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FERROALLOY INDUSTRY PARTICULATE EMISSIONS: SOURCE CATEGORY REPORT

Prepared for

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Prepared by

Air and Energy Engineering Research Laboratory
Research Triangle Park NC 27711

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FERROALLOY INDUSTRY PARTICULATE EMISSIONS: SOURCE CATEGORY REPORT

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ABSTRACT

A review was made of all available data characterizing particulate emissions from ferroalloy producing electric arc furnaces. The data was summarized and rated in terms of reliability. Total and size specific emission factors were developed for the ferroalloy industry. The ferroalloy industry and furnace operation was described in detail with emphasis on factors affecting emissions. A replacement for Section 7.4, Ferroalloy Production in AP-42 was prepared which includes size specific emission factors.

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SECTION 1

INTRODUCTION

The purpose of this program is to provide a summary of the best available information on inhalable particulate matter emissions in the ferroalloy industry. The program objective was to develop reliable total and size specific emission factors for each ferroalloy product group. This will enable a reasonable estimation of emissions from ferroalloy sources to update Section 7.4, Ferroalloy Production, in AP-42, "A Compilation of Emission Factors", which was last revised in February 1972.

Both uncontrolled and controlled emission factors are presented in this report. The uncontrolled emission factors represent emissions that would result from a particulate control system if the control device (baghouse, scrubber, etc.) were bypassed. The controlled emission factors represent emissions from a particulate control system. Size specific emission factors are generally based on the results of cascade impactor sampling conducted simultaneously with total particulate sampling procedures at the inlet or outlet to a control device. The second objective of this program is to present current information on the ferroalloy industry.

The above objectives were met by an intensive, 10 week search for emissions data. Data were collected from the following sources:

- New England Research Application Center (NERAC) computerized literature searches;
- State and Federal regulatory and air planning staffs;
- Industry personnel;
- Environmental consultants;
- GCA/Technology Division files;
- AP-42 ferroalloy background file at EPA's Office of Air Quality Planning and Standards (OAQPS); and
- EPA's Fine Particle Emission Information System (FPEIS).

The particulate emissions data were reviewed, summarized, and ranked according to the criteria provided in the report "Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections,"[1] April 1980. As specified in this document, the data are rated as follows:

- A = Tests performed by a sound methodology and reported in enough detail for adequate validation. These tests are not necessarily EPA reference method tests, although such reference methods are certainly to be used as a guide.

- B = Tests that are performed by a generally sound methodology but lack enough detail for adequate validation.

- C = Tests that are based on an untested or new methodology or that lack a significant amount of background data.

- D = Tests that are based on a generally unacceptable method but may provide an order-of-magnitude value for the source.

After ranking the obtained data, emission factors were calculated using the highest quality data available. The quality of the data used to develop each emission factor is indicated by the emission factor rating. The following ratings were applied to each emission factor.

- A = Excellent--Developed from A-rated test data taken from many randomly chosen facilities in the industry population. The source category* is specific enough to minimize variability within the source category population.

- B = Above Average--Developed only from A-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As in the A rating, the source category is specific enough to minimize variability within the source category population.

- C = Average--Developed only from A- and B-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As in the A rating, the source category is specific enough to minimize variability within the source category population.

- D = Below Average--The emission factor was developed only from A- and B-rated test data from a small number of facilities, and there may be reason to suspect that these facilities do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of the emission factor are footnoted in the emission factor table.

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*Source category: A category in the emission factor table for which an emission factor has been calculated; generally a single process.

- E = Poor--The emission factor was developed from C- and D-rated test data, and there may be reason to suspect that the facilities tested do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of these factors are always footnoted.

This report is structured according to the "Outline for Source Category Reports" which was included in the technical directive to conduct this program. There is necessary duplication of information between Section 5, the proposed AP-42 section, and Sections 1 through 4 of the report in order that the proposed AP-42 section 5 can stand alone once inserted into the AP-42 document.

No environmental measurements were conducted during this program, therefore, no separate QA section is contained in this report. The quality of the existing data has been evaluated as described above.

SECTION 2

INDUSTRY DESCRIPTION

GENERAL

A ferroalloy is an alloy of iron and one or more other elements, for example, silicon. Ferroalloys can contain very little iron, as in 98 percent silicon metal, or consist of mostly iron with small amounts of other elements.

The iron and steel industry consumes approximately 95 percent of the ferroalloys produced in the U.S.[2] The alloys are used to impart unique characteristics and properties to steel and cast iron. The remaining 5 percent are consumed in the production of nonferrous metals including cast aluminum, nickel-cobalt base alloys, titanium alloys, and are also used as raw materials for production of other ferroalloys.

The materials generally considered products of the ferroalloy industry are listed in Table 1. There are other materials which are not considered products of the ferroalloy industry even though they are an alloy of iron and an element or they are produced in the same facilities as ferroalloys. For example, ferrophosphorus is considered a byproduct of phosphorus manufacturing. Calcium carbide, which has a different end-use, is produced at some ferroalloy facilities, but is not considered a product of the ferroalloy industry.

Three major groups of ferroalloys known as bulk alloys constitute approximately 85 percent of the ferroalloys produced in the U.S.[2] The three major groups are ferromanganese, ferrosilicon, and ferrochromium. Subgroups of these bulk alloys include silicomanganese, and silicon metal. The bulk ferroalloys are manufactured in a variety of grades distinguished by carbon, silicon, or aluminum content. Further subclassifications exist for each grade. Fifteen percent of the ferroalloys produced in the U.S. are specialty alloys[3] which are typically produced in small tonnages. Components of specialty alloys and metals include vanadium, columbium, molybdenum, nickel, aluminum, boron, and tungsten.

The United States is still the world's largest producer of ferroalloys even though production has recently declined to 1945 levels. The decline in production is due to an increase in imports and declining requirements for ferroalloys by the iron and steel industry. Imported ferroalloys have increased from approximately 2.4 percent of domestic consumption in 1945 to over 40 percent in the years since 1975.[4]

TABLE 1. FERROALLOY PROCESSES AND RESPECTIVE PRODUCT GROUPS

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

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

[b]The process in which molten charge material is reduced, in an exothermic reaction, by the addition of silicon, aluminum or a combination of the two.

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

[d]The process in which carbon is removed from solid state, high carbon ferrochrome within vacuum furnaces maintained at a temperature near the melting point of the alloy.

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

A list of foreign and domestically owned ferroalloy producers located in the U.S. in 1981 is presented in Table 2. Presently, the industry is unstable in that there are many idle furnaces, plants that are being closed, and older furnaces being replaced by larger, more efficient furnaces. The industry appears to have no plans to expand U.S. production of ferroalloys.

It is interesting to note that many ferroalloy producers are changing ownership. For instance, Airco Alloys, the largest and most diversified domestic producer of ferroalloys, sold all of its ferroalloy operations to Autlan Manganese Corp., and SKW Alloys Inc., both of West Germany and to Macalloy Inc. of the United States in 1979. This change left Union Carbide as the largest wholly domestically owned producer of ferroalloys in the U.S. During July 1981, Union Carbide sold most of its operations (except vanadium and tungsten) in the U.S., Canada and Europe to groups led by Elkem A/S of Norway. Kewicky Bryelko of the United States sold its silicon metal producing facility located in Springfield, Oregon to Dow Corning of the United States in October 1980.

FERROALLOY PRODUCTION PROCESS

The manufacture of ferroalloys is a multistep process. On arrival at the plant, the raw materials which are specified for the desired products are unloaded and stored. These materials are withdrawn, pretreated (by crushing and drying) and then weighed, mixed, and charged to the furnace where smelting takes place. The molten metal is tapped, cast and allowed to cool and solidify. The ferroalloys are crushed prior to shipment. Figure 1 is a general flow schematic of a typical ferroalloy production facility.

Raw materials which include quartz or other forms of silicon, metallic ores, scrap iron, scrap steel, reducing agents such as coal or coke, limestone, and woodchips, are delivered to ferroalloy facilities by ship, railroad cars, trucks, or river barges. The raw materials are stored in open separate storage piles which are sometimes sheltered by block walls, snow fences, or plastic covers. Raw materials are withdrawn from storage to satisfy production requirements. Pretreatment may be necessary to ensure satisfactory furnace operation. Dryers are sometimes used to reduce raw material moisture, which can be as high as 20 percent.[3] Raw materials charged to calcium carbide and chrome ore/lime melt furnaces must be dried; however, drying is not a standard procedure for the production of the major types of ferroalloys. After pretreatment, the materials are conveyed to the mix house. In the mix house, the specified proportions of each raw material are weighed into larry cars, conveyors, buckets or skip hoists and transferred to a hopper above the furnace. The blended raw materials in the hopper are normally charged to the furnace by gravity flow through one or more feed chutes. A few open furnaces use manually operated skip loaders to charge the furnace. Raw materials are charged to the furnace continuously or intermittently, electric power is applied to the furnace continuously.

Tapping, the withdrawal of molten metal and slag from the furnace vessel through the taphole, is performed at 1- to 5-hour intervals and lasts from 10 to 15 minutes. Tapholes are pierced by a shot pellet fired from a gun, by

TABLE 2. PRODUCERS OF FERROALLOYS IN THE UNITED STATES IN 1981[6]

Producer	Former owner[a]	Plant location	Ferroalloy products[b]	Furnace type
Alabama Alloy Co., Inc.		Bessemer, AL	FeSi	Electric
Aluminum Co. of America, Northwest Alloys, Inc.		Addy,, WA	Si, FeSi	Electric
Autlan Manganese Corp., NV	Airco Alloys, Inc.	Mobile, AL	SiMn	Electric
AMAX Inc., Climax Molybdenum Co. Div.		Langeloth, PA	FeMo	Exothermic
Cabot Corp. KBI Div. Penn Rare Metal Div.		Revere, PA	FeCb	Exothermic
Chromasco Ltd., Chromium Mining & Smelting Corp. Div.		Woodstock, IN	FeCr, FeSi	Electric
Dow Corning	Kewicky Bryelko	Springfield OR	Si	Electric
Elkem Metals Company	Union Carbide[c]	Alloy, WV	Si, SrSi	Electric
		Ashtabula, OH	FeSi, SrFeSi,	Electric
		Marietta, OH	FeB, FeCr, FeMn, FeSi, FeV, Si, SiMn	Electric
Engelhard Minerals & Chemicals Corp., Minerals and Chemical Div.		Strasburg, VA	FeV	Exothermic
Foote Mineral Co., Ferroalloys Div.		Cambridge, OH	FeSi, FeV, silvery pig iron, other[d]	Electric
		Graham, WV		Electric
		Keokuk, IA		Electric
Hanna Mining Co., The Hanna Nickel Smelting Co.		Riddle, OR	FeNi, FeSi	Electric
Silicon Div,		Wenatchee, WA	Si, FeSi	Electric
Interlake, Inc., Globe Metallurgical Div.		Beverly, OH	FeCr, FeCrSi, Si, FeSi, SiMn	Electric
		Selma, AL		Electric
International Minerals & Chemical Corp., Industry Group, TAC Alloys Div.		Bridgeport, AL	FeSi	Electric
		Kimbal, IN		Electric

(continued)

TABLE 2 (continued)

Producer	Former owner[a]	Plant location	Ferroalloy products[b]	Furnace type
Macalloy Inc.	Airco Alloys, Inc.	Charleston, SC	FeCr, FeCrSi	Electric
Metallurg, Inc., Shieldalloy Corp.		Newfield, NJ	FeAl, FeB, FeCb, FeTi, FeV, other[d]	Exothermic
Ohio Ferro-Alloys Corp.		Montgomery, AL Philo, OH Powhatan Point, OH	FeB, FeMn, FeSi, Si, SiMn	Electric
Pennzoil Co., Duval Corp.		Sahuarita, AZ	FeMo	Exothermic
Pesses Co., The		Newton Falls, OH Solon, OH Pulaski, PA Fort Worth, TX	FeAl, FeB, FeCb, FeMo, FeNi, FeTi, FeV, FeW, other[d]	Electric & exothermic
Reactive Metals and Alloys Corp.		West Pittsburgh, PA	FeTi, other[d]	Electric
Reading Alloys, Inc.		Robesonia, PA	FeCb, FeV	Exothermic
Satra Corp., Satralloy, Inc. Div.	Foote Mineral Co.	Steubenville, OH	FeCr, FeCrSi	Electric
SEDEMA S.A., Chemetals Corp.		Kingwood, WV	FeMn	Electrolytic
SKW Alloys, Inc.	Airco Alloys Inc.	Calvert City, KY Niagara Falls, NY	FeMn, FeSi, SiMn	Electric Electric
South African Manganese Amcor, Ltd. Roane Ltd.		Rockwood, TN	FeMn, SiMn	Electric
Teledyne, Inc., Teledyne Wah Chang, Albany Div.		Albany, OR	FeCb	Exothermic
Union Carbide Corp., Metals Div.		Niagara Falls, NY	FeV, FeW	Electric
Union Oil Co. of California, Molycorp, Inc.		Washington, PA	FeB, FeMo, FeW	Electric & exothermic

[a]It changed within past 5 years.
[b]FeAl, ferroaluminum; FeB, ferroboron; FeCb, ferrocolumbium; FeCr, ferrochromium; FeCrSi, ferrochromium-silicon; FeMn, ferromanganese; FeMo, ferromolybdenum; FeNi, ferronickel; FeP, ferrophosphorus; FeSi, ferrosilicon; FeTi, ferrotitanium; FeV, ferrovanadium; FeW, ferrotungsten; Si, silicon metal; SiMn, silicomanganese; SrSi, strontium silicon.
[c]Change of ownership from Union Carbide to Elkem Metals Company occurred during July of 1981.
[d]Includes specialty silicon alloys, zirconium alloys, and miscellaneous ferroalloys.

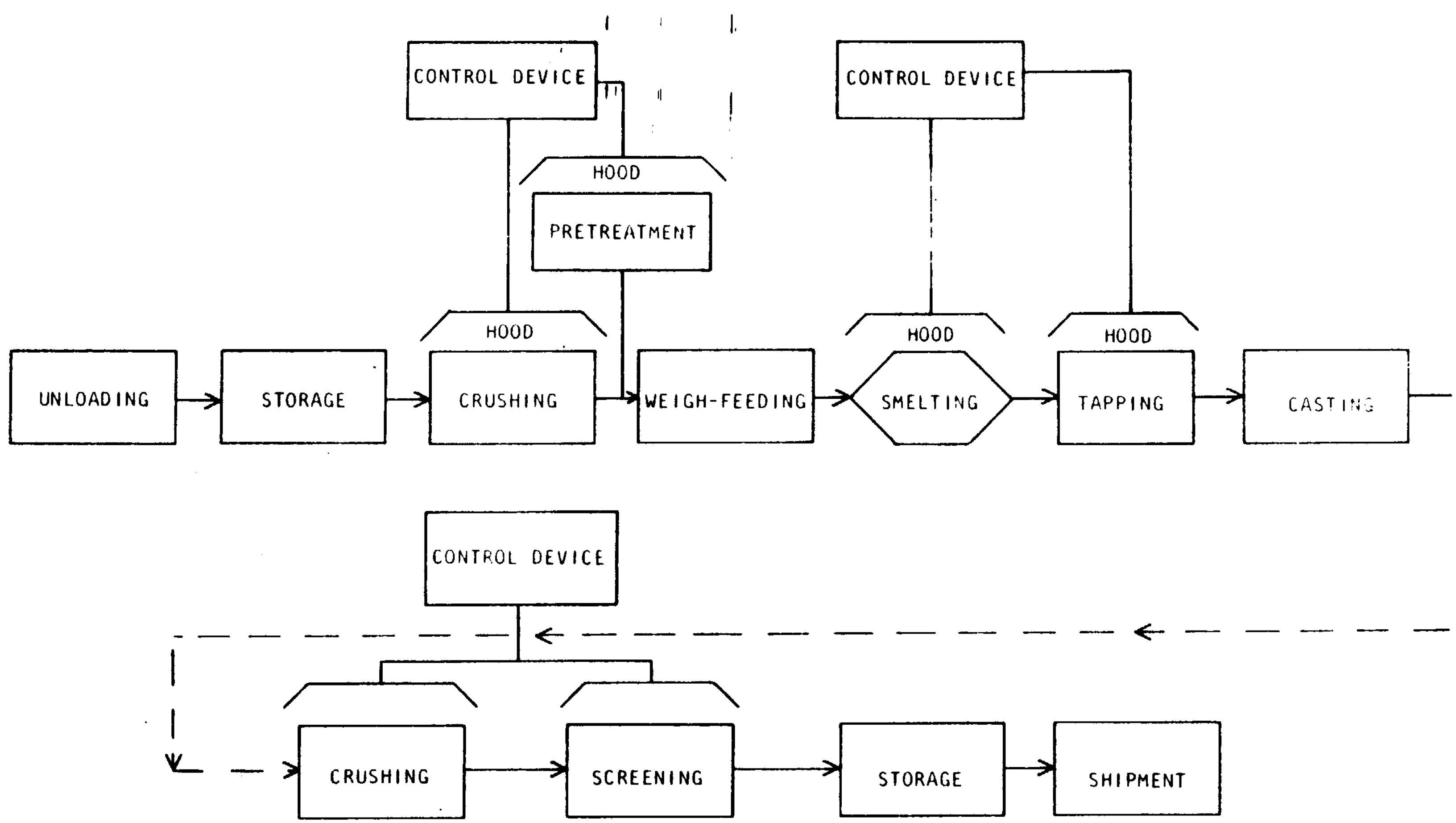

Figure 1. Ferroalloy production flow diagram.

drilling or by oxygen lancing, and may be enlarged during the tap with wooden poles or oxygen lances. The pellet fired from a gun is the procedure typically used to open the taphole. The molten metal flows into a carbon-lined trough arrangement fixed at or near the furnace shell and is poured into carbon-lined runners that direct it either to a reaction ladle or directly to a casting bed or pigging unit. Tapping is terminated by manually inserting a carbon paste plug into the taphole. In some facilities, the molten metal is poured directly into pouring ladles which transport and pour it into reaction ladles, pigging units or cast beds. A reaction ladle is used when additional material is added to produce a specific product or if other treatment, like vacuum degassing, is necessary to meet product specifications.

Pigging units are molds used to produce individual ingots that weigh up to 75 pounds.[3] Cast beds or chills are broad, flat, iron or steel pans that allow heat to dissipate rapidly. While casting in the pigging unit and cast bed, the floating slag containing impurities is skimmed off to a slag pot or slag pot. Slag may be disposed of in landfills, or sold for road ballast. Large ferroalloy castings are broken by drop weights or hammers and then crushed with large jaw crushers, roll mills, or grinders. The crushed product is then sized through various mesh screens. The sized product is either packaged or stockpiled for shipment. Some ferroalloy ingots are not crushed and sized, but are shipped whole.

FURNACE DESCRIPTION

The following furnace types are used to produce ferroalloys:

- Submerged Electric Arc - Open;
- Submerged Electric Arc - Covered;
- Vacuum;
- Induction
- Electrolytic and exothermic processes using reaction vessels are used to produce certain ferroalloys.

Bulk ferroalloys, which comprise 95 percent of all ferroalloys produced in the U.S., are manufactured in submerged electric arc furnaces.[2] These furnaces, which are normally comprised of a cylindrical steel shell with a flat bottom, are supported on an open foundation that permits air cooling and heat dissipation. Two or more layers of carbon blocks lining the bottom interior of the steel shell comprise the hearth. Refractory or carbon bricks line the interior walls of the furnace shell. Molten ferroalloy and slag are removed from the furnace through one or more tapholes located in the lower half of the furnace, just above the carbon hearth.

Some furnaces are designed to rotate at a very slow speed. Some furnaces are split and the two halves rotate at different speeds. The upper part, which rotates more rapidly than the lower part, is a relatively narrow ring with flat interior surfaces. In one design, the ring rotates at 0.1 revolution per hour (rph) while the furnace rotates at 0.01 rph.[22] Furnace rotation supplements manual stoking to prevent the formation of a crust near the electrodes which can result in dangerous "blows," the rapid evolution of trapped gases caused by the collapse of the charge.[23]

Usually, three carbon electrodes are arranged in a triangle formation, extending downward through the charge material to a depth of 3 to 5 ft. These electrodes, which may be prebaked or of the self-baking, Sodenberg type, convert electrical energy to heat by arcing high voltage current through the charge, melting the charge and raising its temperature into the range where mixing and reactions can occur. Electrode depth is continually varied by mechanical or hydraulic means as required to maintain a near uniform electrical load. Individual furnace power consumption rates range from about 7 megawatts to over 50 megawatts, depending on the furnace size and product being made. The average rating for an individual furnace is 17.2 megawatts.[5]

Typical process weights and ferroalloy production related to furnace kilowatt capacity are presented in Table 3. The ferroalloy industry annually consumes approximately 8,900,000 megawatt-hours of electricity. Six percent of the electricity is consumed by pollution control devices. Pollution control devices account for up to 11 percent of the power used to operate open and mix-sealed furnaces and approximately 2 percent of the power used in operating sealed furnaces.[4]

Submerged electric arc furnaces are categorized by the type of furnace top cover used. The two basic categories are open and covered and there are two subtypes for each category. About 86 percent of the submerged electric arc furnaces in the U.S. are of the open type. Covered furnaces comprise the remaining 14 percent of submerged electric arc furnaces.[4]

There are two types of open furnaces; the totally open furnace and the close hooded furnace. Totally open furnaces have an open gap of 1 meter or more between the furnace top and the fume collecting hood. The gap in the close hooded furnace is significantly reduced by movable doors or panels that reduce the amount of air drawn into the hood system.[2] A schematic of totally open furnace is presented in Figure 2.

The covered furnace category is comprised of the mix-sealed furnace and the sealed furnace. In the mix-sealed furnace, a water cooled cover fits tightly onto the furnace. Raw materials are fed through annular gaps around each electrode. The gaps are partially sealed by manual application of raw materials placed around the electrodes. Sealed furnaces are similar to the mix-sealed furnaces except that mechanical seals are used around the electrode and charging occurs through chutes extending through the cover. Schematics of a totally sealed furnace and a mix-sealed furnace are presented in Figures 3 and 4, respectively.

TABLE 3. FERROALLOY PROCESS WEIGHT RATES RELATED TO FURNACE POWER CONSUMPTION[3]

Product	Charge weight rate, lb/lb alloy produced		Furnace load, KW-hr/lb alloy produced		Charge weight rate (lb charged/ MW-hr used)	Product weight rate (lb alloy produced/ MW-hr used)
	Range	Approximate average	Range	Approximate average		
Silvery iron	1.7-1.9	1.8	1.2-1.4	1.3	1380	770
50% FeSi	2.3-2.5	2.5	2.4-2.5	2.5	1000	400
65-75% FeSi	4.3-4.5	4.5	4.2-4.5	4.4	1020	227
Silicon metal	4.6-5.0	4.9	6.0-8.0	7.0	700	144
SMZ[a]	4.3-4.5	4.5	4.2-4.5	4.4	1020	227
CaSi	3.8-4.0	3.9	5.7-6.1	5.9	660	170
HC FeMn	2.9-3.3	3.0	1.0-1.2	1.2	2500	834
SiMn	2.7-3.3	3.1	2.0-2.3	2.2	1410	454
FeMnSi	4.2-4.4	4.3	2.4-3.0	2.7	1590	370
Mn ore/lime melt	3.2-3.6	3.5	0.6-1.0	0.8	4280	1350
Chg Cr	3.7-4.1	4.0	2.0-2.2	2.1	1900	476
HC FeCr	3.7-4.1	4.0	2.0-2.2	2.1	1900	476

(continued)

TABLE 3 (continued)

Product	Charge weight rate, lb/lb alloy produced: Range	Charge weight rate, lb/lb alloy produced: Approximate average	Furnace load, KW-hr/lb alloy produced: Range	Furnace load, KW-hr/lb alloy produced: Approximate average	Charge weight rate (lb charged/ MW-hr used)	Product weight rate (lb alloy produced/ MW-hr used)
Cr ore/lime melt	NA[b]	1.2	0.5-0.7	0.6	2000	1670
FeCrSi	3.2-3.6	3.4	3.6-3.8	3.7	920	270
Ca carbide	1.5-1.7	1.6	1.3-1.4	1.3	1230	770

[a]Si - 60 to 65%; Mn - 5 to 7%; Zr - 5 to 7%.

[b]Data not available.

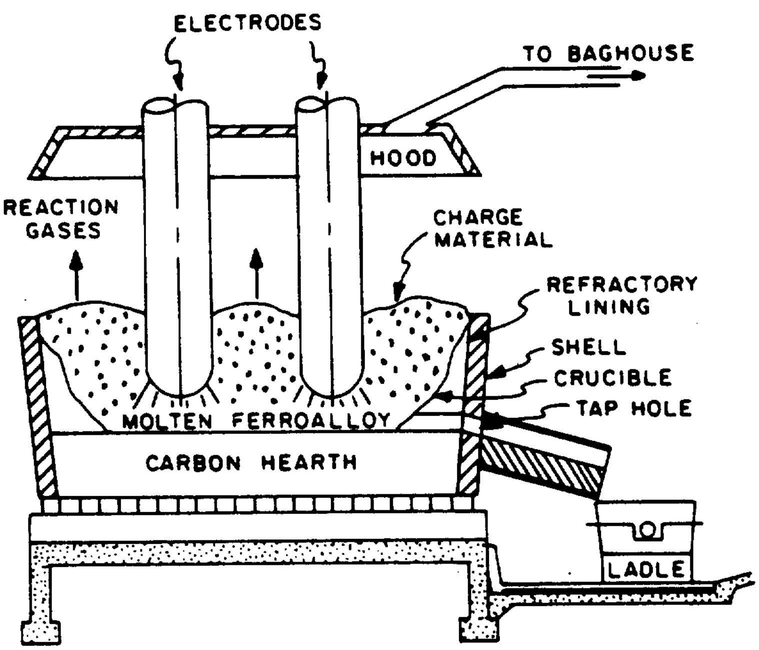

Figure 2. Open furnace.[3]

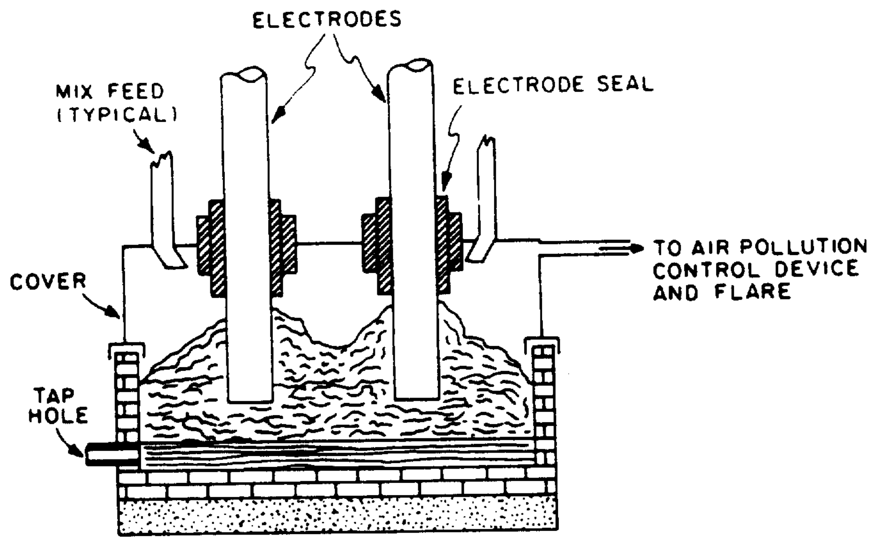

Figure 3. Sealed furnace.[3]

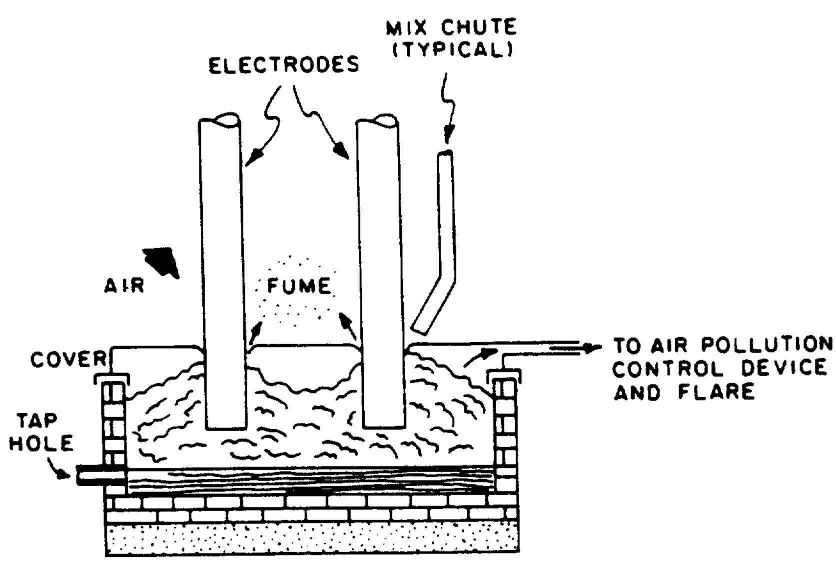

Figure 4. Mix sealed.[3]

A variety of furnace types, including vacuum, induction, electrolytic, and exothermic, are utilized to manufacture specialty alloys. The vacuum furnace is used primarily to produce low carbon (LC) ferrochrome from high carbon (HC) ferrochrome (produced in a submerged electric arc furnace) by removing the carbon in a solid state within the furnace at a temperature near the alloy's melting point. Electric resistance elements supply heat to the furnace. Induction furnaces produce small tonnages of specialty alloys by remelting the materials in specified proportions.

The use of blast furnaces to produce ferromanganese was discontinued in 1977. The iron and steel industry produces some high carbon ferromanganese in blast furnaces, but the process is not considered part of the ferroalloy industry.

The exothermic process is used to produce low-carbon ferrochrome, low and medium carbon ferromanganese, chromium metal, ferrotitanium, ferrocolumbium, and ferrovanadium. Molten alloys (which may first be fused in a furnace) are blended with reducing agents such as silicon and/or aluminum in a reaction ladle. The charge material is reduced, generating considerable heat, and the slag is removed to produce the desired ferroalloy product.

High purity chromium and manganese are produced electrolytically. An electrolyte solution of the desired metal is prepared and a low voltage direct current is passed through the solution causing the ions to deposit on the cathodes.

EMISSION SOURCES

Several types of pollutants are emitted from ferroalloy facilities. Particulate is the major air emission in the industry. Particulate is emitted in the form of dust and fume. Dust is a result of abrasive processes such as raw material handling, storage, crushing, screening, drying, weighing, mixing, and final product handling. Fine particulate that has resulted from condensation from the gas phase, gas phase reaction, or atomization of a fluid is emitted in the form of fumes. Fumes result from furnace operations, furnace tapping, and ladle operations. Potential source of dust and fume emissions are displayed in Figure 5. In addition to particulate, large quantities of carbon monoxide (CO) are emitted from the submerged electric arc furnaces. The weight of carbon monoxide produced sometimes exceeds that of the metallic product.[19]

Electric Arc Furnaces

The submerged electric arc furnace emits particulate in the form of a fume and accounts for an estimated 94 percent of the particulate emissions in the ferroalloy industry. An uncontrolled electric arc furnace may emit between 150 and 2,000 lb of particulate per hour, depending upon the type of alloy produced, type and size of raw materials, operating techniques and furnace operating conditions.

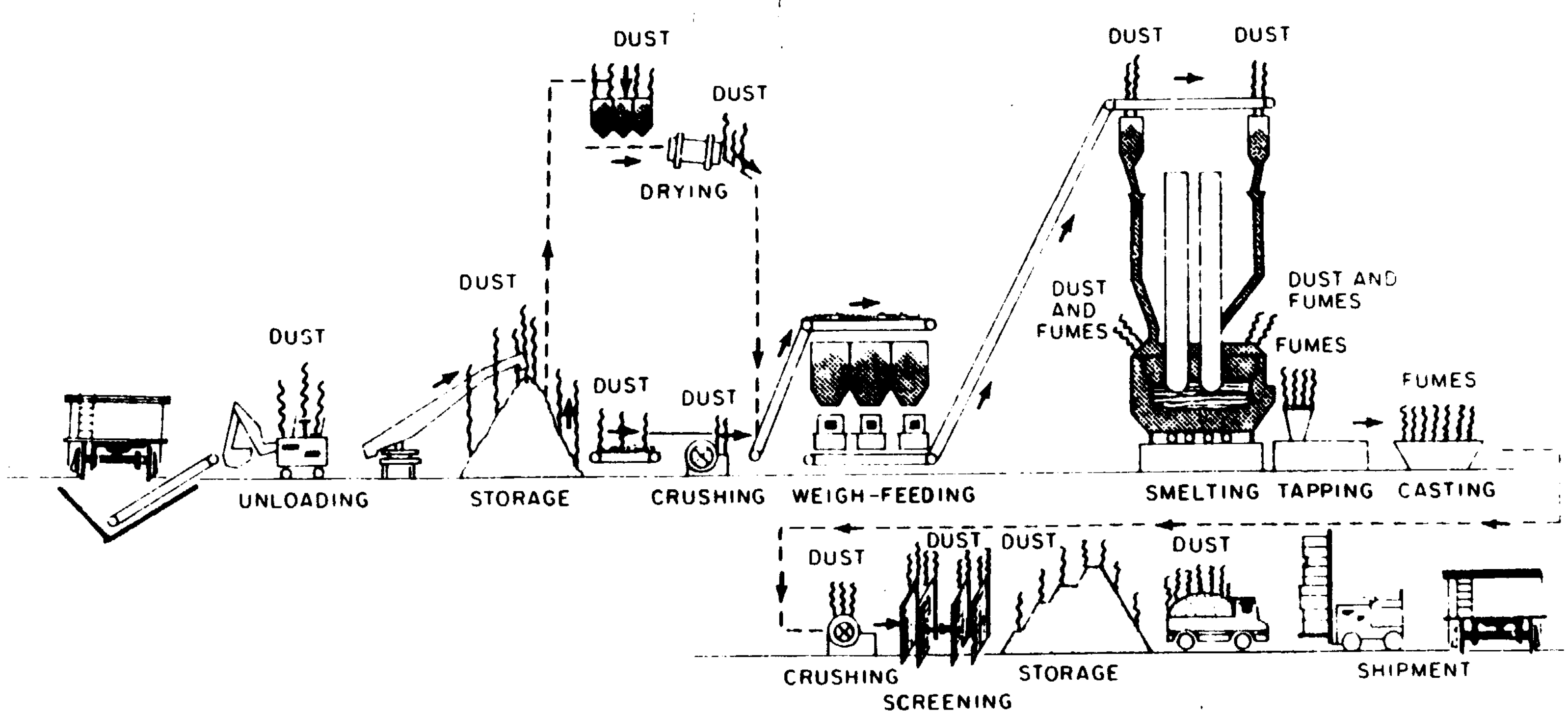

Figure 5. Ferroalloy production flow diagram showing potential emission points.[3]

Large amounts of carbon monoxide and organic matter are emitted by submerged electric arc furnaces. Carbon monoxide is formed as a byproduct of the chemical reaction between the oxygen in the metal oxides of the charge and the carbon contained in the coke or other reducing agent added to the charge. The carbon monoxide rises from a region of higher temperature to an area of lower temperature entraining finer size constituents of the mix and carrying fume and fume precursors to the top of the furnace. The weight of carbon monoxide produced sometimes exceeds that of the metallic product.[19] An increase in moisture in the charge materials, reducing agent volatile matter, thermal decomposition products of raw ore and intermediate products of reaction cause an increase in primary gas generation. These latter sources normally account for less than 30 percent of the carbon monoxide production.

Organic emissions from electric arc furnaces have been measured to range from 71.8 lb/ton of alloy produced in silicon metal producing open furnaces to 1.4 lb of organics per ton of alloy produced in covered ferromanganese furnaces. Benzo(a)pyrene concentrations in emitted furnace gas were greater for three of five furnaces tested by EPA than the 0.02 $\mu g/m^3$ of gas[8] DMEG limit. NO_x and SO_2 concentrations were insignificant (less than 7 lb/hr or 1 to 17 ppm, respectively from five submerged electric arc furnaces tested by EPA.[20]

Ferrosilicon operations producing alloys greater than 75 percent silicon are known as "hot" operations and are subject to "blows." Blows occur when the charge material forms a crust or a bridge and does not descend evenly. When the crust breaks and falls, extremely hot gases are expelled violently from the surface. Molten alloy and slag or charged material may be expelled with the gas.

Manganese operations produce a brown fume consisting of a mixture of SiO_2 and manganese oxides. The manganese oxides arise from the vaporization of manganese or production of a volatile intermediate.[19] Manganese ores can contain a significant amount of water and higher manganese oxides which, when heated to temperatures below 1,000°C, dissociate to lower oxides and oxygen. This can cause sudden releases of gas causing mix to be ejected from the furnace.

Tapping also generates fumes. Since tapholes are opened intermittently, tapping fumes occur only from 10 to 20 percent of the furnace operating time. Some fumes originate from the taphole carbon lip liner, but most result from flow induced by heat transfer from molten metal or slag. Significant fume emissions are intermittently generated after tapping, during conveying, pouring, and casting as a result of heat-induced flow as the molten metal contacts the runners, ladles, cast beds, and ambient air. Typically, extensive hooding around tapping and pouring operations direct fumes to an emission control system.

A gray fume containing a high percentage of amorphous silicon dioxide (SiO_2) is produced from silicon alloys.[19] The SiO_2 results from the oxidation and disproportionation of SiO, a gaseous intermediate at reaction temperatures.[3] The SiO losses increase correspondingly with the increase in the percentage of silicon in the alloy. Thus, more SiO_2 fumes are produced by the production of higher silicon alloys than lower silicon alloys at the same load. Some tars and carbon, also present in the fume, evolve from the coal, coke or wood chips used in the charge.

Hearth buildup of silicon carbide may also result from high silicon operations. If this occurs the electrodes must operate in a higher position, often resulting in more fume. Chromium furnaces produce a light-colored fume, containing SiO_2, MgO, and iron and chromium oxide. Furnaces producing ferrochrome-silicon emit SiO_2 fumes similar to those produced by ferrosilicon.

Additional emissions may be generated by furnaces with self-baking electrodes. Fumes are generated from the electrode paste during heating and baking. These fumes are usually directly vented to the atmosphere. Self-baking electrodes may also increase emissions as a result of "fluting" or grooving of the electrodes in the relatively oxidizing atmosphere. These grooves provide direct passage for fumes to escape from the high temperature regions of the furnace to the surrounding atmosphere.

Along with volatile materials in the furnace charge, the presence of fine or dense material in the feed may cause rough furnace operation. These materials may cause non-uniform descent of charge causing the gas to channel or bypass these obstructions. The sudden collapse of a bridge results in a momentary burst of fume. Less desirable raw materials containing more fumes and volatile matter may be used as dictated by economics, resulting in rough furnace operation and pollution.

Differences in operating techniques affect the amount of fume emissions substantially. Furnace gas production rate is roughly proportional to electrical energy input. Thus, an increase in the electrical load applied to a furnace results in at least a proportional increase in fume emissions.[19] In some instances, emissions increase greater than the proportional increase in electrical load input because of rough operation and inadequate gas withdrawal.

Fume emission can vary depending upon how well and how often a furnace is manually worked or stoked. Some operations, especially silicon metal operations, require stoking to break up crusts, cover areas of gas blows, and allow the flow of reaction gases. Sealed furnaces cannot be stoked. Alloys which are particularly prone to blows, such as silicon metal, are not usually produced in sealed furnaces. Furnace rotation can substitute somewhat for stoking and extra care in material preparation and furnace operation can help to minimize bridging. The accumulation of materials under the cover and in gas take-off ducts, which reduce the gas withdrawal capacity of the exhaust system, can cause abnormally high emissions from sealed furnaces.

Shutdowns and startups of submerged electric arc furnaces, which are designed to operate continuously, can adversely affect emission rates. Normal furnace shutdowns are usually not more than several hours and may average 4 to 10 percent of the operating time. In open furnaces, the control systems usually remain in operation during startup and shutdown; in semi-sealed furnaces the mix seals are empty. Operating under these conditions results in heavier-than-normal emissions which may last from a few days up to a month when starting up a new furnace, a furnace with a cleaned out hearth, or one with a cold hearth after a long shutdown.

Some ferroalloy products are produced from a non-continuous batch operated furnace in which the melt is poured by tilting the furnace. Violent gas eruptions can result following the sudden addition of mix, containing volatile or reactive constituents (coal volatiles, moisture, aluminum), to a hot furnace.[19] In manganese ore-lime melt furnaces, the gas flow immediately following mix addition may be five times greater than the average flow. Temperature and dust loading increase correspondingly with the increase in gas flow. The mix used in chromium ore-lime melt operations contains little or no gas-releasing constituents and does not result in violent initial gas eruptions.

Reaction Ladle Emissions

The chemical constituents of the heat-induced fumes correspond to the oxides of the products being produced, carbon from the reducing agent, and enrichment of SiO_2, CaO, and MgO, if present in the charge. Particle size usually ranges from 0.1 μm to greater than 20.0 μm. Larger particles are sometimes emitted as a result of agglomeration of finer particles or as ejecta from the charge. Collected particulate in the dry state is very light, varying in bulk density between 4 and 30 lb/ft^3.

In addition to heat induced fumes, fumes may be generated as a result of reactions conducted in the reaction ladle such as chlorination, oxidation, slag-metal reactions, and stirring of molten metal with gas. The ladle reactions are intermittent and have not been quantified.

Vacuum, Induction and Other Process Emissions

Emissions from vacuum, induction, electrolytic or exothermic ferroalloy furnaces are negligible in comparison to submerged electric arc furnaces. No particulate emissions are generated by the vacuum process; small quantities of carbon monoxide gas are withdrawn by a steam jet ejector. The induction process does not produce any emissions. No particulate emissions are generated by the electrolytic process, but generation of minor amounts of ammonia or sulfur oxides sometimes occurs. Oxide fumes, whose physical characteristics are similar to those fumes from submerged electric arc furnaces, are produced in the reaction ladle or furnace during the exothermic process. Emission generation correlates with periods of highest temperature and greatest agitation.

Fugitive Dust Emissions

Fugitive dust emissions are generated by raw material storage, transport, unloading and transfer activities. Moisture in the raw materials, which may be as high as 20 percent, can minimize these emissions. Sometimes, raw materials may be dried in rotary or other type dryers prior to charging to reduce off gas volumes and enhance furnace operation. These dryers may generate significant particulate emissions.

Ferroalloys are crushed and screened into different product sizes before marketing. This process creates undersized pieces and airborne particles.[19] The quantity of dust emitted as a result of casting, breaking, and screening operations has not been quantified, but is substantially less than that of furnace emissions.[3]

The properties of particulates emitted as dust are similar to the natural properties of the ores or alloy from which they originate. These dust particles range in size from 3 to 100 μm.[19]

EMISSION CONTROLS

Control devices are always used to control emissions from smelting. Control of emissions from tapping is frequently integrated with the furnace control system. Other particulate-generating activities i.e., storage of materials, crushing, pretreatment of raw materials and crushing and sizing of finished products, are controlled by about one-half of domestic ferroalloy facilities.

Furnace Controls

Hooding constructed around the submerged electric arc furnace tapping area directs fumes to a control system. One primary emission control system is usually all that is needed to capture emissions from open electric arc furnaces, since the emissions from all furnace operations can be collected by the same fume hood.

Two emission capture systems are needed for covered furnaces. A primary capture system withdraws gases from beneath the furnace cover. A secondary system captures fumes released around the electrode seals and during tapping operation. The two capture systems are not usually connected to the same control device. Flares are usually used on sealed and semi-sealed furnaces to combust carbon monoxide at the control system exhaust. Some plants use some or all of the carbon monoxide as a fuel in such processes as kilns or sintering machines.

Gas cleaning devices currently used on submerged electric furnaces to control particulate emissions are the baghouse (fabric filter), high pressure venturi scrubber and electrostatic precipitator (ESP). Fabric filters are employed on 85 percent of the open furnaces in the U.S. Scrubbers are employed on 13 percent and electrostatic precipitators are employed on 2 percent. Scrubbers are used almost exclusively to clean the high temperature combustible gases withdrawn from covered (closed) furnaces. Baghouses are effective in removing particulates from gas streams, but not as effective for capturing organic emissions. Particulate collection efficiencies in excess of 99 percent have been achieved for fabric filters with glass fiber or Nomex bags and for some high pressure drop scrubbers with pressure drops of 13.7 to 23.9 KPA (55 to 96 inches of water).[4] The air-to-cloth ratios in baghouses are 1:1 to 2:1 and bag life is on the order of 2 years. Visible emissions from particulate collectors of less than 10 percent opacity have also been achieved.[3]

The efficiency of a scrubber for controlling organic emissions is in the range of 16 to 97 percent.[4] Electrostatic precipitators (ESPs) are not usually used as control devices in the ferroalloy industry because of potential resistivity problems in the temperature ranges encountered. When used, however, ESPs are typically installed on open furnaces and can be expected to be about 98 percent efficient in particulate removal.[3]

Furnaces and scrubbers utilize large quantities of water. Furnaces use from 3,000 to 10,000 gallons per megawatt-hour of water for noncontact cooling.[3] Scrubber control systems use from 500 to 3,500 gallons per megawatt-hour depending on the type of scrubber and the product being made.[3] Wastewater treatment facilities clean scrubber water so that it can be recycled and/or used as a cooling agent. Treatment facilities for scrubber water differ from facility to facility. Usually, chemical and physical treatment of waste streams is performed. Scrubber water is usually clarified to reduce suspended solids concentration to less than 50 mg/l.[3]

Fugitive Dust Controls

Raw material storage is controlled by storing the materials in separate storage piles sheltered by block walls, snow fences, or plastic covers. The piles are sometimes sprayed with water to help minimize fugitive dust emissions. Dust collection equipment, usually a baghouse, is used to minimize emissions from raw material crushing and sizing of the finished product. Emission control equipment for pretreatment such as drying of raw materials include scrubbers, cyclones, or baghouse collectors. The raw material emission control equipment is sometimes connected to the furnace control system.

Transferring the dust from the baghouse to trucks that remove it from the site is sometimes a problem because of leaks in transfer mechanisms. This can result in dust being resuspended when there is significant wind velocity.

SECTION 3

FERROALLOY PRODUCTION EMISSION FACTORS

TOTAL AND SIZE-SPECIFIC EMISSION FACTORS

Emission factors for uncontrolled and controlled total particulate have been developed in this report for the ferroalloy industry. Size specific emission factors have also been calculated based on cascade impactor test results. These emission factors and size distributions are listed in Tables 4 and 5 and illustrated in Figures 6 through 15.

The data used in the calculation of emission factors presented in this report are from different test reports than the data used in the current AP-42 ferroalloy section (2/72). As shown in Table 6, additional data of improved quality have been developed in the past 10 years. Test data quantifying emissions of sulfur dioxide, carbon monoxide and organics are summarized in Table 7 and emission factors for those emissions are presented in Table 8. The procedures used in compiling this information, calculating the emission factors and rating the emission factors are detailed in the following pages.

DATA REVIEW

All available sources of data were reviewed for the compilation of emission factors. There were no data available from EPA's FPEIS which were useful in the calculation of emission factors.

Sources of data that were the results of actual measurements and observations were considered primary sources. All other sources of data that referred to summarized emission data performed and reported by a different organization or author were considered secondary sources. Only primary sources were considered suitable for calculating emission factors.

The data review process consisted of two steps. The first step consisted of obtaining sources of emission data, and judging if it should be considered a primary or secondary source. If judged secondary, an attempt was made to obtain the primary source(s).

All primary data sources were extensively reviewed and analyzed. The data were ranked using an A through D grading system based on data quality and reliability according to the criteria described earlier, and in the manual "Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections."[1]

TABLE 4. EMISSION FACTORS FOR PARTICULATE FROM SUBMERGED ARC FERROALLOY FURNACES[aa]

Product[bb]	Furnace type	Uncontrolled[cc] particulate emission factors: kg/Mg alloy	lb/ton alloy	kg/MW-hr	lb/MW-hr	Emission Factor Rating (A-E)	Size data	Notes	Control device[dd]	Controlled[cc] emissions: kg/Mg alloy	lb/ton alloy	kg/MW-hr	lb/MW-hr	Emission Factor Rating	Size data	Notes
FeSi (50%)	Open	35	70	7.4	16.3	B	Yes	a,b,c	Baghouse	0.9	1.8	0.2	0.4	B	Yes	a,b
	Covered	46	92	9.3	20.5	E		b	Scrubber--high energy	0.24	0.48	0.05	0.1	E		d
									Scrubber--low energy	4.5	9.0	0.77	1.7	E		d,e
FeSi (75%)	Open	158	316	16	35	E		f								
	Covered	103	206	13	29	E		d,e	Scrubber--low energy	4.0	8.0	0.5	1.1	E		d,e
FeSi (90%)	Open	282	564	24	53	E		f								
Si Metal (98%)	Open	436	872	33	73	B	Yes	g,h	Baghouse	16	32	1.2	2.6	B	Yes	g,h
FeMn (80%)	Open	14	28	4.8	11	B	Yes	i,j	Baghouse	0.24	0.48	0.078	0.2	B	Yes	i,j
									Scrubber--high energy	0.8	1.6	0.34	0.7	E		e,k
FeMn (1% Si)	Covered	6	12	2.4	5.3	E		m,n								
	Sealed	37	74	17	37	E		r,s	Scrubber--high energy	0.25	0.5	0.10	0.2	C		k,p,q
FeCr (High Carbon)	Open	78	157	15	33	C	Yes	t,u	ESP	1.2	2.3	0.23	0.5	C	Yes	t,u
SiMn	Open	96	192	20	44	C	Yes	v,w	Scrubber	2.1	4.2	0.44	1.0	C	Yes	w,x
	Sealed								Scrubber--high energy	0.15	0.30	0.016	0.04	E		s,p

[aa]Particulate emission factors are listed for main furnace dust collection system before and/or after control device. In cases where other emissions such as leaks or tapping are included or quantified separately a comment is footnoted. Other sources of particulate emissions which are not included in this table are: raw material handling, storage and preparation and product crushing, screening, handling and packaging.

[bb](%) refers to percent of main alloying element in product.

[cc]In most source testing, fugitive emissions were not measured or collected. In cases where tapping emissions were controlled by the primary system, their contribution to total emissions could not be determined. Fugitive emissions may vary greatly between sources based on furnace and collection system design and operating practices.

[dd]Low energy scrubber refers to those with $\Delta P < 20$ in. H_2O. High pressure refers to those with $\Delta P > 20$ in. H_2O.

(continued)

TABLE 4 (continued)

[a]Includes fumes captured by a tapping hood (efficiency estimated to be nearly 100%).
[b]References No. 7 and 8.
[c]Emission factor is the average of 3 sources. Fugitive emissions are not included. Fugitive emissions at one of the sources were measured to contribute an additional 10.5 kg/Mg alloy or 2.7 kg/MW-hr. This was approximately half as much as collected by the primary system.
[d]Does not include emissions from tapping or mix seal leaks.
[e]Reference No. 4.
[f]Reference No. 32.
[g]60% of tapping emissions estimated to be captured by emission control system, escaping fugitive emissions not included in emission factor.
[h]References No. 8 and 10.
[i]50% of tapping emissions estimated to be captured by emission control system, escaping fugitive emissions not included in emission factor.
[j]References No. 8 and 9.
[k]Includes fume from primary control system only.
[m]Includes tapping fumes and mix seal leak fugitive emissions. Fugitive emissions measured were 33% of total uncontrolled emissions.
[n]Reference No. 8.
[p]Does not include tapping or fugitive emissions.
[q]Emission factor if uncontrolled tapping and fugitive emissions are included = 2.0 kg/Mg alloy.
[r]Assumed that tapping fumes are not included in emission factor.
[s]Reference No. 11.
[t]Tapping emissions included. Emission factor developed from two test series performed on the same furnace separated by a 7 year time frame. The later test measured emissions 36% less than the initial test.
[u]References No. 12, 13 and 14.
[v]Factor is average of two test series. The tests at one source included fugitive emissions which amounted to 3.4% of total uncontrolled emissions. The second test did not provide enough information to determine if fugitive emissions were included in total.
[w]References No. 15 and 17.
[x]Factors developed from two scrubber controlled sources, one operated at a ΔP = 47-57" H_2O, the other at an unspecified ΔP. Emission factor if uncontrolled tapping operations are included = 4.2 kg/Mg alloy.

TABLE 5. SIZE SPECIFIC EMISSION FACTORS

Product	Control device	Emission Factor Rating (A-E)	Particle[a] size (micrometers)	Cumulative mass % less than stated size	Cumulative mass Emission Factor kg/Mg alloy	(lb/ton alloy)
50% FeSi[b,e] Open furnace	None	B	0.63	45	16	(32)
			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)
50% FeSi[b,e] Open furnace	Baghouse	B	0.63	31	0.28	(0.56)
			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[f,g] Open furnace	None	B	0.63	30	4	(8)
			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)

(continued)

TABLE 5 (continued)

Product	Control device	Emission Factor Rating (A-E)	Particle[a] size (micrometers)	Cumulative mass % less than stated size	Cumulative mass Emission Factor kg/Mg alloy	(lb/ton alloy)
80% FeMn[f,g] Open furnace (cont.)			15.00	96	13	(26)
			20.00	97	14	(27)
			d	100	14	(28)
80% FeMn[f] Open furnace	Baghouse	B	0.63	20	0.048	(0.10)
			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[g,h] Open furnace	None	B	0.63	57	249	(497)
			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)

(continued)

TABLE 5 (continued)

Product	Control device	Emission Factor Rating (A-E)	Particle[a] size (micrometers)	Cumulative mass % less than stated size	Cumulative mass Emission Factor kg/Mg alloy	(lb/ton alloy)
Si Metal	Baghouse	B	1.00	49	7.8	(15.7)
Open furnace			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)
FeCr[b,i]	None	C	0.5	19	12	(24)
Open furnace			1.0	36	22	(44)
			2.0	60	37	(74)
			4.0	76	47	(94)
			10.0[j]	91[j]	56[j]	(112)[j]
			[d]	100	62	(123)
FeCr (HC)[b]	ESP	C	0.5	33	0.30	(0.59)
Open furnace			1.0	47	0 42	(0.85)
			2.5	67	0.60	(1.21)
			5.0	80	0.72	(1.44)
			10.0[j]	90[j]	0.81[j]	(1.62)[j]
				100	0.90	(1.8)

(continued)

TABLE 5 (continued)

Product	Control device	Emission Factor Rating (A-E)	Particle[a] size (micrometers)	Cumulative mass % less than stated size	Cumulative mass Emission Factor kg/Mg alloy	(lb/ton alloy)
SiMn[b,k] Open furnace	None	C	0.5	28	27	(54)
			1.0	44	42	(84)
			2.0	60	58	(115)
			4.0	76	73	(146)
			10.0[j]	96[j]	92[j]	(177)[j]
			d	100	96	(192)
SiMn[m,k] Open furnace	Scrubber	C	0.5	56	1.18	(2.36)
			1.0	80	1.68	(3.44)
			2.5	96	2.02	(4.13)
			5.0	99	2.08	(4.26)
			10.0	99.9[j]	2.10[j]	(4.30)[j]
				100	2.1	(4.3)

[a]Particle aerodynamic diameter based on Task Group on Lung Dynamics definition. (particle density = 1 gr/cm^3).
[b]Tapping emissions included.
[c]References No. 10 and 21.
[d]Total particulate based on Method-5 total catch, see Table 4.
[e]Includes tapping fume, however, tapping capture efficiency was less than 50%.
[f]References No. 21 and 12.
[g]Includes tapping fume, however, tapping capture efficiency was estimated to be 60%.
[h]References No. 21 and 13.
[i]References No. 15, 16 and 17.
[j]Interpolated data.
[k]References No. 18 and 19.
[m]Primary emission control system only, does not include tapping emissions.

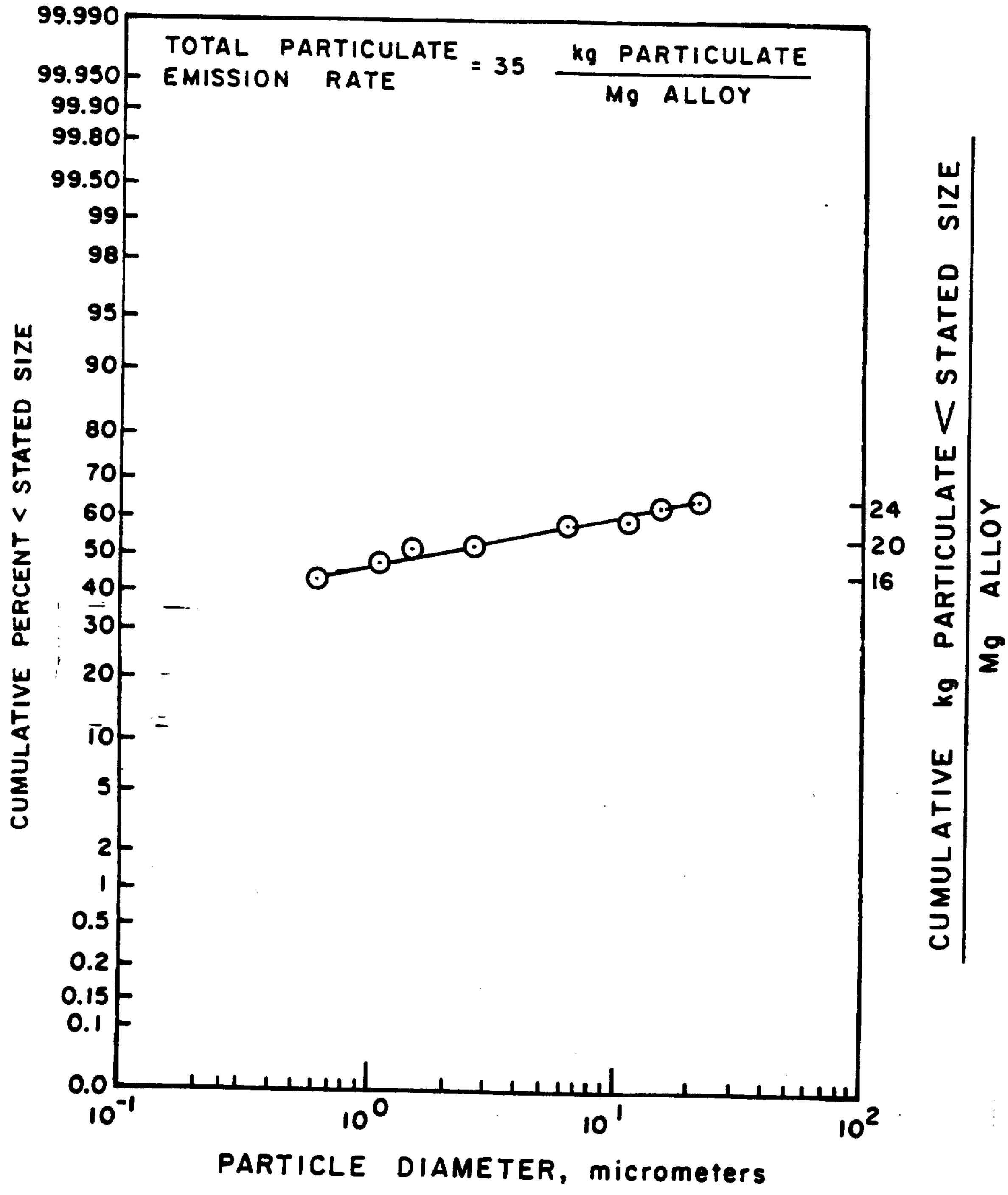

Figure 6. Uncontrolled, 50% FeSi producing, open furnace particle size distribution.

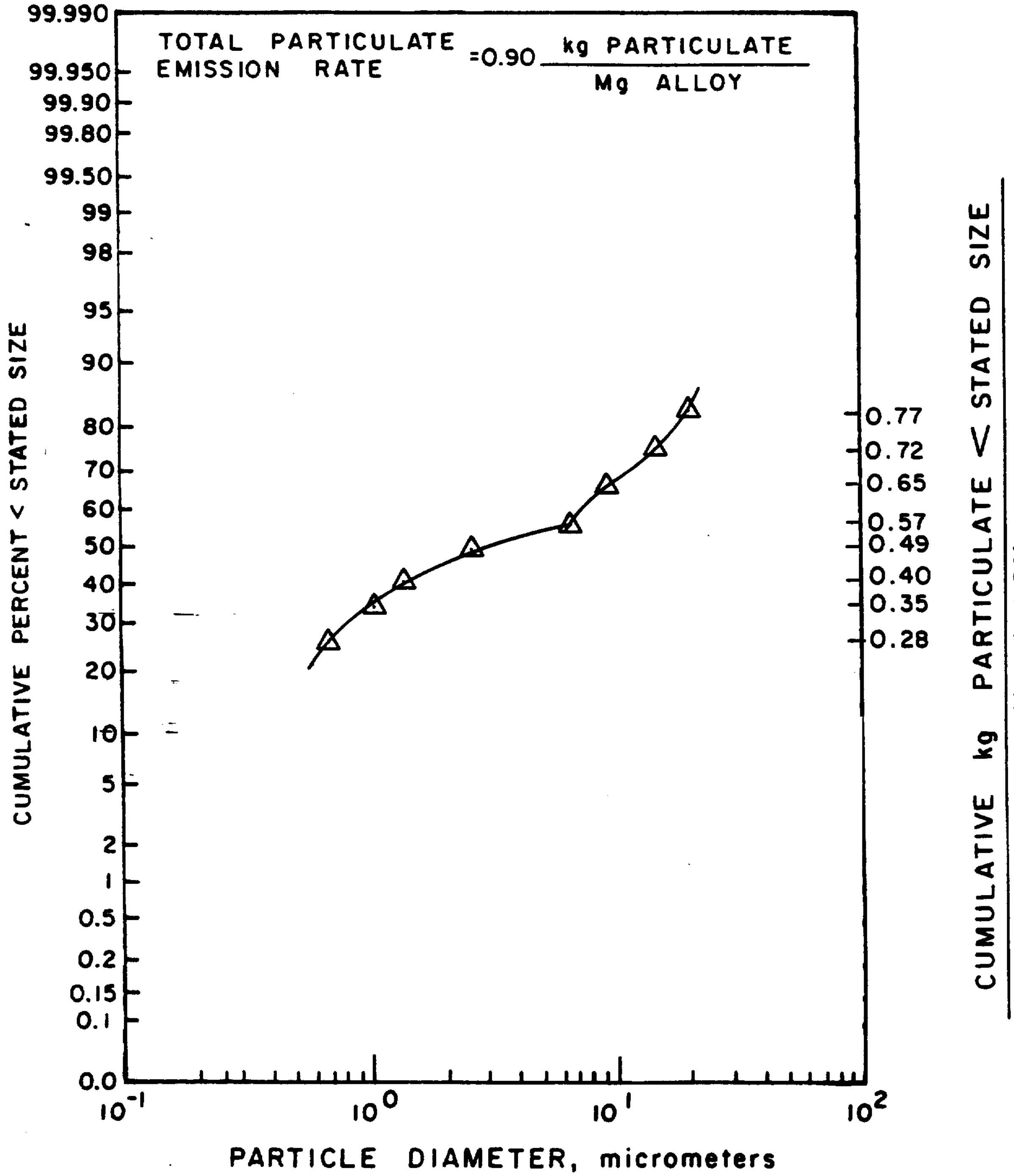

Figure 7. Controlled (baghouse), 50% FeSi, open furnace particle size distribution.

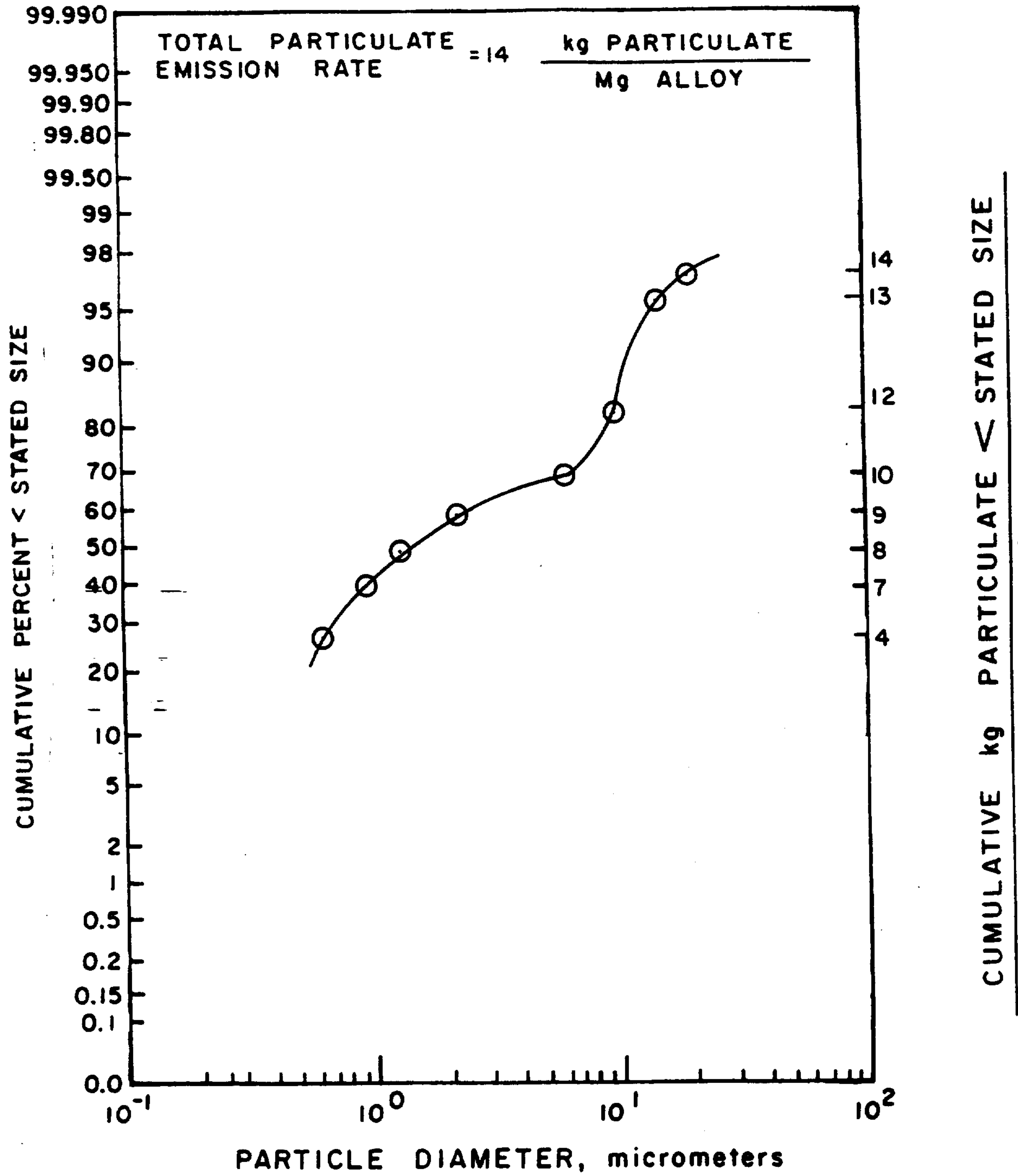

Figure 8. Uncontrolled, 80% FeMn producing, open furnace particle size distribution.

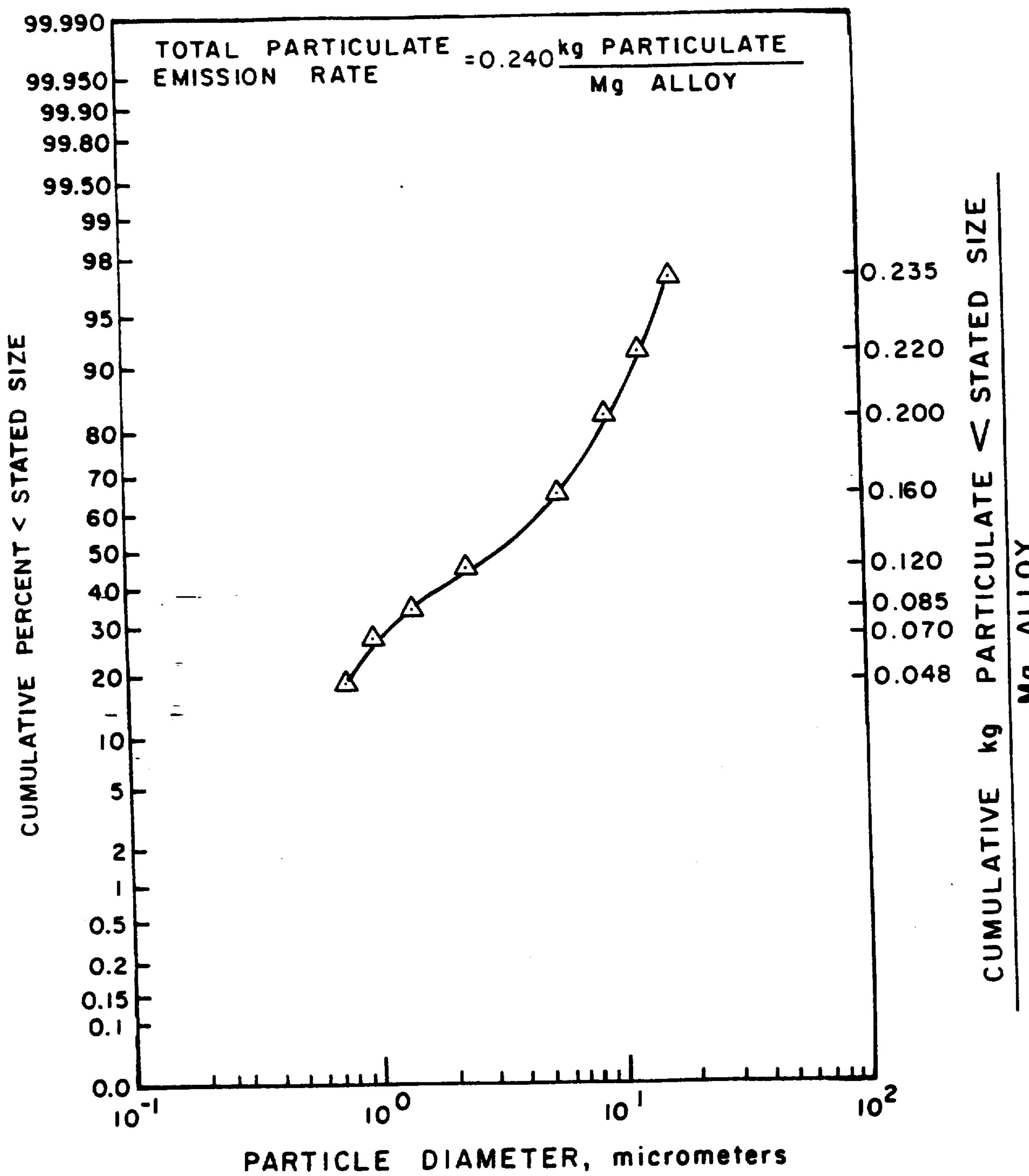

Figure 9. Controlled (baghouse), 80% FeMn producing, open furnace size distribution.

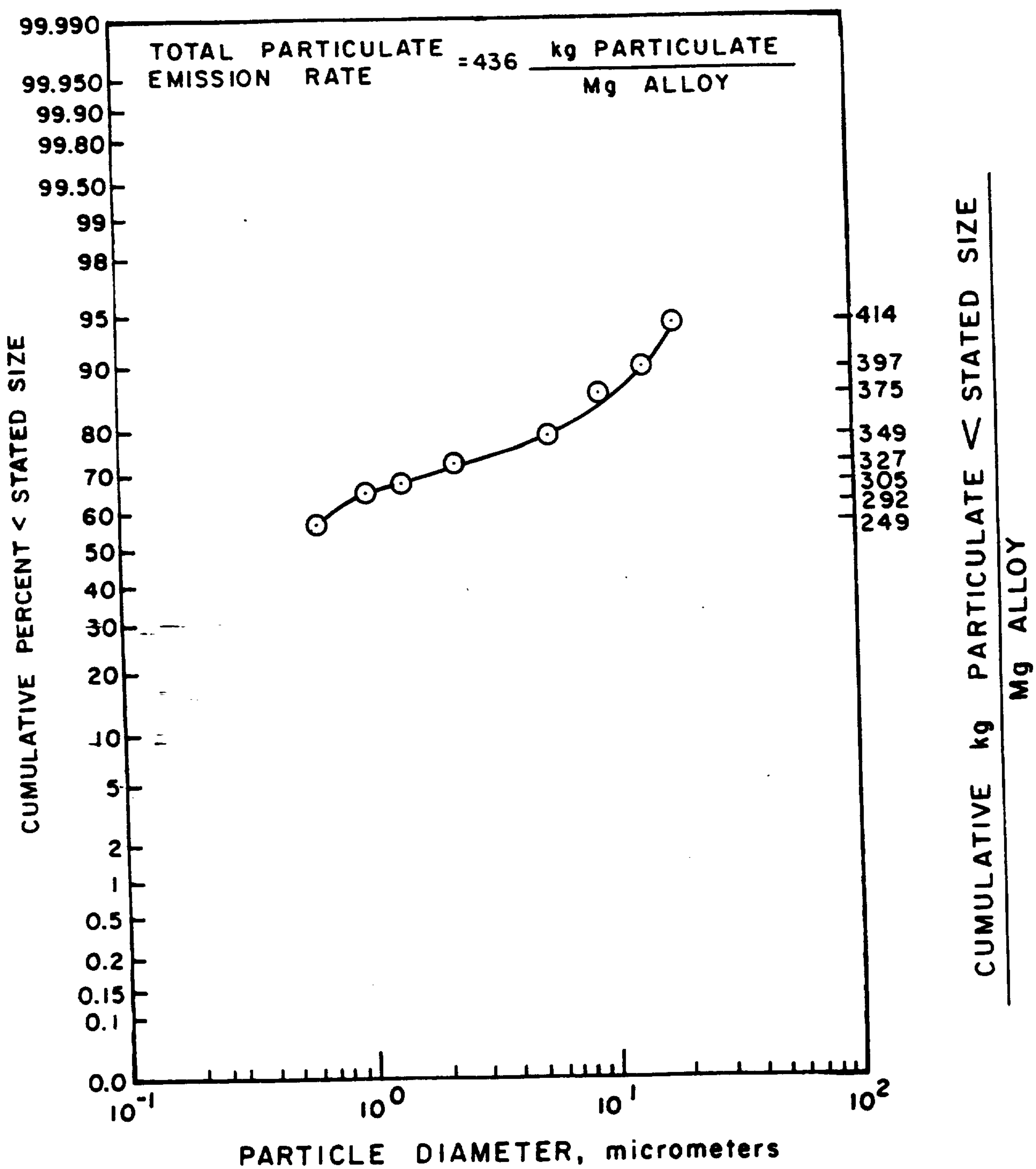

Figure 10. Uncontrolled, Si metal producing, open furnace particle size distribution.

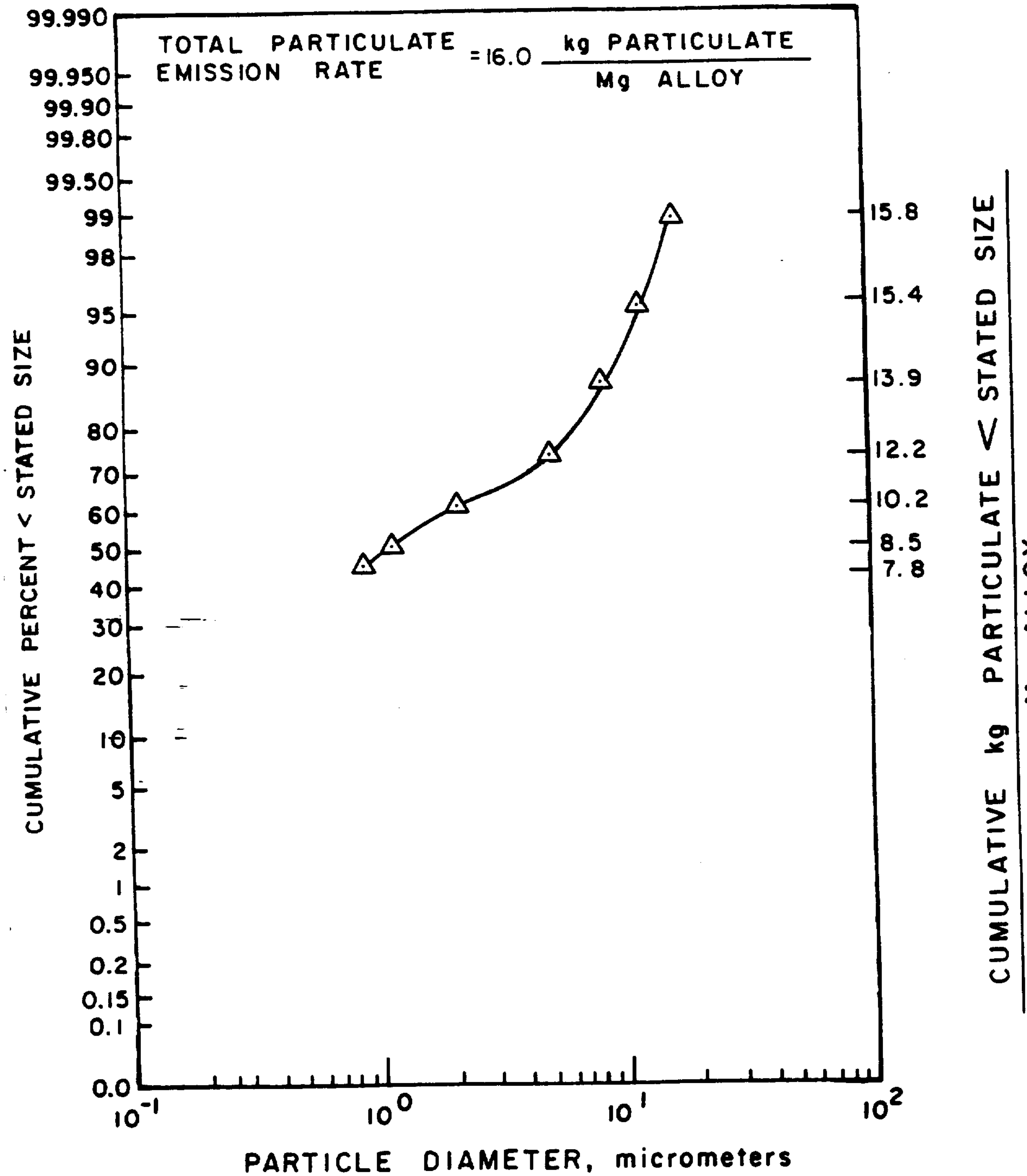

Figure 11. Controlled (baghouse), Si metal producing, open furnace particle size distribution.

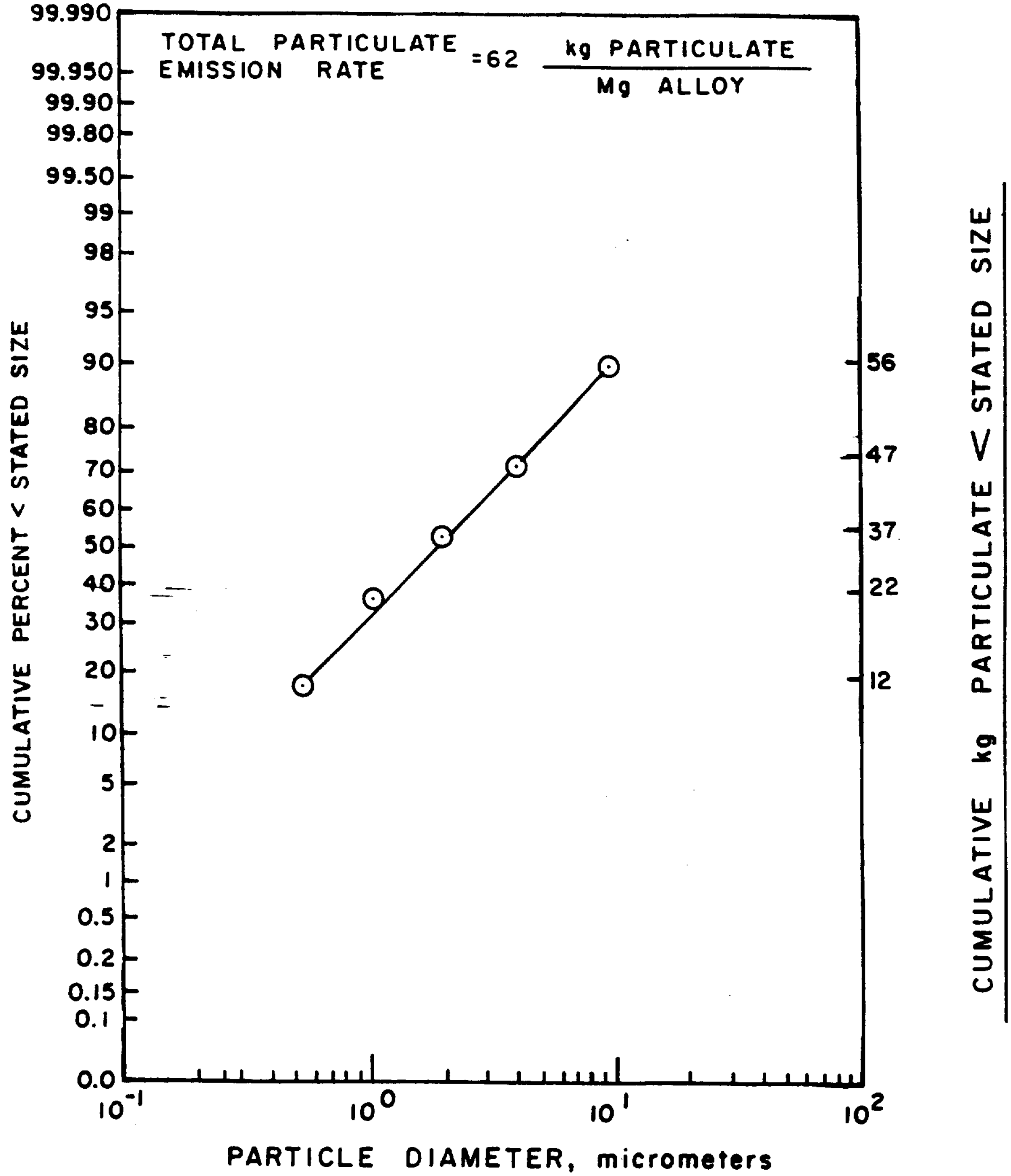

Figure 12. Uncontrolled, FeCr producing, open furnace particle size distribution.

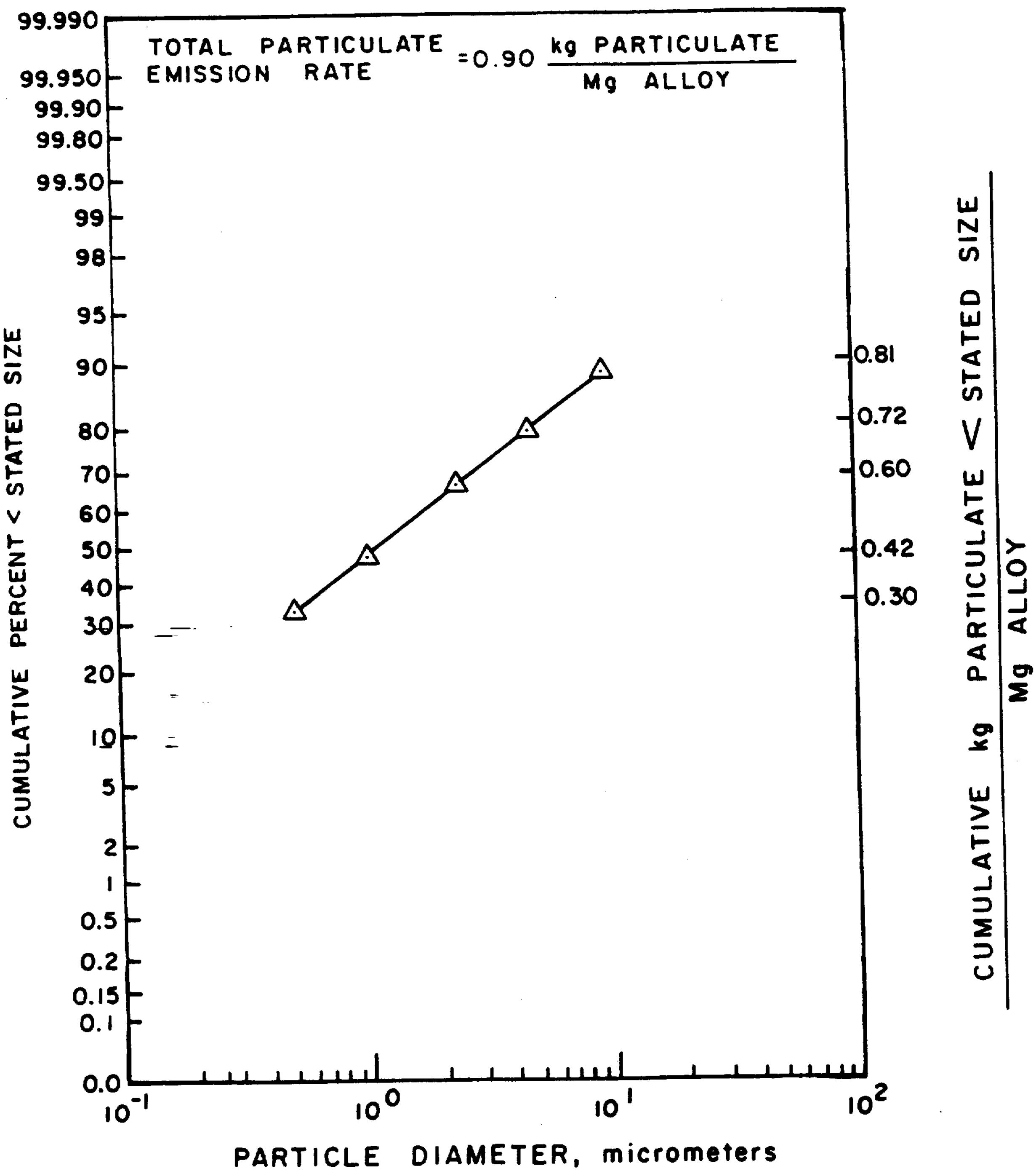

Figure 13. Controlled (ESP), FeCr (HC) producing, open furnace particle size distribution.

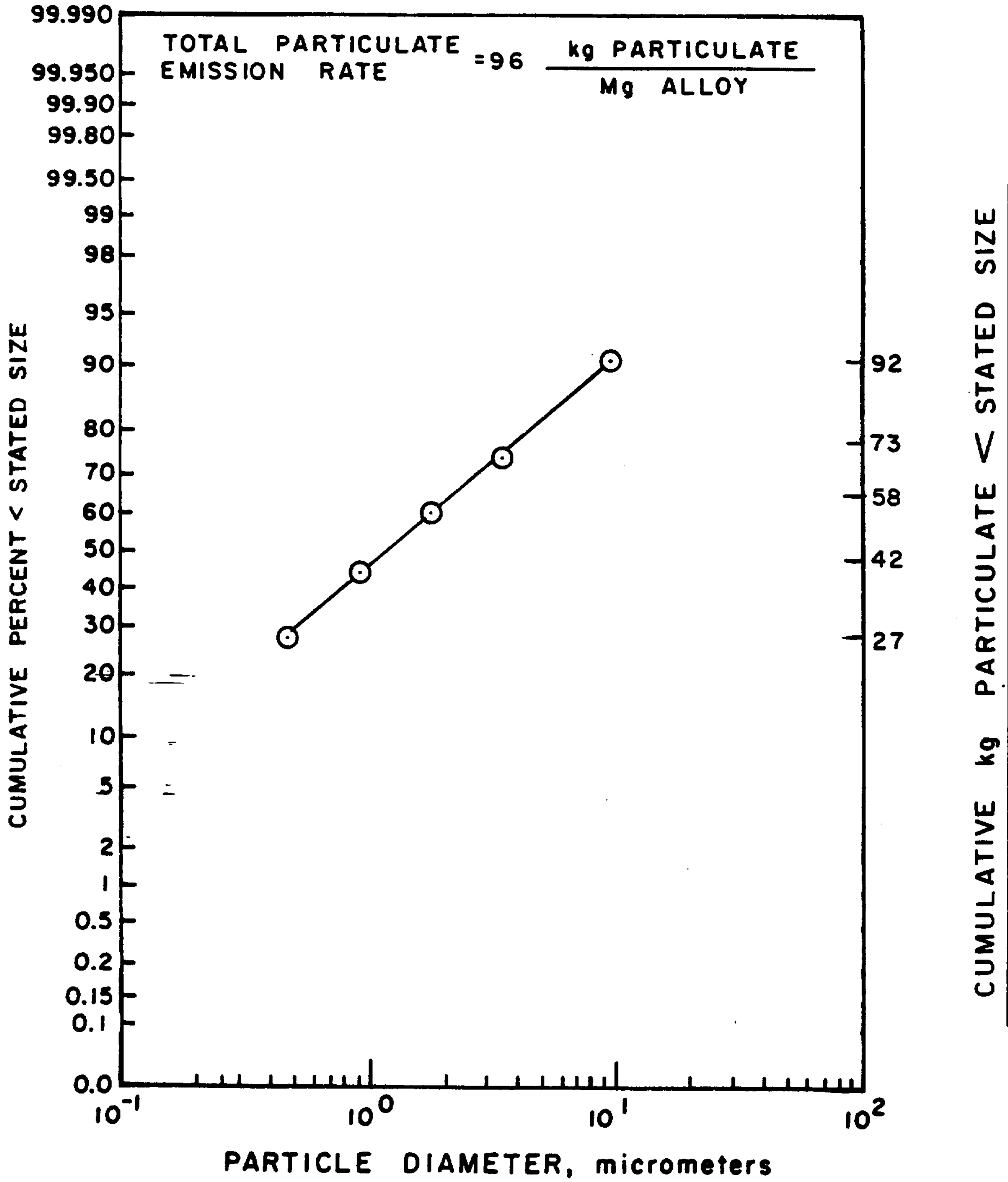

Figure 14. Uncontrolled, SiMn producing, open furnace particle size distribution.

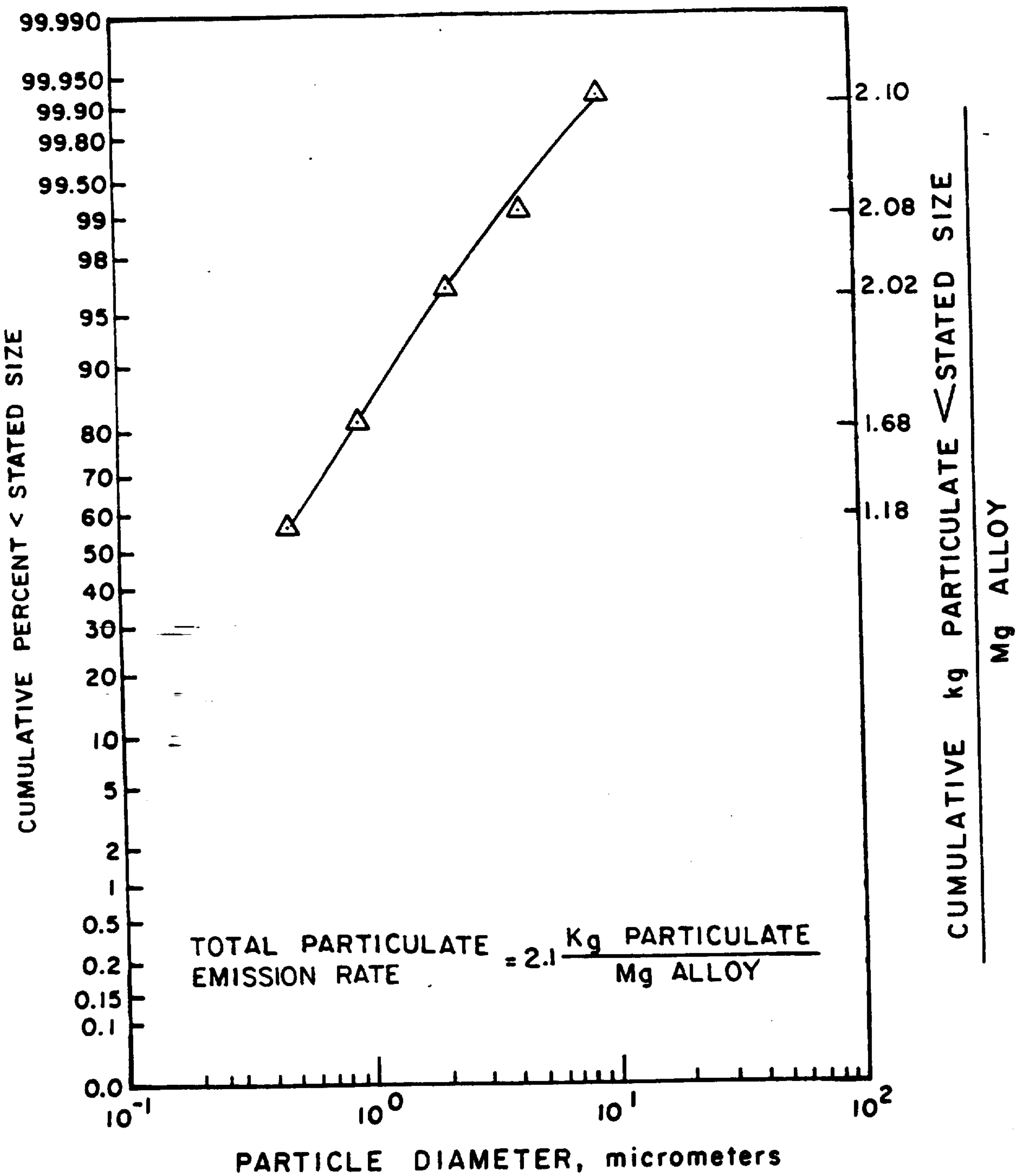

Figure 15. Controlled (scrubber), SiMn producing, open furnace particle size distribution.

TABLE 6. PARTICULATE EMISSION TESTS REVIEWED

Test No.	Product	Furnace type	Control device	Power rating (MW)	Source Reference No.	Uncontrolled: Emission factor (kg/Mg) alloy	Uncontrolled: kg/MW-hr	Uncontrolled: Rating (A-D)	Uncontrolled: Particle size data and rating	Controlled: Emission factor (kg/Mg) alloy	Controlled: kg/MW-hr	Controlled: Rating (A-D)	Controlled: Particle size data and rating
1	FeSi 50%	Open	Baghouse	35	7, 8	35	7.4	A	Yes, A	0.9	0.20	A	Yes, A
2	FeSi 50%	Open	Scrubber	48	4	49	9.7	C	No				
3	FeSi 50%	Covered	Scrubber	45	8	32	7.1	C	No	0.25[a]	0.055	D	No
4	FeSi 50%	Covered	High energy rubber	48	4	46[a,b]	9.3	D	No	0.23[a]	0.047	D	No
5	FeSi 50%	Covered	Low energy scrubber	17	4	69[a,b]	11	D	No	4.5[a]	0.77	D	No
6	FeSi 75%	Covered	Scrubber	17	4	103[a]	13	D	No	4.0[a]	0.50	D	No
7	Si Metal 98%	Open	Baghouse	17	8, 10	436	33	A	Yes, A	16	1.2	A	Yes, A
8	FeMn 80%	Open	Baghouse	10 ea.	8, 9	14	4.8	A	Yes, A	0.24	0.078	A	Yes, A
9	FeMn 80%	Open	High energy scrubber	16	4	49	11	D	No	0.8	0.34	C	No
10	FeMn 80%	Covered	Scrubber	8	4	6[a]	2.4	C	No	0.16[a]	0.07	D	No
11	FeMn 80%	Covered	Scrubber	11	8	10	4.1	C	No	0.25[c]	0.10	B	No
12	FeMn 80%	Sealed		7	11	37	17	D	No				
13	FeCr (HC)	Open	ESP	37	12, 14	81	14.5	B	No	1.1	0.19	B	No
14	FeCr (HC)	Open	ESP	35	13	75	16	B	Yes, C	1.2	0.27	B	Yes, B
15	FeCr (HC)	Open		10	16	84	10	C	No				
16	SiMn	Open	Scrubber	7	15	69	14	B	No	3.2	0.67	B	No
17	SiMn	Open	Scrubber -	27	17	123	25	B	Yes, B	1.1[d]	0.21	B	Yes, B
18	SiMn	Sealed	High energy scrubber	22	11					0.06	0.016	C	No

[a]Primary emission control system tested only.

[b]Not used in category EF calculation because secondary emissions not included.

[c]Emission factor if uncontrolled tapping and fugitive emissions are included = 2.0 kg/Mg. 0.78 kg/MW-hr.

[d]Emission factor if uncontrolled tapping emissions are included = 4.2 kg/Mg, 0.98 kg/MW-hr.

TABLE 7. SULFUR DIOXIDE, CARBON MONOXIDE AND ORGANICS EMISSION TESTS REVIEWED

Test No.	Product	Furnace type	Control device	Power rating (MW)	Source Reference No.	SO_2 lb/ton alloy	Rating (A-D)	CO lb/ton alloy	Rating (A-D)	Organics Uncontrolled lb/ton alloy	Organics Controlled lb/ton alloy	Rating (A-D)
1	FeSi 50%	Open	Baghouse	35	7, 8					6.4[a]	4.4[a]	C
2	FeSi 50%	Open	Scrubber	48	4					2.5[b]		D
3	FeSi 50%	Covered	Scrubber	45	8					15.0[a]	0.61[c]	C
4	FeSi 50%	Covered	High energy scrubber	48	4			2180[b]	D	15.8[b]	0.52[b]	D
5	FeSi 50%	Covered	Low energy scrubber	17	4					7.3[b]	1.5[b]	D
6	FeSi 75%	Covered	Scrubber	17	4			3230[b]	D	20.5[b]	4.8[b]	D
7	Si Metal 98%	Open	Baghouse	17	8, 10					71.8[d]	51.6[d]	C
8	FeMn 80%	Open	Baghouse	10	8, 9					10.6[b]	3.72[b]	C
9	FeMn 80%	Open	High energy scrubber	16	4					1.64[b]	1.36[b]	D
10	FeMn 80%	Covered[d]	Scrubber	8	4			45[e]	D	0.30[b,e]	0.14[b,e]	D
11	FeMn 80%	Covered	Scrubber	11	8					1.38[b]	0.80[b]	C
12	FeMn 80%	Sealed		7	11	0.013[b]	D					
13	FeCr (HC)[f]	Open	ESP	37	12, 14	1.4[g,a]	C					
15	FeCr (HC)[f]	Open	None	10	16	9.3[a]	C					
17	SiMn	Open	Scrubber	27	17	0.070[h,i]	C					
18	SiMn	Sealed	High energy scrubber	22	11	0.021[d]	D	1690[b]	D		0.09[b]	D

[a]Includes tapping emissions.

[b]Primary emission control system tested only, does not include tapping or leak emissions.

[c]Additional emission factor for uncontrolled secondary emissions = 4.26 lb/ton.

[d]Primary hood estimated to capture 60% of tapping emissions.

[e]Mix seal furnace has holes in cover to allow combustion air to enter and burn hot gas.

[f]High carbon.

[g]ESP outlet.

[h]Emissions at outlet of scrubber.

[i]Additional emission factor for uncontrolled tapping emissions = 0.072 lb/ton.

TABLE 8. SULFUR DIOXIDE, CARBON MONOXIDE AND VOC EMISSION FACTOR TABLE[a]

Product	Furnace type	SO_2[b] lb/ton	CO[c] lb/ton	VOC[d] Uncontrolled kg/Mg alloy	VOC[d] Uncontrolled (lb/ton) alloy	VOC Controlled[e] Control device	VOC Controlled[e] kg/Mg alloy	VOC Controlled[e] (lb/ton) alloy
FeSi - 50%	Open			2.25[f]	(4.5)[f]	Baghouse	2.2	(4.4)
	Covered		2180[f]	6.35[f]	(12.7)[f]	Scrubber -- High energy	0.28	(0.56)
						Scrubber -- Low energy	0.75	(1.5)
FeSi - 75%	Covered		3230[f]	10.25[f]	(20.5)	Scrubber	2.4	(4.8)
Si Metal 98%	Open			35.90[f]	(71.8)[f]	Baghouse	25.9	(51.6)
FeMn - 80%	Open			3.05[f]	(6.1)[f]	Baghouse	1.85	(3.7)
						Scrubber -- High energy	0.70	(1.4)
	Covered Sealed	0.009		0.70[f]	(1.4)[f]	Scrubber	0.40	(0.8)
FeCr (HC)	Open	5.48				ESP		
SiMn	Open	0.070[f,h]				Scrubber		
	Sealed	0.021[f]	1690[f]			Scrubber High energy	0.05	(0.10)

[a]All emission factors are rated D.

[b]SO_2 emission will depend on amount of sulfur in the feed materials.

[c]CO emissions are measured before control by flare. CO emissions from open furnaces are low. The quantity of emissions from covered furnaces will vary with the volume of air drawn into the cover. Excess air will reduce CO emissions.

[d]Organic emissions may increase if dirty scrap iron or steel is feed to the furnace.

[e]Controlled emissions are measured before any flare in the control system.

[f]Does not include seal leaks or tapping emissions; hoods on open furnace may capture part of tapping emissions.

[g]Includes tapping emissions.

[h]Emission factor for tapping emissions.

The data review process was conducted on primary data sources describing 17 tests of uncontrolled emissions, and 15 tests of controlled emissions.. The data contained in each test report were used to develop an emission factor specific to that test site. Of the 17 uncontrolled data sources, three were rated A, four were rated B, three were rated C and seven were rated D. Of the 15 controlled data sources, three were rated A, five were rated B, two were rated C, and five were rated D. The data sources were they grouped by product, furnace type, and control device. Source specific emission factors were then calculated and rated.

The ratings assigned to the emission factors reflects the ratings of the data used to develop that emission factor. An A through E scale, as defined earlier, was used to indicate the reliability of each emission factor. A brief summary of the relevant details of each test and the basis for the assigned rating follows.

One source[30] listed in FPEIS was the Chromasco, Woodstock, TN facility. These data were the result of efficiency testing performed on a two phase jet scrubber. The original report was obtained on microfiche. The report lacked information necessary for the calculation and verification of emission factors. Some data concerning production rates and emissions appeared to be very different from the range of expected values based on data from other FeCr producing facilities, therefore none of the data contained in the report were used in the compilation of emission factors.

Fifty Percent FeSi: Open Furnaces

Test Number 1 was performed in March 1980 at the Foote Mineral Co., Graham, WV facility.[7,8] The Number 2 furnace was tested while producing 50 percent FeSi and was observed to operate at 32 MW (design = 35 MW) during the test period. The emission control system included a tapping hood which was judged to be almost 100 percent effective, thus the emission factor is reported to include tapping emissions. The test location at the inlet to the baghouse was located more than 8 diameters downstream of a flow disturbance. Five Method 5, and 17 Andersen cascade impactor runs were performed on the inlet and averaged to determine the reported uncontrolled emission factor. Three Method 5 and nine Andersen Impactor runs were performed on the baghouse outlet. The baghouse outlet sampling was single-point and superisokinetic due to very low flow rates. This is not considered a major problem due to the small particles present in the baghouse outlet stream. Detailed process data were obtained during the test and adequately reported. The tests were conducted according to EPA's inhalable particulate test protocol only during the range of normal furnace operation. No serious problems were uncovered in the review of the reports. This test report was given an A rating.

Test Number 2 was performed at the Union Carbide Corp. (now Elkem Metals), Ashtabula OH plant during April 1979.[4] A 52 MW open furnace was tested. The furnace emission control system did not collect tapping fumes. The test consisted of one test run of 135-minute duration using the Source Assessment Sampling System (SASS). This high volume total particulate sampler, used in Level 1 assessments, was run at the inlet to the control device. Detailed process documentation was not provided. The SASS test method is a generally accepted emission quantification procedure for research type programs, however it is of lower accuracy than Method 5. For this reason the test report was rated C.

Fifty Percent FeSi: Mix-Sealed Covered Furnaces

Test Number 3 was performed at Union Carbide Corp. (now Elkem Metals), Ashtabula, OH plant in November 1980.[8] The emission control system consisted of a scrubber which collected primary emissions by evacuating the covered furnace. A secondary hood, ducted to a baghouse, controlled tapping fumes and fumes escaping the mix seals. The two emission control systems were tested in order to determine the total emissions generated by the furnace. However, the scrubber and baghouse were not tested simultaneously. The test program consisted of three, single point Method 5 runs on the scrubber outlet, two impactor runs on the baghouse inlet. An analysis of scrubber influent and effluent solids was made concurrent with the test runs to determine particulate captured by the scrubber. Six Method 5 runs were performed on the baghouse inlet and three on the outlet. The test results, were averaged, summed and reported as total uncontrolled furnace emissions. Samples for the scrubber solids determination were collected using an automatic composite sampler. Effluent flow rate was determined from overflow weir calculations.

Developing uncontrolled particulate emission factors from scrubber water solids determinations is not a reliable method since other species, such as condensible organic compounds, may be included. Single point testing in a scrubber outlet, where cyclonic flow and other effects reduce the reliability of the data, is also not considered acceptable. However, the combined methods do provide an order of magnitude estimate. The outlet test results represent a much smaller mass of particulate than that reported for the scrubber inlet or secondary emissions captured. The total particulate emission factor thus determined was rated C. The controlled furnace emission factor was calculated from the scrubber outlet data only. The secondary control system handles approximately 10 percent of the uncontrolled emission, however the baghouse outlet emissions were not incorporated into the controlled emission factor because of low baghouse efficiency at the time of the test. The results for controlled primary emissions were also rated C.

Two Andersen impactor runs were made at the inlet to the baghouse. One was performed during tapping and another during a period when no tapping was occurring. Very little information was provided describing particle sizing procedures used in the field or in the subsequent analysis of the data. The particle sizing data obtained were judged unacceptable for development of emission factors because only two runs were made at the secondary emission control system baghouse outlet.

Test Number 4 was performed at the Union Carbide Corp. (now Elkem Metals), Ashtabula, OH plant in April 1979.[4] The 48 MW mix-sealed furnace was sampled with one SASS (Source Assessment Sampling System, a high-volume total particulate sampler used in Level 1 assessments) run. The sample was taken at the gas main bypass stack which was reported to carry 20 percent of the primary emissions exhaust flow after control by dual high energy scrubbers.

Secondary emissions were not measured. During the SASS run, three samples of scrubber influent and effluent water were taken in order to perform a mass balance calculation of particulate collected by the scrubber. Insufficiencies found while reviewing the test included the lack of information describing the test and the process operation during testing. For example, no flow measurements were taken of either the scrubber gas or water discharge rates. Because of these problems, the test report was rated D.

Test Number 5 was conducted at Union Carbide Corp. (now Elkem Metals), Sheffield, AL plant during June 1979.[4] The furnace primary emissions were controlled by dual parallel scrubbers and fugitive emissions collected by a hood and ducted to a baghouse. Testing was performed only on the outlet of one scrubber. Flow and emissions from the other scrubber were assumed to be identical for the purpose of calculating total emissions. One SASS run was performed on the outlet of the scrubber. During the 139-minute test, three samples of scrubber effluent were taken and composited in order to determine solids caught in the scrubber by mass balance calculation. The report did not detail how the scrubber flow rate was determined. Due to this consideration, along with the fact that only one of the two scrubbers was tested a single time by the SASS methodology, which is not highly accurate, the test report was rated D.

Seventy-Five Percent FeSi Covered, Mix Seal Furnace

Test Number 6 was also performed at the Union Carbide Corp. (now Elkem Metals) Sheffield, AL plant during June 1979.[4] The 17 MW furnace tested was controlled by a system similar to that described in the preceding paragraph describing test Number 5. The same test methodology was also used and for similar reasons the test report was also rated D.

Silicon Metal Open Furnace

Test Number 7 was performed at the Interlake Inc. Plant in Selma, AL during January 1981.[8,10] The hood which collected emissions from the open, 17 MW furnace was estimated to also capture 60 percent of the tapping fume. The test program consisted of six Method 5 runs during which 13 Andersen impactor runs were made at the inlet to the baghouse. Five Method 5 runs were made concurrent with nine Andersen Impactor runs on the baghouse outlet. The outlet runs were hyperisokinetic because of very low velocities in the baghouse. The reports contained complete descriptions of test procedures and process data. No significant problems were evident in the review of the test reports, therefore an A rating was assigned.

FeMn Open Furnace

Test Number 8 was conducted at the Roane Limited, Rockwood, TN plant in February 1981.[8,9] The test program consisted of six Method 5 runs at the baghouse inlet during which 16 Andersen impactor runs were completed. Concurrently, four Method 5 runs and 16 Andersen impactor runs were performed on the baghouse outlet. Testing was performed on the emission control system that was common to both furnaces 3 and 4. The canopy hoods were reported to collect less than 50 percent of tapping fumes; however, emissions from tapping were also reported to be light. Testing was performed only during periods when both 10 MW furnaces were operating simultaneously under normal conditions. The test reports reviewed presented process data and test procedures in adequate detail. The only problems apparent from the review of the reports were that the isokinetics on the Method 5 sampling were low, averaging 90 percent, and the outlet sampling was hyperisokinetic because of low velocities in the baghouse. The test report was rated A.

Test Number 9 was conducted at the Union Carbide Corp. (now Elkem Metals), Marietta, OH plant in April 1979.[4] The 16 MW furnace emission control system did not collect tapping fumes. Uncontrolled emissions were determined by adding scrubber outlet emissions with scrubber solids catch. One 117-minute SASS run was performed on the scrubber outlet, during which three scrubber effluent water samples were taken and composited to determine solids catch. Very little process data were reported and there was no description of how the scrubber water feed rate was determined. For these reasons and because only a single SASS test was performed, the uncontrolled emissions test results as reported, were rated D. The controlled emissions data were determined directly from testing and were therefore rated C.

FeMn Covered Furnace, Mix Sealed

Test Number 10 was also performed at the Union Carbide Corp. (now Elkem Metals), Marietta, OH plant (test 11 was also performed at this plant), in April 1979.[4] The test consisted of one SASS run lasting 67 minutes on the scrubber outlet concurrent with effluent water sampling to determine the particulate caught by the scrubber. The scrubber water flow rate was not measured, but was estimated by plant personnel. Emissions from tapping and mix seal leaks were significant and were not quantified. Process data describing operating conditions during the test were not carefully documented and reported. The test results for each controlled and uncontrolled emissions were rated D.

Test Number 11 was performed at the Marietta, OH plant of Union Carbide Corp. (now Elkem Metals) in March 1981.[8] The subject furnace was rated at 8 MW. A scrubber controlled the furnace emissions. Fumes from tapping and mix seal leaks were captured by a secondary hood and exhausted uncontrolled from the building through four stacks. The scrubber outlet and the four secondary hood stacks were tested for a total of five Method 5 runs. Scrubber effluent was automatically composited during the test and analyzed for solids content. Scrubber water feed rate was determined by overflow weir calculations. Each run consisted of a Method 5 run on the scrubber outlet simultaneous with one of the four secondary stacks. The secondary stacks were not all tested. Flow rates on two of the three untested stacks were measured during the test runs. For purposes of total emissions calculations, the particulate concentration for each of the four stacks was assumed to be the same. Approximately two-thirds of the total emissions as measured were captured by the scrubber and one-third were emitted from the four secondary stacks. Process data were taken during the test and reported in detail; the furnace was operating within what is considered the normal range of conditions during the test. The reported test results were rated C. This rating was chosen because the secondary stacks were not tested simultaneously, and measuring solids in scrubber liquor is not an accurate method for determining uncontrolled emissions. The controlled emission factor for the primary emissions was rated B.

FeMn Sealed Furnace

Test Number 12 was conducted at the Union Carbide Corp. Ltd., Canada plant in Beauharnois, Quebec during August 1977.[11] One SASS run was performed at the control system bypass stack. The test was reported with very little detail concerning test and process conditions. The test was run for only 20 minutes and isokinetics were 298 percent. The test was rated D due to its short duration, poor isokinetics, low accuracy of test method, and poor documentation.

FeCr Open Furnace

Test Number 13 was performed at the Airco Alloys and Carbide (now Macalloy Corp.), Charleston, SC plant in June 1978.[12,14] Six Method 5 runs were conducted at both the inlet and outlet to the control device. The capture efficiency of the hood was varied for each run by changing the inlet opening on the ID fan. The data utilized herein was for the run with the largest ID fan opening. These data compare well with the data for Test Number 14. Emissions from tapping were reported to be included in the total particulate results. The test report lacked data describing the test procedures and furnace operating parameters at the time of the test. Supplemental information necessary to calculate emission factors was obtained from plant personnel and estimated using Reference 3. The source emission factor was calculated two ways using information from the above two sources. The resulting emission factors varied by 22 percent. The average of these two methods of calculation was reported in Table 4. The emission factors were assigned a rating of B due to the lack of descriptive process data in the test report.

Test Number 14 was conducted in September 1971 at the same Airco Alloys (now Macalloy Corp.) furnace described above as Test Number 13.[13] The testing consisted of three separate Method 5 runs, each consisting of two trains operated simultaneously at the two inlet ducts. The Method 5 runs were each 100 minutes long. The sampling location was in an expanding section of a rectangular duct. The duct was divided into 25 equal areas for sampling. Controlled emissions were measured at the ESP outlet with three Method 5 tests. Process information was provided indicating that the 35 MW furnace was operating within the range of normal conditions. The canopy hood was reported to effectively capture tapping emissions. It was necessary to use information from Reference 3 relating energy input to alloy production in order to calculate an emission factor based on process production rate. The total particulate emission factor thus determined was rated B. Also conducted were six Brinks impactor runs to measure particle size distribution of the fumes at the inlet and at the outlet to the control device. Flow and volume were determined by pressure drop across a calibrated orifice, not by a dry gas meter. The major problem with the inlet impactor tests was that they were conducted at an expanding section of duct work, which is not ideal. Because of inertial effects of the flow irregularity, the particle size data may be biased. The results thus determined were rated C. The outlet test results were rated B.

Test Number 15 was conducted at the Foote Mineral Corp., Vancoram Operations in Steubenville, OH in May 1971.[16] Testing was done using two different sample methods for total particulate, the OAP method, which is essentially Method 5, and the ASME method which consists of an instack alundum thimble. Due to process abnormalities during some of the tests, only two of the four OAP runs and the two ASME runs were averaged in calculating the emission factor. Only one of two exhaust stacks were tested; emissions from the untested stack were assumed to equal the tested stack. Process data necessary for the calculation of emission factors were not contained in the report and the information needed was assumed using References 3 and 5. The emission factor thus calculated was rated C due to the lack of firsthand reporting of some significant process variables. Three Brinks impactor runs were made during the testing to determine the fume particle size distribution. The test report did not contain significant amounts of descriptive information concerning the size distribution testing. The results were rated C. The calculation of the emission factor is not included in the emission factor example calculation section because it is quality rated less than two other tests and was not included in the calculation of the FeCr emission factor.

SiMn Open Furnaces

Test Number 16 describes the sampling performed at the Chromium Mining and Smelting Corp., Woodstock, TN plant in February 1972.[15] Three Method 5 runs were performed at both the inlet and the outlet to the scrubber. The process was reported to operate normally during the testing. The report did not present data on production rate during testing necessary for the calculation of emission factors. This data was obtained from Reference 3 and the emission factors thereby calculated were rated B.

Test Number 17 was conducted at the Union Carbide Corp. (now Elkem Metals), Marietta, OH plant in August 1971.[17] Primary fumes from furnace Number 1 were sampled in the ductwork prior to the scrubber. Tapping fumes were captured by a separate hood and exhausted directly to the atmosphere through a stack. Nine Method 5 type runs were conducted on the scrubber inlet, seven on the outlet. Six runs were conducted on the two tapping stacks. The report failed to present production data necessary to calculate the emission factor. Data were therefore obtained from Reference 3. Twelve Brinks impactor runs were conducted to measure uncontrolled emissions during the test program, eight on the inlet to the dust collector and four on the tapping stacks. Eight impactor runs were also performed on the scrubber outlet. The report did not provide detailed background information concerning the size distribution tests and analysis. The lack of process and background information resulted in a B rating for both the total particulate and size distribution data.

SiMn Sealed Furnace

Test No. 18 was performed on a sealed SiMn (67 percent) furnace at Union Carbide Corp. in Beauharnais, Quebec.[11] One SASS run was performed at the outlet of the scrubber controlling gases evacuated from the furnace. Secondary emissions were not controlled by the scrubber. Because only one run was performed and there was a lack of important process data, the test results were rated C.

EMISSION FACTOR RATINGS

The emission factor chosen to represent each source category has been ranked according to the following criteria

- A = Excellent--Developed from A-rated test data taken from many randomly chosen facilities in the industry population. The source category is specific enough to minimize variability within the source category population.

- B = Above Average--Developed only from A-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industries. As in the A rating, the source category is specific enough to minimize variability within the source category population.

- C = Average--Developed only from A- and B-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As in the A rating, the source category is specific enough to minimize variability within the source category population.

- D = Below Average--The emission factor was developed only from A- and B-rated test data from a small number of facilities, and there may be reason to suspect that these facilities do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of the emission factor are footnoted in the emission factor table.

- E = Poor--The emission factor was developed from C- and D-rated test data, and there may be reason to suspect that the facilities tested do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of these factors are always footnoted.

Uncontrolled Emissions

The A through E rating criteria for emissions factors are different than the A through D ratings for the test data.

The ferroalloy industry was divided into specific categories for the purpose of developing and presenting emission factors. The total number of furnaces in the industry is 77 as shown in Table 9. Seven specific source

category emission factors were developed from different test series. Viewed in this manner, a sample size of 11 out of a population of 77 is reasonable. The product categories presented previously in Table 4 are specific enough to minimize variability within the source category population. There is no apparent reason to suspect that the facilities tested form a biased sample set.

TABLE 9. FURNACES IN THE UNITED STATES VERSUS FURNACES TESTED AND INCLUDED IN EMISSION FACTOR TABLE[5]

		Furnaces in U.S.[15]		Emission factor developed from	
Product	Furnace type	Number	Avg. size (MW)	Number of furnaces	Size of furnaces (MW)
FeSi	Open	23	25	1	35
	Closed	3	26	1	45
Si Metal	Open	22	17	1	17
FeMn	Open	7	10	2	10, 10
	Closed	6	8	1	8
	Sealed	-	-	1	7
FeCr	Open	8	17	2	36
SiMn	Open	8	15	2	7, 27
Total/Average		77	21	11	

The particulate emission factors for source categories Si metal, 50 percent FeSi, and FeMn open furnaces were rated B (above average) on the A-E scale because they were each developed from a single A rated test series consisting of several runs. The FeMn test was performed on two furnaces operating simultaneously. A single test series was considered a reasonable sample size considering the source category population.

The emission factor for 50 percent FeSi covered furnaces was developed from one C and two D rated test series; all of which used measured scrubber particulate catch in determining uncontrolled emissions. One test included fugitive emissions, however the emission factor for that test is lower than the tests which did not include fugitives. The uncontrolled emission factor is rated E (poor).

The particulate emission factors for FeMn covered furnaces were also developed from a single test series. These tests were rated C due to the use of scrubber water data therefore the assigned emission factor was rated E (poor). The factors for FeCr and SiMn were each developed from two test series. The data from these test series were rated B so the assigned emission factor rating is C (average).

The emission factors for 75 percent FeSi covered furnaces and FeMn sealed furnaces were developed from D quality data since no better data were available. Accordingly, the emission factors are expected to provide only an order of magnitude estimate and are rated E (poor).

The particle size distribution data were assigned an emission factor quality rating using the same criteria as for the particulate data. The size data for FeSi, FeMn and Si metal were obtained during the same test programs as the data used to develop the total particulate emission factors for the same categories. The size distribution and total particulate data were both quality rated A on the A through D scale. The size specific emission factors similar to the total particulate emission factors have been assigned a B (above average) rating on the A through E emission factor scale as only a reasonable number of facilities were tested, not a large number as required for an A rating.

The size distribution data for the FeCr and SiMn categories were each developed from impactor data obtained during one of the two test series used to develop the associated total particulate emission factor. The size data for the FeCr category was rated C on the A-D data qualilty scale and the total particulate emission data were rated B. Size specific emission factors for FeCr are therefore rated E (poor) on the A-E emission factor rating scale. The size data and the total particulate data for the SiMn category are both rated B on the A-D data quality scale. The size specific emission factors have therefore been assigned a C rating (average) on the A-E emission factor rating scale. This is the same rating as applied to the total particulate emission factor.

Controlled Emissions

The total particulate emission factor for the categories FeSi-50 percent, open furnace, baghouse controlled, Si metal, open furnace, baghouse controlled and FeMn-80 percent open furnace, baghouse controlled were each developed from a single A rated test series. The total particulate emission factor was rated B on the A-E emission factor scale. The size distribution data for these three categories developed from the same test programs were also rated B on the A-E scale.

The FeMn-80 percent, covered furnace, scrubber controlled category emission factor was developed from a single B-rated test series, therefore the emission factor is rated C on the A-E emission factor scale.

The FeSi-50 percent, covered furnace, high energy scrubber controlled category emission factor was developed from the average of two tests rated C and D. The emission factor was therefore rated E (poor) on the A-E rating scale. The FeSi-50 percent, covered furnace, low energy scrubber controlled, FeSi-75 percent covered furnace, scrubber controlled, FeMn-80 percent, open furnace, high energy scrubber controlled and SiMn sealed furnace, scrubber controlled category emission factors were developed from a single C or D-rated test series and were therefore also assigned an E (poor) emission factor rating.

The FeCr, open furnace, ESP controlled and SiMn open furnace, scrubber controlled category emission factors were each developed from the average of two B-rated test series. The size distribution data for each of these categories was developed from a single B-rated test series. The total particulate and size specific emission factors for these two categories were each rated C on the A-E emission factor scale.

EMISSION FACTOR CALCULATIONS

When more than one set of test data were available for a given source category and the data were of the same quality rating (see Table 6), the emission factors were averaged to determine the source category emission factor. In cases where emission factors of different quality ratings were available, only data of the higher quality rating were used. In most of the test reports used to compile the source category emission factors, the desired emission factor, in terms of mass of emission per alloy production unit, was calculated by the author and presented in the subject test report.

In cases where the provided information was not in the form of the desired emission factor, it was necessary to calculate it. This involved combining data from both the report and other sources with appropriate assumptions. The emission factors for all but two of the nine categories contained in Table 4 were developed from a single test for which no assumptions or manipulation of the data were necessary.

The emission factors for two categories, FeCr and SiMn, are both calculated from results of two tests which had to be manipulated in order to get them into the required emission factor units. The sources of information, assumptions and calculations associated with those emission factors are detailed in the following paragraphs. Similar calculations were also made for some of the emission factors presented in Table 4; however, not all of these are documented here. In cases where assumptions were made to calculate an emission factor in Table 6, and the data were subsequently quality ranked lower than another data source for the same category, (therefore, not being incorporated into the Ferroalloy Emission Factor Tables 4 and 5) the calculations are not described below.

Example Particulate Emission Factor Calculations

Two methods were used to obtain emissions factors presented in the tables. Method 1 requires that the emission rates in lb/hour and production rates in tons/hour be known. Method 2 requires that following data: emission rates in lb/hour, furnace load in MW-hr and the industry average or unit specific energy consumption, MW-hr per ton of alloy produced for each type ferroalloy produced. The industry average energy consumption was obtained from references 3.

Method 1:

$$\text{Emission factors} = \frac{\text{lb pollutant emitted/hr}}{\text{tons alloy produced/hr}} = \frac{\text{lb pollutant emitted}}{\text{tons alloy produced}}$$

Method 2:

$$\text{Emission factor} = \frac{\text{lb pollutant emitted/hr}}{\text{energy consumption MW-hr}} \times \frac{\text{MW-hr consummed}}{\text{tons alloy produced}}$$

Facility and pollutant specific examples are presented below.

Particulate Emission Factor: Ferrochrome production

1. Test No. 13 performed at Airco Alloys, Charleston, SC (now Macalloy Corp.) in June 1978.[12]

- data from test report:

  average uncontrolled emission rate = 1134 lb/hr
  average furnace load = 35.4 MW
  average controlled emission rate = 15 lb/hr

- data from Reference 14:

  average furnace process rate = 6 ton alloy/hr

- assumption: that during the test period the furnace produced approximately 6 tons of alloy per hour:

- data from reference 3 for (HC) FeCr production industry average MW-hr/ton product = 4.2

Uncontrolled Emission Factor

Method 1:

$$\text{Uncontrolled EF}_1 = \frac{\text{1134 lb particulate/hour}}{\text{6 ton alloy/hr}} = \frac{\text{189 lb particulate}}{\text{ton alloy}}$$

(EF = emission factor)

Method 2:

$$\text{Uncontrolled EF}_2 = \frac{\text{1134 lb particulate}}{\text{35.4 MW-hr}} \times \frac{\text{4.2 MW-hr}}{\text{ton alloy product}} = \frac{\text{135 lb particulate}}{\text{ton alloy}}$$

The average

$$\frac{189 + 135}{2} = \frac{162 \text{ lb particulate}}{\text{ton alloy}} = \frac{81 \text{ kg particulate}}{\text{Mg alloy produced}}$$

Controlled Emission Factor

- A similar calculation with the controlled emission rate of 15 lb/hr yields an EF of 2.1 lb/ton alloy = 1.1 kg/Mg alloy.

2. Test Number 14 - test performed in September 1971 at the same Airco (now Macalloy Corp.) facility as the previous test.[13]

- data from test report:

  average uncontrolled emission rate = 1293 lb/hr
  average furnace load = 36 MW
  average controlled emission rate = 21 lb/hr

- data from Reference 3 for (HC) FeCr production industry average MW-hr/ton product = 4.2

Emission factor calculated by Method 2.

- Uncontrolled emission factor

$$\text{Uncontrolled EF } \frac{1293 \text{ lb particulate}}{36 \text{ MW-hr}} \times \frac{4.2 \text{ MW-hr}}{\text{ton alloy produced}}$$

$$\text{Uncontrolled EF} = 151 \frac{\text{lb particulate}}{\text{ton alloy}} = 75 \frac{\text{kg particulate}}{\text{Mg alloy}}$$

- A similar calculation with the controlled emission rate of 21 lb/hr yields an Ef of 2.5 lb/ton alloy = 1.3 kg/Mg alloy.

The particulate emission factors for FeCr production was taken as the average for the above tests:

$$\text{Uncontrolled EF}_{FeCr} = \frac{151 + 162}{2} = 156.5 \frac{\text{lb particulate}}{\text{ton alloy}} = 78 \frac{\text{kg particulate}}{\text{Mg alloy}}$$

- $$\text{Controlled EF}_{FeCr} = \frac{2.1 + 2.5}{2} = 2.3 \frac{\text{lb particulate}}{\text{ton alloy}}$$

$$\text{Controlled EF}_{FeCr} = 1.2 \frac{\text{kg particulate}}{\text{Mg alloy}}$$

Particulate Emission Factor SiMn Production

3. Test Number 16 - performed at CROMASCO's Woodstock, TN plant in February 1972.[15]

- data from test report:

  average uncontrolled emission rate = 226 lb particulate/hr
  average furnace load = 7.2 MW
  average controlled emission rate = 10.6 particulate/hr

- data from Reference 3: for SiMn production

  industry average MW-hr/ton product = 4.4

$$\text{Uncontrolled EF} = \frac{226 \text{ lb particulate}}{7.2 \text{ MW-hr}} \times \frac{4.4 \text{ MW-hr}}{\text{ton alloy product}}$$

$$\text{Uncontrolled EF} = \frac{138 \text{ lb particulate}}{\text{ton alloy}} = \frac{69 \text{ kg particulate}}{\text{Mg alloy}}$$

$$\text{Controlled EF} = \frac{10.6 \text{ lb particulate}}{7.2 \text{ MW-hr}} \times \frac{4.4 \text{ MW-hr}}{\text{ton alloy product}}$$

$$\text{Controlled EF} = \frac{6.5 \text{ lb particulate}}{\text{ton alloy}} = \frac{3.2 \text{ kg particulate}}{\text{Mg alloy}}$$

4. Test Number 17 - performed at Union Carbide's (now Elkem Metals) Marietta, OH plant in August 1971.[17]

- data average uncontrolled emission rate = 1391 lb particulate/hr
  average furnace load = 25 MW

  average controlled emission rate = 11.8 lb particulate/hr

- data from Reference 3: for SiMn production industry average MW-hr/ton alloy product = 4.4

$$\text{Uncontrolled EF} = \frac{1391 \text{ lb particulate}}{25 \text{ MW-hr}} \times \frac{4.4 \text{ MW-hr}}{\text{ton alloy product}}$$

$$\text{Uncontrolled EF} = \frac{245 \text{ lb particulate}}{\text{ton alloy}} = \frac{123 \text{ kg particulate}}{\text{Mg alloy}}$$

- Average of uncontrolled emission factors calculated from SiMn tests 16 and 17:

$$\text{Uncontrolled EF}_{\text{SiMn}} = \frac{138 + 245}{2} = \frac{192 \text{ lb particulate}}{\text{ton alloy}}$$

$$\text{Uncontrolled EF}_{\text{SiMn}} = \frac{96 \text{ kg particulate}}{\text{Mg alloy}}$$

- Controlled EF $\frac{11.8 \text{ lb part.}}{25 \text{ MW-hr}} \times \frac{4.4 \text{ MW-hr}}{\text{ton alloy product}}$

  Controlled $\frac{2.1 \text{ lb particulate}}{\text{ton alloy}} = \frac{1.1 \text{ kg part.}}{\text{Mg alloy}}$

- Average of controlled emission factors calculated from SiMn tests 16 and 17:

$$\text{Controlled EF} = \frac{6.5 + 2.1}{2} = 4.3 \frac{\text{lb particulate}}{\text{ton alloy}} = 2.1 \frac{\text{kg particulate}}{\text{Mg alloy}}$$

- Test Number 18--performed at Union Carbide's, Beauharnais, Quebec plant in August 1977.[11]

  Data presented in report for scrubber outlet:

  controlled particulate emissions = 64 mg/m^3
  flow rate exhaust = 1.51. m^3/sec
  furnace load = 22.5 MW-hr
  actual energy product ratio = 1.75 kW-hr/lb alloy = 3.5 MW/ton alloy

Emission Factor Calculating Method 1

$$\text{Emission rate} = 64 \text{ mg/m}^3 \times 1.51 \text{ m}^3\text{/sec} \times 3600 \text{ sec/hr} \times 1 \text{ kg}/10^6 \text{ mg}$$
$$= 0.35 \text{ kg/hr} = 0.77 \text{ lb/hr}$$

$$\text{Controlled EF} = \frac{0.77 \text{ lb/hr}}{22.5 \text{ MW-hr}} \times \frac{3.5 \text{ MW}}{\text{ton alloy}} = 0.12 \text{ lb/ton} = \frac{0.06 \text{ kg}}{\text{Mg alloy}}$$

SO_2 Emission Factor Calculations

1) Test Number 17[17] was performed on an open SiMn furnace at the Union Carbide Corp. plant in Marietta, Ohio in 1971

   Scrubber emissions:

   - data from test report:

     scrubber flow = 115,070 dscfm
     SO_2 concentration = 0.35 ppm
     furnace power = 25 MW-hr

   - From reference 3 for SiMn production industry average MW/ton product = 4.4

$$EF = \frac{0.35 \text{ ppm} \times 64 \frac{\text{lb}}{\text{lb-mole}} \times 115070 \frac{\text{dscf}}{\text{Min}} \times 60 \frac{\text{min}}{\text{hour}} \times 4.4 \frac{\text{MW-hr}}{\text{ton alloy}}}{386 \times 10^6 \frac{\text{dscf}}{\text{lb-mole}} \times 25 \text{ MW-hr}}$$

$EF = 0.070$ lb SO_2/ton alloy

4) Test #12 was performed on a sealed furnace producing FeMn at the Union Carbide plant in Beauharnois, Quebec during August 1977.[11]

- data from test report

  flow rate = 2550 scfm
  concentration of SO_2 and reduced sulfur species = 3.1 ppm
  furnace load = 17.3 MW-hr
  production rate = 8.4 ton/hr.

  assume all reduced sulfur is oxidized to SO_2 at flare.

The emission factor for uncontrolled emissions is:

$$EF = \frac{2550 \frac{\text{scf}}{\text{min}} \times 64 \frac{\text{lb}}{\text{lb-mole}} \times 60 \frac{\text{min}}{\text{hr}} \times 3.1 \times 10^{-6}}{386 \frac{\text{scf}}{\text{lb-mole}} \times 8.4 \frac{\text{ton}}{\text{hr}}} = 0.013 \frac{\text{lb } SO_2}{\text{ton alloy}}$$

5) Test #18 was performed during the production of SiMn in the same furnace as test #12.

- data from report:

  scrubber flow = 3200 scfm
  concentration of SO_2 and reduced sulfur species = 4.17 ppm
  furnace load = 22.5 MW-hr
  production rate = 6.25 ton/hr

  assume all reduced sulfur is oxidized to SO_2 at flare.

The emission factor for scrubber emissions is:

$$EF = \frac{3200 \frac{\text{scf}}{\text{min}} \times 64 \frac{\text{lb}}{\text{lb-mole}} \times 60 \frac{\text{min}}{\text{hr}} \times 4.17 \times 10^{-6}}{386 \frac{\text{scf}}{\text{lb-mole}} \times 6.25 \frac{\text{ton}}{\text{hr}}} = 0.021 \frac{\text{lb } SO_2}{\text{ton alloy}}$$

<u>Example CO Emission Factor Calculations</u>

1) Test #4 was performed on a covered furnace producing 50 percent FeSi at Union Carbide Corp.'s Ashtabula, OH plant in April 1979.[4]

- data from test report:

  scrubber flow = 6144 dscfm
  CO concentration = 24.5%
  production rate = 2.7 Mg/hr = 3.0 ton/hr

$$EF = \frac{6144 \frac{\text{dscf}}{\text{min}} \times 28 \frac{\text{lb}}{\text{lb-mole}} \times 60 \frac{\text{min}}{\text{hr}} \times 0.245}{386 \frac{\text{dscf}}{\text{lb-mole}} \times 3 \frac{\text{ton}}{\text{hr}}} = 2180 \frac{\text{lb CO}}{\text{ton alloy}}$$

2) Test #6 was performed on a covered furnace producing 75 percent FeSi at Union Carbide Corp.'s Sheffield, AL plant in June 1979.[4]

- data from test report

  scrubber flow rate = 5526 dscfm
  CO concentration = 28.2%
  production rate = 1.9 Mg/hr = 2.1 ton/hr.

$$EF = \frac{5526\ \frac{dscf}{min} \times 28\ \frac{lb}{lb\text{-}mole} \times 60\ \frac{min}{hr} \times 0.282}{386\ \frac{dscf}{lb\text{-}mole} \times 2.1\ \frac{ton}{hr}} = 3230\ \frac{lb\ CO}{ton\ alloy}$$

3) Test #10 was performed on a covered furnace producing FeMn. The furnace cover had holes cut in it to allow almost complete combustion. The testing occurred at Union Carbide Corp.'s Marietta, OH plant during April 1979.[4]

- data from test report:

  scrubber flow rate = 9010 dscfm
  CO = 0.60%
  production rate = 4.7 Mg/hr=5.2 ton/hr

$$EF = \frac{9010\ \frac{dscf}{min} \times 28\ \frac{lb}{lb\text{-}mole} \times 60\ \frac{min}{hr} \times 0.006}{386\ \frac{dscf}{lb\text{-}mole} \times 5.2\ \frac{ton}{hr}} = 45\ \frac{lb\ CO}{ton\ alloy}$$

4) Test #18 was performed on a sealed furnace producing SiMn at Union Carbide Corp's plant in Beauharnois, Quebec in August 1977.[11]

- data from test report:

  scrubber flow rate = 3200 scfm
  CO = 76 percent
  production rate = 6.25 ton/hr (see SO_2 examples)

$$EF = \frac{3200\ \frac{scf}{min} \times 28\ \frac{lb}{lb\text{-}mole} \times 60\ \frac{min}{hr} \times 0.76}{386\ \frac{scf}{lb\text{-}mole} \times 6.25\ \frac{ton}{hr}} = 1690\ \frac{lb\ CO}{ton\ alloy}$$

Example Organic Emission Factor Calculations

1) Test #18 was performed on a sealed furnace producing SiMn at Union Carbide Corp.'s plant in Beauharnois, Quebec during August 1977.

- data from test report:

  scrubber flow rate = 3200 scfm = 91 m^3/min
  nonmethane organic compound concentration = 47.6 mg/m^3
  production rate = 6.25 ton/hr = 5.67 Mg/hr (see SO_2 example)

the emission factor for scrubber emissions is:

$$EF = \frac{90 \frac{m^3}{min} \times 60 \frac{min}{hr} \times 47.6 \frac{mg}{m^3} \times \frac{1\ kg}{10^6\ mg}}{5.67\ Mg\ alloy/hr} = 0.046 \frac{kg}{Mg\ alloy}$$

$$= 0.09 \frac{lb}{ton\ alloy}$$

SECTION 4

CHEMICAL CHARACTERIZATION

Ferroalloys are grouped according to their primary elemental constituents. A composition summary of the many ferroalloy products appears in Table 10.[3] The range of typical chemical composition of ores used in ferroalloy production is contained in Table 11.[3]

Emissions generated by ferroalloy submerged arc furnaces include particulate matter, organic material and carbon monoxide. Particulate material is generated by two distinct processes. The most significant type of particulate is fume generated in the reaction zone of the furnace. This fume is of amorphous structure and is generated mostly in the form of submicron particles. Particle size has been reported to be generally smaller than 2 microns, ranging from 0.1 to 1.0 μm with a geometric mean of 0.3 to 0.6 μm, depending on the ferroalloy produced.[24] Although the fume is generated as a submicron particle, agglomeration does occur and the effective particle size may be much larger.[24] The bulk density of ferroalloy fume has been reported to vary from from 4 to 30 lb/ft^3.[24] Chemical analysis of the fume indicates it is composed of oxides of the product ferroalloy with the addition of carbon, imparted by the reducing agent, and oxides of other metals contained in the charge.[19] Table 12 presents typical chemical analyses of ferroalloy furnace fume.[19] References 3 and 8 also contain chemical analysis. The chemical and physical analysis of silica fume collected by a baghouse controlling a silicon metal furnace is presented in Table 13.[19]

The second source of particulate emitted from submerged arc furnaces is fine particles of the raw material feedstock entrained in the furnace reaction gases as they flow up through the mix and escape the furnace. Table 9 can be referred to for the chemical composition of typical feed ores.

The relative proportions of the two different particulates described above will depend on several factors; these include furnace design, electrical operating conditions, conditions of charge, degree and frequency of stoking, fines content of charge, and work practices of the furnace operator.

The submerged arc process utilizes carbon to reduce the silicon and metal oxides in the feedstock. This results in the generation of large amounts of carbon monoxide. In some cases, the carbon monoxide produced exceeds the weight of the corresponding ferroalloy produced.[3] The reactions occurring

TABLE 10. COMPOSITION OF FERROALLOYS[a,b]

Ferroalloy	Elemental composition,[c] % by weight (exclusive of Fe)																	
	Al	B	C	Ca	Cb	Co	Cr	Fe	Mn	Mo	Nb	Ni	Si	Ta	Ti	V	W	Zr
Ferromanganese									78									
Spiegeleisen[d]									16–23									
Silicomanganese									63–66				22–28					
High-carbon (HC) ferromanganese			7						78				1					
Medium-carbon (MC) ferromanganese			1.25–1.50						80–85				1.5					
Low carbon (LC) ferromanganese			0.10–0.75															
Electrolytic manganese									99.9									
Manganese-boron	1	21							75				1					
Standard LC ferrochrome			0.020–0.050				6–73											
Simplex ferrochrome			0.010–0.020				68–72											
Ferrochrome							64–67											
Charge Cr							52–55											
9% C Cr			9				65–68											
HS Cr 50			5.5–6 6				65											
Chromsol FeCr			5.5–6 6				65											
Blocking C Reg.			5				60–67											
High carbon (HC) FeCr			4.5–				67–70											
75% Cr							75						0.5					
73% Cr			0.5				73						1.0					

(continued)

TABLE 10 (continued)

Ferroalloy	Elemental composition,[c] % by weight (exclusive of Fe)																	
	Al	B	C	Ca	Cb	Co	Cr	Fe	Mn	Mo	Nb	Ni	Si	Ta	Ti	V	W	Zr
Ferrochromium																		
36/40							36						40					
40/43							40						43					
Silicon Metal								0.35-1.50										
Ferromolybdenum										50-60								
Vanadium Metal																90		
Chromium Metal							99.8											
9% C Metal			9															
Chromium-carbon			5-10				90-95											
50% Ferrosilicon	0.40												50					
65% Ferrosilicon high purity													65					
75% Ferrosilicon																		
0.5% Ca				0.5									75					
Low Al													75					
85% Ferrosilicon													85					
0.5 Ca				0.5									85					
Low Al													85					
0.5 to 1.5% Ca				0.5-1.5									85					
SMZ									5-7				60-65					5-7
Magnesium ferrosilicon																		
5% Mg													50					
9% Mg													50					
Silvery pigiron													14-22					
Ferrotitanium	2												1		25			
30% Ti	3												4		30			
4.5% Al	4.5												0.5		30			
40% Ti	3														40			
70% Ti	4				5										70			

(continued)

TABLE 10 (continued)

Ferroalloy	Elemental composition,[c] % by weight (exclusive of Fe)																
	Al	B	C	Ca	Cb	Co	Cr	Fe	Mn	Mo	Nb	Ni	Si	Ta	Ti	V	W	Zr
Ferrocolumbium					55-60													
40% Cb	1				40													
60% Cb	1				60								1					
65% Cb	1				65								1	3				
70% Cb	1				70								1.5					
62% Cb	1				62													
Ferrotungsten																		
High purity																	77-83	
Low moly																	76-84	
Ferrovanadium																52-75		
Silicomanganese																		
3% C grade			3						65-68				12-14.5					
2% C grade			2						65-68				15-17.5					
1.5% C grade			1.5						65-68				18-20					
Low C									65-68									
High Mn									73									
Calcium Silicon				30-33				1.5-3.0					60-65					
Aluminum	100																	
Ferroaluminum																		
35% Al	35																	
40% Al	40																	
45% Al	45																	
50% Al	50																	
Ferroaluminum-silicon	50												37					
Cobalt metal						100												

(continued)

TABLE 10 (continued)

Ferroalloy	Elemental composition,[c] % by weight (exclusive of Fe)																	
	Al	B	C	Ca	Cb	Co	Cr	Fe	Mn	Mo	Nb	Ni	Si	Ta	Ti	V	W	Zr
Nickel metal												100						
Ferrotantalum	1										9		1	50				
Zirconium-silicon													50					40

[a]American Society for Testing Materials, STP No. 739, Lampman/Peters, Ed., 216 pages.

[b]American Metal Market, February 3, 1972, reproduced from Reference 3.

[c]C, carbon; Ca, calcium; Cb, columbium; Co, cobalt, Cr, chromium; Al, aluminum; Fe, iron; Mn, manganese; Mo, molybdenum; Nb, niobium; Ni, nickel; Si, silicon; Ti, titanium; V, vanadium; W, tungsten; Zr, zirconium; Ta, tantalum; B, boron.

[d]A European produced ferroalloy containing small amounts of manganese.

TABLE 11. CHEMICAL COMPOSITION OF ORES[3]

Chemical constituent	Manganese ore (%)	Silicon ore (%)	Chromium ore (%)
Mn	43 to 54	-	-
SiO_2	4.15	98.5	1.2
Cr_2O_3	-	-	45 to 53
Fe	1 to 2	-	11
Al_2O_3	1 to 3	-	9.8
MgO	0.1 to 2	-	16.6
BaO	1 to 3	-	-
CaO	1 to 3	-	-
P	0.18	-	-
H_2O	5 to 16	-	-

TABLE 12. TYPICAL FURNACE FUME CHARACTERISTICS[19]

Parameter	Furnace product							
	50% FeSi	SMZ[a]	SiMn[b]	SiMn[b]	FeMn	FeCr (HC)	Chrome ore-lime melt	Mn ore-lime melt[b]
Furnace type	Open	Open	Covered	Covered	Open	Covered	Open	Open
Fume shape	Spherical, sometimes in chains	Spherical, sometimes in chains	Spherical	Spherical	Spherical	Spherical	Spherical and irregular	Spherical and irregular
Fume size, microns								
Maximum	0.75	0.8	0.75	0.75	0.75	1.0	0.50	2.0
Most particles	0.05 to 0.3	0.05 to 0.3	0.2 to 0.4	0.2 to 0.4	0.05 to 0.4	0.1 to 0.4	0.05 to 0.2	0.2 to 0.5
X-ray diffraction								
Primary	All fumes were primarily amorphous							
Trace constituents	FeSi, $FeSi_2$	Fe_3O_4, Fe_2O_3, Quartz, SiC	Mn_3O_4, MnO, Quartz	Quartz, SiMn, Spinel	Mn_3O_4, MnO, Quartz	Spinel, Quartz	Spinel	CaO
Chemical analysis, percent								
SiO_2	63 to 88	61.12	15.68	24.60	25.48	20.96	10.86	3.28
FeO	-	14.08	6.75	4.60	5.96	10.92	7.48	1.22
MgO	-	1.08	1.12	3.78	1.03	15.41	7.43	0.96
CaO	-	1.01	-	1.58	2.24	-	15.06	34.24
MnO	-	6.12	31.35	31.92	33.60	2.84	-	12.34
Al_2O_3	-	2.10	5.55	4.48	8.38	7.12	4.88	1.36
LOI[c]	-	-	23.25	12.04	-	-	13.86	11.92
Total Cr as Cr_2O_3	-	-	-	-	-	29.27[d]	14.69	-
SiC	-	1.82	-	-	-	-	-	-
ZrO_2	-	1.26	-	-	-	-	-	-
PbO	-	-	0.47	-	-	-	-	0.98
Na_2	-	-	-	2.12	-	-	1.70	2.05
BaO	-	-	-	-	-	-	-	1.13
K_2O	-	-	-	-	-	-	-	13.08

[a]Si - 60 to 65%; Mn - 5 to 7%; Zr - 5 to 7%.

[b]Manganese fume analyses in particular are subject to wide variations, depending on the ores used.

[c]LOI is loss on ignition at 1000°C.

[d]Fumes from open furnace contain less chrome oxide.

TABLE 13. TYPICAL PROPERTIES OF SILICA FUME FROM BAG COLLECTOR ON SILICON METAL FURNACE[19]

Parameter	Value
SiO_2, % by weight	94.4-96.1
Fe_2O_3	0.34-0.46
MnO	0.09
Al_2O_3	0.21-0.67
CaO	0.35-0.16
MgO	0.23-0.37
K_2O	0.59
Na_2O	0.07-0.12
SO_3	0.35
LOI[a]	1.68-3.22
Surface area, M^2/g	25.9
Particle size range, microns	0.02-0.25
Average particle size, microns	0.12
Bulk density as generated, lb/ft^3	4-6
Bulk density (packed), lb/ft^3	12-14
Color	Gray
pH	6.7
Oil absorption, lb oil/100 lb	85-95
LOI[a] 105°C, 1 hour	0.46%
LOI 1000°C, 1 hour	1.22%

[a]Loss on ignition.

in the production of 50 percent ferrosilicon are described in a simplified form by the following equation:[3]

$$2\ SiO_2 + Fe_2O_3 + 7C \quad 2\ FeSi + 7CO$$

Covered furnaces can emit large quantities of carbon monoxide to the atmosphere if not properly flared. CO emissions are not a problem with open furnaces because oxidation to carbon dioxide occurs as the hot gas mixes with ambient air at the surface of the charge.

The degradation of carbonaceous reducing material; i.e., coal, coke, wood chips, etc. generates organic emissions. Categories of compounds observed in ferroalloy emissions include aliphatic hydrocarbons, aromatic hydrocarbons, fused aromatics, heterocyclic nitrogen, heterocyclic sulfur, ketones, esters, and carboxylic acids. Carcinogens such as benzoapyrene have been found in submerged arc furnace emissions.[8,20] References 8, 9, 12 and 19 contain detailed information on organic compound concentrations measured at specific furnaces. The organic compound emitted can be in the form of gas or it can be adsorbed onto the surface of particulate material.

SECTION 5

PROPOSED AP-42 SECTION FOR FERROALLOY INDUSTRY

The proposed revision to Section 7.4 of AP-42 is presented in the following pages as it would appear in the actual document.

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

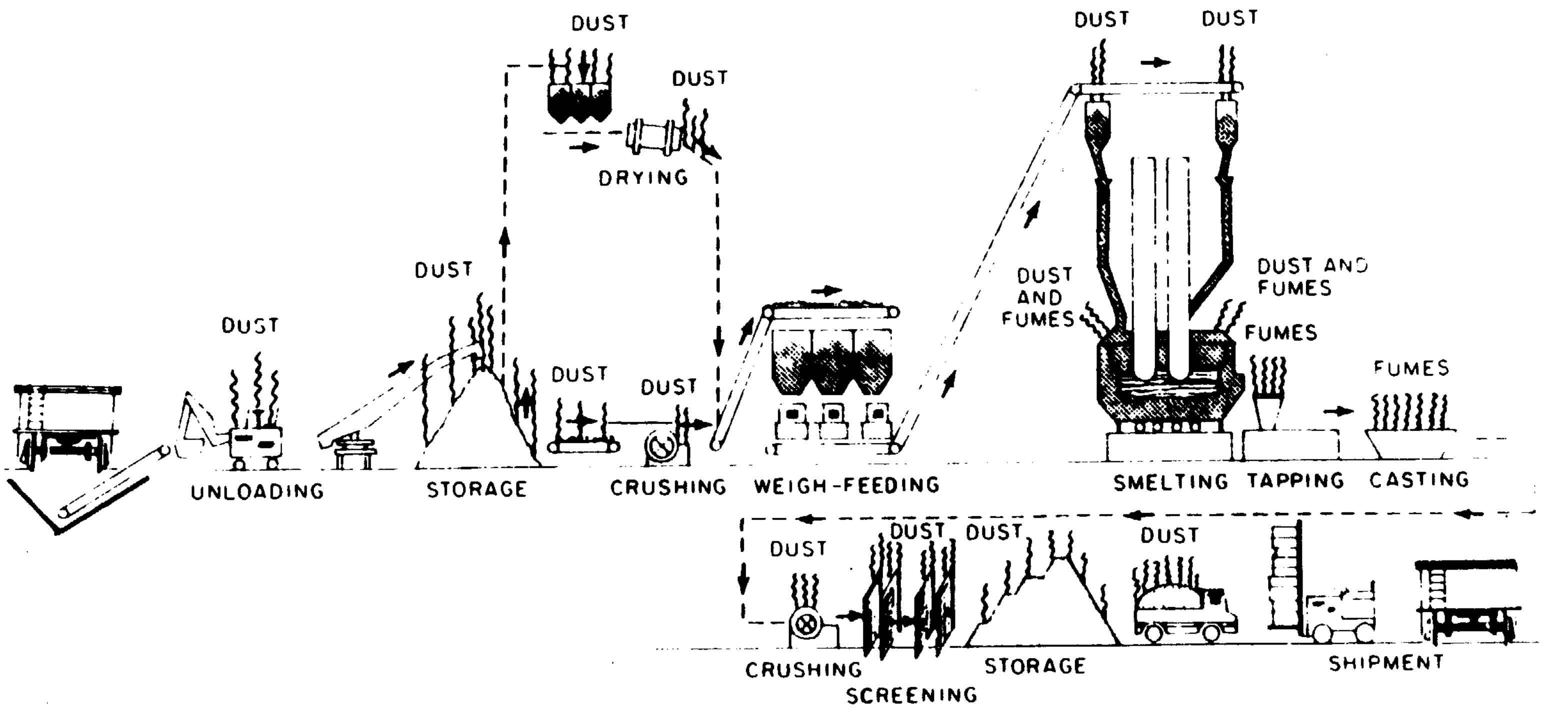

Figure 7.4-1. Typical ferroalloy production process, showing emission points.

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	kg (lb)/Mw-hr	Size data	Notes	Emission Factor Rating	Control device[d]	Particulate emission factors Controlled[c] kg/Mg (lb/ton) alloy	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	158 (316)	16 (35)		k	E	Scrubber					
	Covered	103 (206)	13 (29)		h,j	E	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 alloy	Cumulative mass emission factor (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	Cumulative mass emission factor (lb/ton) alloy	Emission Factor Rating
SiMn Open furnace (cont.)	Scrubber[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.

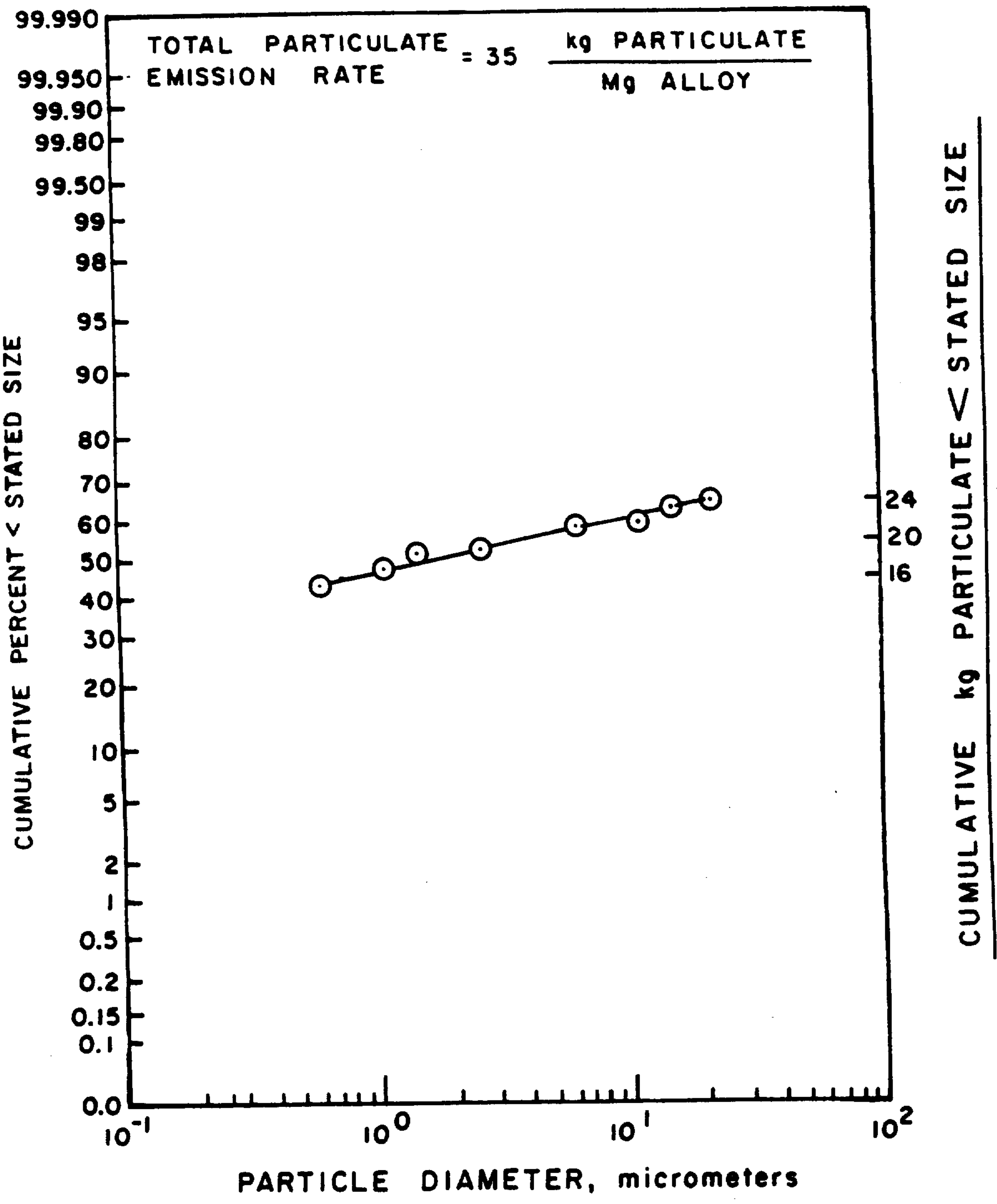

Figure 7.4-2. Uncontrolled, 50% FeSi producing, open furnace particle size distribution.

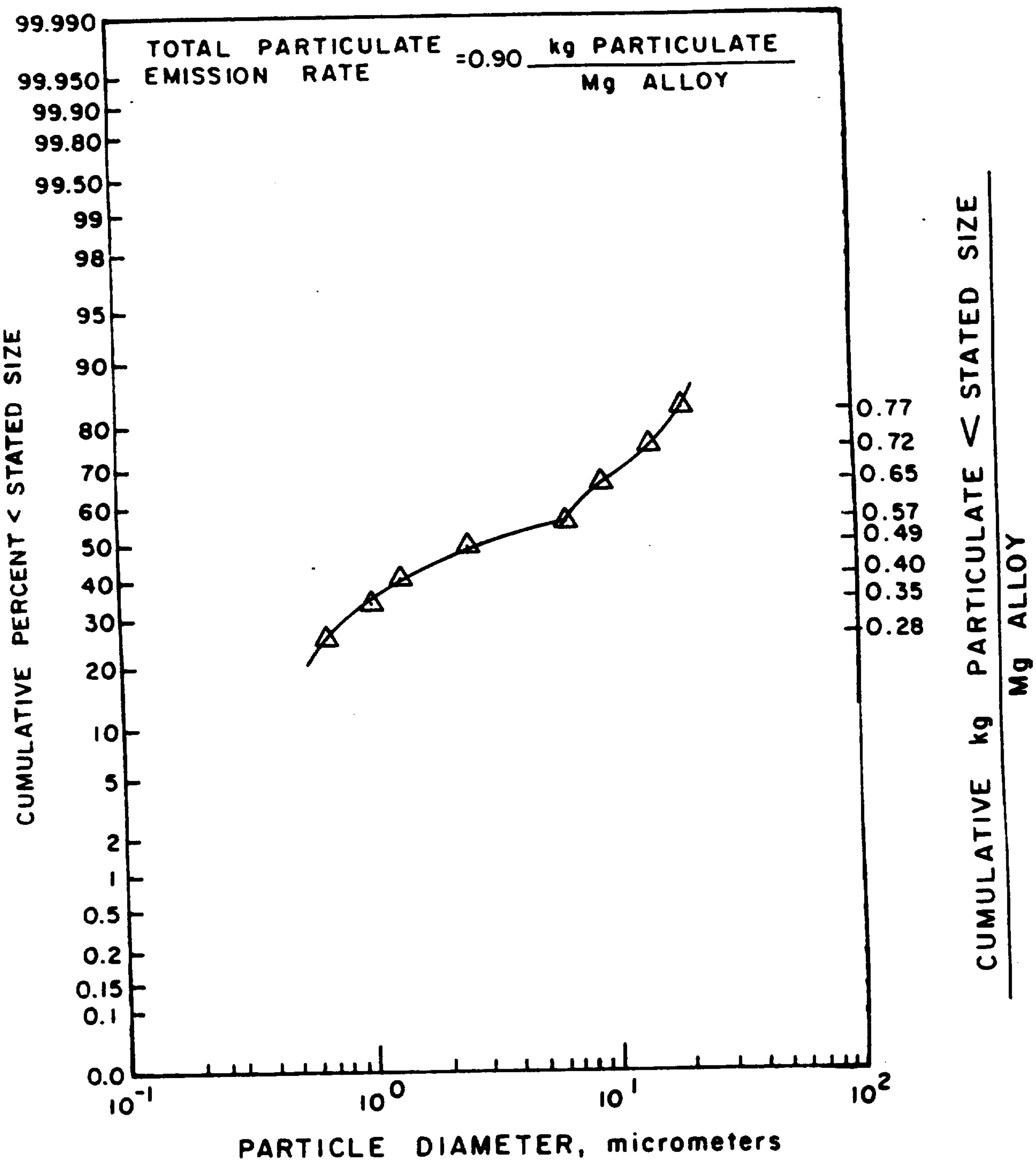

Figure 7.4-3 Controlled (baghouse), 50% FeSi, open furnace particle size distribution

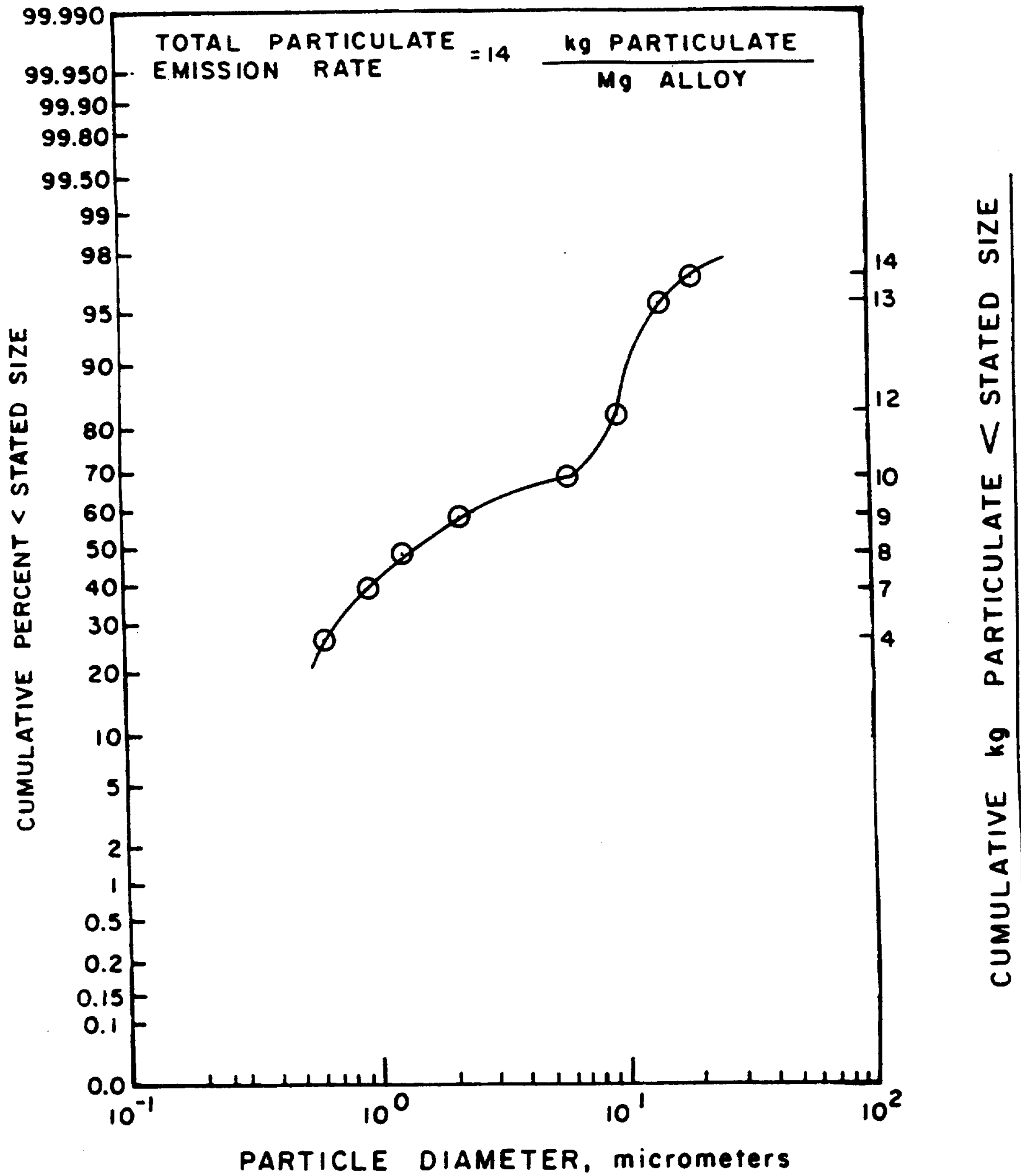

Figure 7.4-4. Uncontrolled, 80% FeMn producing, open furnace particle size distribution

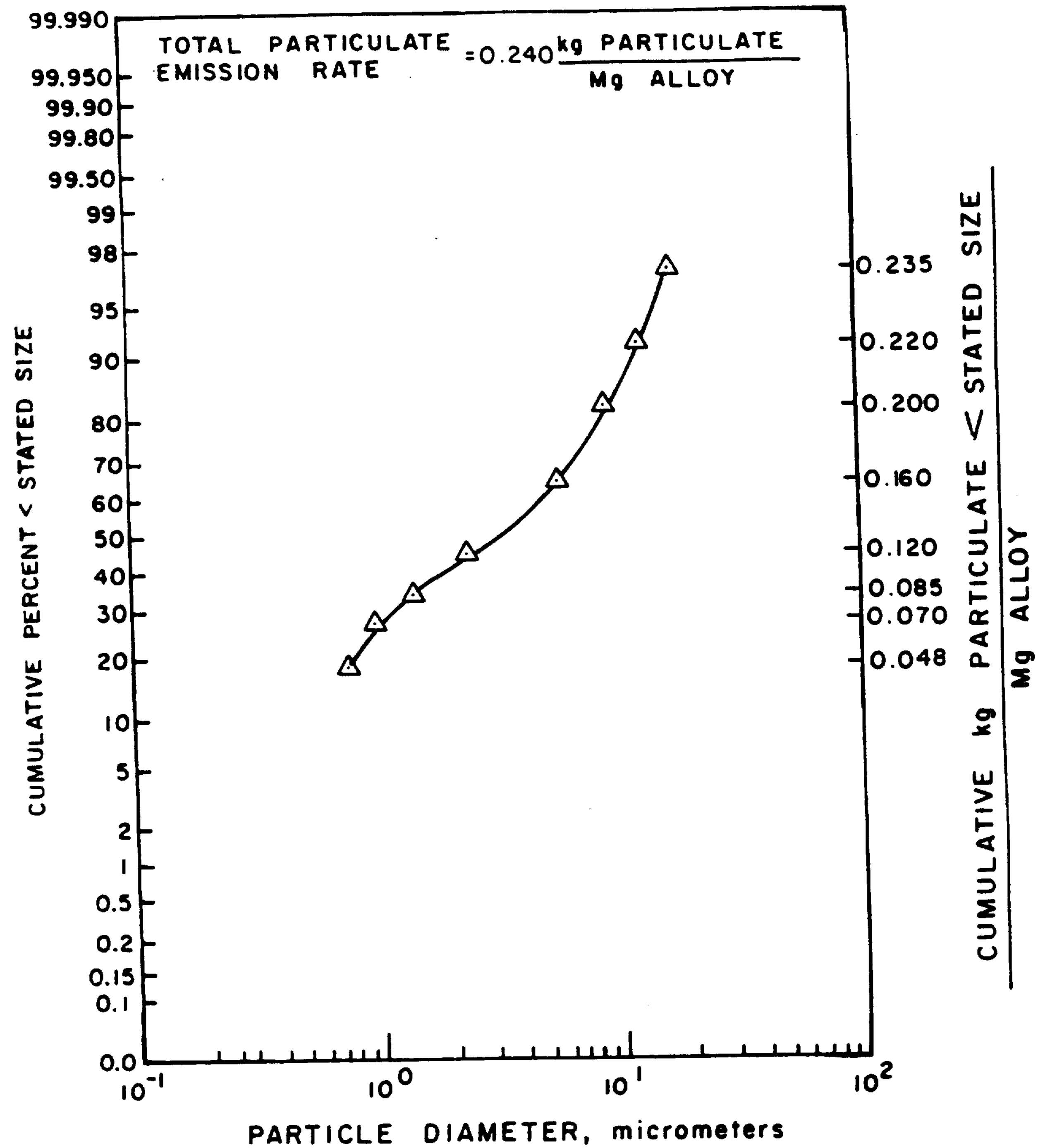

Figure 7.4-5. Controlled (baghouse), 80% FeMn producing, open furnace size distribution

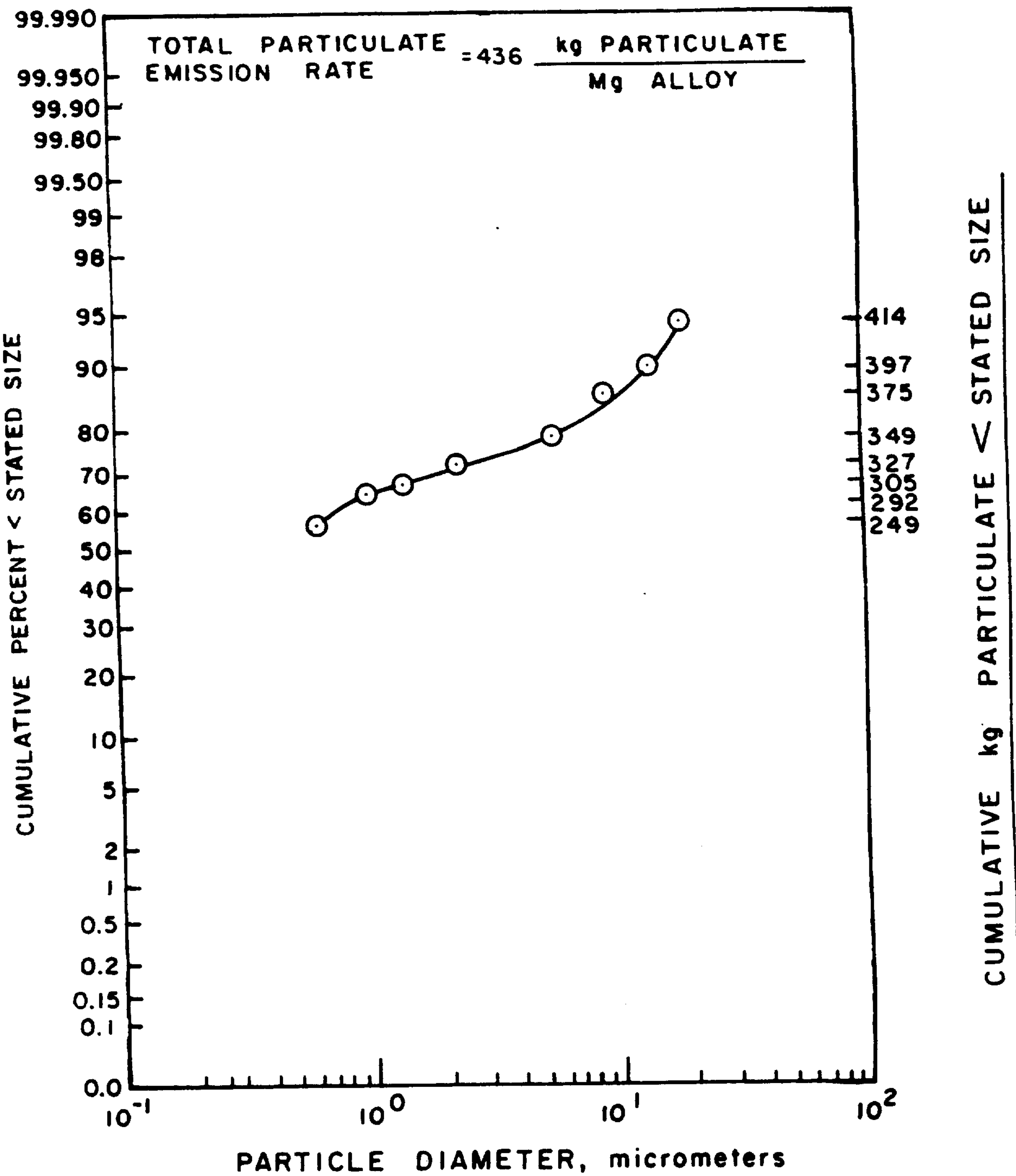

Figure 7.4-6. Uncontrolled, Si metal producing, open furnace particle size distribution

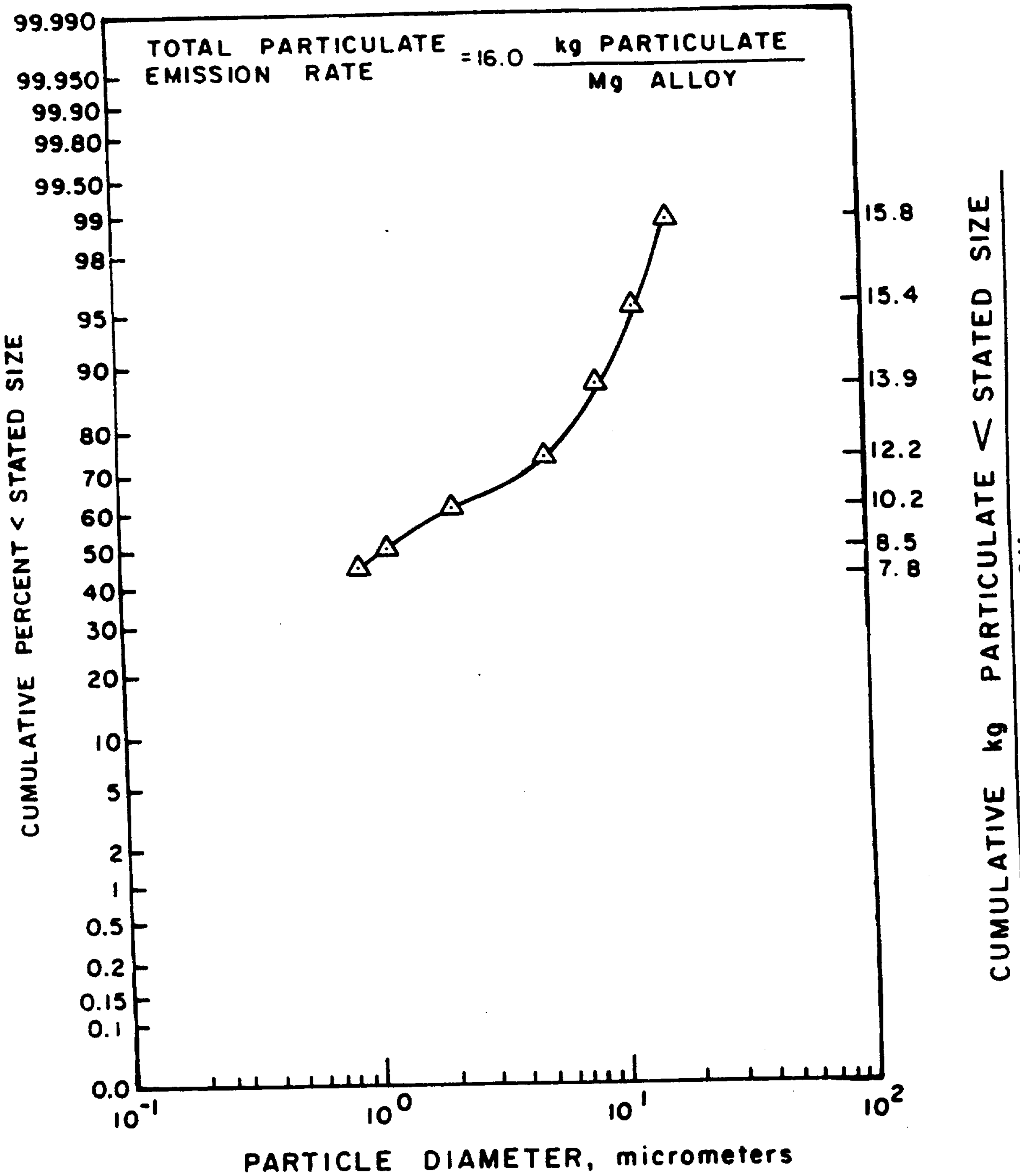

Figure 7.4-7. Controlled (baghouse), Si metal producing, open furnace particle size distribution

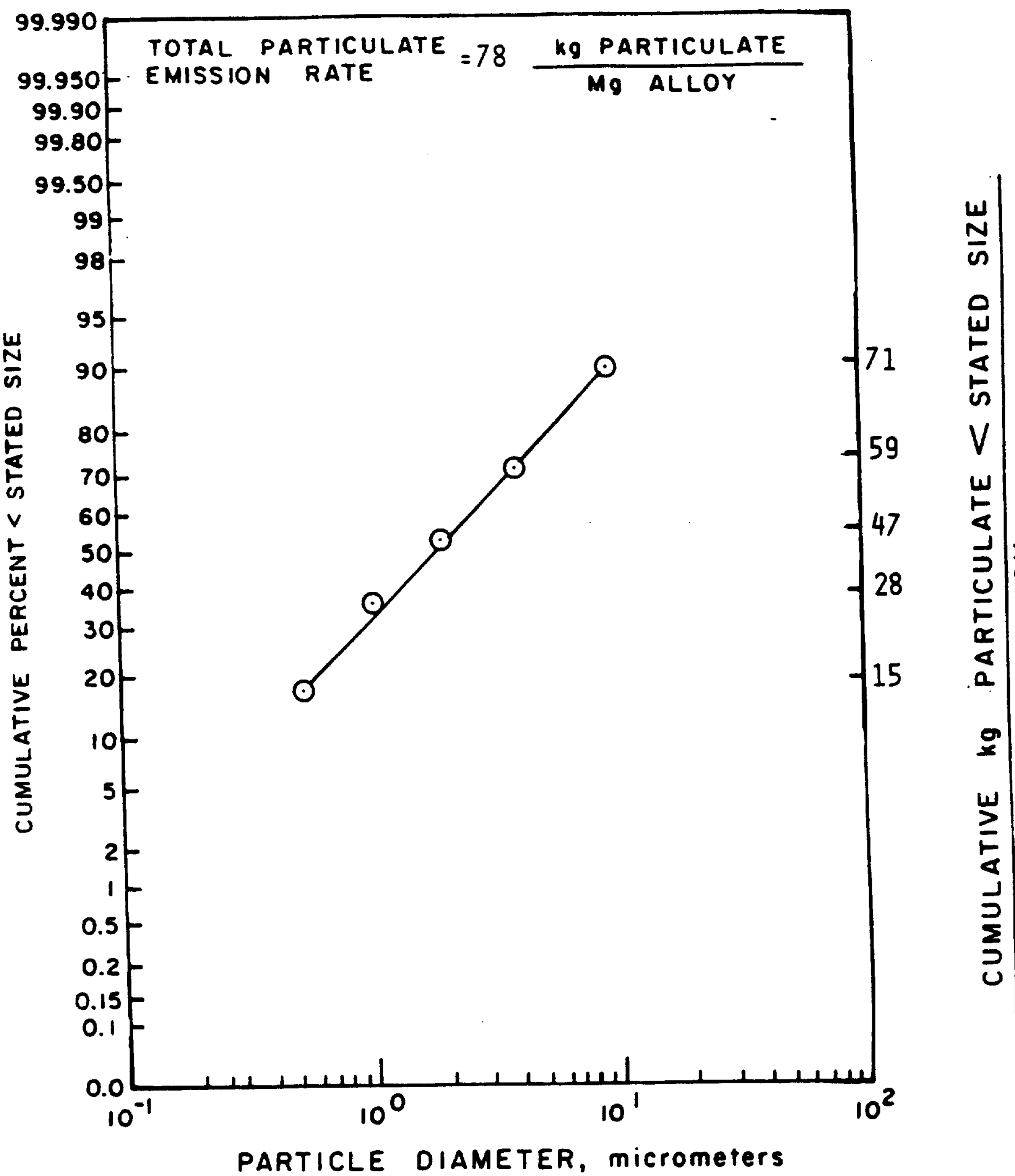

Figure 7.4-8. Uncontrolled, FeCr producing, open furnace particle size distribution

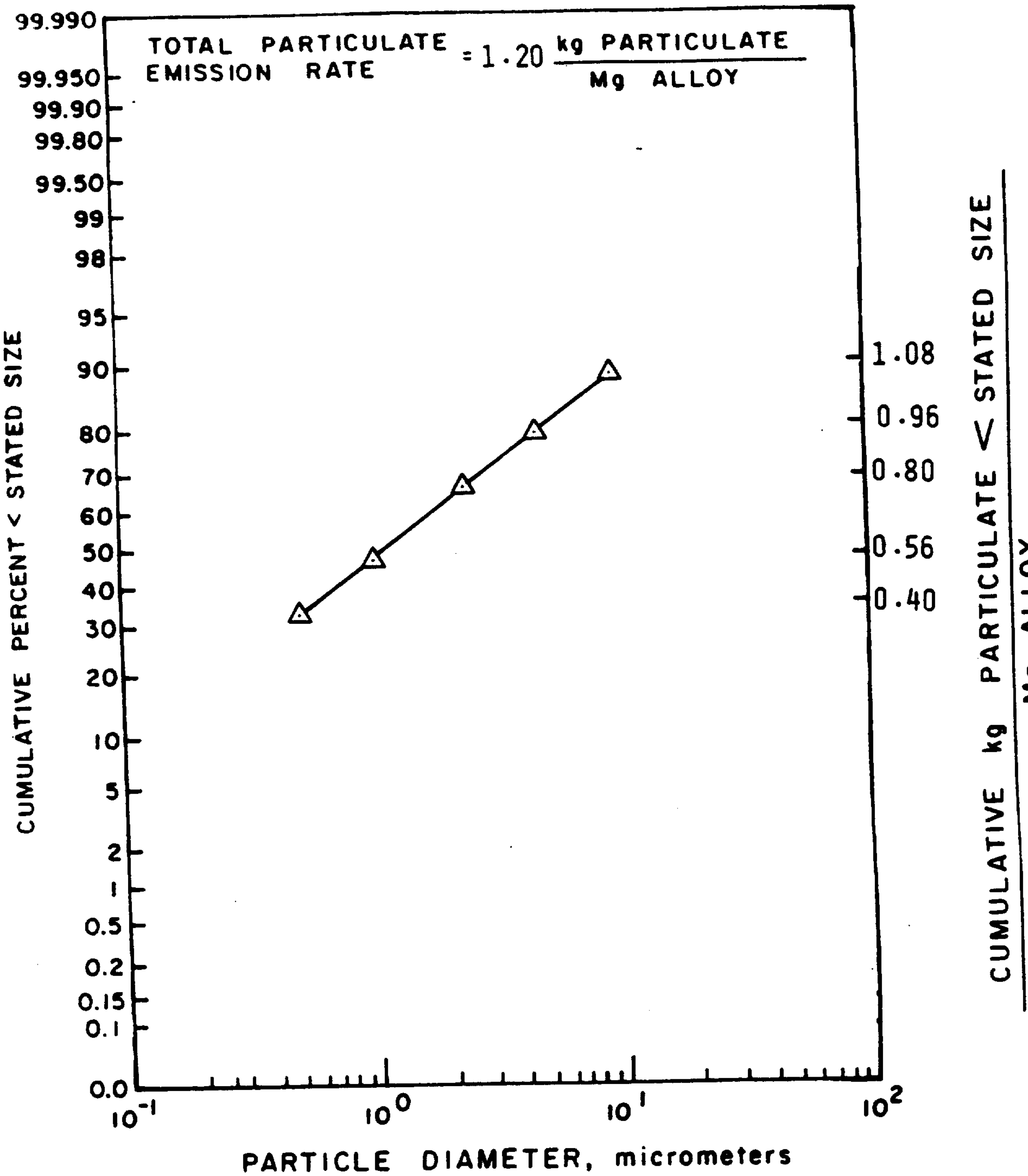

Figure 7.4-9. Controlled (ESP), FeCr (HC) producing, open furnace particle size distribution

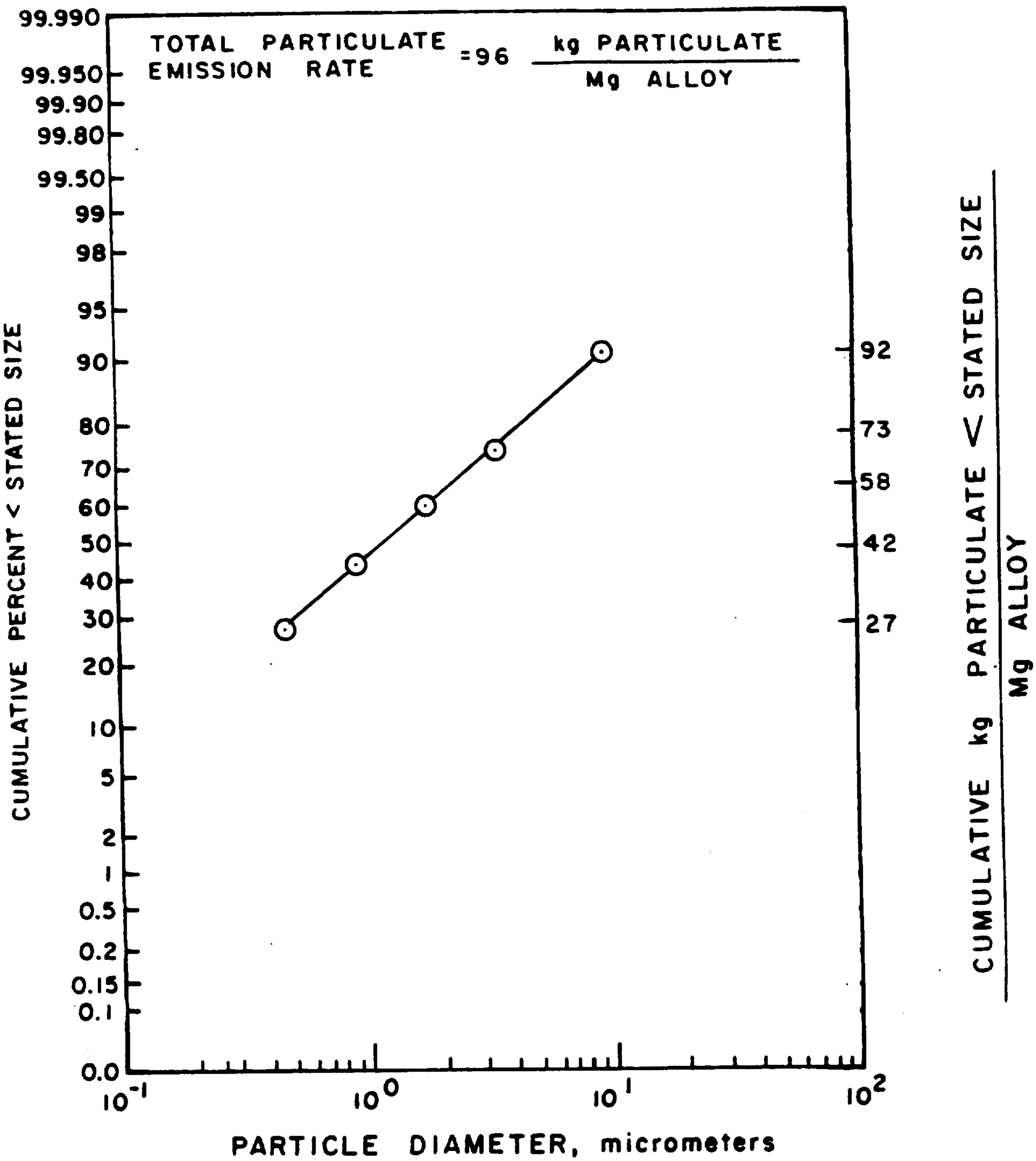

Figure 7.4-10. Uncontrolled, SiMn producing, open furnace particle size distribution

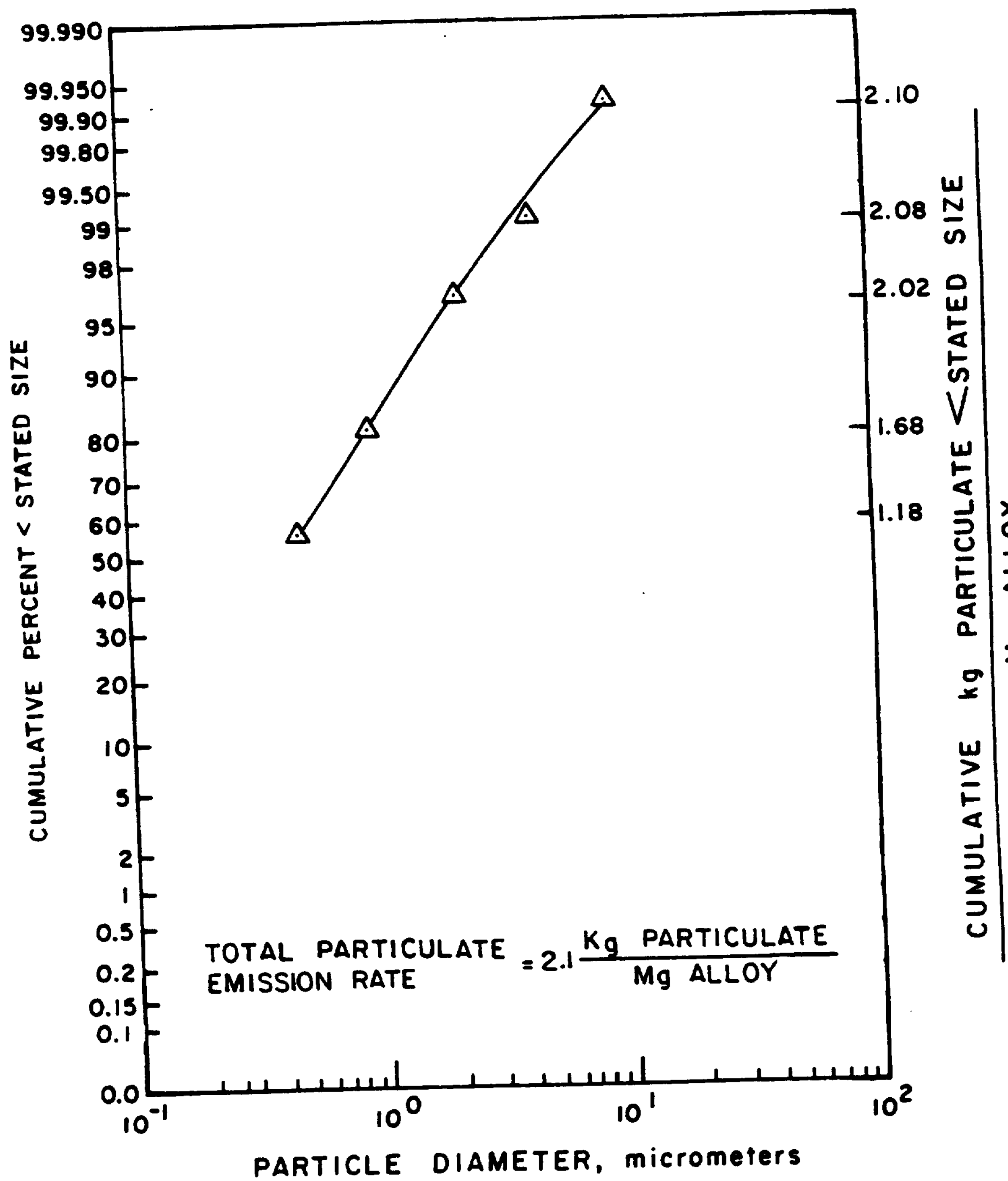

Figure 7.4-11. Controlled (scrubber), SiMn producing, open furnace particle size distribution

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.

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