
6.0	70.5	0.56
10.0	97.1	0.78

NUMBER OF TESTS: 2, conducted after wet scrubber control

STATISTICS:

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	46.3	70.5	97.1
Standard deviation (Cum. %):	0.9	0.9	1.9
Min (Cum. %):	45.4	69.6	95.2
Max (Cum. %):	47.2	71.4	99.0

TOTAL PARTICULATE EMISSION FACTOR: Approximately 0.8 kg particulate/Mg bagasse charged to boiler. This factor is derived from AP-42, Section 1.8, 4/77, which states that the particulate emission factor from an uncontrolled bagasse fired boiler is 8 kg/Mg and that wet scrubbers typically provide 90% particulate control.

SOURCE OPERATION: Source is a Riley Stoker Corp. vibrating grate spreader stoker boiler rated at 120,000 lb/hr but operated during this testing at 121% of rating. Average steam temperature and pressure were 579°F and 199 psig respectively. Bagasse feed rate could not be measured, but was estimated to be about 41 (wet) tons/hr.

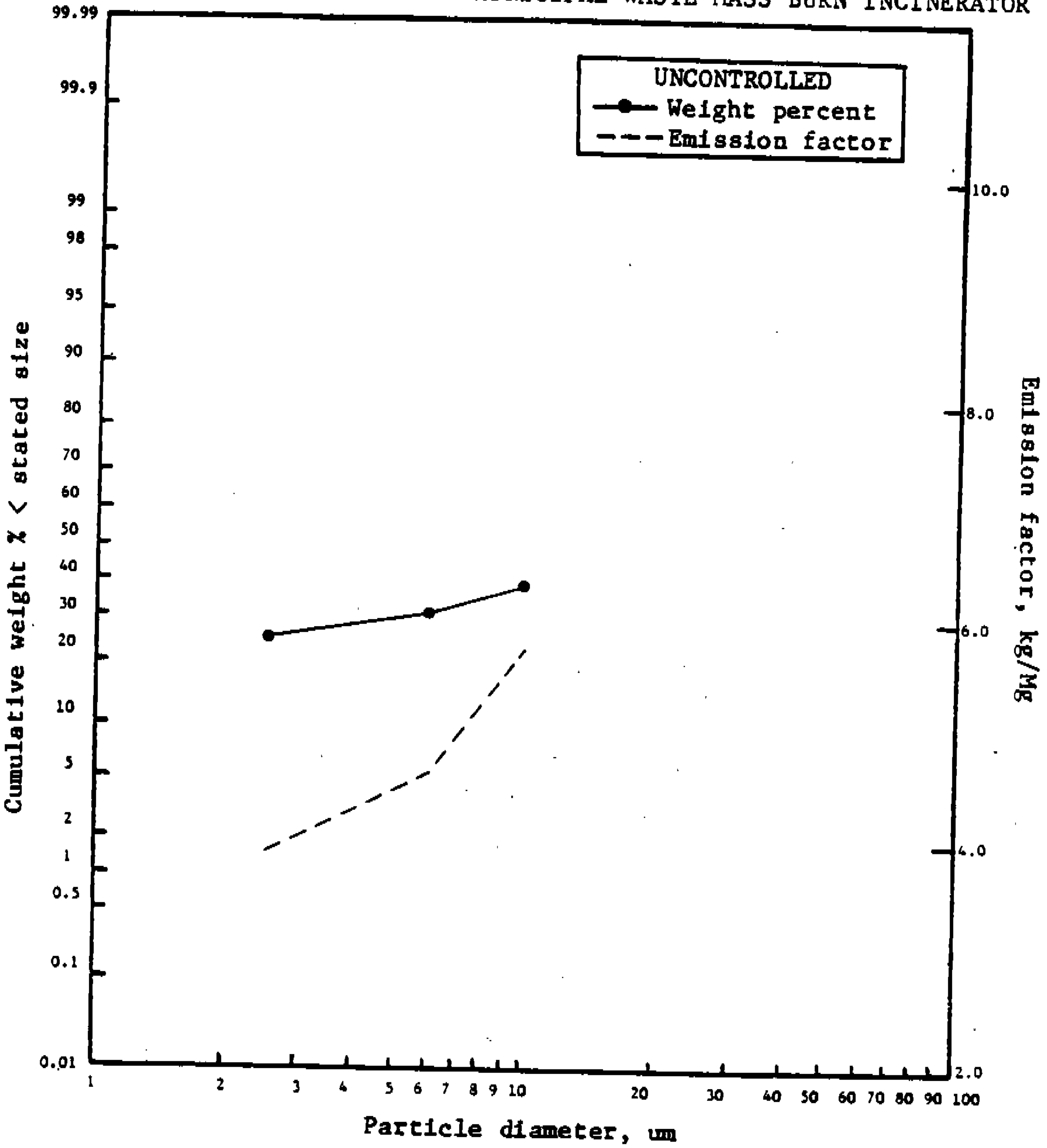
SAMPLING TECHNIQUE: Anderson Cascade impactor.

EMISSION FACTOR RATING: D

REFERENCE:

Emission Test Report, U. S. Sugar Company, Bryant, Fl, EMB-80-WFB-6, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1980.

2.1 REFUSE INCINERATION: MUNICIPAL WASTE MASS BURN INCINERATOR



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg
	Uncontrolled	Uncontrolled
2.5	26.0	3.9
6.0	30.6	4.6
10.0	38.0	5.7

2.1 REFUSE INCINERATION: MUNICIPAL WASTE MASS BURN INCINERATOR

NUMBER OF TESTS: 7, conducted before control

STATISTICS:

Aerodynamic Particle Diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	26.0	30.6	38.0
Standard deviation (Cum. %):	9.5	13.0	14.0
Min (Cum. %):	18	22	24
Max (Cum. %):	40	49	54

TOTAL PARTICULATE EMISSION FACTOR: 15 kg of particulate/Mg of refuse charged. Emission factor from AP-42 Section 2.1.

SOURCE OPERATION: Municipal incinerators reflected in the data base include various mass burning facilities of typical design and operation.

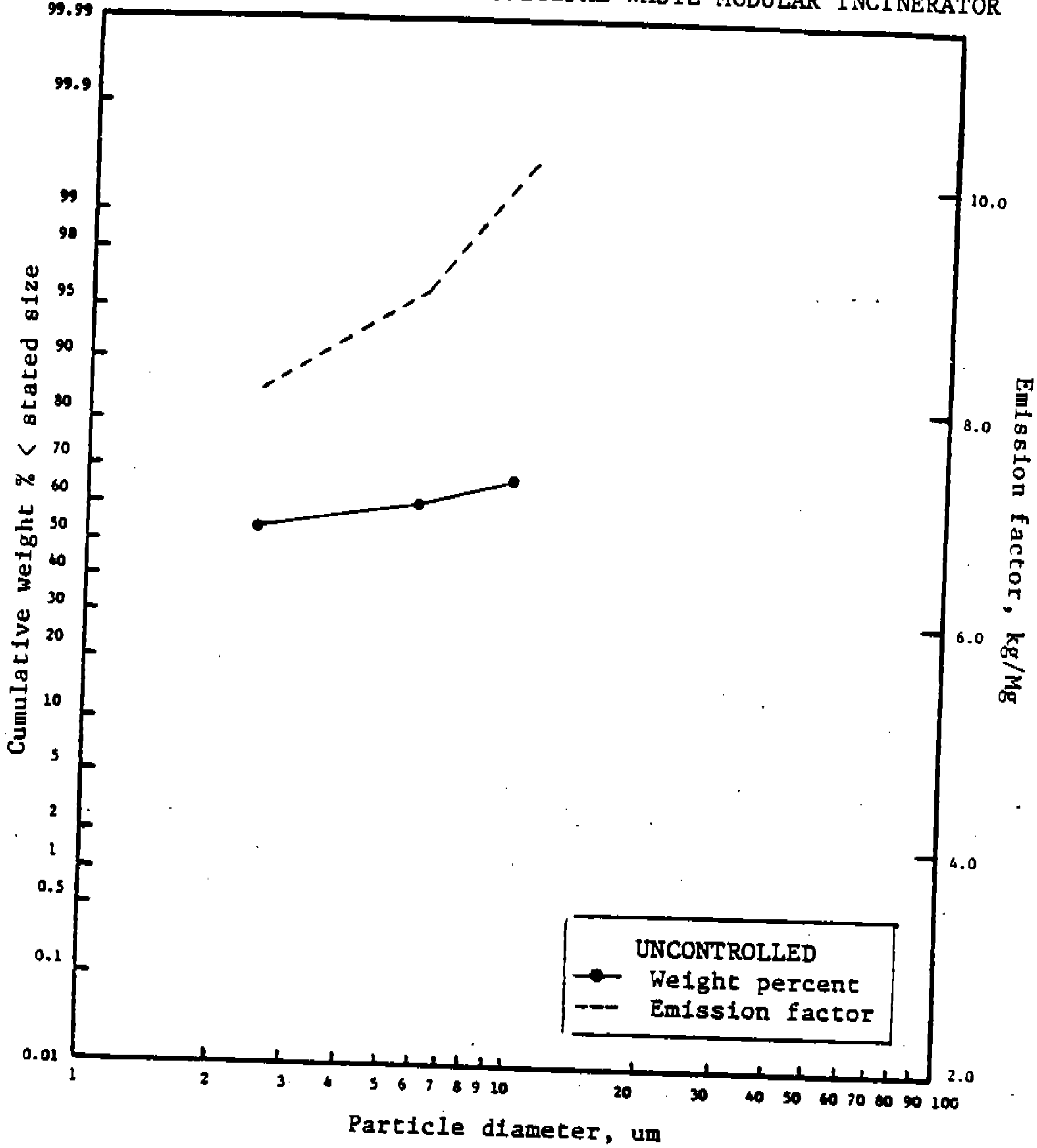
SAMPLING TECHNIQUE: Unknown.

EMISSION FACTOR RATING: D

REFERENCE:

Determination Of Uncontrolled Emissions, Product 2B, Montgomery County, Maryland, Roy F. Weston, Inc., West Chester, PA, August 1984.

2.1 REFUSE INCINERATION: MUNICIPAL WASTE MODULAR INCINERATOR



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg
	Uncontrolled	Uncontrolled
2.5	54.0	8.1
6.0	60.1	9.0
10.0	67.1	10.1

2.1 REFUSE INCINERATION: MUNICIPAL WASTE MODULAR INCINERATOR

NUMBER OF TESTS: 3, conducted before control

STATISTICS: Aerodynamic Particle Diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	54.0	60.1	67.1
Standard deviation (Cum. %):	19.0	20.8	23.2
Min (Cum. %):	34.5	35.9	37.5
Max (Cum. %):	79.9	86.6	94.2

TOTAL PARTICULATE EMISSION FACTOR: 15 kg of particulate/Mg of refuse charged. Emission factor from AP-42.

SOURCE OPERATION: Modular incinerator (2 chambered) operation was at 75.9% of the design process rate (10,000 lb/hr) and 101.2% of normal steam production rate. Natural gas is required to start the incinerator each week. Average waste charge rate was 1.983T/hr. Net heating value of garbage 4200-4800 BTU/lb garbage charged.

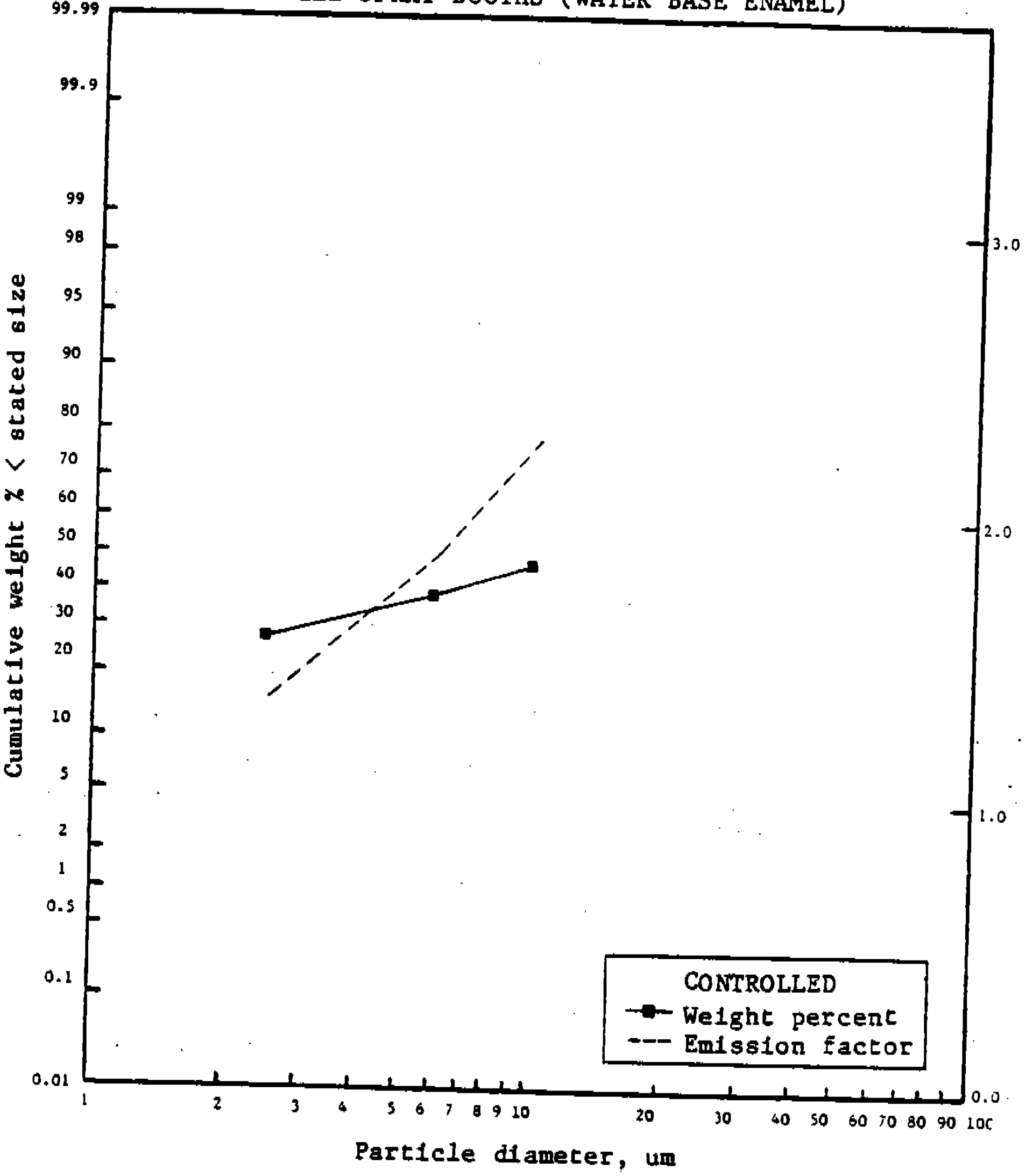
SAMPLING TECHNIQUE: Andersen Impactor

EMISSION FACTOR RATING: C

REFERENCE:

Emission Test Report, City of Salem, Salem, Va, EMB-80-WFB-1, U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1980.

4.2.2.8 AUTOMOBILE & LIGHT DUTY TRUCK SURFACE COATING OPERATIONS: AUTOMOBILE SPRAY BOOTHS (WATER BASE ENAMEL)



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg
	Water curtain controlled	Water curtain controlled
2.5	28.6	1.39
6.0	38.2	1.85
10.0	46.7	2.26

4.2.2.8 AUTOMOBILE AND LIGHT DUTY TRUCK SURFACE COATING OPERATIONS: AUTOMOBILE SPRAY BOOTHS (WATER BASE ENAMEL)

NUMBER OF TESTS: 2, conducted after water curtain control.

STATISTICS:

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	28.6	38.2	46.7
Standard deviation (Cum. %):	14.0	16.8	20.6
Min (Cum. %):	15.0	21.4	26.1
Max (Cum. %):	42.2	54.9	67.2

TOTAL PARTICULATE EMISSION FACTOR: 4.84 kg particulate/Mg of water base enamel sprayed. From References a and b.

SOURCE OPERATION: Source is a water base enamel spray booth in an automotive assembly plant. Enamel spray rate is 568 lbs/hour, but spray gun type is not identified. The spray booth exhaust rate is 95,000 scfm. Water flow rate to the water curtain control device is 7181 gal/min. Source is operating at 84% of design rate.

SAMPLING TECHNIQUE: SASS and Joy trains with cyclones.

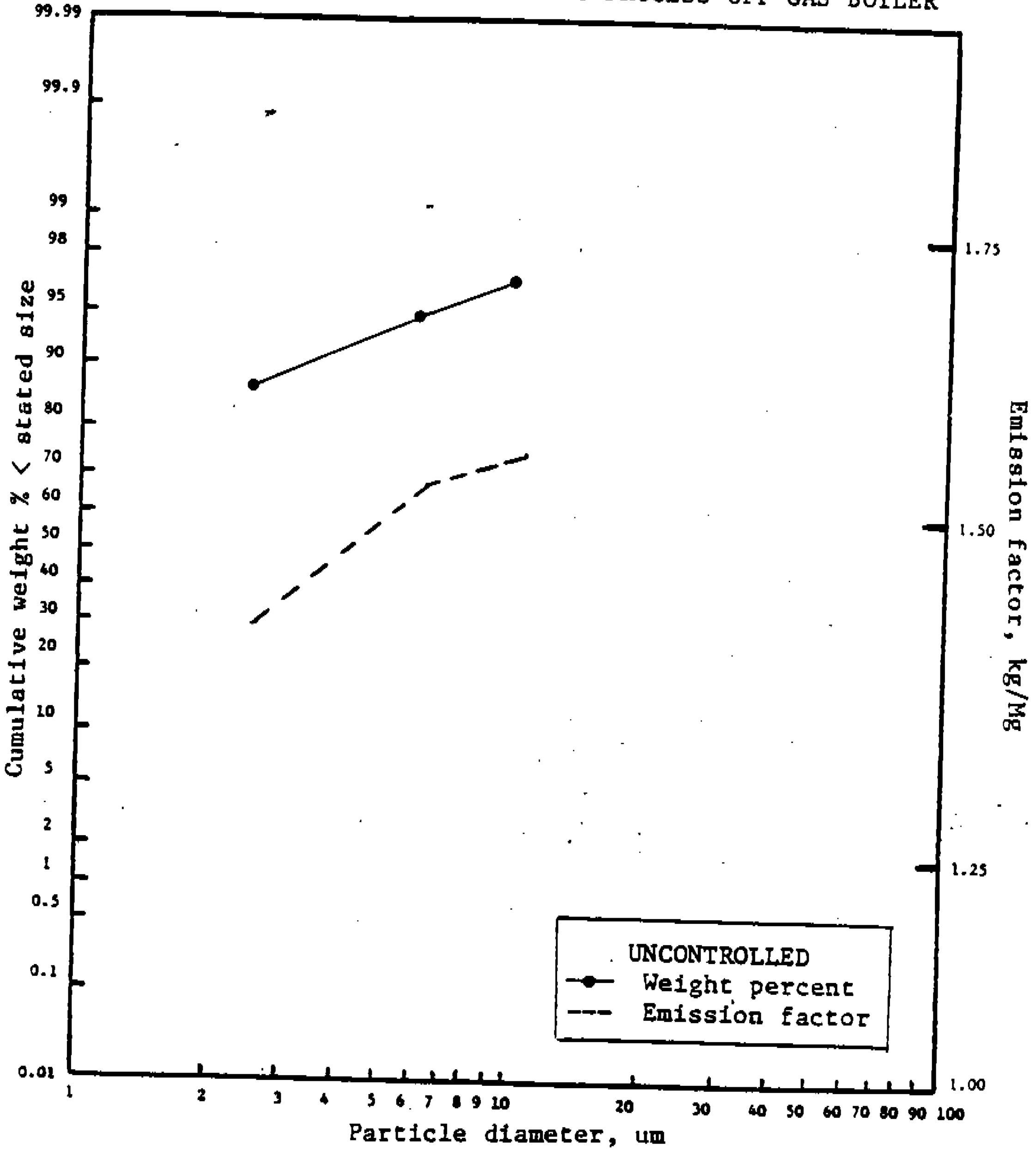
EMISSION FACTOR RATING: D

REFERENCES:

a. H. J. Taback, Fine Particle Emissions from Stationary and Miscellaneous Sources in the South Coast Air Basin, PB 293 923/AS, National Technical Information Service, Springfield, VA, February 1979.

b. Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System, Series Report No. 234, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.

5.3 CARBON BLACK: OIL FURNACE PROCESS OFF GAS BOILER



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg
	Uncontrolled	Uncontrolled
2.5	87.3	1.40
6.0	95.0	1.52
10.0	97.0	1.55

5.3 CARBON BLACK: OIL FURNACE PROCESS OFF GAS BOILER

NUMBER OF TESTS: 3, conducted at off gas boiler outlet

STATISTICS:

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	87.3	95.0	97.0
Standard Deviation (Cum. %):	2.3	3.7	8.0
Min (Cum. %):	76.0	90.0	94.5
Max (Cum. %):	94.0	99	100

TOTAL PARTICULATE EMISSION FACTOR: 1.6 kg particulate/Mg carbon black produced, from reference.

SOURCE OPERATION: Process operation: "normal" (production rate = 1900 kg/hr). Product is collected in fabric filter, but the off gas boiler outlet is uncontrolled.

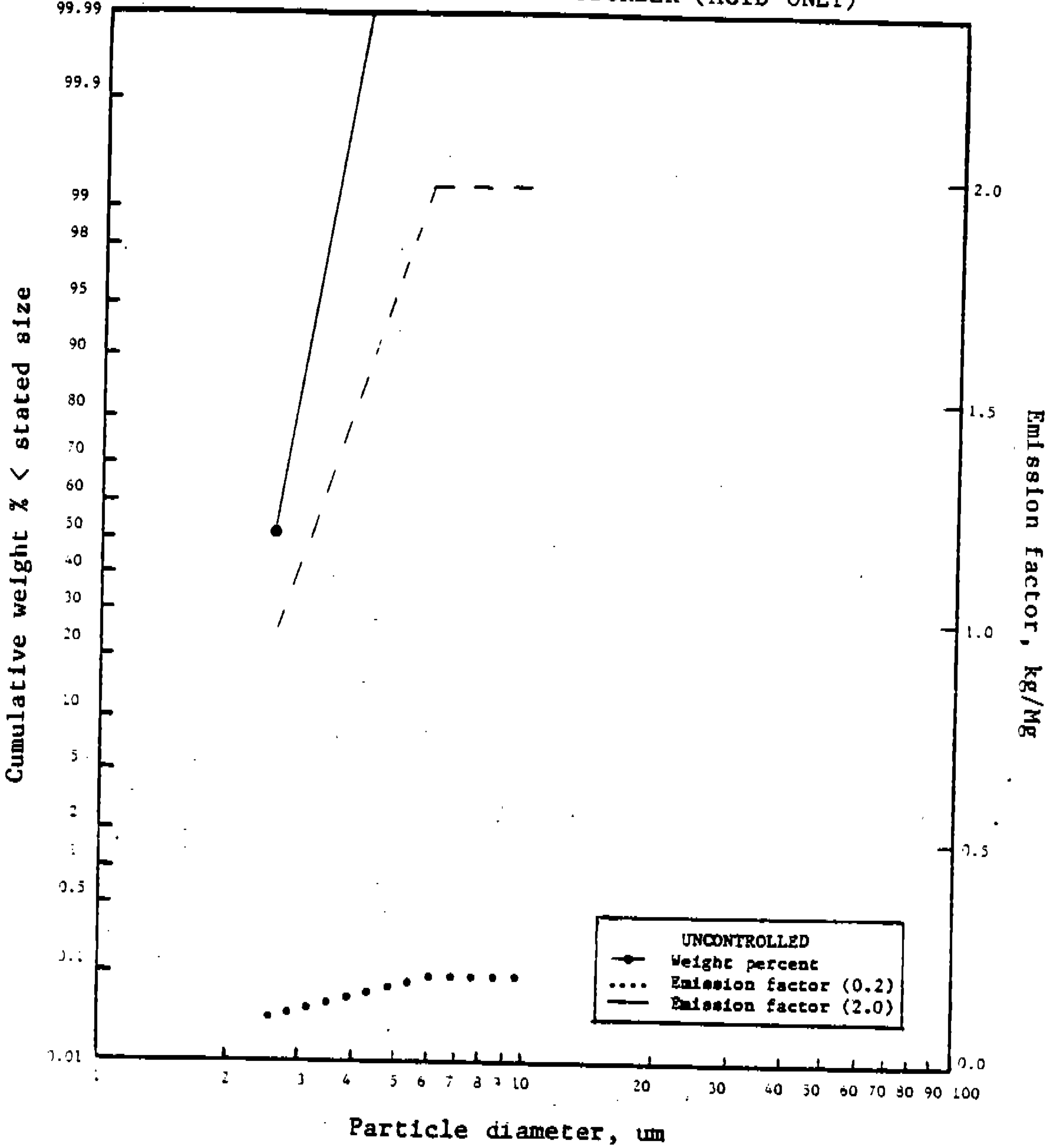
SAMPLING TECHNIQUE: Brinks Cascade Impactor

EMISSION FACTOR RATING: D

REFERENCE:

Air Pollution Emission Test, Phillips Petroleum Company, Toledo, OH, EMB-73-CBK-1, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1974.

5.17 SULFURIC ACID: ABSORBER (ACID ONLY)



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg	
		Uncontrolled	
	Uncontrolled	(0.2)	(2.0)
2.5	51.2	0.10	1.0
6.0	100	0.20	2.0
10.0	100	0.20	2.0

5.17 SULFURIC ACID: ABSORBER (ACID ONLY)

NUMBER OF TESTS: Not available

STATISTICS:

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	51.2	100	100
Standard deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: 0.2 to 2.0 kg acid mist/Mg sulfur charged, for uncontrolled 98% acid plants burning elemental sulfur. Emission factors are from AP-42.

SOURCE OPERATION: Not available

SAMPLING TECHNIQUE: Brink Cascade Impactor

EMISSION FACTOR RATING: E

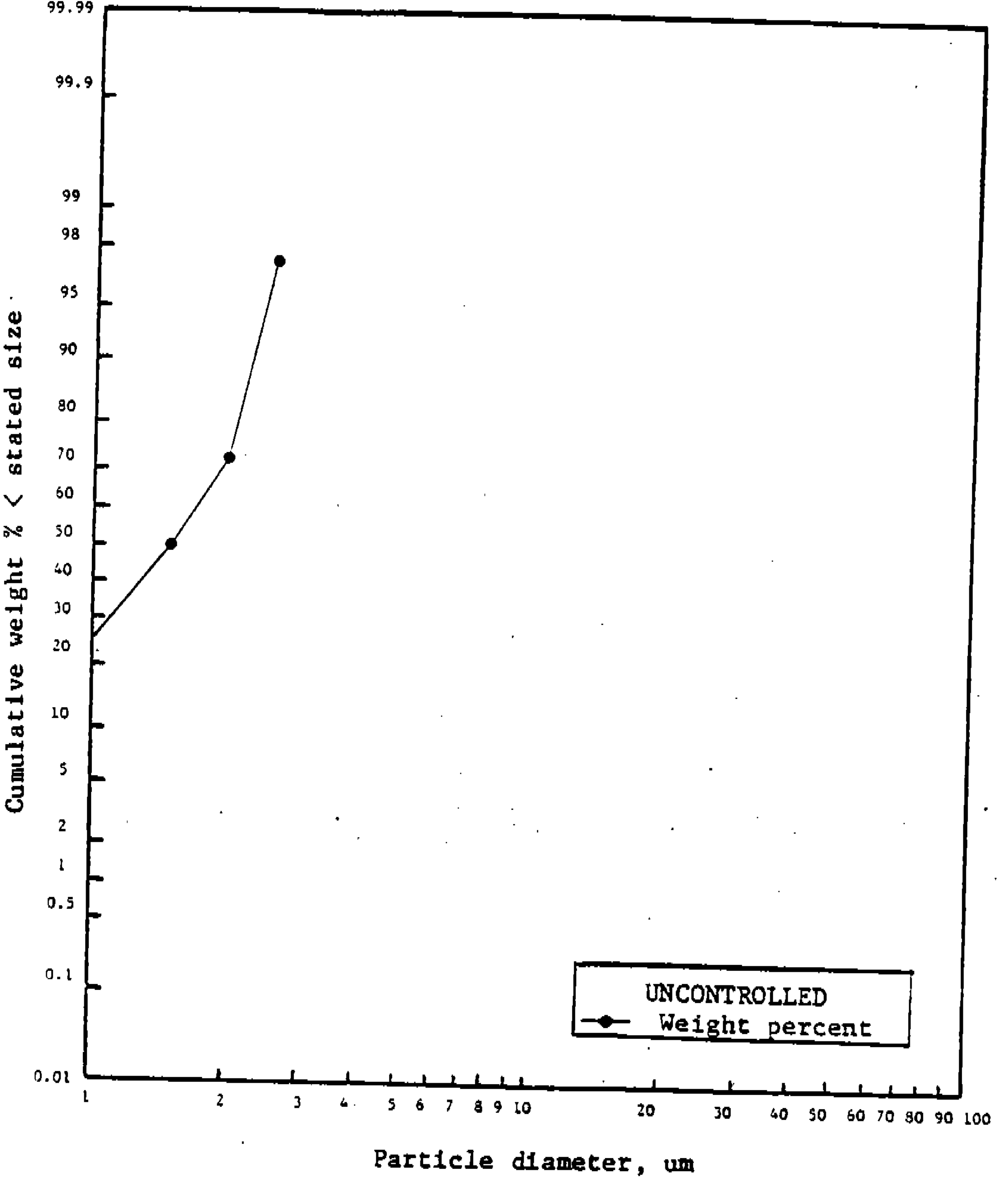
REFERENCES:

a. Final Guideline Document: Control of Sulfuric Acid Mist Emissions from Existing Sulfuric Acid Production Units, EPA-450/2-77-019, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1977.

b. R. W. Kurek, Special Report On EPA Guidelines For State Emission Standards For Sulfuric Acid Plant Mist, E. I. du Pont de Nemours and Company, Wilmington, DE, June 1974.

c. J. A. Brink, Jr., "Cascade Impactor For Adiabatic Measurements", Industrial and Engineering Chemistry, 50:647, April 1958.

5.17 SULFURIC ACID: ABSORBER, 20% OLEUM



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg
	Uncontrolled	Uncontrolled
2.5	97.5	See Table 5.17-2
6.0	100	
10.0	100	

5.17 SULFURIC ACID: ABSORBER, 20% OLEUM

NUMBER OF TESTS: Not available

STATISTICS: Aerodynamic particle diameter (um)*:	1.0	1.5	2.0
Mean (Cum. %):	26	50	73
Standard deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: Acid mist emissions from sulfuric acid plants are a function of type of feed as well as oleum content of product. See AP-42 Section 5.17, Table 5.17-2.

SOURCE OPERATION: Not available

SAMPLING TECHNIQUE: Brink Cascade Impactor

EMISSION FACTOR RATING: E

REFERENCES:

a. Final Guideline Document: Control of Sulfuric Acid Mist Emissions from Existing Sulfuric Acid Production Units, EPA-450/2-77-019, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1977.

b. R. W. Kurek, Special Report On EPA Guidelines For State Emission Standards For Sulfuric Acid Plant Mist, E. I. du Pont de Nemours and Company, Wilmington, DE, June 1974.

c. J. A. Brink, Jr., "Cascade Impactor For Adiabatic Measurements", Industrial and Engineering Chemistry, 50:647, April 1958.

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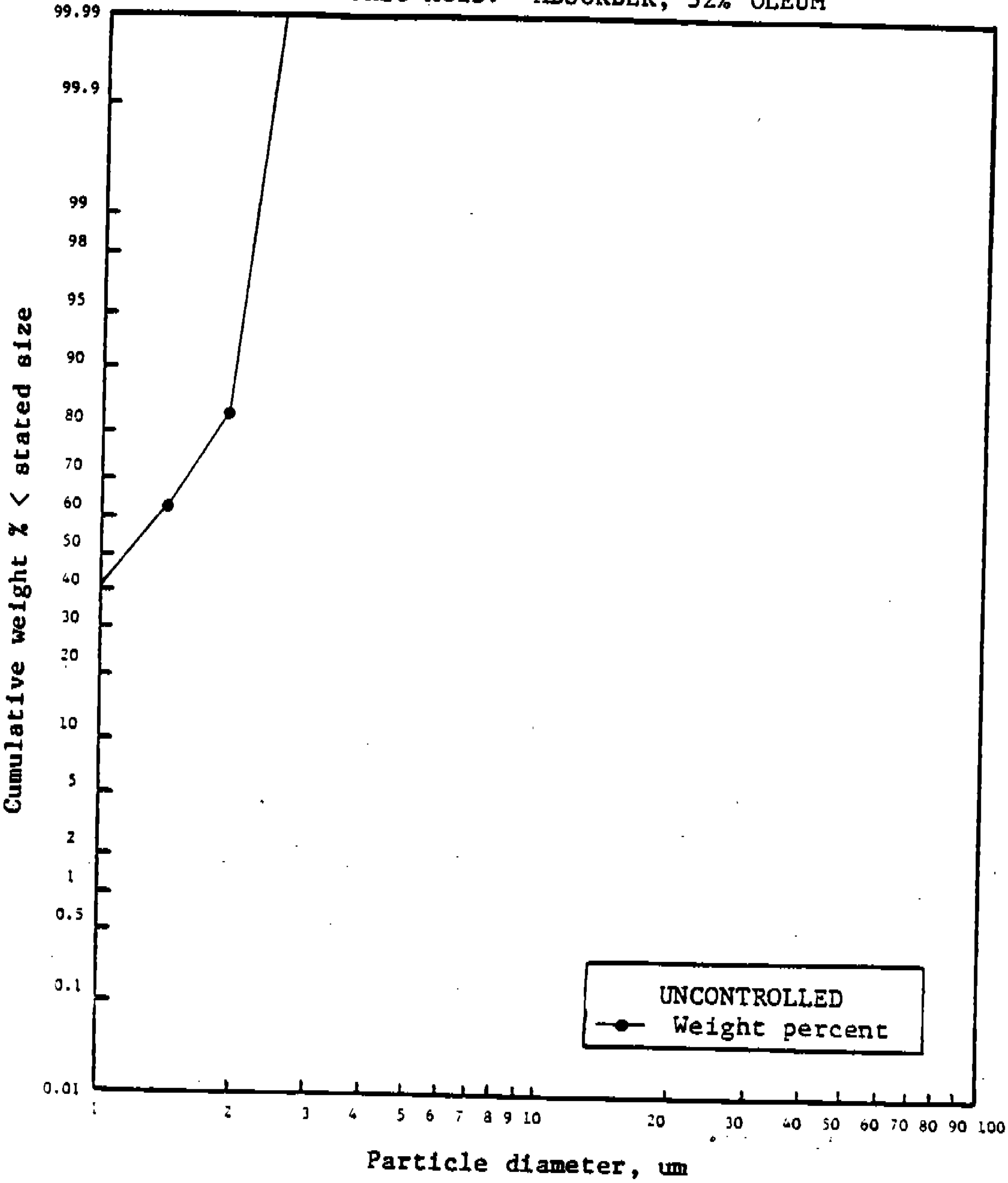
*100% of the particulate is less than 2.5 um in diameter.

5.17 SULFURIC ACID: ABSORBER, 32% OLEUM



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg
	Uncontrolled	Uncontrolled
2.5	100	See Table 5.17-2
6.0	100	
10.0	100	

5.17 SULFURIC ACID: ABSORBER, 32% OLEUM

NUMBER OF TESTS: Not available

STATISTICS: Aerodynamic particle diameter (um)[*]:	1.0	1.5	2.0
Mean (Cum. %):	41	63	84
Standard deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: Acid mist emissions from sulfuric acid plants are a function of type of feed as well as oleum content of product. See AP-42 Section 5.17, Table 5.17-2.

SOURCE OPERATION: Not available

SAMPLING TECHNIQUE: Brink Cascade Impactor

EMISSION FACTOR RATING: E

REFERENCES:

a. *Final Guideline Document: Control of Sulfuric Acid Mist Emissions from Existing Sulfuric Acid Production Units*, EPA-450/2-77-019, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1977.

b. R. W. Kurek, *Special Report On EPA Guidelines For State Emission Standards For Sulfuric Acid Plant Mist*, E. I. du Pont de Nemours and Company, Wilmington, DE, June 1974.

c. J. A. Brink, Jr., "Cascade Impactor For Adiabatic Measurements", *Industrial and Engineering Chemistry*, *50*:647, April 1958.

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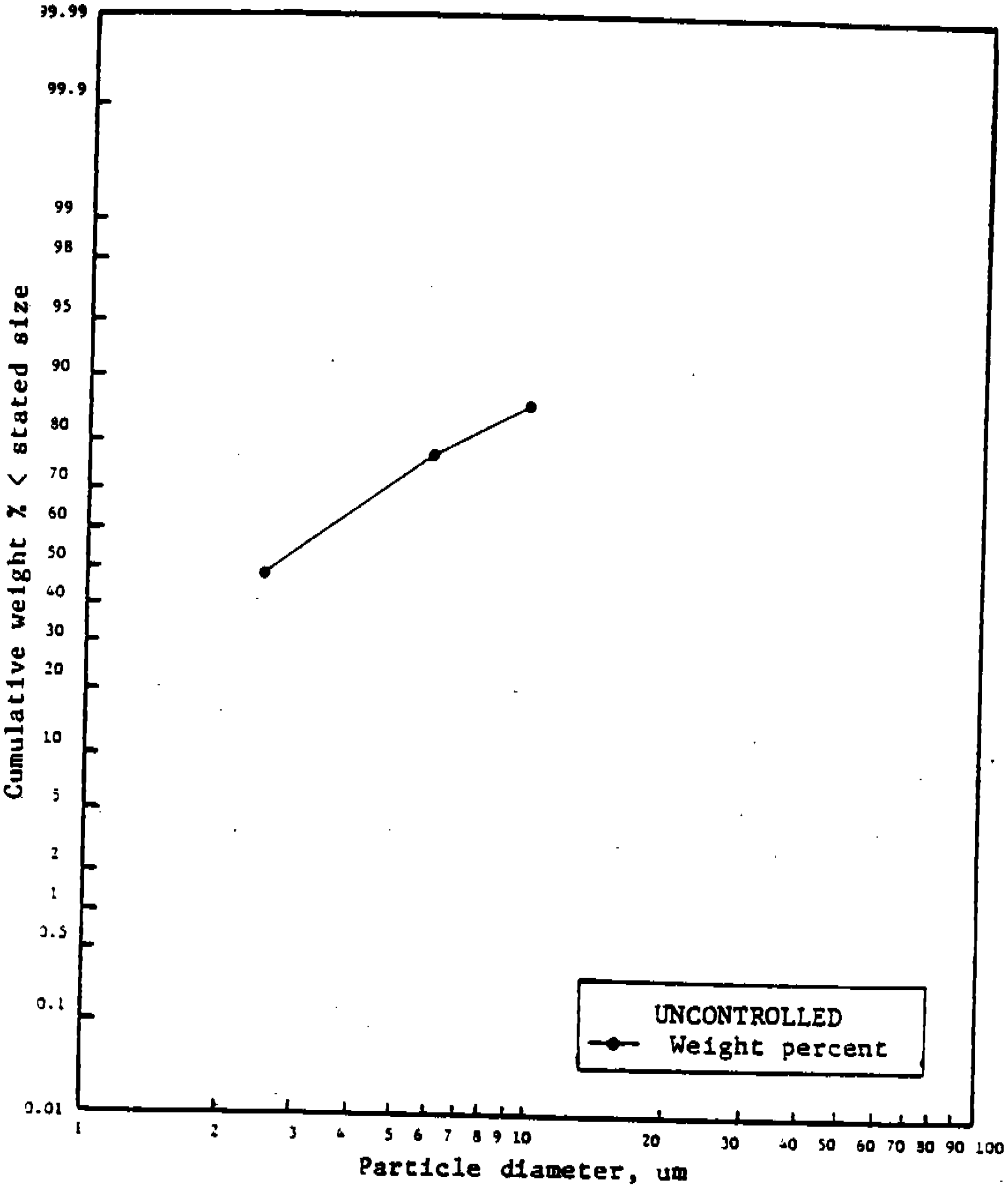
[*] 100% of the particulate is less than 2.5 um in diameter.

5.17 SULFURIC ACID: SECONDARY ABSORBER



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg
	Uncontrolled	Uncontrolled
2.5	48	Not Available
6.0	78	Not Available
10.0	87	Not Available

5.17 SULFURIC ACID: SECONDARY ABSORBER

NUMBER OF TESTS: Not available

STATISTICS:

Particle Size (um):	2.5	6.0	10.0
Mean (Cum. %):	48	78	87
Standard Deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: Acid mist emission factors vary widely according to type of sulfur feedstock. See AP-42 Section 5.17 for guidance.

SOURCE OPERATION: Source is the second absorbing tower in a double absorption sulfuric acid plant. Acid mist loading is 175 - 350 mg/m^3.

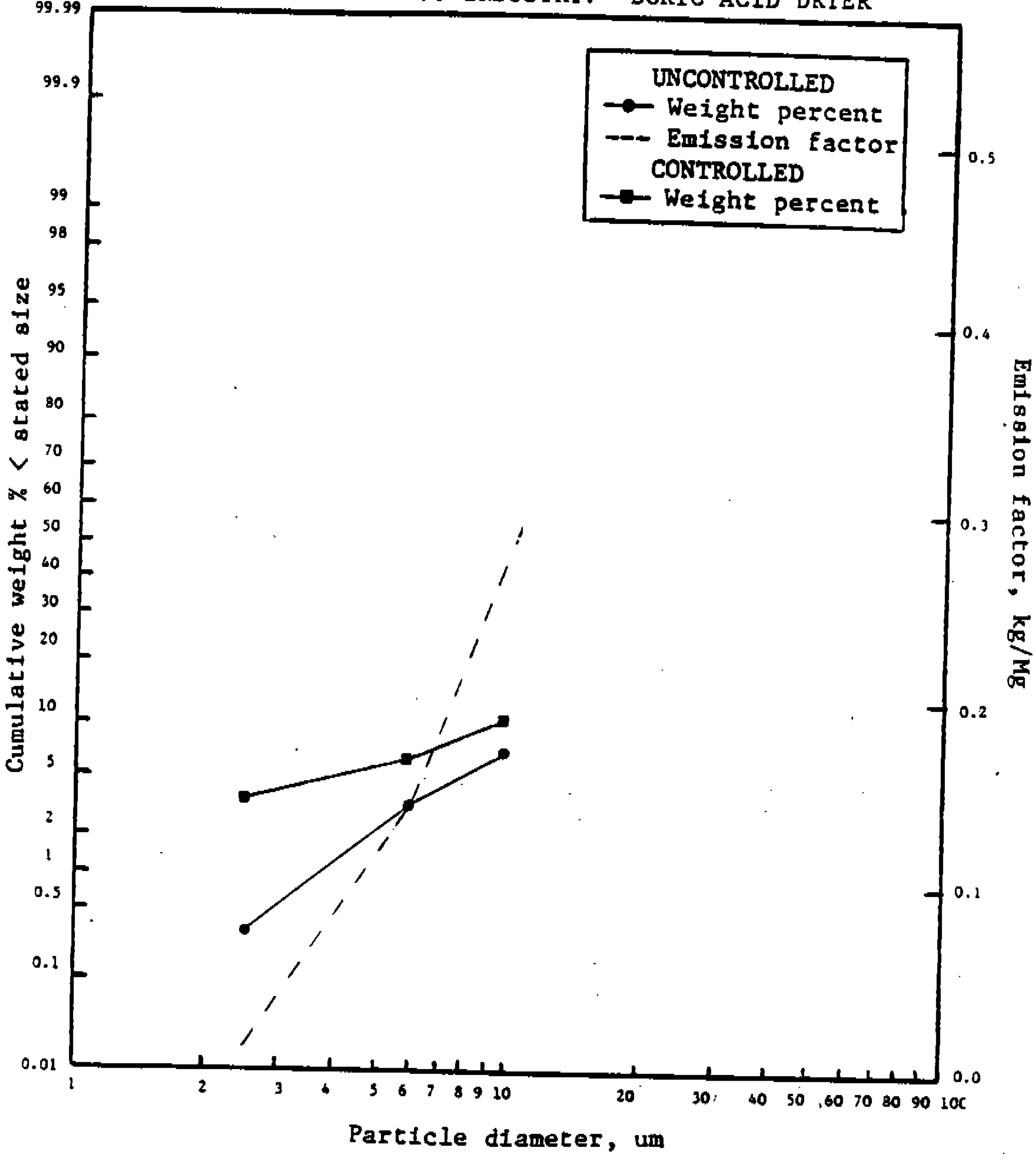
SAMPLING TECHNIQUE: Andersen Impactor

EMISSION FACTOR RATING: E

REFERENCE:

G. E. Harris and L. A. Rohlack, "Particulate Emissions from Non-fired Sources in Petroleum Refineries: A Review of Existing Data", Publication No. 4363, American Petroleum Institute, Washington, DC, December 1982.

5.xx CHEMICAL PROCESS INDUSTRY: BORIC ACID DRYER



Aerodynamic particle diameter, um	Cumulative wt. % < stated size		Emission factor, kg/Mg	
	Uncontrolled	Fabric filter	Uncontrolled	Fabric filter controlled
2.5	0.3	3.3	0.01	0.004
6.0	3.3	6.7	0.14	0.007
10.0	6.9	10.6	0.29	0.011

5.xx BORIC ACID DRYER

NUMBER OF TESTS: a) 1, conducted before controls
b) 1, conducted after fabric filter control

STATISTICS:

(a) Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	0.3	3.3	6.9
Standard Deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

(b) Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	3.3	6.7	10.6
Standard Deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: Before control, 4.15 kg particulate/Mg boric acid dried. After fabric filter control, 0.11 kg particulate/Mg boric acid dried. Emission factors from Reference a.

SOURCE OPERATION: 100% of design process rate.

SAMPLING TECHNIQUE: a) Joy train with cyclones
b) SASS train with cyclones

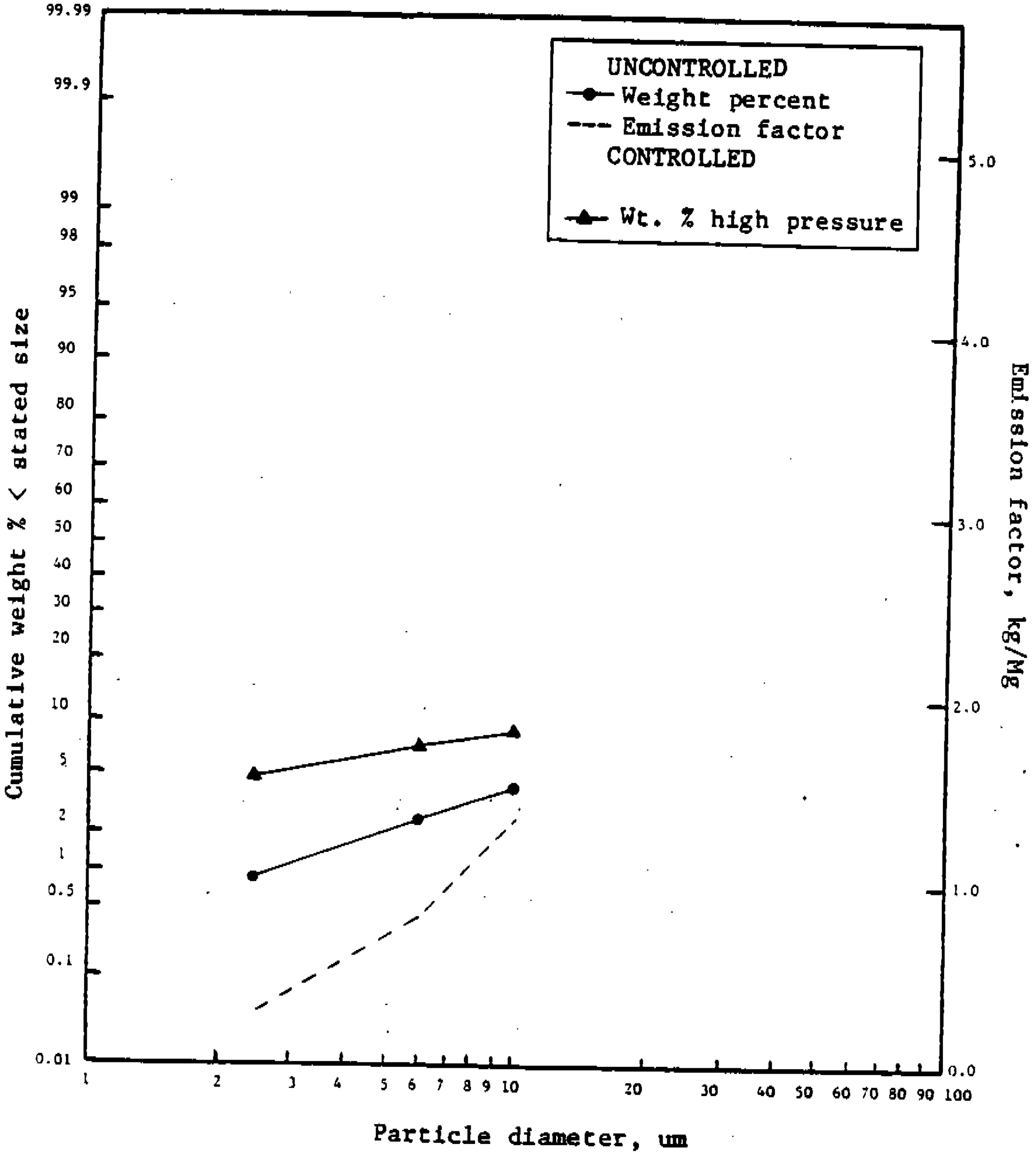
EMISSION FACTOR RATING: E

REFERENCES:

a. H. J. Taback, Fine Particle Emissions from Stationary and Miscellaneous Sources in the South Coast Air Basin, PB 293 923/AS, National Technical Information Service, Springfield, VA, February 1979.

b. Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System, Series Report No. 236, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.

5.xx POTASH (POTASSIUM CHLORIDE) DRYER



Aerodynamic particle diameter (um)	Cumulative wt. % < stated size		Emission factor (kg/Mg)
	Uncontrolled	High pressure drop venturi scrubber	Uncontrolled
2.5	0.95	5.0	0.31
6.0	2.46	7.5	0.81
10.0	4.07	9.0	1.34

5.xx POTASH (POTASSIUM CHLORIDE) DRYER

NUMBER OF TESTS:
a) 7, before control
b) 1, after cyclone and high pressure drop venturi scrubber control

STATISTICS:

a) Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	0.95	2.46	4.07
Standard deviation (Cum. %):	0.68	2.37	4.34
Min (Cum. %):	0.22	0.65	1.20
Max (Cum. %):	2.20	7.50	13.50

b) Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	5.0	7.5	9.0
Standard deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: Uncontrolled emissions of 33 kg particulate/Mg of potassium chloride product from dryer, from AP-42 Section 5.16. It is assumed that particulate emissions from rotary gas fired dryers for potassium chloride are similar to particulate emissions from rotary steam tube dryers for sodium carbonate.

SOURCE OPERATION: Potassium chloride is dried in a rotary gas fired dryer.

SAMPLING TECHNIQUE:
a) Andersen Impactor
b) Andersen Impactor

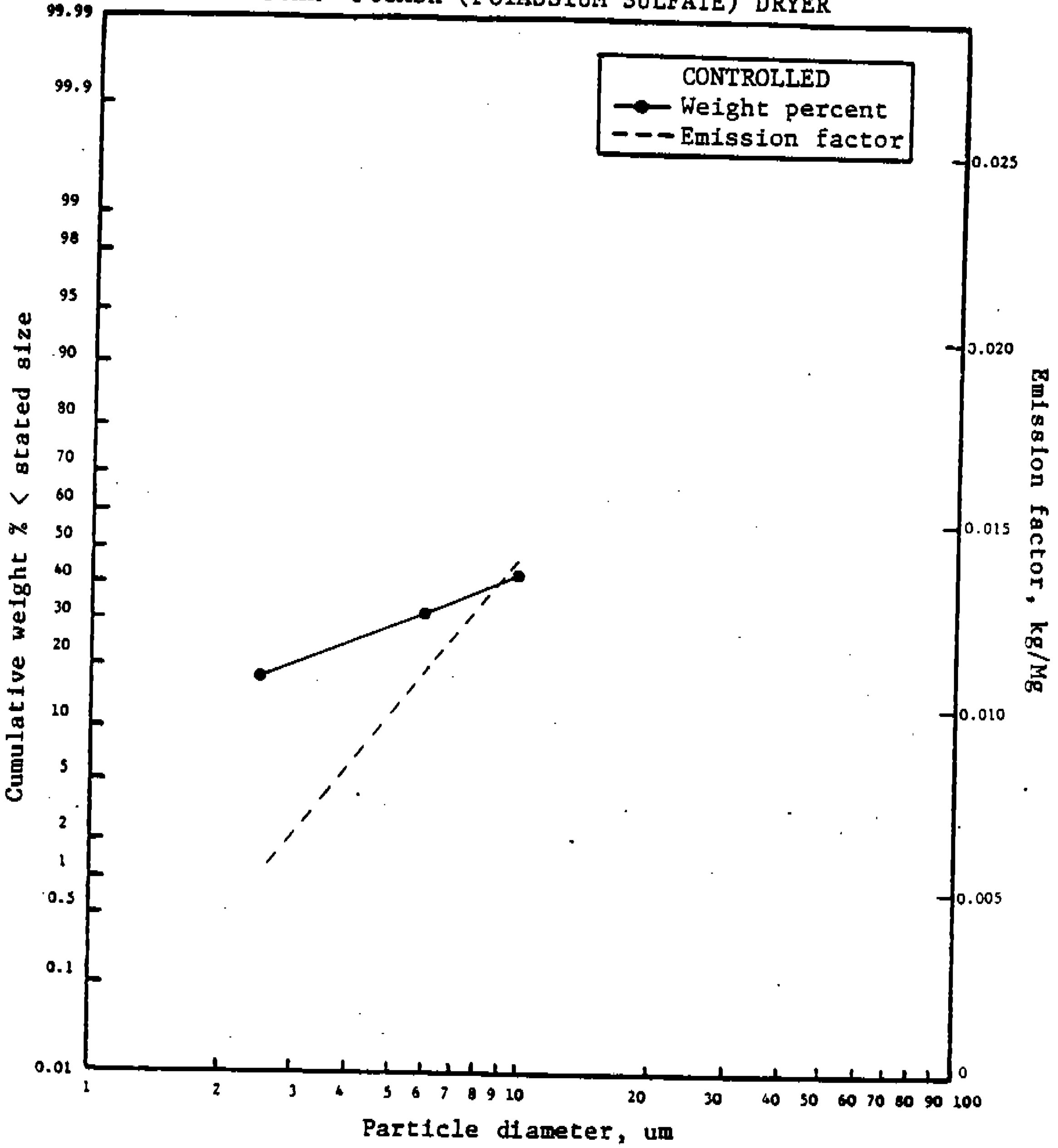
EMISSION FACTOR RATING: C

REFERENCES:

a) Emission Test Report, Kerr-Magee, Trona, CA, EMB-79-POT-4, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1979.

b) Emission Test Report, Kerr-Magee, Trona, CA, EMB-79-POT-5, U. S. Environmental Protection Agency, Research Triangle Park, NC April 1979.

5.xx POTASH (POTASSIUM SULFATE) DRYER



Aerodynamic particle diameter (um)	Cumulative wt. % < stated size	Emission factor, kg/Mg
	Controlled with fabric filter	Controlled with fabric filter
2.5	18.0	0.006
6.0	32.0	0.011
10.0	43.0	0.014

5.xx POTASH (POTASSIUM SULFATE) DRYER

NUMBER OF TESTS: 2, conducted after fabric filter

STATISTICS:

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	18.0	32.0	43.0
Standard deviation (Cum. %):	7.5	11.5	14.0
Min (Cum. %):	10.5	21.0	29.0
Max (Cum. %):	24.5	44.0	14.0

TOTAL PARTICULATE EMISSION FACTOR: After fabric filter control, 0.033 kg of particulate per Mg of potassium sulfate product from the dryer. Calculated from an uncontrolled emission factor of 33 kg/Mg and control efficiency of 99.9 %. From Reference a and AP-42 Section 5.16. It is assumed that particulate emissions from rotary gas fired dryers are similar to those from rotary steam tube dryers.

SOURCE OPERATION: Potassium sulfate is dried in a rotary gas fired dryer.

SAMPLING TECHNIQUE: Andersen Impactor

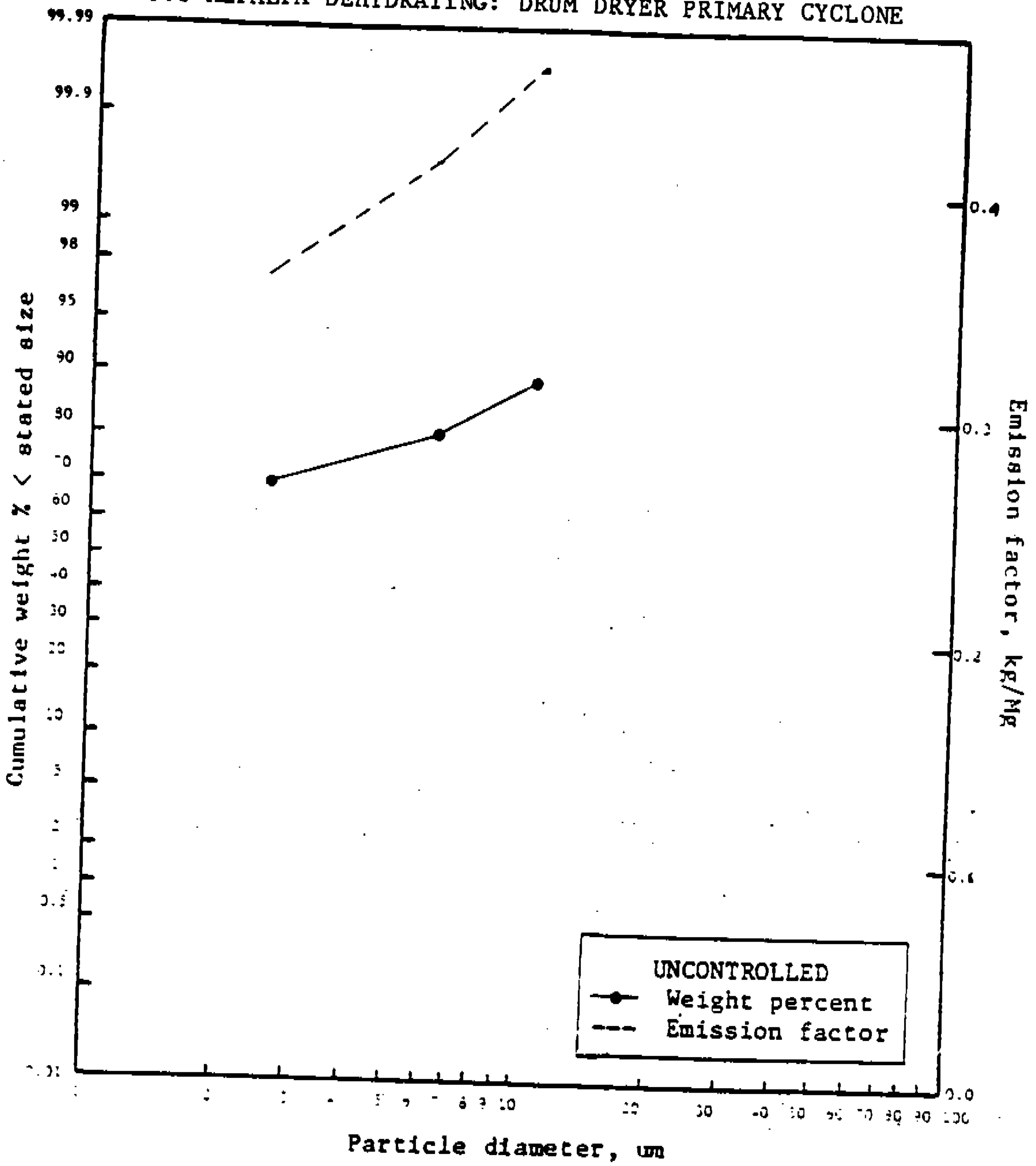
EMISSION FACTOR RATING: E

REFERENCES:

a) Emission Test Report, Kerr-McGee, Trona, CA, EMB-79-POT-4, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1979.

b) Emission Test Report, Kerr-McGee, Trona, CA, EMB-79-POT-5, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1979.

6.1 ALFALFA DEHYDRATING: DRUM DRYER PRIMARY CYCLONE



Aerodynamic Particle diameter, um	Cum. wt. % < stated size	Emission factor, kg/Mg
	Uncontrolled	Uncontrolled
2.5	70.6	3.5
6.0	82.7	4.1
10.0	90.0	4.5

6.1 ALFALFA DEHYDRATING: DRUM DRYER PRIMARY CYCLONE

NUMBER OF TESTS: 1, conducted before control

STATISTICS:	Aerodynamic particle diameter (um):	2.5	6.0	10.0
	Mean (Cum. %):	70.6	82.7	90.0
	Standard deviation (Cum. %)			
	Min (Cum. %):			
	Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: 5.0 kg particulate/Mg alfalfa pellets before control. Factor from AP-42.

SOURCE OPERATION: During this test, source dried 10 tons of alfalfa/hour in a direct fired rotary dryer.

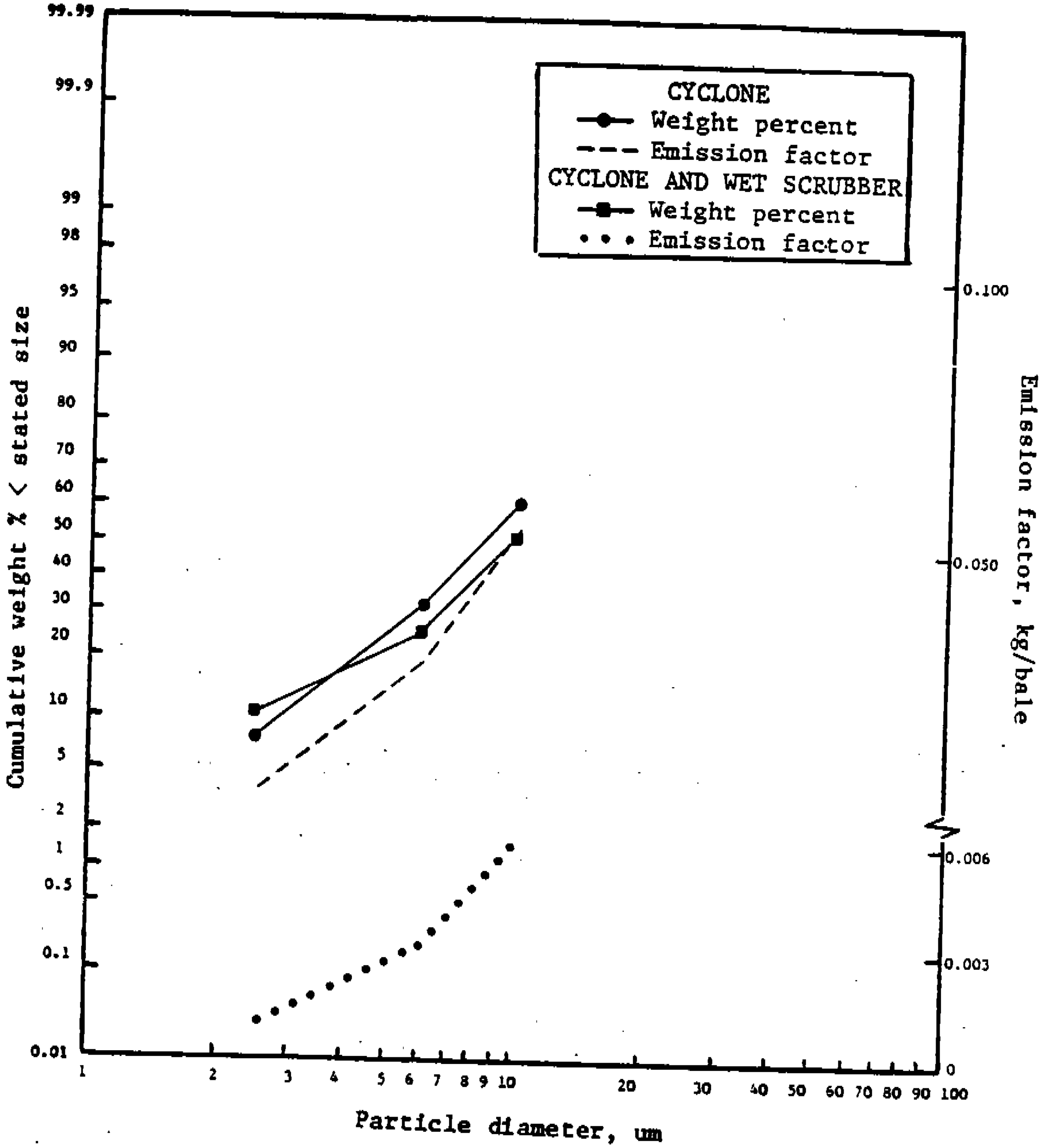
SAMPLING TECHNIQUE: Nelson Cascade Impactor

EMISSION FACTOR RATING: E

REFERENCE:

Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System, Series Report No. 152, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.

6.3 COTTON GINNING: BATTERY CONDENSER



Aerodynamic particle diameter (um)	Cumulative wt. % < stated size		Emission factor (kg/bale)	
	With cyclone	With cyclone & wet scrubber	With cyclone	With cyclone & wet scrubber
2.5	8	11	0.007	0.001
6.0	33	26	0.028	0.003
10.0	62	52	0.053	0.006

6.3 COTTON GINNING: BATTERY CONDENSER

NUMBER OF TESTS: a) 2, after cyclone
b) 3, after wet scrubber

STATISTICS:

Aerodynamic particle diameter (um):	2.5	6.0	10.0
a) Mean (Cum. %):	8	33	62
Standard deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			
b) Mean (Cum. %):	11	26	52
Standard deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: Particulate emission factor for battery condensers with typical controls is 0.09 kg (0.19 lb)/bale of cotton. From AP-42. Factor with wet scrubber after cyclone is 0.012 kg (0.026 lb)/bale. Scrubber efficiency is 86%. From Reference b.

SOURCE OPERATION: During tests, source was operating at 100% of design capacity. No other information on source is available.

SAMPLING TECHNIQUE: UW Mark 3 Impactor

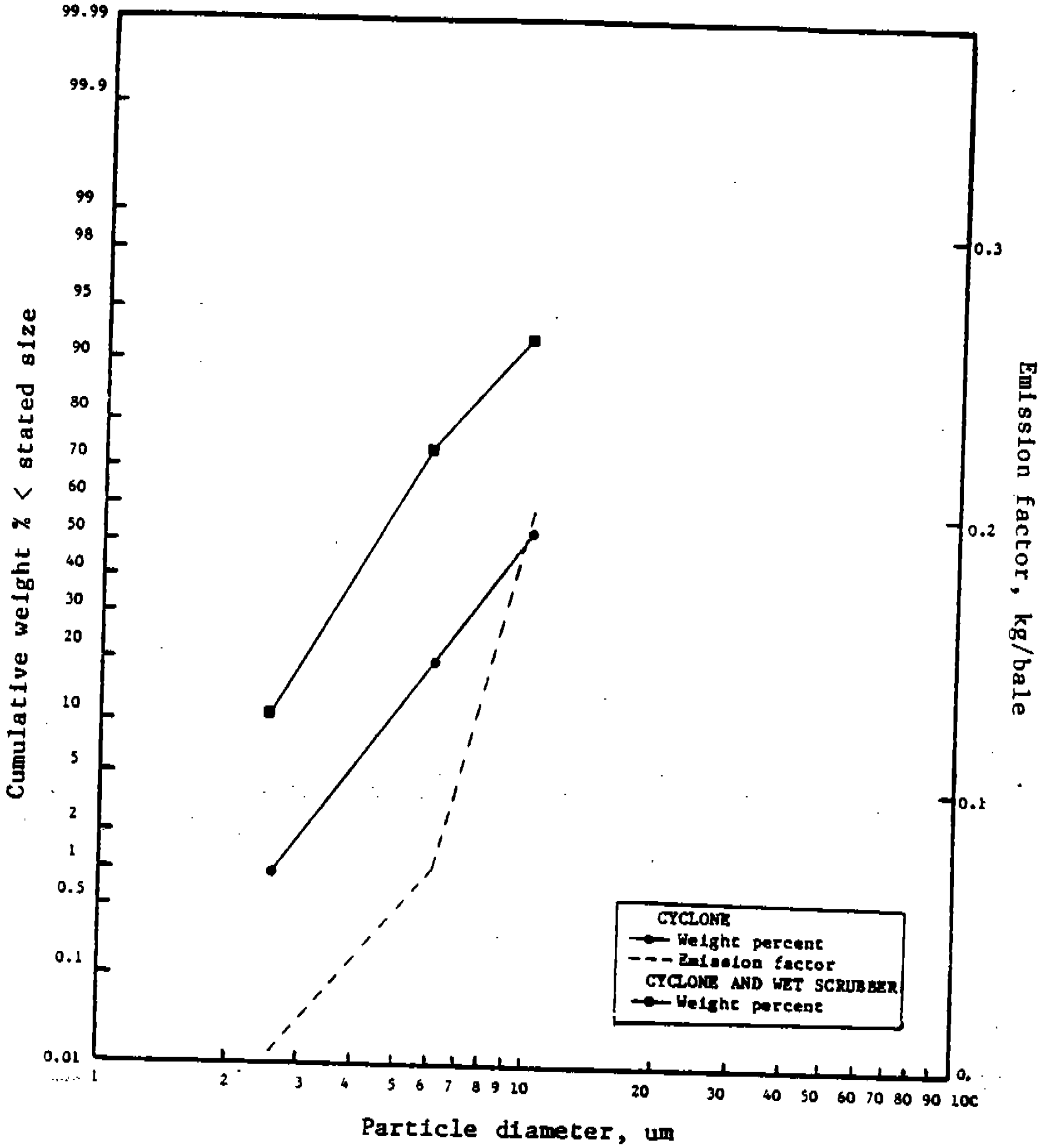
EMISSION FACTOR RATING: E

REFERENCES:

a) Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System (FPEIS), Series Report No. 27, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.

b) Robert E. Lee, Jr., et al., "Concentration And Size Of Trace Metal Emissions From A Power Plant, A Steel Plant, And A Cotton Gin", Environmental Science And Technology, 9(7):643-7, July 1975.

6.3 COTTON GINNING: LINT CLEANER AIR EXHAUST



Aerodynamic particle diameter (um)	Cumulative wt. % < stated size		Emission factor (kg/bale)
	After cyclone	After cyclone & wet scrubber	After cyclone
2.5	1	11	0.004
6.0	20	74	0.07
10.0	54	92	0.20

6.3 COTTON GINNING: LINT CLEANER AIR EXHAUST

NUMBER OF TESTS: a) 4, after cyclone
b) 4, after cyclone and wet scrubber

STATISTICS: a)

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	1	20	54
Standard deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

b)

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	11	74	92
Standard deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: 0.37 kg particulate/bale of cotton processed, with typical controls. Factor is from AP-42.

SOURCE OPERATION: Testing was conducted while processing both machine picked and ground harvested upland cotton, at a production rate of about 6.8 bales/hr.

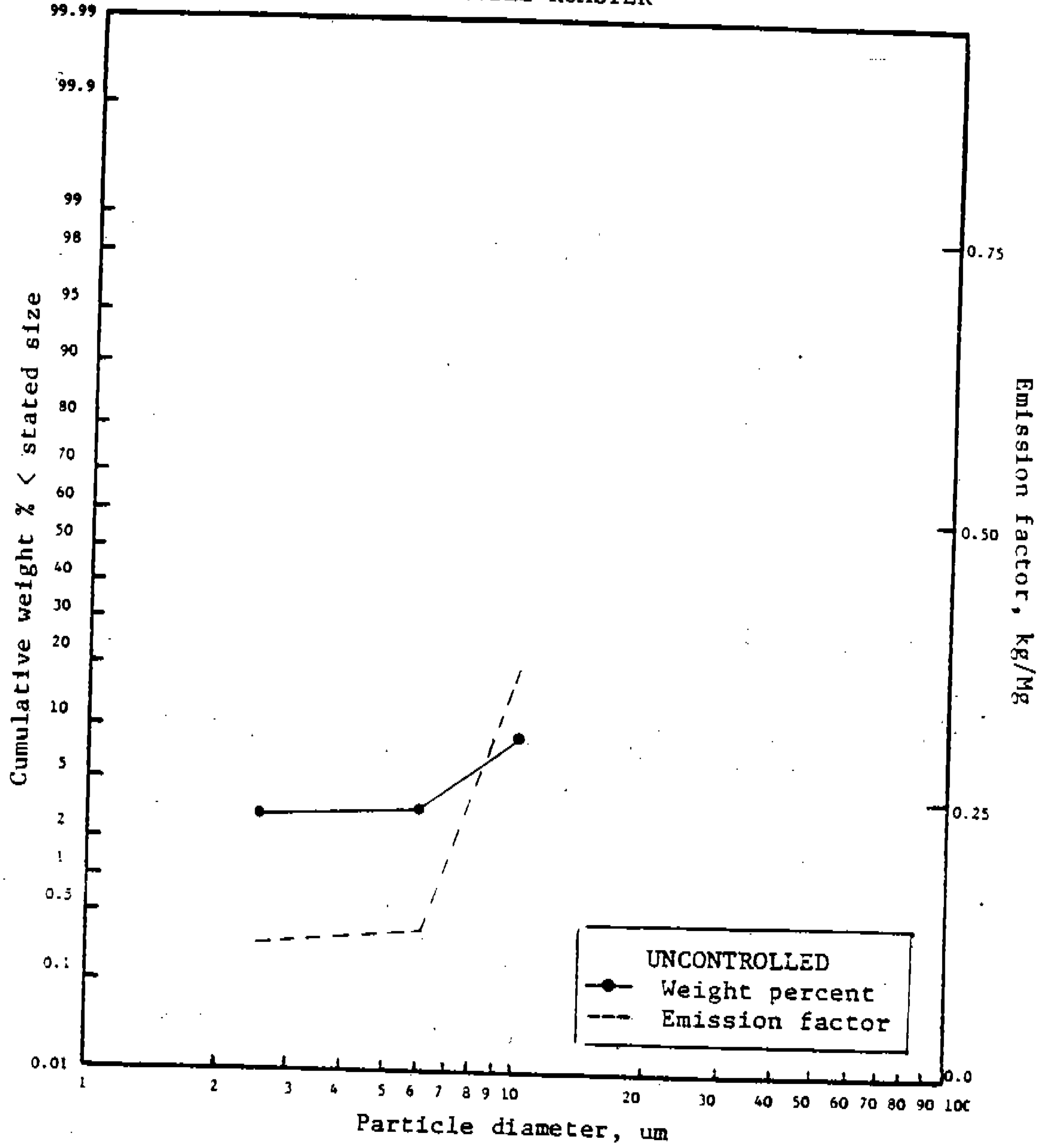
SAMPLING TECHNIQUE: Coulter counter.

EMISSION FACTOR RATING: E

REFERENCE:

S. E. Hughs, et al., "Collecting Particles From Gin Lint Cleaner Air Exhausts", presented at the 1981 Winter Meeting of the American Society of Agricultural Engineers, Chicago, IL, December 1981.

6.4 FEED AND GRAIN MILLS AND ELEVATORS: CAROB KIBBLE ROASTER



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg
	Uncontrolled	Uncontrolled
2.5	3.0	0.11
6.0	3.2	0.12
10.0	9.6	0.36

6.4 FEED AND GRAIN MILLS AND ELEVATORS: CAROB KIBBLE ROASTER

NUMBER OF TESTS: 1, conducted before controls

STATISTICS: Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	3.0	3.2	9.6
Standard deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: 3.8 kg/Mg carob kibble roasted. Factor from Reference a, pg. 4-175.

SOURCE OPERATION: Source roasts 300 kg carob pods per hour, 100% of the design rate. Roaster heat input is 795 kj/hr of natural gas.

SAMPLING TECHNIQUE: Joy train with 3 cyclones.

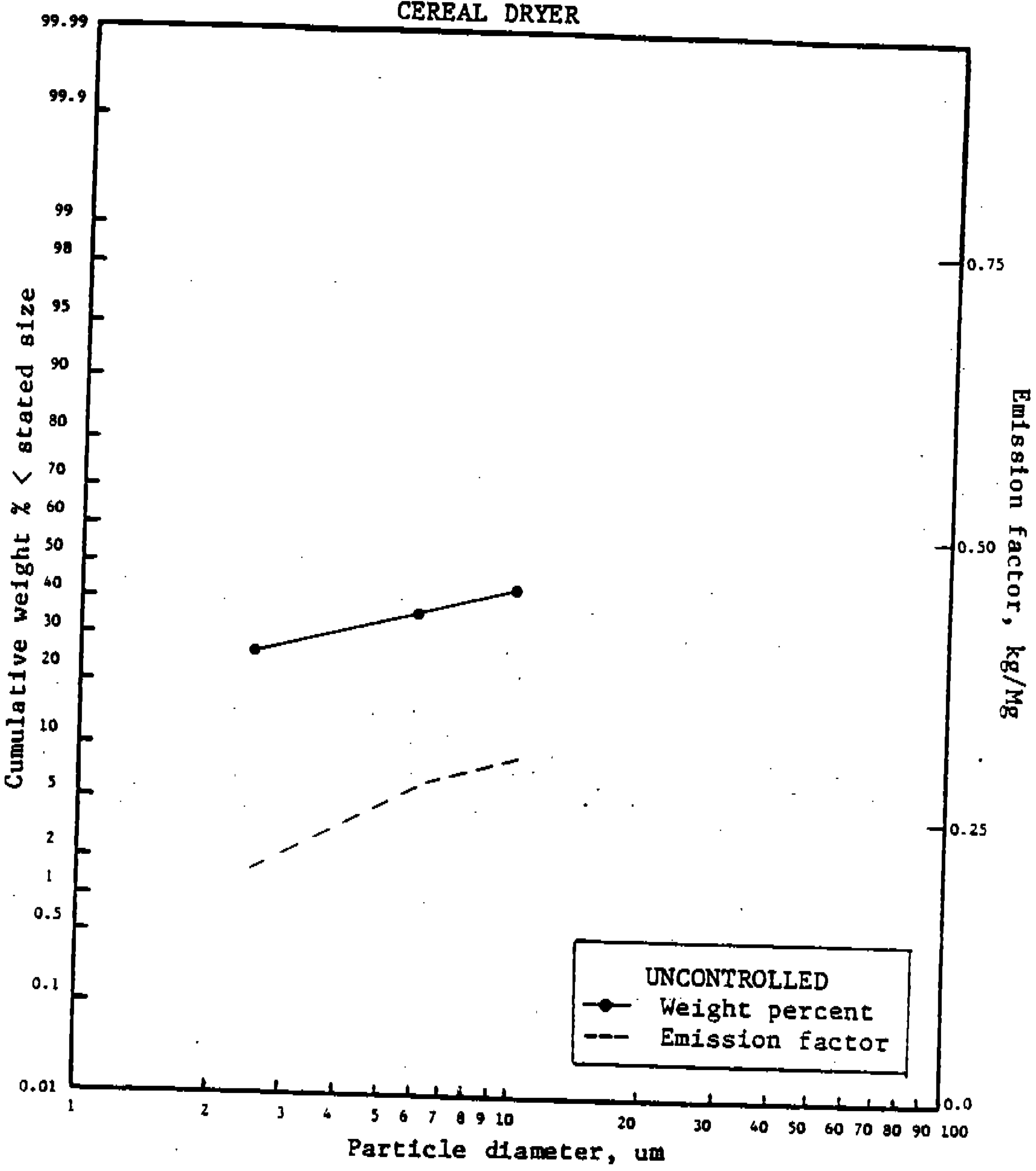
EMISSION FACTOR RATING: E

REFERENCES:

a. H. J. Taback, Fine Particle Emissions from Stationary and Miscellaneous Sources in the South Coast Air Basin, PB 293 923/AS, National Technical Information Service, Springfield, VA, February 1979.

b. Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System Series, Report No. 229, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.

6.4 FEED AND GRAIN MILLS AND ELEVATORS: CEREAL DRYER



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg
	Uncontrolled	Uncontrolled
2.5	27	0.20
6.0	37	0.28
10.0	44	0.33

6.4 FEED AND GRAIN MILLS AND ELEVATORS: CEREAL DRYER

NUMBER OF TESTS: 6, conducted before controls

STATISTICS:

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	27	37	44
Standard deviation (Cum. %):	17	18	20
Min (Cum. %):	13	20	22
Max (Cum. %):	47	56	58

TOTAL PARTICULATE EMISSION FACTOR: 0.75 kg particulate/Mg cereal dried. Factor taken from AP-42.

SOURCE OPERATION: Confidential.

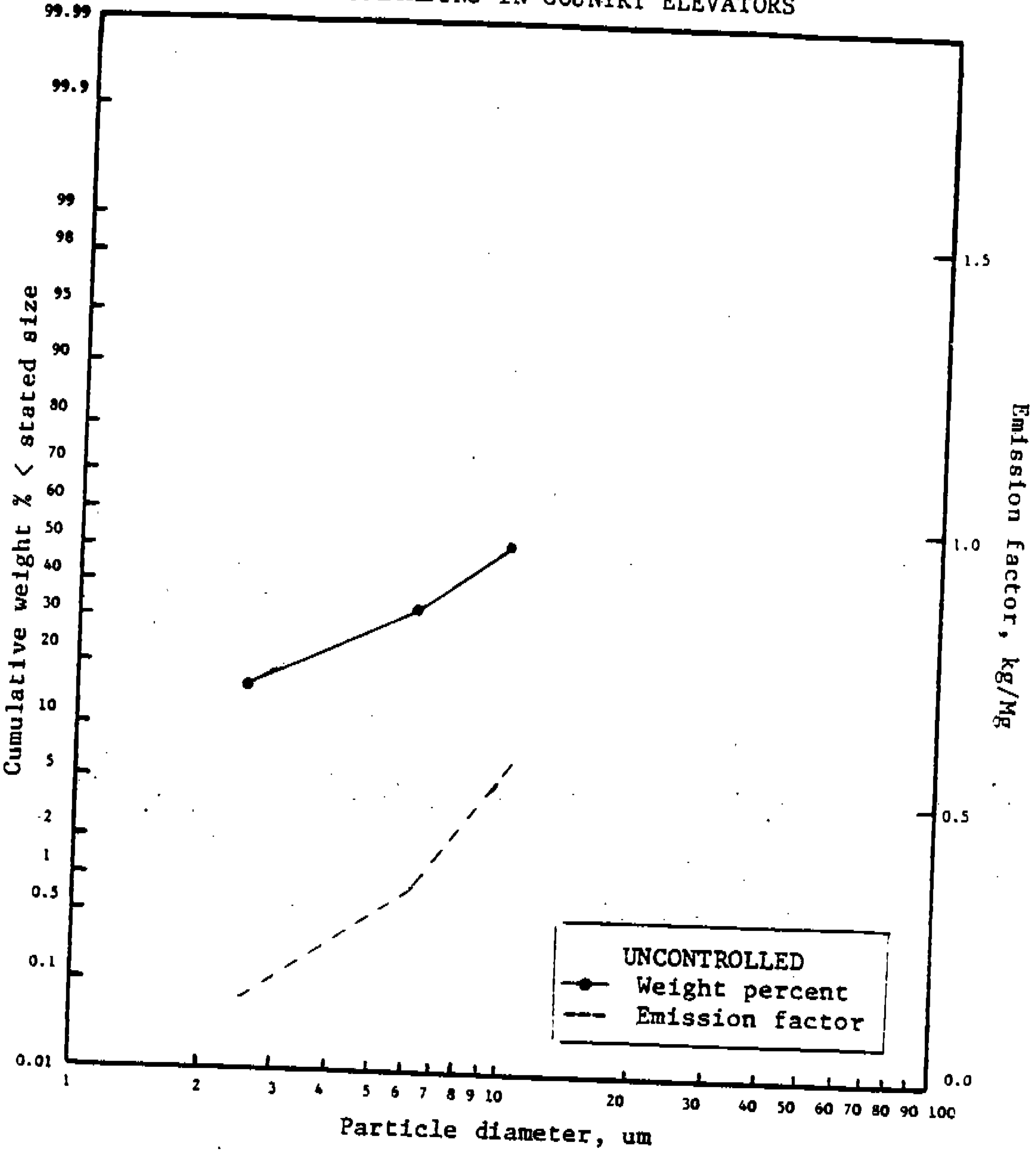
SAMPLING TECHNIQUE: Andersen Mark III Impactor

EMISSION FACTOR RATING: C

REFERENCE:

Confidential test data from a major grain processor, PEI Associates, Inc., Golden, CO, January 1985.

6.4 FEED AND GRAIN MILLS AND ELEVATORS: GRAIN UNLOADING IN COUNTRY ELEVATORS



Aerodynamic particle diameter, um	Cumulative wgt. % <stated size	Emission factor, kg/Mg
	Uncontrolled	Uncontrolled
2.5	13.8	0.13
6.0	30.5	0.33
10.0	49.0	0.56

6.4 FEED AND GRAIN MILLS AND ELEVATORS: GRAIN UNLOADING IN COUNTRY ELEVATORS

NUMBER OF TESTS: 2, conducted before control

STATISTICS:

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	13.8	30.5	49.0
Standard deviation (Cum. %):	3.3	2.5	-
Min (Cum. %):	10.5	28.0	49.0
Max (Cum. %):	17.0	33.0	49.0

TOTAL PARTICULATE EMISSION FACTOR: 0.3 kg particulate/Mg of grain unloaded, without control. Emission factor from AP-42.

SOURCE OPERATION: During testing, the facility was continuously receiving wheat of low dockage. The elevator is equipped with a dust collection system which serves the dump pit boot and leg.

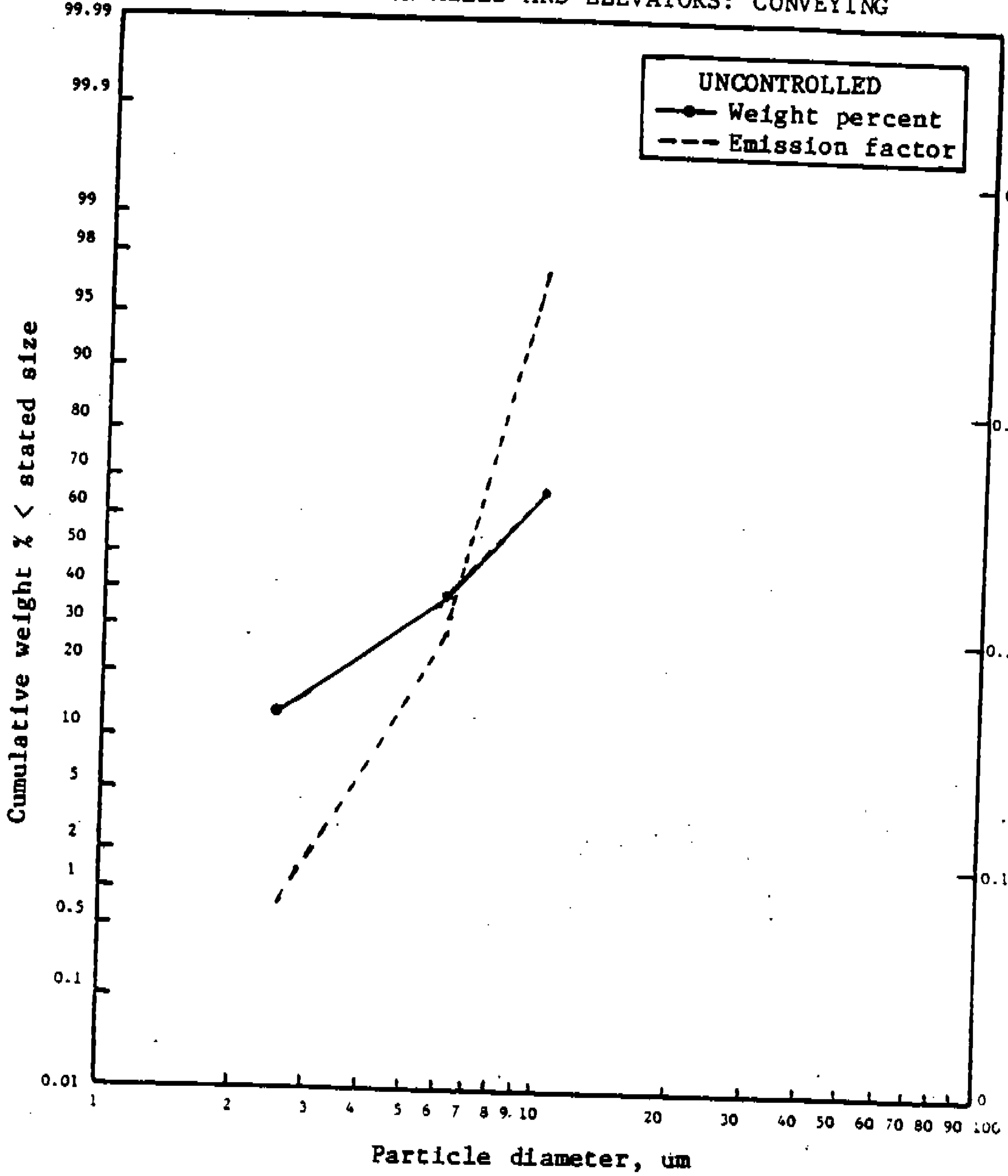
SAMPLING TECHNIQUE: Nelson Cascade Impactor

EMISSION FACTOR RATING: D

REFERENCES:

a. Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System (FPEIS), Series Report No. 154, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.

b. Emission Test Report, Uniontown Co-op, Elevator No. 2, Uniontown, WA, Report No. 75-34, Washington State Department Of Ecology, Olympia, WA, October 1975.



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg
	Uncontrolled	Uncontrolled
2.5	16.8	0.08
6.0	41.3	0.21
10.0	69.4	0.35

6.4 FEED AND GRAIN MILLS AND ELEVATORS: CONVEYING

NUMBER OF TESTS: 2, conducted before control

STATISTICS: Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	16.8	41.3	69.4
Standard deviation (Cum. %):	6.9	16.3	27.3
Min (Cum. %):	9.9	25.0	42.1
Max (Cum. %):	23.7	57.7	96.6

TOTAL PARTICULATE EMISSION FACTOR: 0.5 kg particulate/Mg of grain processed, without control. Emission factor from AP-42.

SOURCE OPERATION: Grain is unloaded from barges by "marine leg" buckets lifting the grain from the barges and discharging it onto an enclosed belt conveyer, which transfers the grain to the elevator. These tests measured the combined emissions from the "marine leg" bucket unloader and the conveyer transfer points. Emission rates averaged 1956 lbs particulate/hour (0.67 kg/Mg grain unloaded). Grains are corn and soy beans.

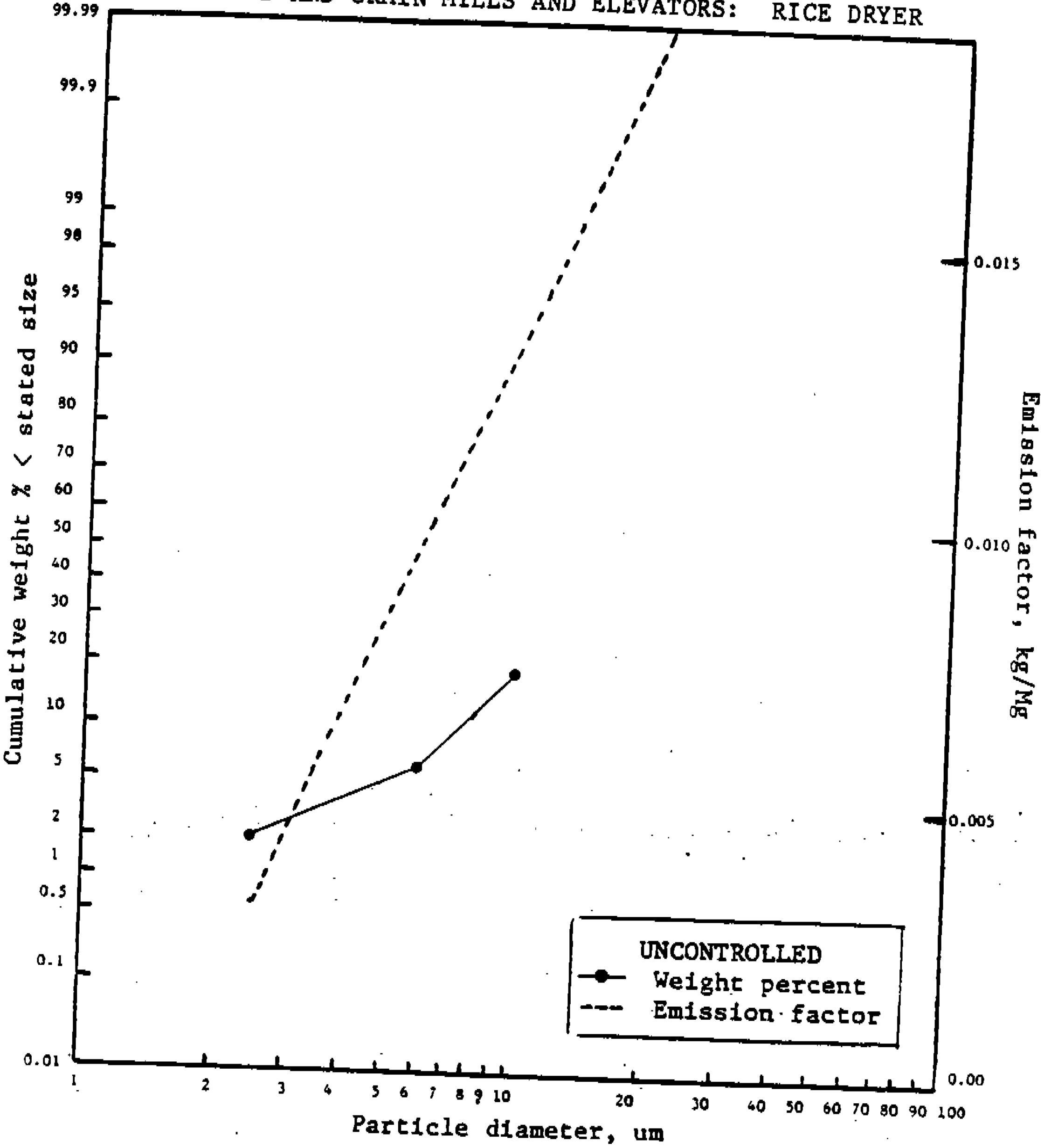
SAMPLING TECHNIQUE: Brinks Model B Cascade Impactor

EMISSION FACTOR RATING: D

REFERENCE:

Air Pollution Emission Test, Bunge Corporation, Destrehan, LA, EMB-74-GRN-7, U. S. Environmental Protection Agency, Research Triangle Park, NC, January 1974.

6.4 FEED AND GRAIN MILLS AND ELEVATORS: RICE DRYER



Aerodynamic Particle diameter, um	Cumulative wt. % < Stated Size	Emission Factor (kg/Mg)
	Uncontrolled	Uncontrolled
2.5	2.0	0.003
6.0	8.0	0.01
10.0	19.5	0.029

6.4 FEED AND GRAIN MILLS AND ELEVATORS: RICE DRYER

NUMBER OF TESTS: 2, conducted on uncontrolled source.

STATISTICS:	Aerodynamic Particle Diameter (um):	2.5	6.0	10.0
	Mean (Cum. %):	2.0	8.0	19.5
	Standard Deviation (Cum. %):	-	3.3	9.4
	Min (Cum. %):	2.0	3.1	10.1
	Max (Cum. %):	2.0	9.7	28.9

TOTAL PARTICULATE EMISSION FACTOR: 0.15 kg particulate/Mg of rice dried. Factor from AP-42, Table 6.4-1, footnote b for column dryer.

SOURCE OPERATION: Source operated at 100% of rated capacity, drying 90.8 Mg rice/hr. The dryer is heated by four 9.5 kg/hr burners.

SAMPLING TECHNIQUE: Sass train with cyclones.

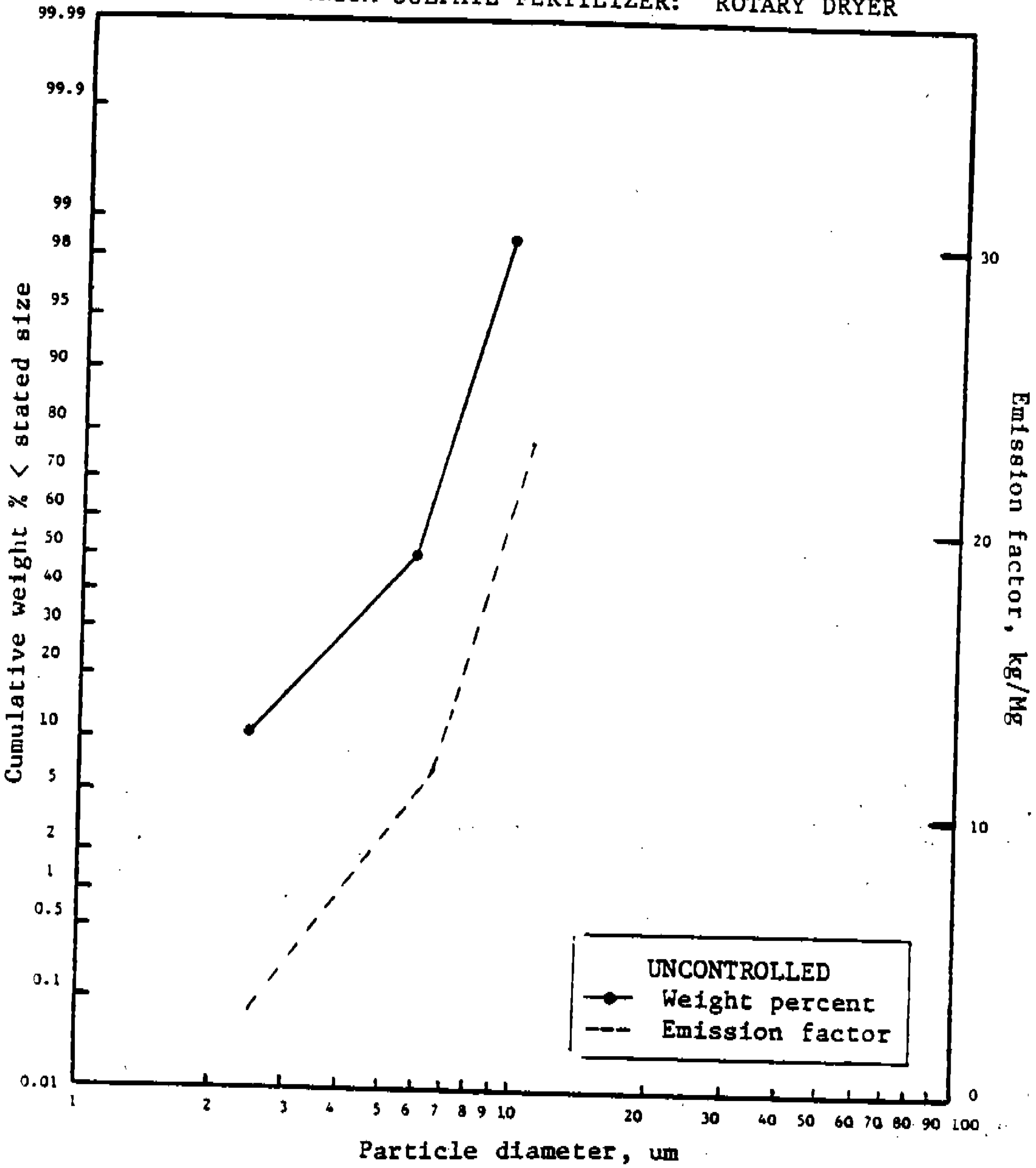
EMISSION FACTOR RATING: D

REFERENCES:

a. H. J. Taback, Fine Particle Emissions from Stationary and Miscellaneous Sources in the South Coast Air Basin, PB 293 923/AS, National Technical Information Service, Springfield, VA, February 1979.

b. Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System, Series Report No. 228, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.

6.18 AMMONIUM SULFATE FERTILIZER: ROTARY DRYER



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg
	Uncontrolled	Uncontrolled
2.5	10.8	2.5
6.0	49.1	11.3
10.0	98.6	22.7

6.18 AMMONIUM SULFATE FERTILIZER: ROTARY DRYER

NUMBER OF TESTS: 3, conducted before control.

STATISTICS: Aerodynamic particle diameter (um)	2.5	6.0	10.0
Mean (Cum. %):	10.8	49.1	98.6
Standard Deviation (Cum. %):	5.1	21.5	1.8
Min (Cum. %):	4.5	20.3	96.0
Max (Cum. %):	17.0	72.0	100.0

TOTAL PARTICULATE EMISSION FACTOR: 23 kg particulate/Mg of ammonium sulfate produced. Factor from AP-42.

SOURCE OPERATION: Testing was conducted at three ammonium sulfate plants operating rotary dryers within the following production parameters:

Plant	A	C	D
% of design process rate	100.6	40.1	100
production rate, Mg/hr	16.4	6.09	8.4

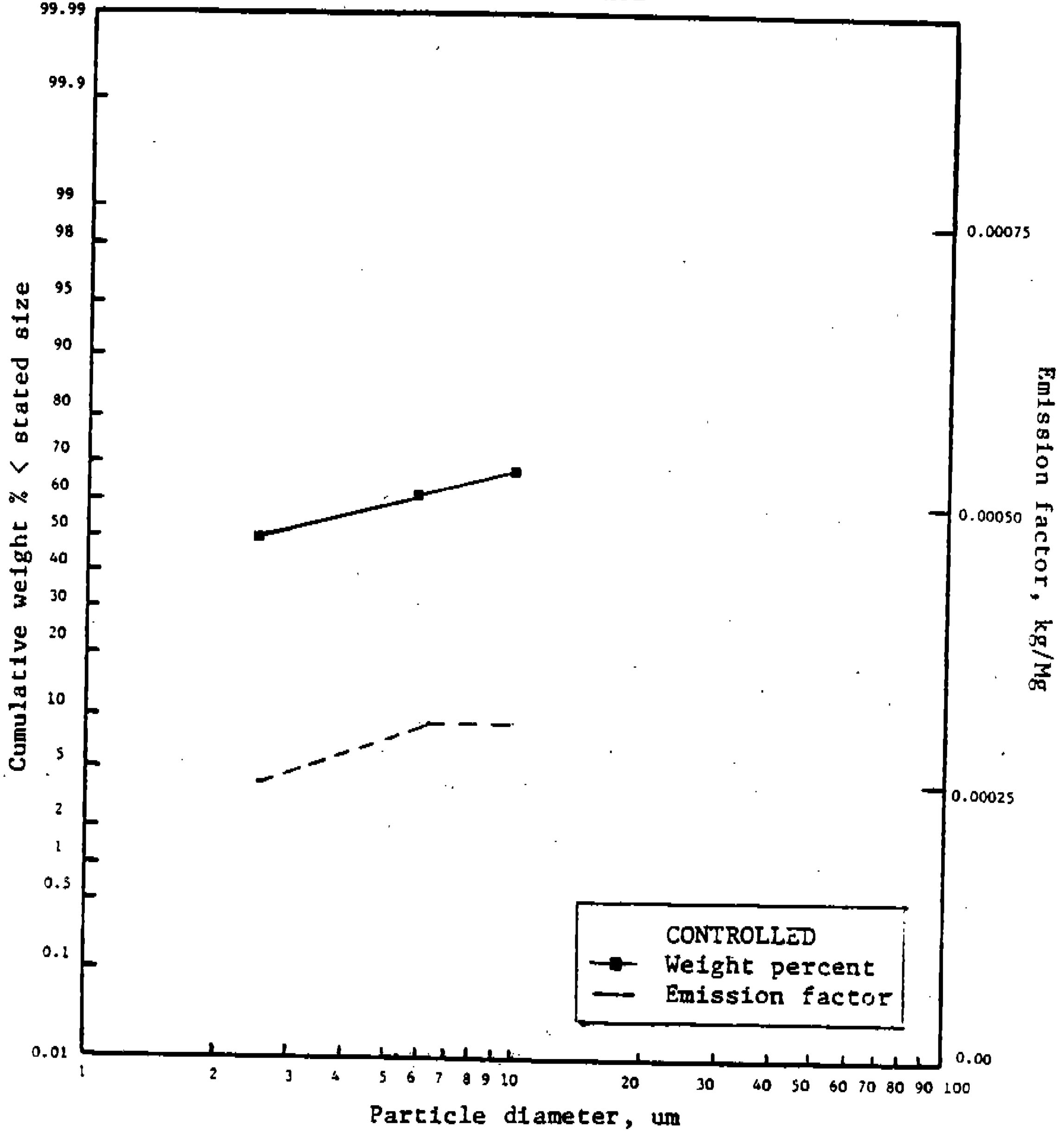
SAMPLING TECHNIQUE: Andersen Cascade Impactors

EMISSION FACTOR RATING: C

REFERENCE:

Ammonium Sulfate Manufacture - Background Information For Proposed Emission Standards, EPA-450/3-79-034a, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1979.

7.1 PRIMARY ALUMINUM PRODUCTION: BAUXITE PROCESSING - FINE ORE STORAGE



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg
	Fabric filter controlled	Fabric filter controlled
2.5	50.0	0.00025
6.0	62.0	0.0003
10.0	68.0	0.0003

7.1 PRIMARY ALUMINUM PRODUCTION: BAUXITE PROCESSING - FINE ORE STORAGE

NUMBER OF TESTS: 2, after fabric filter control

STATISTICS:

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	50.0	62.0	68.0
Standard deviation (Cum. %):	15.0	19.0	20.0
Min (Cum. %):	35.0	43.0	48.0
Max (Cum. %):	65.0	81.0	88.0

TOTAL PARTICULATE EMISSION FACTOR: 0.0005 kg particulate/Mg of ore filled, with fabric filter control. Factor calculated from emission and process data in reference.

SOURCE OPERATION: The facility purifies bauxite to alumina. Bauxite ore, unloaded from ships, is conveyed to storage bins from which it is fed to the alumina refining process. These tests measured the emissions from the bauxite ore storage bin filling operation (the ore drop from the conveyer into the bin), after fabric filter control. Normal bin filling rate is between 425 and 475 tons per hour.

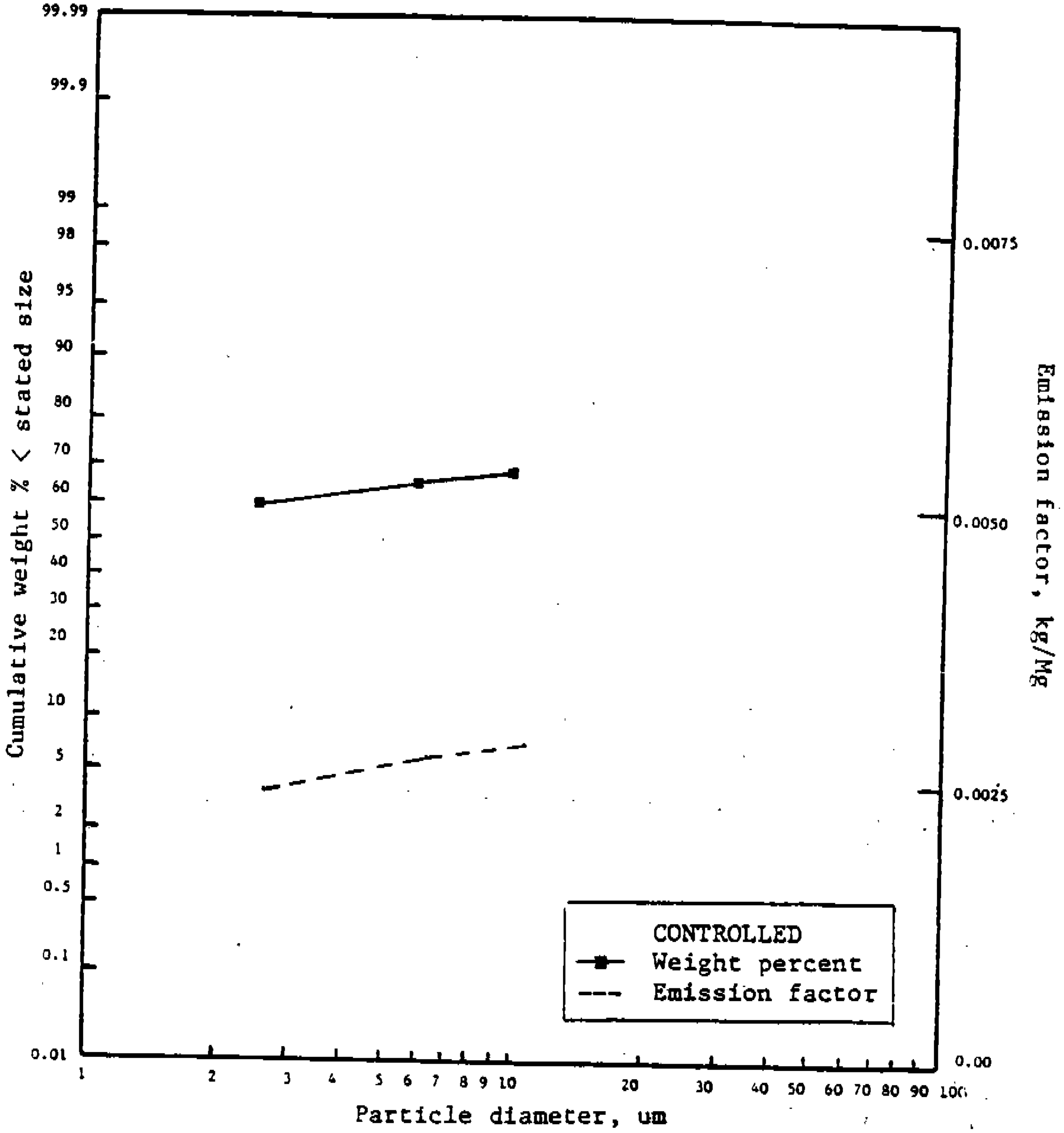
SAMPLING TECHNIQUE: Andersen Impactor

EMISSION FACTOR RATING: E

REFERENCE:

Emission Test Report, Reynolds Metals Company, Corpus Christi, TX, EMB-80-MET-9, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1980.

7.1 PRIMARY ALUMINUM PRODUCTION: BAUXITE PROCESSING
UNLOADING ORE FROM SHIP



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg
	Wet scrubber controlled	Wet scrubber controlled
2.5	60.5	0.0024
6.0	67.0	0.0027
10.0	70.0	0.0028

7.1 PRIMARY ALUMINUM PRODUCTION: BAUXITE PROCESSING
UNLOADING ORE FROM SHIP

NUMBER OF TESTS: 1, after venturi scrubber control

STATISTICS:

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	60.5	67.0	70.0
Standard deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: 0.004 kg particulate/Mg bauxite ore unloaded after scrubber control. Factor calculated from emission and process data contained in reference.

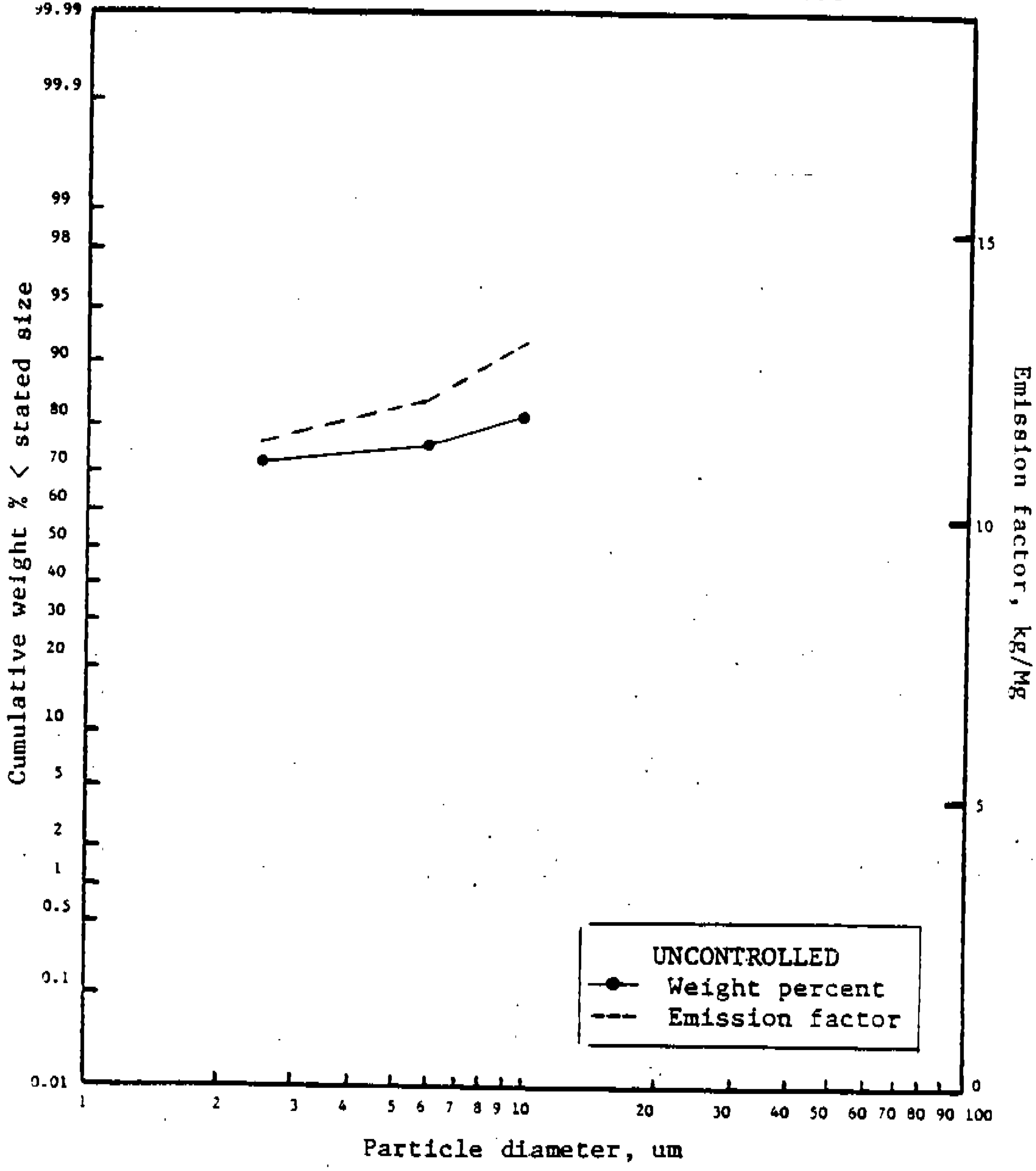
SOURCE OPERATION: The facility purifies bauxite to alumina. Ship unloading facility normally operates at 1500-1700 tons/hr, using a self contained extendable boom conveyor that interfaces with a dockside conveyor belt through an accordion chute. The emissions originate at the point of transfer of the bauxite ore from the ship's boom conveyer as the ore drops through the the chute onto the dockside conveyer. Emissions are ducted to a dry cyclone and then to a Venturi scrubber. Design pressure drop across scrubber is 15 inches, and efficiency during test was 98.4 percent.

SAMPLING TECHNIQUE: Andersen Impactor

EMISSION FACTOR RATING: E

REFERENCE:

Emission Test Report, Reynolds Metals Company, Corpus Christi, TX, EMB-80-MET-9, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1980.



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg
	Uncontrolled	Uncontrolled
2.5	72.2	11.6
6.0	76.3	12.2
10.0	82.0	13.1

7.13 STEEL FOUNDRIES: CASTINGS SHAKEOUT

NUMBER OF TESTS: 2, conducted at castings shakeout exhaust hood before controls

STATISTICS: Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	72.2	76.3	82.0
Standard deviation (Cum. %):	5.4	6.9	4.3
Min (Cum. %):	66.7	69.5	77.7
Max (Cum. %):	77.6	83.1	86.3

TOTAL PARTICULATE EMISSION FACTOR: 16 kg particulate/Mg metal melted, without controls. Although no nonfurnace emission factors are available for steel foundries, emissions are presumed to be similar to those in iron foundries. Nonfurnace emission factors for iron foundries are presented in AP-42.

SOURCE OPERATION: Source is a steel foundry casting steel pipe. Pipe molds are broken up at the castings shakeout operation. No additional information is available.

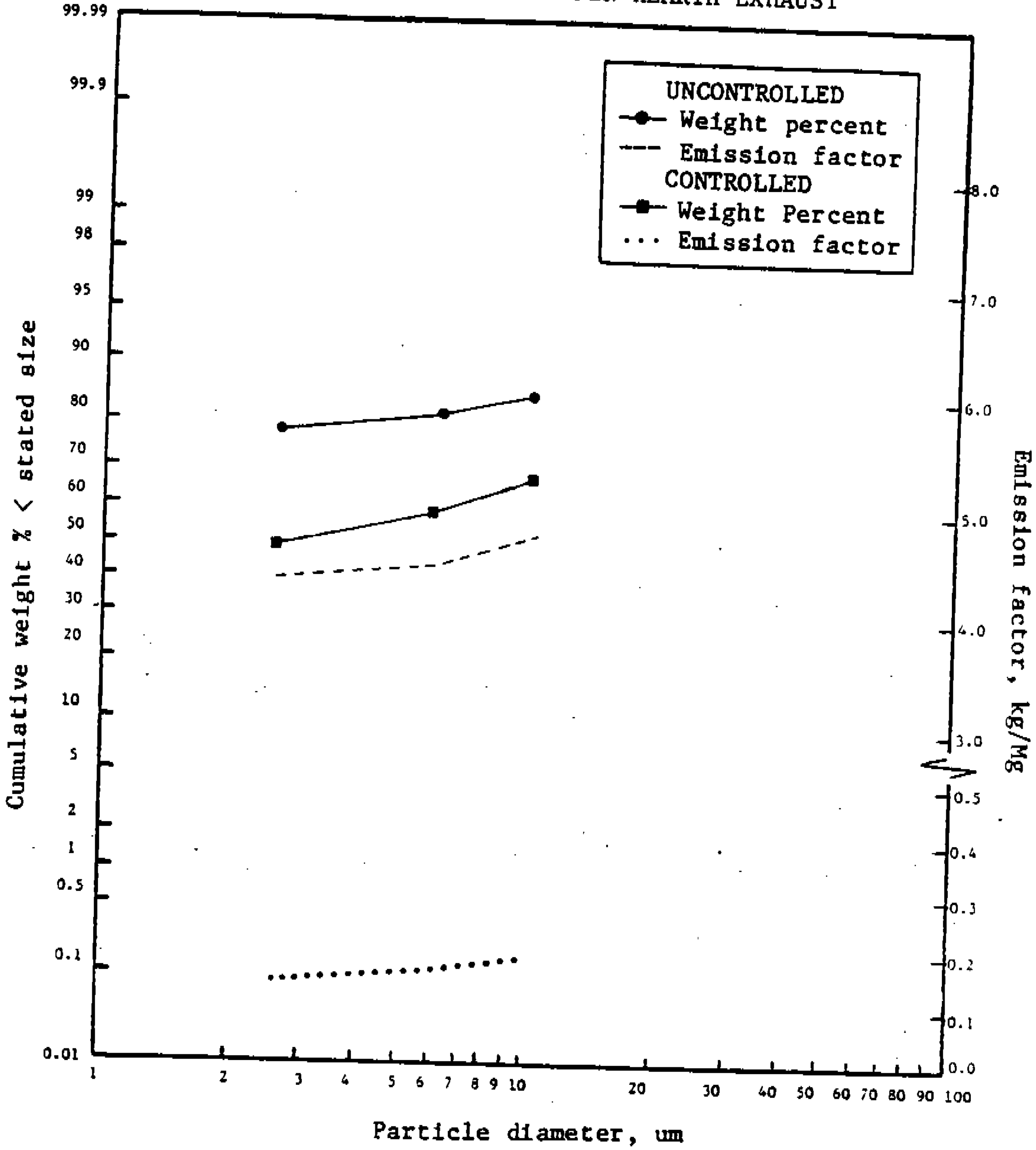
SAMPLING TECHNIQUE: Brinks Model BMS-11 Impactor

EMISSION FACTOR RATING: D

REFERENCE:

Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System, Series Report No. 117, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.

7.13 STEEL FOUNDRIES: OPEN HEARTH EXHAUST



Aerodynamic particle diameter, um	Cumulative wt. % < stated size		Emission Factor (kg/Mg)	
	Uncontrolled	ESP	Uncontrolled	ESP
2.5	79.6	49.3	4.4	0.14
6.0	82.8	58.6	4.5	0.16
10.0	85.4	66.8	4.7	0.18

7.13 STEEL FOUNDRIES: OPEN HEARTH EXHAUST

NUMBER OF TESTS: a) 1, conducted before control
b) 1, conducted after ESP control

STATISTICS: a) Aerodynamic particle diameter (um):

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	79.6	82.8	85.4
Standard Deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

b) Aerodynamic particle diameter (um):

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	49.3	58.6	66.8
Standard Deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: 5.5 kg particulate/Mg metal processed, before control. Emission factor from AP-42. AP-42 gives an ESP control efficiency of 95 to 98.5%. At 95% efficiency, factor after ESP control is 0.275 kg particulate/Mg metal processed.

SOURCE OPERATION: Source produces steel castings by melting, alloying, and casting pig iron and steel scrap. During these tests, source was operating at 100% of rated capacity of 8260 kg metal scrap feed/hour, fuel oil fired, and 8 hour heats.

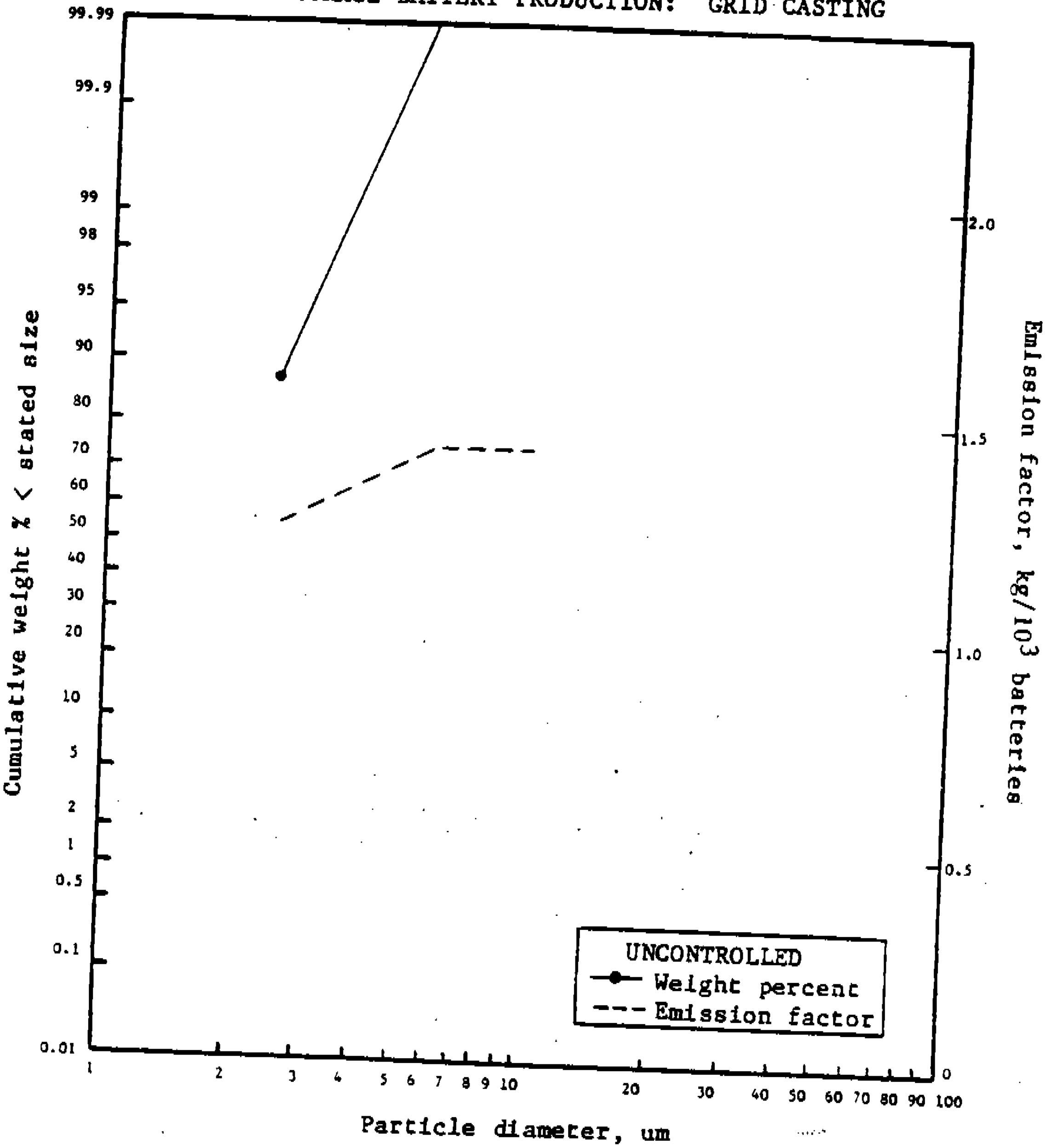
SAMPLING TECHNIQUE: a) Joy train with 3 cyclones
b) Sass train with cyclones

EMISSION FACTOR RATING: E

REFERENCE:

Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System, Series Report No. 233, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.

7.15 STORAGE BATTERY PRODUCTION: GRID CASTING



Aerodynamic particle diameter (um)	Cumulative wt. % < stated size	Emission factor (kg/10^3 batteries)
	Uncontrolled	Uncontrolled
2.5	87.8	1.25
6.0	100	1.42
10.0	100	1.42

7.15 STORAGE BATTERY PRODUCTION: GRID CASTING

NUMBER OF TESTS: 3, conducted before control

STATISTICS:

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	87.8	100	100
Standard deviation (Cum. %):	10.3	-	-
Min (Cum. %):	75.4	100	100
Max (Cum. %):	100	100	100

Impactor cut points were so small that most data points had to be extrapolated.

TOTAL PARTICULATE EMISSION FACTOR: 1.42 kg particulate/10^3 batteries produced, without controls. Factor from AP-42.

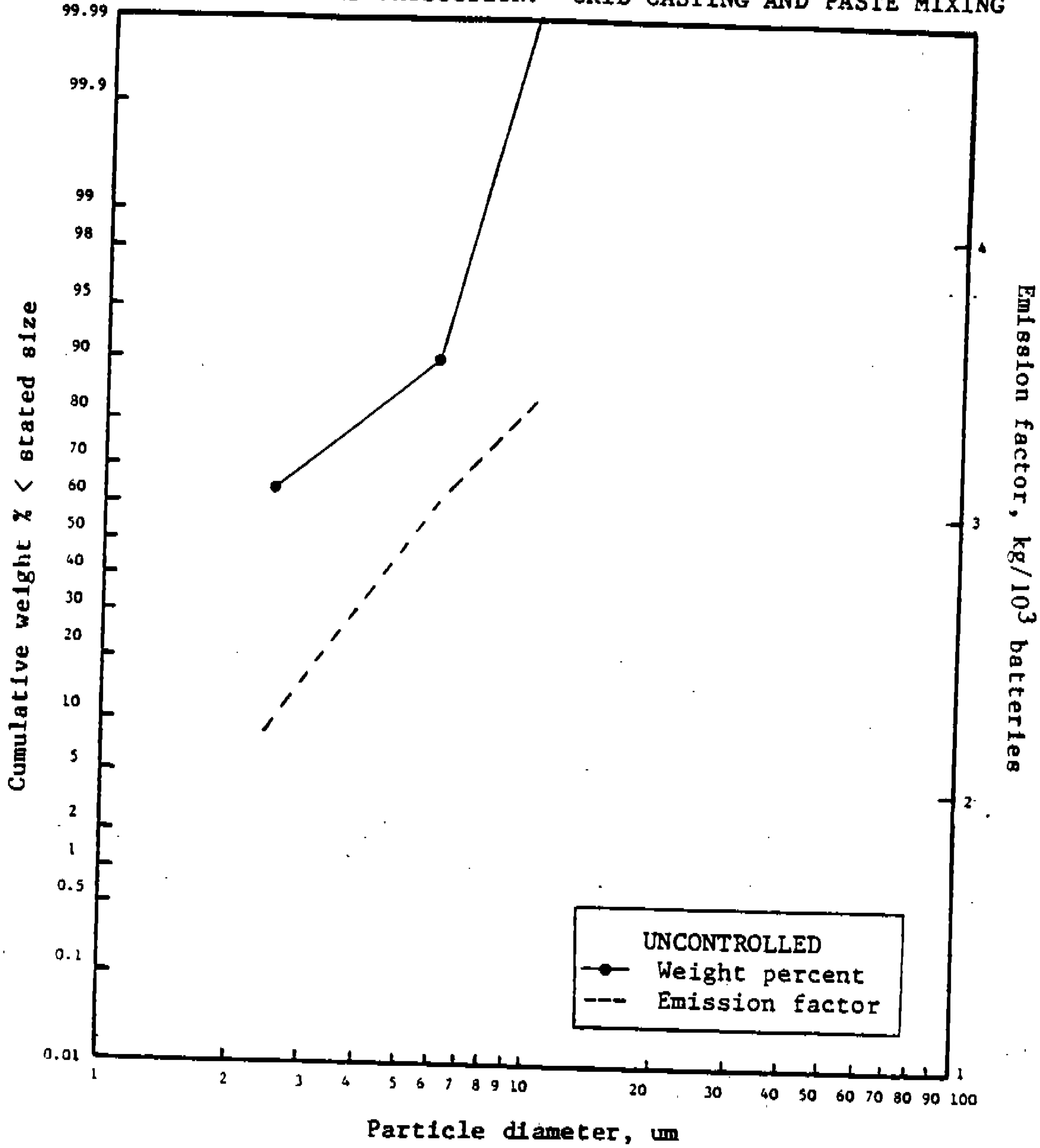
SOURCE OPERATION: During tests, plant was operated at 39% of design process rate. Six of nine of the grid casting machines were operating during the test. Typically, 26,500 to 30,000 pounds of lead per 24 hour day are charged to the grid casting operation.

SAMPLING TECHNIQUE: Brinks Impactor

EMISSION FACTOR RATING: E

REFERENCE:

Air Pollution Emission Test, Globe Union, Inc., Canby, OR, EMB-76-BAT-4, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1976.



Aerodynamic particle diameter (um)	Cumulative wt. % < stated size	Emission factor (kg/10^3 batteries)
	Uncontrolled	Uncontrolled
2.5	65.1	2.20
6.0	90.4	3.05
10.0	100	3.38

7.15 STORAGE BATTERY PRODUCTION: GRID CASTING AND PASTE MIXING

NUMBER OF TESTS: 3, conducted before control

STATISTICS:

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	65.1	90.4	100
Standard deviation (Cum. %):	24.8	7.4	-
Min (Cum. %):	44.1	81.9	100
Max (Cum. %):	100	100	100

TOTAL PARTICULATE EMISSION FACTOR: 3.38 kg particulate/10^3 batteries, without controls. Factor is from AP-42, and is the sum of the individual factors for grid casting and paste mixing.

SOURCE OPERATION: During tests, plant was operated at 39% of the design process rate. Grid casting operation consists of 4 machines. Each 2,000 lb/hr paste mixer is controlled for product recovery by a separate low energy impingement type wet collector designed for an 8 - 10 inch w. g. pressure drop at 2,000 acfm.

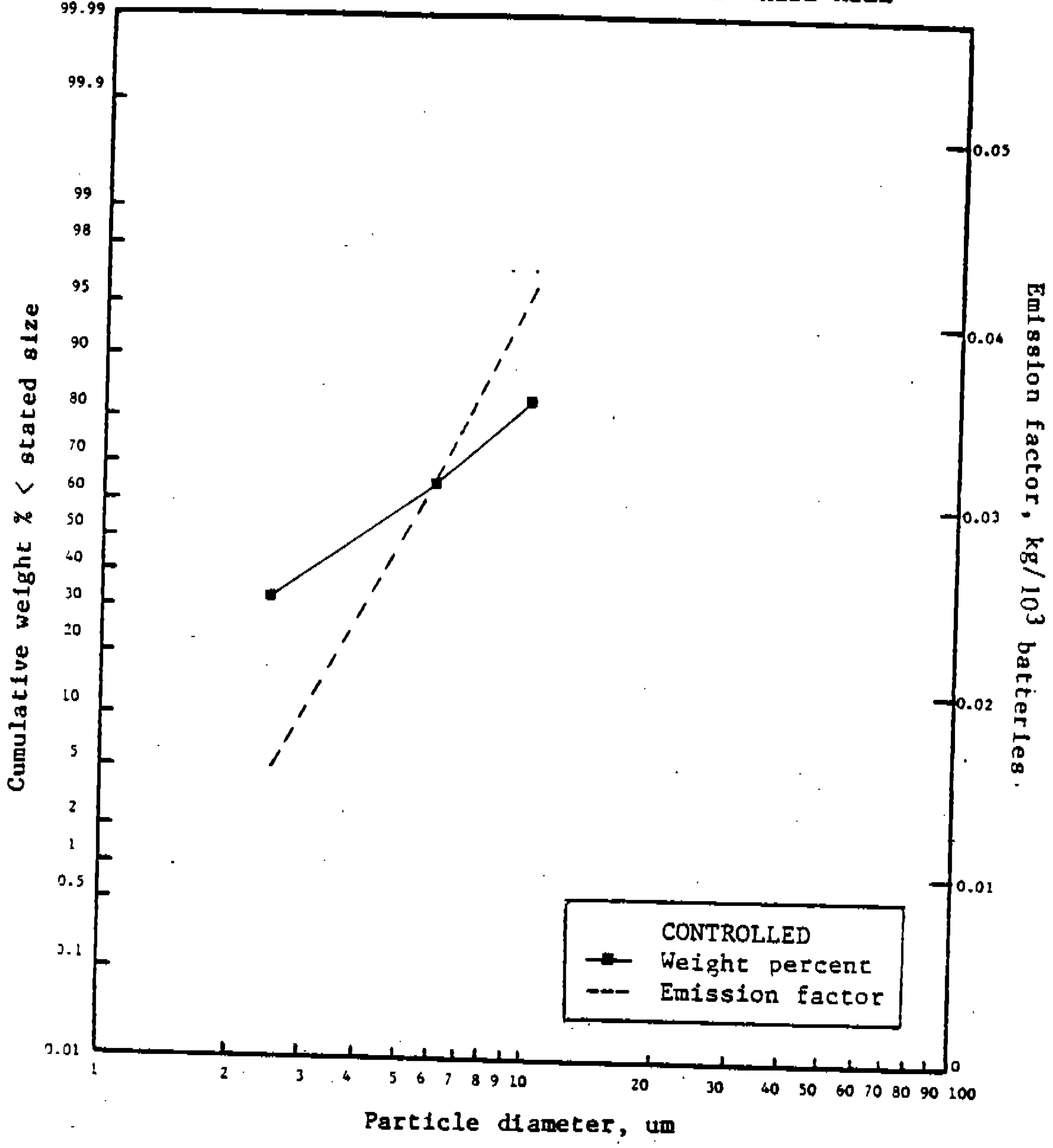
SAMPLING TECHNIQUE: Brinks Impactor

EMISSION FACTOR RATING: E

REFERENCE:

Air Pollution Emission Test, Globe Union, Inc., Canby, OR, EMB-76-BAT-4, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1976.

7.15 STORAGE BATTERY PRODUCTION: LEAD OXIDE MILL



Aerodynamic particle diameter (um)	Cumulative wt. % < stated size	Emission factor (kg/10^3 batteries)
	After fabric filter	After fabric filter
2.5	32.8	0.016
6.0	64.7	0.032
10.0	83.8	0.042

7.15 STORAGE BATTERY PRODUCTION: LEAD OXIDE MILL

NUMBER OF TESTS: 3, conducted after fabric filter

STATISTICS: Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	32.8	64.7	83.8
Standard deviation (Cum. %):	14.1	29.8	19.5
Min (Cum. %):	17.8	38.2	61.6
Max (Cum. %):	45.9	97.0	100

TOTAL PARTICULATE EMISSION FACTOR: 0.05 kg particulate/10^3 batteries, after typical fabric filter control (oil to cloth ratio of 4:1). Emissions from a well controlled facility (fabric filters with an average air to cloth ratio of 3:1) were 0.025 kg/10^3 batteries (Table 7.15-1 of AP-42).

SOURCE OPERATION: Plant receives metallic lead and manufactures lead oxide by the ball mill process. There are 2 lead oxide production lines, each with a typical feed rate of 15 one hundred pound lead pigs per hour. Product is collected with a cyclone and baghouses with 4:1 air to cloth ratios.

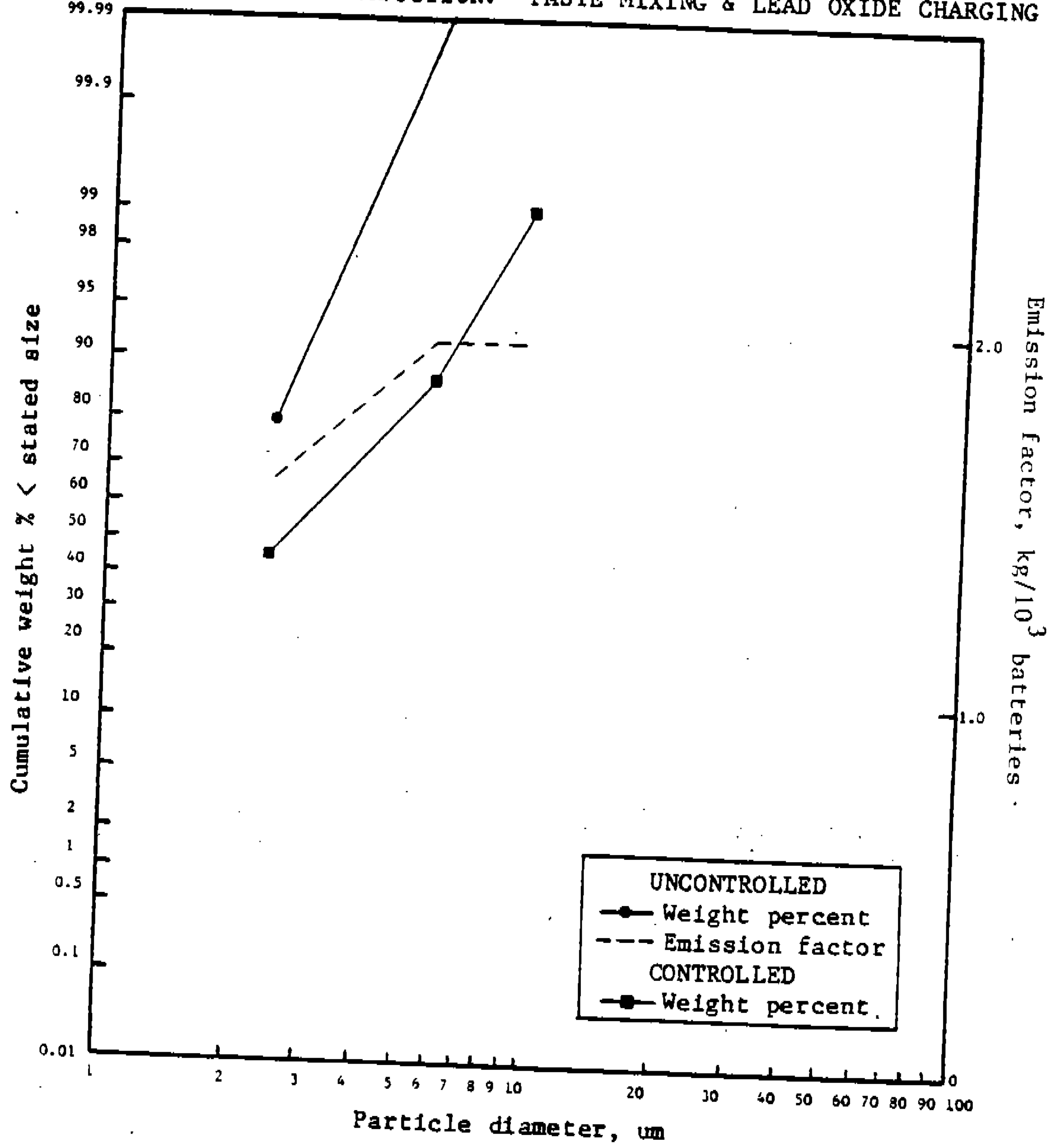
SAMPLING TECHNIQUE: Andersen Impactor

EMISSION FACTOR RATING: E

REFERENCE:

Air Pollution Emission Test, ESB Canada Limited, Mississouga, Ontario, EMB-76-BAT-3, U. S. Environmental Protection Agency, Research Triangle Park, NC, August 1976.

7.15 STORAGE BATTERY PRODUCTION: PASTE MIXING & LEAD OXIDE CHARGING



Aerodynamic particle diameter (um)	Cumulative wt. % < stated size		Emission factor (kg/10^3 batteries)
	Uncontrolled	Fabric filter	Uncontrolled
2.5	80	47	1.58
6.0	100	87	1.96
10.0	100	99	1.96

7.15 STORAGE BATTERY PRODUCTION: PASTE MIXING & LEAD OXIDE CHARGING

NUMBER OF TESTS:
a) 1, conducted before control
b) 4, conducted after fabric filter control

STATISTICS: a)

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	80	100	100
Standard deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

b)

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	47	87	99
Standard deviation (Cum. %):	33.4	14.5	0.9
Min (Cum. %):	36	65	98
Max (Cum. %):	100	100	100

Impactor cut points were so small that many data points had to be extrapolated. Reliability of particle size distributions based on a single test is questionable.

TOTAL PARTICULATE EMISSION FACTOR: 1.96 kg particulate/10^3 batteries, without controls. Factor from AP-42.

SOURCE OPERATION: During test, plant was operated at 39% of the design process rate. Plant has normal production rate of 2,400 batteries per day and maximum capacity of 4,000 batteries per day. Typical amount of lead oxide charged to the mixer is 29,850 lb/8 hour shift. Plant produces wet batteries, except formation is carried out at another plant.

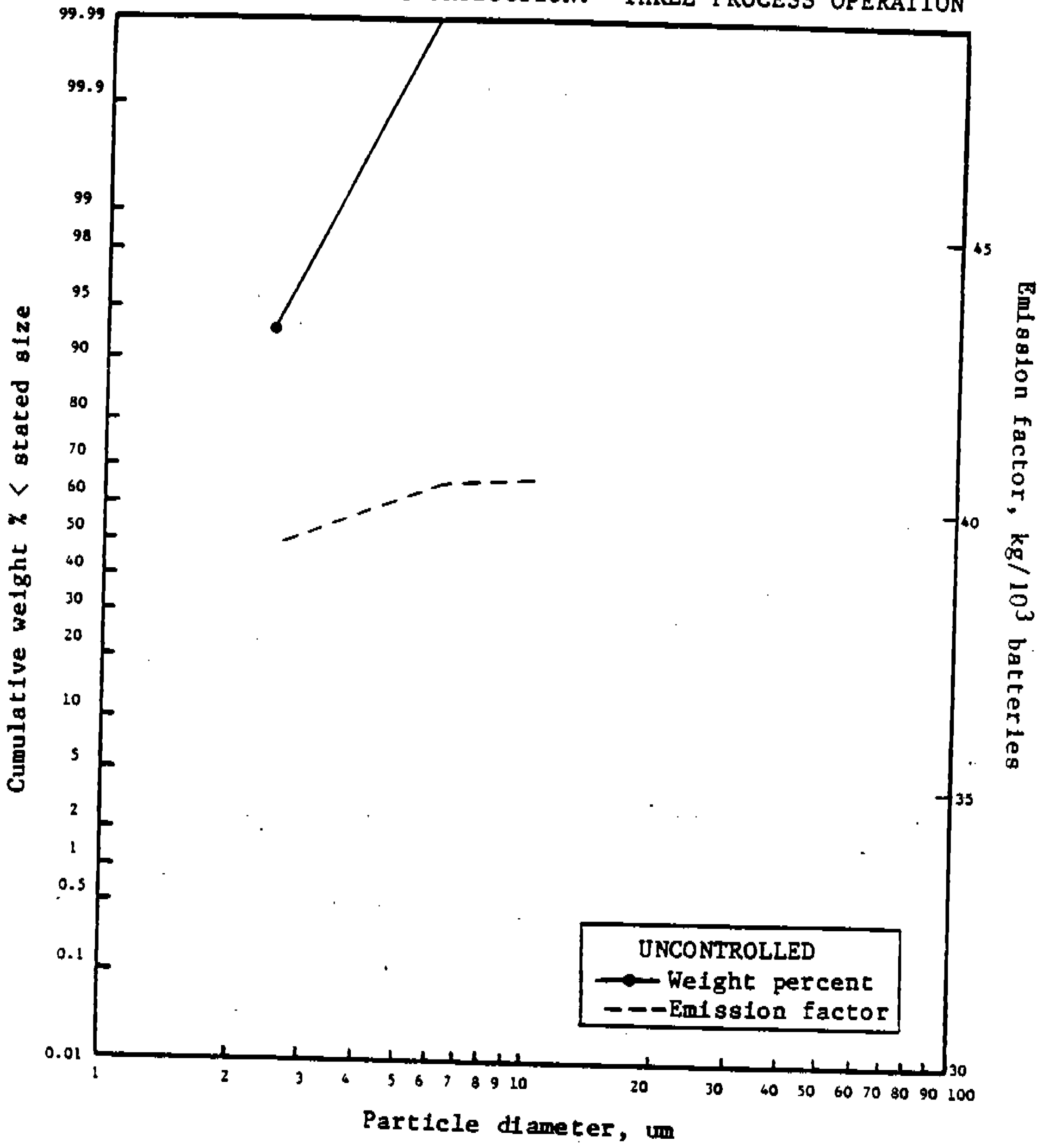
SAMPLING TECHNIQUE:
a) Brinks Impactor
b) Andersen

EMISSION FACTOR RATING: E

REFERENCE:

Air Pollution Emission Test, Globe Union, Inc., Canby, OR, EMB-76-BAT-4, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1976.

7.15 STORAGE BATTERY PRODUCTION: THREE PROCESS OPERATION



Aerodynamic particle diameter (um)	Cumulative wt. % < stated size	Emission factor (kg/10^3 batteries)
	Uncontrolled	Uncontrolled
2.5	93.4	39.3
6.0	100	42
10.0	100	42

7.15 STORAGE BATTERY PRODUCTION: THREE PROCESS OPERATION

NUMBER OF TESTS: 3, conducted before control

STATISTICS:

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	93.4	100	100
Standard deviation (Cum. %):	6.43		
Min (Cum. %):	84.7		
Max (Cum. %):	100		

Impactor cut points were so small that data points had to be extrapolated.

TOTAL PARTICULATE EMISSION FACTOR: 42 kg particulate/10^3 batteries, before controls. Factor from AP-42.

SOURCE OPERATION: Plant representative stated that the plant usually operated at 35% of design capacity. Typical production rate is 3,500 batteries per day (dry and wet), but up to 4,500 batteries per day can be produced. This is equivalent to normal and maximum daily element production of 21,000 and 27,000 battery elements, respectively.

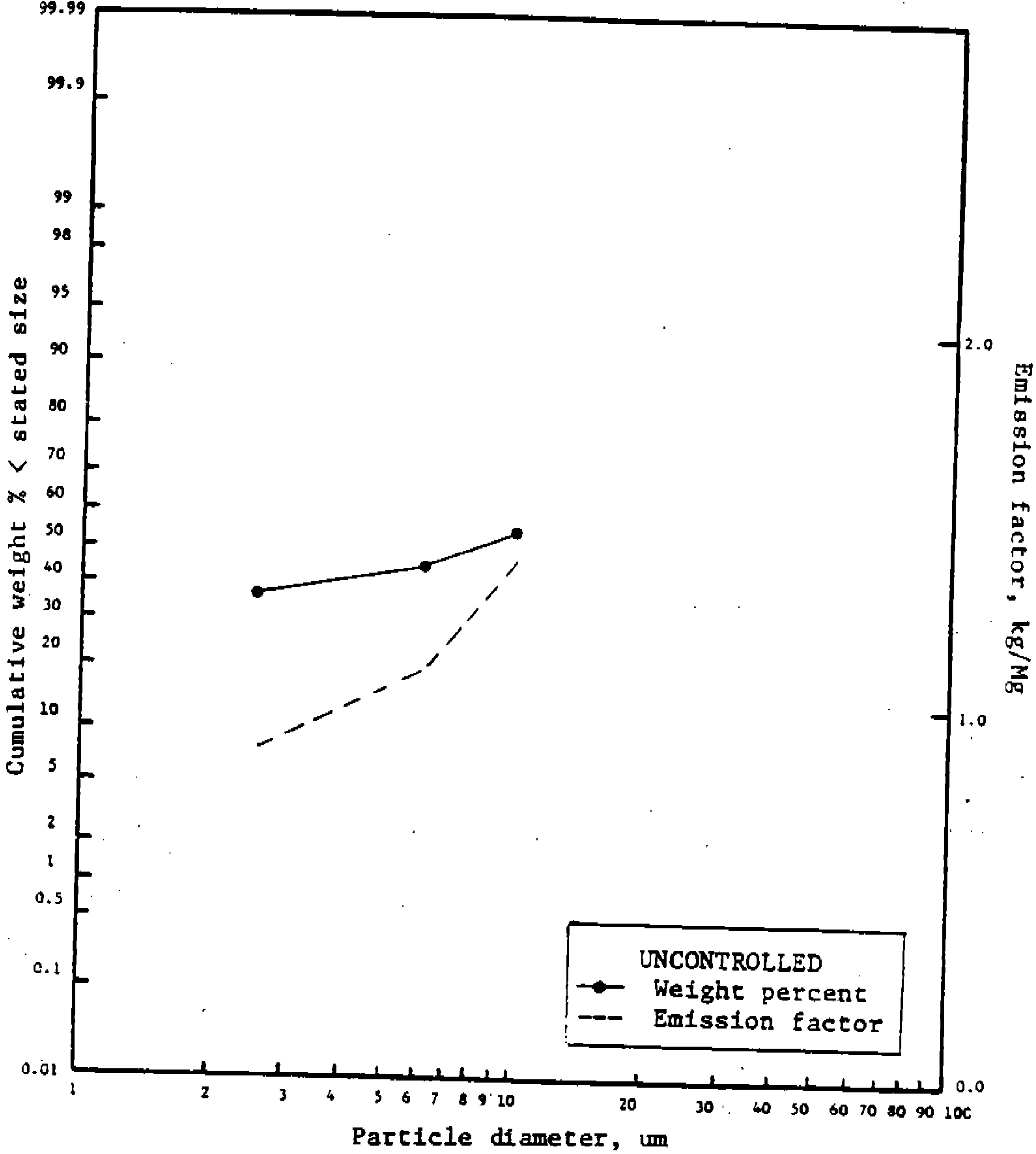
SAMPLING TECHNIQUE: Brinks Impactor

EMISSION FACTOR RATING: E

REFERENCE:

<u>Air Pollution Emission Test, ESB Canada Limited, Mississouga, Ontario</u>, EMB-76-BAT-3, U. S. Environmental Protection Agency, Research Triangle Park, NC, August 1976.

7.xx BATCH TINNER



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg
	Uncontrolled	Uncontrolled
2.5	37.2	0.93
6.0	45.9	1.15
10.0	55.9	1.40

7.xx BATCH TINNER

NUMBER OF TESTS: 2, conducted before controls

STATISTICS:

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	37.2	45.9	55.9
Standard deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: 2.5 kg particulate/Mg tin consumed, without controls. Factor from AP-42, Section 7.14.

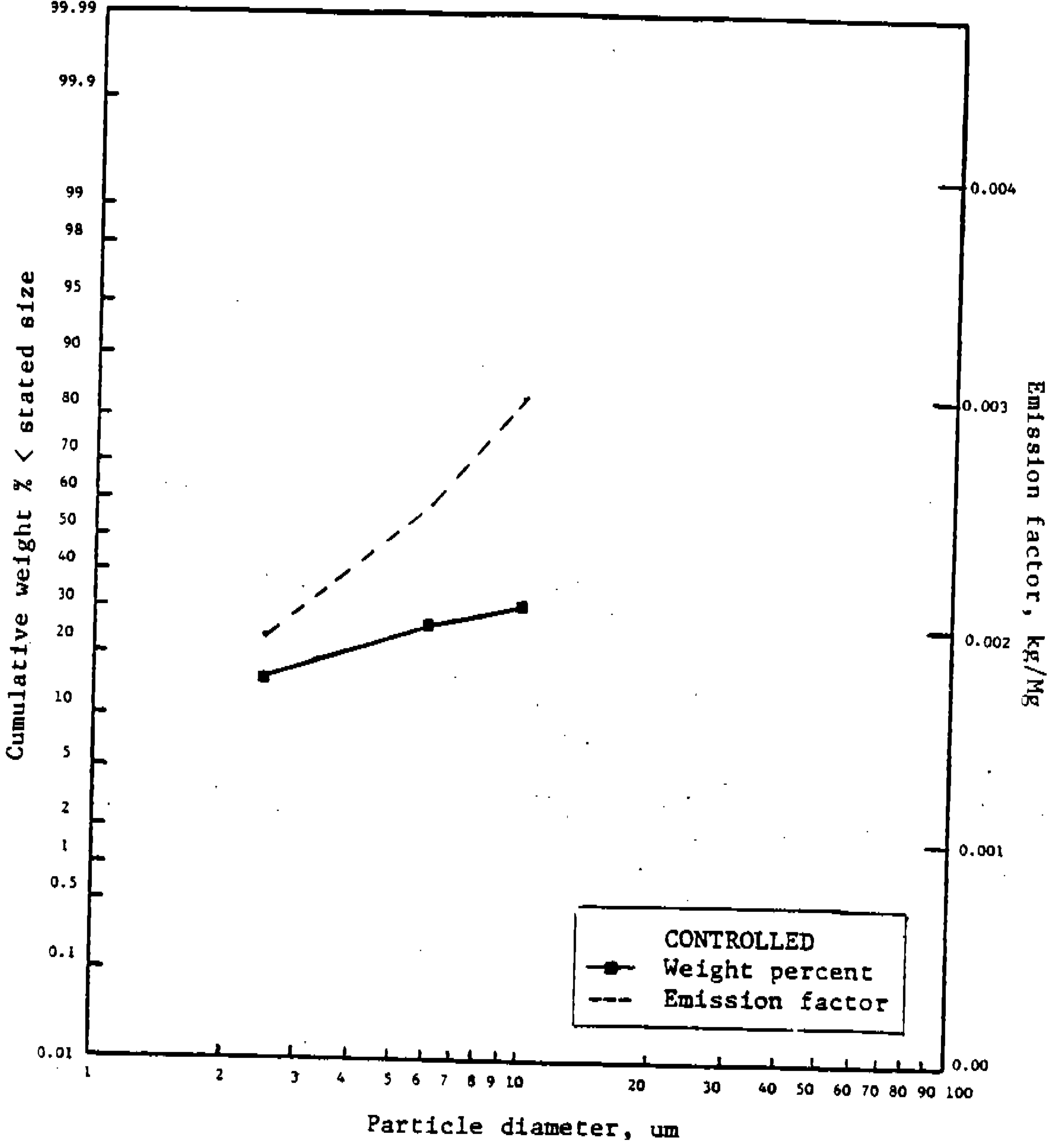
SOURCE OPERATION: Source is a batch operation applying a lead/tin coating to tubing. No further source operating information is available.

SAMPLING TECHNIQUE: Andersen Mark III Impactor

EMISSION FACTOR RATING: D

REFERENCE:

Confidential test data, PEI Associates, Inc., Golden, CO, January 1985.



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg
	After fabric filter control	After fabric filter control
2.5	16	0.002
6.0	26	0.0025
10.0	31	0.003

8.9 COAL CLEANING: DRY PROCESS

NUMBER OF TESTS: 1, conducted after fabric filter control

STATISTICS:

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	16	26	31
Standard deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: 0.01 kg particulate/Mg of coal processed. Emission factor is calculated from data in AP-42, assuming 99% particulate control by fabric filter.

SOURCE OPERATION: Source cleans coal with the dry (air table) process. Average coal feed rate during testing was 70 tons/hr/table.

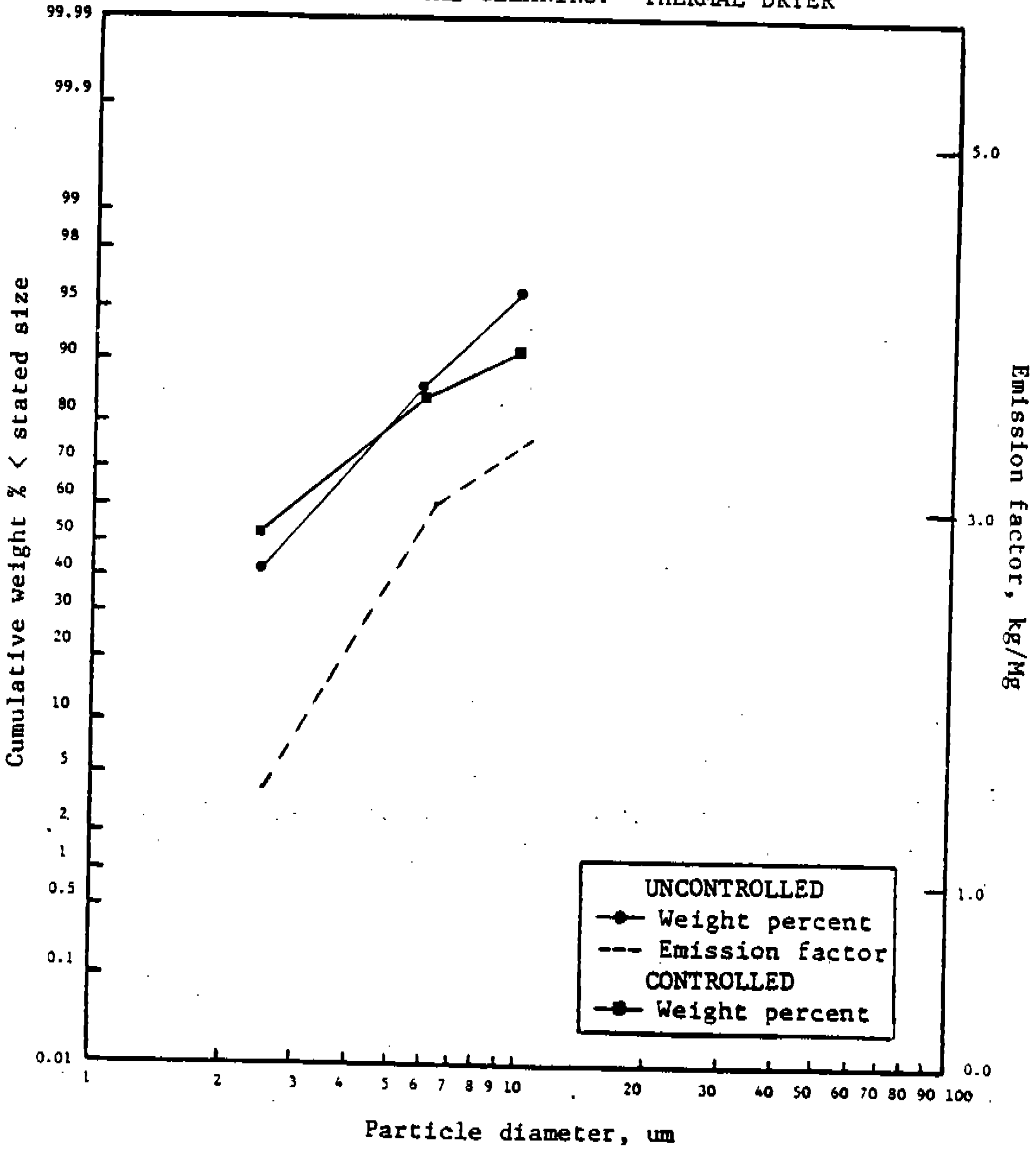
SAMPLING TECHNIQUE: Coulter counter

EMISSION FACTOR RATING: E

REFERENCE:

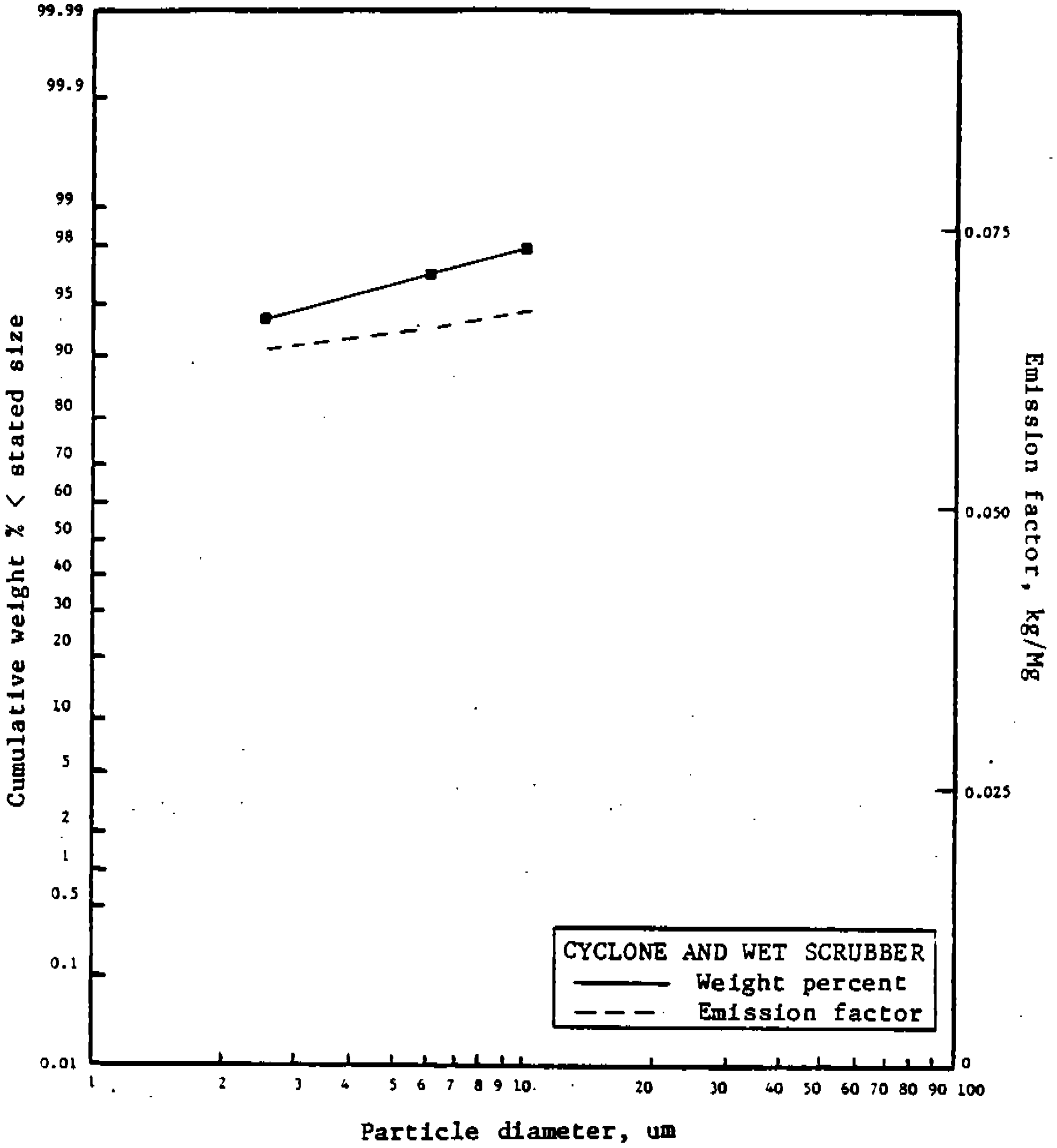
R. W. Kling, Emissions from the Florence Mining Company Coal Processing Plant at Seward, PA, Report No. 72-CI-4, York Research Corporation, Stamford, CT, February 1972.

SECTION 8.9 COAL CLEANING: THERMAL DRYER



Aerodynamic particle diameter, um	Cumulative wt. % < stated size		Emission factor, kg/Mg	
	Uncontrolled	After wet scrubber	Uncontrolled	After wet scrubber
2.5	42	53	1.47	0.016
6.0	86	85	3.01	0.026
10.0	96	91	3.36	0.027

8.18 PHOSPHATE ROCK PROCESSING: CALCINER



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg
	After cyclone[a] and wet scrubber	After cyclone[a] and wet scrubber
2.5	94.0	0.064
6.0	97.0	0.066
10.0	98.0	0.067

[a] Cyclones are typically used in phosphate rock processing as product collectors. Uncontrolled emissions are emissions in the air exhausted from such cyclones.

NUMBER OF TESTS:
a) 1, conducted before control
b) 1, conducted after wet scrubber control

STATISTICS:

a) Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	42	86	96
Standard deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

b) Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	53	85	91
Standard deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: 3.5 kg particulate/Mg of coal processed, (after cyclone) before wet scrubber control. After wet scrubber control, 0.03 kg/Mg. These are site specific emission factors and are calculated from process data measured during source testing.

SOURCE OPERATION: Source operates a thermal dryer to dry coal cleaned by wet cleaning process. Combustion zone in the thermal dryer is about 1000°F, and the air temperature at the dryer exit is about 125°F. Coal processing rate is about 450 tons per hour. Product is collected in cyclones.

SAMPLING TECHNIQUE:
a) Coulter counter
b) Each sample was dispersed with aerosol OT, and further dispersed using an ultrasonic bath. Isoton was the electrolyte used.

EMISSION FACTOR RATING: E

REFERENCE:

R. W. Kling, Emission Test Report, Island Creek Coal Company Coal Processing Plant, Vansant, Virgina, Report No. Y-7730-H, York Research Corporation, Stamford, CT, February 1972.

8.18 PHOSPHATE ROCK PROCESSING: CALCINER

NUMBER OF TESTS: 6, conducted after wet scrubber control

STATISTICS:

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	94.0	97.0	98.0
Standard deviation (Cum. %):	2.5	1.6	1.5
Min (Cum. %):	89.0	95.0	96.0
Max (Cum. %):	98.0	99.2	99.7

TOTAL PARTICULATE EMISSION FACTOR: 0.0685 kg particulate/Mg of phosphate rock calcined, after collection of airborne product in a cyclone, and wet scrubber controls. Factor from reference cited below.

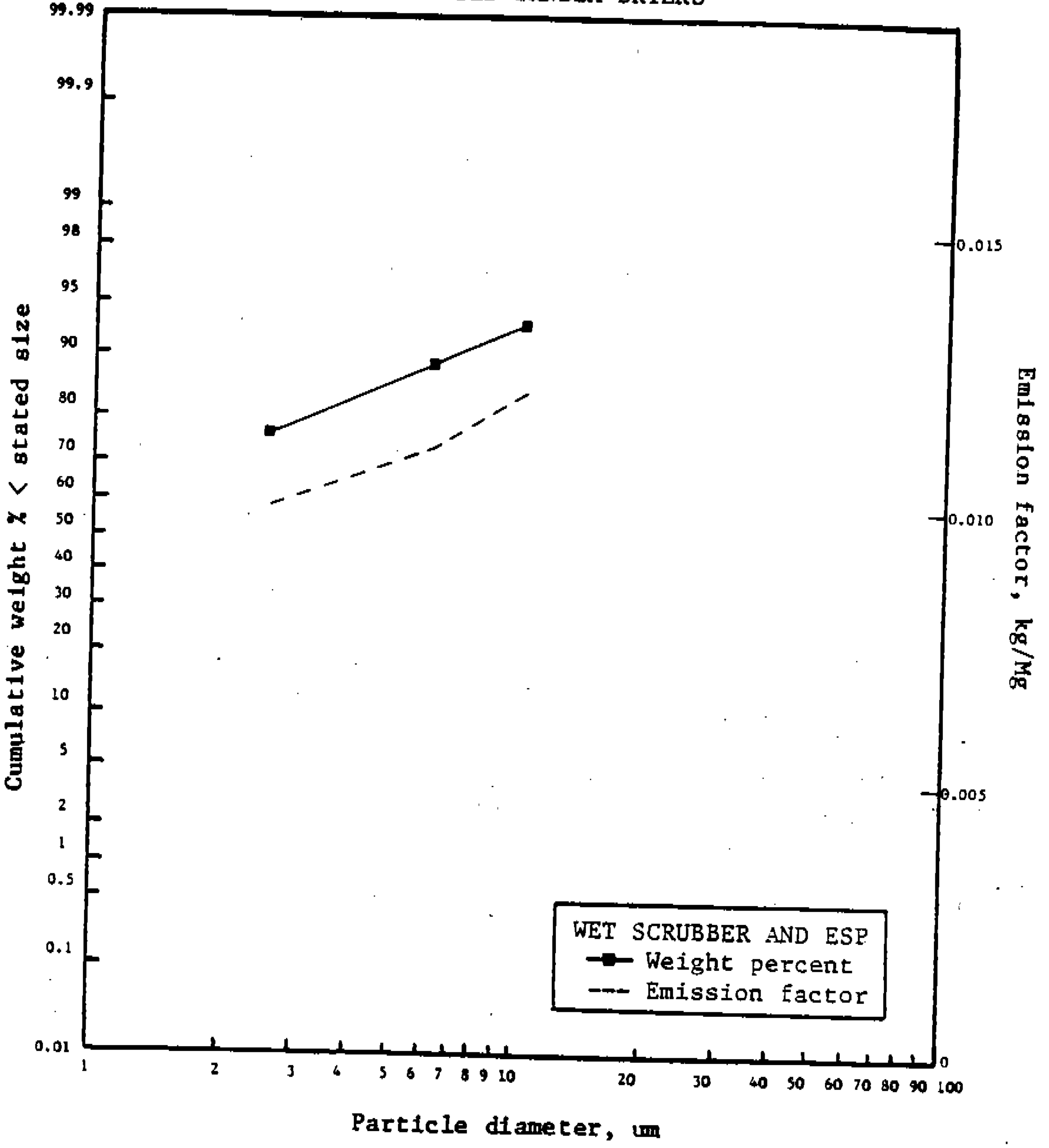
SOURCE OPERATION: Source is a phosphate rock calciner fired with #2 oil, with a rated capacity of 70 tons/hour. Feed to the calciner is beneficiated rock.

SAMPLING TECHNIQUE: Andersen Impactor.

EMISSION FACTOR RATING: C

REFERENCE: Air Pollution Emission Test, Beker Industries, Inc., Conda, ID, EMB-75-PRP-4, U. S. Environmental Protection Agency, Research Triangle Park, NC, November 1975.

8.18 PHOSPHATE ROCK PROCESSING: OIL FIRED ROTARY AND FLUIDIZED BED TANDEM DRYERS



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg
	After wet scrubber and ESP control	After wet scrubber and ESP control
2.5	78.0	0.010
6.0	88.8	0.011
10.0	93.8	0.012

8.18 PHOSPHATE ROCK PROCESSING:
OIL FIRED ROTARY AND FLUIDIZED BED TANDEM DRYERS

NUMBER OF TESTS: 2, conducted after wet scrubber and electrostatic precipitator control

STATISTICS:

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	78.0	88.8	93.8
Standard deviation (Cum. %):	22.6	9.6	2.5
Min (Cum. %):	62	82	92
Max (Cum. %):	94	95	95

TOTAL PARTICULATE EMISSION FACTOR: 0.0125 kg particulate/Mg phosphate rock processed, after collection of airborne product in a cyclone and wet scrubber/ESP controls. Factor from reference cited below.

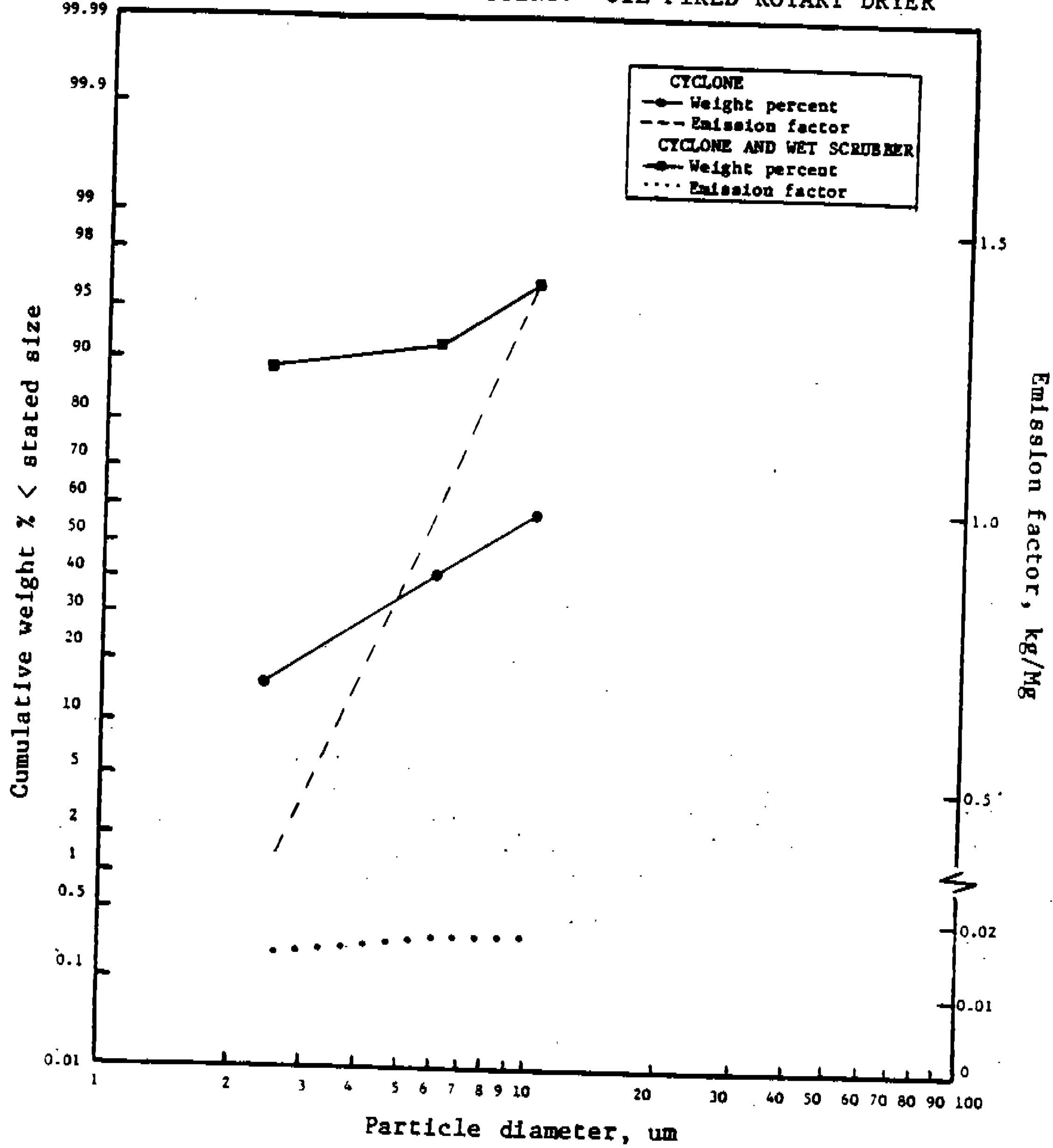
SOURCE OPERATION: Source operates a rotary and a fluidized bed dryer to dry various types of phosphate rock. Both dryers are fired with No. 5 fuel oil, and exhaust into a common duct. The rated capacity of the rotary dryer is 300 tons/hr, and that of the fluidized bed dryer is 150-200 tons/hr. During testing, source was operating at 67.7% of rated capacity.

SAMPLING TECHNIQUE: Andersen Impactor

EMISSION FACTOR RATING: C

REFERENCE: Air Pollution Emission Test, W. R. Grace Chemical Company, Bartow, FL, EMB-75-PRP-1, U. S. Environmental Protection Agency, Research Triangle Park, NC, January 1976.

8.18 PHOSPHATE ROCK PROCESSING: OIL FIRED ROTARY DRYER



Aerodynamic particle diameter, (um)	Cumulative wt. % < stated size		Emission factor, kg/Mg	
	After cyclone[a]	After wet scrubber	After cyclone[a]	After wet scrubber
2.5	15.7	89	0.38	0.017
6.0	41.3	92.3	1.00	0.018
10.0	58.3	96.6	1.41	0.018

[a] Cyclones are typically used in phosphate rock processing as product collectors. Uncontrolled emissions are emissions in the air exhausted from such cyclones.

8.18 PHOSPHATE ROCK PROCESSING: OIL FIRED ROTARY DRYER

NUMBER OF TESTS: a) 3, conducted after cyclone
b) 2, conducted after wet scrubber control

STATISTICS:

a) Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	15.7	41.3	58.3
Standard deviation (Cum. %):	5.5	9.6	13.9
Min (Cum. %):	12	30	43
Max (Cum. %):	22	48	70

b) Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	89.0	92.3	96.6
Standard Deviation (Cum. %):	7.1	6.0	3.7
Min (Cum. %):	84	88	94
Max (Cum. %):	94	96	99

Impactor cut points for the tests conducted before control are small, and many of the data points are extrapolated. These particle size distributions are related to specific equipment and source operation, and are most applicable to particulate emissions from similar sources operating similar equipment. Table 8.18-2, Section 8.18, AP-42 presents particle size distributions for generic phosphate rock dryers.

TOTAL PARTICULATE EMISSION FACTORS: After cyclone, 2.419 kg particulate/Mg rock processed. After wet scrubber control, 0.019 kg/Mg. Factors from reference cited below.

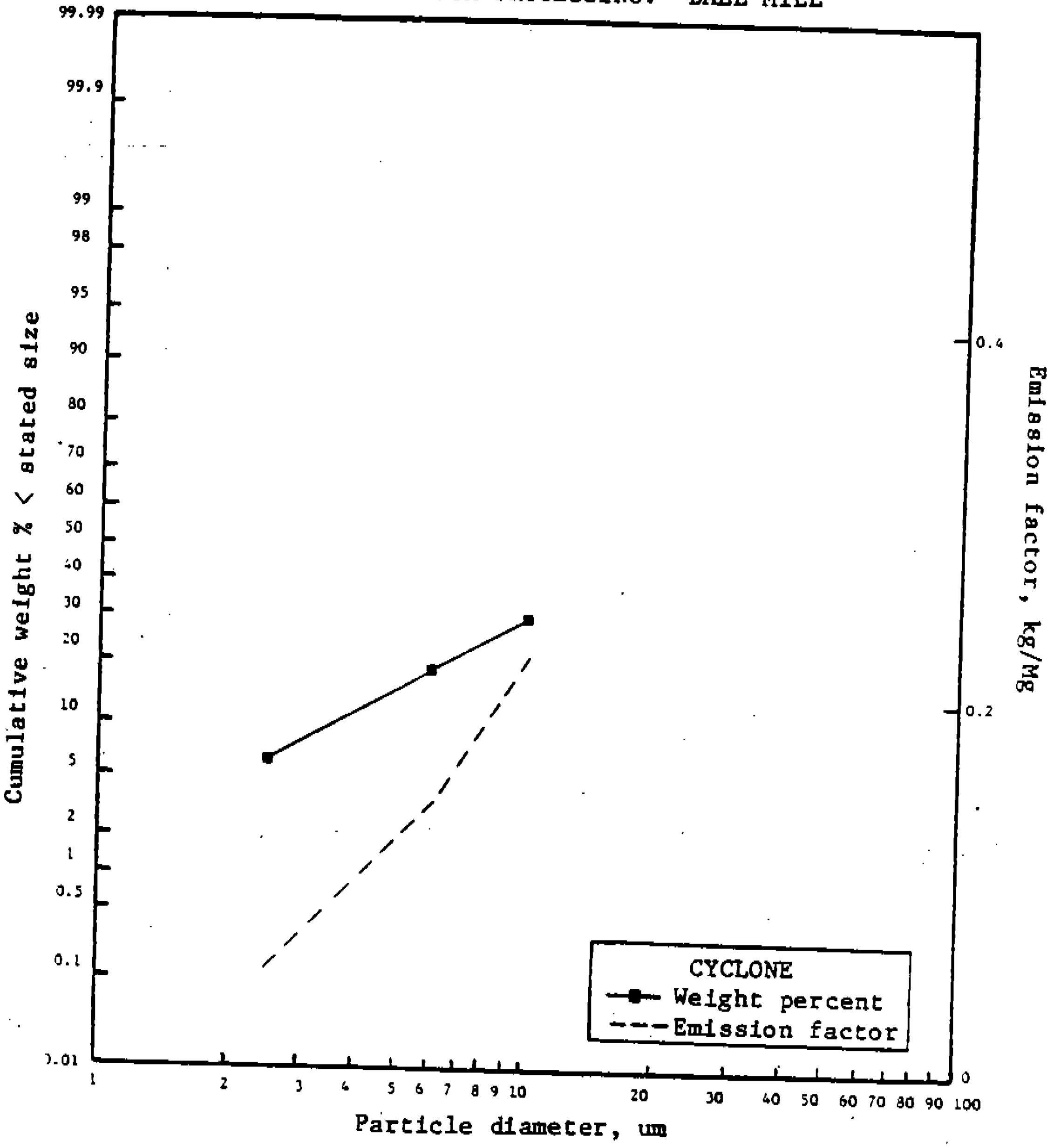
SOURCE OPERATION: Source dries phosphate rock in #6 oil fired rotary dryer. During these tests, source operated at 69% of rated dryer capacity of 350 ton/day, and processed coarse pebble rock.

SAMPLING TECHNIQUE: a) Brinks Cascade Impactor
b) Andersen Impactor

EMISSION FACTOR RATING: D

REFERENCE: Air Pollution Emission Test, Mobil Chemical, Nichols, FL, EMB-75-PRP-3, U. S. Environmental Protection Agency, Research Triangle Park, NC, January 1976.

8.18 PHOSPHATE ROCK PROCESSING: BALL MILL



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg
	After cyclone[a]	After cyclone[a]
2.5	6.5	0.05
6.0	19.0	0.14
10.0	30.8	0.22

[a] Cyclones are typically used in phosphate rock processing as product collectors. Uncontrolled emissions are emissions in the air exhausted from such cyclones.

8.18 PHOSPHATE ROCK PROCESSING: BALL MILL

NUMBER OF TESTS: 4, conducted after cyclone

STATISTICS:

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	6.5	19.0	30.8
Standard deviation (Cum. %):	3.5	0.9	2.6
Min (Cum. %):	3	18	28
Max (Cum. %):	11	20	33

Impactor cutpoints were small, and most data points were extrapolated.

TOTAL PARTICULATE EMISSION FACTOR: 0.73 kg particulate/Mg of phosphate rock milled, after collection of airborne product in cyclone. Factor from reference cited below.

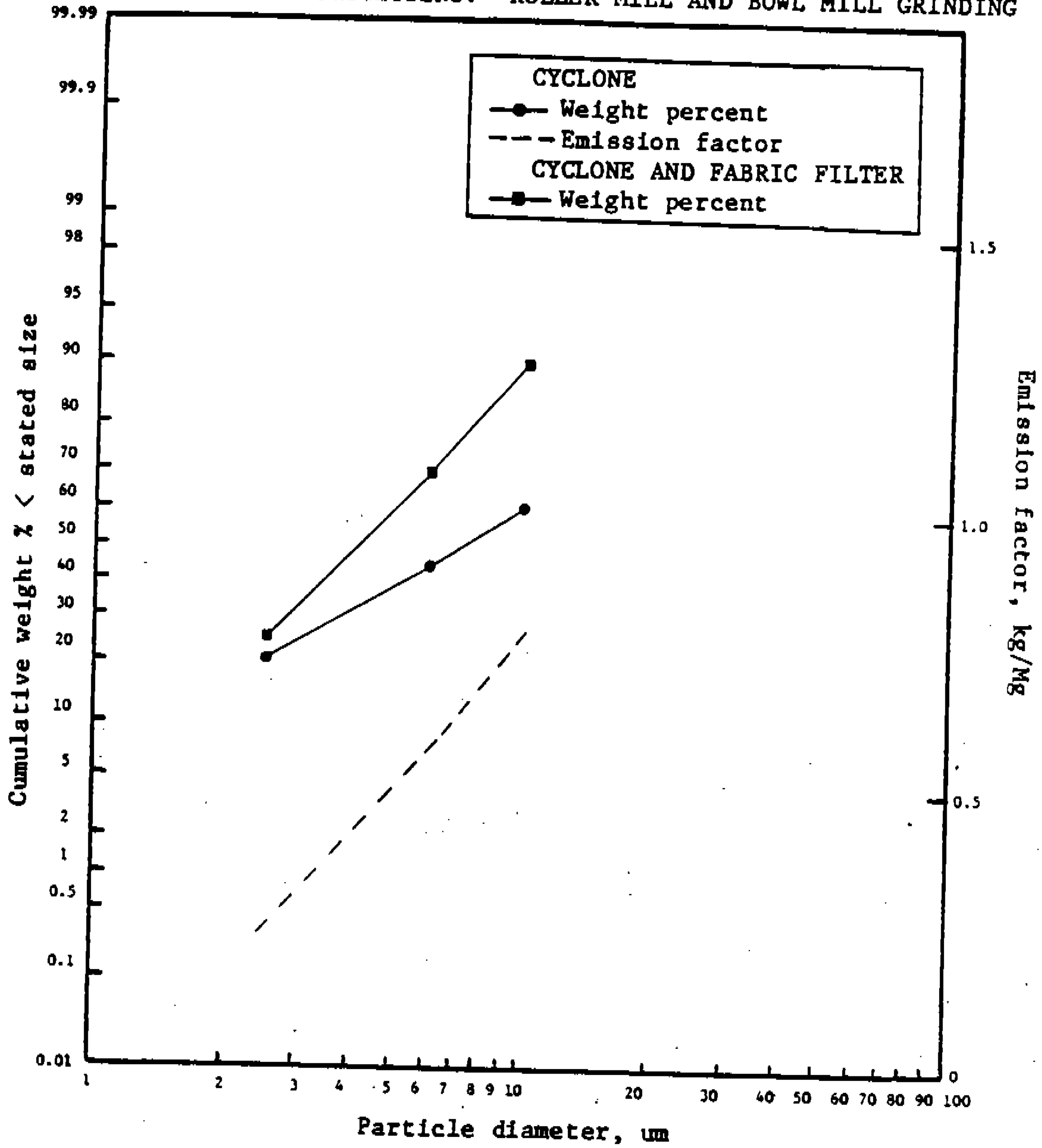
SOURCE OPERATION: Source mills western phosphate rock. During testing, source was operating at 101% of rated capacity, producing 80 tons/hour.

SAMPLING TECHNIQUE: Brinks Impactor

EMISSION FACTOR RATING: C

REFERENCE: Air Pollution Emission Test, Beker Industries, Inc., Conda, ID, EMB-75-PRP-4, U. S. Environmental Protection Agency, Research Triangle Park, NC, November 1975.

8.18 PHOSPHATE ROCK PROCESSING: ROLLER MILL AND BOWL MILL GRINDING



Aerodynamic particle diameter, um	Cumulative wt. % < stated size		Emission factor, kg/Mg	
	After cyclone[a]	After fabric filter	After cyclone[a]	After fabric filter
2.5	21	25	0.27	Negligible
6.0	45	70	0.58	Negligible
10.0	62	90	0.79	Negligible

[a] Cyclones are typically used in phosphate rock processing as product collectors. Uncontrolled emissions are emissions in the air exhausted from such cyclones.

8.18 PHOSPHATE ROCK PROCESSING: ROLLER MILL AND BOWL MILL GRINDING

NUMBER OF TESTS: a) 2, conducted after cyclone
b) 1, conducted after fabric filter control

STATISTICS: a) Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	21.0	45.0	62.0
Standard deviation (Cum. %):	1.0	1.0	0
Min (Cum. %):	20.0	44.0	62.0
Max (Cum. %):	22.0	46.0	62.0

b) Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	25	70	90
Standard deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: 0.73 kg particulate/Mg of rock processed, after collection of airborne product in a cyclone. After fabric filter control, 0.001 kg particulate/Mg rock processed. Factors calculated from data in reference cited below. AP-42 (2/80) specifies a range of emissions from phosphate rock grinders (uncontrolled). See Table 8.18-1 for guidance.

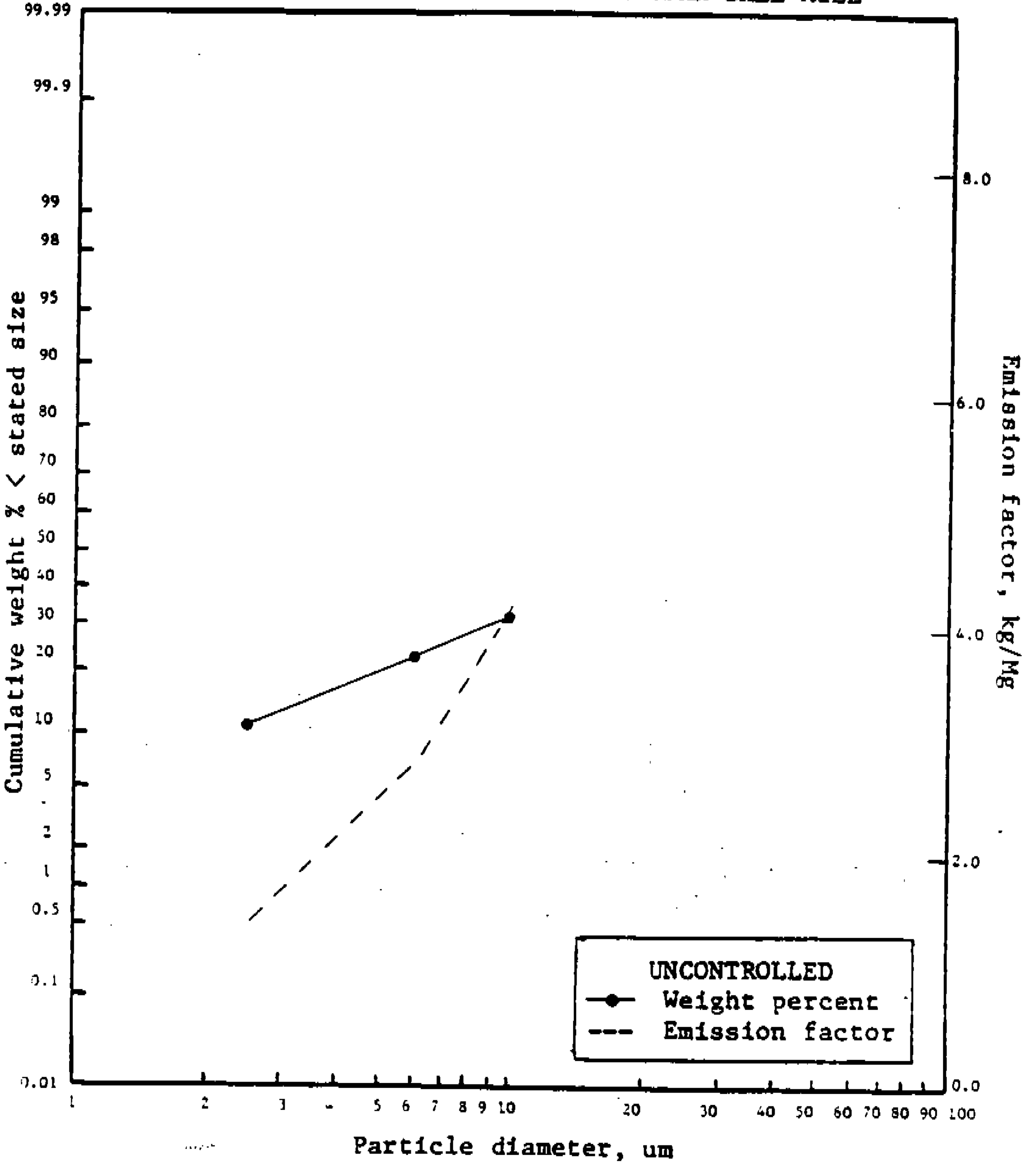
SOURCE OPERATION: During testing, source was operating at 100% of design process rate. Source operates 1 roller mill with a rated capacity of 25 tons/hr of feed, and 1 bowl mill with a rated capacity of 50 tons/hr of feed. After product has been collected in cyclones, emissions from each mill are vented to a common baghouse. Source operates 6 days/week, and processes Florida rock.

SAMPLING TECHNIQUE: a) Brinks Cascade Impactor
b) Andersen Impactor

EMISSION FACTOR RATING: D

REFERENCE: Air Pollution Emission Test, The Royster Company, Mulberry, FL, EMB-75-PRP-2, U. S. Environmental Protection Agency, Research Triangle Park, NC, January 1976.

8.xx NONMETALLIC MINERALS: FELDSPAR BALL MILL



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg
	Before controls	Before controls
2.5	11.5	1.5
6.0	22.8	2.9
10.0	32.3	4.2

8.xx NONMETALLIC MINERALS: FELDSPAR BALL MILL

NUMBER OF TESTS: 2, conducted before controls

STATISTICS:

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	11.5	22.8	32.3
Standard deviation (Cum. %):	6.4	7.4	6.7
Min (Cum. %):	7.0	17.5	27.5
Max (Cum. %):	16.0	28.0	37.0

TOTAL PARTICULATE EMISSION FACTOR: 12.9 kg particulate/Mg feldspar produced. Calculated from data in reference and related documents.

SOURCE OPERATION: After crushing and grinding of feldspar ore, source produces feldspar powder in a ball mill.

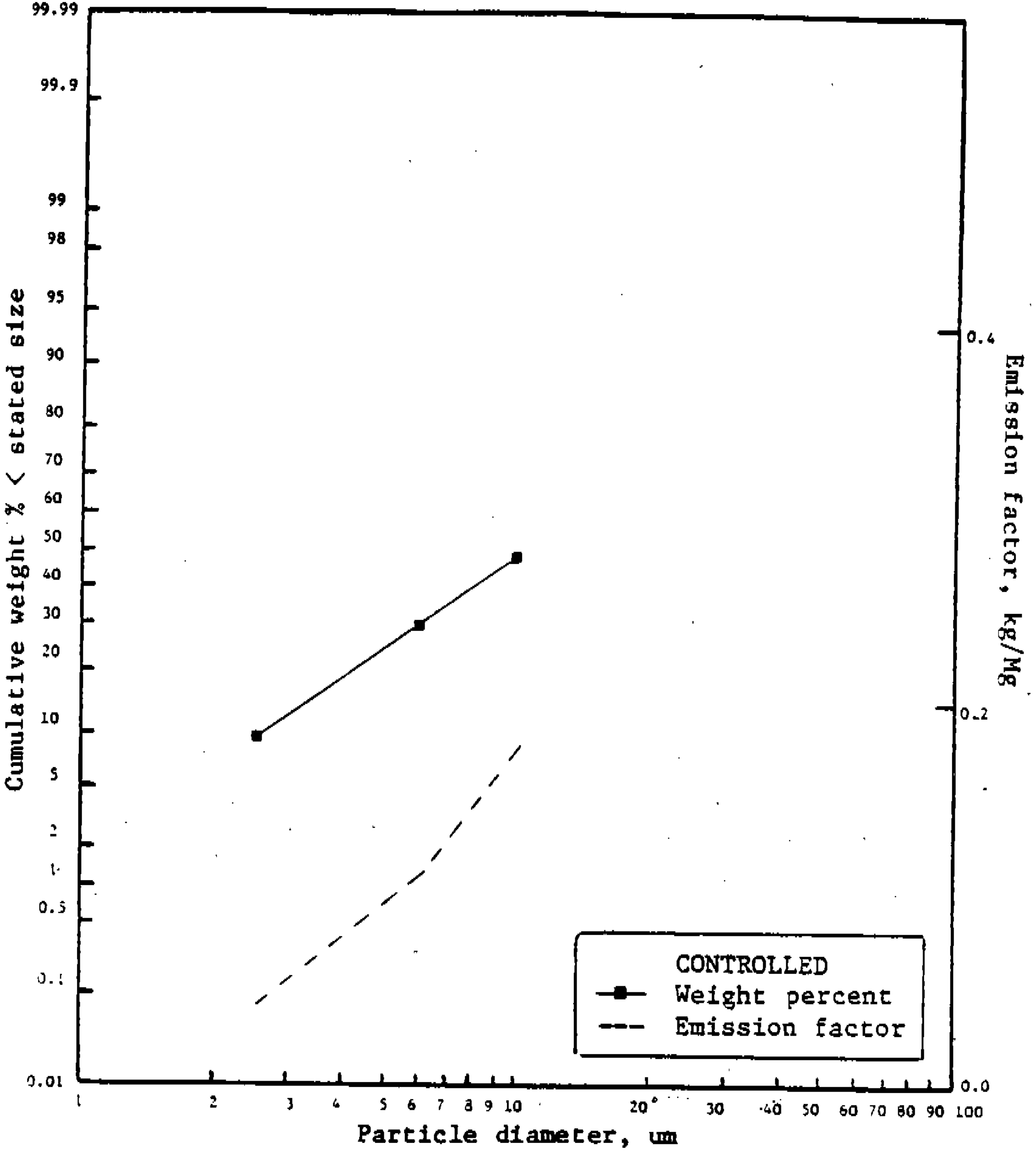
SAMPLING TECHNIQUE: Alundum thimble followed by 12 inch section of stainless steel probe followed by 47 mm type SGA filter contained in a stainless steel Gelman filter holder. Laboratory analysis methods: microsieve and electronic particle counter.

EMISSION FACTOR RATING: D

REFERENCE:

Air Pollution Emission Test, International Minerals and Chemical Company, Spruce Pine, NC, EMB-76-NMM-1, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1976.

8.xx NONMETALLIC MINERALS: FLUORSPAR ORE ROTARY DRUM DRYER



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg
	After fabric filter control	After fabric filter control
2.5	10	0.04
6.0	30	0.11
10.0	48	0.18

8.xx NONMETALLIC MINERALS: FLUORSPAR ORE ROTARY DRUM DRYER

NUMBER OF TESTS: 1, conducted after fabric filter control

STATISTICS: Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	10	30	48
Standard deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: 0.375 kg particulate/Mg ore dried, after fabric filter control. Factors from reference.

SOURCE OPERATION: Source dries fluorspar ore in a rotary drum dryer at a feed rate of 2 tons/hour.

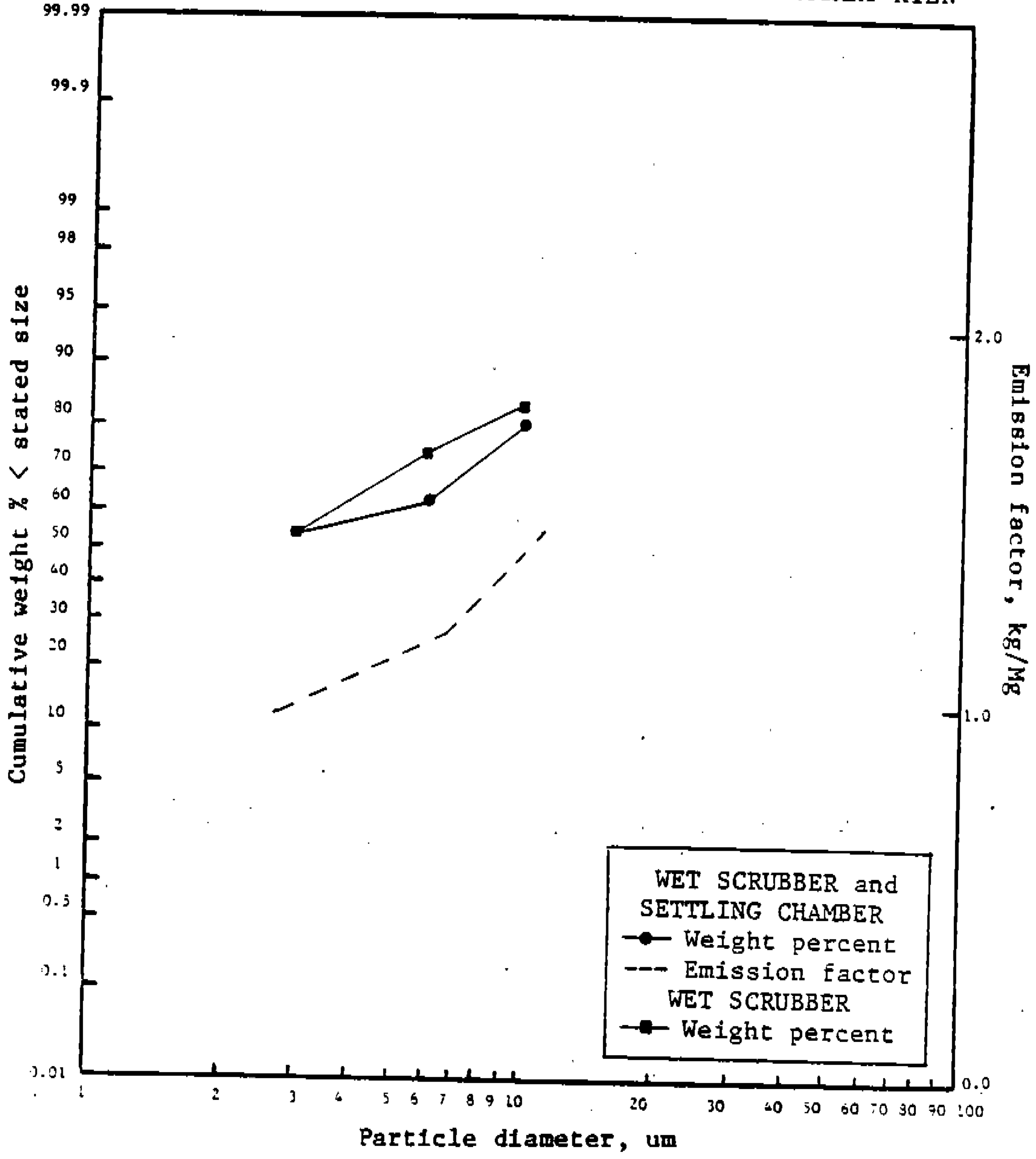
SAMPLING TECHNIQUE: Andersen Mark III Impactor

EMISSION FACTOR RATING: E

REFERENCE:

Confidential test data from a major fluorspar ore processor, PEI Associates, Inc., Golden, CO, January 1985.

8.xx LIGHTWEIGHT AGGREGATE (CLAY): COAL FIRED ROTARY KILN



Aerodynamic particle diameter (um)	Cumulative wt. % < stated size		Emission factor (kg/Mg)
	Wet scrubber and settling chamber	Wet scrubber	Wet scrubber and settling chamber
2.5	55	55	0.97
6.0	65	75	1.15
10.0	81	84	1.43

8.xx LIGHTWEIGHT AGGREGATE (CLAY): COAL FIRED ROTARY KILN

NUMBER OF TESTS: a) 4, conducted after wet scrubber control
b) 8, conducted after settling chamber and wet scrubber control

STATISTICS:

a) Aerodynamic particle diameter, (um):	2.5	6.0	10.0
Mean (Cum. %):	55	75	84
Standard Deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

b) Aerodynamic particle diameter, (um):	2.5	6.0	10.0
Mean (Cum. %):	55	65	81
Standard Deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: 1.77 kg particulate/Mg of clay processed, after control by settling chamber and wet scrubber. Calculated from data in Reference c.

SOURCE OPERATION: Sources produce lightweight clay aggregate in pulverized coal fired rotary kilns. Kiln capacity for Source b is 750 tons/day, and operation is continuous.

SAMPLING TECHNIQUE: Andersen Impactor

EMISSION FACTOR RATING: C

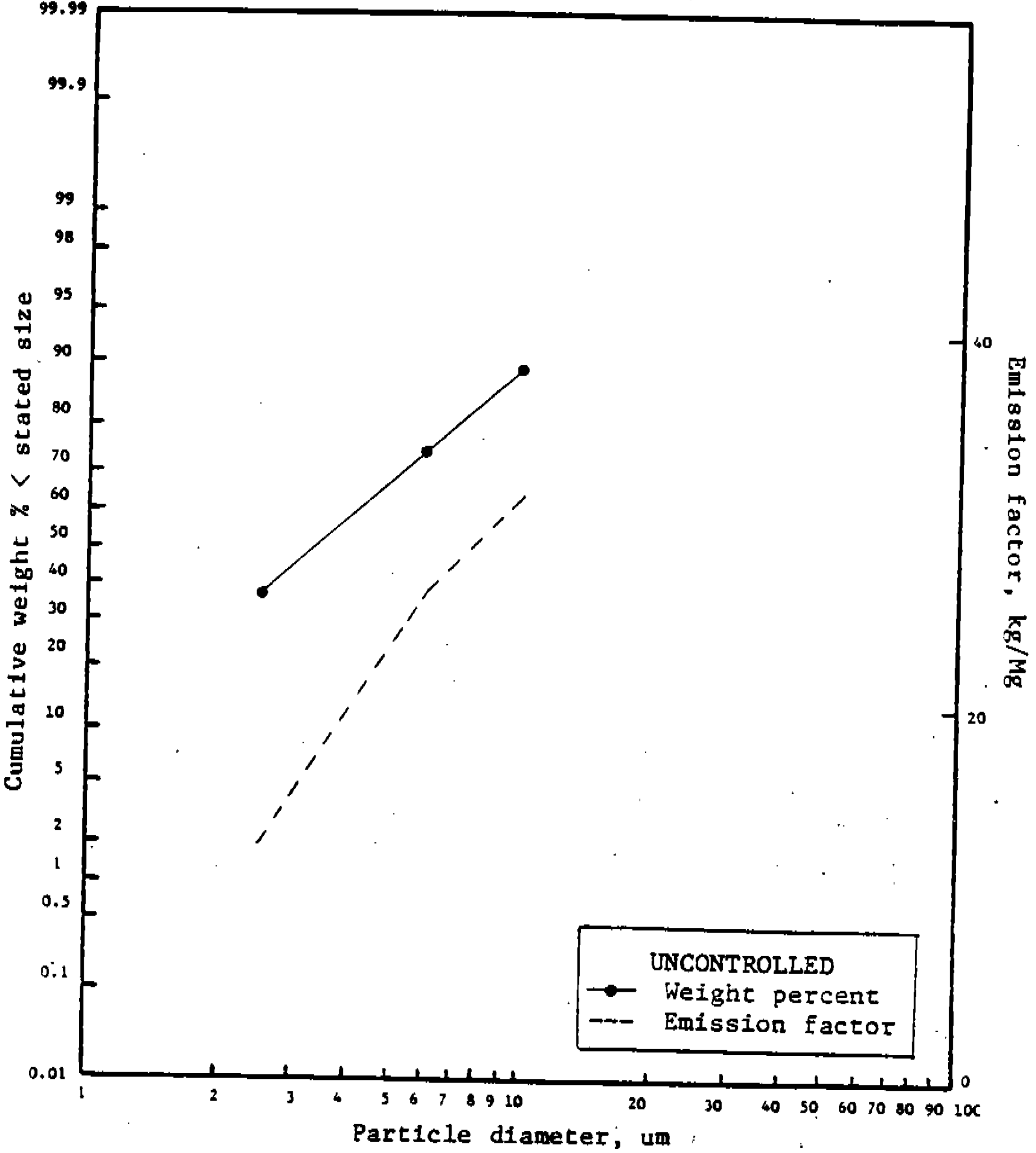
REFERENCES:

a. Emission Test Report, Lightweight Aggregate Industry, Texas Industries, Inc., EMB-80-LWA-3, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1981.

b. Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System, Series Report No. 341, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.

c. Emission Test Report, Lightweight Aggregate Industry, Arkansas Lightweight Aggregate Corporation, EMB-80-LWA-2, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1981.

8.xx LIGHTWEIGHT AGGREGATE (CLAY): DRYER



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg
	Uncontrolled	Uncontrolled
2.5	37.2	13.0
6.0	74.8	26.2
10.0	89.5	31.3

8.xx LIGHTWEIGHT AGGREGATE (CLAY): DRYER

NUMBER OF TESTS: 5, conducted before controls

STATISTICS:

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	37.2	74.8	89.5
Standard deviation (Cum. %):	3.4	5.6	3.6
Min (Cum. %):	32.3	68.9	85.5
Max (Cum. %):	41.0	80.8	92.7

TOTAL PARTICULATE EMISSION FACTOR: 35 kg/Mg clay feed to dryer. From AP-42, Section 8.7.

SOURCE OPERATION: No information on source operation is available

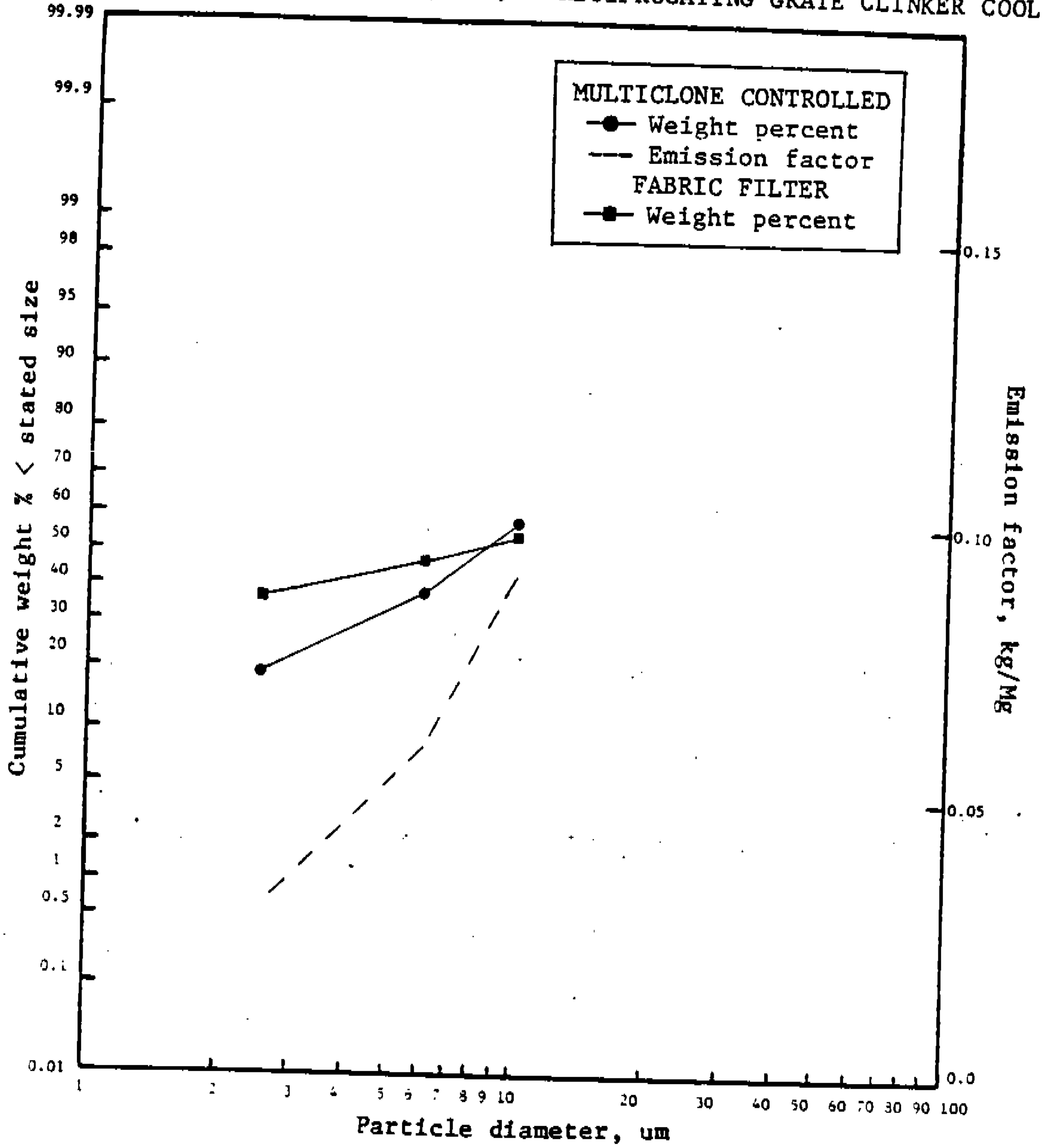
SAMPLING TECHNIQUE: Brinks impactor

EMISSION FACTOR RATING: C

REFERENCE:

Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System, Series Report No. 88, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.

8.xx LIGHTWEIGHT AGGREGATE (CLAY): RECIPROCATING GRATE CLINKER COOLER



Aerodynamic particle diameter, um	Cumulative wt. % < stated size		Emission factor, kg/Mg
	Multiclone	Fabric filter	Multiclone
2.5	19.3	39	0.03
6.0	38.1	48	0.06
10.0	56.7	54	0.09

8.xx LIGHTWEIGHT AGGREGATE (CLAY): RECIPROCATING GRATE CLINKER COOLER

NUMBER OF TESTS: a) 12, conducted after Multiclone control
b) 4, conducted after Multiclone and fabric filter control

STATISTICS:

a) Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	19.3	38.1	56.7
Standard deviation (Cum. %):	7.9	14.9	17.9
Min (Cum. %):	9.3	18.6	29.2
Max (Cum. %):	34.6	61.4	76.6
b) Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	39	48	54
Standard deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: 0.157 kg particulate/Mg clay processed, after multiclone control. Factor calculated from data in Reference b. After fabric filter control, particulate emissions are negligible.

SOURCE OPERATION: Sources produce lightweight clay aggregate in a coal fired rotary kiln and reciprocating grate clinker cooler.

SAMPLING TECHNIQUE: a) Andersen Impactor
b) Andersen Impactor

EMISSION FACTOR RATING: C

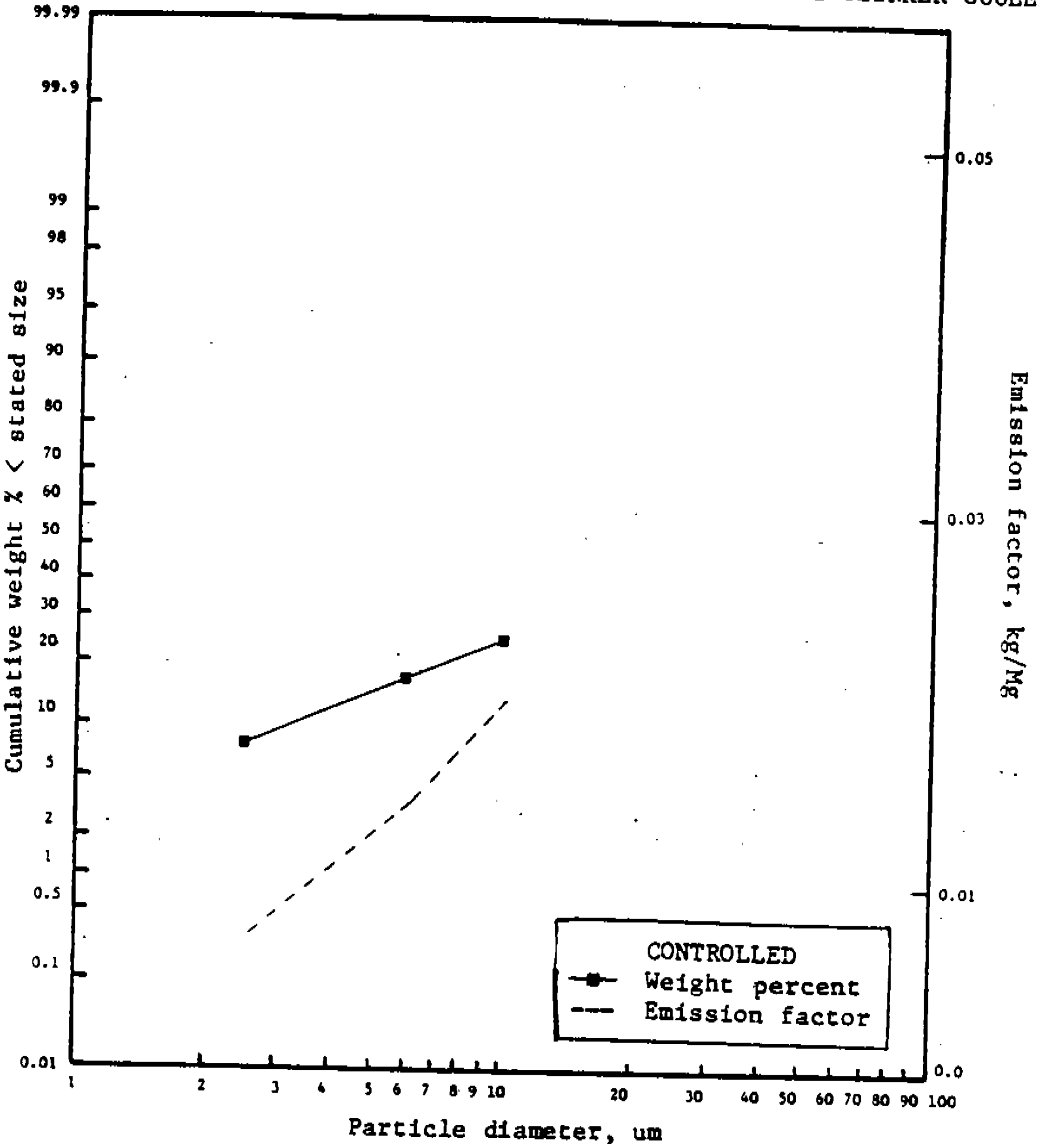
REFERENCES:

a. Emission Test Report, Lightweight Aggregate Industry, Texas Industries, Inc., EMB-80-LWA-3, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1981.

b. Emission Test Report, Lightweight Aggregate Industry, Arkansas Lightweight Aggregate Corporation, EMB-80-LWA-2, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1981.

c. Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System, Series Report No. 342, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.

8.xx LIGHTWEIGHT AGGREGATE (SHALE): RECIPROCATING GRATE CLINKER COOLER



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg
	Settling chamber control	Settling chamber control
2.5	8.2	0.007
6.0	17.6	0.014
10.0	25.6	0.020

8.xx LIGHTWEIGHT AGGREGATE (SHALE): RECIPROCATING GRATE CLINKER COOLER

NUMBER OF TESTS: 4, conducted after settling chamber control

STATISTICS:

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	8.2	17.6	25.6
Standard deviation (Cum. %):	4.3	2.8	1.7
Min (Cum. %):	4.0	15.0	24.0
Max (Cum. %):	14.0	21.0	28.0

TOTAL PARTICULATE EMISSION FACTOR: 0.08 kg particulate/Mg of aggregate produced. Factor calculated from data in reference.

SOURCE OPERATION: Source operates two kilns to produce lightweight shale aggregate, which is cooled and classified on a reciprocating grate clinker cooler. Normal production rate of the tested kiln is 23 tons/hr, about 66% of rated capacity. Kiln rotates at 2.8 rpm. Feed end temperature is 1100°F.

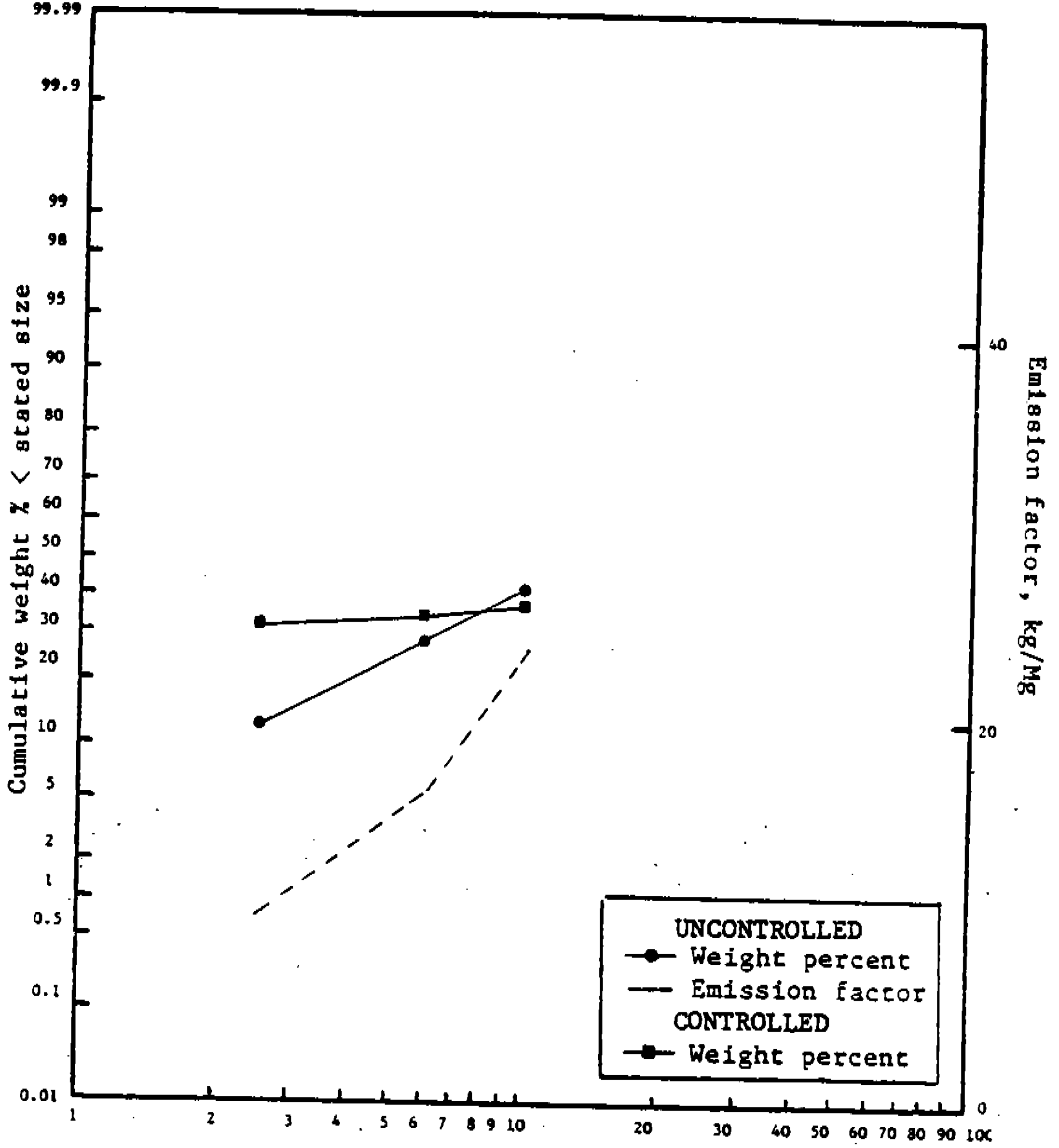
SAMPLING TECHNIQUE: Andersen Impactor

EMISSION FACTOR RATING: B

REFERENCE:

Emission Test Report, Lightweight Aggregate Industry, Vulcan Materials Company, EMB-80-LWA-4, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1982.

8.xx LIGHTWEIGHT AGGREGATE (SLATE): COAL FIRED ROTARY KILN



Aerodynamic particle diameter, um	Cumulative wt. % < stated size		Emission factor, kg/Mg	
	Without controls	After wet scrubber control	Without controls	After wet scrubber control
2.5	13	33	7.3	0.59
6.0	29	36	16.2	0.65
10.0	42	39	23.5	0.70

8.xx LIGHTWEIGHT AGGREGATE (SLATE): COAL FIRED ROTARY KILN

NUMBER OF TESTS: a) 3, conducted before control
b) 5, conducted after wet scrubber control

STATISTICS:

a) Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	13.0	29.0	42.0
Standard deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

b) Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	33.0	36.0	39.0
Standard deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: For uncontrolled source, 56.0 kg particulate/Mg of feed. After wet scrubber control, 1.8 kg particulate/Mg of feed. Factors are calculated from data in reference.

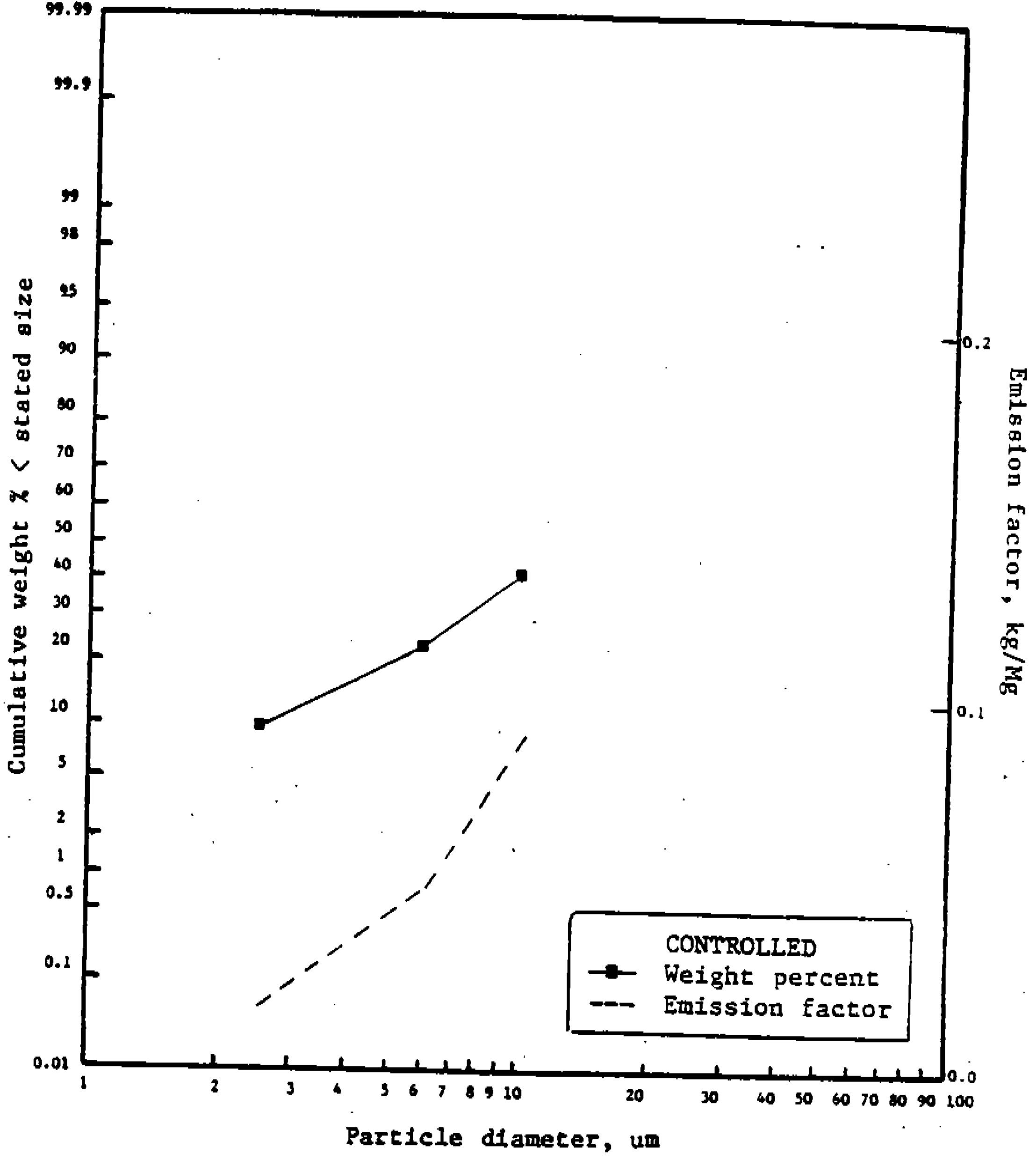
SOURCE OPERATION: Source produces light weight aggregate from slate in coal fired rotary kiln and reciprocating grate clinker cooler. During testing source was operating at a feed rate of 33 tons/hr., 83% rated capacity. Firing zone temperatures are about 2125°F and kiln rotates at 3.25 RPM.

SAMPLING TECHNIQUE: a. Bacho
b. Andersen Impactor

EMISSION FACTOR RATING: C

REFERENCE:

Emission Test Report, Lightweight Aggregate Industry, Galite Corporation, EMB-80-LWA-6, U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1982.



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg
	After settling chamber control	After settling chamber control
2.5	9.8	0.02
6.0	23.6	0.05
10.0	41.0	0.09

8.xx LIGHTWEIGHT AGGREGATE (SLATE): RECIPROCATING GRATE CLINKER COOLER

NUMBER OF TESTS: 5, conducted after settling chamber control

STATISTICS: Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	9.8	23.6	41.0
Standard deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: 0.22 kg particulate/Mg of raw material feed. Factor calculated from data in reference.

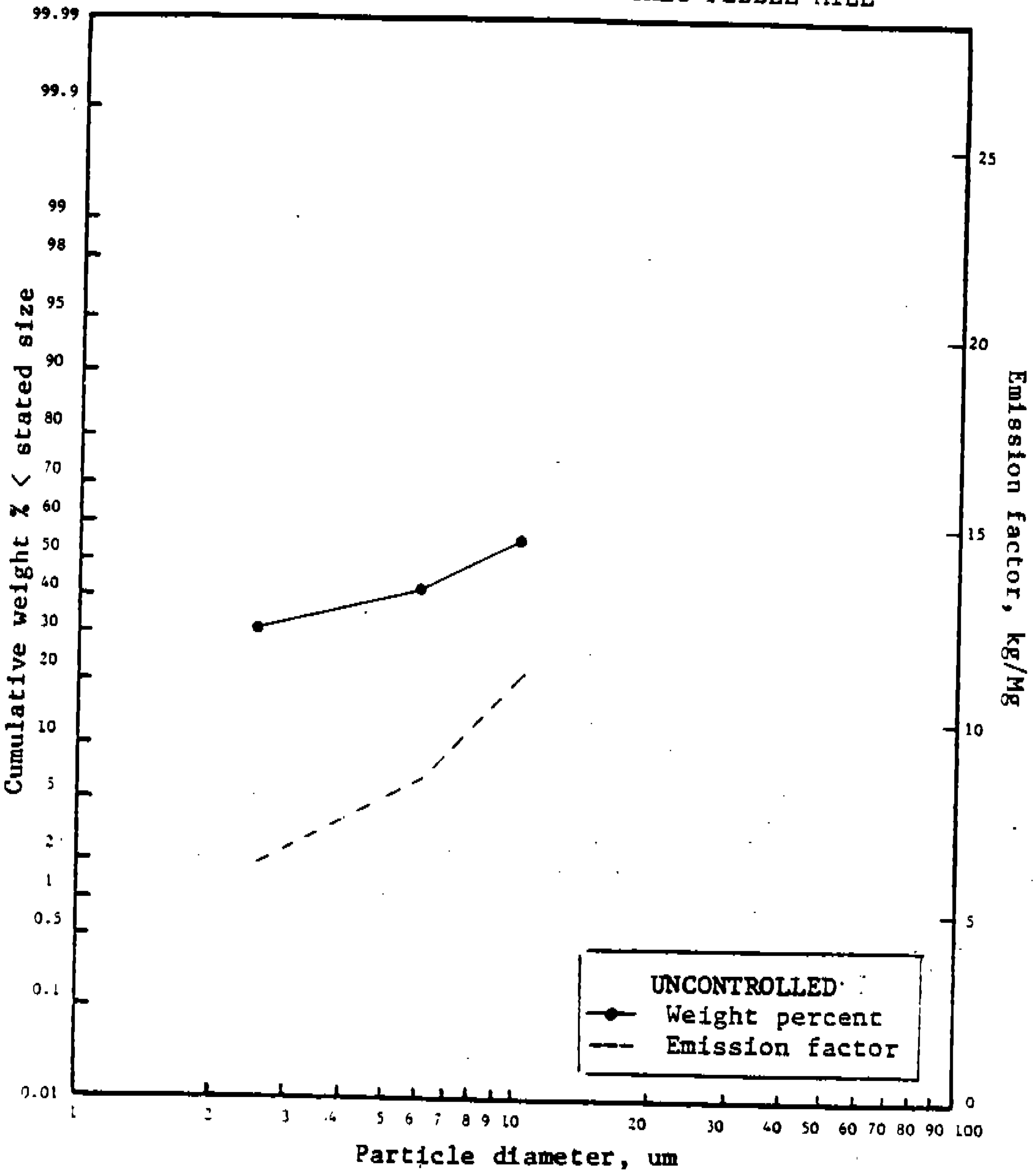
SOURCE OPERATION: Source produces lightweight slate aggregate in a cool fired kiln and a reciprocating grate clinker cooler. During testing, source was operating at a feed rate of 33 tons/hr, 83% of rated capacity. Firing zone temperatures are about 2125°F, and kiln rotates at 3.25 rpm.

SAMPLING TECHNIQUE: Andersen Impactors

EMISSION FACTOR RATING: C

REFERENCE:

Emission Test Report, Lightweight Aggregate Industry, Galite Corporation, EMB-80-LWA-6, U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1982.



Aerodynamic particle diameter, um	Cumulative wt. % < stated size	Emission factor, kg/Mg
	Before controls	Before controls
2.5	30.1	5.9
6.0	42.4	8.3
10.0	56.4	11.1

8.xx NONMETALLIC MINERALS: TALC PEBBLE MILL

NUMBER OF TESTS: 2, conducted before controls

STATISTICS:

Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	30.1	42.4	56.4
Standard deviation (Cum. %):	0.8	0.2	0.4
Min (Cum. %):	29.5	42.2	56.1
Max (Cum. %):	30.6	42.5	56.6

TOTAL PARTICULATE EMISSION FACTOR: 19.6 kg particulate/Mg ore processed. Calculated from data in reference.

SOURCE OPERATION: Source crushes talc ore then grinds crushed ore in a pebble mill. During testing, source operation was normal, according to the operators. An addendum to reference indicates throughput varied between 2.8 and 4.4 tons/hour during these tests.

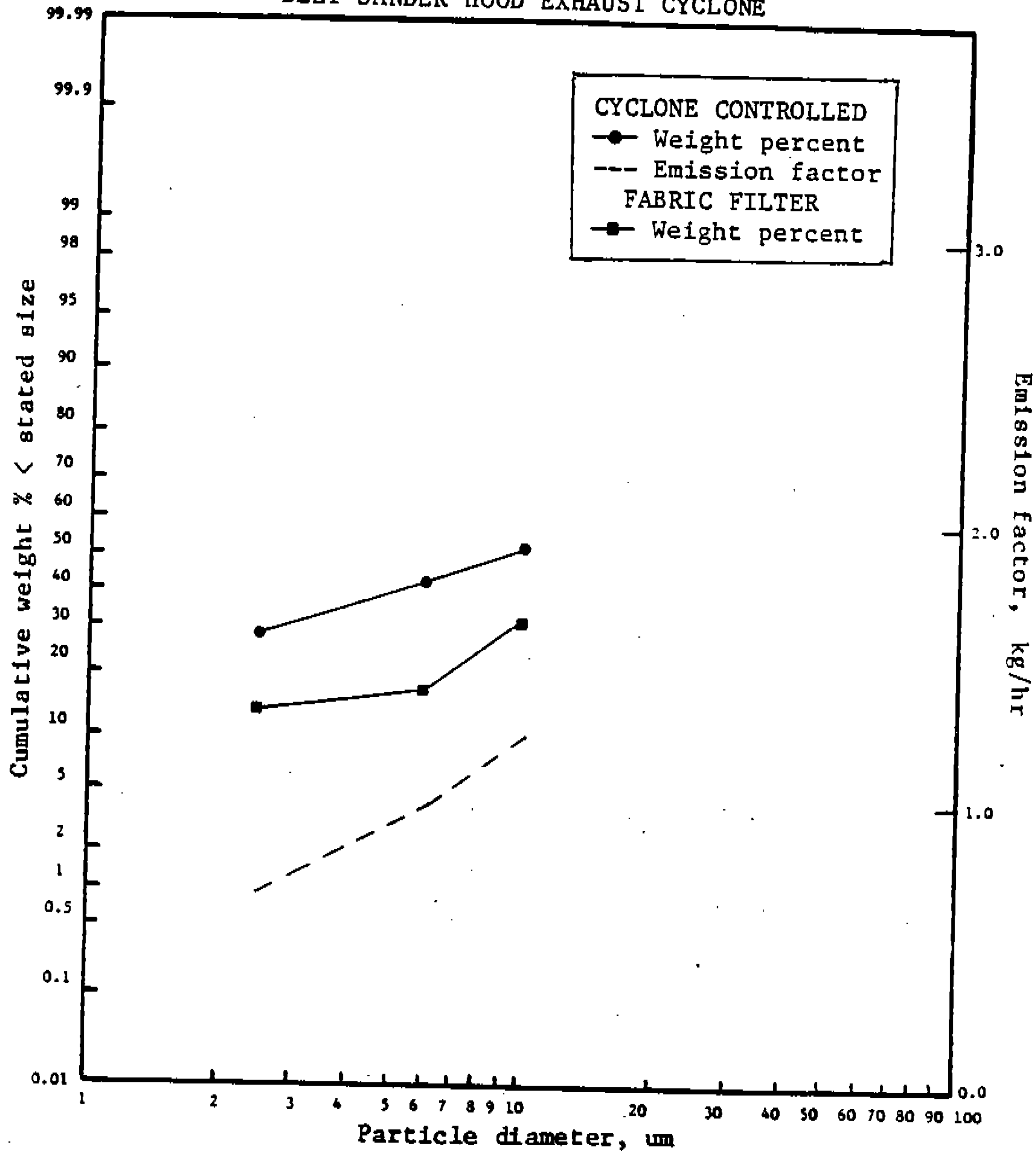
SAMPLING TECHNIQUE: Sample was collected in an alundum thimble and analyzed with a Spectrex Prototron Particle Counter Model ILI 1000.

EMISSION FACTOR RATING: E

REFERENCE:

Air Pollution Emission Test, Pfizer, Inc., Victorville, CA, EMB-77-NMM-5, U. S. Environmental Protection Agency, Research Triangle Park, NC, July 1977.

10.4 WOODWORKING WASTE COLLECTION OPERATIONS: BELT SANDER HOOD EXHAUST CYCLONE



Aerodynamic particle diameter, um	Cumulative wt. % < stated size		Emission factor, kg/hour of cyclone operation
	Cyclone	After cyclone and fabric filter	After cyclone collector
2.5	29.5	14.3	0.68
6.0	42.7	17.3	0.98
10.0	52.9	32.1	1.22

10.4 WOODWORKING WASTE COLLECTION OPERATIONS: BELT SANDER HOOD EXHAUST CYCLONE

NUMBER OF TESTS: a) 1, conducted after cyclone control
b) 1, after cyclone and fabric filter control

STATISTICS:

a) Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	29.5	42.7	52.9
Standard deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

b) Aerodynamic particle diameter (um):	2.5	6.0	10.0
Mean (Cum. %):	14.3	17.3	32.1
Standard deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: 2.3 kg particulate/hr of cyclone operation. For cyclone controlled source, this emission factor applies to typical large diameter cyclones into which wood waste is fed directly, not to cyclones that handle waste previously collected in cyclones. If baghouses are used for waste collection, particulate emissions will be negligible. Accordingly, no emission factor is provided for the fabric filter controlled source. Factors from AP-42.

SOURCE OPERATION: Source was sanding 2 ply panels of mahogany veneer, at 100% of design process rate of 1110 m^2/hr.

SAMPLING TECHNIQUE: a) Joy train with 3 cyclones
b) Sass train with cyclones

EMISSION FACTOR RATING: E

REFERENCE:

Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System, Series Report No. 238, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.

APPENDIX C.2

GENERALIZED PARTICLE SIZE DISTRIBUTIONS

CONTENTS

APPENDIX C.2

GENERALIZED PARTICLE SIZE DISTRIBUTIONS

C.2.1 Rationale For Developing Generalized Particle Size Distributions

The preparation of size specific particulate emission inventories requires size distribution information for each process. Particle size distributions for many processes are contained in appropriate industry sections of this document. Because particle size information for many processes of local impact and concern are unavailable, this Appendix provides "generic" particle size distributions applicable to these processes. The concept of the "generic particle size distribution is based on categorizing measured particle size data from similar processes generating emissions from similar materials. These generic distributions have been developed from sampled size distributions from about 200 sources.

Generic particle size distributions are approximations. They should be used only in the absence of source-specific particle size distributions for areawide emission inventories.

C.2.2 How To Use The Generalized Particle Size Distributions For Uncontrolled Processes

Figure C.2-1 provides an example calculation to assist the analyst in preparing particle size specific emission estimates using generic size distributions.

The following instructions for the calculation apply to each particulate emission source for which a particle size distribution is desired and for which no source specific particle size information is given elsewhere in this document:

1. Identify and review the AP-42 Section dealing with that process.
2. Obtain the uncontrolled particulate emission factor for the process from the main text of AP-42, and calculate uncontrolled total particulate emissions.
3. Obtain the category number of the appropriate generic particle size distribution from Table C.2-1.
4. Obtain the particle size distribution for the appropriate category from Table C.2-2. Apply the particle size distribution to the uncontrolled particulate emissions.

Instructions for calculating the controlled size specific emissions are given in C.2.3 and illustrated in Figure C.2-1.

Figure C.2-1. EXAMPLE CALCULATION FOR DETERMINING UNCONTROLLED AND CONTROLLED PARTICLE SIZE SPECIFIC EMISSIONS.

SOURCE IDENTIFICATION

Source name and address: ABC Brick Manufacturing
24 Dusty Way
Anywhere, USA

Process description: Dryers/Grinders

AP-42 Section: 8.3, Bricks And Related Clay Products

Uncontrolled AP-42 emission factor: 96 lbs/ton (units)

Activity parameter: 63,700 tons/year (units)

Uncontrolled emissions: 3057.6 tons/year (units)

UNCONTROLLED SIZE EMISSIONS

Category name: Mechanically Generated/Aggregate, Unprocessed Ores

Category number: 3

	Particle size (µm)		
	≤ 2.5	≤ 6	≤ 10
Generic distribution, Cumulative percent equal to or less than the size:	15	34	51
Cumulative mass ≤ particle size emissions (tons/year):	458.6	1039.6	1559.4

CONTROLLED SIZE EMISSIONS*

Type of control device: Fabric Filter

	Particle size (µm)		
	0 - 2.5	2.5 - 6	6 - 10
Collection efficiency (Table C.2-3):	99.0	99.5	99.5
Mass in size range** before control (tons/year):	458.6	581.0	519.8
Mass in size range after control (tons/year):	4.59	2.91	2.60
Cumulative mass (tons/year):	4.59	7.50	10.10

* These data do not include results for the greater than 10 µm particle size range.

** Uncontrolled size data are cumulative percent equal to or less than the size. Control efficiency data apply only to size range and are not cumulative.

TABLE C.2-1. PARTICLE SIZE CATEGORY BY AP-42 SECTION

AP-42 Section	Source Category	Category Number[c]
	External combustion	
1.1	Bituminous coal combustion	a
1.2	Anthracite coal combustion	a
1.3	Fuel oil combustion	a
	Utility, residual oil	a
	Industrial, residual oil	a
	Utility, distillate oil	a
	Commercial, residual oil	a
	Commercial, distillate	a
	Residential, distillate	a
1.4	Natural gas combustion	a
1.5	Liquefied petroleum gas	a
1.6	Wood waste combustion in boilers	a
1.7	Lignite, combustion	a
1.8	Bagasse Combustion	b
1.9	Residential fireplaces	a
1.10	Wood stoves	a
1.11	Waste oil combustion	2
	Solid waste disposal	
2.1	Refuse Incinerators	b
2.3	Conical burners (wood waste)	2
	Internal combustion engine	
	Highway vehicles[d]	a
3.2	Off highway	1
	Chemical process	
5.4	Charcoal production	9
5.8	Hydrofluoric acid	
	Spar drying	3
	Spar handling	3
	Transfer	3
5.10	Paint	4
5.11	Phosphoric acid (thermal process)	a
5.12	Phthalic anhydride	9
5.16	Sodium carbonate	a
5.17	Sulfuric acid	b
	Food and agricultural	
6.1	Alfalfa dehydrating	
	Primary cyclone	b
	Meal collector cyclone	7
	Pellet cooler cyclone	7
	Pellet regrind cyclone	7
6.2	Coffee roasting	6
6.3	Cotton ginning	b
6.4	Feed and grain mills and elevators	
	Unloading	b
	Food and agricultural (cont.)	
	Grain elevators	6
	Grain processing	7
6.5	Fermentation	6&7
6.7	Meat smokehouses	9
6.8	Ammonium nitrate fertilizers	a
6.10	Phosphate fertilizers	3
6.10.3	Ammonium phosphates	
	Reactor/ammoniator-granulator	4
	Dryer/cooler	4
6.11	Starch manufacturing	7
6.14	Urea manufacturing	a
6.16	Defoliation and harvesting of cotton	
	Trailer loading	6
	Transport	6
6.17	Harvesting of grain	
	Harvesting machine	6
	Truck loading	6
	Field transport	6
6.18	Ammonium sulfate manufacturing	
	Rotary dryer	b
	Fluidized-bed dryer	b
	Metallurgical industry	
7.1	Primary aluminum production	
	Bauxite grinding	4
	Aluminum hydroxide calcining	5
	Anode baking furnace	9
	Prebake cell	a
	Vertical Soderberg	8
	Horizontal Soderberg	a
7.2	Coke manufacturing	a
7.3	Primary copper smelting	a
7.4	Ferroalloy production	a
7.5	Iron and steel production	
	Blast furnace	
	Slips	a
	Cast house	a
	Sintering	
	Windbox	a
	Sinter discharge	a
	Basic oxygen furnace	a
	Electric arc furnace	a
7.6	Primary lead smelting	a
7.7	Zinc smelting	8
7.8	Secondary aluminum	
	Sweating furnace	8
	Smelting	
	Crucible furnace	8
	Reverberatory furnace	a
7.9	Secondary copper smelting and alloying	8
7.10	Gray iron foundries	a

a. Categories with particle size data specific to process included in the main body of the text.
b. Categories with particle size data specific to process included in Appendix C.1.
c. Data for each numbered category are shown in Table C.2-2.
d. Highway vehicles data are reported in AP-42 Volume II: Mobile Sources.

TABLE C.2-1 (continued).

AP-42 Section	Source Category	Category Number[c]
	Metallurgical industry (cont.)	
7.11	Secondary lead processing	a
7.12	Secondary magnesium smelting	8
7.13	Steel foundries	
	melting	b
7.14	Secondary zinc smelting	8
7.15	Storage battery production	b
7.18	Leadbearing ore crushing and grinding	4
	Mineral products	
8.1	Asphaltic concrete plants	
	Process	a
8.3	Bricks and related clay products	
	Raw materials handling	
	Dryers, grinders, etc.	b
	Tunnel/periodic kilns	
	Gas fired	a
	Oil fired	a
	Coal fired	a
8.5	Castable refractories	
	Raw material dryer	3
	Raw material crushing and screening	3
	Electric arc melting	8
	Curing oven	3
8.6	Portland cement manufacturing	
	Dry process	
	Kilns	a
	Dryers, grinders, etc.	4
	Wet process	
	Kilns	a
	Dryers, grinders, etc.	4
8.7	Ceramic clay manufacturing	
	Drying	3
	Grinding	4
	Storage	3
8.8	Clay and fly ash sintering	
	Fly ash sintering, crushing, screening and yard storage	5
	Clay mixed with coke	
	Crushing, screening, and yard storage	3
8.9	Coal cleaning	3
8.10	Concrete batching	3
8.11	Glass fiber manufacturing	
	Unloading and conveying	3
	Storage bins	3
	Mixing and weighing	3
	Glass furnace - wool	a
	Glass furnace - textile	a
8.13	Glass manufacturing	a
8.14	Gypsum manufacturing	
	Rotary ore dryer	a
	Roller mill	4
	Mineral products (cont.)	
	Impact mill	4
	Flash calciner	a
	Continuous kettle calciner	a
8.15	Lime manufacturing	a
8.16	Mineral wool manufacturing	
	Cupola	8
	Reverberatory furnace	8
	Blow chamber	8
	Curing oven	9
	Cooler	9
8.18	Phosphate rock processing	
	Drying	a
	Calcining	a
	Grinding	b
	Transfer and storage	3
8.19.1	Sand and gravel processing	
	Continuous drop	
	Transfer station	a
	Pile formation - stacker	a
	Batch drop	a
	Active storage piles	a
	Vehicle traffic unpaved road	a
8.19.2	Crushed stone processing	
	Dry crushing	
	Primary crushing	a
	Secondary crushing and screening	a
	Tertiary crushing and screening	3
	Recrushing and screening	4
	Fines mill	4
	Screening, conveying, and handling	a
8.22	Taconite ore processing	
	Fine crushing	4
	Waste gas	a
	Pellet handling	4
	Grate discharge	5
	Grate feed	4
	Bentonite blending	4
	Coarse crushing	3
	Ore transfer	3
	Bentonite transfer	4
	Unpaved roads	a
8.23	Metallic minerals processing	a
8.24	Western surface coal mining	a
	Wood processing	
10.1	Chemical wood pulping	a
	Miscellaneous sources	
11.2	Fugitive dust	a

a. Categories with particle size data specific to process included in the main body of the text.
b. Categories with particle size data specific to process included in Appendix C.1.
c. Data for each numbered category are shown in Table C.2-2.

Figure C.2-2. CALCULATION SHEET.

SOURCE IDENTIFICATION

Source name and address: ______________________________

____

____

Process description: ______________________________

AP-42 Section: ______________________________

Uncontrolled AP-42 emission factor: ______________________________ (units)

Activity parameter: ______________________________ (units)

Uncontrolled emissions: ______________________________ (units)

UNCONTROLLED SIZE EMISSIONS

Category name: ______________________________

Category number: ________

	Particle size (μm)		
	≤ 2.5	≤ 6	≤ 10
Generic distribution, Cumulative percent equal to or less than the size:			
Cumulative mass ≤ particle size emissions (tons/year):			

CONTROLLED SIZE EMISSIONS*

Type of control device: ______________________________

	Particle size (μm)		
	0 - 2.5	2.5 - 6	6 - 10
Collection efficiency (Table C.2-3):			
Mass in size range** before control (tons/year):			
Mass in size range after control: (tons/year):			
Cumulative mass (tons/year):			

* These data do not include results for the greater than 10 μm particle size range.

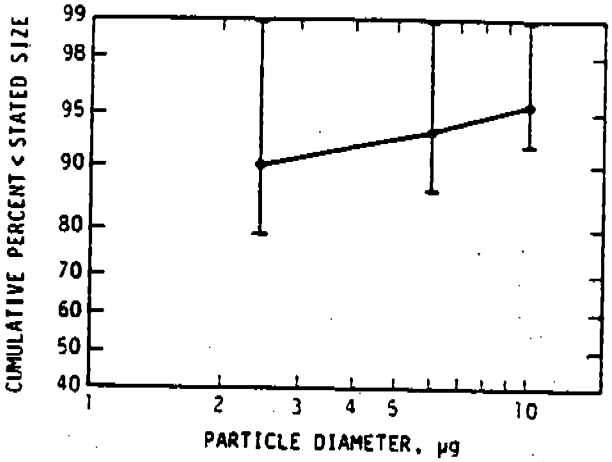
** Uncontrolled size data are cumulative percent equal to or less than the size. Control efficiency data apply only to size range and are not cumulative.

TABLE C.2-2. DESCRIPTION OF PARTICLE SIZE CATEGORIES

Category: 1
Process: Stationary Internal Combustion Engines
Material: Gasoline and Diesel Fuel

Category 1 covers size specific emissions from stationary internal combustion engines. The particulate emissions are generated from fuel combustion.

REFERENCE: 1, 9



Particle size, μm	Cumulative % less than or equal to stated size (uncontrolled)	-Minimum Value	Maximum Value	Standard Deviation
1.0[a]	82			
2.0[a]	88			
2.5	90	78	99	11
3.0[a]	90			
4.0[a]	92			
5.0[a]	93			
6.0	93	86	99	7
10.0	96	92	99	4

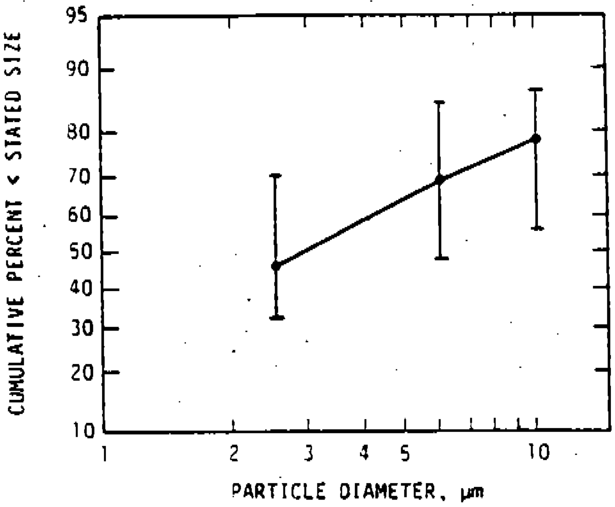
[a] Value calculated from data reported at 2.5, 6.0, and 10.0 μm. No statistical parameters are given for the calculated value.

TABLE C.2-2 (continued).

Category: 2
Process: Combustion
Material: Mixed Fuels

Category 2 covers boilers firing a mixture of fuels, regardless of the fuel combination. The fuels include gas, coal, coke, and petroleum. Particulate emissions are generated by firing these miscellaneous fuels.

REFERENCE: 1



Particle size, μm	Cumulative % less than or equal to stated size (uncontrolled)	Minimum Value	Maximum Value	Standard Deviation
1.0[a]	23			
2.0[a]	40			
2.5	45	32	70	17
3.0[a]	50			
4.0[a]	58			
5.0[a]	64			
6.0	70	49	84	14
10.0	79	56	87	12

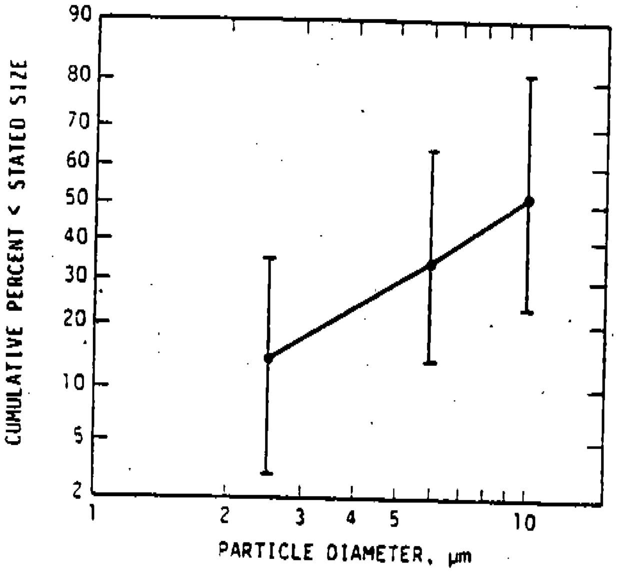
[a] Value calculated from data reported at 2.5, 6.0, and 10.0 μm. No statistical parameters are given for the calculated value.

TABLE C.2-2 (continued).

Category: 3
Process: Mechanically Generated
Material: Aggregate, Unprocessed Ores

Category 3 covers material handling and processing of aggregate and unprocessed ore. This broad category includes emissions from milling, grinding, crushing, screening, conveying, cooling, and drying of material. Emissions are generated through either the movement of the material or the interaction of the material with mechanical devices.

REFERENCE: 1-2, 4, 7



Particle size, µm	Cumulative % less than or equal to stated size (uncontrolled)	Minimum Value	Maximum Value	Standard Deviation
1.0[a]	4			
2.0[a]	11			
2.5	15	3	35	7
3.0[a]	18			
4.0[a]	25			
5.0[a]	30			
6.0	34	15	65	13
10.0	51	23	81	14

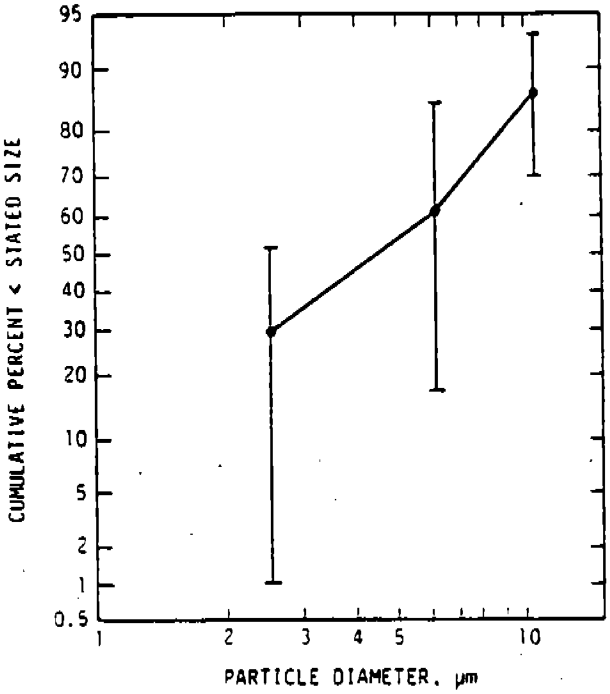
[a] Value calculated from data reported at 2.5, 6.0, and 10.0 µm. No statistical parameters are given for the calculated value.

TABLE C.2-2 (continued).

Category: 4
Process: Mechanically Generated
Material: Processed Ores and Non-metallic Minerals

Category 4 covers material handling and processing of processed ores and minerals. While similar to Category 3, processed ores can be expected to have a greater size consistency than unprocessed ores. Particulate emissions are a result of agitating the materials by screening or transfer, during size reduction and beneficiation of the materials by grinding and fine milling, and by drying.

REFERENCE: 1



Particle size, µm	Cumulative % less than or equal to stated size (uncontrolled)	Minimum Value	Maximum Value	Standard Deviation
1.0[a]	6			
2.0[a]	21			
2.5	30	1	51	19
3.0[a]	36			
4.0[a]	48			
5.0[a]	58			
6.0	62	17	83	17
10.0	85	70	93	7

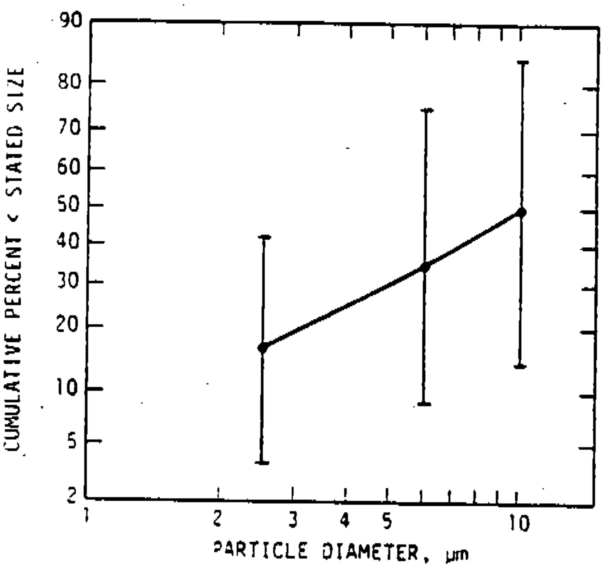
[a] Value calculated from data reported at 2.5, 6.0, and 10.0 µm. No statistical parameters are given for the calculated value.

TABLE C.2-2 (continued).

Category: 5
Process: Calcining and Other Heat Reaction Processes
Material: Aggregate, Unprocessed Ores

Category 5 covers the use of calciners and kilns in processing a variety of aggregates and unprocessed ores. Emissions are a result of these high temperature operations.

REFERENCE: 1-2, 8



Particle size, µm	Cumulative % less than or equal to stated size (uncontrolled)	Minimum Value	Maximum Value	Standard Deviation
1.0[a]	6			
2.0[a]	13			
2.5	18	3	42	11
3.0[a]	21			
4.0[a]	28			
5.0[a]	33			
6.0	37	13	74	19
10.0	53	25	84	19

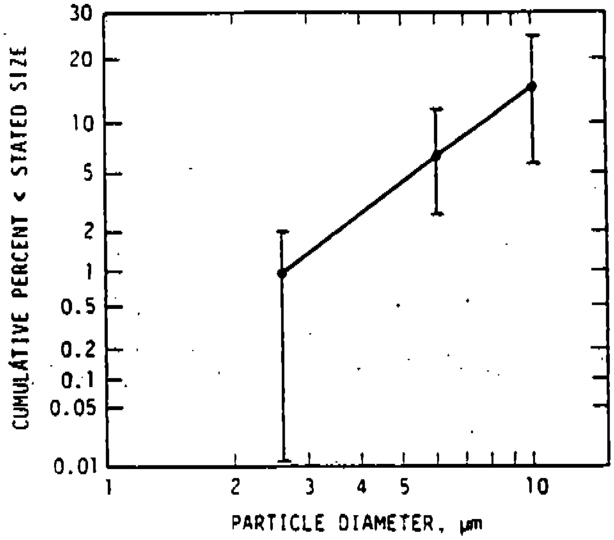
[a] Value calculated from data reported at 2.5, 6.0, and 10.0 µm. No statistical parameters are given for the calculated value.

TABLE C.2-2 (continued).

Category: 6
Process: Grain Handling
Material: Grain

Category 6 covers various grain handling (versus grain processing) operations. These processes could include material transfer, ginning and other miscellaneous handling of grain. Emissions are generated by mechanical agitation of the material.

REFERENCE: 1, 5



Particle size, µm	Cumulative % less than or equal to stated size (uncontrolled)	Minimum Value	Maximum Value	Standard Deviation
1.0[a]	.07			
2.0[a]	.60			
2.5	1	0	2	1
3.0[a]	2			
4.0[a]	3			
5.0[a]	5			
6.0	7	3	12	3
10.0	15	6	25	7

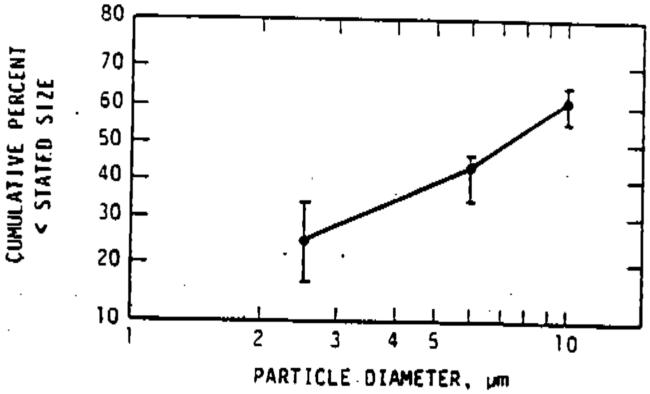
[a] Value calculated from data reported at 2.5, 6.0, and 10.0 µm. No statistical parameters are given for the calculated value.

TABLE C.2-2 (continued).

Category: 7
Process: Grain Processing
Material: Grain

Category 7 covers grain processing operations such as drying, screening, grinding and milling. The particulate emissions are generated during forced air flow, separation or size reduction.

REFERENCE: 1-2



Particle size, µm	Cumulative % less than or equal to stated size (uncontrolled)	Minimum Value	Maximum Value	Standard Deviation
1.0[a]	8			
2.0[a]	18			
2.5	23	17	34	9
3.0[a]	27			
4.0[a]	34			
5.0[a]	40			
6.0	43	35	48	7
10.0	61	56	65	5

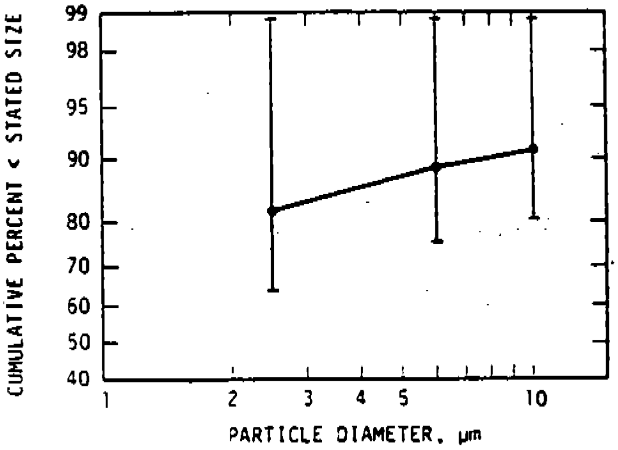
[a] Value calculated from data reported at 2.5, 6.0, and 10.0 µm. No statistical parameters are given for the calculated value.

TABLE C.2-2 (continued).

Category: 8
Process: Melting, Smelting, Refining
Material: Metals, except Aluminum

Category 8 covers the melting, smelting, and refining of metals (including glass) other than aluminum. All primary and secondary production processes for these materials which involve a physical or chemical change are included in this category. Materials handling and transfer are not included. Particulate emissions are a result of high temperature melting, smelting, and refining.

REFERENCE: 1-2



Particle size, μm	Cumulative % less than or equal to stated size (uncontrolled)	Minimum Value	Maximum Value	Standard Deviation
1.0[a]	72			
2.0[a]	80			
2.5	82	63	99	12
3.0[a]	84			
4.0[a]	86			
5.0[a]	88			
6.0	89	75	99	9
10.0	92	80	99	7

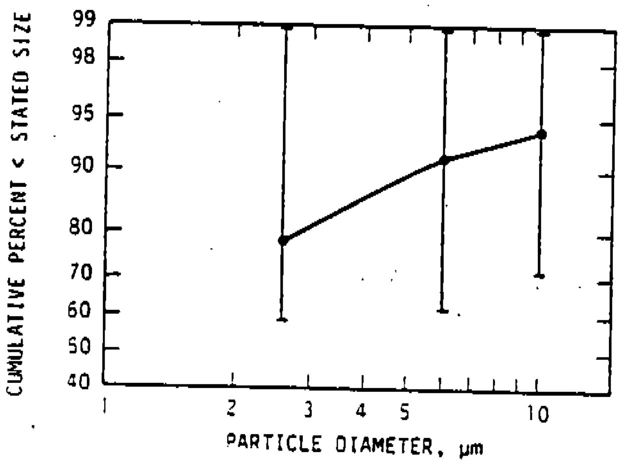
[a] Value calculated from data reported at 2.5, 6.0, and 10.0 μm. No statistical parameters are given for the calculated value.

TABLE C.2-2 (continued).

Category: 9
Process: Condensation, Hydration, Absorption, Prilling and Distillation
Material: All

Category 9 covers condensation, hydration, absorption, prilling, and distillation of all materials. These processes involve the physical separation or combination of a wide variety of materials such as sulfuric acid and ammonium nitrate fertilizer. (Coke ovens are included since they can be considered a distillation process which separates the volatile matter from coal to produce coke.)

REFERENCE: 1, 3



Particle size, µm	Cumulative % less than or equal to stated size (uncontrolled)	Minimum Value	Maximum Value	Standard Deviation
1.0[a]	60			
2.0[a]	74			
2.5	78	59	99	17
3.0[a]	81			
4.0[a]	85			
5.0[a]	88			
6.0	91	61	99	12
10.0	94	71	99	9

[a] Value calculated from data reported at 2.5, 6.0, and 10.0 µm. No statistical parameters are given for the calculated value.

C.2.3 How To Use The Generalized Particle Size Distributions For Controlled Processes

To calculate the size distribution and the size specific emissions for a source with a particulate control device, the user first calculates the uncontrolled size specific emissions. Next, the fractional control efficiency for the control device is estimated, using Table C.2-3. The Calculation Sheet provided (Figure C.2-2) allows the user to record the type of control device and the collection efficiencies from Table C.2-3, the mass in the size range before and after control, and the cumulative mass. The user will note that the uncontrolled size data are expressed in cumulative fraction less than the stated size. The control efficiency data apply only to the size range indicated and are not cumulative. These data do not include results for the greater than 10 μm particle size range. In order to account for the total controlled emissions, particles greater than 10 μm in size must be included.

C.2.4 Example Calculation

An example calculation of uncontrolled total particulate emissions, uncontrolled size specific emissions, and controlled size specific emission is shown on Figure C.2-1. A blank Calculation Sheet is provided in Figure C.2-2.

TABLE C.2-3 TYPICAL COLLECTION EFFICIENCIES OF VARIOUS PARTICULATE CONTROL DEVICES.[a,b]
(percent)

Type of collector	Particle size, μm		
	0 - 2.5	2.5 - 6	6 - 10
Baffled settling chamber	NR	5	15
Simple (high-throughput) cyclone	50	75	85
High-efficiency and multiple cyclones	80	95	95
Electrostatic precipitator (ESP)	95	99	99.5
Packed-bed scrubber	90	95	99
Venturi scrubber	90	95	99
Wet-impingement scrubber	25	85	95
Fabric filter	99	99.5	99.5

[a] The data shown represent an average of actual efficiencies. The efficiencies are representative of well designed and well operated control equipment. Site specific factors (e.g., type of particulate being collected, varying pressure drops across scrubbers, maintenance of equipment, etc.) will affect the collection efficiencies. The efficiencies shown are intended to provide guidance for estimating control equipment performance when source-specific data are not available.

[b] Reference: 10

NR = Not reported.

References for Appendix C.2

1. Fine Particle Emission Inventory System, Office of Research and Development, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1985.

2. Confidential test data from various sources, PEI Associates, Inc., Cincinnati, OH, 1985.

3. Final Guideline Document: Control of Sulfuric Acid Production Units, EPA-450/2-77-019, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1977.

4. Air Pollution Emission Test, Bunge Corp., Destrehan, LA., EMB-74-GRN-7, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1974.

5. I. W. Kirk, "Air Quality in Saw and Roller Gin Plants", Transactions of the ASAE, 20:5, 1977.

6. Emission Test Report, Lightweight Aggregate Industry, Galite Corp., EMB-80-LWA-6, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1982.

7. Air Pollution Emission Test, Lightweight Aggregate Industry, Texas Industries, Inc., EMB-80-LWA-3, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1975.

8. Air Pollution Emission Test, Empire Mining Company, Palmer, Michigan, EMB-76-IOB-2, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1975.

9. H. Taback , et al., Fine Particulate Emission from Stationary Sources in the South Coast Air Basin, KVB, Inc., Tustin, CA 1979.

10. K. Rosbury, Generalized Particle Size Distributions for Use in Preparing Particle Size Specific Emission Inventories, U. S. Environmental Protection Agency, Contract No. 68-02-3890, PEI Associates, Inc., Golden, CO, 1985.

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16. ABSTRACT

In this Supplement to the Fourth Edition of AP-42, new or revised emissions data are presented for Bituminous And Subbituminous Coal Combustion; Anthracite Coal Combustion; Fuel Oil Combustion; Natural Gas Combustion; Wood Waste Combustion In Boilers; Lignite Combustion; Sodium Carbonate; Primary Aluminum Production; Coke Production; Primary Copper Smelting; Ferroalloy Production; Iron And Steel Production; Primary Lead Smelting; Zinc Smelting; Secondary Aluminum Operations; Gray Iron Foundries; Secondary Lead Smelting; Asphaltic Concrete Plants; Bricks And Related Clay Products; Portland Cement Manufacturing; Concrete Batching; Glass Manufacturing; Lime Manufacturing; Construction Aggregate Processing; Taconite Ore Processing; Western Surface Coal Mining; Chemical Wood Pulping; Appendix C.1, "Particle Size Distribution Data And Sized Emission Factors For Selected Sources"; and Appendix C.2, "Generalized Particle Size Distributions".

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Stationary Sources Point Sources Area Sources Emission Factors Emissions		

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