Acurex Draft Final
Report 83-123/EE
January 1983

INHALABLE PARTICULATE SOURCE CATEGORY REPORT FOR THE KRAFT PULP INDUSTRY

By

Acurex Corporation
Energy & Environmental Division
485 Clyde Avenue
Mountain View, California 94042

Contract 68-02-3156
Technical Directive No. 9

Project Officer

Dale Harmon
Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

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OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

SUBJECT: REVIEW OF INHALABLE PARTICULATE SOURCE CATEGORY REPORT FOR THE KRAFT PULP INDUSTRY

DATE:

FROM: PETER WESTLIN

TO: ROBERT WALSH

WE HAVE REVIEWED THE SUBJECT REPORT AND FIND THE TEST METHODS AND DATA REDUCTION PROCEDURES ACCEPTABLE. I HAVE MADE A FEW EDITORIAL COMMENTS IN THE MARGINS, ESPECIALLY IN THE INTRODUCTION.

EPA Form 1320-6 (Rev. 6-72)

SECTION 1

INTRODUCTION

There is increasing interest in the presence of fine particulate MATTER in the atmosphere and how well existing technology is controlling fine particulate emissions. This concern is BECAUSE ~~due to the fact that~~ fine partic~~ulate~~LES in the ambient air (i.e., particles smaller than 20 microns in size) ~~has been proven to be~~ ARE respirable. The physiological response to inhalation of fine partic~~ulate~~LES differs widely~~, however,~~ depending on chemical composition.

This document is a source category report on inhalable particulate MATTER emitted by the kraft pulp industry. The source category report summarizes available data on inhalable particulate emissions from sources typical of the industry.

The primary objective of this report is to develop reliable total and size-specific emission factors for controlled and uncontrolled emissions for each emission source in the kraft pulp industry.

The second objective of this report is to summarize existing data on chemical characterization of inhalable particulate emissions.

Finally, this report provides a replacement for Section 10.1.2 "Kraft Pulping" in AP-42 "Compilation of Air Pollutant Emission Factors," last revised in April 1977. The replacement section contains current information on the kraft pulp industry as well as the size-specific emission factors developed during this study. Sections 10.1.3 "Acid Sulfite Pulping" and 10.1.4 "Neutral Sulfite Semichemical (NSSC) Pulping" were not revised.

These objectives were met by an intensive literature search which included personal contact with individuals and organizations known to be familiar with the kraft pulp industry. Sources for data included:

- DIALOG computerized literature searches
- Control agencies
  - U.S. Environmental Protection Agency
  - State and local air pollution control agencies
  - Canadian Air Pollution Control Directorate
- Trade organizations
  - National Council of the Paper Industry for Air and Steam Improvement (NCASI)
  - Technical Association of the Pulp and Paper Industry (TAPPI)
- Industry contacts
  - Kraft pulp industry
  - Vendors of control equipment for the kraft pulp industry
- AP-42 kraft pulp industry file at the Office of Air Quality Planning and Standards (OAQPS)
- Fine Particle Emission Information System (FPEIS)

The data which were obtained were reviewed, analyzed, and ranked according to the criteria provided in the report "Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections" April 1980.[1-1] If there ~~was~~ were no reason to exclude particular data from consideration, each data set was assigned a ranking. The data were ranked 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 performed by a generally sound methodology but lack enough detail for adequate validation.

C -- Tests based on an untested or new methodology or lacking a significant amount of background data.

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

Upon ranking the data, a single emission factor was calculated The reliability of this emission factor is indicated by an Emission Factor Rating. The ratings are subjective quality evaluations rather than statistical confidence intervals and range from A (excellent) to E (poor) as follows:

A -- Excellent. Developed only 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 for 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.

Process and control system operating data were obtained and summarized. Cyclic or other peculiarities which may affect emissions were identified and presented in both the kraft pulp industry description section and in the proposed AP-42 section. Because of the nature of AP-42, certain duplication of information occurs in Sections 1 through 4 and Section 5 of this report.

References for Section 1

1-1. Compilation of Air Pollutant Emission Factors, Third Edition, U.S. Environmental Protection Agency, AP-42, April 1981.

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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.

SECTION 2

KRAFT PULP INDUSTRY

2.1 GENERAL

Pulping is the conversion of fibrous raw materials such as wood, used paper, or cotton into a material that can be converted into paper, paperboard, and building materials. The principal source of these fibers is wood, and the fiberous material ready to be made into paper is called pulp or wood cellulose.

Pulp is produced by two general methods: mechanicallly by shredding or grinding the wood to free the fibers, or chemically by cooking wood chips in an aqueous solution of pulping chemicals that dissolve the lignin binding material. Lignin is an amorphous polymeric substance related to cellulose that bonds the cellulose fibers together and forms the woody cell walls of plants. Generally wood contains 25 to 30 percent lignin on a dry basis.

In 1976, there were about 120 kraft pulp mills located in 28 states throughout the United States.[2-1] The majority of the mills are concentrated in the Southeast with the remainder concentrated in the Northwest and Northeast. A list of all kraft pulp mills operating in the United States as of 1976 is included as Appendix A.

In 1974, these mills produced 32,342,000 tons (2.93×10^{10} kg) of kraft pulp nearly all of which went into the production of paper, paperboard, and similar products. This represents approximately 70 percent of the pulp produced in the United States. Individual mill sizes range from 180 to 2,550 tons (1.6×10^5 to 2.3×10^6 kg) of pulp per day with the average being 770 tons (7×10^5 kg) per day.

The growth rate of the industry averaged 5-1/2 percent per year between 1956 and 1975. Growth has declined to 2-1/2 percent per year since 1975.[2-1]

The chemical pulping industry can be divided into four pulping categories: kraft, sulfite, neutral sulfite semichemical (NSSC), and soda. The basic differences among these pulping processes is in the digestion of the wood chips. Kraft pulping uses a solution of sodium hydroxide (NaOH) and sodium sulfide (Na_2S) to accomplish the digestion. Sulfite pulping uses liquors containing sulfurous acid (H_2SO_3) and the bisulfite of calcium ($Ca(HSO_3)_2$), sodium ($NaHSO_3$), magnesium ($Mg(HSO_3)_2$), or ammonia (NH_4HSO_3). Neutral sulfite semichemical (NSSC) pulping uses a nearly neutral sulfite solution containing an alkaline agent such as sodium carbonate (Na_2CO_3), sodium bicarbonate ($NaHCO_3$), or NaOH. Soda pulping uses a solution of NaOH as the cooking liquor.

The soda pulping process has declined to relative insignificance in recent years.

2.2 KRAFT PULP PRODUCTION PROCESS

The production of kraft pulp from wood is illustrated in Figure 2-1.[2-1] The kraft pulping process is the most widely used pulping process today. This is because of the efficient recovery and recycling of pulping chemicals, the strength of the pulp produced by the process, and the capability of using nearly all wood species to produce the pulp.

The pulping process is accomplished by chipping the wood into small pieces, transporting these wood chips to large pressure vessels (digesters, averaging about 4,000 ft^3 (110 m^3) in volume), and digesting the chips at elevated temperature and pressure in a cooking liquor consisting of a solution of NaOH and Na_2S. The aqueous solution of NaOH and Na_2S is known as white liquor. The NaOH in the white liquor is the principal pulping chemical. It permits the pulping of nearly all wood species. Na_2S speeds up the removal of lignin and provides a buffering action that allows digestion to take place at a lower $(OH)^-$ ion concentration. This results in less damage to the pulp fibers and stronger pulps than those obtained in sulfite, NSSC, or soda pulping processes.[2-2]

Digesters are operated either in a batch or continuous mode (Figures 2-2 and 2-3.[2-3] The wood chips are generally digested at 340° to 360°F (170° to 180°C) and at pressures ranging from 100 to 135 pounds per square inch gauge (6.9×10^5 to 9.3×10^5 Pa). Depending upon the grade of wood chips, 45 to 55 percent of the wood reacts with the pulping chemicals to become soluble in the aqueous solution. This soluble portion of the wood consists of most of the lignin and hemi-celluloses and a small part of the

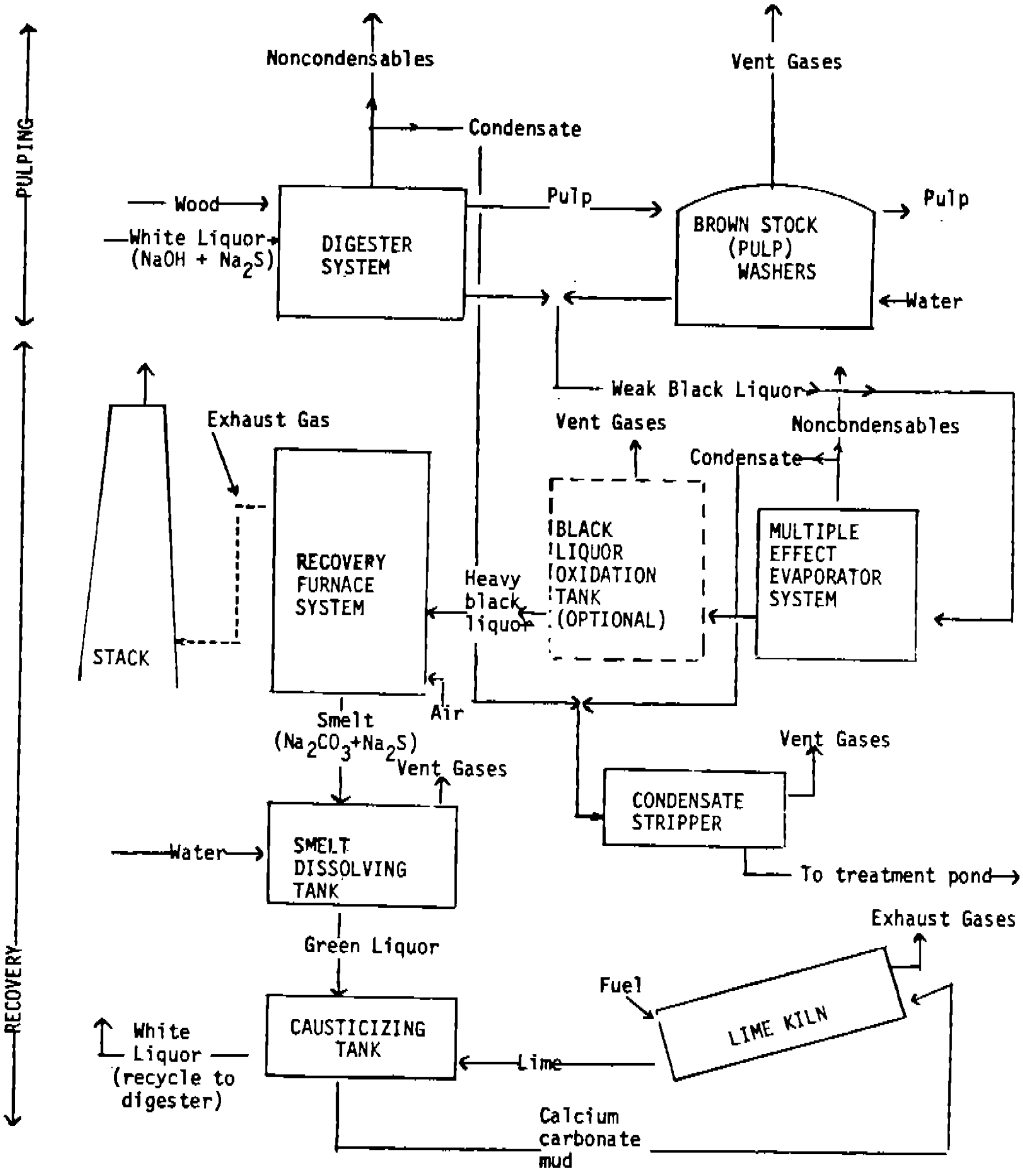

Figure 2-1. Kraft pulping process.

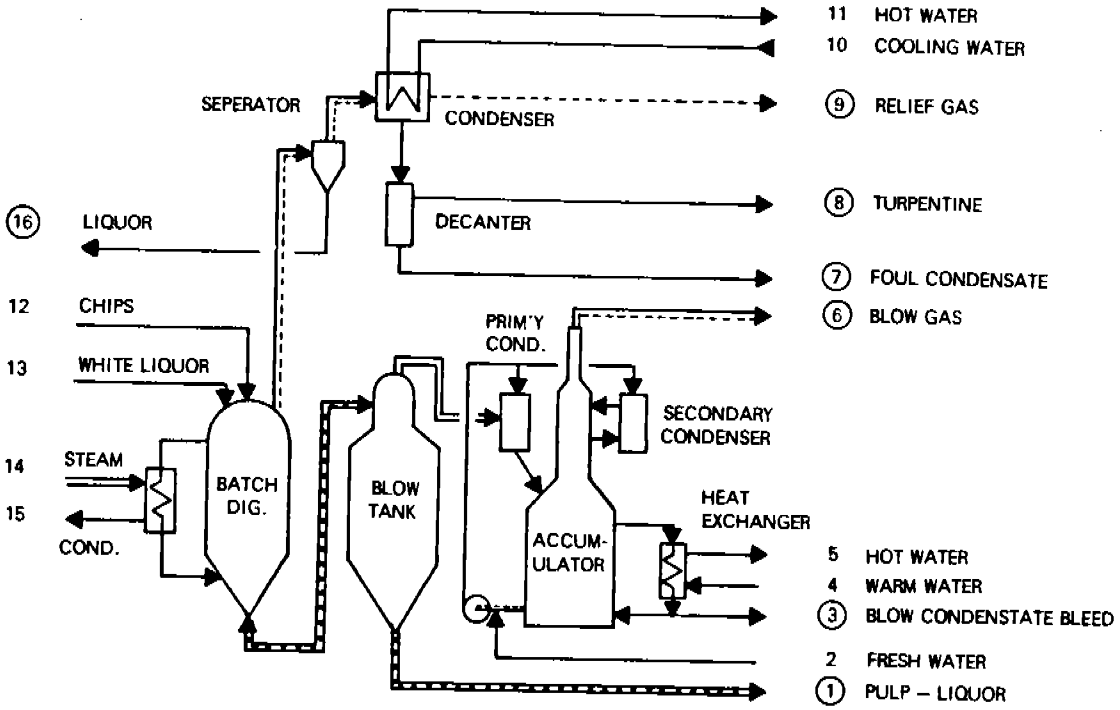

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Figure 2-2. Batch digester flow sheet.

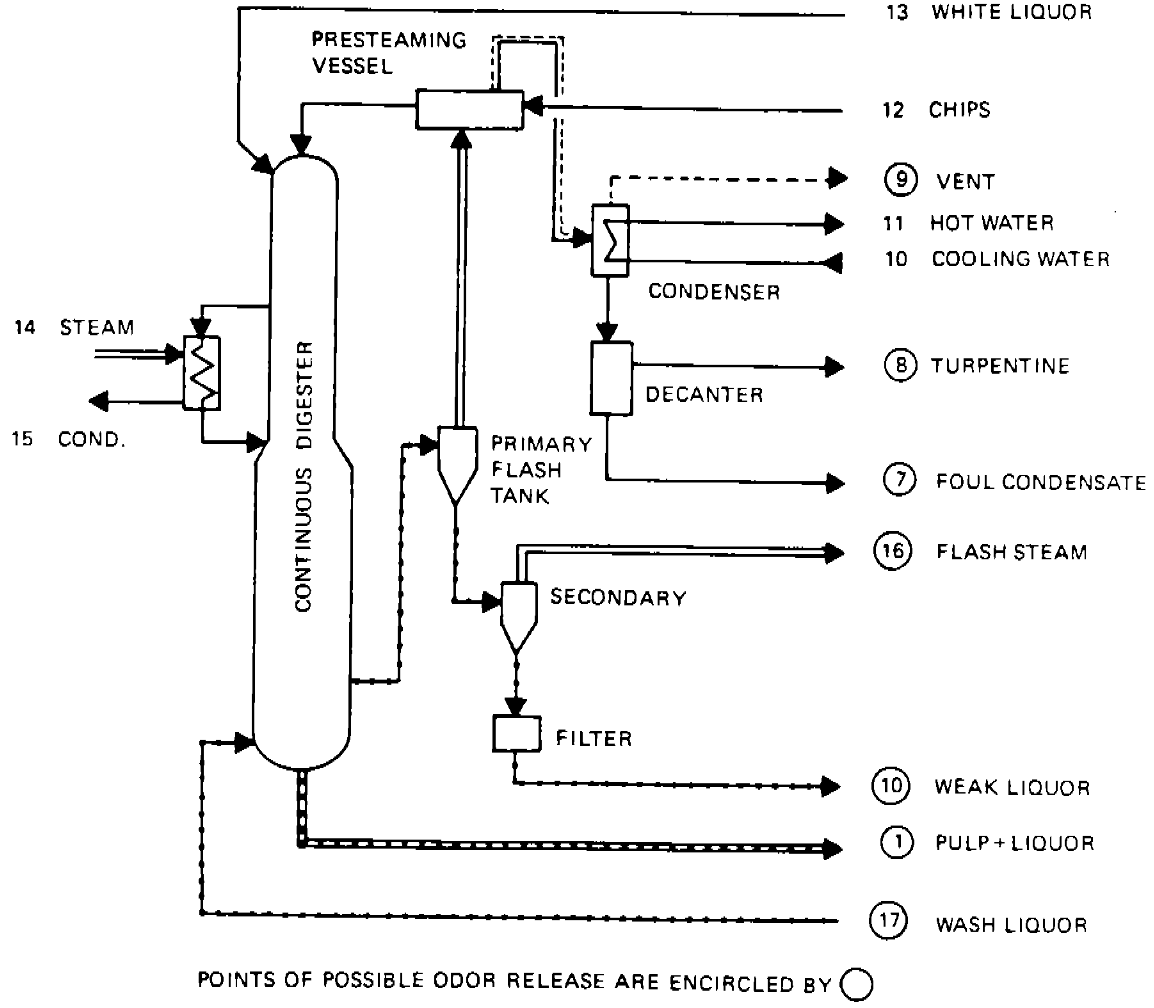

Figure 2-3. Continuous digester flow sheet.

cellulose. What remains of the wood, in the form of cellulose fibers, is the pulp.

To maintain proper cooking pressures within the digester, gases formed during digestion are vented. The composition and quantity of these digester gases differ between batch and continuous digesters. Variations also result from type of wood, temperature of cooking, cooking time, and sulfide concentration in the wood. In the cooking process, the sulfide ion reacts with the lignin in the wood to produce hydrogen sulfide (H_2S) and organic sulfide compounds (mostly methyl mercaptan (CH_3SH), dimethyl sulfide ($(CH_3)_2S$), and dimethyl disulfide ($(CH_3)_2S_2$). The sulfide compounds are expressed as sulfur and are known as total reduced sulfur (TRS). The disagreeable odor from kraft pulp mills can be traced to these compounds and their low threshold odor levels (1 to 10 ppb).[2-2] Digester gas may also contain turpentine and traces of methanol (CH_3OH), ethanol (CH_3CH_2OH), and acetone (CH_3COCH_3).

At some mills the digester gases are first cooled to condense and recover turpentine prior to venting, especially if softwood is being pulped. These noncondensible relief-vent systems are used during the course of the cooking. At the end of the cooking cycle the pulp is discharged from the digester into an atmospheric tank usually referred to as a blow tank. For a batch process digester there may be a surge of gaseous emissions from this process resulting in blow gases which contain considerable amounts (26,000 ppm) of total reduced sulfur (TRS). Continuous digestors present fewer problems in that contaminated condensates and sulfur compounds flow at a regular rate while with batch digesters large amounts of steam and noncondensible gases are blow off when the contents of the digester are blown to the blow tank at atmospheric pressure. Thus one can design controls for an average flow of gases with continuous digesters while one must provide control for peak gaseous emission with batch digesters. The steam in both the relief and blow gases is usually condensed to recover the heat while the noncondensible gases are vented or treated. Incineration in a lime kiln is the preferred method of treatment for these noncondensible gases.

Incineration produces sulfur dioxide (SO_2) which is retained in the lime instead of being emitted to the atmosphere. Other methods of treatment of noncondensible gases are scrubbing with NaOH which removes only H_2S and CH_3SH and scrubbing with chlorine solutions which is of limited effectiveness.

Often the chlorine scrubbing uses chlorination stage bleachery effluent from a bleaching plant which is at the same site as the kraft pulp mill.

The pulp slurry from the blow tank is generally screened through coarse screens known as knotters before it is washed. This process removes uncooked slivers and knots which are usually returned to the digesters for repulping.

Washing the pulp slurry is accomplished in a sequential countercurrent operation removing the spent white liquor and dissolved wood material (lignin, hemi-cellulose and a small amount of cellulose) from the pulp slurry. Generally three stages of vacuum drum washers are employed. The third stage is washed with hot, fresh (or recycled) water. The filtrates move countercurrently to the second and then the first stage becoming what is termed weak black liquor (12 to 18 percent) solids. This weak black liquor is extracted from the first stage and is sent to multiple effect evaporators in the recovery plant. Mills containing continuous digesters sometimes do part of their washings in the digesters, thereby eliminating one or two stages of vacuum drum washers. Recently, some of the drum washers have been replaced with diffusion washers which oxidize sulfur. The brown stock pulp resulting from these washings is further cleaned in screens and centrifugal cleaners before it is made into end products or bleached. No significant particulate matter emissions result from this cleaning process, however, gaseous emissions mainly in the form of $(CH_3)_2S$ and $(CH_3)_2S_2$ have been found at the washer and knotter hoods, the filtrate tanks, and at the vacuum pumps.

The chemical recovery system is the heart of the kraft pulping process. The NaOH and Na_2S must be recovered to permit viable economic operation of the kraft pulp mill. The weak black liquor (12 to 18 percent solids) recovered from the pulp at the washers is concentrated into a stronger black liquor (40 to 55 percent solids) by multiple effect evaporators. The concentration of the black liquor is necessary to permit combustion of the dissolved organic material in the recovery furnace. Liquid condensate and noncondensible vent gases give rise to emissions from this evaporation-concentration process. These evaporator gases contain sulfur and organic compounds which are boiled off from the weak black liquor or formed during the evaporation process. A major difference between evaporator gases and digester gases is that the evaporator gases are predominantly H_2S and CH_3SH while digester gases contain these gases as well as $(CH_3)_2S$) and $(CH_3)_2S_2$. Evaporator gas TRS emissions can be controlled through NaOH scrubbing while components of the digester gases ($(CH_3)_2S$ and $(CH_3)_2S_2$) cannot be controlled by this process. Incineration in a lime kiln is another possible control technique for evaporator gases. No significant particulate matter emissions result from the operation of multiple effect evaporators.

Multiple effect evaporators normally have three to seven stages. A diagram of a multiple effect long-tube vertical evaporator system is shown in Figure 2-4[2-2]. In this long-tube vertical shell-and-tube type evaporator the weak black liquor (12 to 18 percent solids) is fed to the tube side of the latter evaporation effects (or stages) while steam is supplied to the first effect's shell side. This steam-liquor countercurrent operation generally concentrates the black liquor solution to 40 to 55 percent solids. As shown in Figure 2-4, the weak black liquor moves through the tube side of the multiple effects from the last to the first. As the black liquor proceeds, it is heated by the condensation of the vapor that is driven off the boiling black liquor in the tube side of each preceding effect (on the left in Figure 2-4). The water vapor that is evaporated from the last effect (the far right effect in Figure 2-4) is generally condensed in one of two types of condensers with steam injectors: surface condensers and direct contact barometric condensers. The steam injectors are employed to remove noncondensibles. The multiple effect evaporators are normally operated at pressures of 20 to 40 psig (1.4×10^5 to 2.8×10^5 Pa) in the strong liquor outlet stage (left-hand side of Figure 2-4) and a vacuum of 25 to 28 in. of mercury (8.4×10^5 to 9.5×10^5 Pa) in the condenser stage (right-hand side of Figure 2-4).

To reduce possible TRS emissions from the last concentration step for black liquor (to increase its solid content from 40 to 55 percent to 60 to 70 percent) the moderately strong black liquor (solids content: 40 to 55 percent), is oxidized in oxygen or air. The process oxidizes Na_2S to $Na_2S_2O_3$ or a higher oxidation state. The oxidation of Na_2S to $Na_2S_2O_3$ is given in the following equation:

$$2Na_2S + O_2 + H_2O \rightarrow Na_2S_2O_3 + 2NaOH$$

The $Na_2S_2O_3$ will not react with CO_2 and SO_2 in the recovery furnace gases to produce H_2S as Na_2S does. Thus, the black liquor oxidation results in lower H_2S emission rates. This oxidation can be performed on either the weak or moderately strong black liquor and is accomplished by employing air sparging

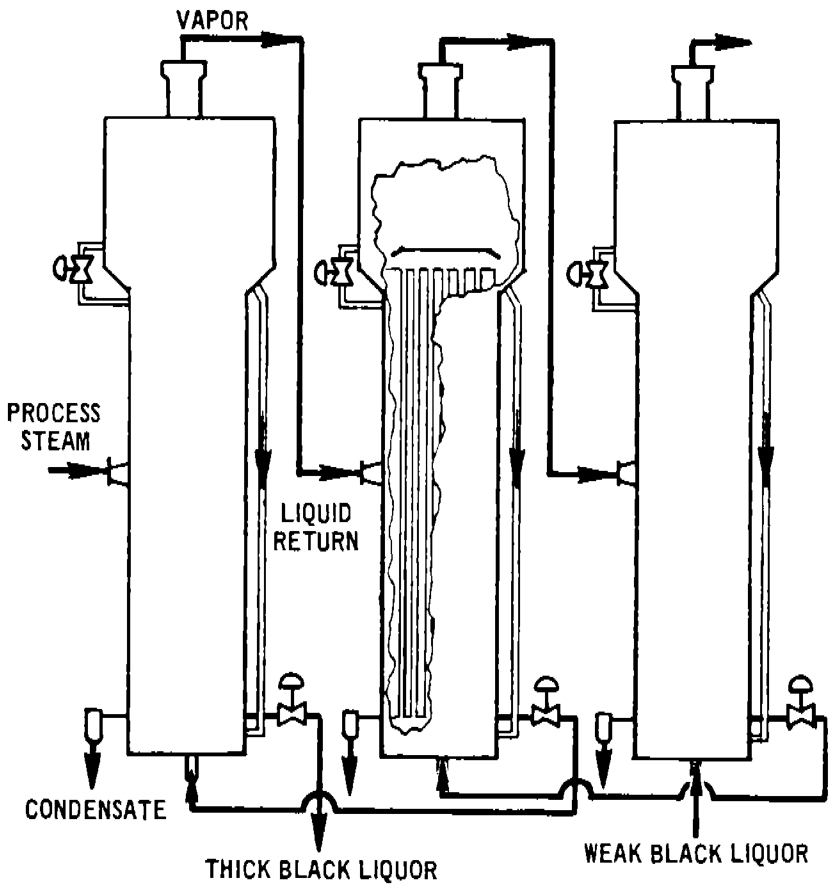

Figure 2-4. Multiple effect long-tube vertical evaporators (backward feed).

reactors (with and without mechanical mixers), packed towers, and bubble tray columns in single and multiple stages to provide the necessary contact between the liquor and the air. The oxidation of the weak liquor may reduce emissions in the evaporation process, but there exists the possibility of reversion to the sulfide in later evaporation stages or in storage. No significant particulate matter emissions result from this black liquor oxidation.

The final concentration of the black liquor (from 40 to 55 percent solids to 60 to 70 percent solids) occurs in kraft recovery furnaces with direct contact evaporators (DCE) and kraft recovery furnaces without direct contact evaporators (low-odor furnaces). In the kraft recovery furnaces equipped with direct contact evaporators, the flue gas from the furnace is brought in contact with the moderately strong black liquor.

This final concentration process serves two purposes. Not only is it a final concentration process for the black liquor, but it also functions as a particulate emission control device which reduces particulate emitted by the recovery furnace by up to 50 percent.

Three types of direct contact evaporators are used to carry out this final concentration:

- When cyclone evaporators are used, the black liquor is sprayed into the hot gas stream from the recovery furnace, then the black liquor is removed by the cyclone. These cyclone evaporators are commonly believed to remove 40 to 50 percent of the particulate matter leaving the recovery furnace[2-2].
- In recovery furnaces employing cascade evaporators for the final black liquor concentration step, the black liquor is contacted with recovery furnace flue gas through the use of rotating wheels. The bottom portions of these rotating wheels move through a vat of black liquor that is carried into a moving beam of hot combustion gases. The cascade evaporator is believed to remove 40 to 50 percent of the particulate matter emitted from the recovery furnace.[2-2]
- The venturi recovery unit is the third type of direct contact evaporator used in the final concentration step of the black liquor. Venturi recovery units have been designed to remove at least 90 percent of particulate matter emitted from a source. When employed in the final concentration step for black liquor, the

black liquor is mixed with a stream of recovery furnace flue gases at a venturi throat, and then is separated by a centrifugal separator.

One problem arising from direct contact evaporation as the final step in black liquor concentration is the liberation of maladorous sulfur gases arising from CO_2 and SO_2 in the flue gas reacting with Na_2S in the black liquor to form H_2S and other reduced sulfur compounds. Emission of these maladorous sulfur compounds may be reduced by black liquor oxidation which rids the black liquor of Na_2S.

The kraft recovery furnaces without direct contact evaporators (low-odor furnaces) employ two designs for final concentration of the black liquor. The first design uses additional stages of indirect evaporation of the black liquor plus added heat exchange in the furnace. This extended economizer section recovers the heat from the recovery furnace flue gas that is normally used in the direct contact evaporator to concentrate the black liquor. Thus the heat content of the flue gas is used, but the flue gas itself (containing CO_2 and SO_2) never contacts the black liquor in this final concentration step. The other system utilizes a flue gas-to-air heat exchanger and air direct contact evaporator. The flue gas is used to heat ambient air via a heat exchanger. This air is then used to concentrate the black liquor in a direct contact evaporator. What has occurred is that the recovery furnace flue gas with its CO_2 and SO_2 (which promotes H_2S emissions) is replaced with air that contains minimal CO_2 and SO_2, thereby reducing malodorous sulfur gas emissions. After the air has been used in the direct contact evaporator to concentrate black liquor, it is then used as combustion air in the recovery furnace. While reducing the pollution problems associated with malodorous sulfur compounds, the recovery systems without flue gas direct contact evaporators have a particulate matter emission rate that is approximately double that arising from recovery systems with flue gas direct contact evaporators.

Once the solid content of the black liquor has been raised to 60 to 70 percent, the solution should support combustion, allowing recovery of chemicals from the black liquor. The chemicals should be recovered in the reduced state (that is, the sulfur should be present as sulfide and not sulfate). One of the useful byproducts of the combustion of the black liquor is the steam generated. The concentrated black liquor (60 to 70 percent solids) is usually mixed with any makeup chemicals (i.e., NA_2SO_4) before being sprayed into the recovery furnace for burning.

Recovery furnaces are one of the three major sources of particulate matter emissions in the kraft pulp mill industry. Figure 2-5 is a sketch of a recovery furnace showing the major operating zones. The black liquor is sprayed in small droplets over the cross section of the furnace. As the droplets fall through the drying section, they should be dried to a concentration where the heating value of the organic material in the black liquor will support reasonably stable combustion. The black liquor dry solids consisting primarily of Na_2S and Na_2CO_3 fall to the bottom of the furnace as a molten smelt and are removed to a smelt dissolving tank. The primary air flow is used to maintain a reducing atmosphere at the bottom of the furnace (to convert sulfur to sulfide and not to sulfate) and to maintain a proper smelt bed temperature. If the temperature of the smelt bed is too high, excessive amounts of sodium compounds will be volatilized from the bed, creating high particulate matter emission rates. If the smelt bed temperature is too low, insufficient sodium compounds will be volatilized into the reducing zone. This will result in higher sulfur compound emissions (TRS) as these compounds would normally react with the volatilized sodium compounds. The secondary air is used to create an oxidation zone where sulfur compounds can be ozidized to less odorous forms of sulfur such as SO_2.

The molten smelt in the recovery furnace is continuously discharged into a smelt dissolving tank (3,000 ft^3 to 5,000 ft^3 (85 m^3 to 140 m^3)) located beneath the recovery furnace. The molten smelt mixture, primarily consisting of Na_2S and Na_2CO_3, is mixed with water in the smelt tank to produce what is called green liquor. The smelt drops through steam shatter sprays into the dissolving tanks. The tanks are equipped with agitators to assist in dissolving the smelt. When the hot smelt contacts the water, copious amounts of steam are produced. Some particulate matter, consisting of both dissolved and undissolved NaOH, Na_2S, and Na_2CO_3, is entrained by the steam and carried out of the stack with the steam. Some reduced sulfur gases may also be formed by reactions in the tank and carried out with the steam. The smelt dissolving tank is one of the main particulate matter sources in the kraft pulp mill industry.

The dissolved Na_2CO_3 in the green liquor is later causticized by adding quicklime (calcium oxide (CaO)) to it. The CaO is wetted (slaked) by the water in the green liquor to form calcium hydroxide ($Ca(OH)_2$) for the

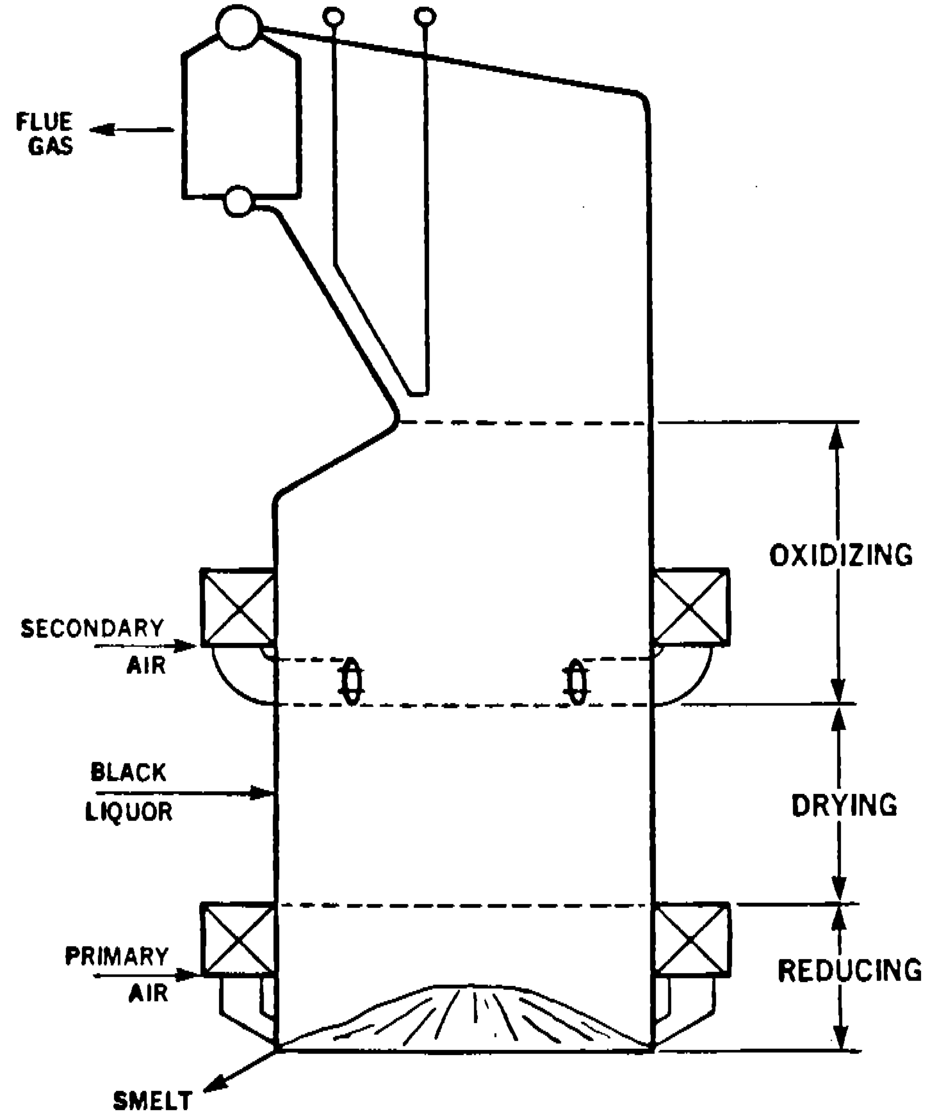

Figure 2-5. Recovery unit furnace zones.[2-4]

causticizing reaction. The following reactions in the causticizer form NaOH which is part of the white cooking liquor NaOH and Na_2S.

$$CaO + H_2O \rightarrow Ca(OH)_2$$

$$Ca(OH)_2 + Na_2CO_3 \rightarrow 2NaOH + CaCO_3$$

As the lime moves down through the kiln, it agglomerates into small pellets and is finally calcined to calcium oxide in the high-temperature zone near the burner. Particulate matter is generated by the rolling and tumbling action of the material in the kiln. This material is carried along by the combustion gases. Some sodium compounds which vaporize at the high-temperature zone of the kiln and later condense also produce particulate matter emissions. Generally, the lime kiln particulate emissions are controlled by wet scrubbers.

Particulate Controls

The particulate control technologies used in the kraft pulp industry are presented in this section. Alternative particulate controls are presented for emissions from:

- Recovery furnaces
- Lime kilns
- Smelt dissolving tank vents

Recovery Furnaces

Until recently, all recovery furnaces used a direct contact evaporator to concentrate the black liquor. However, it may also scrub particulate from the gas stream, removing up to 50 percent of the particulate in the gas stream.

As mentioned earlier, most direct contact evaporators are the cascade type in which the gases pass over a trough filled with black liquor. The liquor is scooped up by a rotating paddle wheel and cascades through the gas stream. Some kraft pulp mills use cyclones or venturis as the direct contact evaporator, with the black liquor again serving as the particulate scrubbing media. Occasionally, two venturis are used in series to increase particulate collection, obviating the need for additional controls. However, nearly all recovery furnaces now use electrostatic precipitators (ESP's) as their primary particulate control devices.[2-1] The design removal efficiency varies, however, ranging from 90 percent in the older installations to greater than 99 percent in the newer installations.

In some older installations, the existing units have been approved by installing scrubbers downstream from the ESP's. While in Sweden such practice is employed to increase heat recovery, the purpose in the United States is to improve particulate control removal efficiency. The scrubbers are used to reduce "snowing" (the emission of white particles resembling snowflakes) from inefficient ESP's. As the scrubbers are primarily low energy scrubbers, little additional removal would result of fine particulate which is emitted from a well designed and maintained ESP. It is reported that the principal cause of snowing is the electrode rapping done to dislodge collected material on the collection plates. The salt cake particles tend to be light and fluffy and upon rapping is dislodged and reentrained in the exhaust gases. Other causes of snowing are excessive electrical sparking and overloading during sootblowing or abnormal furnace operation.

Lime Kilns

Nearly all lime kilns are controlled with venturi scrubbers.[2-1] The typical venturi scrubber on a lime kiln in the kraft pulp industry operates with pressure drops ranging from 10 to 25 in. of water (2.5×10^3 to 6.2×10^3 Pa). With such pressures, removal efficiencies of about 99 percent are possible. Impingement scrubbers have also been used in the industry with pressure drops of 5 to 6 in. (1.2×10^3 to 1.5×10^3 Pa) of water which result in removal efficiencies of only 90 percent.

While ESP's are found on lime kilns in Sweden, only one installation in the United States employs an ESP. At that installation, an ESP has been retrofitted to control particulate emissions from 3 lime kilns with removal efficiency of about 99 percent.

Smelt Dissolving Tank Vents

Exhaust gases from smelt dissolving tank vents are ducted through demister pads, packed towers, or venturi scrubbers for particulate control. Demister pads are basically five wire mesh screens about 1 ft (0.3 cm) thick which act as a low energy scrubber. Droplets condense on the mesh and are backflushed with water sprays into the smelt dissolving tank. Low pressure drop venturis (6 to 8 in. of water (1.5×10^3 to 2.0×10^3 Pa)) and packed towers are also used in the industry with particulate removal efficiency of up to 95 percent.

Occasionally, smelt dissolving tank gases are combined with recovery furnace gases and ducted to a common ESP.[2-1]

References for Section 2

2-1. U.S. Environmental Protection Agency. "Standards Support and Environmental Impact Statement." _Volume 1: Proposed Standards of Performance for Kraft Pulp Mills_. EPA 450/2-76-014-a, 1976.

2-2. _Atmospheric Emissions from the Pulp and Paper Manufacturing Industry_. Cooperative Study of EPA (450/1-73-002) and NCASI. Atmospheric Quality Improvement Technical Bulletin No. 69.

2-3. U.S. Environmental Protection Agency. _Environmental Pollution Control: Pulp and Paper Industry, Part I Air_. EPA-625/7-76-001, 1976.

2-4. Environmental Protection Service of Canada. _Air Pollution Emission and Control Technology: Wood Pulping Industry_. EPS-3-AP-77-6, 1979.

SECTION 3

KRAFT PULP INDUSTRY EMISSION FACTORS

Cumulative size-specific emission factors have been developed for the kraft pulp industry based upon Southwest Research Institute (SoRI) two-cyclone train and cascade impactor test results. Emission factors are presented for uncontrolled and controlled emissions from

- Recovery furnaces
- Lime kilns
- Smelt dissolving tank vents

As described previously, an extensive literature review was conducted to locate inhalable particulate data. Sources of data that reported the results of measurements and observations of the author were considered as primary sources. Secondary sources were those where the author reported emission data performed by a different organization. Initially, only primary sources were considered suitable for calculating inhalable particulate emission factors.

When attempts failed to obtain the primary sources on which key secondary sources were based, it became necessary to utilize certain secondary sources in the development of inhalable particulate emission factors for the kraft pulp industry.

All data sources thus collected were ranked using the A through D grading system based on data quality and reliability according to the criteria from AP-42,$^{3-1}$ described in Section 2.

3.1 EMISSION FACTORS BASED UPON A-RATED DATA

As described earlier, preference was given to emission factors that could be calculated directly from the data available. Table 3-1 presents a summary of the A-rated emission data. Data were available for both a direct contact evaporator recovery furnace and a nondirect contact evaporator

TABLE 3-1. SUMMARY OF A-RATED EMISSION DATA

Emission point	Source	Control device	Type of emission data	Date	Reference
Recovery furnace (DCE)	Longview Fiber Company Longview, WA	ESP	Controlled and uncontrolled	September 1981	3-2
Recovery furnace (Non-DCE)	St. Regis Paper Company Tacoma, WA	ESP	Controlled and uncontrolled	September 1981	3-2
Lime kiln	Longview Fiber Company Longview, WA	Venturi scrubber	Controlled and uncontrolled	September-October 1981	3-2

recovery furnace, and for a lime kiln. Similar data for emissions from a smelt dissolving tank vent were judged to be unacceptable for calculation of emission factors for reasons described under "Other Emission Data."

Recovery Furnace (DCE), Longview Fibre

Data were obtained from a series of particulate mass and particle size tests conducted on the no. 19 recovery furnace at the Longview Fibre Company. The purpose of the tests was to quantify and characterize particulate matter particle size emission factors at 15 and 2.5 μm diameters for uncontrolled and controlled emissions. The no. 19 recovery furnace was manufactured by Combustion Engineering and burns 240 to 280 gal/min (1.5×10^{-2} to 1.8×10^{-2} m^3/sec) of black liquor with a solids content of approximately 65 percent. Makeup salt is seldom added during the process. Particulate matter in the furnace exhaust gases is removed by a Research-Cottrell ESP. It has two parallel chambers, each having eight electrical fields. The results of the emission tests on the no. 19 recovery furnace are summarized in Table 3-2 and the cumulative emission factors are shown graphically in Figures 3-1 and 3-2.

Recovery Furnace (Non-DCE), St. Regis Paper Co.

A series of particulate mass and particle size tests similar to those at Longview Fibre were conducted on the non-DCE recovery furnace at St. Regis Paper Co. The purpose was to quantify and characterize particulate matter particle size emission factors at 15 and 2.5 μm diameter for uncontrolled and controlled emissions. The no. 4 recovery furnace, on which the tests were made, was manufactured by Combustion Engineering. The furnace burns 200 to 250 gal/min (1.3×10^{-2} to 1.6×10^{-2} m^3/sec) of black liquor with a solids content of approximately 65 percent. The amount of makeup salt in the process varies with different white liquor cooking batches. Particulate matter is removed from the flue gases by a Wheelabrator/Lurgi ESP with two parallel chambers with four electrical fields per chamber. The results of the emission tests on the no. 4 furnace are summarized in Table 3-3 and the cumulative emission factors shown graphically in Figures 3-3 and 3-4.

Lime Kiln, Longview Fibre Co.

The data for the lime kiln presented here were obtained from a series of particulate mass and particle size tests conducted on the no. 2 lime kiln at Longview Fibre Company. The purpose of the tests was to quantify and characterize particulate matter particle size emission factors for uncontrolled and controlled emissions. Uncontrolled emissions were measured using SoRI two-cyclone train with backup filter. Controlled emissions were

TABLE 3-2. EMISSION FACTORS BASED ON PARTICULATE MASS AND SoRI TWO-CYCLONE SIZE DISTRIBUTION DATA[a]

	Size distribution mass		Emission factors	
Particle size (μm)	Uncontrolled (percent)	Controlled (percent)	Uncontrolled (lb/ton)[b]	Controlled (lb/ton)[b]
Total	100.00	100.00	97.03	0.736
>15	4.02	22.30	3.95	0.169
2.5 to 15	18.37	31.77	18.38	0.238
<2.5	77.61	30.16	74.70	0.330

[a] Data represent the average of three tests.

[b] Tons of air-dried pulp. To convert to kilograms per metric ton, multiply by 0.5.

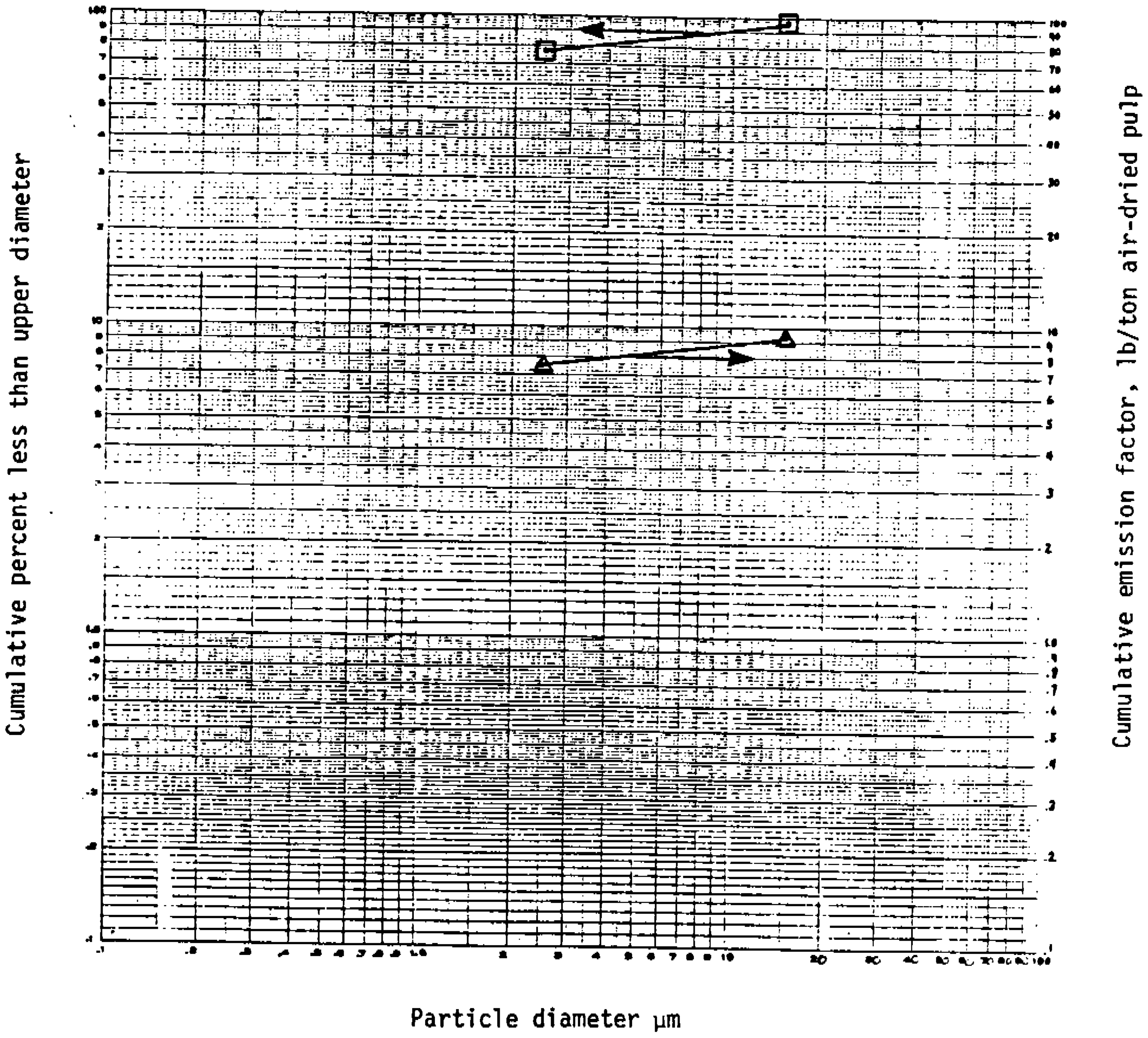

Figure 3-1. Cumulative size distribution and emission factors for uncontrolled emissions from a recovery furnace (DCE).[3-2]

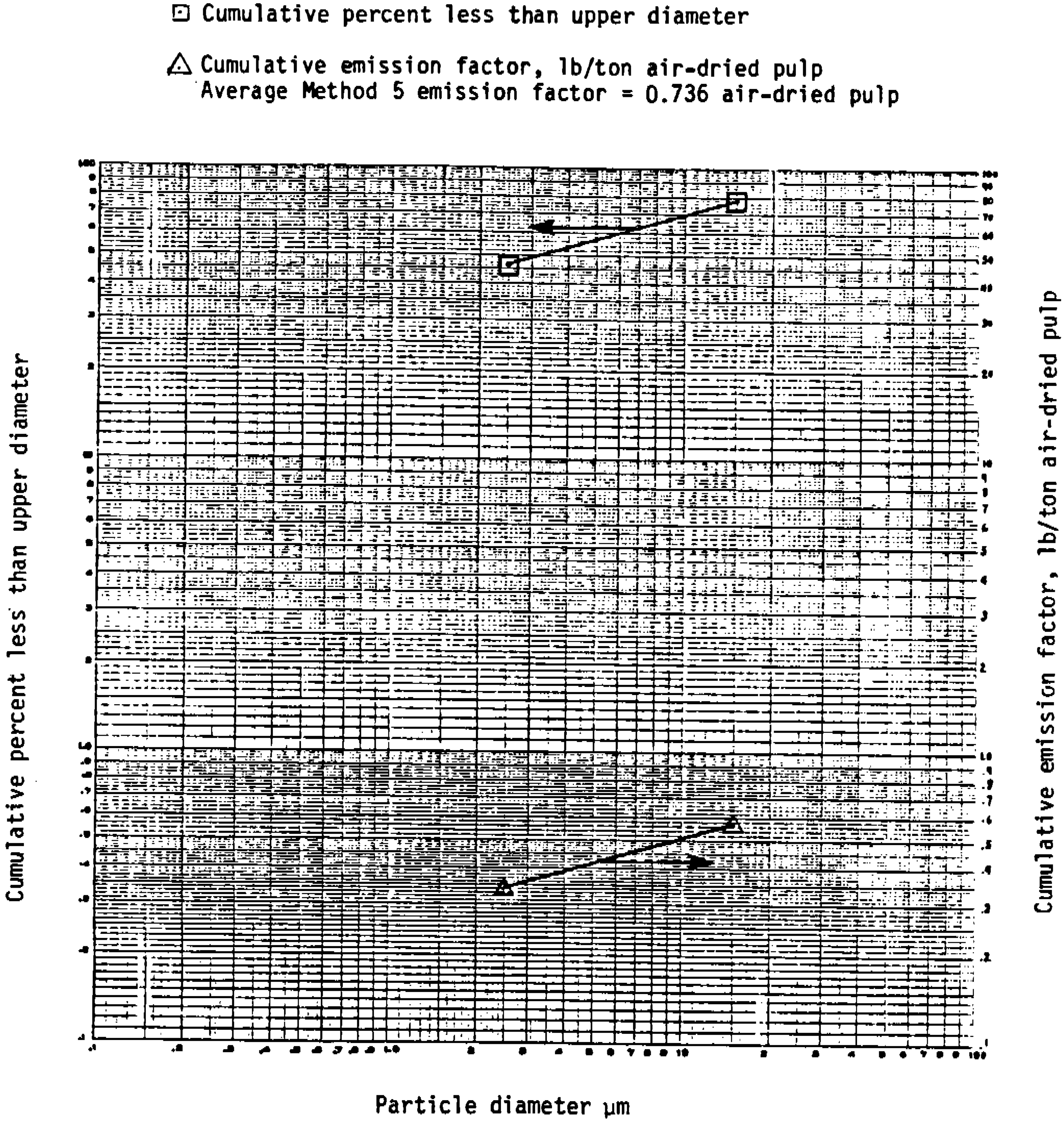

Figure 3-2. Cumulative size distribution and emission factors for ESP-controlled emissions from a recovery furnace (DCE).[3-2]

TABLE 3-3. EMISSION FACTORS BASED ON PARTICULATE MASS AND SoRI TWO-CYCLONE SIZE DISTRIBUTION DATA[a]

	Size distribution mass		Emission factors	
Particle size (μm)	Uncontrolled (percent)	Controlled (percent)	Uncontrolled (lb/ton)[b]	Controlled (lb/ton)[b]
Total	100	100	99.07	1.66
>15	19.22	17.95	18.80	0.36
2.5 to 15	9.97	11.85	9.90	0.19
<2.5	70.82	70.20	70.39	1.12

[a] Data represents the average of two tests.

[b] Tons of air-dried pulp. To convert to kilograms per metric ton, multiply by 0.5.

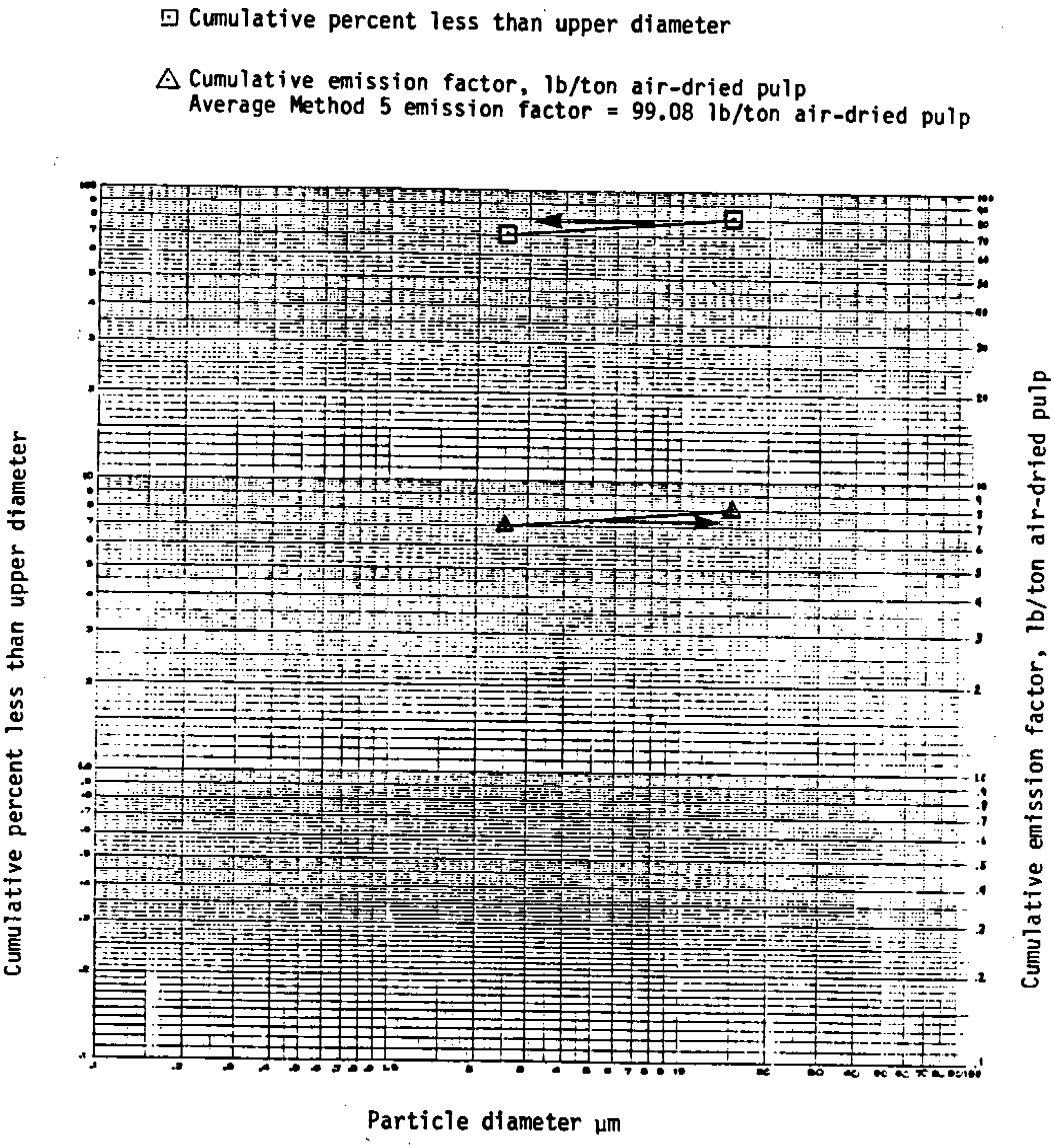

Figure 3-3. Cumulative size distribution and emission factors for uncontrolled emissions from a recovery furnace (Non-DCE).[3-2]

□ Cumulative percent less than upper diameter.

△ Cumulative emission factor, lb/ton air-dried pulp
Average Method 5 emission factor = 1.661 lb/ton.

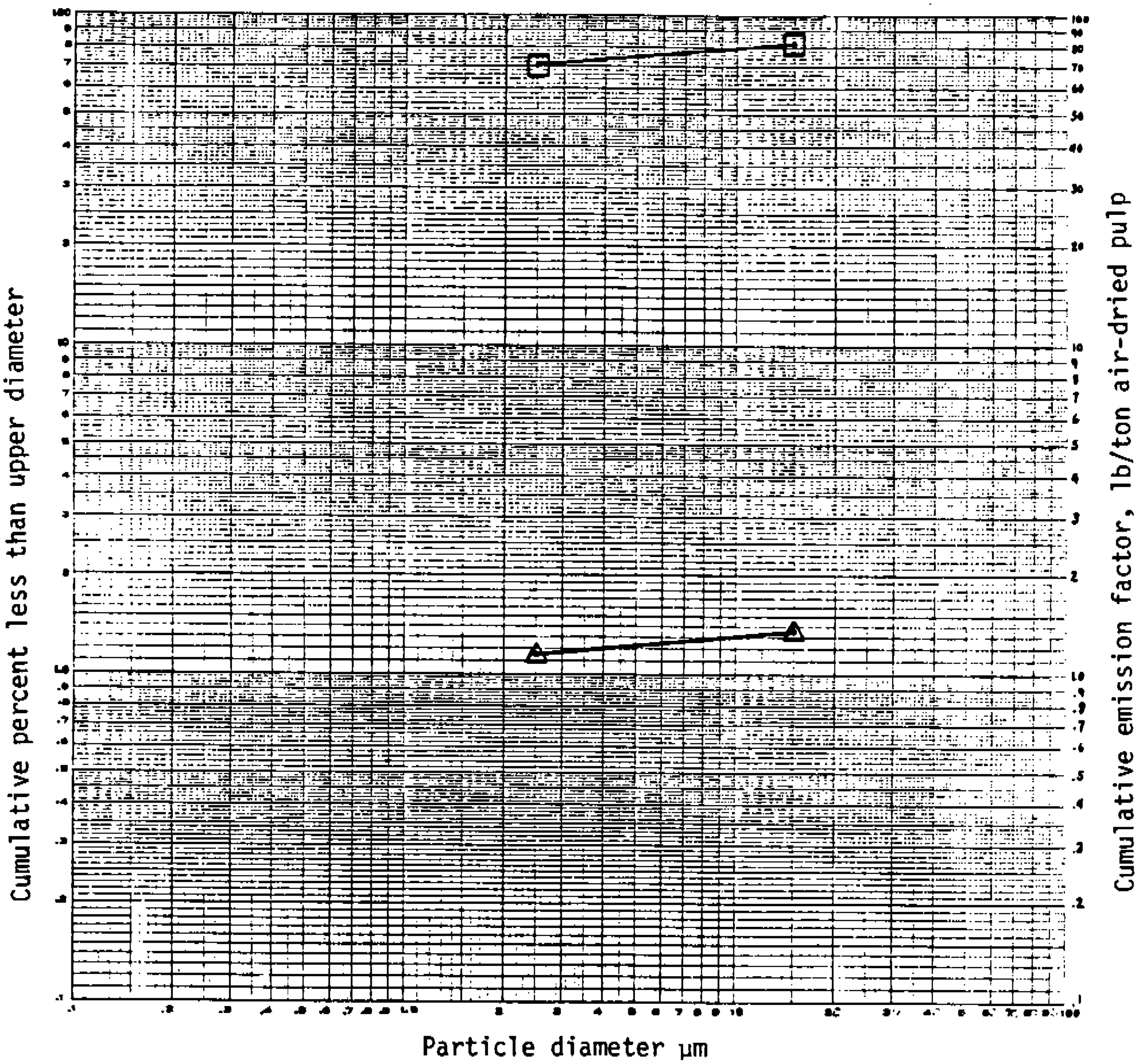

Figure 3-4. Cumulative size distribution and emission factors for ESP controlled emissions from a recovery furnace (Non-DCE).[3-2]

measured using an Anderson Mark III impactor with a 15-μm precutter. The no. 2 lime kiln was built by Traylor and produces 120 tons/day (1.1×10^5 kg/day) of lime. It is equipped with a Ducon Venturi scrubber to control particulate emissions. The results of the emission tests on the lime kiln are summarized in Tables 3-4 and 3-5 and presented graphically in Figures 3-5 and 3-6.

3.2 EMISSION FACTOR BASED UPON B-RATED DATA

Table 3-6 presents a summary of the B-rated emission data. Data were rated B because the cumulative size-specific emission factors must be obtained by multiplying the mass emission factor presented in AP-42[3-1] by the appropriate size distribution factor. Data were not available with which to calculate size-specific emission factors directly. The majority of data obtained through the extensive literature search fall into this category, as shown in Table 3-6, and are from a single reference, Technical Bulletin No. 94 published by NCASI[3-3]. The sources of the data were not identified in the bulletin and, therefore, data were identified in this report by the reference number assigned to them in Technical Bulletin No. 94.[3-3]

Recovery Furnace (DCE) -- Uncontrolled Emissions

Bosch et al.[3-3,3-6,3-8] and Pilat et al.[3-8] measured the size distribution of particulates emitted from a DCE recovery furnace for the purpose of evaluating a new type of cascade impactor. Cumulative weight percentages were arithmetically averaged to obtain the size distribution shown in Figure 3-7.

Larssen et al.[3-3,3-9] conducted tests on the DCE recovery furnace sampled previously by Bosch et al. using a University of Washington Mark I cascade impactor. The results obtained are shown in Figure 3-8.

Kutyna[3-3] measured the particle size distribution in the uncontrolled flue gas from a DCE recovery boiler using a Brink cascade impactor and in-line cyclone. The results are presented in Figure 3-9.

The results of these measurements on uncontrolled emissions are summarized in Table 3-7 for the cut points of concern. The values were obtained directly from the Figures presented in Technical Bulletin No. 94.[3-3]

Recovery Furnace (DCE) -- Controlled Emissions

Particle size distribution for controlled emissions from DCE recovery furnaces corresponded in both cases to furnaces equipped with ESP's. Kutyna[3-3] sampled a recovery furnace equipped with a four-field ESP to obtain

TABLE 3-4. EMISSION FACTORS BASED ON PARTICULATE MASS AND SoRI TWO-CYCLONE SIZE DISTRIBUTION DATA

Particle size (μm)	Size distribution mass uncontrolled (percent)	Emission factors uncontrolled (lb/ton)[b]
Total	100.00	82.04
>15	68.37	55.85
2.5 to 15	18.87	15.71
<2.5	12.77	10.47

[a] Data represent the average of two tests.

[b] Tons of air-dried pulp. To convert to kilograms per metric ton, multiply by 0.5.

TABLE 3-5. EMISSION FACTORS BASED ON PARTICULATE MASS AND ANDERSON IMPACTOR SIZE DISTRIBUTION DATA[a]

Particle size d_{50} (μm)	Cumulative mass (percent)	Cumulative emission factor controlled (lb/ton)[b]
11.6	71.59	0.44
10.5	71.07	0.44
6.7	70.87	0.44
4.4	69.50	0.43
2.4	68.78	0.43
1.3	66.86	0.41
0.68	59.77	0.37
0.37	43.54	0.27

[a] Data represent the average of two tests.

[b] Tons of air-dried pulp. To convert to kilograms per metric ton, multiply by 0.5.

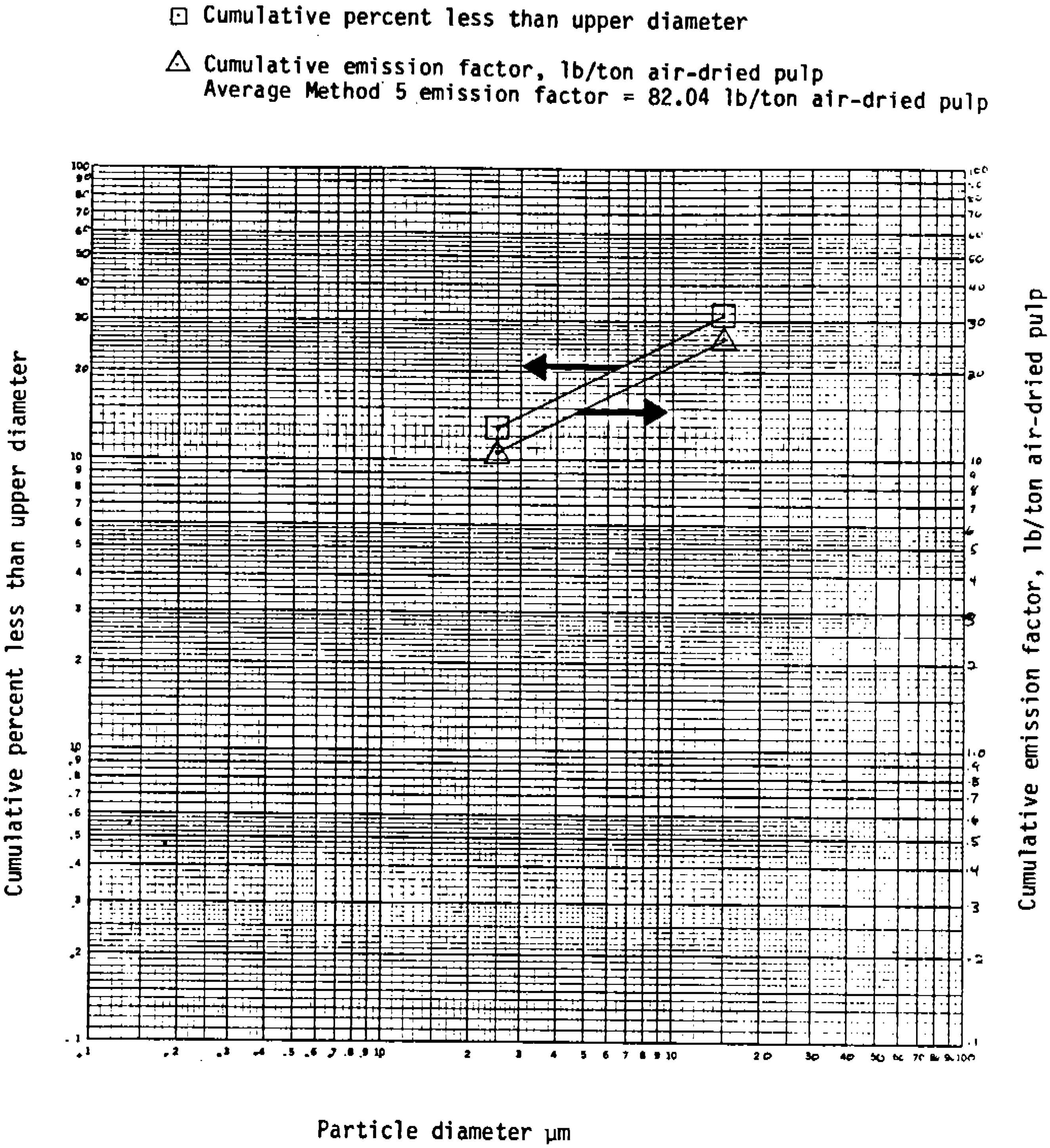

Figure 3-5. Cumulative size distribution and emission factors for uncontrolled emissions from a lime kiln.[3-2]

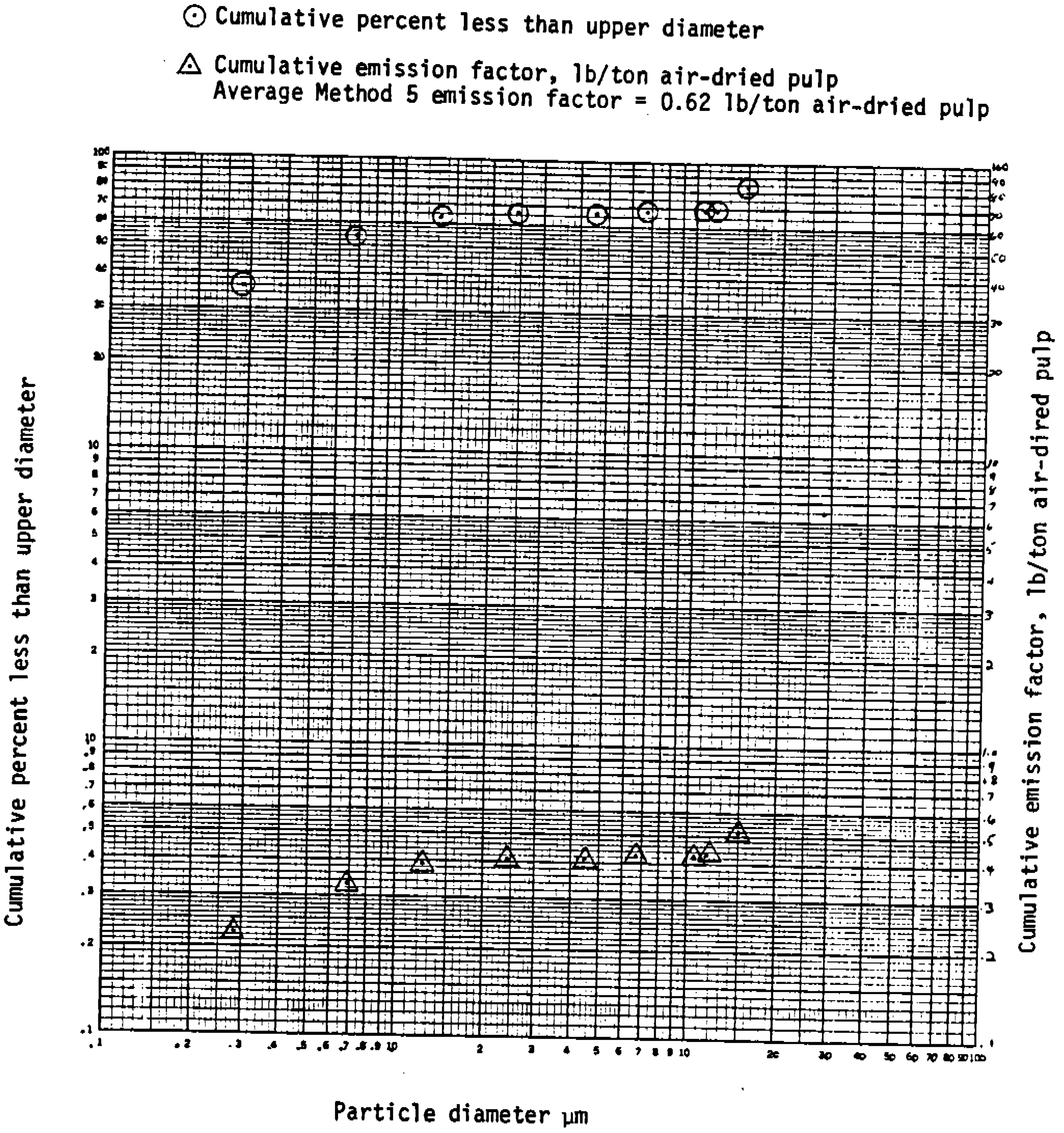

Figure 3-6. Cumulative size distribution and emission factors for venturi-scrubber-controlled emissions from a lime kiln.[3-2]

TABLE 3-6. SUMMARY OF B-RATED EMISSION DATA

Emission point	Source and location	Control device	Type of emission data	Date	Reference
Recovery furnace (DCE)	St. Regis Paper Co. Tacoma, WA "49"	--	Uncontrolled	June-July 1969	3-3,3-6,3-8
Recovery furnace (DCE)	Not specified "53"	ESP	Uncontrolled	Not specified	3-3,3-9
Recovery furnace (DCE)	Not specified "54"	ESP	Uncontrolled and controlled	Not specified	3-3
Recovery furnace (DCE)	Not specified	ESP	Controlled	Not specified	3-4
Recovery boiler (non-DCE)	Not specified "47"	--	Uncontrolled	Not specified	3-3,3-5
Recovery furnace (non-DCE)	Not specified "56"	ESP	Controlled	Not specified	3-3
Recovery furnace (non-DCE)	Not specified "57"	ESP	Controlled	Not specified	3-3
Recovery furnace (non-DCE)	Not specified "58"	ESP	Controlled	Not specified	3-3
Recovery furnace (non-DCE)	Not specified	ESP	Controlled	Not specified	3-3
Lime kiln	Not specified "61"	--	Uncontrolled	Not specified	3-3
Lime kiln	Not specified "62"	Venturi scrubber	Controlled	Not specified	3-3
Lime kiln	Not specified "63"	ESP	Controlled	Not specified	3-3
Smelt dissolving tank vent	Not specified "64"	Packed tower	Uncontrolled	Not specified	3-3
Smelt dissolving tank vent	Not specified "65"	Packed tower	Controlled	Not specified	3-3
Smelt dissolving tank vent	Not specified "66"	Venturi scrubber	Controlled	Not specified	3-3

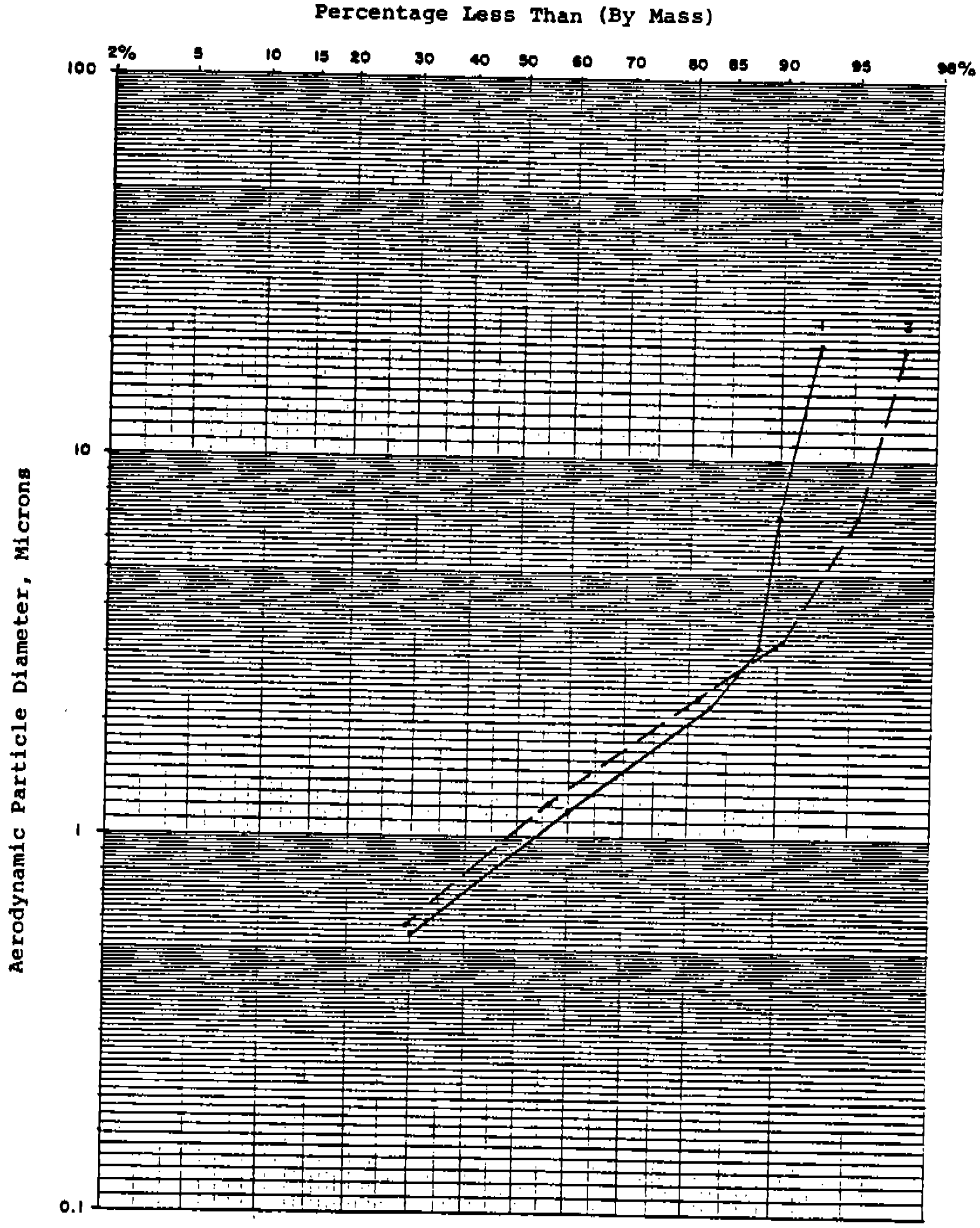

Figure 3-7. Cumulative size distribution for uncontrolled emissions from a recovery furnace (DCE).[3-3]

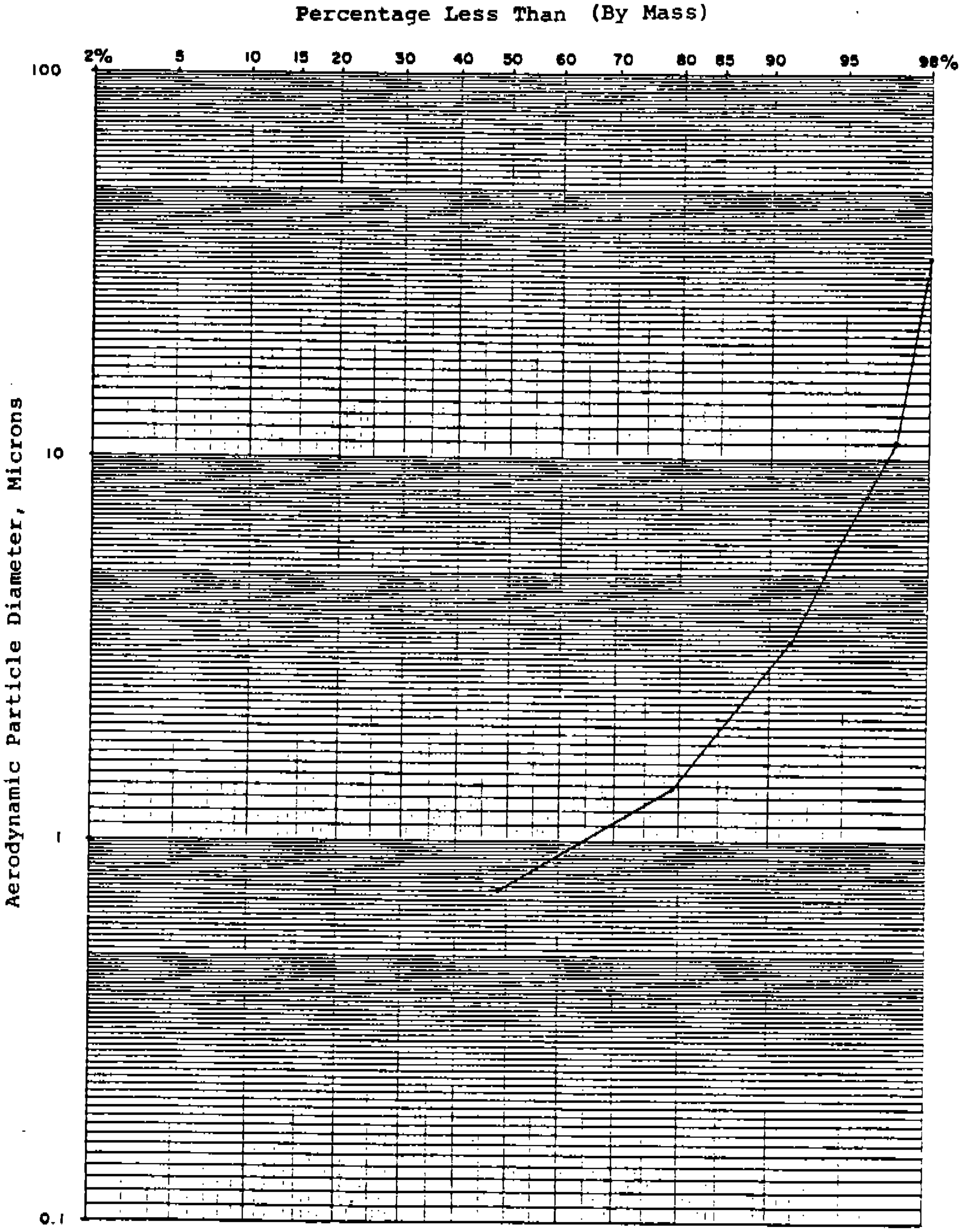

Figure 3-8. Cumulative size distribution for uncontrolled emissions from a recovery furnace (DCE).[3-3]

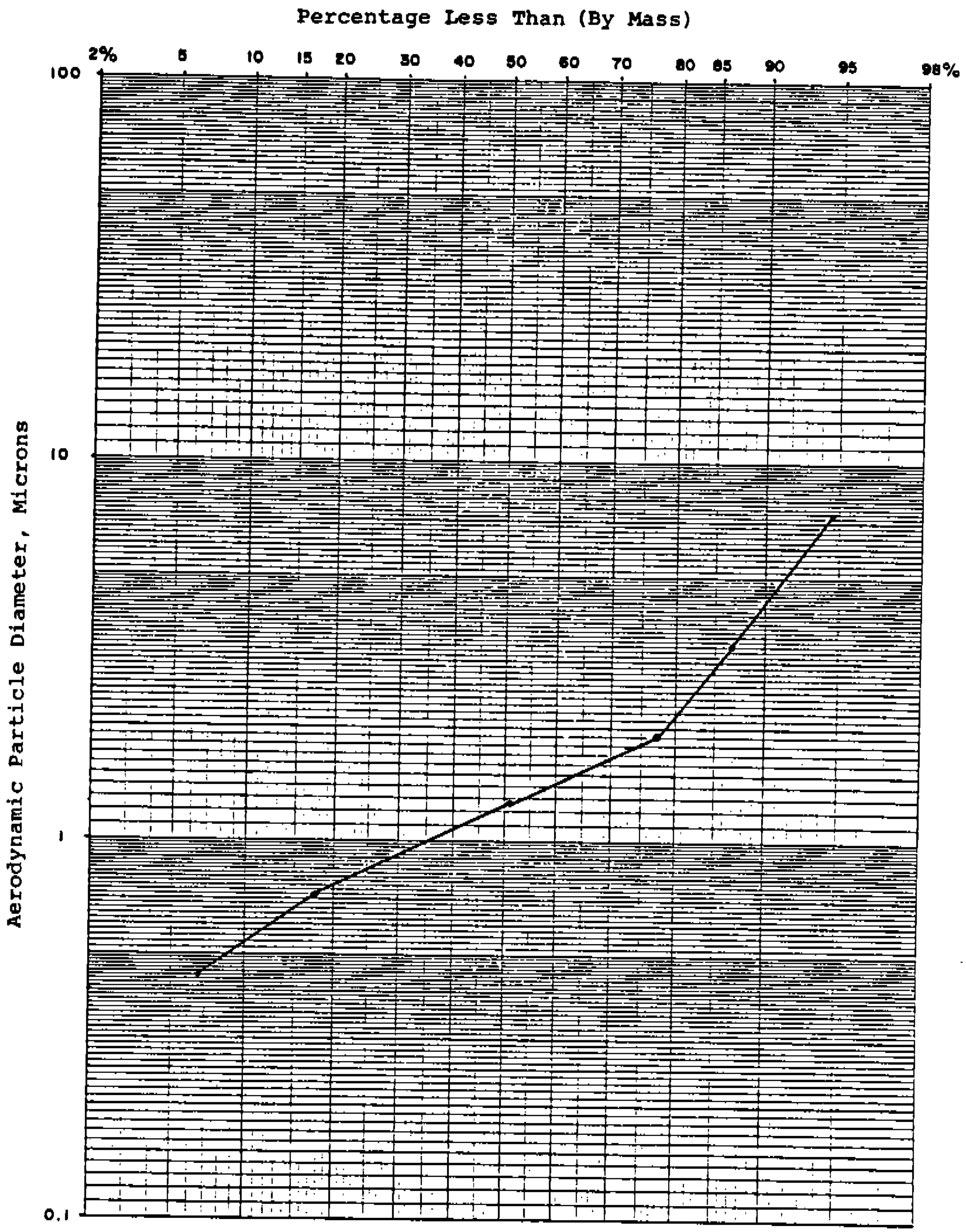

Figure 3-9. Cumulative size distribution for uncontrolled emissions from a recovery furnace (DCE).3-3

TABLE 3-7. SUMMARY OF B-RANKED PARTICLE SIZE DISTRIBUTION DATA FOR UNCONTROLLED EMISSIONS FROM A RECOVERY FURNACE (DCE)

Source	Reference	Cumulative percent less than							
		Total	15 μm	10 μm	6 μm	2.5 μm	1.25 μm	1.00 μm	0.625 μm
Unspecified "49"	3-3,3-6,3-8	100.0	93.0	91.0	89.5	83.0	63.0	53.0	33.5
Unspecified "53"	3-3,3-5	100.0	97.0	96.0	94.0	85.0	56.5	48.0	31.5
Unspecified "54"	3-3	100.0	--	--	93.0	82.5	50.0	35.0	14.5
Mean		100.0	95.0	93.5	92.2	83.5	56.5	45.3	26.5

the results presented in Figure 3-10. Additional data, shown in Figure 3-11, were obtained from NCASI.[3-4] Both sets of data are summarized in Table 3-8.

Recovery Furnace (Non-DCE) -- Uncontrolled Emissions

Only one set of data was found for uncontrolled emissions from a non-DCE recovery furnace. Paul[3-3,3-5] reported results for a series of four sampling tests as shown in Figure 3-12. The important data points are tabulated in Table 3-9.

Recovery furnace (non-DCE) -- Controlled Emissions

A significant amount of data exists on emissions from non-DCE recovery furnaces equipped with ESP's.

Figure 3-13[3-3] presents data for a non-DCE recovery furnace equipped with an ESP with a design efficiency of 99.8 percent. Seven particle sizing tests were conducted over a 10-day period on another non-DCE recovery furnace equipped with an ESP.[3-3] The Mark III cascade impactor was used to obtain the data shown in Figure 3-14. The same furnace was sampled subsequently by NCASI using the Mark III cascade impactor with the results shown in Figure 3-15.[3-3] As reported, the change in distribution to greater fine particulate was due to the application of increased insulation to minimize heat losses prior to flue gases exiting the stack.

Four Mark III cascade impactor tests were made at a non-DCE recovery furnace equipped with a two-chamber, four-field ESP.[3-13] The results are shown in Figure 3-16. It has been reported that the first three tests were under normal plant operating conditions but the fourth test occurred during "slightly abnormal furnace operation and power regulation difficulties with the last field of the ESP."

The data for non-DCE recovery furnaces is summarized in Table 3-10. The arithmetic mean was calculated for the cut points of concern for emissions from non-DCE recovery furnaces controlled with ESP's.

Lime Kiln -- Uncontrolled Emissions

Figure 3-17 presents the results of five tests performed on a lime kiln with the venturi scrubber not functioning.[3-3] The results for tests 1, 2, 4, and 5 were obtained with the Mark I cascade impactor while the results for test 3 were obtained with a Mark III cascade impactor. The data are summarized in Table 3-11.

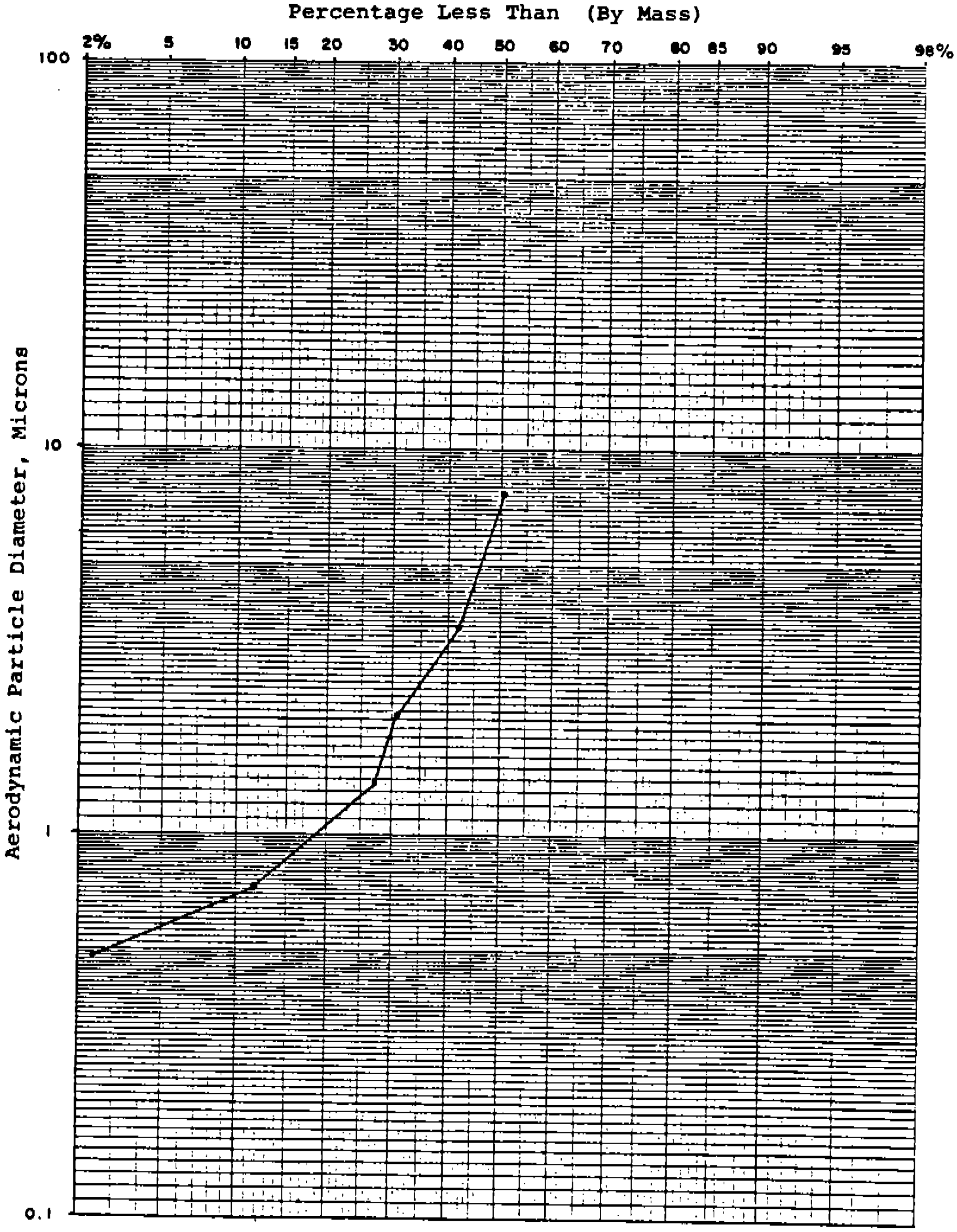

Figure 3-10. Cumulative size distribution for ESP-controlled emissions from a recovery furnace (DCE).3-3

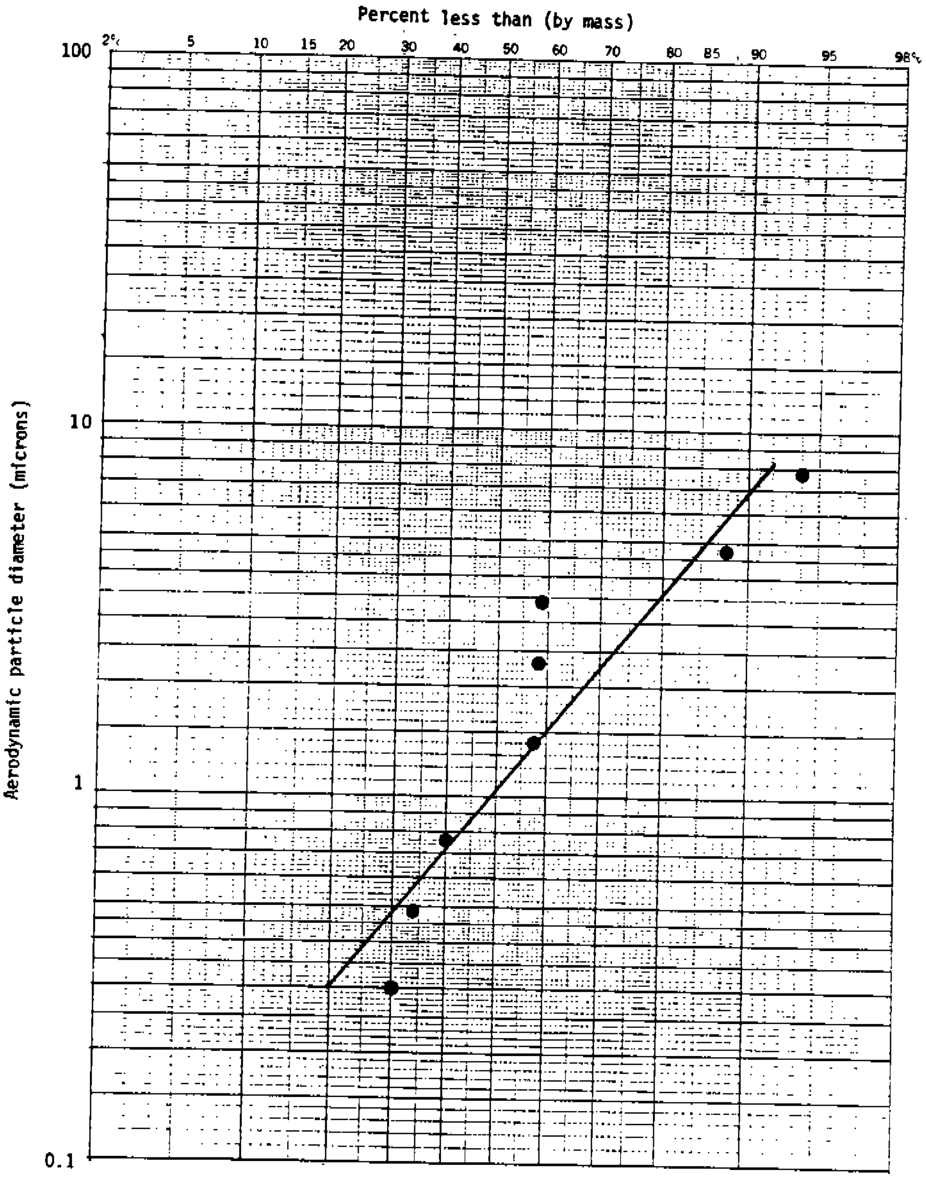

Figure 3-11. Cumulative size distribution for ESP controlled emissions from a recovery furnace (DCE).3-4

TABLE 3-8. SUMMARY OF B-RANKED PARTICLE SIZE DISTRIBUTION DATA FOR ESP-CONTROLLED EMISSIONS FROM A RECOVERY FURNACE (DCE)

Source	Reference	Cumulative percent less than							
		Total	15 µm	10 µm	6 µm	2.5 µm	1.25 µm	1.00 µm	0.625 µm
Unspecified "54"	3-3	100.0	--	--	48.0	35.0	25.0	18.5	7.0
Unspecified	3-4	100.0	--	--	88.5	72.5	56.0	50.0	37.5
Mean		100.0	--	--	68.2	53.8	40.5	34.2	22.2

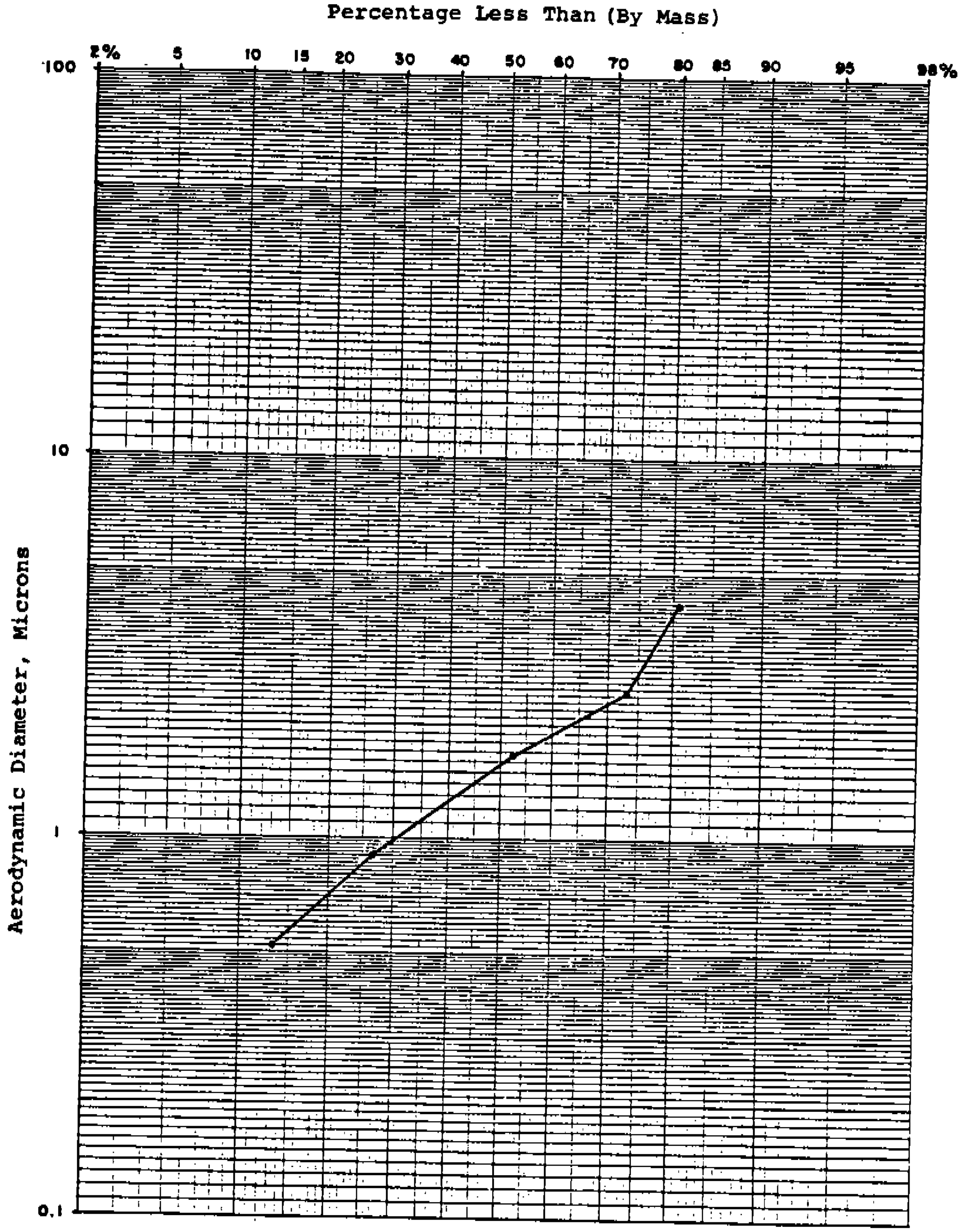

Figure 3-12. Cumulative size distribution for uncontrolled emissions from a recovery furnace (non-DCE).3-3

TABLE 3-9. SUMMARY OF B-RANKED PARTICLE SIZE DISTRIBUTION DATA FOR UNCONTROLLED EMISSIONS FROM A RECOVERY FURNACE (NON-DCE)

		Cumulative percent less than							
Source	Reference	Total	15 µm	10 µm	6 µm	2.5 µm	1.25 µm	1.00 µm	0.625 µm
Unspecified "47"	3-3,3-5	100.0	--	--	--	78.0	40.0	30.0	17.0

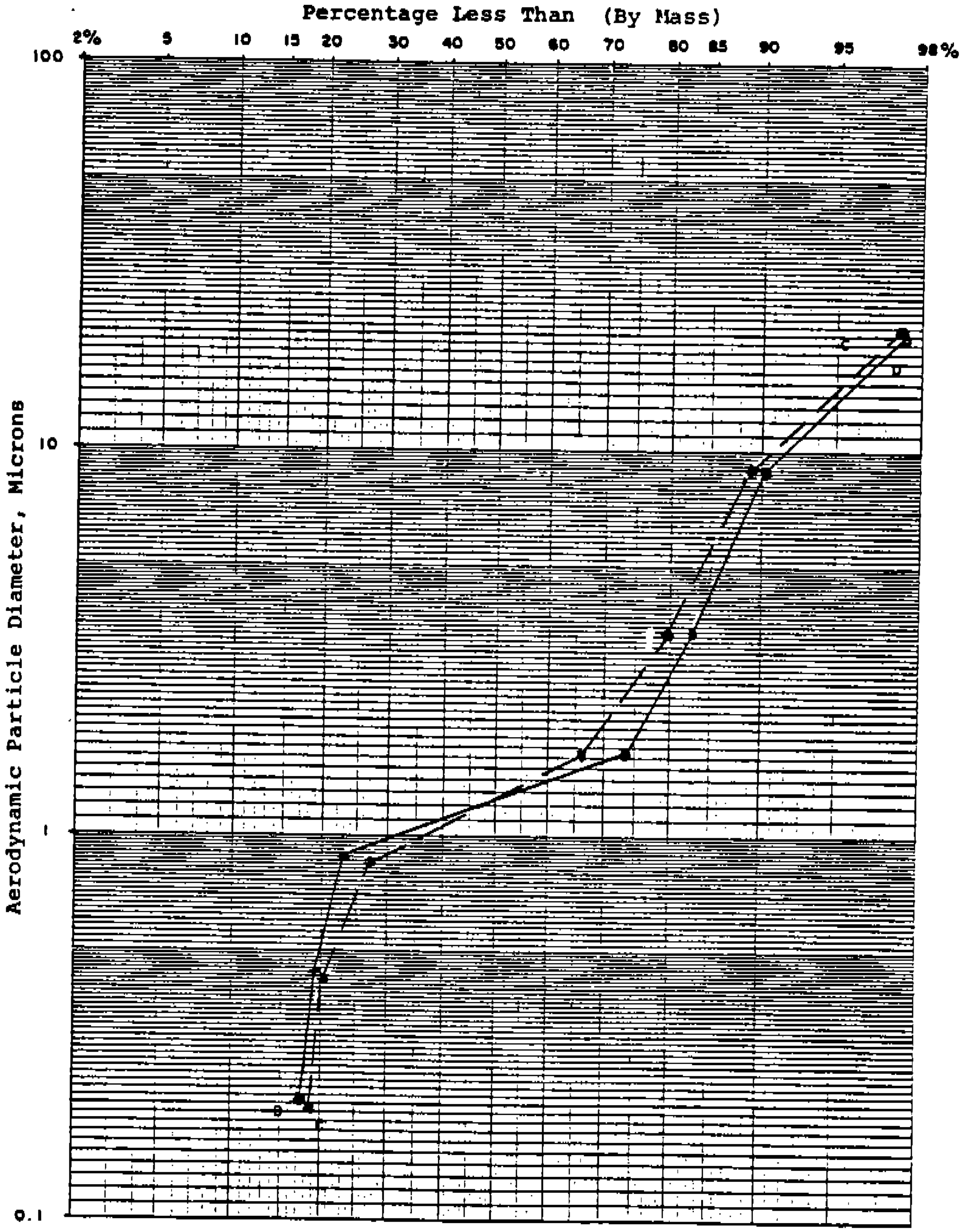

Figure 3-13. Cumulative size distribution for ESP-controlled emissions from a recovery furnace (non-DCE).3-3

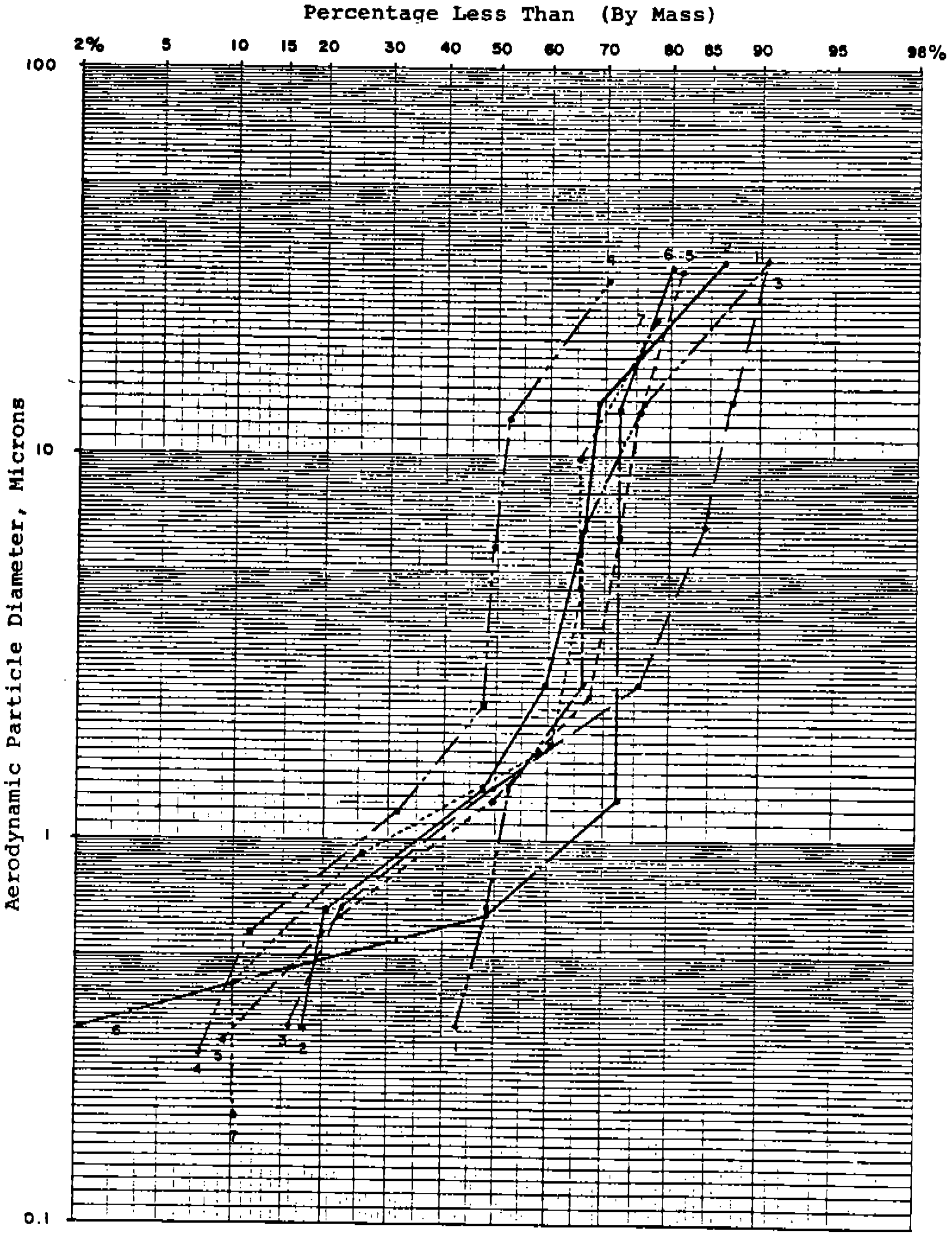

Figure 3-14. Cumulative size distribution for ESP-controlled emissions from a recovery furnace (non-DCE).3-3

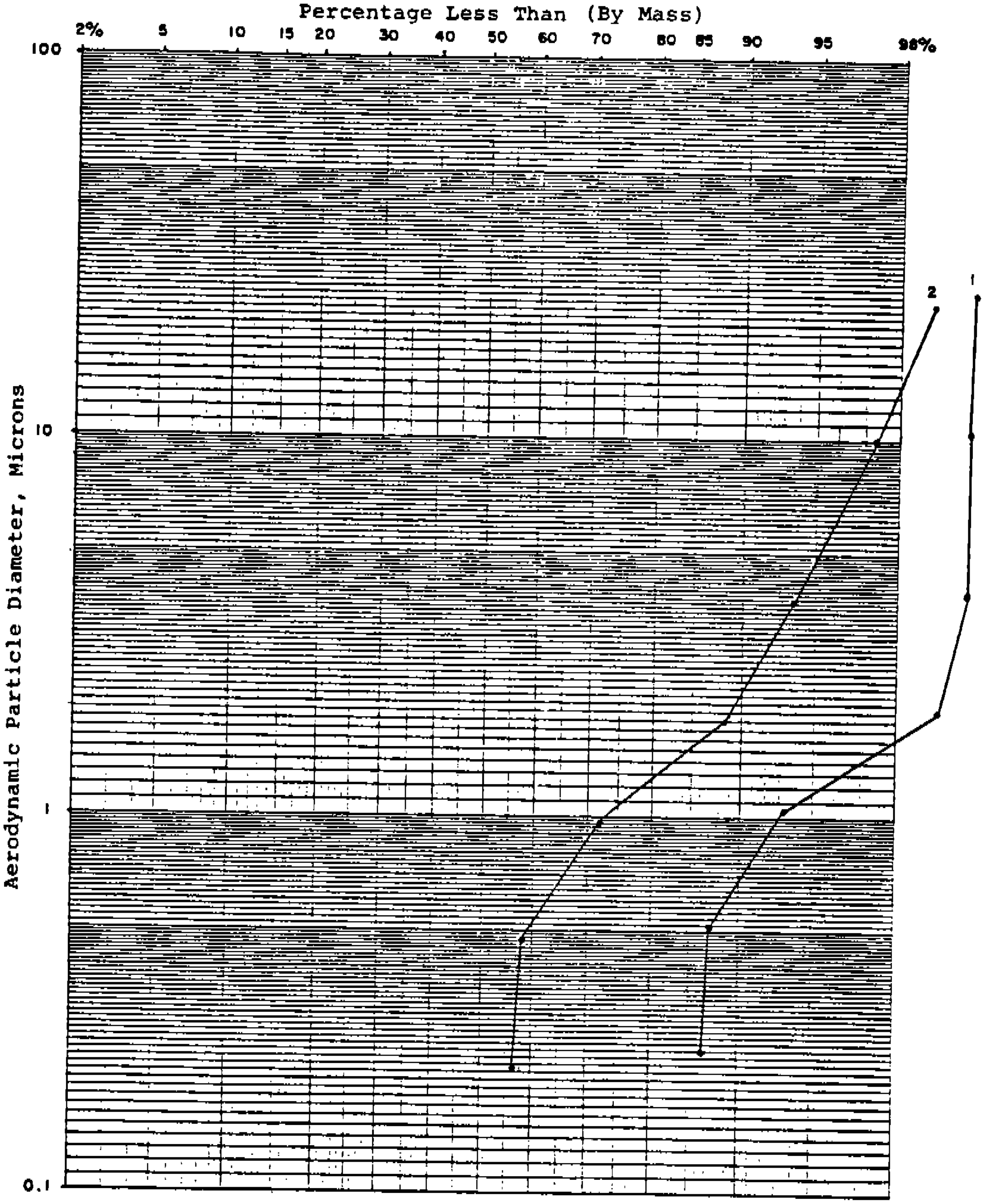

Figure 3-15. Cumulative size distribution for ESP-controlled emissions from a recovery furnace (non-DCE).[3-3]

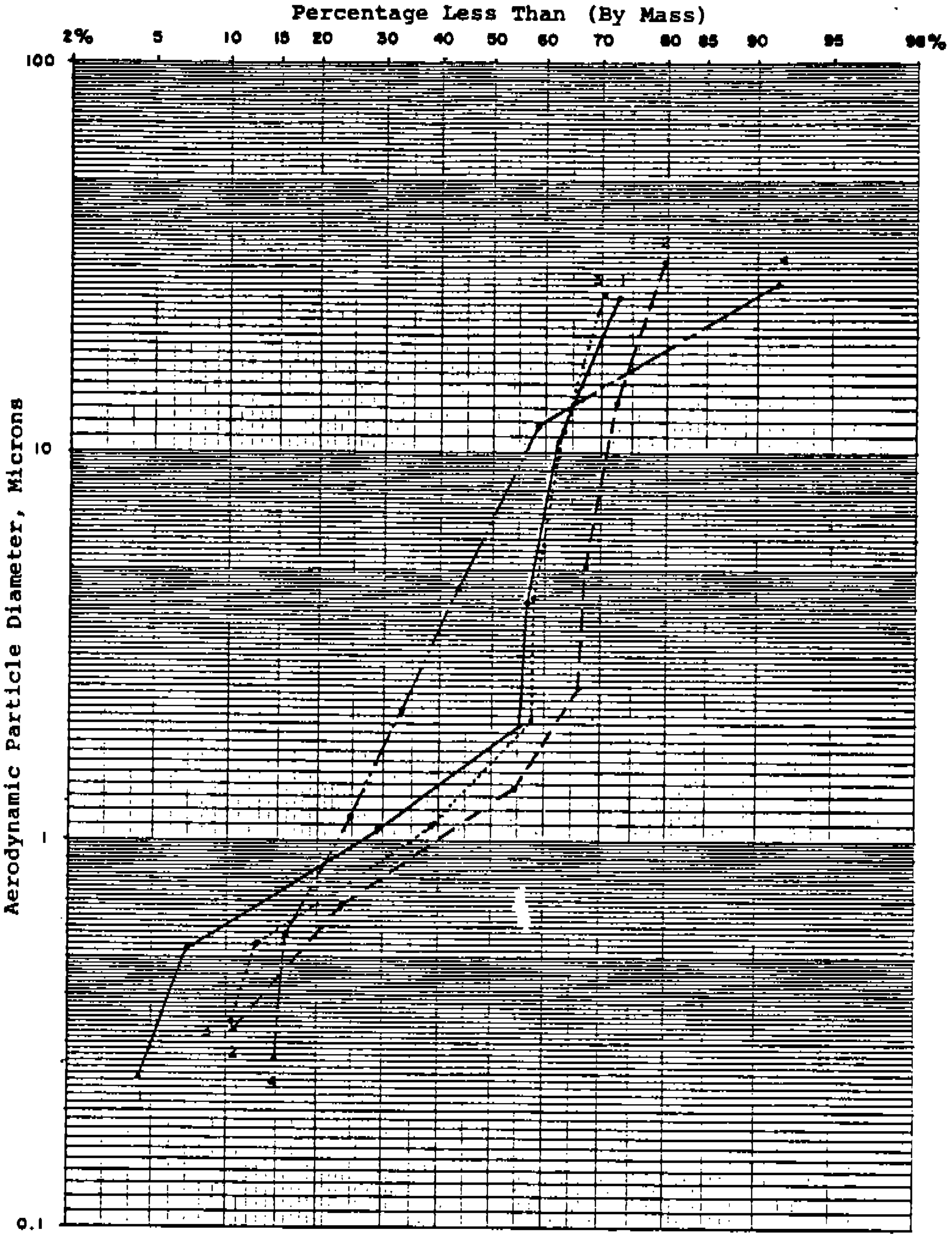

Figure 3-16. Cumulative size distribution for ESP-controlled emissions from a recovery furnace (non-DCE).[3-3]

TABLE 3-10. SUMMARY OF B-RANKED PARTICLE SIZE DISTRIBUTION DATA FOR ESP-CONTROLLED EMISSIONS FROM A RECOVERY FURNACE (NON-DCE)

Source	Reference	Cumulative percent less than							
		Total	15 μm	10 μm	6 μm	2.5 μm	1.25 μm	1.00 μm	0.625 μm
Unspecified "56"	3-3	100.0	95.0	90.5	85.5	75.0	50.0	36.5	24.0
		100.0	96.0	92.0	88.0	79.5	50.0	31.0	21.0
Unspecified "57"	3-3	100.0	78.0	72.5	66.0	66.0	52.0	51.0	48.0
		100.0	71.0	68.0	66.0	59.0	45.0	35.0	20.0
		100.0	88.0	86.0	83.6	75.5	46.0	37.0	22.0
		100.0	56.0	51.5	49.6	57.6	33.0	26.0	13.0
		100.0	76.5	74.5	72.0	67.5	50.0	40.0	22.0
		100.0	74.0	72.5	72.0	72.0	72.0	64.5	45.0
		100.0	72.5	66.0	66.0	62.5	42.0	30.0	16.5
Unspecified "58"	3-3	100.0	99.0	99.0	99.0	98.5	95.5	93.0	89.0
		100.0	98.0	97.5	96.0	91.0	80.0	73.0	63.0
Unspecified "59"	3-3	100.0	67.0	62.0	59.0	56.0	36.0	26.5	11.0
		100.0	73.5	71.0	68.0	66.0	50.0	40.0	21.5
		100.0	66.0	62.5	60.0	58.0	42.5	35.0	17.0
		100.0	71.0	56.0	48.0	35.0	26.0	23.0	17.0
Mean		100.0	78.8	74.8	71.9	67.3	51.3	42.4	29.6

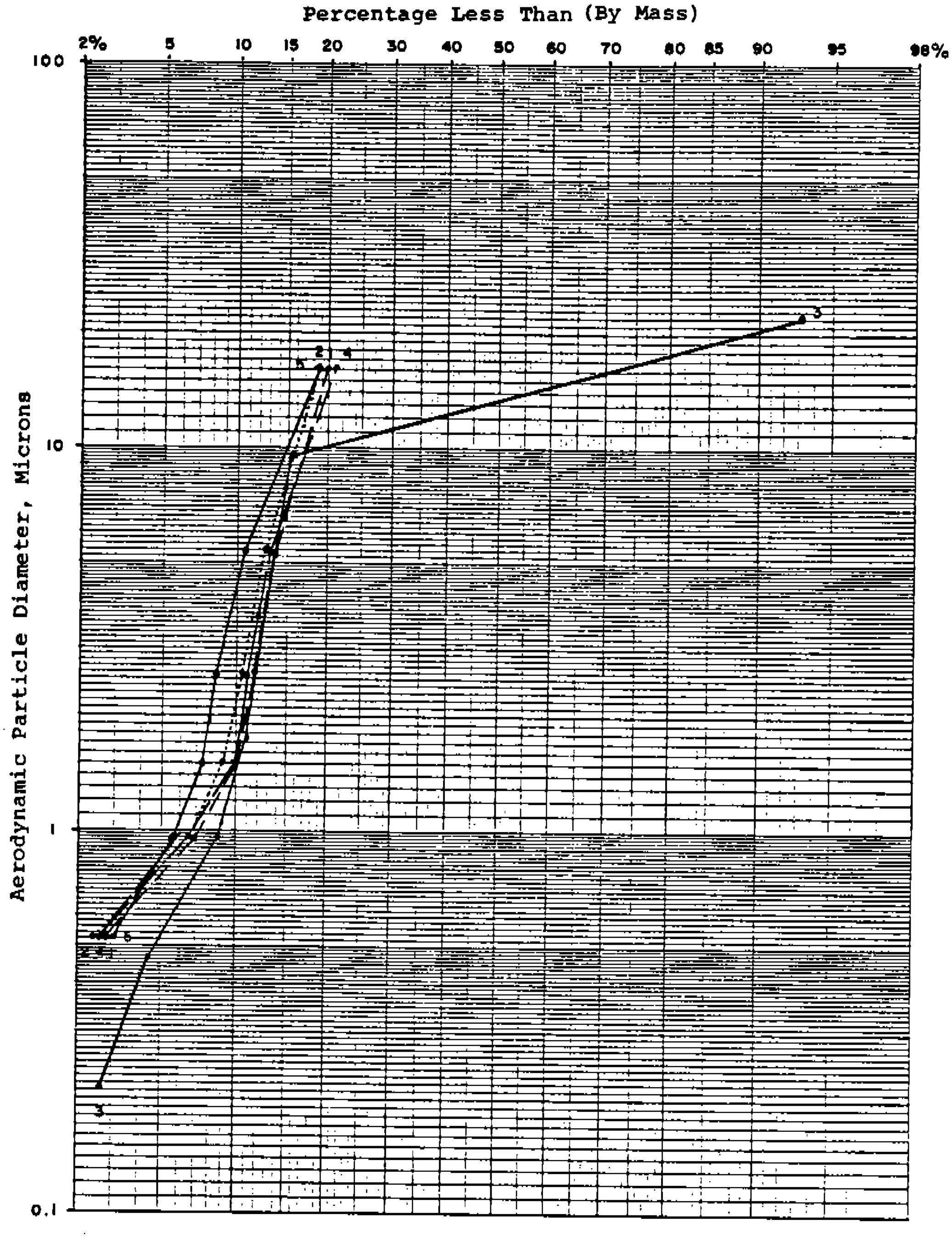

Figure 3-17. Cumulative size distribution for uncontrolled emissions from a lime kiln.[3-3]

TABLE 3-11. SUMMARY OF B-RANKED PARTICLE SIZE DISTRIBUTION DATA FOR UNCONTROLLED EMISSIONS FROM A LIME KILN

		Cumulative percent less than							
Source	Reference	Total	15 μm	10 μm	6 μm	2.5 μm	1.25 μm	1.00 μm	0.625 μm
Unspecified "61"	3-3	100.0	19.5	17.0	14.5	11.5	8.5	7.5	3.5
		100.0	18.0	16.0	13.0	10.5	8.0	7.0	3.5
		100.0	62.5	19.0	14.0	11.0	9.5	8.5	5.5
		100.0	20.5	17.0	14.0	11.5	8.5	7.0	5.5
		100.0	18.0	15.0	11.5	8.0	6.5	5.5	3.5
Mean		100.0	27.7	16.8	13.4	10.5	8.2	7.1	3.9

Lime Kiln -- Controlled Emissions

Particle size distribution data are available for a lime kiln whose emissions are controlled with a venturi scrubber and for a lime kiln equipped with an ESP.

The lime kiln with the venturi scrubber was sampled on four occasions with a modified University of Washington cascade impactor employing a heat tape to provide heating to the impactor.[3-3] The results of the four tests are shown in Figure 3-18 and summarized in Table 3-12.

The lime kiln with an ESP actually is three lime kilns exhausting to a common two-chamber, four-field ESP. Four tests, whose results are shown in Figure 3-19, were made using a Mark III cascade impactor. The cut points of concern are summarized in Table 3-13.

Smelt Dissolving Tank Vents -- Uncontrolled Emissions

Two tests were made to determine uncontrolled particle size distributions from a smelt dissolving tank vent.[3-3] The results shown in Figure 3-20 were obtained using the Mark II cascade impactor. The data are summarized in Table 3-14.

Smelt Dissolving Tank Vents -- Controlled Emissions

Data were available for particle size distributions from a smelt dissolving tank vent equipped with a packed tower and for a tank equipped with a venturi scrubber.

The modified Mark III cascade impactor was used to obtain the results shown in Figure 3-21[3-3] for the smelt dissolving tank with a packed tower. The results are summarized in Table 3-15.

The same modified Mark III cascade impactor was used to obtain the results presented in Figure 3-22.[3-3] The tank in this case was equipped with a high-energy venturi scrubber operating at 16 in. of water (4×10^3 Pa) pressure drop. The cut points of concern are summarized in Table 3-16.

Emission Factor Calculations

As mentioned earlier, there are insufficient process and production data for the size distributions presented in this section, to calculate cumulative size-specific emission factors directly. However, emission factors can be calculated by applying the mean cumulative percentages for each cut point to the mass emission factor presented in AP-42. Example:

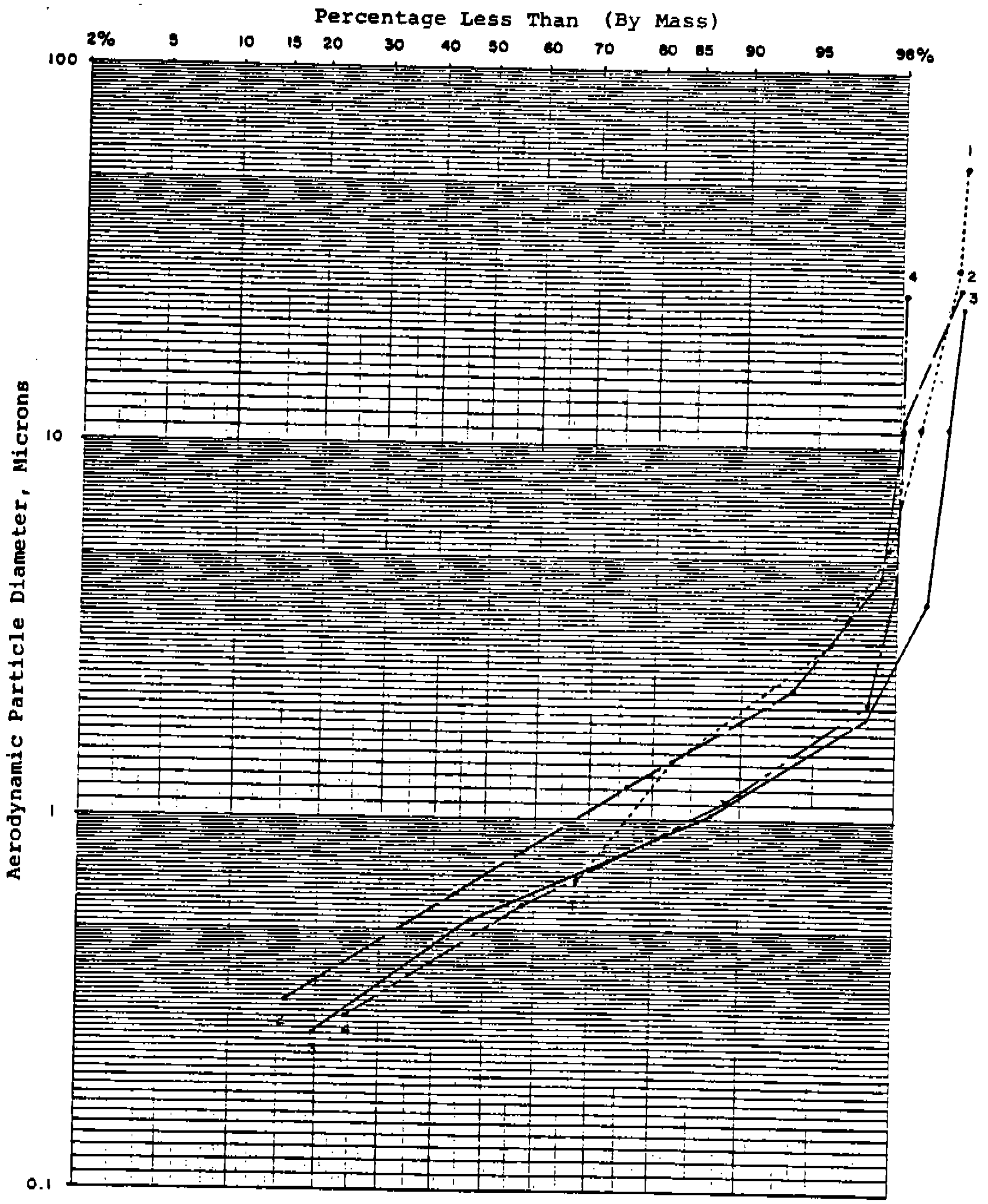

Figure 3-18. Cumulative size distribution for venturi-scrubber-controlled emissions from a lime kiln.[3-3]

TABLE 3-12. SUMMARY OF B-RANKED PARTICLE SIZE DISTRIBUTION DATA FOR VENTURI-SCRUBBER-CONTROLLED EMISSIONS FROM A LIME KILN

		Cumulative percent less than							
Source	Reference	Total	15 µm	10 µm	6 µm	2.5 µm	1.25 µm	1.00 µm	0.625 µm
Unspecified "62"	3-3	100.0	99.0	98.5	98.0	94.0	80.0	77.0	--
		100.0	98.5	98.0	98.0	94.5	77.5	67.5	44.0
		100.0	99.5	99.0	99.0	98.0	91.5	86.0	57.5
		100.0	98.5	98.0	98.0	97.5	91.0	85.0	61.5
Mean		100.0	98.9	98.3	98.2	96.0	85.0	78.9	54.3

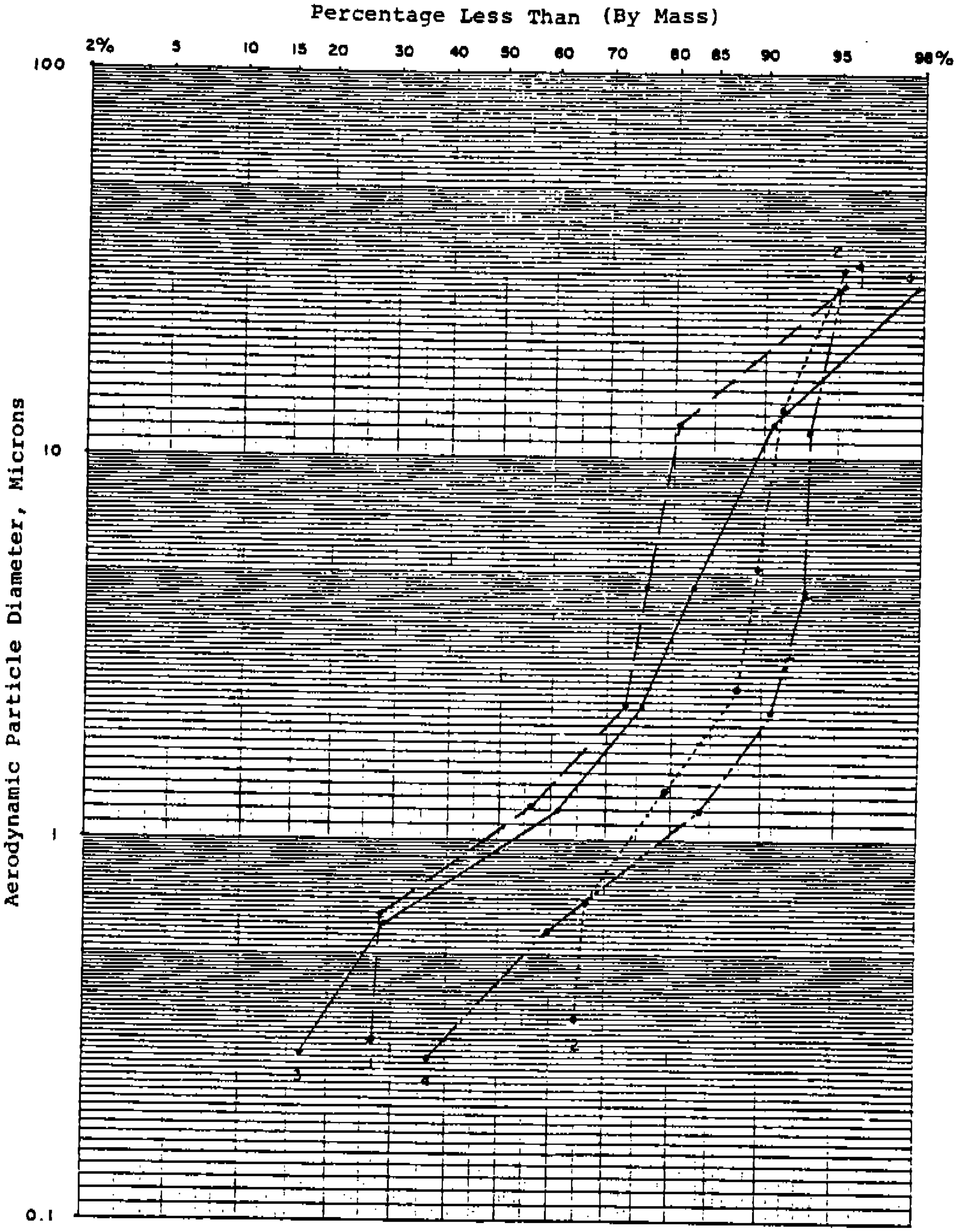

Figure 3-19. Cumulative size distribution for ESP-controlled emissions from a lime kiln.3-3

TABLE 3-13. SUMMARY OF B-RANKED PARTICLE SIZE DISTRIBUTION DATA FOR ESP-CONTROLLED EMISSIONS FROM A LIME KILN

		Cumulative percent less than							
Source	Reference	Total	15 µm	10 µm	6 µm	2.5 µm	1.25 µm	1.00 µm	0.625 µm
Unspecified "63"	3-3	100.0	86.0	80.0	77.5	73.5	57.0	47.0	28.0
		100.0	92.0	91.5	90.0	88.0	78.0	73.5	66.5
		100.0	93.0	89.5	85.5	78.5	62.0	52.5	30.5
		100.0	94.0	93.0	93.0	92.0	84.0	78.5	62.5
Mean		100.0	91.2	88.5	86.5	83.0	70.2	62.9	46.9

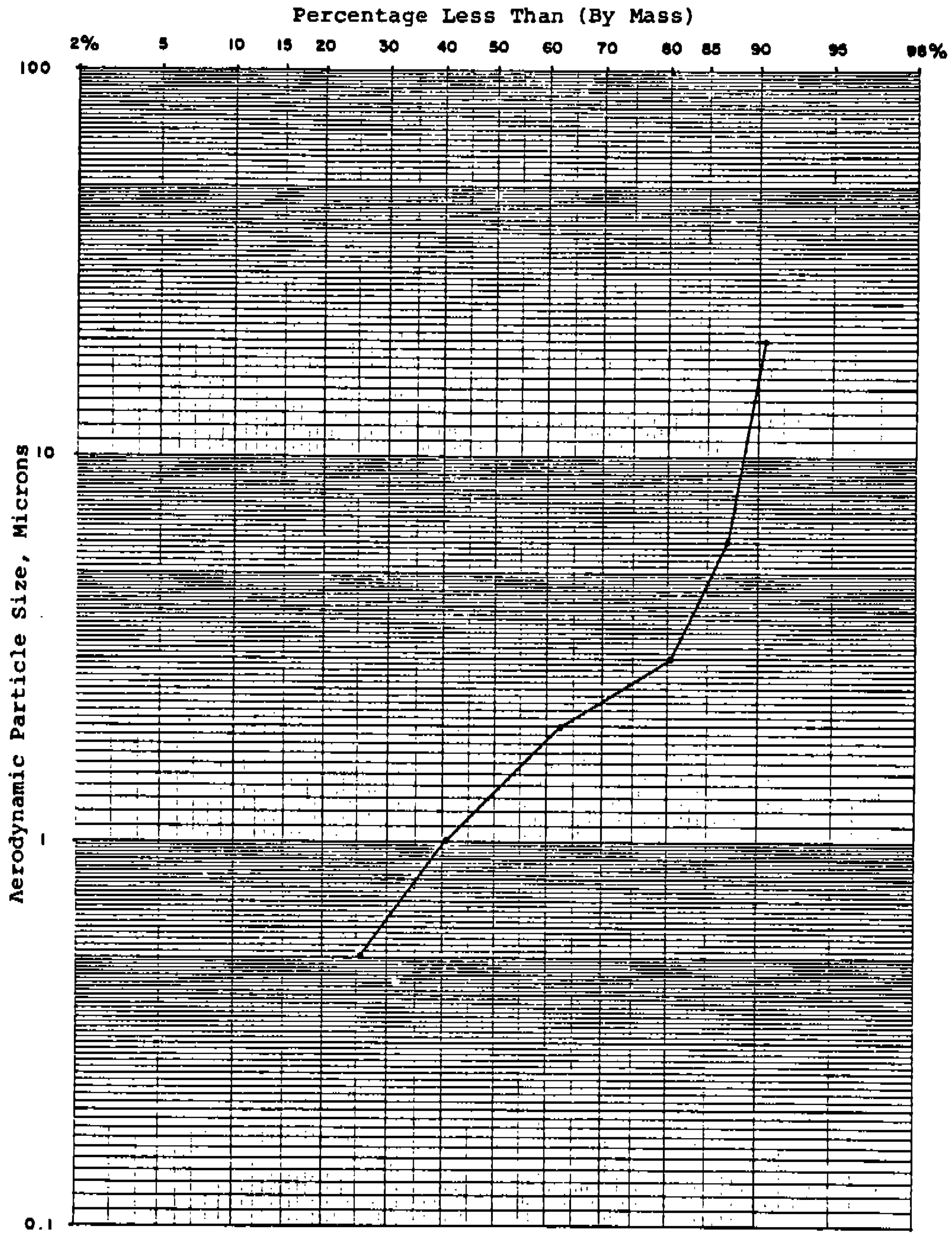

Figure 3-20. Cumulative size distribution for uncontrolled emissions from a smelt dissolving tank vent.[3-3]

TABLE 3-14. SUMMARY OF PARTICLE SIZE DISTRIBUTION DATA FOR UNCONTROLLED EMISSIONS FROM A SMELT DISSOLVING TANK VENT

Source	Reference	Cumulative percent less than							
		Total	15 µm	10 µm	6 µm	2.5 µm	1.25 µm	1.00 µm	0.625 µm
Unspecified "64"	3-3	100.0	90.0	88.5	87.0	73.0	47.5	40.0	25.5

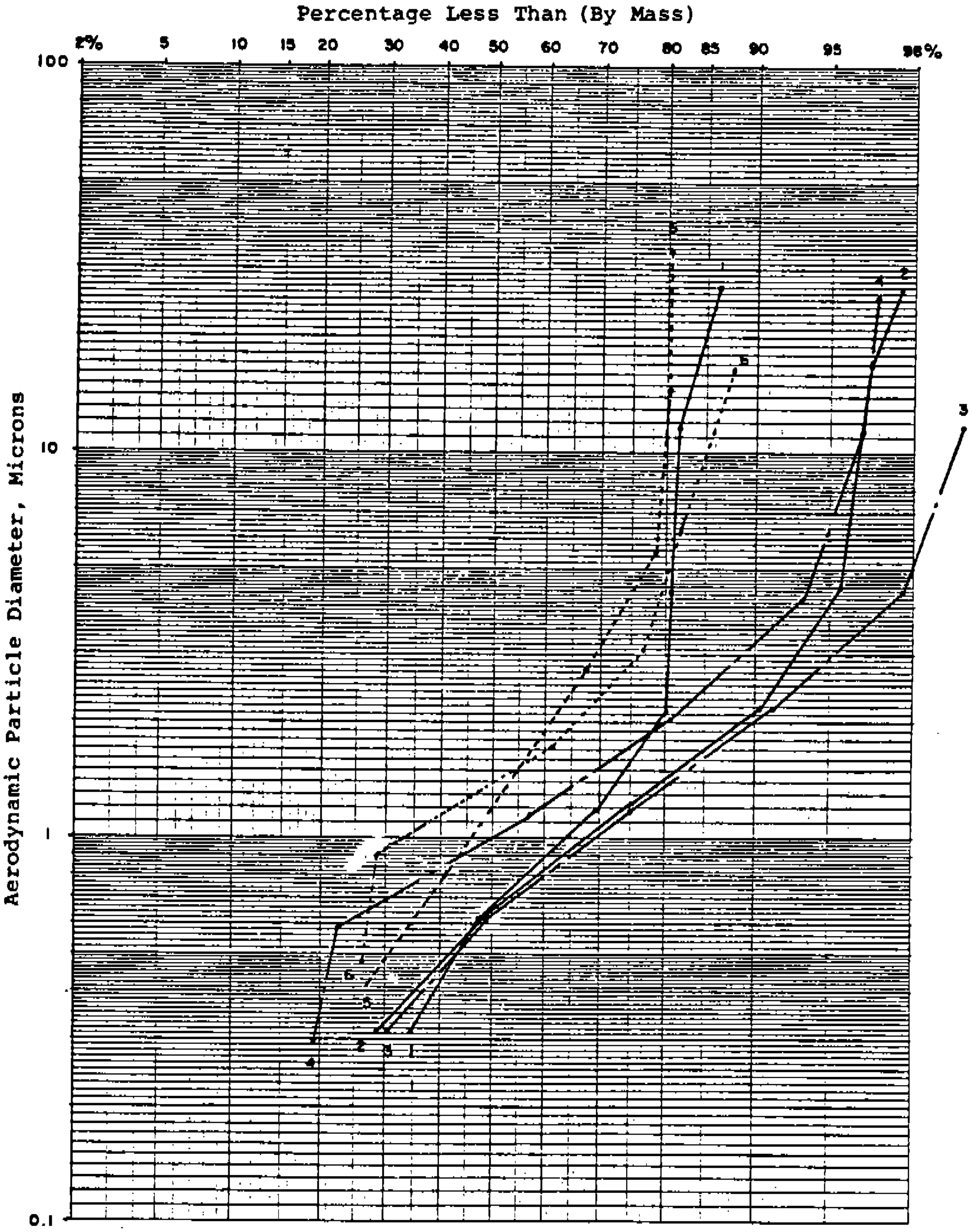

Figure 3-21. Cumulative size distribution for packed-tower-controlled emissions from a smelt dissolving tank vent.[3-3]

TABLE 3-15. SUMMARY OF B-RANKED PARTICLE SIZE DISTRIBUTION DATA FOR PACKED-TOWER-CONTROLLED EMISSIONS FROM A SMELT DISSOLVING TANK

		Cumulative percent less than							
Source	Reference	Total	15 µm	10 µm	6 µm	2.5 µm	1.25 µm	1.00 µm	0.625 µm
Unspecified "65"	3-3	100.0	93.5	93.0	93.0	93.0	76.0	62.0	32.0
		100.0	94.0	94.0	94.0	89.0	76.0	67.0	43.0
		100.0	98.0	97.0	94.0	70.0	43.0	35.0	20.0
		100.0	--	98.0	94.0	61.0	30.0	22.0	10.5
		100.0	96.0	96.0	96.0	91.5	72.0	64.0	49.0
		100.0	88.5	88.0	87.5	85.0	67.0	57.0	36.0
		100.0	98.5	98.5	98.0	96.0	72.0	62.0	39.0
		100.0	98.5	98.5	98.0	96.0	74.0	65.0	44.5
Mean		100.0	95.3	95.3	94.3	85.2	63.8	54.2	34.2

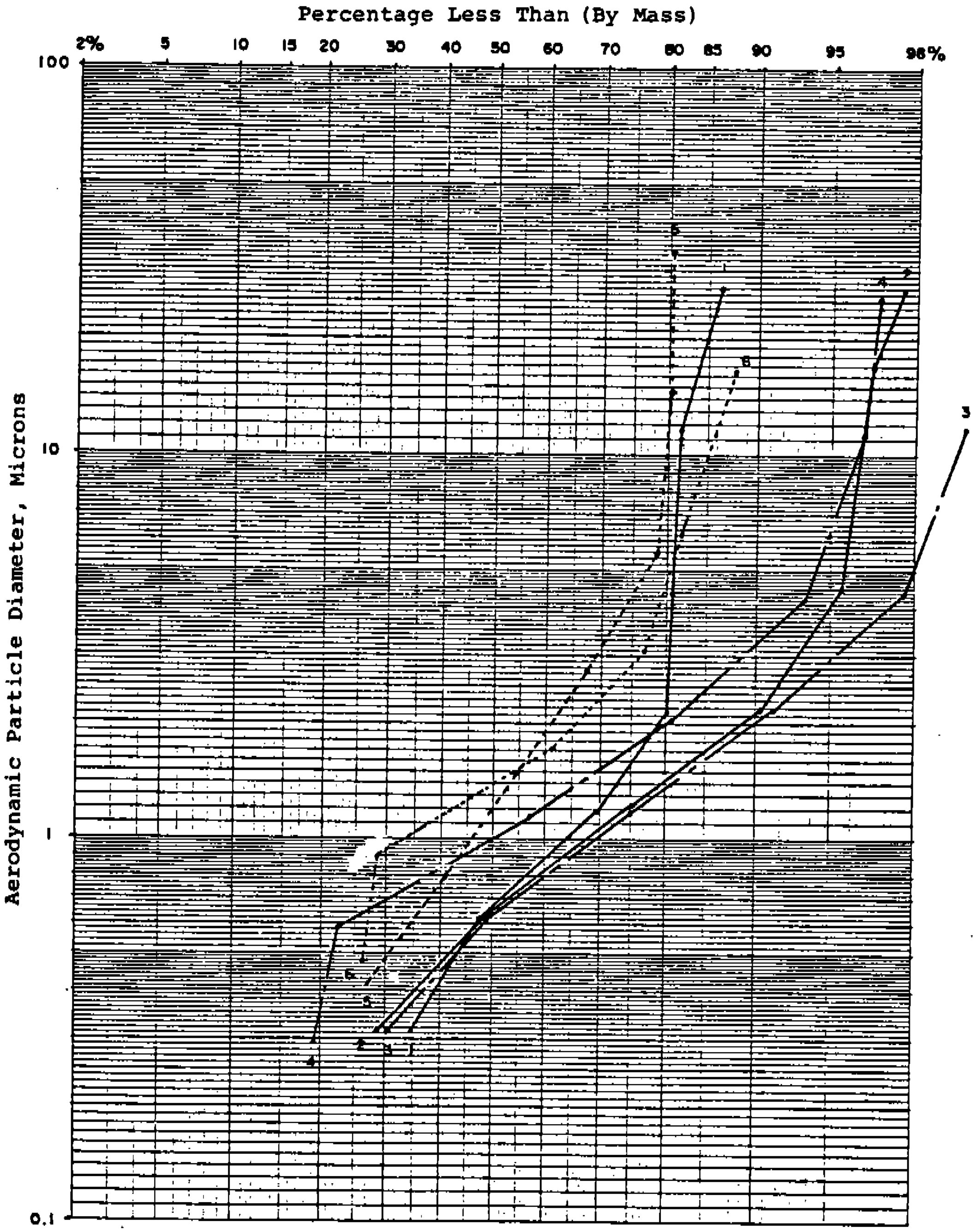

Figure 3-22. Cumulative size distribution for venturi-scrubber-controlled emissions from a smelt dissolving tank vent.3-3

TABLE 3-16. SUMMARY OF B-RANKED PARTICLE SIZE DISTRIBUTION DATA FOR VENTURI-SCRUBBER-CONTROLLED EMISSIONS FROM A SMELT DISSOLVING TANK VENT

Source	Reference	Cumulative percent less than							
		Total	15 µm	10 µm	6 µm	2.5 µm	1.25 µm	1.00 µm	0.625 µm
Unspecified "66"	3-3	100.0	85.0	81.0	81.0	80.0	71.0	63.5	48.0
		100.0	97.0	96.0	96.0	92.0	75.0	67.0	48.0
		100.0	--	99.0	98.5	93.0	77.0	68.5	49.0
		100.0	97.0	96.0	95.0	85.0	62.0	50.0	25.0
		100.0	80.5	80.0	78.5	66.0	51.0	46.0	35.0
		100.0	--	85.0	81.5	72.0	45.0	33.0	27.0
Mean		100.0	89.9	89.5	88.4	81.3	63.5	54.7	38.7

- Source: DCE recovery furnace
- Emissions: Uncontrolled
- Mean particle size distribution

Mean cumulative percentage less than							
Total	15 μm	12 μm	6 μm	2.5 μm	1.2 μm	1.00 μm	0.625 μm
100.0	95.0	93.5	92.2	83.5	56.5	45.3	26.5

- Mass emission factor:[3-1] 50 lb/ton of air-dried pulp
- Assumption: During the tests, the uncontrolled emissions from the recovery furnaces were approximately equal to the mass emission factor
- Size-specific emission factors (EF)*

$$EF_{15\mu m} = \text{mass emission factor} \times \frac{\text{Mean cumulative percentage Less than } 15\ \mu m}{100}$$

$$= 150\ \text{lb/ton} \times 95.0/100$$

$$= 142\ \text{lb/ton}$$

Similarly

$EF_{10\mu m} = 140$ lb/ton

$EF_{6\mu m} = 138$ lb/ton

$EF_{2.5\mu m} = 125$ lb/ton

$EF_{1.25\mu m} = 85$ lb/ton

$EF_{1.00\mu m} = 68$ lb/ton

$EF_{0.625\mu m} = 40$ lb/ton

The cumulative size-specific emission factors thus calculated are summarized in Table 3-17. For each source, the uncontrolled and controlled emission factors are given as well as the mass emission factor upon which the size-specific emission factor are based. Figures 3-23 through 3-28 grpahically depict the cumulative size-specific emission factors.

To convert to kilograms per metric ton, multiply by 0.5.

TABLE 3-17. SUMMARY OF B-RANKED PARTICLE SIZE DISTRIBUTION AND CUMULATIVE SIZE-SPECIFIC EMISSION FACTORS

			Cumulative percent less than							
Source	Control device	Mass emission factor	Total	15 µm	10 µm	6 µm	2.5 µm	1.25 µm	1.00 µm	0.625 µm
Recovery furnace	Uncontrolled	150 lb/ton[a]	100.0 150	95.0 142	93.5 140	92.2 138	83.5 125	56.5 85	45.3 68	26.5 40.
	ESP	8 lb/ton[a]	100.0 8.0	-- --	-- --	68.2 5.5	53.8 4.3	40.5 3.2	34.2 2.7	22.2 1.8
Recovery furnace (non-DCE)	Uncontrolled	99 lb/ton[b]	100.0 99	-- --	-- --	-- --	78.0 77	40.0 40	30.0 30	17.0 17
	ESP	1.7 lb/ton[b]	100.0 1.7	78.8 1.3	74.8 1.3	71.9 1.2	67.3 1.1	51.3 0.9	42.4 0.7	29.6 0.5
Lime kiln	Uncontrolled	45 lb/ton[a]	100.0 45	27.7 12	16.8 7.6	13.4 6.0	10.5 4.7	8.2 3.7	7.1 3.2	3.9 1.8
	Venturi scrubber	3 lb/ton[a]	100.0 3	98.9 3	98.3 2.9	98.2 2.9	96.0 2.9	85.0 2.6	78.9 2.4	54.3 1.6
	ESP	3 lb/ton[c]	100.0 3	91.2 2.7	88.5 2.7	86.5 2.6	83.0 2.5	70.2 2.1	62.9 1.9	46.9 1.4
Smelt dissolving tank vent	Uncontrolled	5 lb/ton[a]	100.0 5	90.0 4.5	88.5 4.4	87.0 4.3	73.0 3.6	47.5 2.4	40.0 2.0	25.5 1.3
	Packed tower	1 lb/ton[a]	100.0 1	95.3 0.95	95.3 0.95	94.3 0.94	85.2 0.85	63.8 0.64	54.2 0.54	34.2 0.34
	Venturi scrubber	0.13 lb/ton[b]	100.0 0.13	89.9 0.12	89.5 0.12	88.4 0.11	81.3 0.10	63.5 0.08	54.7 0.07	38.7 0.05

[a] Source: AP-42 Compilation of Air Pollutant Emission Factors.[3-1]

[b] Source: Particulate Mass and Particulate Size Measurements at Representative Kraft Pulp Mills.[3-2]

[c] Assumption that controlled emissions from a venturi scrubber and ESP are comparable. No other data exist.

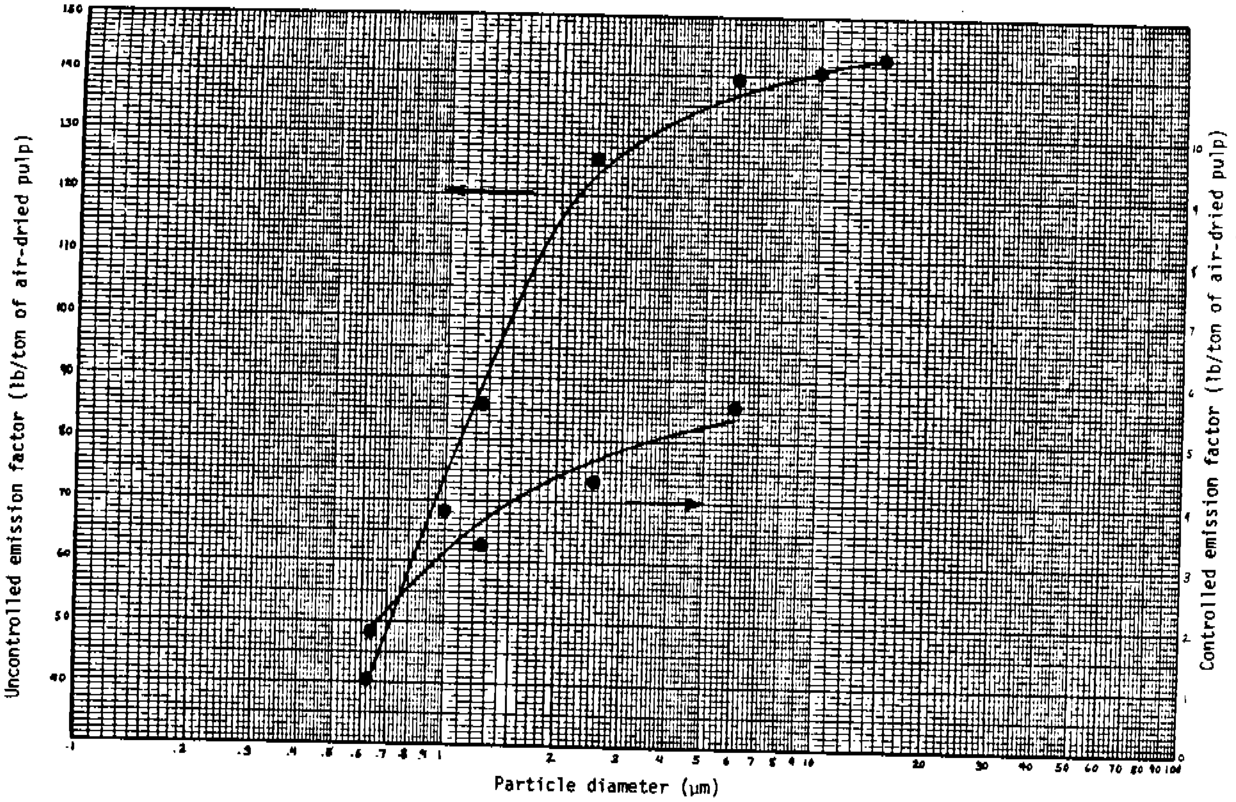

Figure 3-23. Cumulative size-specific emission factors for a recovery furnace (DCE) with an ESP.

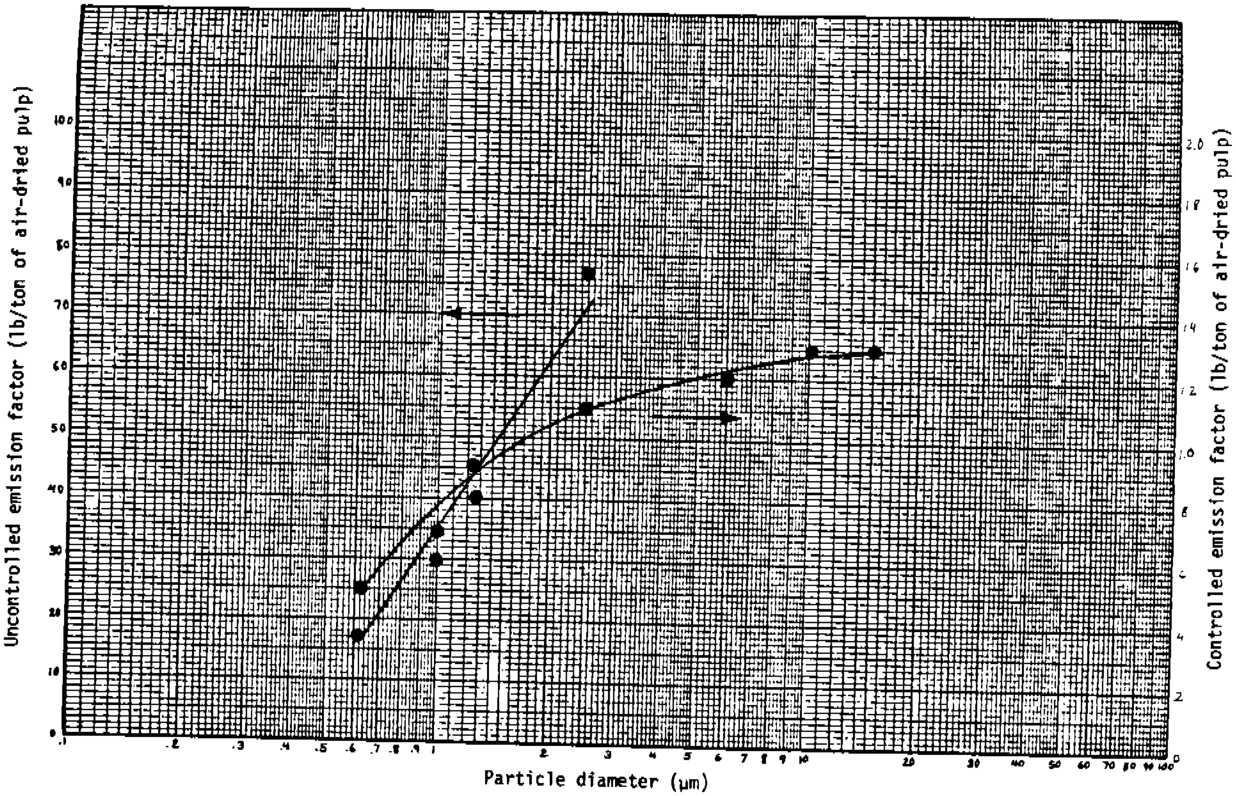

Figure 3-24. Cumulative size-specific emission factors for a recovery furnace (non-DCE) with an ESP.

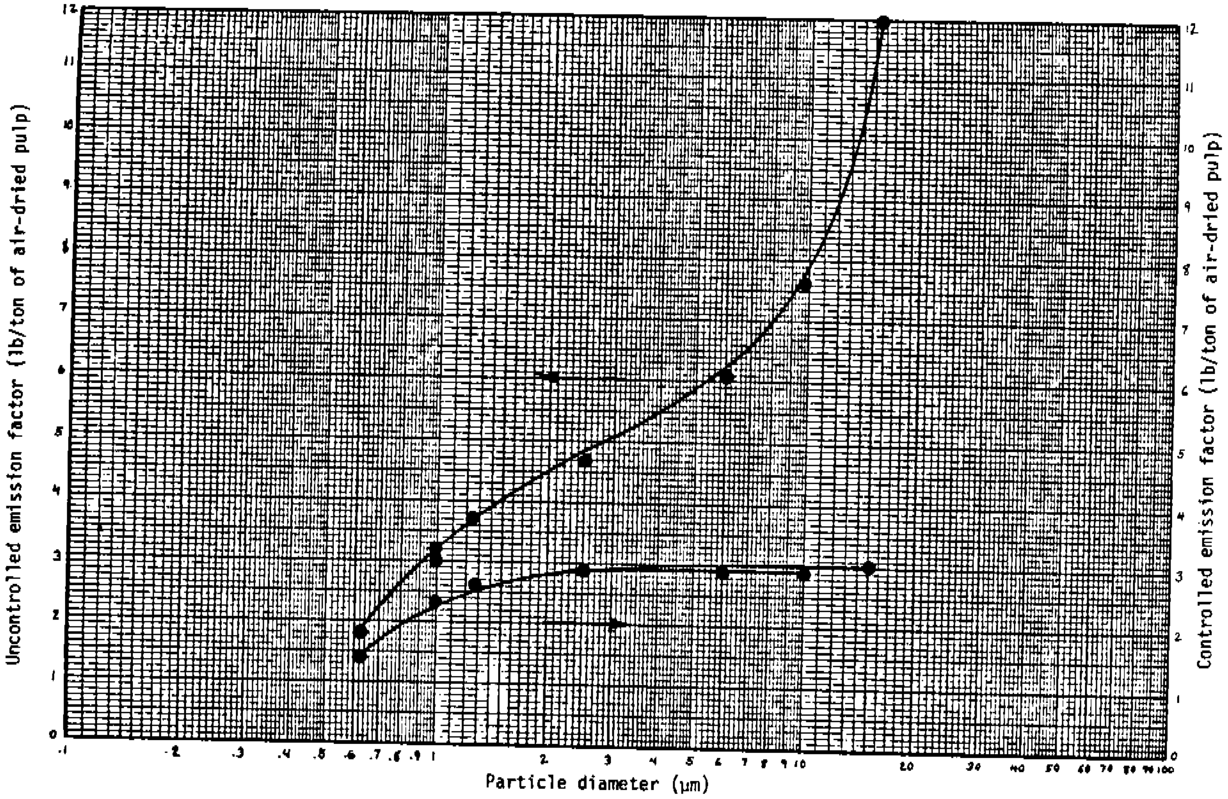

Figure 3-25. Cumulative size-specific factors for a lime kiln with a venturi scrubber.

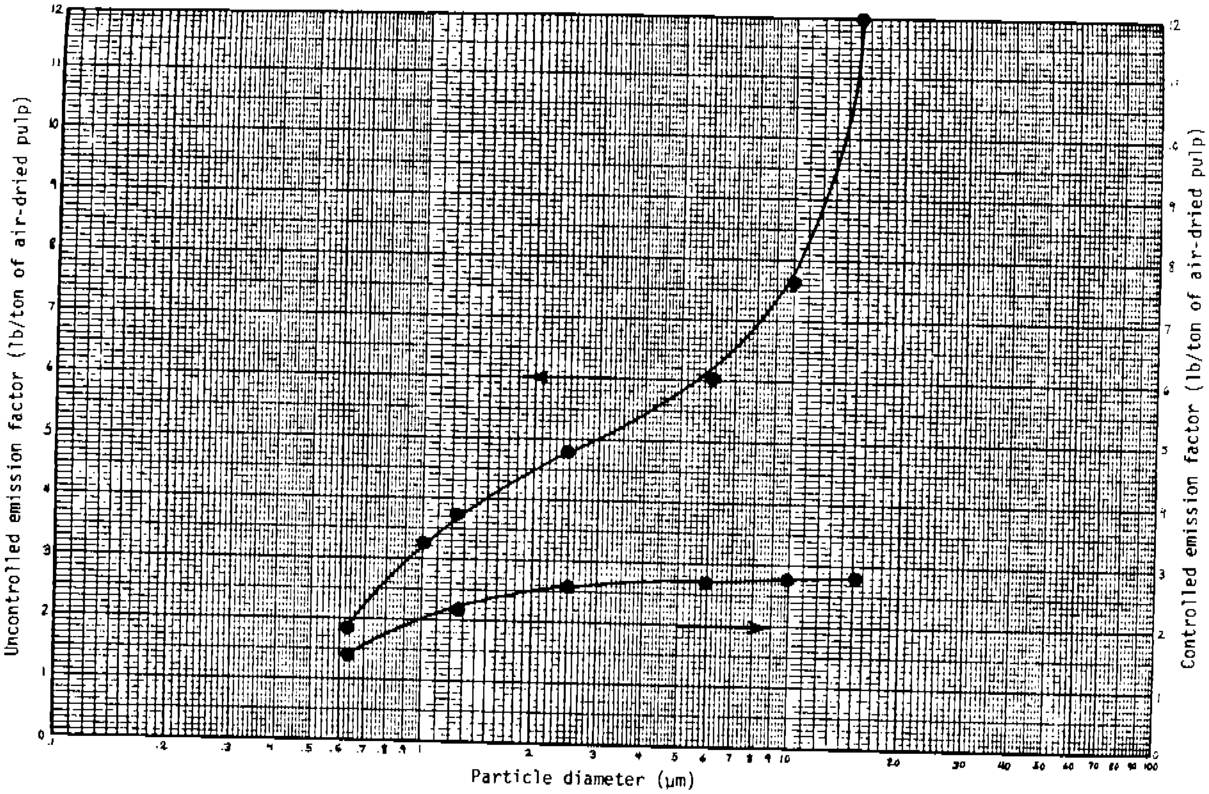

Figure 3-26. Cumulative size-specific emission factors for a lime kiln with an ESP.

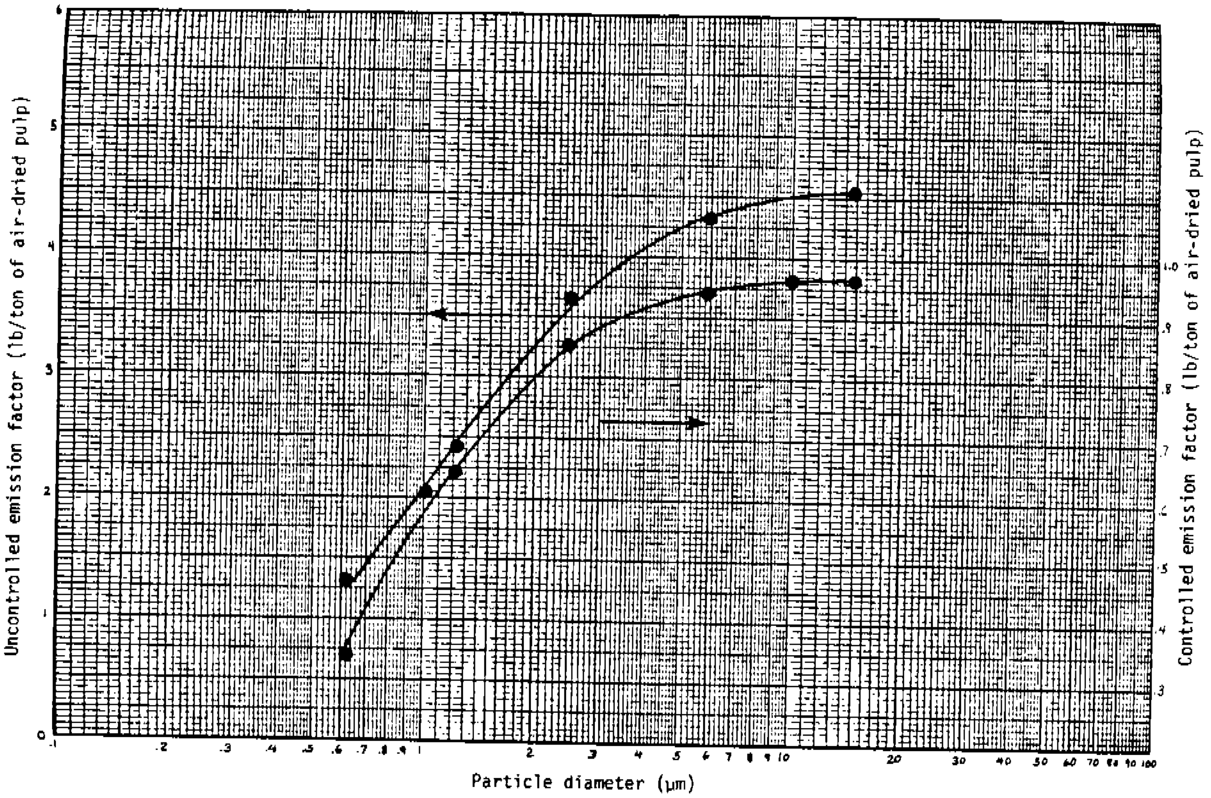

Figure 3-27. Cumulative size-specific emission factors for a smelt dissolving tank vent with a packed tower.

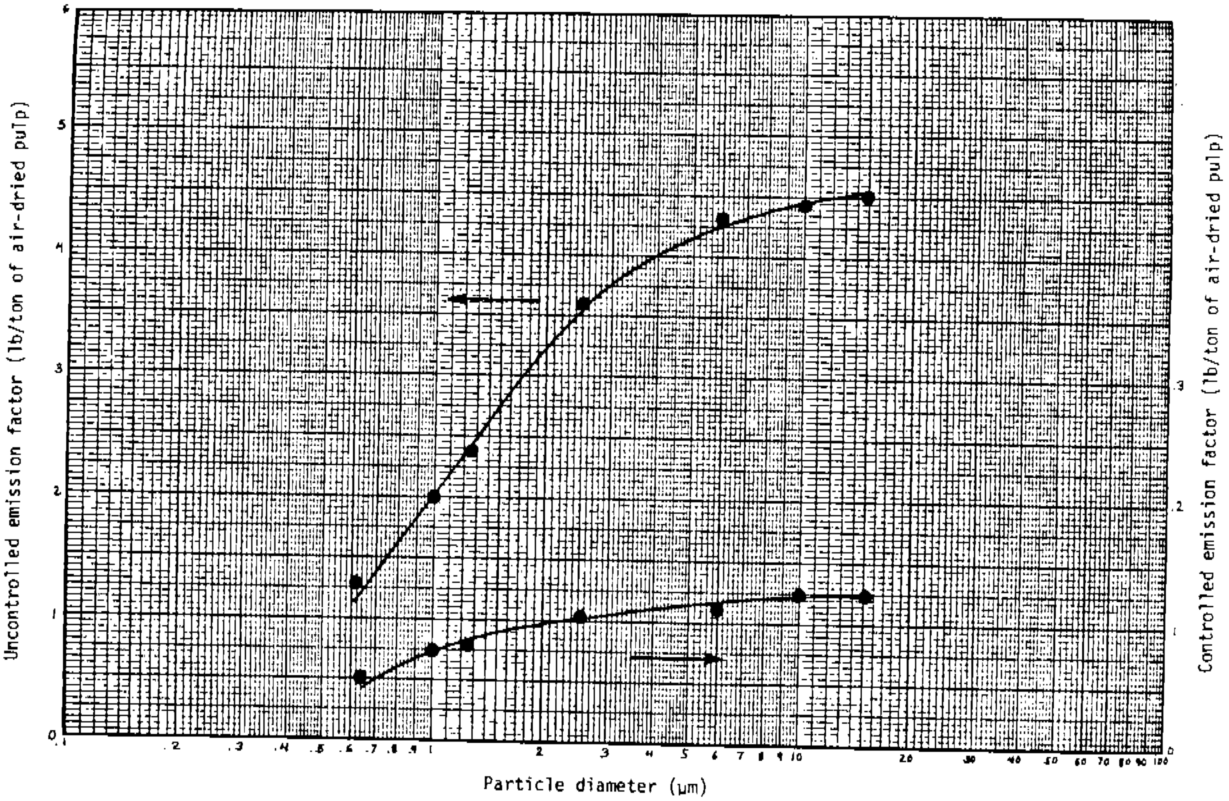

Figure 3-28. Cumulative size-specific emission factors for a smelt dissolving tank vent with a venturi scrubber.

3.3 OTHER EMISSION DATA

During the literature search other cumulative size-specific emission factor and particle size distribution data were found, but were judged unsatisfactory for analysis. These data are summarized in Table 3-18.

Recovery Boiler, Hoerner Waldorf Mill

Data on a series of tests performed on a recovery boiler at the Hoerner Waldorf Mill are available in Fine Particle Emission Information System (FPEIS).[3-1] It was noted in the data that the "operating parameters changed frequently during the test period." In addition, data were not available on the feed material or feedrate. Because of the uncertainty in operating conditions, it was decided not to include the data in the report at this time.

Recovery Boiler, Confidential Source

Based upon the data presented in the FPEIS report,[3-12] it appeared that the data were obtained under nonisokinetic conditions. Until the isokineticity can be reviewed or references can be located attesting to proper sampling conditions, the data are not acceptable for this report.

Recovery Boiler, Confidential Source

Similiar doubts regarding the isokineticity of the data presented in test series 84[3-12] and, again, the data are not acceptable at this line.

Recovery Boiler, Longview Fibre

Insufficient data are presented in test series 148[3-13] to explain the significant differences between subseries runs 1 and 2. Because of that difference it was assumed that operating and/or test conditions changed significantly during the test, and that this change invalidated one or both of the data sets. As it was not possible to determine whether just one run or both were invalidated, the data for both runs were judged unacceptable.

Lime Kiln, Weyerhaeuser

Data from references 3-14 through 3-17 were the results of sampling conducted under the EPA/IERL Mobile Device Test Program. A probe was inserted into the exhaust end of the lime kiln. The gases were ducted off to a mobile baghouse and measurements made before and after the control device. Because the data were obtained on a slipstream, the results may not be truly representative. Therefore, the data were not analyzed to obtain cumulative size specific emission factors.

TABLE 3-18. SUMMARY OF OTHER EMISSION DATA

Emission point	Source	Control device	Type of emission data	Date	Reference
Recovery Boiler	Hoerner Waldorf Mill Missoula, MT	ESP	Uncontrolled and controlled	March to June 1973	3-10
Recovery boiler (DCE)	Confidential	ESP	Uncontrolled and controlled	November 1975	3-11
Recovery boiler (DCE)	Confidential	ESP	Uncontrolled and controlled	December 1975	3-12
Recovery boiler (DCE)	Lonview Fibre Longview, WA	ESP	Controlled	June 1975	3-13
Lime kiln	Weyerhaeuser Plymouth, NC	Fabric filter	Controlled	April to September 1975	3-14
Lime kiln	Weyerhaeuser Plymouth, NC	Fabric filter	Controlled	April to September 1975	3-15
Lime kiln	Weyerhaeuser Plymouth, NC	Fabric filter	Controlled	April to September 1975	3-16
Lime kiln	Weyerhaeuser Plymouth, NC	Fabric filter	Controlled	April to September 1975	3-17
Smelt dissolving tank vents	St. Regis Paper Company Tacoma, WA	Ducon wetted fan	Uncontrolled and controlled	September 1981	3-2

Smelt Dissolving Tank Vents, St. Regis Paper Company

The data[3-2] presented for the smelt dissolving tank vents were obtained from a series of particulate mass and particle size tests conducted on the two smelt dissolving tanks for the no. 4 recovery furnace at St. Regis Paper Company. The data has been presented in this report because:

- Uncontrolled emission tests were performed at the same sampling locations as the controlled emissions test, with the scrubber fans turned off but with the water sprays left on due to plant personnel error
- Each test consists of simultaneous testing of two ducts (east and west). Although the combined totals for most of the data were consistent from test to test, there were considerable differences between the two ducts.

3.4 CONCLUSIONS

Cumulative size-specific emission factors based upon A-ranked data were compared to those that were based upon B-ranked data. Upon comparison it was evident that there was great inconsistency between the cumulative emission factors derived with the SoRI two-cyclone train (the A-ranked data) and the factors derived from cascade impactor data (primarily B-ranked data). Cumulative size-specific emission factors based upon B-ranked data were chosen as being more representative because:

- Significantly more tests were made using the cascade impactor
- The tests represented conditions at more than one site
- At least part of the data has been published and subject to review and comment

Therefore, the cumulative emission factors included in the proposed AP-42 section on kraft pulp mills are based upon B-ranked data. As a result, the emission factors have been assigned a C rating.

References for Section 3

3-1. Compilation of Air Pollutant Emission Factors, Third Edition, U.S. Environmental Protection Agency, AP-42, April 1981.

3-2. Best, R. Particulate Mass and Particulate Size Measurements at Representative Kraft Pulp Mills. Prepared by Acurex Corporation for the U.S. Environmental Protection Agency under contract no. 68-02-3159, August 1982.

3-3. A Study of Particulate Size Distribution in Emissions from Controlled Sources in the Kraft Process. National Council of the Paper Industry for Air and Steam Improvement, Inc., Technical Bulletin No. 94, May 1978.

3-4. Personal communication, J. Pinkerton, National Council of the Paper Industry for Air and Steam Improvement, Inc. to H. Modetz, Acurex Corporation, September 15, 1982.

3-5. Paul, J., Application of Electrostatic Precipitators for the Control of Fumes from Low Odor Pulp Mill Recovery Boilers. Journal of the Air Pollution Control Association, February 1975, p. 158-162.

3-6. Bosch, J., M. Pilat, and B. Hrutfiord, "Size Distribution of Aerosols from a Kraft Mill Recovery Furnace," Journal of the Technical Association of the Pulp and Paper Industry, November 1971, p. 1871-1875.

3-7. The Electrostatic Precipitator Manual, Chapter IX, Section 2611-907, The McIlvaine Company, March 1976, p. 101.1-103.1.

3-8. Pilat, M. D. Ensor, and J. Bosch, Source Test Cascade Impactor, Atmospheric Environment, Volume 4, 1970, p. 671-679.

3-9. Larssen, S., D. Ensor, and M. Pilat, "Relationship of Plume Opacity to the Properties of Particulates Emitted from Kraft Recovery Furnaces," Journal of the Technical Association of the Pulp and Paper Industry, January 1972, p. 88-92.

3-10. FPEIS Test Series 18, U.S. Environmental Protection Agency, May 1982.

3-11. FPEIS Test Series 83, U.S. Environmental Protection Agency, May 1982.

3-12. FPEIS Test Series 84, U.S. Environmental Protection Agency, May 1982.

3-13. FPEIS Test Series 148, U.S. Environmental Protection Agency, May 1982.

3-14. FPEIS Test Series 104, U.S. Environmental Protection Agency, May 1982.

3-15. FPEIS Test Series 105, U.S. Environmental Protection Agency, May 1982.

3-16. FPEIS Test Series 106, U.S. Environmental Protection Agency, May 1982.

3-17. FPEIS Test Series 107, U.S. Environmental Protection Agency, May 1982.

SECTION 4
CHEMICAL CHARACTERIZATION

Data which presented the specific chemical characteristics of inhalable particulate was not located. However, there are data which generally characterize the fine particulate.

Recovery Furnaces

Bosch et al.[4-1,4-2] reported that makeup of recovery furnace particulate is generally a sodium-salt. However, in two cases, the presence of a black ash was noted. Separation of the two materials indicated that the carbonaceous black ash had a mass mean diameter of 30 μm while the sodium-salts had a mass mean diameter of 0.9 μm.

Collins et al.[4-2] studied the composition of recovery furnace fine particulate. It was reported that the particulate is 85 percent Na_2SO_4, with lesser quantities of NaCl, Na_3SO_3, and black ash. Collins et al. also reported that enhancement of smelt and ignited black liquor may result in changes to the Na_2SO_4 content.

Subsequent analyses[4-2] on a non-DCE recovery furnace substantiated the work of Collins, et al., with 80 to 90 percent of the fine particulate being Na_2SO_4.

Lime Kilns

Chemical analyses reported uncontrolled lime kiln emissions to be approximately 10 percent sodium-salt.[4-3] For a venturi-scrubber-equipped lime kiln, studies have indicated that roughly 55 to 60 percent of the total particulate exists as Na_2SO_4 with 0.5 to 1 percent calcium-salt, and minor burnouts of trace elements.[4-2]

Smelt Dissolving Tank Vent

Minimal data were found on smelt dissolving tank vent emissions. A Na_2SO_4 and Na_2CO_3 composition has been suggested.[4-2]

References for Section 4

4-1. Bosch, J., M. Pilat, and B. Hrutfiord, "Size Distribution of Aerosols From a Kraft Mill Recovery Furnace," Journal of the Technical Association of the Pulp and Paper Industry, November 1971, p. 1871-1875.

4-2. A Study of Particulate Size Distribution in Emissions from Controlled Sources in the Kraft Process, National Council of the Paper Industry for Air and Steam Improvement, Inc., Technical Bulletin No. 94, May 1978.

SECTION 5

PROPOSED AP-42 SECTION

10. WOOD PRODUCTS INDUSTRY

Wood processing involves the conversion of raw wood to pulp, pulpboard, or one of several types of wallboard including plywood, particleboard, or hardboard. This section presents emissions data for chemical wood pulping, for pulpboard and plywood manufacturing, and for woodworking operations. The burning of wood waste in boilers and conical burners is not included as it is discussed in Chapters 1 and 2 of this publication.

10.1 CHEMICAL WOOD PULPING

10.1.1 General[1]

Chemical wood pulping involves the extraction of cellulose from wood by dissolving the lignin that binds the cellulose fibers together. The principal processes used in chemical pulping are kraft, sulfite, neutral sulfite semichemical (NSSC), dissolving, and soda. The first three of these display the greatest potential for causing air pollution. The kraft process accounts for about 65 percent of all pulp produced in the United States. Together, the sulfite and NSSC processes account for less than 20 percent of the total. The choice of pulping process is determined by the product being made, by the type of wood species available, and by economic considerations.

10.1.2 Kraft Pulping

10.1.2.1 Process Description[1,2] -- The kraft process (see Figure 10.1.2-1) involves the cooking of wood chips under pressure in the presence of a cooking liquor in either a batch or a continuous digester. The cooking liquor, or "white liquor," consisting of an aqueous solution of sodium sulfide and sodium hydroxide, dissolves the lignin that binds the cellulose fibers together.

When cooking is completed, the contents of the digester are forced into the blow tank. Here the major portion of the spent cooking liquor, which contains the dissolved lignin, is drained, and the pulp enters the initial stage of washing. From the blow tank the pulp passes through the knotter

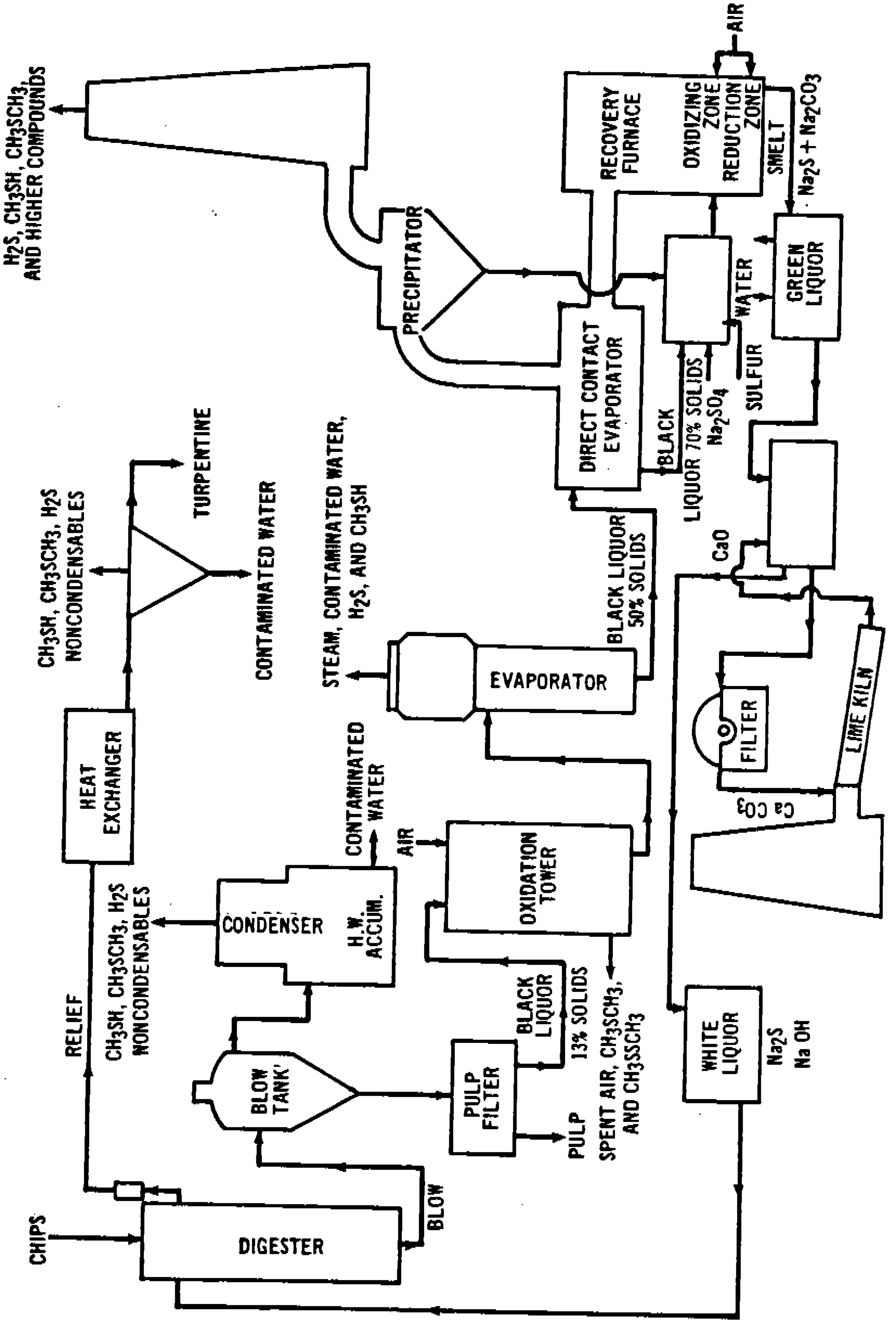

Figure 10.1.2-1. Typical kraft sulfate pulping and recovery process.

where unreacted chunks of wood are removed. The pulp is than washed and, in some mills, bleached before being pressed and dried into the finished product.

It is economically necessary to recover both the inorganic cooking chemicals and the heat content of the spent "black liquor," which is separated from the cooked pulp. Recovery is accomplished by first concentrating the liquor to a level that will support combustion and then feeding it to a furnace where burning and chemical recovery take place.

Initial concentration of the weak black liquor, which contains about 15 percent solids, occurs in the multiple-effect evaporator. Here process steam is passed countercurrent to the liquor in a series of evaporator tubes that increase the solids content to 40 to 55 percent. Further concentration is than effected in a direct contact evaporator or an indirect contact evaporator. A direct contact evaporator consists generally of a scrubbing device (a cyclonic or venturi scrubber or a cascade evaporator) in which hot combustion gases from the recovery furnace mix with the incoming black liquor to raise its solids content to 55 to 70 percent. An indirect contact evaporator uses the heat content of the hot combustion gases to raise the solid contents of the black liquor. This is accomplished by using heat exchangers. In this case there is no direct contact between hot combustion gases and black liquor in the final concentration stage.

The black liquor concentrate is then sprayed into the recovery furnace where the organic content supports combustion. The inorganic compounds fall to the bottom of the furnace and are discharged to the smelt dissolving tank to form a solution call "green liquor." The green liquor is then conveyed to a causticizer where slaked lime (calcium hydroxide) is added to convert the solution back to white liquor, which can be reused in subsequent cooks. Residual lime sludge from the causticizer can be recycled after being dewatered and calcined in the hot lime kiln.

Many mills need more steam for process heating, for driving equipment, for providing electric power, etc., than can be provided by the recovery furnace alone. Thus, conventional industrial boilers that burn coal, oil, natural gas, and in some cases, bark and wood waste are commonly employed.

10.1.2.2 Emissions and Controls[1-6,17] -- Particulate emissions from the kraft process occur primarily from the recovery furnace, the lime kiln, and the smelt dissolving tank. These emissions consist mainly of sodium salts but include some calcium salts from the lime kiln. They are caused primarily by the carryover of solids plus the sublimation and condensation of the inorganic chemicals.

Particulate control is provided on recovery furnaces in a variety of ways. In mills where either a cyclonic scrubber or cascade evaporator serves as the direct contact evaporator, further control is necessary as these devices are generally only 20 to 50 percent efficient for particulates. Most often in these cases, an electrostaic precipitator is employed after the direct contact evaporator to provide an overall particulate control efficiency of 85 to $\geq$ 99 percent particulate control. In either case, auxiliary scrubbers may be included after the precipitator or the venturi scrubber to provide additional control of particulates.

Particulate control on lime kilns is generally accomplished by scrubbers. Smelt dissolving tanks are commonly controlled by mesh pads but employ scrubbers when further control is needed.

The characteristic odor of the kraft mill is caused in large part by the emission of hydrogen sulfide. The major source is the direct contact evaporator in which the sodium sulfide in the black liquor reacts with the carbon dioxide in the furnace exhaust. The use of indirect contact evaporators can significantly reduce the emission of hydrogen sulfide. The lime kiln can also be a potential source as a similar reaction occurs involving residual sodium sulfide in the lime mud. Lesser amounts of hydrogen sulfide are emitted with the noncondensible off-gasses from the digesters and multiple-effect evaporators.

The kraft-process odor also results from an assortment of organic sulfur compounds, all of which have extremely low odor thresholds. Methyl mercaptan and dimethyl sulfide are formed in reactions with the wood component lignin. Dimethyl disulfide is formed through the oxidation of mercaptan groups derived from the lignin. These compounds are emitted from many points within a mill; however, the main sources are the digester/blow tank systems and the direct contact evaporator.

Although odor control devices, per se, are not generally employed in kraft mills, control of reduced sulfur compounds can be accomplished by process modifications and by optimizing operating conditions. For example, black liquor oxidation systems, which oxidize sulfides into less reactive thiosulfates, can considerably reduce odorous sulfur emissions from the direct contact evaporator, although the vent gases from such systems become minor odor sources themselves. Noncondensible odorous gases vented from the digester/blow tank system and multiple-effect evaporators can be destroyed by thermal oxidation, usually by passing them through the lime kiln. Optimum operation of the recovery furnace, by avoiding overloading and by maintaining sufficient oxygen residual and turbulence, significantly reduces emissions of reduced sulfur compounds from this source. In addition, the use of fresh water instead of contaminated condensates in the scrubbers and pulp washers further reduces odorous emissions. The effect of any of these modifications on a given mill's emissions will vary considerably.

Several new mills have incorporated recovery systems that eliminate the conventional direct contact evaporators. In one system, preheated combustion air rather than flue gas provides direct contact evaporation. In the other, the multiple-effect evaporator system is extended to replace the direct contact evaporator altogether. In both of these systems, reduced sulfur emissions from the recovery furnace/direct contact evaporator reportedly can be reduced by more than 95 percent from conventional uncontrolled systems.

Sulfur dioxide emissions result mainly from oxidation of reduced sulfur compounds in the recovery furnace. It is reported that the direct contact evaporator absorbs 50 to 80 percent of these emissions; further scrubbing, if employed, can reduce them another 10 to 20 percent.

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

Some nitrogen oxides are also emitted from the recovery furnace and lime kilns although the amounts are relatively small. Indications are that nitrogen oxide emissions from each of these sources are on the order of 1 pound per air-dried ton (0.5 kg/air-dried MT) of pulp produced.[5,6]

A major source of emissions in a kraft mill is the boiler for generating auxiliary steam and power. The fuels used are coal, oil, natural gas, or bark/wood waste. Emission factors for boilers are presented in Section 1.

Table 10.1.2-1 presents emission factors for a conventional kraft mill. The most widely used particulate control devices are shown along with the odor reductions resulting from black liquor oxidation and incineration of noncondensible off-gases. Tables 10.1.2-2 through 10.1.2-7 present cumulative size distribution data and size-specific emission factors for particulate emissions from sources within a conventional kraft mill. Uncontrolled and controlled size-specific emission factors are presented in Figures 10.1.2-2 through 10.1.2-7.[17]

10.1.3 Acid Sulfite Pulping

Section 10.1.3 has not been revised.

10.1.4 Neutral Sulfite Semichemical (NSSC) Pulping

Section 10.1.4 has not been revised.

TABLE 10.1.2-1. EMISSION FACTORS FOR SULFATE PULPING[a]
(unit weights of air-dried unbleached pulp)
EMISSION FACTOR RATING: A

Source	Type control	Particulates[b]		Sulfur dioxide (SO_2)[c]		Carbon monoxide[d]		Hydrogen sulfide($S^=$)[e]		RSH, RSR, RSSR($S^=$)[e,f]	
		lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Digester relief and blow tank	Untreated[g]	–	–	–	–	–	–	0.1	0.05	1.5	0.75
Brown stock washers	Untreated	–	–	0.01	0.005	–	–	0.02	0.01	0.2	0.1
Multiple effect evaporators	Untreated[g]	–	–	0.01	0.005	–	–	0.1	0.05	0.4	0.2
Recovery boiler and direct contact evaporator	Untreated[h]	150	75	5	2.5	2 - 60	1 - 30	12[i]	6[i]	1[i]	0.5[i]
	Venturi scrubber[j]	47	23.5	5	2.5	2 - 60	1 - 30	12[i]	6[i]	1[i]	0.5[i]
	Electrostatic precipitator	8	4	5	2.5	2 - 60	1 - 30	12[i]	6[i]	1[i]	0.5[i]
	Auxiliary scrubber	3 - 15[k]	1.5 - 7.5[k]	3	1.5	2 - 60	1 - 30	12[i]	6[i]	1[i]	0.5[i]
Smelt dissolving tank	Untreated	5	2.5	0.1	0.05	–	–	0.04	0.02	0.4	0.2
	Mesh pad	1	0.5	0.1	0.05	–	–	0.04	0.02	0.4	0.2
Lime kilns	Untreated	45	22.5	0.3	0.15	10	5	0.5	0.25	0.25	0.125
	Scrubber	3	1.5	0.2	0.1	10	5	0.5	0.25	0.25	0.125
Turpentine condenser	Untreated	–	–	–	–	–	–	0.01	0.005	0.5	0.25
Miscellaneous sources[l]	Untreated	–	–	–	–	–	–	–	–	0.5	0.25

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

[b] References 1, 7, 8.

[c] References 1, 7, 9, 10.

[d] References 6, 11. Use higher value for overloaded furnaces.

[e] References 1, 4, 7-10, 12, 13. These reduced sulfur compounds are usually expressed as sulfur.

[f] RSH-methyl mercaptan; RSR-dimethyl sulfide; RSSR-dimethyl disulfide.

[g] If the noncondensible gases from these sources are vented to the lime kiln, recovery furnace, or equivalent, the reduced sulfur compounds are destroyed.

[h] These factors apply when either a cyclonic scrubber or cascade evaporator is used for direct contact evaporation with no further controls.

[i] These reduced sulfur compounds (TRS) are typically reduced by 50 percent when black liquor oxidation is employed but can be cut by 90 to 99 percent when oxidation is complete and the recovery furnace is operated optimally.

[j] These factors apply when a venturi scrubber is used for direct contact evaporation with no further controls.

[k] Use 15(7.5) when the auxiliary scrubber follows a venturi scrubber and 3(1.5) when employed after an electrostatic precipitator.

[l] Includes knotter vents, brownstock seal tanks, etc. When black liquor oxidation is included, a factor of 0.6(0.3) should be used.

What about includ NSPS in table?

TABLE 10.1.2-2. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFIC EMISSION FACTORS FOR A RECOVERY FURNACE (DCE) WITH AN ESP
EMISSION FACTOR RATING: C

Particle size (µm)	Cumulative mass percent less than stated size		Cumulative emission factors (lb/ton of air-dried pulp)	
	Uncontrolled	Controlled	Uncontrolled	Controlled
Total	100	100	150	8.0
15	95.0	--	142	--
10	93.5	--	140	--
6	92.2	68.2	137	5.3
2.5	83.5	53.8	123	4.5
1.25	56.5	40.5	87	3.5
1.00	45.3	34.2	73	3.0
0.625	26.5	22.2	40	1.7

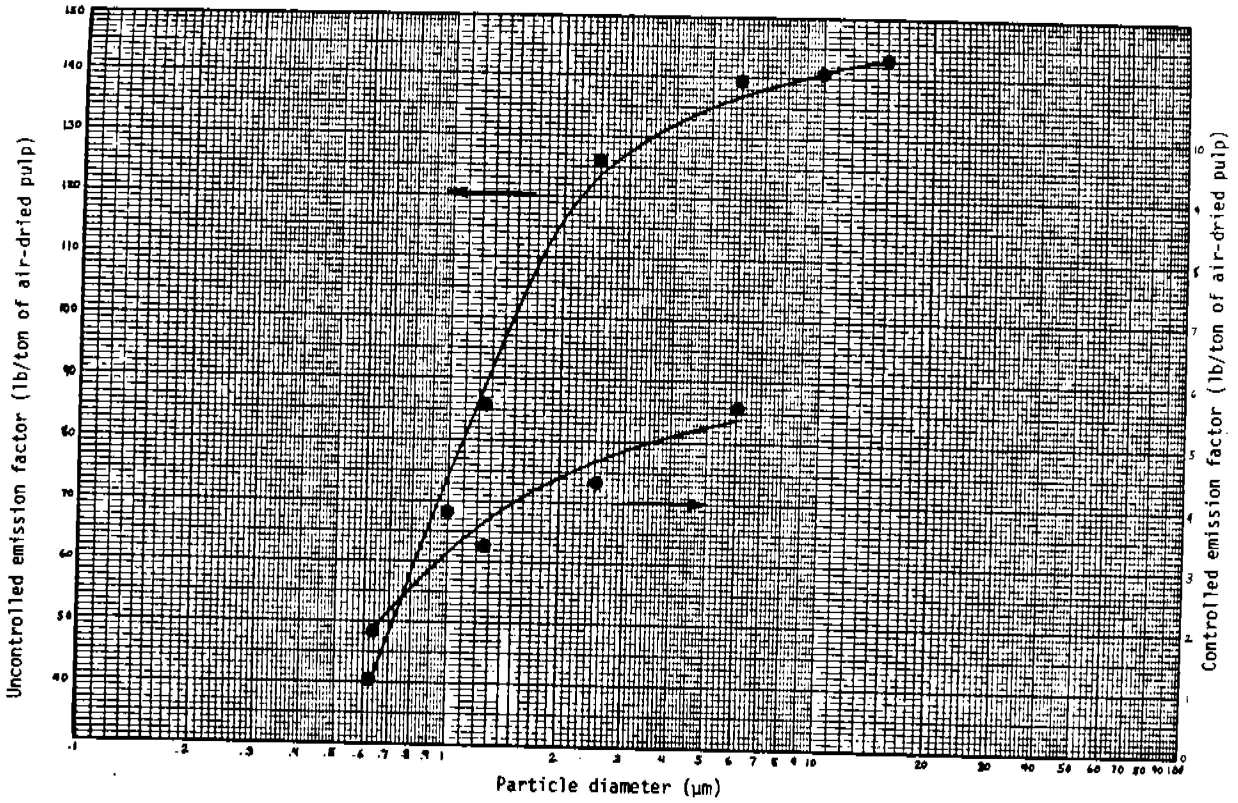

Figure 10.1.2-2. Cumulative size-specific emission factors for a recovery furnace (DCE) with an ESP.

TABLE 10.1.2-3. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFIC EMISSION FACTORS FOR A RECOVERY FURNACE (NON-DCE) WITH A ESP
EMISSION FACTOR RATING: C

Particle size (µm)	Cumulative mass percent less than stated size		Cumulative emission factors (lb/ton of air-dried pulp)	
	Uncontrolled	Controlled	Uncontrolled	Controlled
Total	100	100	99	1.7
15	--	78.8	--	1.3
10	--	74.8	--	1.3
6	--	71.9	--	1.2
2.5	78.0	67.3	72	1.1
1.25	40.0	51.3	51	0.9
1.00	30.0	42.4	35	0.7
0.625	17.0	29.6	16	0.5

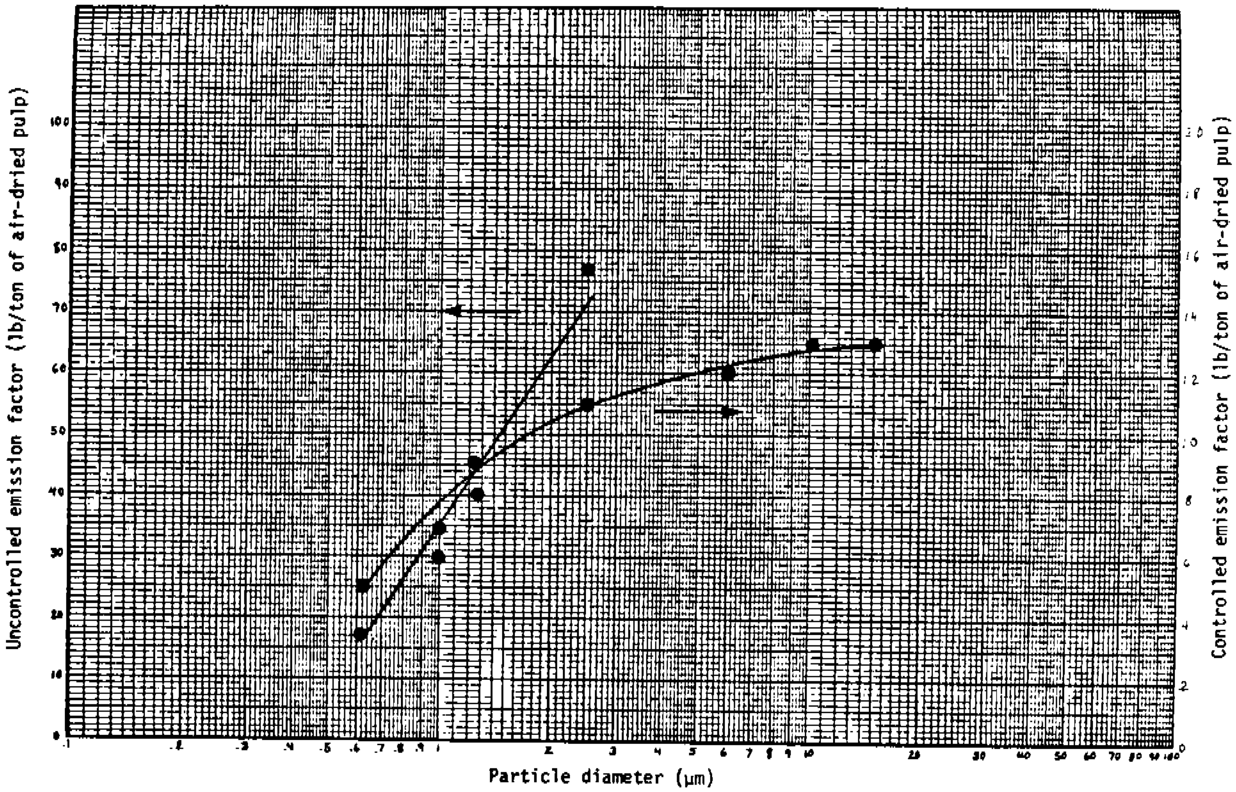

Figure 10.1.2-3. Cumulative size-specific emission factors for a recovery furnace (non-DCE) with an ESP.

TABLE 10.1.2-4. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFIC EMISSION FACTORS FOR A LIME KILN WITH A VENTURI SCRUBBER EMISSION FACTOR RATING: C

Particle size (µm)	Cumulative mass percent less than stated size		Cumulative emission factors (lb/ton of air-dried pulp)	
	Uncontrolled	Controlled	Uncontrolled	Controlled
Total	100	100	45.0	3.0
15	27.7	98.9	12.0	3.0
10	16.8	98.3	7.7	3.0
6	13.4	98.2	6.2	2.9
2.5	10.5	96.0	4.8	2.9
1.25	8.2	85.0	3.7	2.5
1.00	7.1	78.9	3.2	2.3
0.625	3.9	54.3	1.8	1.4

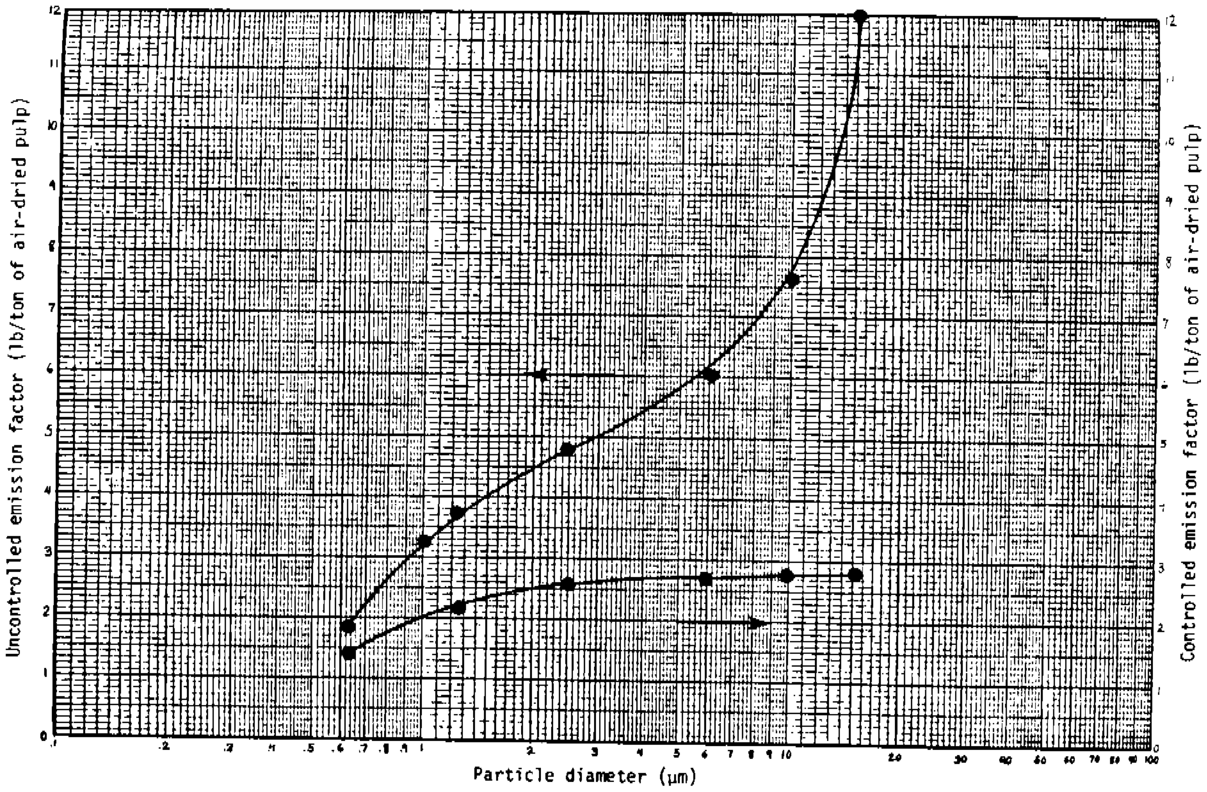

Figure 10.1.2-4. Cumulative size-specific emission factors for a lime kiln with a venturi scrubber.

TABLE 10.1.2-5. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFIC EMISSION FACTORS FOR A LIME KILN WITH AN ESP
EMISSION FACTOR RATING: C

Particle size (μm)	Cumulative mass percent less than stated size		Cumulative emission factors (lb/ton of air-dried pulp)	
	Uncontrolled	Controlled	Uncontrolled	Controlled
Total	100	100	45.0	3.0
15	27.7	98.9	12.0	2.8
10	16.8	98.3	7.7	2.8
6	13.4	98.2	6.2	2.7
2.5	10.5	96.0	4.8	2.5
1.25	8.2	85.0	3.7	2.2
1.00	7.1	78.9	3.2	2.0
0.625	3.9	54.3	1.8	1.4

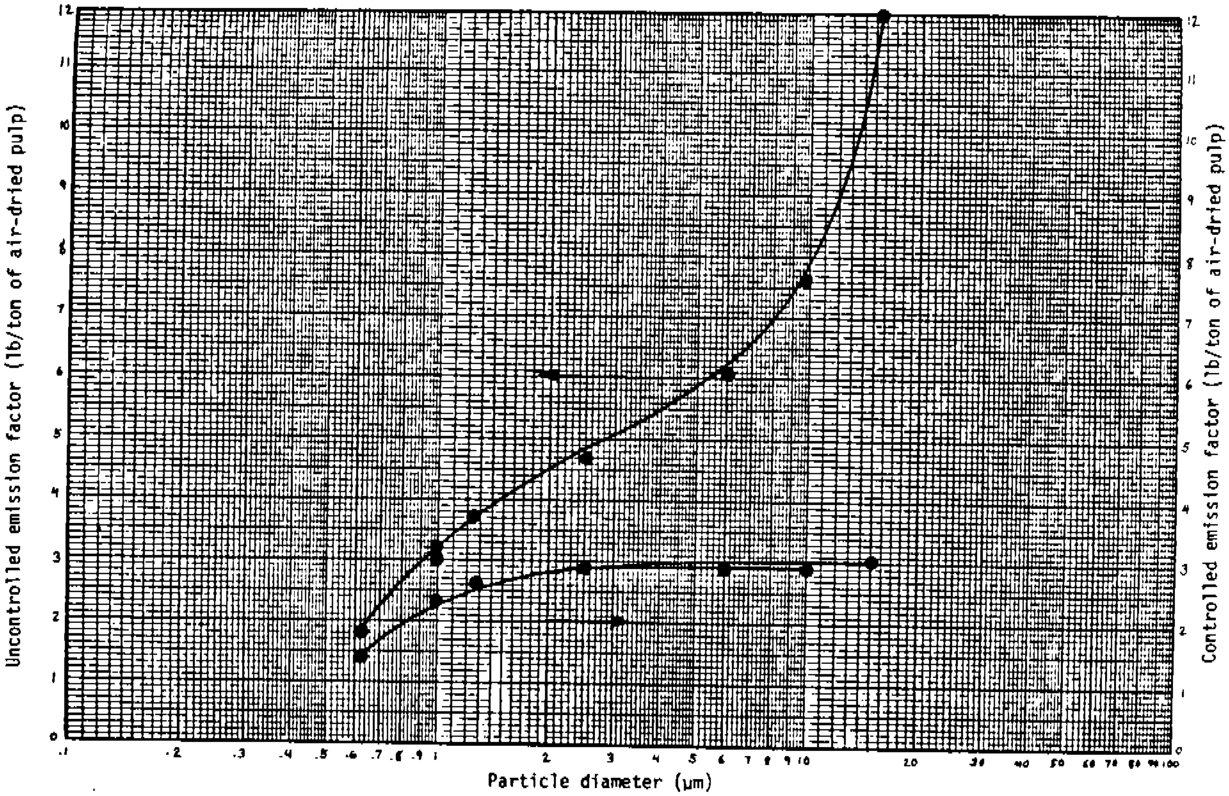

Figure 10.1.2-5. Cumulative size-specific emission factors for a lime kiln with an ESP.

TABLE 10.1.2-6. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFIC EMISSION FACTORS FOR A SMELT DISSOLVING TANK VENT WITH A PACKED TOWER
EMISSION FACTOR RATING: C

Particle size (µm)	Cumulative mass percent less than stated size		Cumulative emission factors (lb/ton of air-dried pulp)	
	Uncontrolled	Controlled	Uncontrolled	Controlled
Total	100	100	5.0	1.00
15	90.0	95.3	4.5	0.95
10	88.5	95.3	4.4	0.95
6	87.0	94.3	4.3	0.93
2.5	73.0	85.2	3.6	0.85
1.25	47.5	63.8	2.4	0.65
1.00	40.0	54.2	2.0	0.58
0.625	25.5	34.2	1.2	0.34

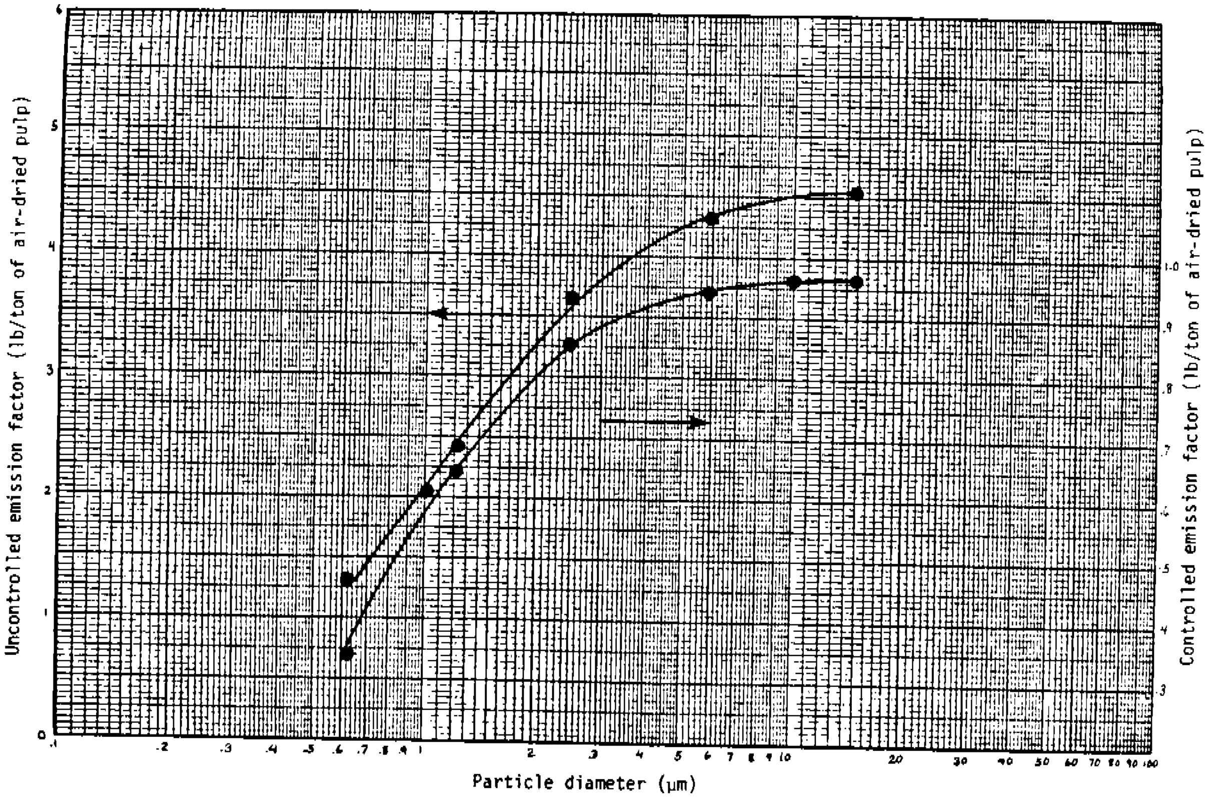

Figure 10.1.2-6. Cumulative size-specific emission factors for a smelt dissolving tank vent with a packed tower.

TABLE 10.1.2-7. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFIC EMISSION FACTORS FOR A SMELT DISSOLVING TANK VENT WITH A VENTURI SCRUBBER
EMISSION FACTOR RATING: C

Particle size (μm)	Cumulative mass percent less than stated size		Cumulative emission factors (lb/ton of air-dried pulp)	
	Uncontrolled	Controlled	Uncontrolled	Controlled
Total	100	100	5.0	0.13
15	90.0	89.9	4.5	0.12
10	88.5	89.5	4.4	0.12
6	87.0	88.4	4.3	0.11
2.5	73.0	81.3	3.6	0.10
1.25	47.5	63.5	2.4	0.08
1.00	40.0	54.7	2.0	0.07
0.625	25.5	38.7	1.2	0.05

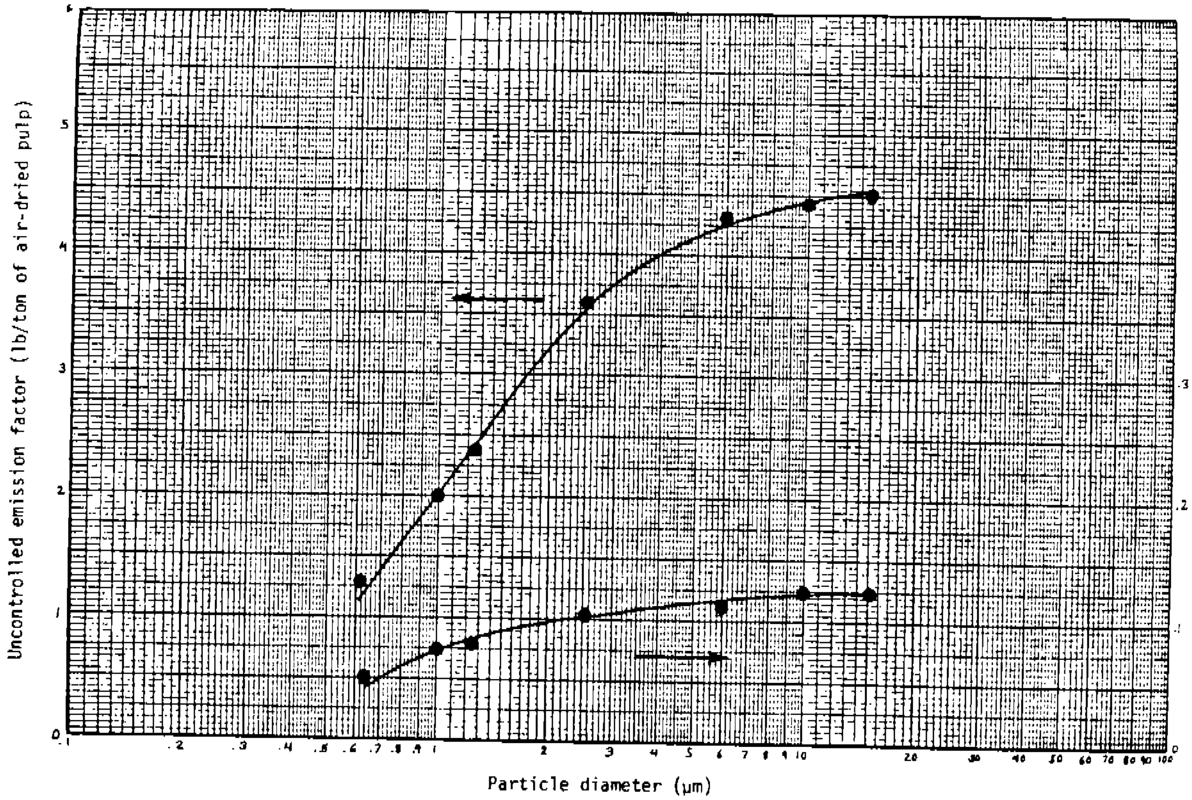

Figure 10.1.2-7. Cumulative size-specific emission factors for a smelt dissolving tank vent with a venturi scrubber.

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APPENDIX A

LIST OF KRAFT PULP MILLS

LIST OF KRAFT PULP MILLS

Owners	Size (ton/day)	Location	Paper and paperboard produced at this location
ALABAMA			
Allied Paper, Inc. (Subsidiary of SCM)	490	Jackson	Printing and writing papers
American Can Company	900	Butler	Tissue; toweling; box, paper, and package board
Champion International	500	Courtland	Uncoated printing, writing, business, and converting papers
Container Corporation of America (Subsidiary of MARCOR)	850	Brewton	Paperboard, food-liquid board, kraft paper, linerboard
Georgia Kraft Corporation (50 percent owned by Inland Container; 50 percent owned by Mead Corporation)	975	Mahrt	Linerboard, kraft board
Gulf States Paper Corporation	400	Demopolis	Paperboard
Gulf States Paper Corporation	475	Tuscaloosa	Kraft bag and wrapping
Hammermill Paper Company	500	Selma	None
International Paper Company	1,350	Mobile	Paper
Kimberly-Clark Corportation	585	Coosa Pines	Newsprint
MacMillan Bloedel Ltd.	925	Pine Hill	Paperboard
Scott Paper Company	1,400	Mobile	Tissue and other paper grades
Union Camp Corporation	930	Montgomery	Paperboard
ARIZONA			
Southwest Forest Industries	600	Snowflake	Newsprint, linerboard
ARKANSAS			
Georgia-Pacific Corporation	1,500	Crossett	Kraft paper, tissue, and paperboard
Great Northern Nekoosa Corporation	400	Ashdown	Business communications papers
Green Bay Packing, Inc.	650	Morrilton	Paperboard
International Paper Company	750	Camden	Paper
International Paper Company	1,900	Pine Bluff	Paper and board
Weyerhaeuser Company	230	Pine Bluff	Paper and board
CALIFORNIA			
Crown Simpson Company (jointly owned by Crown Zellerbach and Simpson Lee Paper Company)	600	Fairhaven	None
Fibreboard Corporation	450	Antioch	Paperboard
Louisiana-Pacific Corporation	700	Samoa	None
Simpson Lee Paper Company	160	Anderson	Coated printing paper, machine finish grades
FLORIDA			
Alton Box Board Company	650	Jacksonville	Board
Container Corporation of America (Subsidiary of MARCOR)	1,400	Fernandina Beach	Paperboard

Source: Standards Support and Environmental Impact Statement Volume I: Proposed Standards of Performance for Kraft Pulp Mills.

LIST OF KRAFT PULP MILLS (Continued)

Owners	Size (ton/day)	Location	Paper and paperboard produced at this location
FLORIDA (Continued)			
Hudson Pulp and Paper Corporation	950	Palatka	Tissue and bag papers
International Paper Company	1,500	Panama City	Containerboard
Proctor & Gamble Company	900	Foley	None
St. Joe Paper Company	1,300	Port St. Joe	Paperboard
St. Regis Paper Company	1,510	Jacksonville	Kraft paper and board
St. Regis Paper Company	1,050	Pensacola	Paper and board
GEORGIA			
Continentil Can Company	800	Augusta	Paperboard
Continentil Can Company	600	Port Wentworth	Paperboard
Brunswick Pulp and Paper Company (50 percent owned by Mead Corporation, 50 percent owned by Scott Paper)	1,550	Brunswick	Paperboard
Georgia Kraft Corporation (50 percent owned by Inland Container Corporation, 50 percent owned by Mead Corporation)	1,550	Krannert (Rome)	Paperboard (containerboard)
Georgia Kraft Corporation (50 percent owned by Inland Container Corporation, 50 percent owned by Mead Corporation)	900	Macon	Paperboard (containerboard)
Gilman Paper Company	1,100	St. Marys	Paper and board
Great Northern Nekoosa Corporation	1,780	Cedar Springs	Paper and corrugating medium
Interstate Paper Corporation	550	Riceboro	Paperboard and kraft board
ITT Rayonier, Inc.	1,250	Jesup	None
Owens-Illinois, Inc.	875	Valdosta	Board
Union Camp Corporation	2,550	Savannah	Paperboard, unbleached paper, and semichemical medium
IDAHO			
Potlatch Corporation	950	Lewiston	Paperboard and tissue
KENTUCKY			
Western Kraft (division of Willamette Industries, Inc.)	320	Hawesville	None
Westvaco	600	Wickliffe	Fine papers
LOUISIANA			
Boise Cascade Corporation	1,250	DeRidder	Newsprint and linerboard
Boise Cascade Corporation	325	Elizabeth	Bag, bag lining, converting, envelopes, wrapping
Continental Can Company	1,400	Hodge	Coarse paper and paperboard

Source: Standards Support and Environmental Impact Statement Volume I: Proposed Standards of Performance for Kraft Pulp Mills.

LIST OF KRAFT PULP MILLS (Continued)

Owners	Size (ton/day)	Location	Paper and paperboard produced at this location
LOUISIANA (Continued)			
Crown Zellerbach	1,350	Bogalusa	Paperboard, Kraft wrapping and bag
Crown Zellerbach	500	St. Francisville	Coated papers, Kraft paper and board
Georgia-Pacific Corporation	1,600	Port Hudson	None
International Paper Company	1,100	Bastrop	Kraft paper and board
International Paper Company	1,650	Springhill	Paper and board
Western Kraft	450	Campti	Paper and board
Olin Kraft, Inc.	1,150	West Monroe	Kraft paper and board, and corrugating medium
Pineville Kraft Corporation	880	Pineville	Kraft liner board
MAINE			
Diamond International Corporation	425	Old Town	Tissue
Georgia-Pacific Corporation	1,170	Woodland	Printing papers and newsprint
International Paper Company	1,150	Jay (Androscoggin)	Bond, carbonizing, and coated printing papers
Lincoln Pulp and Paper Company, Inc. Division of Premoid	320	Lincoln	Fine paper and tissue
Oxford Paper (Division of Ethyl Corporation)	585	Rumford	Fine printing and publishing papers
S. D. Warren Company, Division of Scott Paper Company	300	Westbrook	Specialty and other papers
MARYLAND			
Westvaco Corporation	665	Luke	Fine papers
MICHIGAN			
Mead Corporation	600	Escanaba	Coated printing papers
Scott Paper Company	225	Muskegon	Fine papers
MINNESOTA			
Boise Cascade Corporation	465	International Falls	Printing, publishing and white papers; insulation board
Potlatch Corporation	400	Cloquet	Printing and business paper
MISSISSIPPI			
International Paper Company	715	Moss Point	Paper
International Paper Company	1,000	Natchez	None
International Paper Company	1,200	Vicksburg	Containerboard
St. Regis Paper Company	1,792	Monticello	Linerboard and paper
MONTANA			
Hoerner Waldorf Corporation	1,200	Missoula	Paperboard

Source: Standards Support and Environmental Impact Statement Volume I: Proposed Standards of Performance for Kraft Pulp Mills.

LIST OF KRAFT PULP MILLS (Continued)

Owners	Size (ton/day)	Location	Paper and paperboard produced at this location
NEW HAMPSHIRE			
Brown Company	700	Berlin-Gorham	Paper, printing, industrial tissue and towel, corrugating
NEW YORK			
International Paper Company	590	Ticonderoga	Book and business grades
NORTH CAROLINA			
Champion International	1,360	Canton	Uncoated printing, writing, and converting papers, bleached paperboard for milk and folding cartons
Federal Paper Board Company	1,200	Riegelwood	Paperboard
Hoerner Waldorf Corporation	950	Roanoke Rapids	Paperboard
Weyerhaeuser Company	640	New Bern	None
Weyerhaeuser Company	1,500	Plymouth	Paperboard and fine papers
OHIO			
Mead Corporation	540	Chillocothe	Fine papers
OKLAHOMA			
Weyerhaeuser Company	1,600	Valliant	Paperboard
OREGON			
American Can Company	340	Halsey	Tissue
Boise Cascade Corporation	1,050	St. Helens	Specialty and fine papers
Crown Zellerbach	916	Clatskanie	Newsprint, tissue, industrial
Georgia-Pacific	1,250	Toledo	Kraft paper, paperboard
International Paper Company	600	Gardiner	Paperboard
Western Kraft (Willamette Industries, Inc.)	600	Albany	Kraft papers, corrugating medium
Weyerhaeuser Company	1,150	Springfield	Paperboard
PENNSYLVANIA			
Appleton Papers, Inc. (Division of National Cash Register)	180	Roaring Springs	Fine papers
P. H. Glatfelter Co.	500	Sprint Grove	Printing and writing papers
Penntech Papers, Inc.	180	Johnsonburg	Fine, printing, publishing, and business paper
SOUTH CAROLINA			
Bowater, Inc.	1,000	Catawba	Book papers
International Paper Company	1,830	Georgetown	Board and corrugating medium
South Carolina Ind., Inc. (79 percent owned by Stone Container Corporation)	675	Florence	Paperboard
Westvaco Corporation	1,989	Charleston	Paperboard

Source: Standards Support and Environmental Impact Statement Volume I: Proposed Standards of Performance for Kraft Pulp Mills.

LIST OF KRAFT PULP MILLS (Concluded)

Owners	Size (ton/day)	Location	Paper and paperboard produced at this location
TENNESSEE			
Bowater, Inc.	500	Calhoun	Newsprint
Packaging Corporation of America (Subsidiary of Tenneco)	775	Counce	Paperboard
TEXAS			
Champion International	820	Pasadena	Uncoated and coated printing, writing, and converting papers
International Paper Company	650	Texarkana	Paperboard
Owens-Illinois, Inc.	900	Orange	Board
Southland Paper Mills, Inc.	500	Houston	Newsprint and kraft paper
Southland Paper Mills, Inc.	400	Lufkin	Newsprint
Temple-Eastex, Inc. (Subsidiary of Time, Inc.)	1,300	Evadale	Paper and paperboard
VIRGINIA			
Chesapeake Corporation of Virginia	1,150	West Point	Coarse paper and paperboard
Continental Can Company	900	Hopewell	Paperboard
Union Camp Corporation	1,500	Franklin	Paperboard and fine, industrial, and coarse papers
Westvaco Corporation	1,000	Covington	Paperboard and corrugating medium
WASHINGTON			
Boise Cascade Corporation	700	Wallula	Linerboard and corrugating medium
Crown Zellerbach	730	Camas	Tissues; industrial, and fine papers
Crown Zellerbach	420	Port Townsend	Paper and paperboard
Longview Fibre Company	1,900	Longview	Paperboard and kraft paper
St. Regis Paper Company	1,029	Tacoma	Linerboard; natural and white paper
Weyerhaeuser Company	375	Everett	None
Weyerhaeuser Company	700	Longview	Paperboard and bristol papers
WISCONSIN			
Consolidated Papers, Inc.	395	Wisconsin Rapids	None
Great Northern Nekoosa Corporation	330	Nekoosa	Business communications papers
Hammermill Paper Company	356	Kaukauna	Packaging and special industrial papers
Mosinee Paper Corporation	175	Mosinee	Paper and paperboard

Source: Standards Support and Environmental Impact Statement Volume I: Proposed Standards of Performance for Kraft Pulp Mills.

APPENDIX B

LIST OF CONTACTS

LIST OF CONTACTS

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APPENDIX C

GLOSSARY OF TERMS

Black liquor (weak):	A solution of spent white liquor and pulp washwater
Black liquor (strong):	Weak black liquor which has been concentrated in multiple effect evaporators and which received its final concentration in either direct contact or nondirect contact evaporators. The strong black liquor has a solid content of approximately 65 percent.
Green liquor:	An aqueous solution of sodium carbonate and sodium sulfide
Kraft pulping:	Pulping where the digestion of wood chips is done with a solution of sodium hydroxide and sodium sulfide
Lignin:	Amorphous polymeric substance related to cellulose that bonds cellulose fibers together
NSSC:	Neutral sulfite semichemical process uses a nearly neutral sulfite solution containing sodium carbonate, sodium bicarbonate, or sodium hydroxide
Oxidation efficiency:	Percentage of sodium sulfide in the black liquor that is oxidized by blowing air or oxygen through the liquor
Pulping:	Conversion of fibrous raw materials into a material which can be converted into paper, paperboard, and building materials
Recovery furnace:	Also called recovery boiler. Unit used to incinerate recovered cooking liquor to produce steam to reprocess cooking chemical.
Smelt:	Molten chemicals from the recovery furnace -- mostly sodium carbonate and sulfide
Snow:	Fluffy white particles emitted from an ESP because of reentrainment or overloading

Soda pulping:	Pulping where the digestion of wood chips is done with a solution of sodium hydroxide
Sulfidity:	In white liquor, the percentage of sodium sulfide to sodium sulfide plus sodium hydroxide where all compounds are expressed as sodium oxide
Sulfite pulping:	Pulping where the digestion of wood chips is done with sulfurous acid, and containing bisulfite of calcium, sodium, magnesium, or ammonia
Weak wash:	Recovered liquor from lime mud washing
White liquor:	An aqueous solution of sodium hydroxide and sodium sulfide

Chemical Symbols

$CaCO_3$	calcium carbonate
CaO	calcium oxide
$Ca(HSO_3)_2$	calcium bisulfite
$Ca(OH)_2$	calcium hydroxide
CH_3OH	methanol
CH_3CH_2OH	ethanol
CH_3COCH_3	acetone
Cl_2	chlorine
ClO_2	chlorine dioxide
CO_2	carbon dioxide
H_2	hydrogen
H_2O	water
H_2S	hydrogen sulfide
H_2SO_3	sulfurous acid
$Mg(HSO_3)_2$	magnesium bisulfite
N_2	nitrogen
Na	sodium
NaCl	sodium chloride
Na_2CO_3	sodium carbonate
N_aHCO_3	sodium bicarbonate
$NaHSO_3$	sodium bisulfite
NaOH	sodium hydroxide
Na_2S	sodium sulfide
Na_2SO_4	sodium sulfate
$Na_2S_2O_4$	sodium thiosulfate
NH_3	ammonia
NH_4HSO_3	ammonium bisulfite
O_2	oxygen
RSH	methyl mercaptan - CH_3SH
RSR	dimethyl sulfide - $(CH_3)_2S$
RSSR	dimethyl disulfide - $(CH_3)_2S_2$
SO_2	sulfur dioxide