

## SECTION 11

### MINERALS

#### 11.1 INTRODUCTION

The processing of minerals for building materials is an important source of particle emissions (Shannon et al., 1971; Vandegrift et al. 1970). Emissions from the following mineral industries will be discussed:

1. Cement
2. Asphalt Road-Mix
3. Lime
4. Gypsum
5. Asbestos
6. Glass
7. Rock, Sand and Gravel

#### 11.2 CEMENT

Cement is the mineral-based binder used in the making of concrete for building material. The production of portland cement involves the comminution, classification and firing of calcareous (chalk-like), siliceous (sandy), argillaceous (clayey) and ferriferous (iron containing) rock (Kreichelt et al., 1967). These processes produce major amounts of airborne fine particles (Shannon et al., 1971).

##### 11.2.1 Process Description

The two major process variations for cement-making are dry grinding vs. slurry preparation and feeding. The quarrying and crushing of limestone and rock products in general are major sources of fine particle emissions in themselves and are covered in Section 11.8 below.

The raw materials may be charged to the kiln in either slurry form or dry (pneumatically or mechanically) (Kreichelt et al., 1967). The wet process allows more reliable feeding and reduced fugitive dust emissions. With the dry process, the raw materials must be dried before blending to reduce grinding power and ensure thorough mixing. Often the drying and the grinding/blending operation are done in one vessel. Drying is effected by the combustion of fossil fuel. Some of the fines generated in the grinder are entrained in the drier offgases. The characteristics of such emissions are covered below in Section 11.2.2.

The largest source of fine particle emissions in the cement plant is the rotary kiln (Shannon et al., 1971). The clinkering operation is done just below the point of fusion of the kiln

feeds (about 1,500°C) (Kreichelt et al., 1967) and requires direct contact with a flame. Substantial amounts of dust are entrained in the combustion gases from the kiln (Shannon et al., 1971; Kreichelt et al., 1962).

After several hours residence time in the kiln, the clinker is air cooled and some of it is entrained in the cooling air. The characteristics of clinker cooler offgases are given in Section 11.2.2 below.

### 11.2.2 Source Characteristics

Figures 11.2.2-1 and 11.2.2-2 show particle size distributions measured from dry cement kilns. Figures 11.2.2-3 and 11.2.2-4 show particle size distribution for controlled and uncontrolled wet cement kilns. Figure 11.2.2-5 shows particle size distributions for cement clinker cooler emissions.

Particle characteristics for various operations in cement manufacturing are shown in Table 11.2.2-1. Chemical composition is presented in Table 11.2.2-2 and Table 11.2.2-3 shows characteristics of the gas stream.

### 11.2.3 Control Technology

The most common particulate control devices for both dry and wet process rotary kilns are fabric filters and electrostatic precipitators (Minicucci et al., 1980). Multicyclones are also used, but usually only as a precut or roughing stage before a baghouse or ESP.

Filter installations have been successful on wet and dry kiln offgases (Minicucci et al., 1980). When used in combination with multicyclones, particle collection efficiencies of 95.5 to 99.5% have been realized. Cooling the kiln exhaust gases before filtration decreases the filter face velocity and prolongs the fabric life. However, over cooling of wet process offgases may lead to condensation on the filter and attendant plugging to corrosion.

Electrostatic precipitators have often been used to control particle emissions from cement kilns (Minicucci et al., 1980). The particle removal efficiency is over 99%. Wet process kiln gases have a lower resistivity due to their higher humidity. Humidification of dry kiln gases improves ESP performance. The reliability of ESP's on cement kiln gases has only been "medium". After many hours of operation, insulating deposits on the collection plates decrease the field strength, and therefore, the effectiveness of ESP's.

Only multicyclones and fabric filters have been commercially proven as particulate removal devices on clinker cooler offgases.

The experience with multicyclones and fabric filters is similar to that on rotary kilns, which is discussed above. Clinker cooler dust is more abrasive, however. This necessitates more rugged materials of construction.

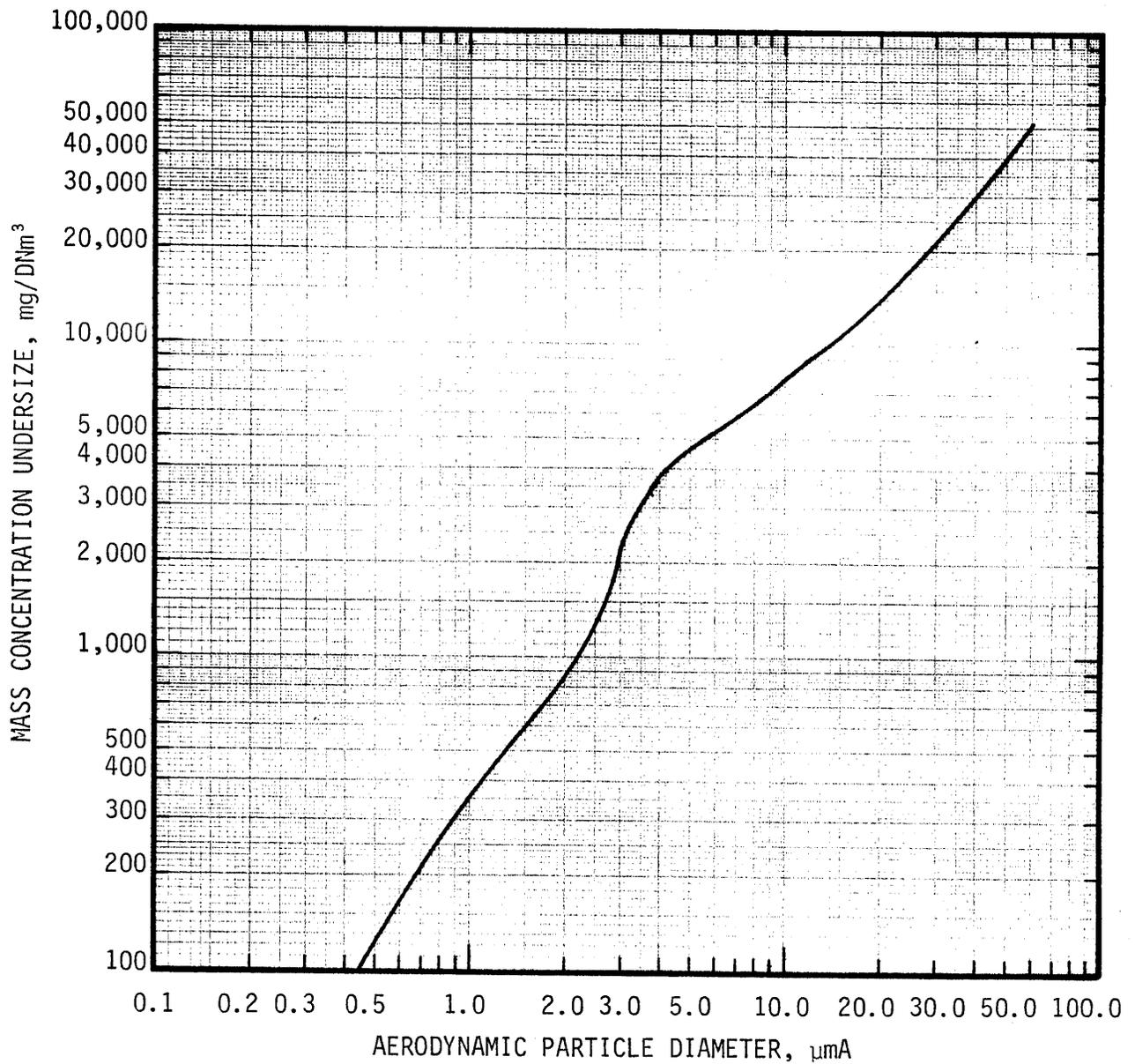


Figure 11.2.2-1. Particle size distribution for cement plants, dry kiln offgas, effluent of multicyclone pre-cut (FPEIS, Test Series No. 157, 1976).

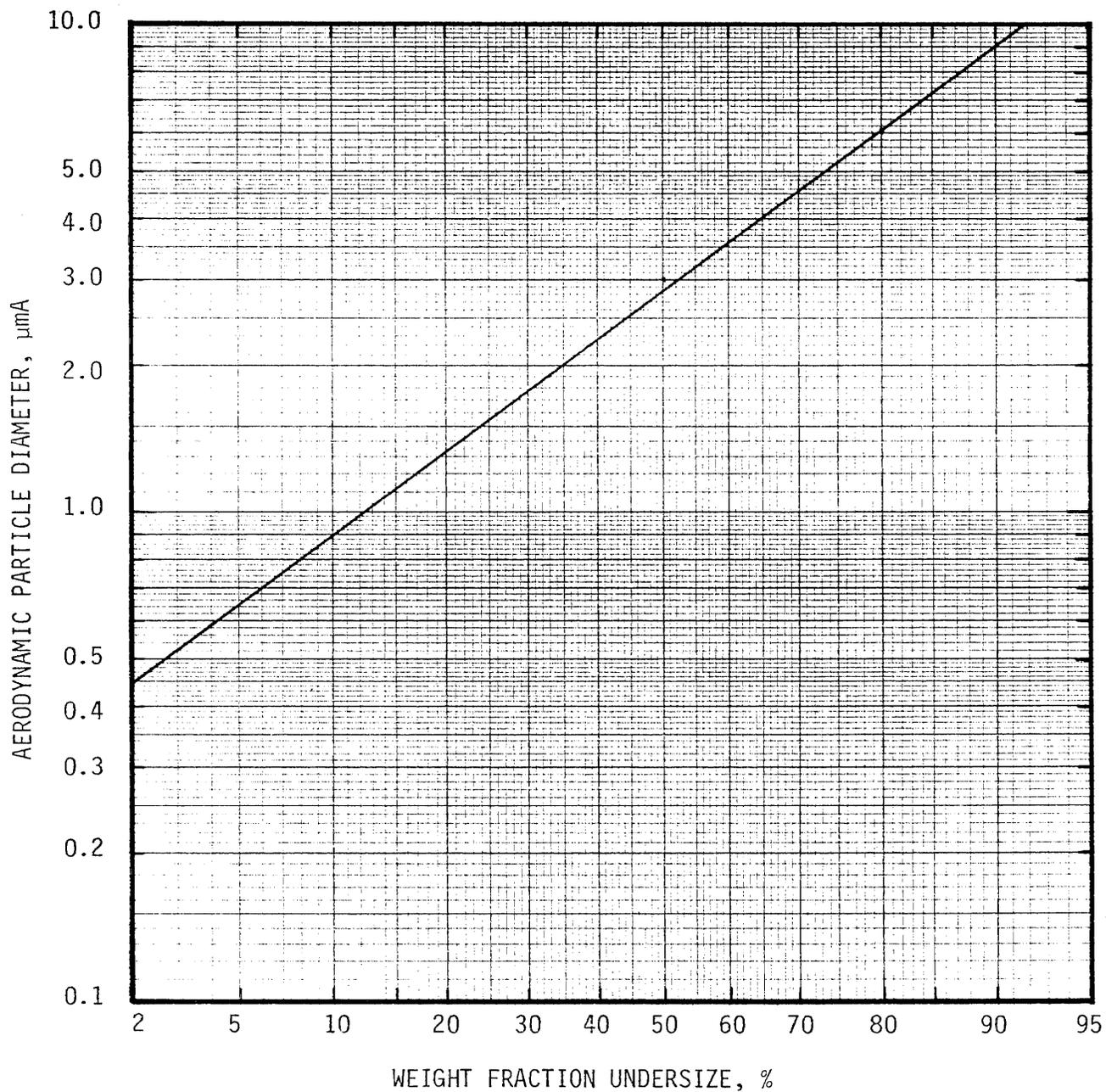


Figure 11.2.2-2. Particle size distribution for the offgas of a dry process cement kiln controlled by baghouse (Taback et al, 1979).

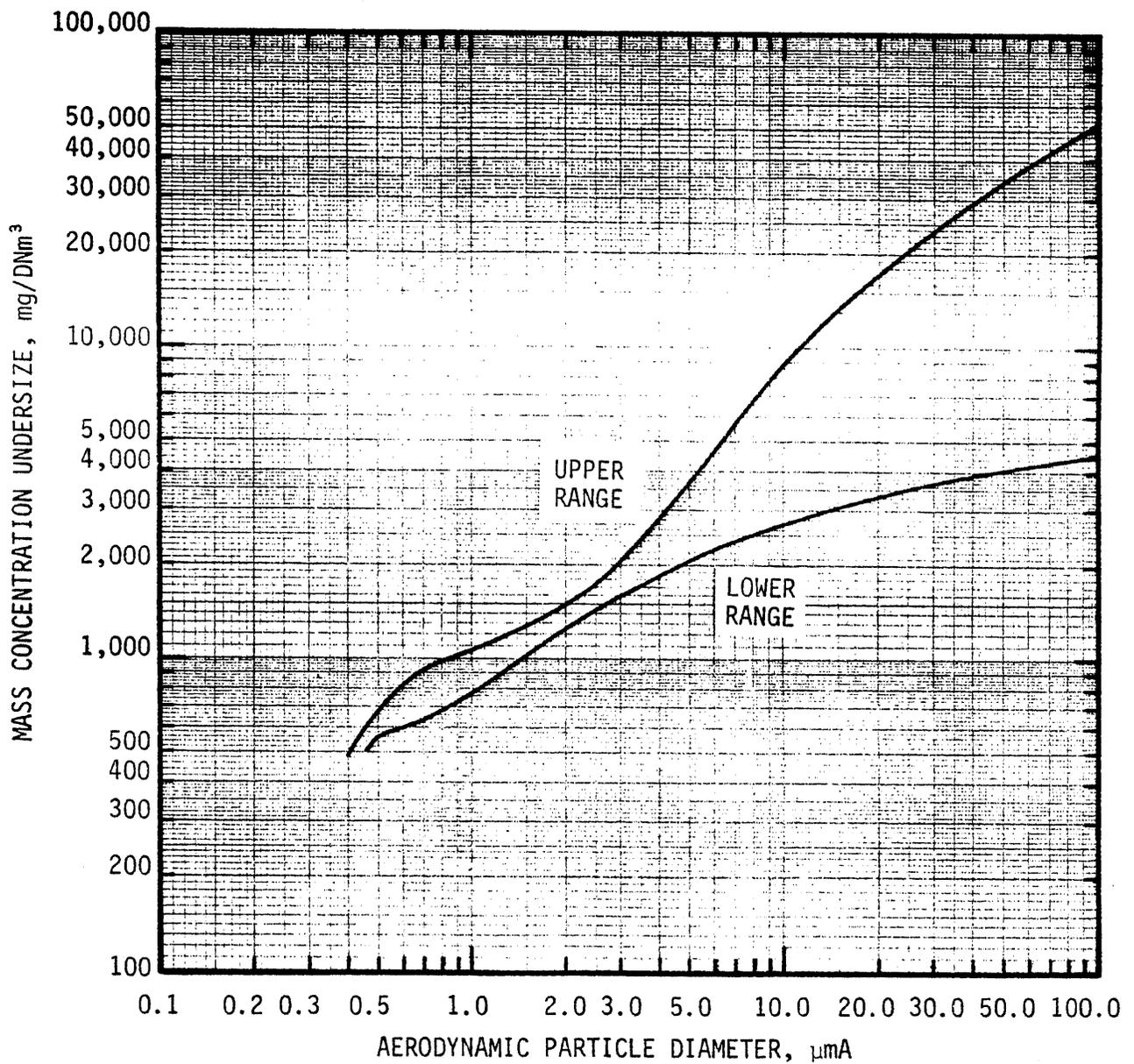


Figure 11.2.2-3. Particle size distribution for an uncontrolled cement plant wet kiln offgas (FPEIS, Test Series No. 80, 1975).

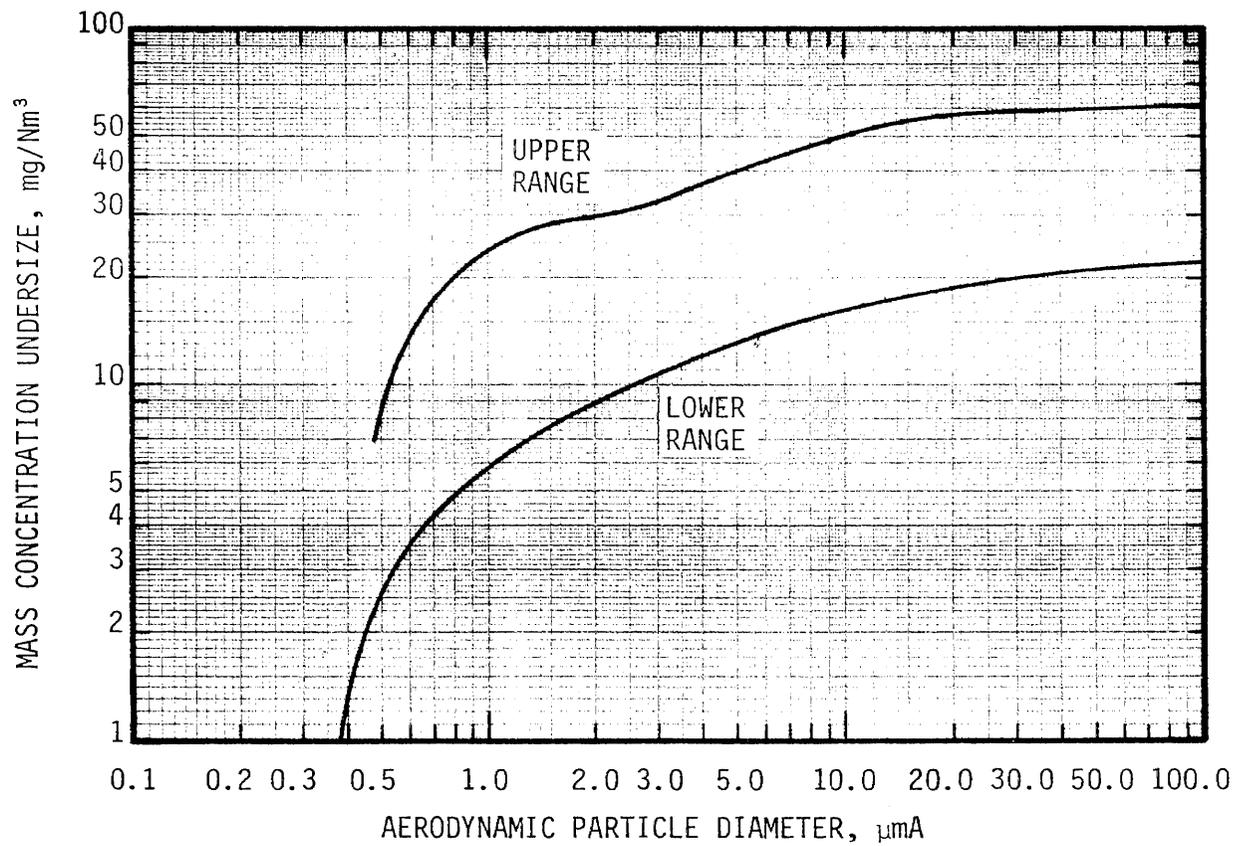


Figure 11.2.2-4. Particle size distribution from a cement plant wet process kiln controlled by an electrostatic precipitator (FPEIS, Test Series No. 80, 1975).

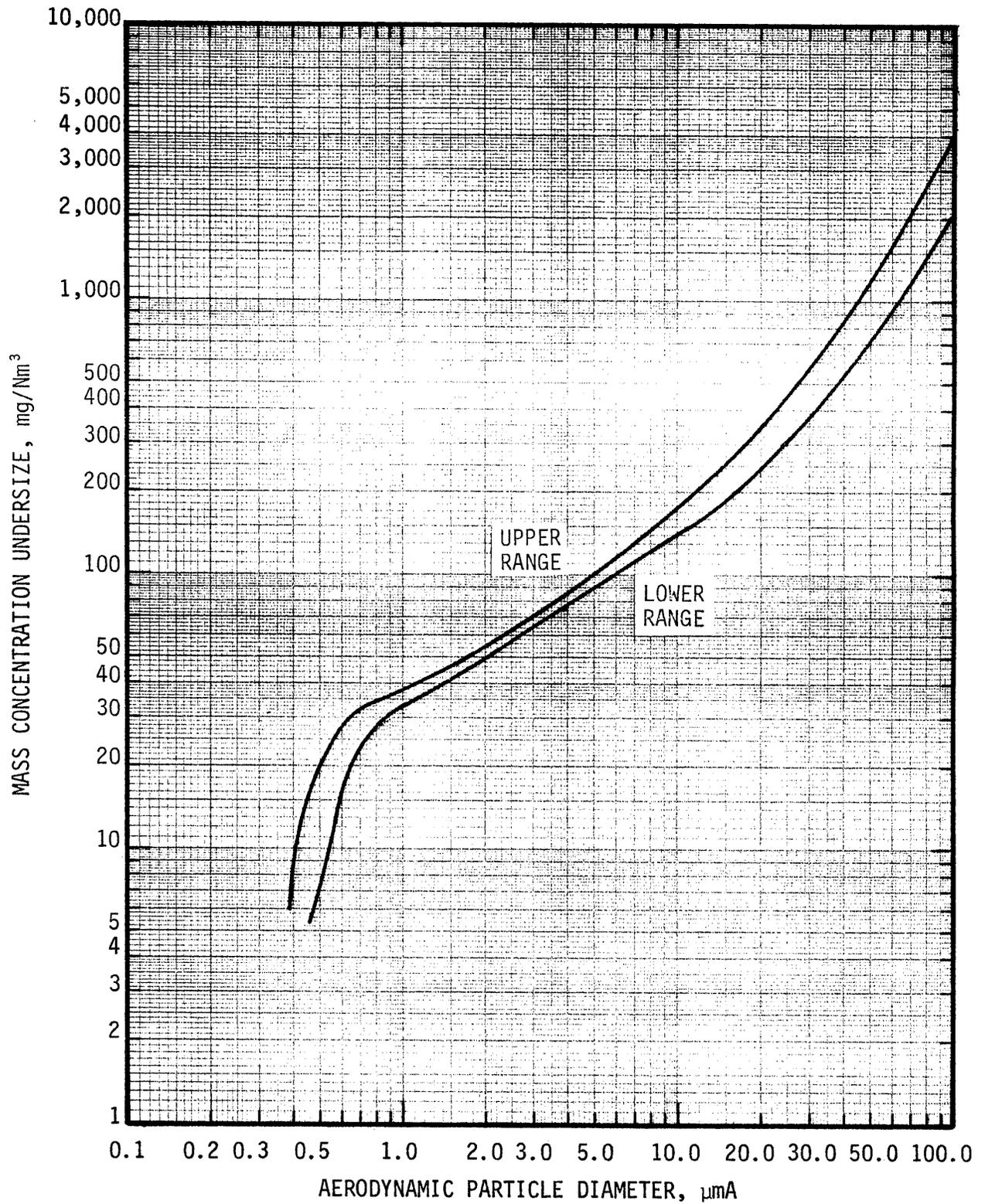


Figure 11.2.2-5. Particle size distribution for an uncontrolled cement plant clinker cooler offgas (FPEIS, Test Series No. 86, 1975).

TABLE 11.2.2-1. PARTICLE CHARACTERISTICS FOR CEMENT PLANTS

Process	Mass Concentration, mg/Nm <sup>3</sup>				Particle Density g/cm <sup>3</sup>	Particle Resistivity ohm-cm
	Total	Uncontrolled <3 μm	Total	Controlled <3 μm		
Cement Manufacturing						
Dry Kiln	2,500-100,000 <sup>a,b,c</sup>	500-2,000 <sup>c</sup>	10-100 <sup>a,b</sup>	5-50 <sup>b</sup>	2.6-3.2 <sup>d</sup>	10 <sup>10</sup> -10 <sup>11</sup> <sup>d</sup>
Wet Kiln	2,000-70,000 <sup>e</sup>	1,000-5,000 <sup>e</sup>	30-500 <sup>e</sup>	10-50 <sup>e</sup>	2.6-3.2 <sup>d</sup>	10 <sup>9</sup> -10 <sup>10</sup> <sup>d</sup>
Drier/Grinder	30,000-250,000 <sup>d</sup>	-	70-200 <sup>f</sup>	-	-	-
Clinker Cooler	500-5,000 <sup>g</sup>	50-100 <sup>g</sup>	-	-	3.6-3.9 <sup>d</sup>	-

<sup>a</sup>Kreichelt et al. (1967)

<sup>b</sup>Taback et al. (1979)

<sup>c</sup>FPEIS Test Series No. 157. (1976)

<sup>d</sup>Vandegrift et al. (1970)

<sup>e</sup>FPEIS Test Series Nos. 80, 158, 159

<sup>f</sup>VDI 2094, 1967

<sup>g</sup>FPEIS, Test Series No. 86, 1975

TABLE 11.2.2-2. PARTICLE CHEMICAL COMPOSITION FOR CEMENT PLANTS<sup>a</sup>

<u>Component</u>	<u>Composition, Wt. %</u>
CaO	39 -50
SiO <sub>2</sub>	10 -19
Fe <sub>2</sub> O <sub>3</sub>	2 -11
Al <sub>2</sub> O <sub>3</sub>	2 - 8
K <sub>2</sub> O	2 - 8
Na <sub>2</sub> O	0.9- 1.1
MgO	1.3- 2.5

<sup>a</sup>Vandegrift et al.(1970)

TABLE 11.2.2-3. GAS CHARACTERISTICS FOR CEMENT PLANTS

<u>Process</u>	<u>Production Rate</u>	<u>Gas Flowrate Nm<sup>3</sup>/kg (unless otherwise noted)</u>	<u>Temperature °C</u>	<u>Chemical Composition, % vol, dry (unless otherwise noted)</u>
Dry Kiln	1-20 <sup>a,c</sup> kg/s (100-1,600 MT/day)	1-10 <sup>a,b,c</sup>	340-420 <sup>c</sup>	CO <sub>2</sub> 19-24 <sup>c</sup> O <sub>2</sub> 1-4 CO 0-2 N <sub>2</sub> Balance, dry H <sub>2</sub> O 6-10 <sup>c</sup> (Wet basis)
Wet Kiln	3.5-16 <sup>a,c</sup> kg/s (300-1,400 MT/day)	2.5-12 <sup>a,b,c,e</sup>	130 <sup>c</sup> -340 <sup>b</sup>	CO <sub>2</sub> 10-12 <sup>e,f</sup> O <sub>2</sub> 4-8 CO 0-2 N <sub>2</sub> Balance, dry H <sub>2</sub> O 25-40 <sup>b,c</sup> (Wet basis)
Drier/Grinder	1-40 <sup>c</sup> kg/s (5-150 MT/hr)	0.8-1.5 <sup>b</sup>	70-150 <sup>c</sup>	O <sub>2</sub> 21 N <sub>2</sub> 79 H <sub>2</sub> O 7-20 <sup>b,c</sup> (Wet basis)
Clinker Cooler	3-25 <sup>c</sup> kg/s (12-90 MT/hr)	1.0-1.8 <sup>c</sup>	150-350 <sup>c,9</sup>	O <sub>2</sub> 21 N <sub>2</sub> 79 H <sub>2</sub> O (Ambient)

<sup>a</sup>Kreichelt et al. (1967)

<sup>b</sup>Andegrift et al. (1970)

<sup>c</sup>VDI, 2094, 1967

<sup>d</sup>FPEIS, Test Series No. 157, 1976

<sup>e</sup>FPEIS, Test Series Nos. 158, 159

<sup>f</sup>FPEIS, Test Series No. 80, 1975

<sup>9</sup>FPEIS, Test Series No. 86, 1975

Several other methods have been tried less frequently (Minicucci et al., 1980):

1. Clinker cooler design and modifications. Clinker coolers in new kiln installations are more efficient, so they exhaust all of their offgas into the kiln, eliminating the cooler offgas vent entirely.
2. Wet scrubbers. High efficiencies require high pressure drops.
3. Granular bed filter (with multicyclone precut). A GBF is less temperature sensitive than a fabric filter. Efficiencies are 95 to 99.5%. Reliability is medium.
4. Electrostatic precipitators. 80 to 99.9% efficiency. Medium reliability. Other comments are the same as for kilns above.

Data on the control of cement plant dryer-grinders is scarce. Both fabric filters and electrostatic precipitators have been used for particle control in Europe (VDI 2094, 1967). Efficiencies of greater than 99% are reported.

### 11.3 ASPHALT ROAD-MIX

#### 11.3.1 Process Description

Hot-mix asphalt paving consists of a combination of aggregates uniformly mixed and coated with asphalt cement. An asphalt batch plant is used to heat, mix, and combine the aggregate and asphalt in the proper proportions to give the desired paving mix. After the material is mixed, it is transported to the paving site and spread as a loosely compacted layer with a uniformly smooth surface. While still hot, the material is compacted by heavy motor-driven rollers to produce a smooth, well-compacted road surface.

Asphalt paving mixes may be produced from a wide range of aggregate combinations, each having particular characteristics and suited to specific design and construction uses. Aside from the amount and grade of asphalt cement used, the principal characteristics of the mix are determined by the size distribution of the siliceous aggregate. Aggregates of all sizes up to 6.4 cm (2½ in.) are used in hot-mix asphalt paving. The coarse aggregates usually consist of crushed stone, crushed slag, crushed gravel and decomposed granite. The fine aggregate fraction consists of finely ground rock, limestone, hydrated lime, or portland cement.

Asphalt cement is used in amounts of 3-12% by weight and is made from refined petroleum. Asphalt composed of high molecular weight compounds, so it is dense, viscous and has a high boiling point.

A typical hot-mix asphalt paving batch plant usually consists of an oil or gas-fired rotary drier, a screening and classifying system, weigh boxes for asphalt cement and aggregate, a

mixer, and the necessary conveying equipment consisting of bucket elevators and belt conveyors. Equipment for the storage of sand, gravel, asphalt cement, and fuel oil is provided in most plants. Heaters for the asphalt cement and fuel oil tanks are also used. Aggregate is usually conveyed from the storage bins to the rotary drier by means of a belt conveyor and bucket elevator. The dried aggregate is conveyed by a bucket elevator to the screening equipment where it is classified and dumped into elevated storage bins, then to the weigh hopper, and then dropped into the mixer along with hot asphalt cement. The batch is mixed and then dumped into waiting trucks for transportaion to the paving site.

### 11.3.2 Source Characteristics

The major point of emission of airborne fine particles from asphalt batch plants is the rotary aggregate dryer. Fine particles are generated by attrition of the aggregate during tumbling. The products of combustiton of drier fuel contact the aggregate turbulently and entrain the fines. Data on the particles and gas stream may be found in Tables 11.3.2-1, and 2. Information on the particle size distribution from controlled and uncontrolled dryers is given in Figures 11.3.2-1 and 11.3.2-2.

### 11.3.3 Control Technology

The commercially proven methods of controlling particle emissions from the aggregate dryers of asphalt road-mix plants follow:

1. Wet scrubbers. Venturi and centrifugal scrubbers are the most widely used. Efficiencies vary from 86-99.8%. No values for reliability were reported. Aggregate recovery cyclones precede these devices.
2. Fabric filters. Particle collection efficiencies are about 99.8%. Product recovery cyclone precedes filter. Solids may or may not be returned to the process.
3. Electrostatic precipitators. ESP's are rarely used in this application. The efficiency for particle removal is about 99%. ESP's are used in conjunction with a cyclone for product recovery.

There are several modifications to the drying process which reduce particle emissions, but they are less frequently practiced than the above control methods. These include:

1. Lowering gas velocity. Running at reduced load or replacement of the dryer with one of larger diameter results in lower gas velocities and reduced particle emissions.

TABLE 11.3.2-1. PARTICLE CHARACTERISTICS FOR ASPHALT ROAD-MIX PLANTS

Process	Mass Concentration, mg/Nm <sup>3</sup>				Particle Density g/cm <sup>3</sup>	Particle Resistivity ohm-cm
	Uncontrolled		Controlled			
	Total	<3 μm	Total	<3 μm		
Asphalt Road-Mix Plants						
Aggregate Dryer	10,000-100,000 <sup>a,b</sup>	150-1,000 <sup>a</sup>	20-150 <sup>a</sup>	10-150 <sup>a</sup>	2.6-2.8 <sup>c</sup>	-

<sup>a</sup>FPEIS, Test Series No. 41, 1974

<sup>b</sup>Taback et al. (1979)

<sup>c</sup>Vandegrift et al. (1970)

TABLE 11.3.2-2 GAS CHARACTERISTICS FOR ASPHALT ROAD-MIX PLANTS

<u>Process</u>	<u>Production Rate</u>	<u>Gas Flowrate</u> Nm <sup>3</sup> /kg (unless otherwise noted)	<u>Temperature</u> °C	<u>Chemical Composition,</u> % vol, dry (unless otherwise noted)
Asphalt Road-Mix Plant				
Aggregate Dryer	25-40 <sup>a</sup> kg/s (2,200-3,600 MT/day)	0.1-0.8 <sup>a</sup>	80-220 <sup>b</sup>	CO <sub>2</sub> 4 <sup>a</sup> -8 <sup>c</sup> O <sub>2</sub> 10-15 <sup>c</sup> N <sub>2</sub> Balance H <sub>2</sub> O 20-30 <sup>a,c</sup> (Wet Basis)

<sup>a</sup>Danielson and Brown, (1973)

<sup>b</sup>VDI 2283, 1967

<sup>c</sup>A.P.T. estimate

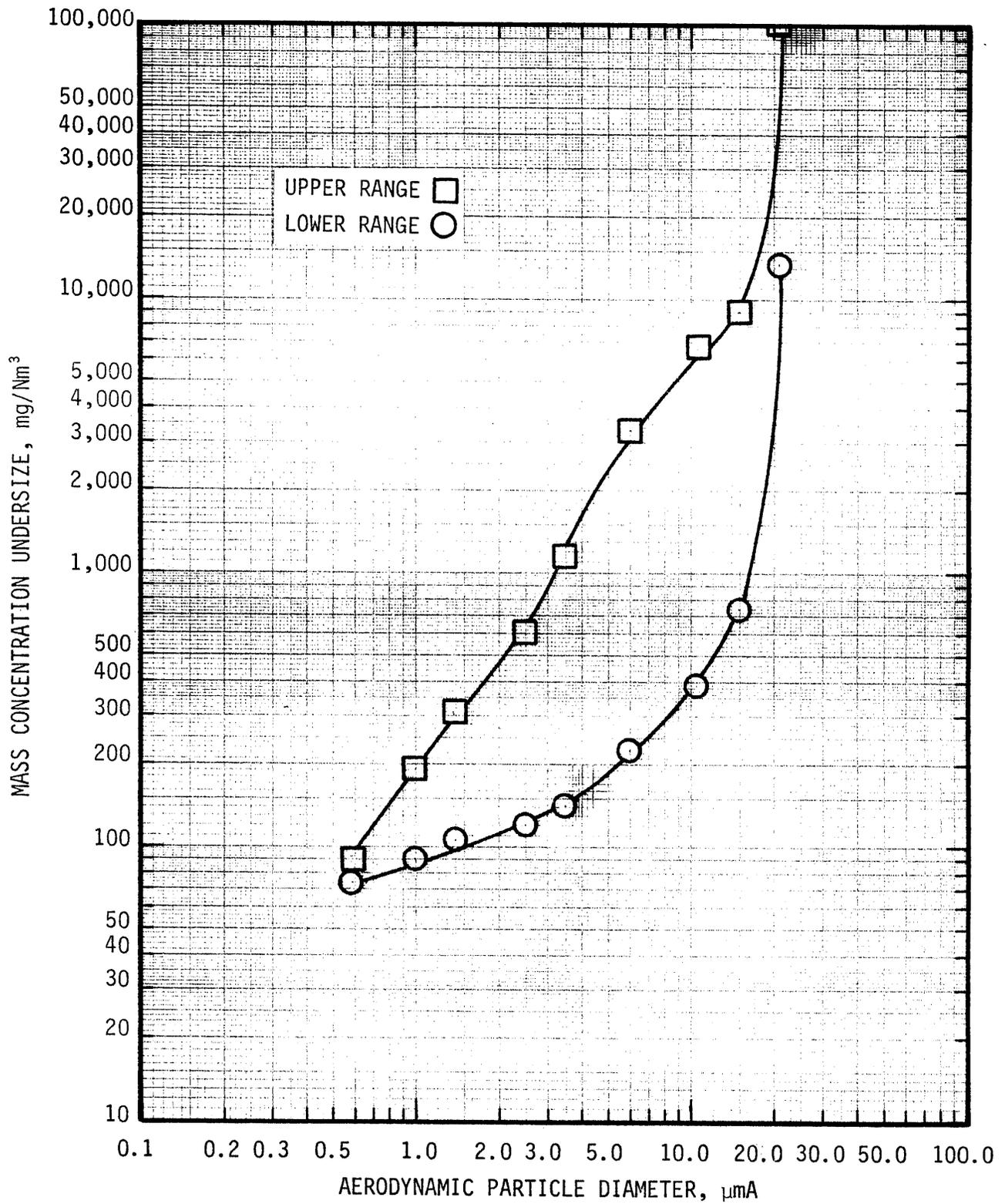


Figure 11.3.2-1. Particle size distribution for uncontrolled asphalt road-mix plant aggregate drier offgas (FPEIS).

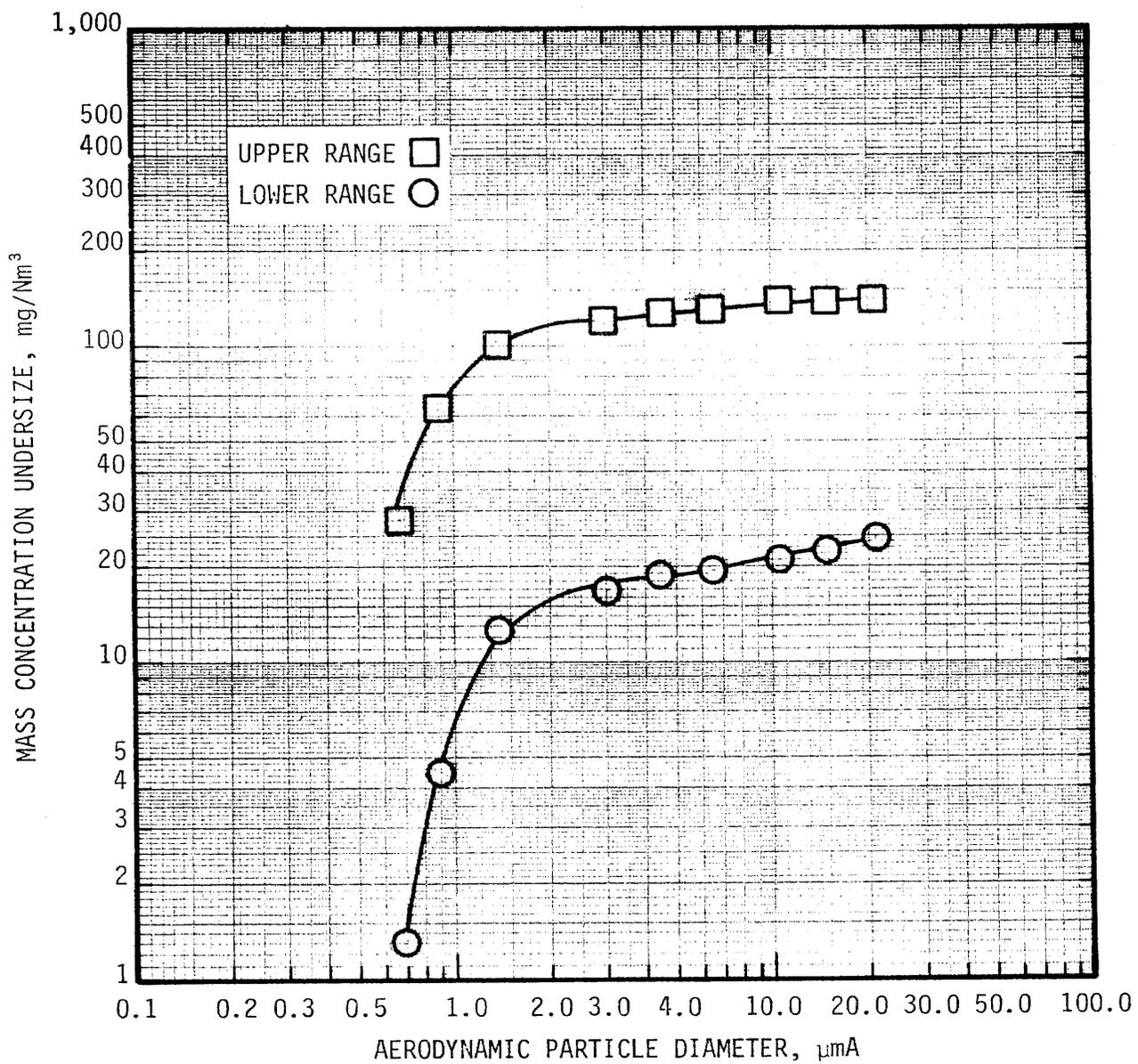


Figure 11.3.2-2. Particle size distribution for the offgas from a wet scrubber on a asphalt road-mix plant aggregate drier (FPEIS).

2. Replacement of rotary dryer with cascade dryer. The cascade dryer allows many stages of contact at lower efficiency (and less entrainment) than a single stage rotary dryer. This generally means higher equipment costs.
3. Combination of wet, cold aggregate with asphalt before heating. The asphalt serves to reduce the entrainment of fine particles. However:
  - a. The resulting aerosol is coated with asphalt.
  - b. The road mix is of poorer quality.

#### 11.4 LIME

##### 11.4.1 Process Description

Lime (calcium oxide) is one of the most widely used chemicals. It is used for medicinal purposes, insecticides, plant and animal food, gas absorption, precipitation, dehydration, and causticizing (Shreve, 1956). It is also employed as a reagent in the sulfite process for papermaking, manufacturing of high-grade steel and cement, manufacturing of soap, rubber, varnish, refractories, and sandlime brick.

Calcium occurs naturally most often as limestone (calcium carbonate). Lime is made from limestone by calcination (driving off carbon dioxide gas at high temperatures) after it is crushed to make it more reactive.

During the calcination of limestone, moisture and volatile organic matter are first driven off (Lewis and Crocker, 1969). Decomposition requires a temperature of 930°C for high-calcium stone.

##### 11.4.2 Source Characteristics

Rotary calcining kilns constitute the largest single source of particulate matter in the lime industry. Abrasion of limestone in the kiln produces dust (Vandegrift et al., 1970). The stone becomes more friable as it approaches the decomposition temperature, dusting increases, and the high-velocity gases from direct-fire fuel combustion blow the dust from the kiln. This dust is hot, dry, difficult to wet, and prone to be electrostatically charged. It is of mixed composition, varying all the way from raw limestone to final calcined product. It will also be mixed with fly ash, tars, and unburned carbon if pulverized coal is used as the fuel. The properties of particulate emissions from rotary limestone calcining kilns are given in Figure 11.4.2-1 and Tables 11.4.2-1, 2 and 3.

##### 11.4.3 Control Technology

The state-of-the-art methods for controlling lime kiln particle emissions are the following:

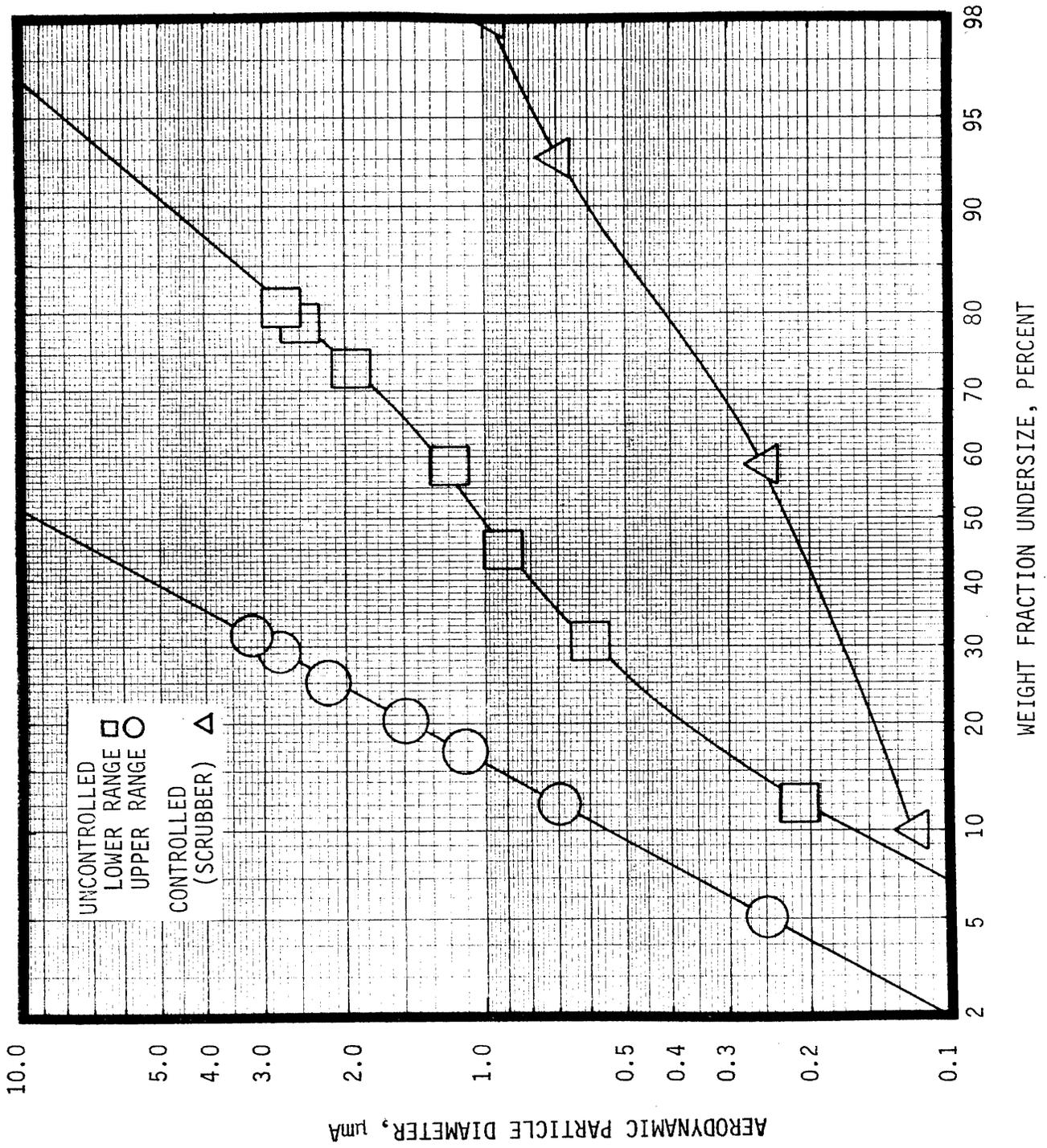


Figure 11.4.2-1. Particle size distribution for uncontrolled and controlled lime plant kiln offgas (Shannon et al. 1971).

TABLE 11.4.2-1. PARTICLE CHARACTERISTICS FOR LIME PLANTS

Process	Mass Concentration, mg/Nm <sup>3</sup>				Particle Density g/cm <sup>3</sup>	Particle Resistivity ohm-cm
	Total	Uncontrolled <3 μm	Total	Controlled <3 μm		
Lime Production						
Rotary Kiln	5,000- 50,000 <sup>a</sup>		2-500 <sup>a</sup>	0.4-300 <sup>b</sup>	2.6-3.0 <sup>a</sup>	-

<sup>a</sup>Vandegrift et al. (1970)

<sup>b</sup>Shannon et al. (1971)

TABLE 11.4.2-2. PARTICLE CHEMICAL COMPOSITION FOR  
LIME CALCINING KILN OFFGAS<sup>a</sup>

<u>Component</u>	<u>Composition, Wt. %</u>
CaCO <sub>3</sub>	23 -61
CaO	6 -66
Na <sub>2</sub> CO <sub>3</sub>	<b>1.4</b>
MgCO <sub>3</sub>	1.4-18.7
Fe <sub>2</sub> O <sub>3</sub> , Al <sub>2</sub> O <sub>3</sub>	2.9

<sup>a</sup>Vandegrift et al. (1970)

TABLE 11.4.2-3. GAS CHARACTERISTICS FOR LIME PLANTS

<u>Process</u>	<u>Production Rate</u>	<u>Gas Flowrate</u> Nm <sup>3</sup> /kg (unless otherwise noted)	<u>Temperature</u> °C	<u>Chemical Composition,</u> % vol, dry (unless otherwise noted)
Lime Production Rotary Kiln	0.6-7 <sup>a</sup> kg/s (50-600 MT/day)	2-6 <sup>b</sup>	400-1,000 <sup>a</sup>	CO <sub>2</sub> 24-37 <sup>a,b</sup> O <sub>2</sub> ~1 <sup>a</sup> N <sub>2</sub> Balance, dry H <sub>2</sub> O ~15 <sup>a</sup> (Wet basis)

<sup>a</sup>Hardison and Herington (1970)

<sup>b</sup>Lewis and Crocker (1969)

1. Wet scrubbers. The types of scrubbers used are:
  - a. Cyclonic (single or multistage)
  - b. Spray/Impingement Plate
  - c. VenturiEfficiencies of 84 to 99.7% have been reported. Pre-cleaning is often done with either settling chambers or cyclones. The ability to handle hot kiln offgases is an advantage of scrubbers on this application.
2. Fabric filters. Glass bag collectors have been used on lime kiln gases with temperatures up to about 290°C. Efficiencies are good, 99.9%. Settling chambers or cyclones are used for pre-cleaning.
3. Electrostatic precipitators. Particle removal efficiencies of 95-99+% are reported. Settling chambers or cyclones are used as roughing stages.

## 11.5 GYPSUM CALCINING

Gypsum is calcium sulfate dehydrate. It is usually mined or quarried from sedimentary stratigraphic deposits which contain limestone and salt. Upon slight heating, gypsum may be partially dehydrated (calcined) to the hemihydrate (plaster of paris).

Gypsum is used universally for interior walls, partitions, and ceilings, either in plaster or in prefabricated products (Greber et al., 1979). Crude gypsum is marketed for use in cement, agriculture, or fillers. Calcined gypsum is marketed in the form of plaster or prefabricated products, such as lath, veneer base, sheathing, and wallboard.

### 11.5.1 Process Description

Gypsum is mined and crushed onsite at the deposit. It is then trucked to a processing plant where it undergoes screening, secondary crushing of the underflow, drying, and tertiary grinding. The oversize from the screening operation is used for portland cement manufacture. Drying is required before the final comminution step because the increased surface area resulting from secondary crushing makes the moist gypsum highly agglomerative.

After tertiary grinding the gypsum is conveyed to the calcining kiln. Gypsum calcining is distinguished from drying (also called dehydration) because bound water is being removed from the solid. To convert calcium dehydrate to hemihydrate, gypsum is maintained at 160°C for 2-3 hours. Heat for the reaction is supplied by fuel combustion. To minimize the calciner vessel volume the gypsum contacts the flame directly and is ground fine (100% passing 100 mesh) to increase the surface area.

Particles are entrained in the combustion gases for the following reasons:

1. The fine solids undergo further size reduction in the rotating kiln, making them more easily entrained.
2. The turbulence of the combustion zone increases particle entrainment.

#### 11.5.2 Source Characteristics

Data on gypsum calcining kiln emissions are not easily found. A size distribution for the particulate emissions from an uncontrolled kiln was not located.

Figure 11.5.2-1 shows the particle size distribution from a gypsum calcining kiln controlled by a baghouse. Information on the properties of the particles and their carrier gas is contained in Tables 11.5.2-1, 2, and 3.

#### 11.5.3 Control Technology

The particle emissions from gypsum calcining kilns are controlled by control devices, such as:

1. Cyclones
2. Wet Scrubber
3. Electrostatic Precipitators
4. Filters

Cyclones are usually used in combination with scrubbers, ESP's or filters. Little data exist on gypsum plant emissions or control device performance. From the data of Greber et al. (1979, and Taback et al. (1979), an efficiency of greater than 99% for a baghouse may be expected.

### 11.6 ASBESTOS MINING AND MILLING

The term asbestos refers to any of six naturally occurring mineral silicates. 95% of U. S. production is chrysotile, a hydrated silicate of magnesium (Sittig, 1975). Electron microscopy reveals that the smallest fibrous subdivision of a chrysotile fiber, called a fibril, has an average outside diameter of 0.034  $\mu\text{m}$ .

#### 11.6.1 Process Description

In 1970, approximately 60% of the asbestos produced in the United States was from California. Normally chrysotile is found in veins, surrounded by rock formation. In San Benito and Fresno counties, high concentrations of chrysotile occur as loosely bound, short-fibers, which are exposed to the atmosphere (U.S. EPA, 1973).

In California, the asbestos mines are open-pit or surface mines. In surface mining, the operations of removing overburden, scraping and shoveling of ore, preliminary screening of ore,

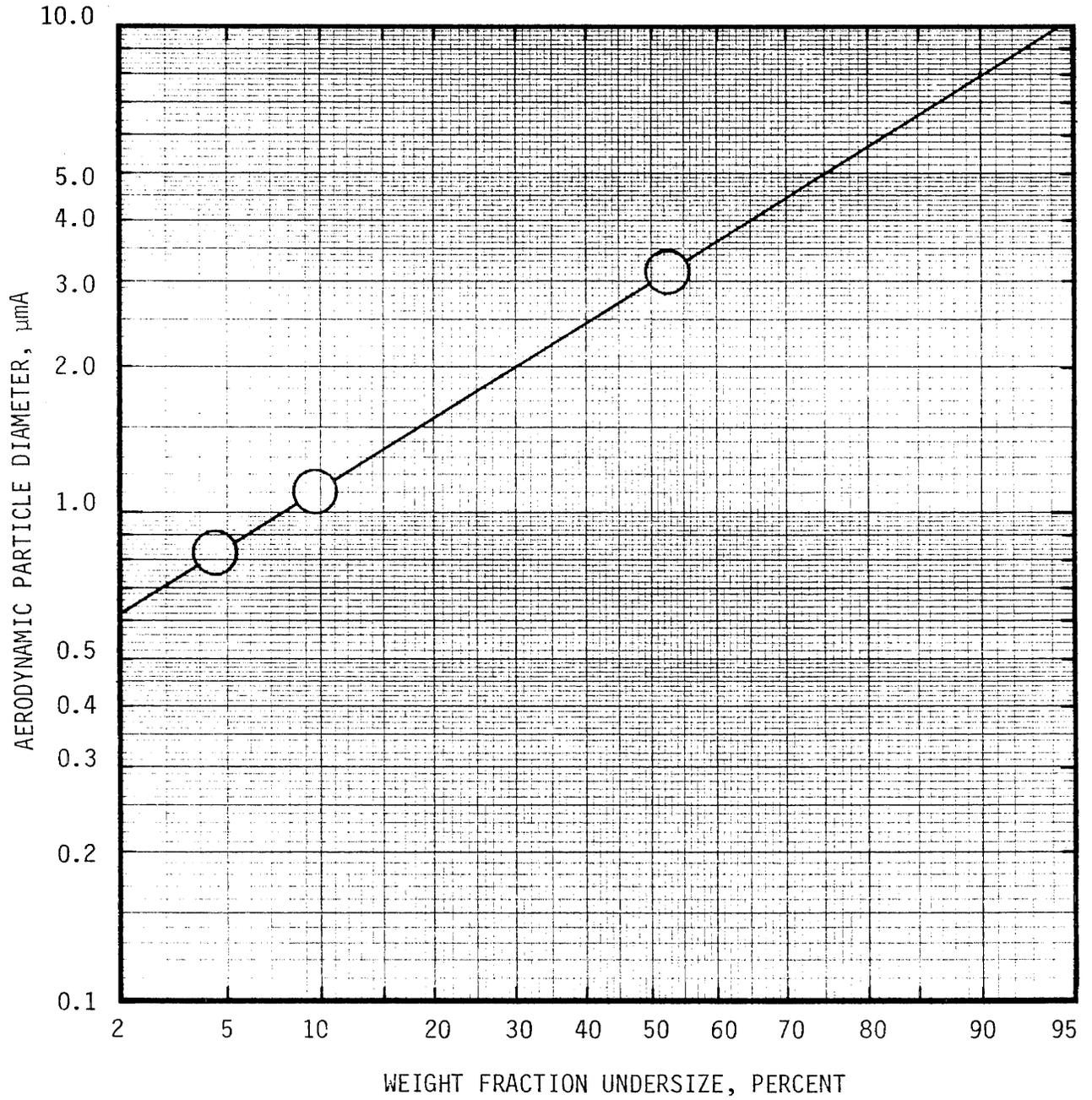


Figure 11.5.2-1. Particle size distribution for the effluent gases of a gypsum calcining oven, controlled by baghouse (Taback et al., 1979).

TABLE 11.5.2-1. PARTICLE CHARACTERISTICS FOR GYPSUM CALCINING

<u>Process</u>	Mass Concentration, mg/Nm <sup>3</sup>				Particle Density g/cm <sup>3</sup>	Particle Resistivity ohm-cm
	<u>Uncontrolled</u>		<u>Controlled</u>			
	<u>Total</u>	<u>&lt;3 μm</u>	<u>Total</u>	<u>&lt;3 μm</u>		
Gypsum Calciner	~45,000 <sup>a</sup>	-	~130 <sup>b</sup>	~65 <sup>b</sup>	-	-

<sup>a</sup> Greber et al. (1979)

<sup>b</sup> Taback et al. (1979)

TABLE 11.5.2-2. PARTICLE CHEMICAL COMPOSITION  
FOR A GYPSUM CALCINING KILN<sup>a</sup>

Component	Composition, Wt. %			
	<u>&gt;10 <math>\mu\text{m}</math>A</u>	<u>10-3 <math>\mu\text{m}</math>A</u>	<u>3-1 <math>\mu\text{m}</math>A</u>	<u>&lt;1 <math>\mu\text{m}</math>A</u>
Calcium	10	9	15	13
Iron				1
Sulfates	62	57	61	12
Carbon	2			1
Other (Oxygen, Sodium, Aluminum, Magnesium)	26	37	24	74

<sup>a</sup>Taback et al.(1979)

TABLE 11.5.2-3. GAS CHARACTERISTICS FOR GYPSUM PLANTS<sup>a</sup>

<u>Process</u>	<u>Production Rate</u>	<u>Gas Flowrate</u> Nm <sup>3</sup> /kg (unless otherwise noted)	<u>Temperature</u> °C	<u>Chemical Composition,</u> % vol, dry (unless otherwise noted)
Gypsum Calciner	3 kg/s (250 MT/day)	~1	~210	CO <sub>2</sub> ~0.5 O <sub>2</sub> ~19 N <sub>2</sub> ~Balance, dry H <sub>2</sub> O ~24 (Wet basis)

<sup>a</sup>Taback et al. (1979)

conveying of ore, loading of ore into trucks, and the unloading of ore from trucks into hoppers at the mill can generate emissions of asbestos dust. Some ores have a high moisture content (as much as 20 percent in Fresno and San Benito counties), and, therefore, emissions from processing these ores are less than those encountered with dry ores. The emission sources associated with underground mining installations include sorting, conveying, loading, and unloading operations, which are performed outside the mines (U.S. EPA, 1973).

Asbestos can be processed using a wet or dry method according to Greber et al. (1979). In the dry process, the quarried asbestos ore is crushed in jaw or gyratory crushers to a size of 3.8 to 5.1 cm. The crushed ore is dried to 1 percent or less moisture in rotary or vertical dryers before being crushed again in hammermills, cone crushers, or gyratory crushers. The ore is sent from the secondary crushers to a series of shaker screens, where the asbestos fibers are separated from the rock and air-classified into a series of grades according to length. The graded fibers are bagged for shipment.

In the wet process, ore is "ploughed" in horizontal benches and allowed to air-dry. It is then screened and transported to the mill for processing. Processing consists of further screening, wet crushing, fiber classification, filtering, and drying. Process water is used for wet processing and classifying of asbestos fibers.

#### 11.6.2 Source Characteristics

Asbestos fibers and other particles are emitted during removal of overburden and preparation of the ore body for open-pit mining. Further release occurs during ore-breaking. Each piece of process equipment in the dry milling of asbestos produces dust emissions. Dust sources are minimized in the wet process by use of water throughout the operation.

Table 11.6.2-1 gives the chemical composition of chrysotile. No data were found on the size or quantity of particle emissions.

#### 11.6.3 Control Technology

Various types of wetting agents reduce dust emissions at open-pit mines. Greber et al. (1979) reported that the relatively high moisture content of ore at a California mine, keep dust emissions to a minimum.

Most mines use fabric filters to control dry milling operations. All conveyors are enclosed and conveyor transfer points are aspirated to the fabric filters (Greber, et al., 1979). Cyclones and scrubbers have also been used to control asbestos milling operations (U.S. EPA, 1973).

TABLE 11.6.2-1. CHEMICAL COMPOSITION  
OF CHRYSOTILE ASBESTOS

<u>Chemical Compound</u>	<u>Weight %</u>
SiO <sub>2</sub>	37-44
MgO	39-44
FeO	0- 6.0
Fe <sub>2</sub> O <sub>3</sub>	0.1- 5.0
Al <sub>2</sub> O <sub>3</sub>	0.2- 1.5
CaO	trace- 5.0
H <sub>2</sub> O	12-15

<sup>a</sup>U.S. EPA, 1973

## 11.7 GLASS MELTING FURNACES

The glass manufacturing industry is divided into the following product categories: flat glass, glass containers, pressed and blown glass, and fiberglass. In California there are 16 glass container manufacturers, 5 pressed and blown glass operations, 4 flat glass manufacturers, and 4 fiberglass plants, according to the U. S. Environmental Protection Agency, 1979.

According to Spinosa et al. (1979), the glass melting operation is the major source of emissions in glass manufacturing. The emissions from glass melting include fine particles,  $\text{NO}_x$ ,  $\text{SO}_x$ , CO and hydrocarbons.

### 11.7.1 Process Description

Glass is a mixture of various inorganic oxides which is formed by the fusion of dry materials at about  $1540^\circ\text{C}$  (Steenberg, 1975). Glass can be formed from various combinations of oxides to give hundreds of glass types with various properties. Spinosa et al. (1973) discussed the different types of glass which are commonly used in glass products. Most glass is formed primarily from silica sand ( $\text{SiO}_2$ ). About 90% of the glass being made is soda-lime glass (Danielson, 1973).

Soda-lime glass is produced in large capacity, direct-fired, regenerative furnaces. Other types of glass, are often produced in batch furnaces, which cause only minor air pollution problems, according to Danielson, 1973.

### 11.7.2 Source Characteristics

The major type of pollutant released in glass melting consists of particles which form when compounds vaporize from the molten glass surface, combine with combustion products, and then condense in the checkerwork or stack (U. S. Environmental Protection Agency, 1979). Sodium sulfate, which forms the largest percentage of particle emissions from soda-lime glass manufacturing, is formed in this way. Particles formed by condensation are very fine as shown in Figure 11.7.2-1.

The chemical composition of the particle emissions will vary with the raw materials used to make the glass. Toxic emissions, such as lead and arsenic, will occur when they are contained in the feed material. Table 11.7.2-2 shows the chemical composition of emissions from glass melting furnaces. Flint and amber glass are both soda-lime glass used for glass containers. Flint glass includes clear and green glass (Spinosa et al., 1979).

Table 11.7.2-1 shows particle characteristics for glass melting furnaces. Table 11.7.2-3 shows gas characteristics.

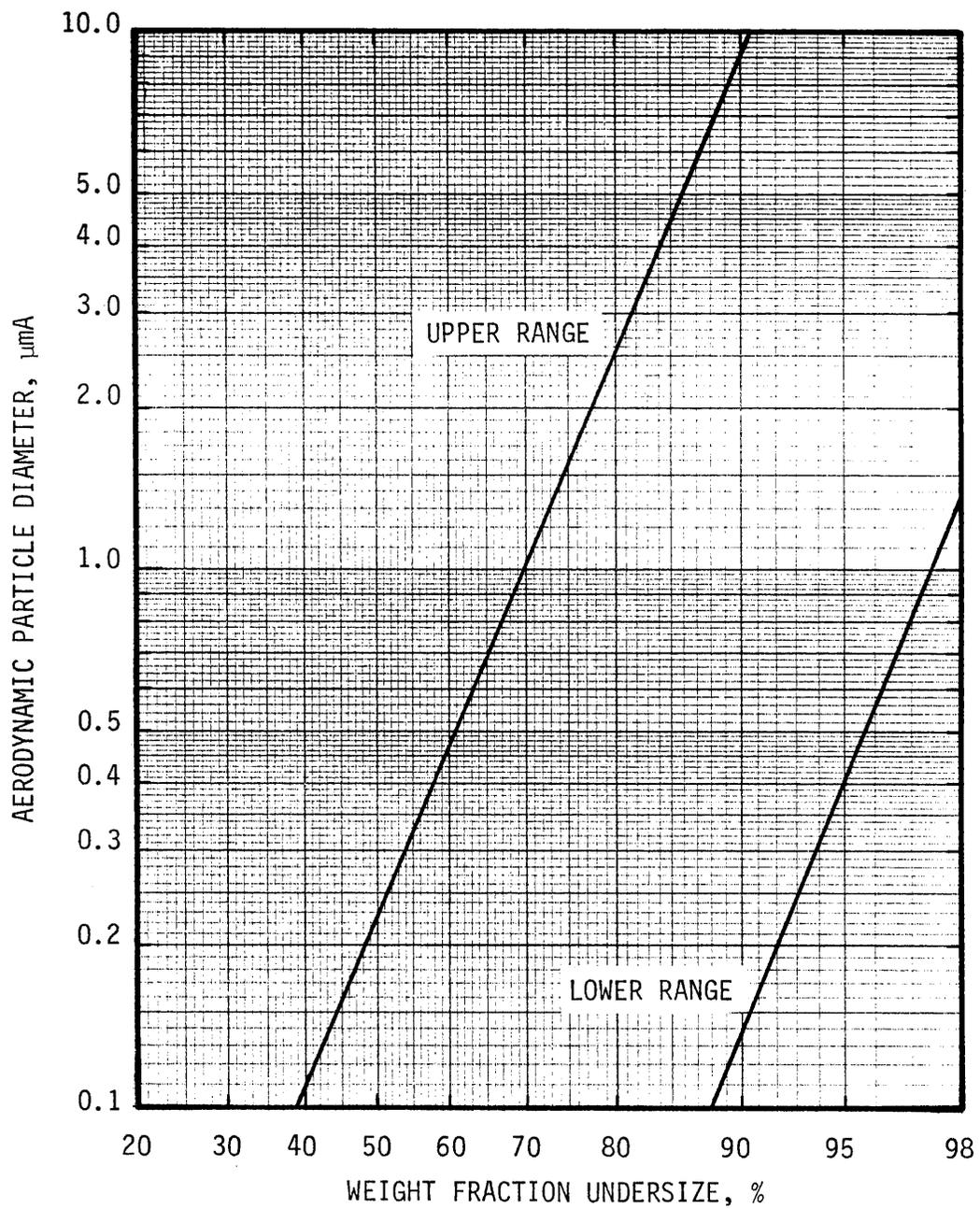


Figure 11.7.2-1. Particle size distribution for the uncontrolled effluent gas from a glass melting furnace (Stockham, 1971; Danielson, 1973; Spinosa et al., 1979).

TABLE 11.7.2-1. PARTICLE CHARACTERISTICS FOR GLASS MELTING

Process	Mass Concentration, mg/Nm <sup>3</sup>				Particle Density g/cm <sup>3</sup>	Particle Resistivity ohm-cm
	<u>Uncontrolled</u>		<u>Controlled</u>			
	<u>Total</u>	<u>&lt;3 μm</u>	<u>Total</u>	<u>&lt;3 μm</u>		
Glass Melting Furnace	80-500 <sup>a,b</sup>	60-500 <sup>c,d,e</sup>	10-60 <sup>a,b</sup>	8-50 <sup>a</sup>	-	-

<sup>a</sup>Taback et al. (1979)

<sup>b</sup>Steenberg (1974)

<sup>c</sup>Stockham (1971)

<sup>d</sup>Danielson (1973)

<sup>e</sup>Spinosa et al. (1979)

TABLE 11.7.2-2. PARTICLE CHEMICAL COMPOSITION  
FOR GLASS MELTING FURNACES<sup>a</sup>

Composition, Wt. %

<u>Component</u>	<u>Flint Glass Plant</u>	<u>Amber Glass Plant</u>
SiO <sub>2</sub>	0.3- 4.1	0.03-0.1
CaO	2 -19	0.8 -1.7
SO <sub>3</sub>	25 -40	47
B <sub>2</sub> O <sub>3</sub>	0 - 1.3	0 -3.7
As <sub>2</sub> O <sub>3</sub>		0 -7.7
PbO		0 -0.4
K <sub>2</sub> O and Na <sub>2</sub> O	28 -40	26 -30
Al <sub>2</sub> O <sub>3</sub>	0.2- 3.5	
F	0 - 9	
Fe <sub>2</sub> O <sub>3</sub>	0 - 0.6	0 -0.1
MgO	0 - 1.4	
ZnO		0 -0.5
R <sub>2</sub> O <sub>3</sub>	0 - 6.5	
Ignition Loss (CO <sub>2</sub> )	7.5- 30	10 -26

<sup>a</sup>Danielson (1973)

TABLE 11.7.2-3. GAS CHARACTERISTICS FOR GLASS MELTING PLANTS

<u>Process</u>	<u>Production Rate</u>	<u>Gas Flowrate Nm<sup>3</sup>/kg (unless otherwise noted)</u>	<u>Temperature °C</u>	<u>Chemical Composition,<sup>e</sup> % vol, dry (unless otherwise noted)</u>
Glass Melting Furnace	20-400 <sup>a,b,c</sup> MT/day 0.23-4.6 kg/s	4-8 <sup>c,d</sup>	160-900 <sup>a,c,d</sup>	CO <sub>2</sub> 6-9 O <sub>2</sub> 9-13 NO <sub>x</sub> 100-700ppmv N <sub>2</sub> Balance, dry H <sub>2</sub> O 8-12 (Wet basis)

<sup>a</sup>Spinoso et al. (1979)

<sup>b</sup>U.S. Environmental Protection Agency, 1979

<sup>c</sup>Taback et al. (1979)

<sup>d</sup>Steenberg (1974)

<sup>e</sup>Danielson (1973)

### 11.7.3 Control Technology

Process modifications which decrease volatile compounds in the feed or which lower the furnace temperature are effective in decreasing emissions. The U. S. Environmental Protection Agency, 1979, reports that arsenic has been removed from the feed in glass container manufacture and feed rates of soda, fluorides, and selenium have been reduced. Danielson, 1973, recommends that the sulfate content of the charge be reduced as much as possible. The reduction in feed constituents can only be decreased to a certain point before the quality of the glass is reduced or product specifications are not met.

The addition of larger amounts of cullet reduces the energy required to form the glass. Therefore, a lower temperature is required, less fuel is used, and emissions are reduced. The amount of cullet which can be added is limited by the availability of waste glass and the effect of impurities on the glass quality.

Electric boosting reduces the furnace temperature and therefore the emissions level. In all electric melters, the surface of melt is maintained at ambient temperature and the raw material is fed continuously over the entire surface. As glass is withdrawn from the melter the raw material gradually sinks in the furnace and is melted. The U. S. Environmental Protection Agency, 1979, reports that this process minimizes losses from vaporization. Usually they are vented openly inside the furnace building.

The all-electric melter has not been used to produce glass in large capacity. Also, not all glasses can be melted electrically and others attack the electrodes (U. S. Environmental Protection Agency, 1979).

ESP's are the most common control device used and can be designed for 99% collection efficiency. Baghouses are also used and show collection efficiencies of 99% also. Care must be taken to keep the gas temperature above the dew point, according to Danielson (1973). Venturi scrubbers have also been used. Disposal of water waste is a problem. However, the U. S. Environmental Protection Agency, 1979, reports a 75-85% reduction in sulfur oxide emission for a Venturi scrubber.

The EPA also reports the use of two developing systems. In one, chromatographic solids are injected into the exhaust stream to agglomerate submicron particles and absorb gases. A conventional fabric filter is used for collection. 85-95% efficiencies were reported for collection of particles.

Pilot testing of fiber bed mist eliminators for particle control on a glass melting furnace were reported. Efficiency data is inconclusive according to the U. S. Environmental Protection Agency (1979).

11.8           ROCK, SAND AND GRAVEL  
11.8.1         Process Description

The conversion of naturally occurring minerals into crushed stone products involves a series of interrelated physical operations (Vandegrift et al., 1970). Quarrying, transporting, crushing, size classification, and drying are common to almost all methods of mineral production. Particulate air pollution may result from any or all of these operations. The dust emitted is usually a heavy particulate released at ambient temperature.

The crushing plant operations common to most crushed stone installations are primary crushing, scalping, secondary crushing, tertiary or finishing crushing, final screening, conveying, storage and shipping, and in some instances, washing. Depending on the purpose of the plant and the kind of rock processed, all or only a few of these operations take place.

At a typical operation the product from the secondary crushing stage (usually 2.5 cm or less in size) is transported to a secondary screen for further sizing. Sized material from this screen is conveyed or discharged directly to tertiary crushing, which takes place on cone crushers or hammermills. The product from the tertiary crushers is shuttled back to the secondary screen, forming a closed circuit with a fixed top size. The throughs from this screen are discharged to a conveyor and elevated to a screen house or tower containing multiple-screen lines for final sizing. At this point, end products of desired gradation are chuted directly to finished product bins or transported by conveyors or trucks to stockpiles in open areas.

Sometimes stone washing is required to meet particular end product specifications or demands, such as those for concrete aggregate. Washing plants consist of a number of fine mesh screens onto which the material falls and is sprayed with a heavy water-spray. Unwanted fines are usually discharged to a settling pond.

11.8.2         Source Characteristics

Particle size distributions for rock screening and handling and for rock crushing are shown in Figures 11.8.2-1 and 11.8.2-2. Tables 11.8.2-1 and 11.8.2-2 show particle and gas characteristics for rock, sand and gravel plants.

11.8.3         Control Technology

Operations at a typical nonmetallic mineral processing plant generate dust at many points, including the crushers, grinders, screens, conveyor transfer points, and storage facilities. Consequently, effective emission control is complex and difficult. Control methods include wet dust suppression, dry collection, and a combination of the two. In wet dust suppression, moisture is introduced into the material flow, causing fine particulate

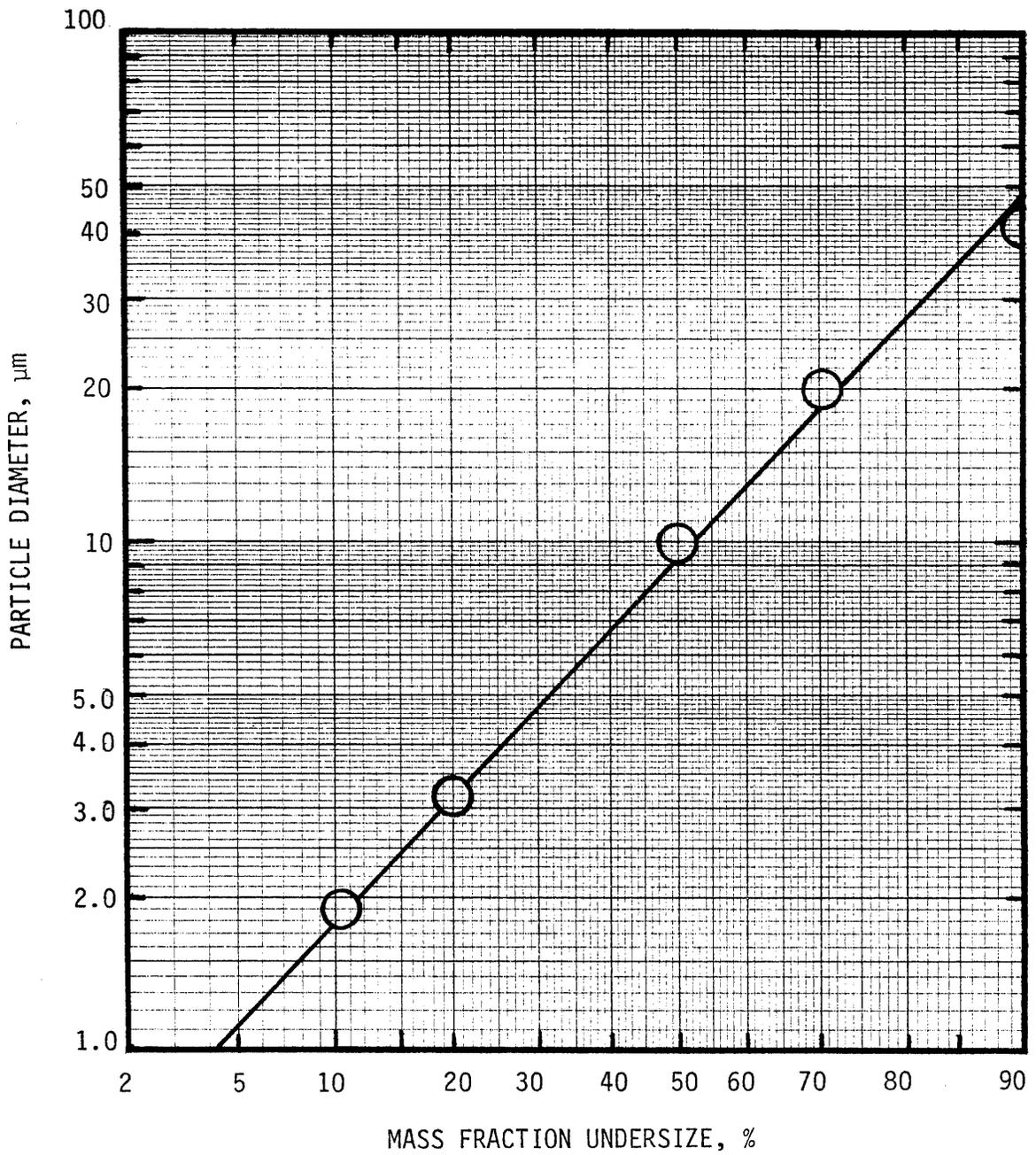


Figure 11.8.2-1. Particle size distribution for rock screening and handling operations (Vandegrift et al., 1970).

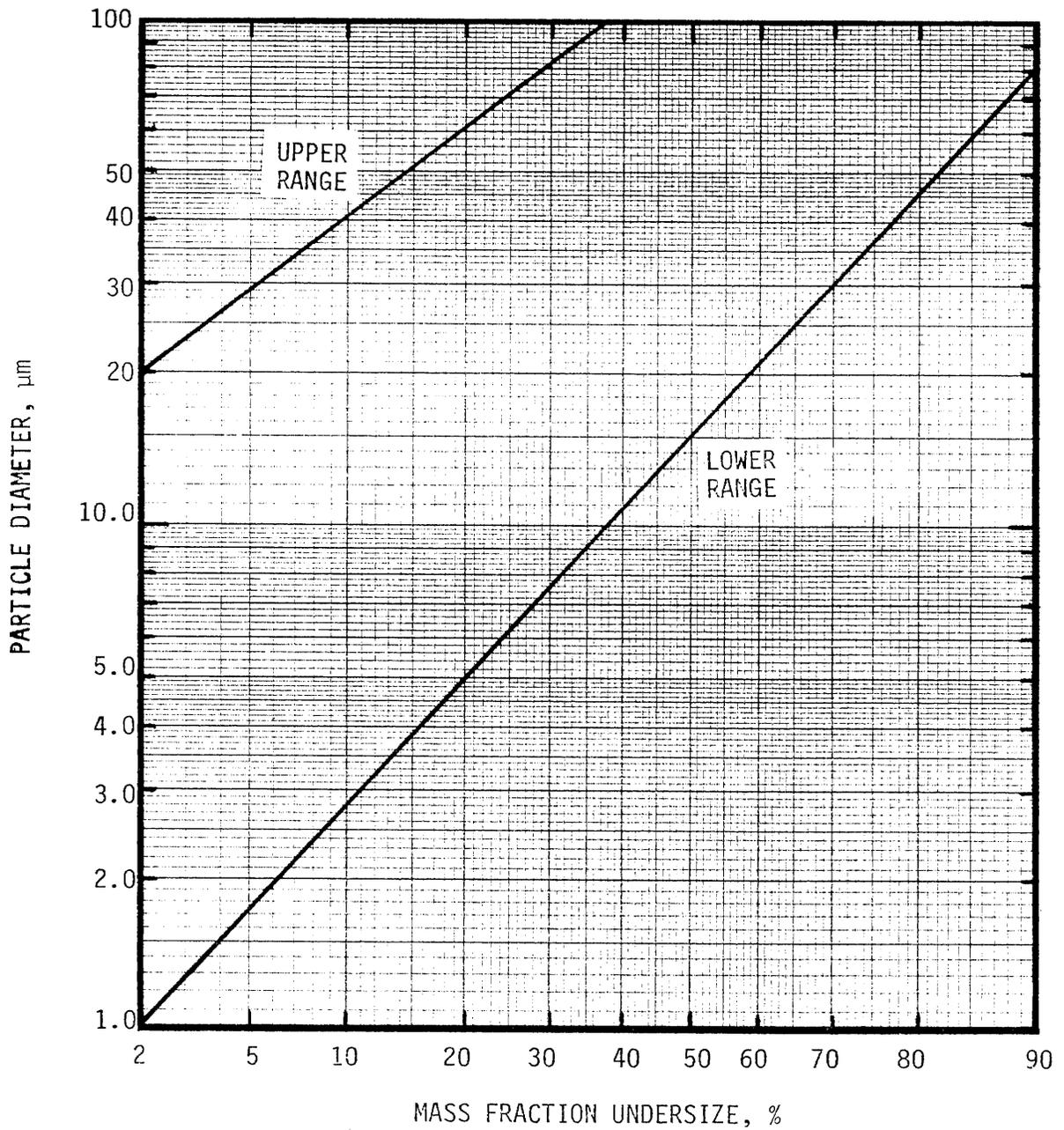


Figure 11.8.2-2. Particle size distribution for uncontrolled rock crushing operations (Shannon et al., 1971; Vandegrift et al., 1970; Wachter, 1980).

TABLE 11.8.2-1. PARTICLE CHARACTERISTICS FOR ROCK, SAND AND GRAVEL PLANT EMISSIONS

Process	Mass Concentration, mg/Nm <sup>3</sup>				Particle Density g/cm <sup>3</sup>	Particle Resistivity ohm-cm
	Uncontrolled		Controlled			
	Total	<3 μm	Total	<3 μm		
Rock, Sand & Gravel	-	-	-	-	-	-
Primary Crushing	-	-	-	-	-	-
Screening/ Handling	20,000 <sup>c*</sup>	4,000 <sup>b</sup>	50 <sup>c*</sup>	-	-	-
Secondary Crushing	10,000 <sup>a</sup> - 15,000	-	20-500 <sup>a</sup>	-	-	-
Aggregate/Sand Drying	10,000 - 90,000 <sup>b</sup>	-	See Section 11.3	-	-	-
Fines Milling	20,000 <sup>c*</sup>	-	50 <sup>c*</sup>	-	-	-
Abrasive Blasting	-	-	-	-	-	-

<sup>a</sup>Steenberg (1971)

<sup>b</sup>Vandegrift et al., (1970)

<sup>c</sup>Gerstle and Szabo (1978)

\*Screening, Handling and Milling Combined.

TABLE 11.8.2-2. GAS CHARACTERISTICS FOR ROCK, SAND & GRAVEL PLANT EMISSIONS.

<u>Process</u>	<u>Production Rate</u>	<u>Gas Flowrate Nm<sup>3</sup>/kg (unless otherwise noted)</u>	<u>Temperature °C</u>	<u>Chemical Composition, % vol, dry (unless otherwise noted)</u>
Rock, Sand and Gravel				
Primary Crushing	-	-	Ambient <sup>b</sup>	-
Screening/ Handling	28-56 <sup>b</sup> kg/s (100-200 MT/hr)	0.2-0.4 <sup>b*</sup>	Ambient <sup>b</sup>	-
Secondary Crushing	40-170 <sup>a</sup> kg/s (150-600 MT/hr)	~0.12 <sup>a</sup>	Ambient <sup>a</sup>	Air <sup>a</sup>
Aggregate/Sand Drying		See Section 11.3		
Fines Milling	28-56 <sup>b</sup> kg/s (100-200 MT/hr)	0.2-0.4 <sup>b*</sup>	Ambient <sup>b</sup>	-
Abrasive Blasting	-	-	-	-

<sup>a</sup>Steenberg (1971)

<sup>b</sup>Gerstle and Szabo (1978)

\*Screening, Handling and Milling Combined

matter to remain with the material flow rather than become airborne. Dry collection involves hooding and enclosing dust producing points and exhausting emissions to a collection device. Combination systems apply both methods at different stages throughout the processing plant. Housing process equipment in enclosed structures is another effective means of preventing atmospheric emissions. Such buildings generally must be vented through a control device.

The fabric filter or baghouse is the most effective dust collection device in the mineral industry. Most crushing plants use mechanical shaker-type collectors, which require periodic shutdown for cleaning (after four or five hours of operation). These units normally are equipped with cotton sateen bags and operated at an air-to-cloth ratio of two or three to one. Greater than 99% efficiency can be attained with a baghouse, even on submicron particle sizes.

Other collection devices include cyclones, scrubbers, and electrostatic precipitators. Cyclones demonstrate high efficiencies (95-99%) for coarse particles, but their efficiencies are poor (less than 85%) for medium and fine particles. High-energy scrubbers and electrostatic precipitators could conceivably achieve results similar to that of a fabric filter, but these methods do not appear to be used in the industry. Scrubbers are not used often because the particles which are removed from the gas end up mixed with the spray water. This makes it more difficult to recover the fines for sale. Recovery of saleable solids from baghouses and ESP's is economically attractive.

## 11.9 CALCULATIONS

Control devices evaluated for mineral industrial emission sources are listed in Table 11.9.1. The calculation results are presented in Tables 11.9.2 through 11.9.8.

Because of very high resistivity of lime and glass dust, ( $\sim 10^{10}$ - $10^{11}$  Ohm-m), ESP is not recommended for emission control.

A duty factor of 0.8 for cement, lime and rock handling industries and a factor of 0.25 for asphalt and glass industries is used for estimating operating costs for control devices.

TABLE 11.9.1. LIST OF PERFORMANCE CALCULATIONS

Emission Source	Control Device								
	ESP	Pulse Charging ESP	Precharging ESP	Filter	Electrified Filter	Venturi Scrubber	Calvert Collision Scrubber	Charged Particle/Charged Drop Spray Scrubber	F/C Scrubber
Cement - dry kiln	X			X	X	X	X	X	
Cement - wet kiln	X		X	X	X	X	X	X	
Cement - clinker cooler	X			X	X	X	X	X	
Asphalt - roadmix plant	X		X	X	X	X	X	X	
Lime - plant kiln				X	X	X	X	X	
Glass - melting furnace				X	X	X	X	X	
Rock screening and handling	X			X	X	X	X	X	

## CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

PROCESS	EMISSION SOURCE	PL	CONTROL TECHNOLOGY	INDUSTRY:	Minerals	SECTION:	CAPITAL, OPERATING, ANNUALIZED COSTS, \$		EFFY REL (%)	REL (%)	ENVIR S USE	REMARKS	REF
							ANNUALIZED COSTS, \$	ENVIR S USE					
Cement	Dry kiln off gas	PM	Scrubber Venturi				15,087/m <sup>3</sup> /s	8.2kW/m <sup>3</sup> /s	99.4	1	E=90% for dpa < 3µm at a scrubber pressure drop of 45 cm W.C.		
							13,764/m <sup>3</sup> /s						
							16,219/m <sup>3</sup> /s						
Cement	Dry kiln off gas	PM	Scrubber CP/CD Spray Scrubber						99.97	5	E=99.5% for dpa < 3µm. 3-stage scrubber with L/G= 4x10 <sup>-4</sup> m <sup>3</sup> /m <sup>3</sup> per stage.		
Cement	Dry kiln off gas	PM	Filter				28,445/m <sup>3</sup> /s	9.6kW/m <sup>3</sup> /s	99.6	1	E=99.3% for dpa < 3µm. Air/cloth = 0.93 m/min.		
							12,388/m <sup>3</sup> /s						
							15,729/m <sup>3</sup> /s						
Cement	Dry kiln off gas	PM	Filter				17,298/m <sup>3</sup> /s	8.4kW/m <sup>3</sup> /s	98.2	1	E=95.5% for dpa < 3µm. Air/cloth = 3.1 m/min.		
							11,059/m <sup>3</sup> /s						
							13,091/m <sup>3</sup> /s						

## CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

INDUSTRY: Minerals

SECTION:

PROCESS	EMISSION SOURCE	PL CONTROL TECHNOLOGY	CAPITAL, OPERATING, ANNUALIZED COSTS, \$	EFFY REL (%)	REL (%)	ENERGY USE	ENVIR IMPACT	REMARKS	REF
Cement	Dry kiln off gas	PM Filter	18,804/m <sup>3</sup> /s	96.9	1	11.0kW/m <sup>3</sup> /s	E=90.7% for dpa < 3µmA. Air/cloth =5.5 m/min.		
			12,118/m <sup>3</sup> /s						
			14,327/m <sup>3</sup> /s						
Cement	Dry kiln off gas	PM Scrubber Calvert Collision Scrubber	8,065/m <sup>3</sup> /s	99.4	2	5.2kW/m <sup>3</sup> /s	E=90.0% for dpa < 3µmA at a scrubber pressure drop of 27.0 cm W.C.		
			12,172/m <sup>3</sup> /s						
			13,484/m <sup>3</sup> /s						
Cement	Dry kiln off gas	PM Scrubber Calvert Collision Scrubber	5,263/m <sup>3</sup> /s	98.2	2	2.7kW/m <sup>3</sup> /s	E=75% for dpa < 3µmA at a scrubber pressure drop of 11 cm W.C.		
			10,928/m <sup>3</sup> /s						
			11,785/m <sup>3</sup> /s						
Cement	Dry kiln off gas	PM Filter Electrostatically Augmented Filter		99.98	4		E=99.96% for dpa < 3µmA at full ESP power. ESP SCA = 8.9 m <sup>2</sup> /m <sup>3</sup> /s. Air cloth = 1.76 m/min.		

CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

PROCESS	EMISSION SOURCE	PL CONTROL TECHNOLOGY	CAPITAL, OPERATING, ANNUALIZED COSTS, \$	EFFY REL (%)	REL (%)	ENERGY USE S	ENVIR IMPACT	REMARKS	REF
Cement	Dry kiln off gas	PM ESP	11,026/m <sup>3</sup> /s	90.0	1	2.1kW/m <sup>3</sup> /s	E=50% for dpa< 3µmA. Corona power = 40 W/m <sup>3</sup> /s. SCA = 25m <sup>2</sup> /m <sup>3</sup> /s.		
			6,968/m <sup>3</sup> /s						
			8,263/m <sup>3</sup> /s						
Cement	Dry kiln off gas	PM ESP	19,094/m <sup>3</sup> /s	94.4	1	2.5kW/m <sup>3</sup> /s	E=75% for dpa< 3µmA. Corona power = 64 W/m <sup>3</sup> /s. SCA = 50m <sup>2</sup> /m <sup>3</sup> /s.		
			7,676/m <sup>3</sup> /s						
			9,919/m <sup>3</sup> /s						
Cement	Dry kiln off gas	PM ESP	27,161/m <sup>3</sup> /s	98.0	1	3.0kW/m <sup>3</sup> /s	E=90% for dpa< 3µmA. Corona power = 120 W/m <sup>3</sup> /s. SCA = 75 m <sup>2</sup> /m <sup>3</sup> /s.		
			8,394/m <sup>3</sup> /s						
			11,585/m <sup>3</sup> /s						

INDUSTRY: Minerals

TABLE 11.9.3

CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

PROCESS	EMISSION SOURCE	PL	CONTROL TECHNOLOGY	INDUSTRY:	MINERALS	CAPITAL, OPERATING, ANNUALIZED COSTS, \$	EFFY REL (%)	REL (%)	ENERGY USE	ENVIR IMPACT	REMARKS	REF
Cement	Wet kiln off gas	PM	Scrubber CP/CD Spray Scrubber		Minerals		99.97	5			E=99.38% for dpa < 3µm. 3-stage scrubber with L/G=4x10 <sup>-4</sup> m <sup>3</sup> /m <sup>3</sup> per stage.	
Cement	Wet kiln off gas	PM	Filter			23,865/m <sup>3</sup> /s	98.2	1	9.4kw/m <sup>3</sup> /s		E=99.5% for dpa < 3µm. Air/cloth = 0.93 m/min.	
						25,891/m <sup>3</sup> /s						
						28,694/m <sup>3</sup> /s						
Cement	Wet kiln off gas	PM	Filter			15,399/m <sup>3</sup> /s	97.0	1	8.4kw/m <sup>3</sup> /s		E=91.1% for dpa < 3µm. Air/cloth = 3.1 m/min.	
						24,573/m <sup>3</sup> /s						
						26,382/m <sup>3</sup> /s						
Cement	Wet kiln off gas	PM	Filter			17,407/m <sup>3</sup> /s	95.1	1	11.0kw/m <sup>3</sup> /s		E=80.6% for dpa < 3µm. Air/cloth = 5.5 m/min.	
						25,360/m <sup>3</sup> /s						
						27,404/m <sup>3</sup> /s						

CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

PROCESS	EMISSION SOURCE	PL CONTROL TECHNOLOGY	INDUSTRY:	Minerals	SECTION:	CAPITAL, OPERATING, ANNUALIZED COSTS, \$	EFFY REL (%)	REL (%)	ENERGY USE S	ENVIR IMPACT	REMARKS	REF
Cement	Wet kiln off gas	Scrubber Venturi	PM	31,042/m <sup>3</sup> /s								
				34,756/m <sup>3</sup> /s								
Cement	Wet kiln off gas	Scrubber Venturi	PM	8,882/m <sup>3</sup> /s	98.0	1	3.3kW/m <sup>3</sup> /s				E=50% for dpa< 3µm at a scrubber pressure drop of 16 cm W.C.	
				24,957/m <sup>3</sup> /s								
				26,402/m <sup>3</sup> /s								
Cement	Wet kiln off gas	Scrubber Calvert Collision Scrubber	PM	16,783/m <sup>3</sup> /s	99.6	2	13.1kW/m <sup>3</sup> /s				E=90% for dpa< 3µm at a scrubber pressure drop of 72.0 cm W.C.	
				29,840/m <sup>3</sup> /s								
				32,572/m <sup>3</sup> /s								
Cement	Wet kiln off gas	Scrubber Calvert Collision Scrubber	PM	4,492/m <sup>3</sup> /s	98.8	2	2.3kW/m <sup>3</sup> /s				E=75% for dpa< 3µm at a scrubber pressure drop of 10 cm W.C.	
				24,507/m <sup>3</sup> /s								
				25,239/m <sup>3</sup> /s								

## CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

PROCESS	EMISSION SOURCE	PL	CONTROL TECHNOLOGY	CAPITAL, OPERATING, ANNUALIZED COSTS, \$	EFFY REL (%)	REL (%)	ENERGY USE S	ENVIR IMPACT	REMARKS	REF						
											INDUSTRY:	SECTION:				
Cement	Wet kiln off gas	PM	Filter Electro- statically Augmented Filter	Minerals	99.98	4	1	2.1kW/m <sup>3</sup> /s	E=99.87% for dpa < 3µm at full ESP power: ESP SCA = 8.9 m <sup>2</sup> /m <sup>3</sup> /s. Air/ cloth = 1.76 m/min.							
Cement	Wet kiln off gas	PM	ESP	Minerals	90.8	1	1	2.1kW/m <sup>3</sup> /s	E=50% for dpa < 3µm. Corona power = 56 W/m <sup>3</sup> /s. SCA = 25 m <sup>2</sup> /m <sup>3</sup> /s.							
Cement	Wet kiln off gas	PM	ESP	Minerals	97.5	1	1	3.8kW/m <sup>3</sup> /s	E=75% for dpa < 3µm. Corona power = 632 W/m <sup>3</sup> /s. SCA = 25 m <sup>2</sup> /m <sup>3</sup> /s.							
Cement	Wet kiln off gas	PM	ESP	Minerals	99.2	1	1	4.1kW/m <sup>3</sup> /s	E=90% for dpa < 3µm. Corona power = 671 W/m <sup>3</sup> /s. SCA = 50m <sup>2</sup> /m <sup>3</sup> /s.							

## CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

INDUSTRY: Minerals

SECTION:

PROCESS	EMISSION SOURCE	PL	CONTROL TECHNOLOGY	CAPITAL, OPERATING, ANNUALIZED COSTS, \$	EFFY REL (%)	REL (%)	S	ENERGY USE	ENVIR IMPACT	REMARKS	REF
Cement	Wet kiln off gas	PM	ESP ESP with SoRI Pre- charger		92.2		4			E=50% for dpa < 3 $\mu$ mA. Corona power=7W/m <sup>3</sup> /s. SCA = 25 m <sup>2</sup> /m <sup>3</sup> /s. Precharger power = 15 W/m <sup>3</sup> /s.	
Cement	Wet kiln off gas	PM	ESP ESP with SoRI Pre- charger		97.5		4			E=75% for dpa < 3 $\mu$ mA. Corona power=14W/m <sup>3</sup> /s. SCA = 50 m <sup>2</sup> /m <sup>3</sup> /s. Precharger power = 15 W/m <sup>3</sup> /s.	
Cement	Wet kiln off gas	PM	ESP ESP with SoRI Pre- charger		99.25		4			E=90% for dpa < 3 $\mu$ mA. Corona power=30W/m <sup>3</sup> /s. SCA = 50 m <sup>2</sup> /m <sup>3</sup> /s. Precharger power = 15 W/m <sup>3</sup> /s.	

## CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

PROCESS	EMISSION SOURCE	PL CONTROL TECHNOLOGY	INDUSTRY:	SECTION:	CAPITAL, OPERATING, ANNUALIZED COSTS, \$	EFFY REL (%)	REL (%)	ENVIR S USE	REMARKS	REF
Cement	Clinker cooler off gas	PM Scrubber CP/CD Spray Scrubber	Minerals		99.99	5		E=99.2% for dpa < 3µmA. 3-stage scrubber with L/G=4x10 <sup>-4</sup> m <sup>3</sup> /m <sup>3</sup> per stage.		
Cement	Clinker cooler off gas	PM Filter			28,482/m <sup>3</sup> /s	97.5	1	9.6kw/m <sup>3</sup> /s	E=99.5% for dpa < 3µmA. Air/cloth = 0.93 m/min.	
Cement	Clinker cooler off gas	PM Filter			19,636/m <sup>3</sup> /s	96.4	1	8.4kw/m <sup>3</sup> /s	E=93.0% for dpa < 3µmA. Air/cloth = 3.1 m/min.	
Cement	Clinker cooler off gas	PM Filter			21,572/m <sup>3</sup> /s	94.1	1	11.0kw/m <sup>3</sup> /s	E=83.2% for dpa < 3µmA. Air/cloth = 5.5 m/min.	
					11,129/m <sup>3</sup> /s					
					13,663/m <sup>3</sup> /s					

## CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

PROCESS	EMISSION SOURCE	PL CONTROL TECHNOLOGY	INDUSTRY:	Minerals	SECTION:	CAPITAL, OPERATING, ANNUALIZED COSTS, \$	EFFY REL (%)	REL (%)	S	ENERGY USE	ENVIR IMPACT	REMARKS	REF
Cement	Clinker cooler off gas	PM Scrubber Venturi				25,798/m <sup>3</sup> /s 17,733/m <sup>3</sup> /s 21,931/m <sup>3</sup> /s	99.5		1	14.8kw/m <sup>3</sup> /s		E=75% for dpa < 3µm at a scrubber pressure drop of 84 cm W.C.	
Cement	Clinker cooler off gas	PM Scrubber Venturi				12,637/m <sup>3</sup> /s 12,182/m <sup>3</sup> /s 14,239/m <sup>3</sup> /s	98.9		1	3.3kw/m <sup>3</sup> /s		E=50% for dpa < 3µm at a scrubber pressure drop of 16 cm W.C.	
Cement	Clinker cooler off gas	PM Scrubber Calvert Collision Scrubber				16,735/m <sup>3</sup> /s 15,676/m <sup>3</sup> /s 18,400/m <sup>3</sup> /s	99.8		2	10.9kw/m <sup>3</sup> /s		E=90% for dpa < 3µm at a scrubber pressure drop of 60 cm W.C.	
Cement	Clinker cooler off gas	PM Scrubber Calvert Collision Scrubber				6,902/m <sup>3</sup> /s 11,529/m <sup>3</sup> /s 12,653/m <sup>3</sup> /s	99.4		2	2.3kw/m <sup>3</sup> /s		E=75% for dpa < 3µm at a scrubber pressure drop of 10 cm W.C.	

TABLE 11.9.4

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## CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

PROCESS	EMISSION SOURCE	PL CONTROL TECHNOLOGY	INDUSTRY:	CAPITAL, OPERATING, ANNUALIZED COSTS, \$	EFFY REL (%)	REL (%)	ENERGY USE S	ENVIR IMPACT	REMARKS	REF
Cement	Clinker cooler off gas	PM Filter Electrostatically Augmented Filter	Minerals		99.99	4			E=99.87% for dpa < 3µm at full ESP power. ESP SCA = 8.9 m <sup>2</sup> /m <sup>3</sup> /s. Air/cloth = 1.76 m/min.	
Cement	Clinker cooler off gas	PM ESP		10,711/m <sup>3</sup> /s 5,193/m <sup>3</sup> /s 6,451/m <sup>3</sup> /s	96.0	1	2.0kW/m <sup>3</sup> /s		E=50% for dpa < 3µm. Corona power = 37 W/m <sup>3</sup> /s. SCA = 25 m <sup>2</sup> /m <sup>3</sup> /s.	
Cement	Clinker cooler off gas	PM ESP		10,711/m <sup>3</sup> /s 5,597/m <sup>3</sup> /s 6,856/m <sup>3</sup> /s	98.9	1	2.9kW/m <sup>3</sup> /s		E=75% for dpa < 3µm. Corona power = 316 W/m <sup>3</sup> /s. SCA = 25 m <sup>2</sup> /m <sup>3</sup> /s.	
Cement	Clinker cooler off gas	PM ESP		17,173/m <sup>3</sup> /s 5,896/m <sup>3</sup> /s 7,913/m <sup>3</sup> /s	99.6	1	2.9kW/m <sup>3</sup> /s		E=90% for dpa < 3µm. Corona power = 268 W/m <sup>3</sup> /s. SCA = 50m <sup>2</sup> /m <sup>3</sup> /s.	

CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

PROCESS	EMISSION SOURCE	PL	CONTROL TECHNOLOGY	INDUSTRY:	SECTION:	CAPITAL, OPERATING, ANNUALIZED COSTS, \$	EFFY REL (%)	REL (%)	ENERGY USE	ENVIR IMPACT	REMARKS	REF
Asphalt	Road mix plant aggregate drier off gas	PM	Scrubber	Minerals			99.98		5		E=99.41% for dpa< 3µmA. 3-stage scrubber with L/G=4x10 <sup>-4</sup> m <sup>3</sup> /m <sup>3</sup> per stage.	
Asphalt	Road mix plant aggregate drier off gas	PM	Filter			26,750/m <sup>3</sup> /s	99.7		1	8.3kw/m <sup>3</sup> /s	E=99.3% for dpa< 3µmA. Air/cloth = 0.93 m/min.	
						7,044/m <sup>3</sup> /s						
						10,186/m <sup>3</sup> /s						
Asphalt	Road mix plant aggregate drier off gas	PM	Filter			20,440/m <sup>3</sup> /s	99.0		1	8.1kw/m <sup>3</sup> /s	E=95.1% for dpa< 3µmA. Air/cloth = 3.1 m/min.	
						6,220/m <sup>3</sup> /s						
						8,621/m <sup>3</sup> /s						
Asphalt	Road mix plant aggregate drier off gas	PM	Filter			22,850/m <sup>3</sup> /s	98.3		1	10.8kw/m <sup>3</sup> /s	E=89.9% for dpa< 3µmA. Air/cloth = 5.5 m/min.	
						6,873/m <sup>3</sup> /s						
						9,557/m <sup>3</sup> /s						

## CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

PROCESS	EMISSION SOURCE	PL CONTROL TECHNOLOGY	INDUSTRY:	MINERALS	CAPITAL, OPERATING, ANNUALIZED COSTS, \$	EFFY REL (%)	REL (%)	ENERGY USE \$	ENVIR IMPACT	REMARKS	REF
Asphalt	Road mix plant aggregate drier off gas	PM Scrubber Venturi		Minerals	21,534/m <sup>3</sup> /s	99.6	1	10.1kW/m <sup>3</sup> /s		E=90% for dpa< 3μm at a scrubber pressure drop of 56 cm W.C.	
					8,412/m <sup>3</sup> /s						
					11,917/m <sup>3</sup> /s						
Asphalt	Road mix plant aggregate drier off gas	PM Scrubber Venturi		Minerals	13,009/m <sup>3</sup> /s	99.1	1	2.6kW/m <sup>3</sup> /s		E=75% for dpa< 3μm at a scrubber pressure drop of 12 cm W.C.	
					7,082/m <sup>3</sup> /s						
					9,199/m <sup>3</sup> /s						
Asphalt	Road mix plant aggregate drier off gas	PM Scrubber Calvert Collision Scrubber		Minerals	11,673/m <sup>3</sup> /s	99.6	2	5.8kW/m <sup>3</sup> /s		E=90% for dpa< 3μm at a scrubber pressure drop of 30 cm W.C.	
					7,452/m <sup>3</sup> /s						
					9,352/m <sup>3</sup> /s						
Asphalt	Road mix plant aggregate drier off gas	PM Scrubber Calvert Collision Scrubber		Minerals	7,740/m <sup>3</sup> /s	98.5	2	2.3kW/m <sup>3</sup> /s		E=75% for dpa< 3μm at a scrubber pressure drop of 10 cm W.C.	
					6,813/m <sup>3</sup> /s						
					8,073/m <sup>3</sup> /s						

CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

SECTION:

INDUSTRY: Minerals

CAPITAL,  
OPERATING,

ANNUALIZED EFFY REL ENERGY ENVIR  
COSTS, \$ (%) (%) S USE IMPACT

PROCESS EMISSION SOURCE PL CONTROL TECHNOLOGY COSTS, \$ (%) (%) S USE IMPACT REMARKS REF

Asphalt Road mix plant aggregate drier off gas PM Filter Electro-statically Augmented Filter 10,133/m<sup>3</sup>/s 3,928/m<sup>3</sup>/s 5,118/m<sup>3</sup>/s 99.98 78.0 1 1.9kW/m<sup>3</sup>/s E=99.94% for dpa< 3µm at full ESP power. ESP SCA = 8.9 m<sup>2</sup>/m<sup>3</sup>/s. Air/cloth = 1.76 m/min.

Asphalt Road mix plant aggregate drier off gas PM ESP 10,133/m<sup>3</sup>/s 3,928/m<sup>3</sup>/s 5,118/m<sup>3</sup>/s 78.0 1 1.9kW/m<sup>3</sup>/s E=50% for dpa< 3µm. Corona power = 20 W/m<sup>3</sup>/s. SCA = 25m<sup>2</sup>/m<sup>3</sup>/s.

Asphalt Road mix plant aggregate drier off gas PM ESP 10,133/m<sup>3</sup>/s 4,376/m<sup>3</sup>/s 5,566/m<sup>3</sup>/s 92.0 1 2.2kW/m<sup>3</sup>/s E=75% for dpa< 3µm. Corona power = 133 W/m<sup>3</sup>/s. SCA = 25m<sup>2</sup>/m<sup>3</sup>/s.

Asphalt Road mix plant aggregate drier off gas PM ESP 10,133/m<sup>3</sup>/s 4,803/m<sup>3</sup>/s 5,993/m<sup>3</sup>/s 98.8 1 3.9kW/m<sup>3</sup>/s E=90% for dpa< 3µm. Corona power = 854 W/m<sup>3</sup>/s. SCA = 25m<sup>2</sup>/m<sup>3</sup>/s.



CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

PROCESS	EMISSION SOURCE	PL CONTROL TECHNOLOGY	INDUSTRY:	Minerals	SECTION:	CAPITAL, OPERATING, ANNUALIZED COSTS, \$	EFFY REL (%)	REL (%)	ENVIR S USE IMPACT	REMARKS	REF
Lime	Plant kiln off gas	PM Scrubber CP/CD Spray Scrubber					99.8	5		E=99.4% for dpa < 3µm. 3-stage scrubber with L/G=4x10 <sup>-4</sup> /m <sup>3</sup> /m <sup>3</sup> per stage.	
Lime	Plant kiln off gas	PM Filter				35,173/m <sup>3</sup> /s	99.5	1	9.6kW/m <sup>3</sup> /s	E=99.4% for dpa < 3µm. Air/cloth = 0.93 m/min.	
						30,123/m <sup>3</sup> /s					
						34,254/m <sup>3</sup> /s					
Lime	Plant kiln off gas	PM Filter				24,025/m <sup>3</sup> /s	94.6	1	8.4kW/m <sup>3</sup> /s	E=87.5% for dpa < 3µm. Air/cloth = 3.1 m/min.	
						27,942/m <sup>3</sup> /s					
						30,764/m <sup>3</sup> /s					
Lime	Plant kiln off gas	PM Filter				25,531/m <sup>3</sup> /s	91.2	1	11.0kW/m <sup>3</sup> /s	E=75.6% for dpa < 3µm. Air/cloth = 5.5 m/min.	
						28,427/m <sup>3</sup> /s					
						31,426/m <sup>3</sup> /s					

TABLE 11.9.6

CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

PROCESS	EMISSION SOURCE	PL CONTROL TECHNOLOGY	CAPITAL, OPERATING, ANNUALIZED COSTS, \$	EFFY REL (%)	REL (%)	ENERGY USE	ENVIR IMPACT	REMARKS	REF
Lime	Plant kiln off gas	PM Scrubber Venturi	44,561/m <sup>3</sup> /s	92.1	1	30.3kW/m <sup>3</sup> /s	E=75% for dpa< 3µmA at a scrubber pressure drop of 175 cm W.C.		
			43,346/m <sup>3</sup> /s						
			50,598/m <sup>3</sup> /s						
Lime	Plant kiln off gas	PM Scrubber Venturi	14,557/m <sup>3</sup> /s	84.4	1	4.0kW/m <sup>3</sup> /s	E=50% for dpa< 3µmA at a scrubber pressure drop of 20 cm W.C.		
			29,256/m <sup>3</sup> /s						
			31,626/m <sup>3</sup> /s						
Lime	Plant kiln off gas	PM Scrubber Calvert Collision Scrubber	22,000/m <sup>3</sup> /s	96.9	2	14.8kW/m <sup>3</sup> /s	E=90% for dpa< 3µmA at a scrubber pressure drop of 84 cm W.C.		
			36,625/m <sup>3</sup> /s						
			40,205/m <sup>3</sup> /s						
Lime	Plant kiln off gas	PM Scrubber Calvert Collision Scrubber	7,740/m <sup>3</sup> /s	91.6	2	2.3kW/m <sup>3</sup> /s	E=75% for dpa< 3µmA at a scrubber pressure drop of 10 cm W.C.		
			29,620/m <sup>3</sup> /s						
			30,879/m <sup>3</sup> /s						

INDUSTRY: Minerals

CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

PROCESS	EMISSION SOURCE	PL CONTROL TECHNOLOGY	INDUSTRY:	SECTION:	CAPITAL, OPERATING, ANNUALIZED COSTS, \$	EFFY REL (%)	REL (%)	ENERGY USE	ENVIR IMPACT	REMARKS	REF
Lime	Plant kiln off gas	PM Filter	Minerals			99.87		4		E=99.60% for dpa< 3µm at full ESP power. ESP SCA = 8.9m <sup>2</sup> /m <sup>3</sup> /s. Air/ cloth = 1.76 m/min.	

CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

SECTION:

INDUSTRY: Minerals

PROCESS	EMISSION SOURCE	PL CONTROL TECHNOLOGY	CAPITAL, OPERATING, ANNUALIZED COSTS, \$	EFFY REL (%)	REL (%)	ENERGY USE S	ENVIR IMPACT	REMARKS	REF
Glass	Melting furnace	PM Scrubber CP/CD Spray Scrubber		99.8	5			E=99.7% for dpa < 3µmA. 3-stage scrubber with L/G=4x10 <sup>-4</sup> m <sup>3</sup> /m <sup>3</sup> per stage.	
Glass	Melting furnace	PM Filter	35,173/m <sup>3</sup> /s 11,487/m <sup>3</sup> /s 15,619/m <sup>3</sup> /s	90.0	1	9.6kW/m <sup>3</sup> /s		E=87.8% for dpa < 3µmA. Air/cloth = 0.93 m/min.	
Glass	Melting furnace	PM Filter	24,025/m <sup>3</sup> /s 10,169/m <sup>3</sup> /s 12,991/m <sup>3</sup> /s	56.2	1	8.4kW/m <sup>3</sup> /s		E=46.4% for dpa < 3µmA. Air/cloth = 3.1 m/min.	
Glass	Melting furnace	PM Scrubber Venturi	41,661/m <sup>3</sup> /s 24,804/m <sup>3</sup> /s 31,584/m <sup>3</sup> /s	45.6	1	27.7kW/m <sup>3</sup> /s		E=31.8% for dpa < 3µmA at a scrubber pressure drop of 160 cm W.C. Higher than 50% efficiency cannot be obtained.	

CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

PROCESS	EMISSION SOURCE	PL	CONTROL TECHNOLOGY	ANNUALIZED COSTS, \$	EFFY REL (%)	REL (%)	ENERGY USE	ENVIR IMPACT	REMARKS	REF
Glass	Melting furnace	PM	Scrubber Calvert Collision Scrubber	13,148/m <sup>3</sup> /s	78.7	2	7.1kw/m <sup>3</sup> /s		E=74.1% for dpa< 3µm at a scrubber pressure drop of 38 cm W.C.	
				14,733/m <sup>3</sup> /s						
				16,872/m <sup>3</sup> /s						
Glass	Melting furnace	PM	Filter Electrostatically Augmented Filter		92.2	4		E=90.3% for dpa< 3µm at full ESP power. ESP SCA = 8.9 m <sup>2</sup> /m <sup>3</sup> /s. Air/cloth = 1.76 m/min.		

INDUSTRY: Minerals

SECTION:

CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

PROCESS	EMISSION SOURCE	PL	CONTROL TECHNOLOGY	INDUSTRY:	MINERALS	SECTION:	CAPITAL, OPERATING, ANNUALIZED COSTS, \$	EFFY REL (%)	REL (%)	ENERGY USE, S	ENVIR IMPACT	REMARKS	REF
Rock	Screening & handling operations	PM	Scrubber CP/CD Spray Scrubber		Minerals		99.87	5				E=99.3% for dpa< 3µmA. 3-stage scrubber with L/G=4x10 <sup>-4</sup> m <sup>3</sup> /m <sup>3</sup> per stage.	
Rock	Screening & handling operations	PM	Filter				19,932/m <sup>3</sup> /s	99.5	1	6.8kW/m <sup>3</sup> /s		E=99.3% for dpa< 3µmA. Air/cloth = 0.93 m/min.	
							8,745/m <sup>3</sup> /s						
							11,086/m <sup>3</sup> /s						
Rock	Screening & handling operations	PM	Filter				16,668/m <sup>3</sup> /s	98.1	1	7.6kW/m <sup>3</sup> /s		E=95.5% for dpa< 3µmA. Air/cloth = 3.1 m/min.	
							15,442/m <sup>3</sup> /s						
							17,400/m <sup>3</sup> /s						
Rock	Screening & handling operations	PM	Filter				19,445/m <sup>3</sup> /s	96.5	1	10.5kW/m <sup>3</sup> /s		E=90.0% for dpa< 3µmA. Air/cloth = 5.5 m/min.	
							16,682/m <sup>3</sup> /s						
							18,966/m <sup>3</sup> /s						

## CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

PROCESS	EMISSION SOURCE	PL	CONTROL TECHNOLOGY	CAPITAL, OPERATING, ANNUALIZED COSTS, \$		EFFY REL (%)	REL (%)	ENVIR S USE	REMARKS	REF	
				ANNUALIZED COSTS, \$	OPERATING COSTS, \$						
Rock	Screening & handling operations	PM	Scrubber Venturi	14,574/m <sup>3</sup> /s	18,964/m <sup>3</sup> /s	98.7	1	5.0kW/m <sup>3</sup> /s	E=90.0% for dpa < 3µm at a scrubber pressure drop of 26 cm W.C.		
				21,336/m <sup>3</sup> /s							
				12,249/m <sup>3</sup> /s	17,856/m <sup>3</sup> /s	97.0	1	3.0kW/m <sup>3</sup> /s	E=75% for dpa < 3µm at a scrubber pressure drop of 14 cm W.C.		
Rock	Screening & handling operations	PM	Scrubber Venturi	11,573/m <sup>3</sup> /s	19,394/m <sup>3</sup> /s	97.9	2	6.4kW/m <sup>3</sup> /s	E=90% for dpa < 3µm at a scrubber pressure drop of 34 cm W.C.		
				21,278/m <sup>3</sup> /s							
				7,148/m <sup>3</sup> /s	17,259/m <sup>3</sup> /s	94.3	2	2.5kW/m <sup>3</sup> /s	E=75% for dpa < 3µm at a scrubber pressure drop of 11 cm W.C.		
Rock	Screening & handling operations	PM	Scrubber Calvert Collision Scrubber	18,422/m <sup>3</sup> /s							

CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

PROCESS	EMISSION SOURCE	PL	CONTROL TECHNOLOGY	CAPITAL, OPERATING, ANNUALIZED COSTS, \$	EFFY REL. (%)	ENVIR S USE	REMARKS	REF
Rock	Screening & handling operations	PM	Filter Electro- statically Augmented Filter		99.98	4	E=99.95% for dpa < 3µm at full ESP power. ESP SCA = 8.9m <sup>2</sup> /m <sup>3</sup> /s. Air/cloth = 1.76 m/min.	
Rock	Screening & handling operations	PM	ESP	7,741/m <sup>3</sup> /s 9,602/m <sup>3</sup> /s 10,512/m <sup>3</sup> /s	80.0	1	E=50% for dpa < 3µm. Corona power = 28 W/m <sup>3</sup> /s. SCA = 25m <sup>2</sup> /m <sup>3</sup> /s.	
Rock	Screening & handling operations	PM	ESP	7,741/m <sup>3</sup> /s 10,587/m <sup>3</sup> /s 11,496/m <sup>3</sup> /s	92.0	1	E=75% for dpa < 3µm. Corona power = 134W/m <sup>3</sup> /s. SCA = 25m <sup>2</sup> /m <sup>3</sup> /s.	
Rock	Screening & handling operations	PM	ESP	7,741/m <sup>3</sup> /s 11,498/m <sup>3</sup> /s 12,407/m <sup>3</sup> /s	97.7	1	E=90% for dpa < 3µm. Corona power = 797 W/m <sup>3</sup> /s. SCA = 25m <sup>2</sup> /m <sup>3</sup> /s.	

INDUSTRY: Minerals

SECTION:

## SECTION 11

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## SECTION 12

### SURFACE COATING OPERATIONS

#### 12.1 INTRODUCTION

Surface coating operations represent the largest source of fine particle emissions in the organic solvents category. Surface coating is the application of a finely divided solid, dispersed in a liquid solvent, to a surface. The solvent evaporates leaving a dry finish on the surface. Surface coating operations include the application of paint, enamel, and varnishes to metal and wood items; the application of finishes to paper and fabric, and printing operations.

California industries which are the largest contributors of particle emissions from surface coating operations (California Air Resources Board, 1980) are:

1. Can Manufacturing
2. Automobile Manufacturing
3. Metal and Wood Furniture Manufacturing

The primary pollution control concern in surface coating operations is the reduction of organic solvent emissions. Therefore control equipment to remove particle emissions must be compatible with, or enhance, the equipment for solvent control.

#### 12.2 CAN MANUFACTURING

##### 12.2.1 Process Description

Cans are used as containers for various products such as beverages, food products and paints. The cans are manufactured from either two or three pieces, according to the U. S. Environmental Protection Agency (1977b).

Figure 12.2.1-1 shows the processes involved in the two piece can manufacture. Figure 12.2.1-2 shows the steps for three piece manufacturing. According to Minicucci et al. (1980), the spraying operations produce particle emissions consisting of coating drops which miss the can. The Emission Inventory System includes data on particle emissions from the baking ovens. The ovens are generally natural gas-fired and operate between 110 and 200°C, depending on the type of coating. The exhaust flows are between 60 and 200 Nm<sup>3</sup>/min.

##### 12.2.2 Source Characteristics

Discussion of particle emissions from can manufacturing were not found in literature. Therefore the size distribution data for automobile coating in Section 12.3.2 will be used.

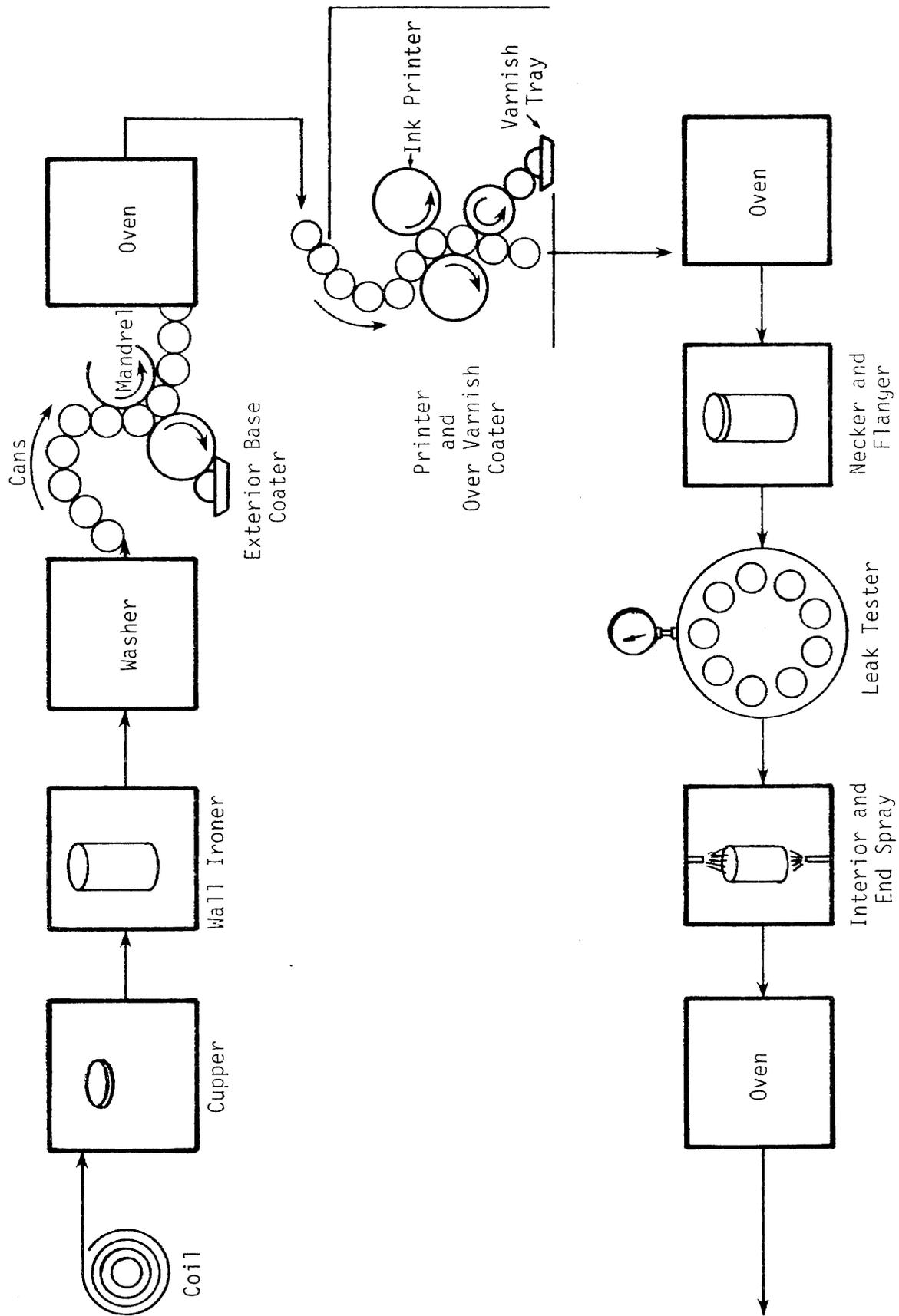


Figure 12.2.1-1. Two piece can manufacture (U.S. Environmental Protection Agency, 1977a)

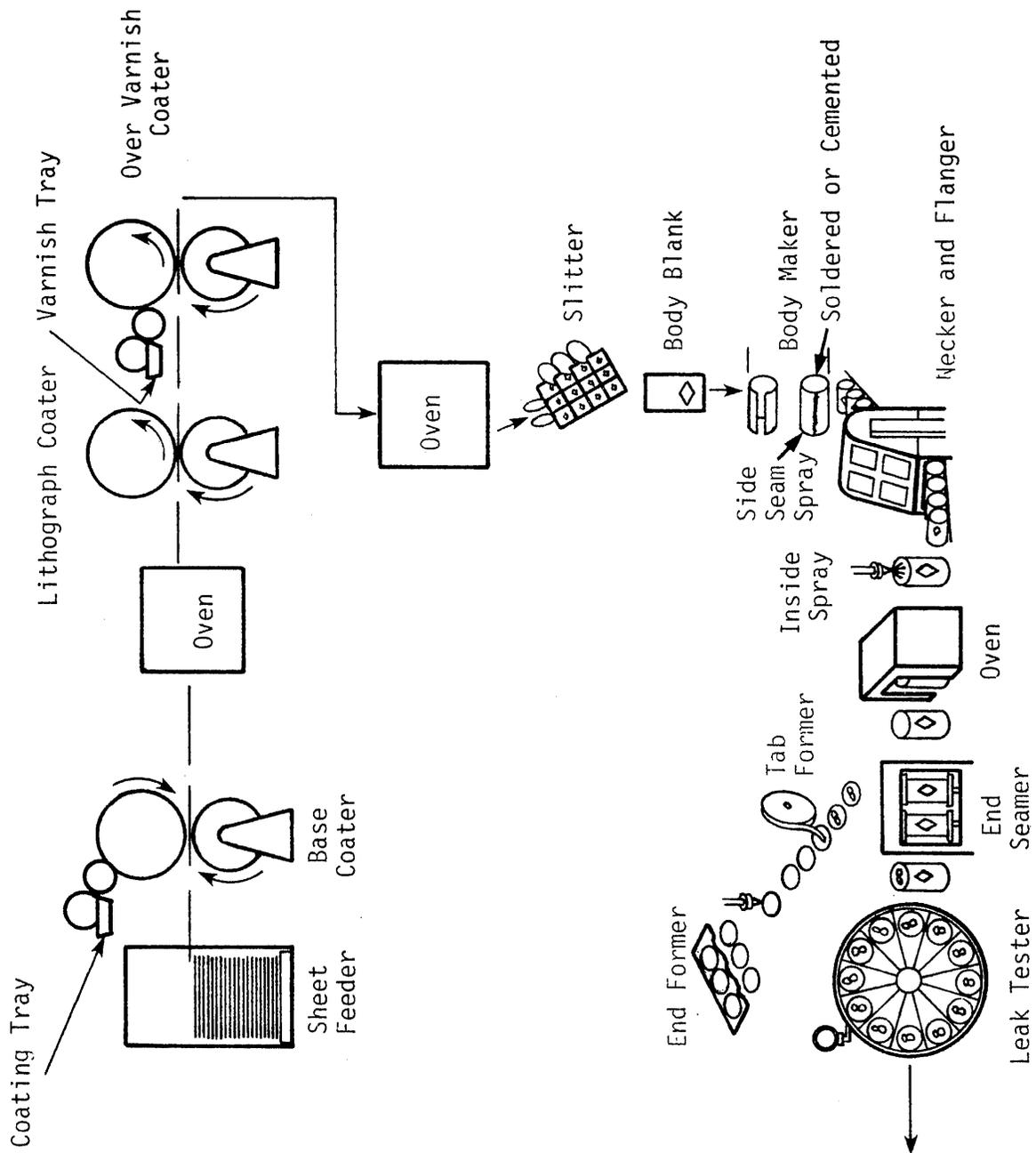


Figure 12.2.1-2. Three piece can manufacture (U.S. Environmental Protection Agency, 1977b).

### 12.2.3 Control Technology

The spray coating equipment was not described in detail. Minicucci et al. (1980) presented the same control methods for can coating as for automobiles. Section 12.3.3 describes devices used in automobile spray booths to remove overspray.

A powder coating technique has been used in can manufacture as a method of reducing organic solvent emissions. Particles of solid resins are sprayed onto the object and then melted into a continuous film. The excess powder is collected by a vacuum system. The U. S. Environmental Protection Agency report (1976) reports that the particles are generally greater than 15 micrometers in diameter, so fine particle emissions should not be a problem. The technique has not been widely applied because of problems in changing colors and obtaining the same quality coat as with liquid spray.

## 12.3 AUTOMOBILE COATING

### 12.3.1 Process Description

The application of paint to auto bodies in manufacturing plants requires several steps as shown in the flow diagram in Figure 12.3.1-1.

According to the U. S. Environmental Protection Agency (1977a), the body is first given a pretreatment, usually a phosphate wash, and then a primer is applied. Dipping techniques are used to apply water borne enamels. Organic solvent borne primers are also used and these are sprayed on. The application area is followed by a flashoff area, where some of the solvent evaporation occurs. The body then passes into a curing oven where solvent evaporation is completed.

The topcoat (or coats) is applied in a paint spray booth by a combination of automatic and manual sprays. Each topcoat is followed by a curing oven. When topcoating is completed, the painted body is sent to the trim shop where assembly is completed. Coatings which are damaged are repaired in a special spray booth.

Hoods and fenders may be coated on a separate line or the same line as the bodies. Various small parts are coated on a separate line.

In spray booths, paint is forced through spray gun nozzles by compressed air. To maintain the concentration of solvent vapor at safe levels, the booth is ventilated by fans. Spray booths on the assembly line are sometimes several hundred feet long. The exhaust volume from the booths is very large ( $> 2,800 \text{ Nm}^3/\text{min}$ ).

Figures 12.3.1-2 and 12.3.1-3 show booths where overspray is controlled by a water wash. Small items may be painted in booths where only dry baffles or a felt filter are used to collect the overspray.

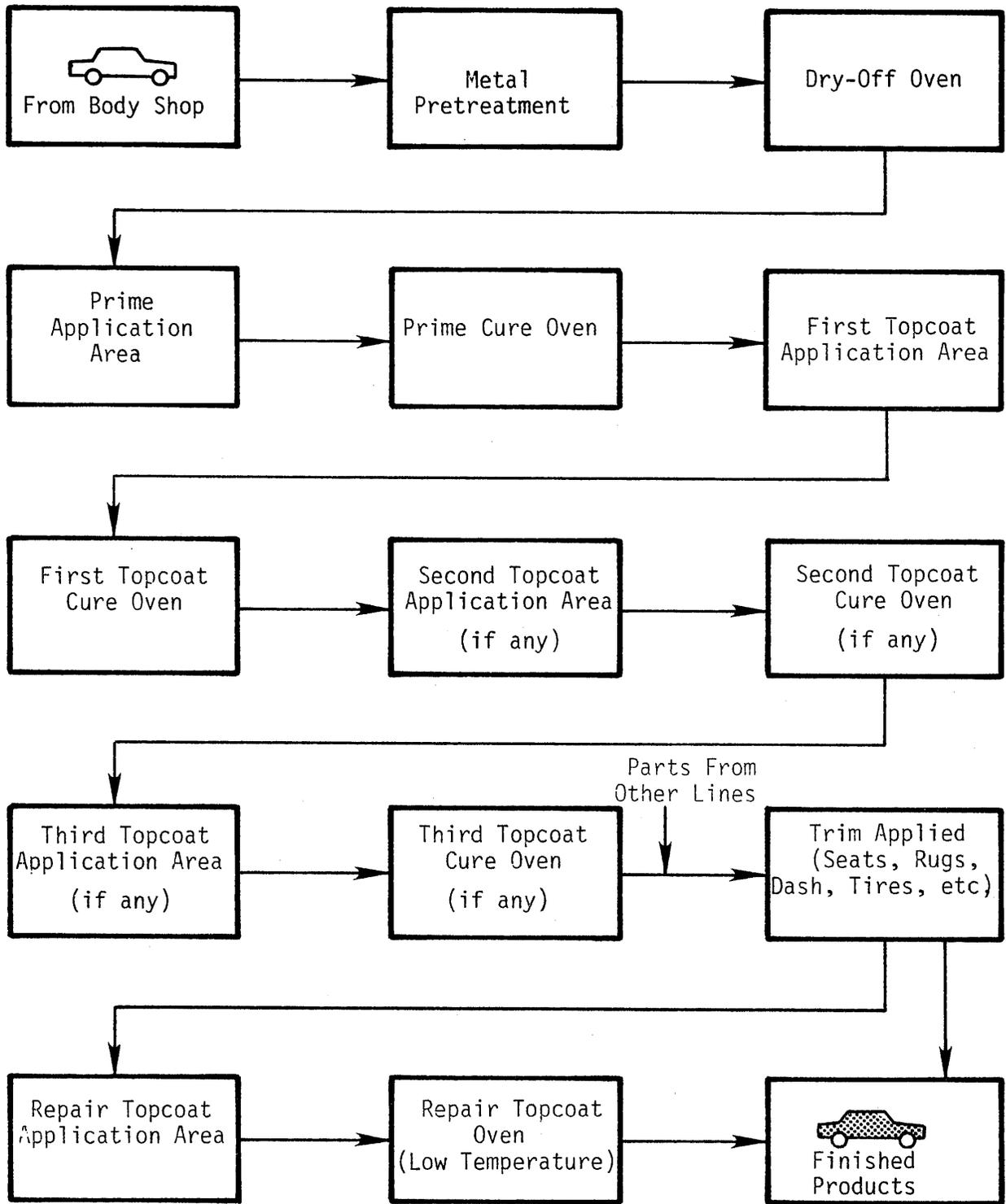


Figure 12.3.1-1. Automobile surface coating flow diagram (U.S. Environmental Protection Agency, 1977b).

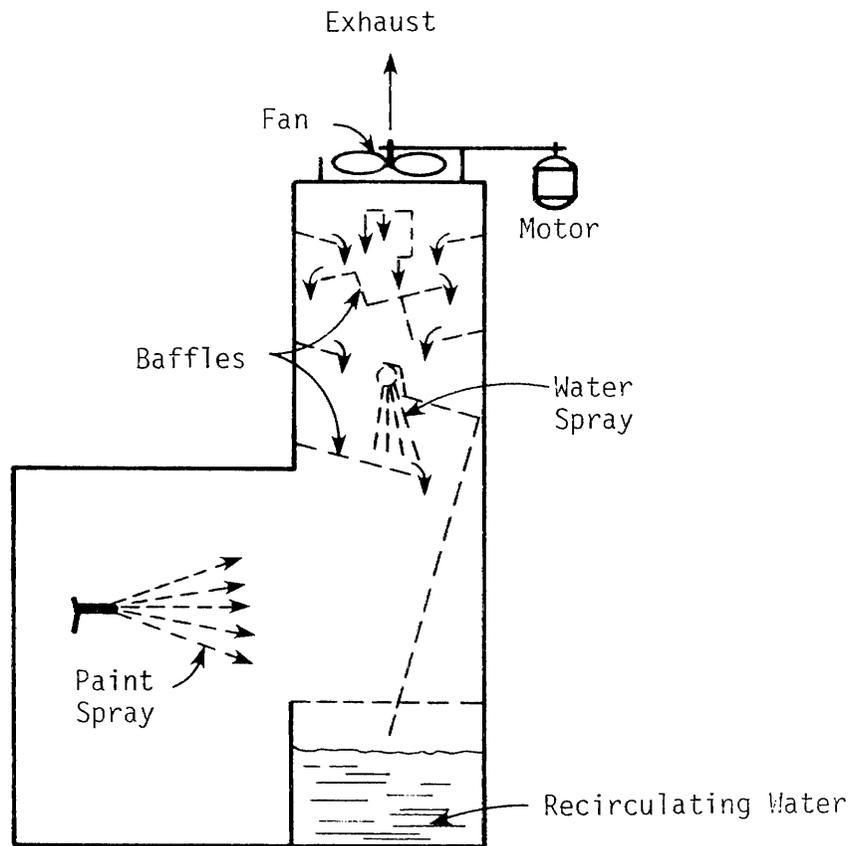


Figure 12.3.1-2. Water wash spray booth (Steenberg, 1974).

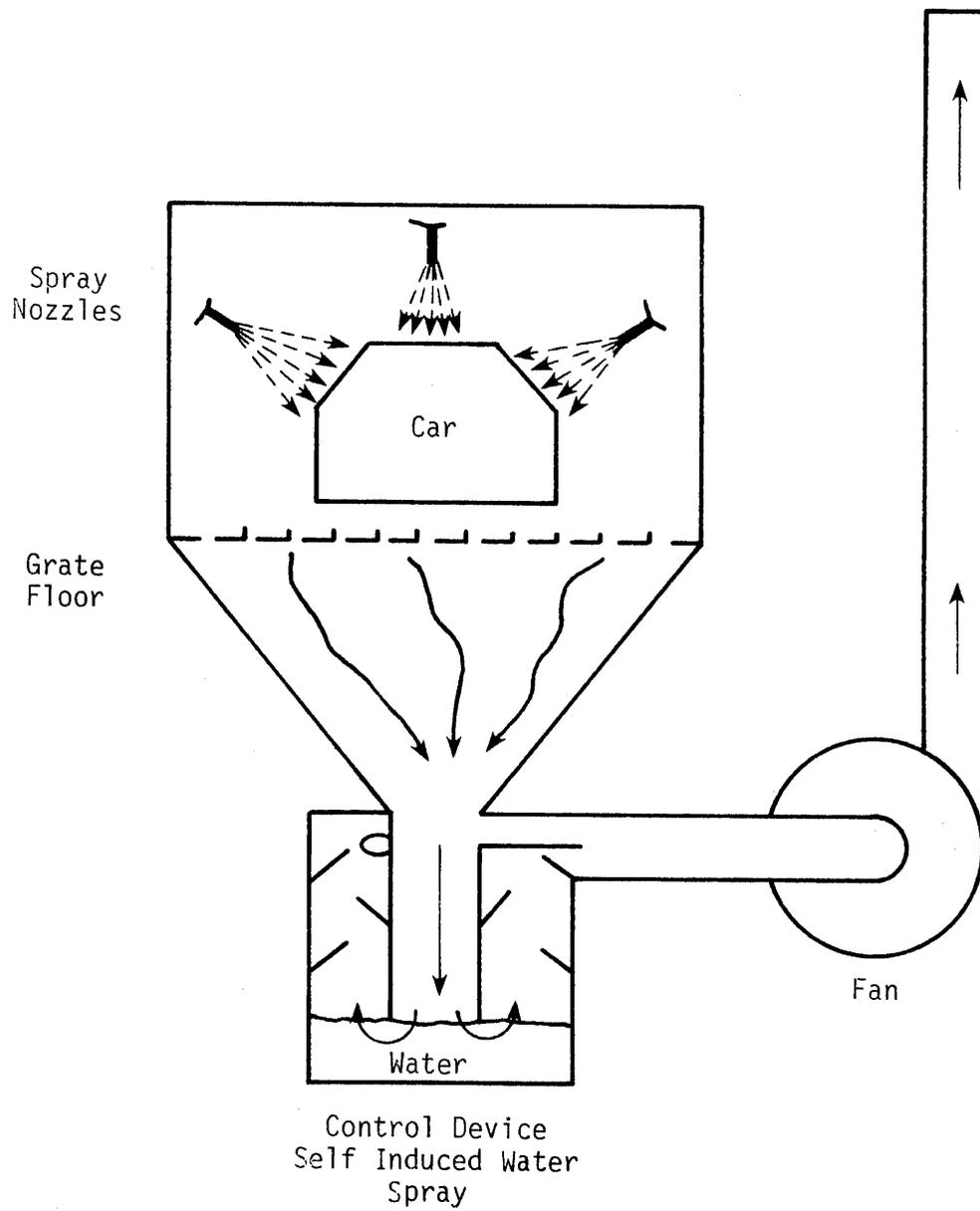


Figure 12.3.1-3. Down draft water-wash spray booth (Taback et al., 1979).

### 12.3.2 Source Characteristics

Paint spray booths are the major source of the particle emissions in automobile coating. The portion of the spray which is not deposited on the article is known as overspray. 35-90% of the spray may be overspray. 60% is common according to Danielsen (1973).

Figure 12.3.2-1 shows a particle size distribution curve for an auto spray booth reported by Taback et al. (1980). The sampling was done downstream of the exhaust fan on the type of booth shown in Figure 12.3.1-3. Two tests were run on water borne paints and two on solvent borne. The curve shown is the average of the four tests.

Table 12.4.2-1 shows particle characteristics for spray booths. Table 12.4.2-2 shows gas characteristics.

### 12.3.3 Control Technology

Particle emissions are controlled by baffles, felt filter pads or water sprays. According to Steenberg (1974), the efficiency of baffles and filters can be as high as 90%. Efficiencies of 95% can be obtained with water curtains with a liquid-to-gas ratio of 1.3 to 4.7 liters/Nm<sup>3</sup> of exhaust air.

Electrostatic spraying is a technique which reduces the amount of overspray. The paint drops are given a negative charge and the article to be sprayed is grounded. Due to electrostatic attraction, a greater portion of the drops are deposited on the article and fewer bounce off.

The control of organic solvent emissions is achieved by passing the gas through activated carbon beds or by incineration. Either catalytic or thermal incineration is used, but concentrations are generally too low for catalytic incineration.

## 12.4 FURNITURE MANUFACTURING

### 12.4.1 Process Description

Surface coatings are applied to both metal and wood furniture. Figure 12.4.1-1 shows the methods used to apply surface coatings to metal furniture. As with other surface coating operations, the spray method is the main source of particulate emissions.

A discussion of surface coating in the wood furniture industry was not located. However, spray booths are a source of particle emissions in this industry (California Air Resources Board, 1980). Sanding operations are also a source. This is discussed in Section 14.

In the metal furniture industry, furniture pieces may be coated before or after being assembled. They are cleaned to remove scale, grease and oil before coatings are applied. This can be done by an alkaline cleaner, organic solvent cleaning or sand blasting.

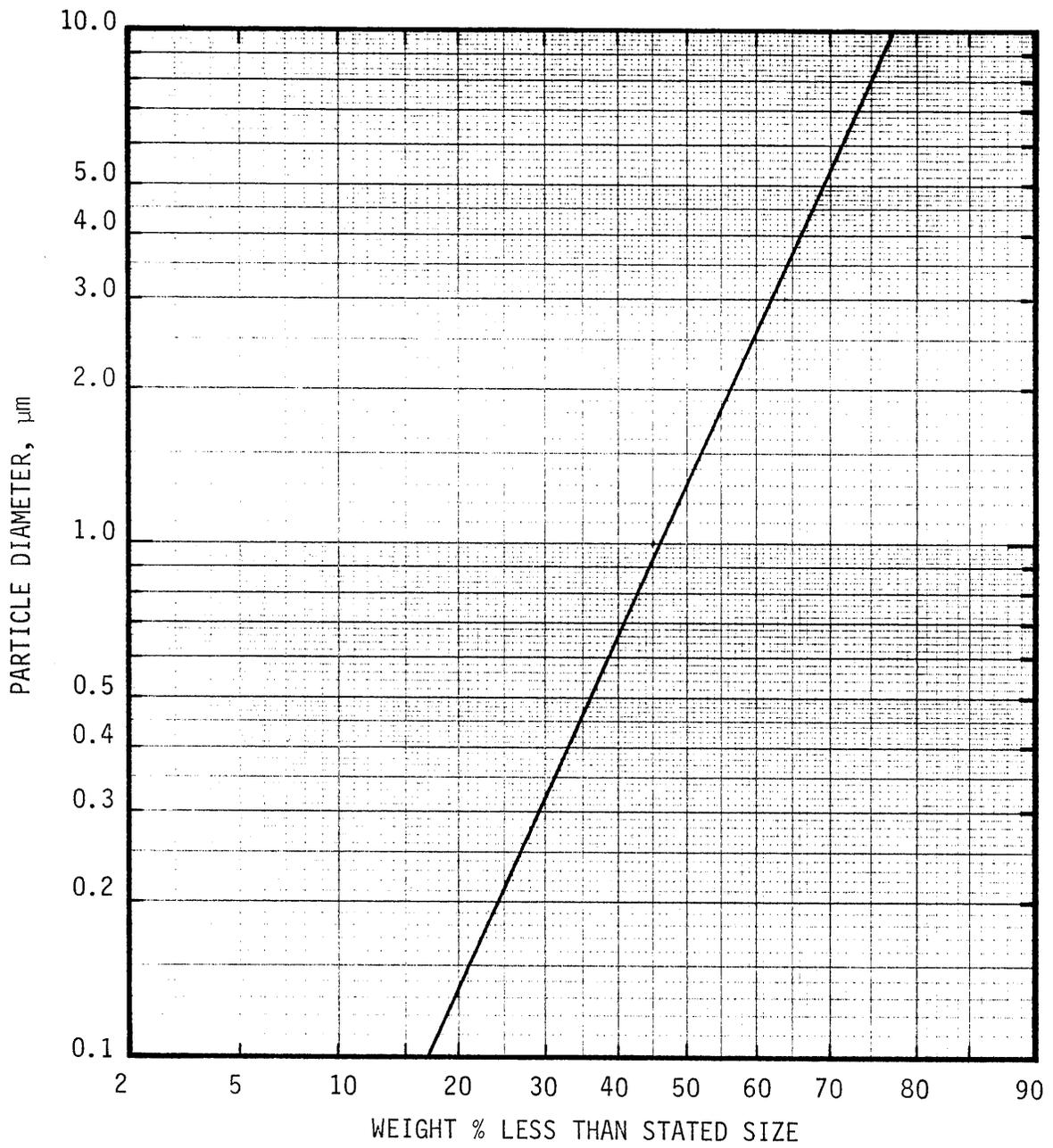


Figure 12.3.2-1. Particle size distribution, paint spray booth (Taback et al., 1979).

TABLE 12.3.2-1. AUTOMOBILE SURFACE COATING PARTICLE CHARACTERISTICS<sup>a</sup>

Mass Concentration, mg/Nm<sup>3</sup>

<u>Process</u>	<u>Uncontrolled</u>		<u>Controlled</u>		<u>Particle Density</u> g/cm <sup>3</sup>	<u>Particle Resistivity</u> ohm-cm
	<u>Total</u>	<u>&lt;3 μm</u>	<u>Total</u>	<u>&lt;3 μm</u>		
Spray Booth, Scrubber controlled	6-8	<3	6-8	4-5		10 <sup>14</sup>

<sup>a</sup>Taback et al. (1979)

TABLE 12.3.2-2. AUTOMOBILE SURFACE COATING GAS CHARACTERISTICS<sup>a</sup>

<u>Process</u>	<u>Production Rate</u>	<u>Gas Flowrate Nm<sup>3</sup>/kg (unless otherwise noted)</u>	<u>Temperature °C</u>	<u>Chemical Composition, % vol, dry (unless otherwise noted)</u>
Spray Booth, Scrubber controlled		2,600-6,700 Nm <sup>3</sup> /min	~20	

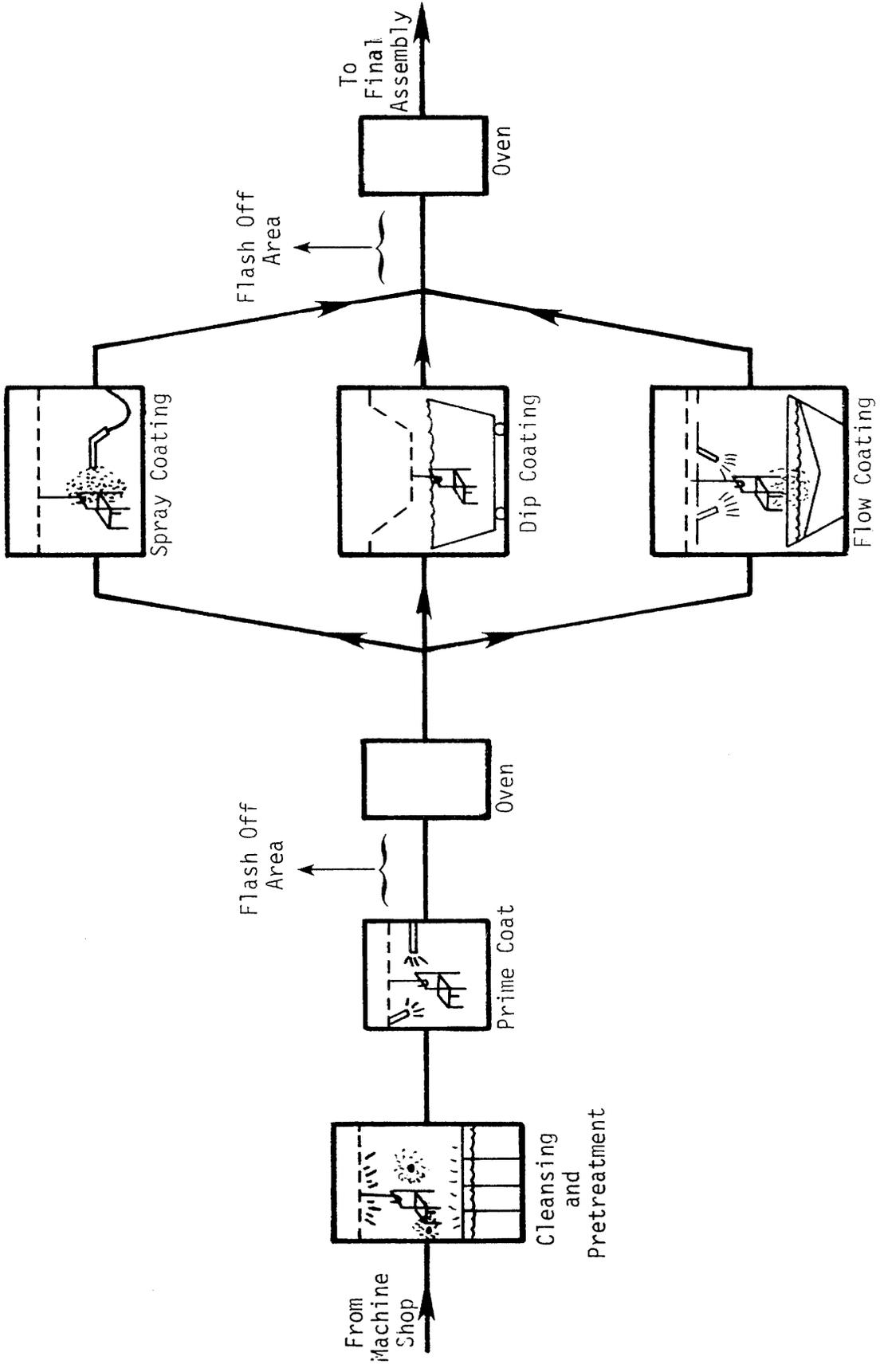


Figure 12.4.1-1. Metal furniture surface coating (U.S. Environmental Protection Agency, 1977b).

Usually only one coat is applied, however, a prime coat can be used. There are three basic methods for applying either a prime or topcoat: spray methods, flow coating, and dip coating. If only one or two colors are needed, the last two methods are used.

Flow coating involves conveying the piece over an enclosed tank and covering the piece with pumped streams of coating. Excess coating drains into a tank, is filtered and reused. Dip coating is the immersion of the pieces in a coating bath. The pieces are removed and the excess drains back.

Spray coating is done in booths similar to those used for automobiles (Figures 12.3.1-2 and 12.3.1-3), though not as large. Most spray coating in metal furniture facilities is done manually. Electrostatic spray coating (Section 12.3.3) and powder coating (Section 12.2.3) are also used.

Coating operations are followed by a flashoff area and then a baking oven. The baking ovens operate between 160 and 230°C (300-450°F). They have high air flow rates to maintain a solvent concentration below 25% of the lower explosive limit (LEL) and to maintain negative pressure.

#### 12.4.2 Source Characteristics

No details on source characteristics for furniture surface coating were located. The information in Section 12.3.2 will be used.

#### 12.4.3 Control Technology

Refer to Section 12.3.3 for discussion of particulate control for spray booths.

### 12.5 CALCULATIONS

Filter, the Venturi scrubber, the Calvert Collision scrubber, and the charged particle/charged drop spray scrubber were evaluated for controlling the particle emissions from a paint spray booth. Due to the high resistivity of paint particles (approx.  $10^{14}$  Ohm-cm), control with ESP is not recommended.

Calculation results are shown in Table 12.5-1. The operating costs of the control devices were estimated based on 1 shift/day for the whole year.

CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

PROCESS	EMISSION SOURCE	PL CONTROL TECHNOLOGY	INDUSTRY:	SECTION:	ANNUALIZED COSTS, \$	EFFY REL (%)	REL (%)	ENVIR S USE	IMPACT	REMARKS	REF								
												CAPITAL, OPERATING,	ENERGY						
Surface Coating	Spray booth	PM Scrubber Charged Part./ Charged Spray Scrubber	Automobile		99.7	5				E=99.5% for dpa< 3µmA. 3-stage scrubber with QL/QG = 4 X 10 <sup>-4</sup> m <sup>3</sup> /m <sup>3</sup> .									
Surface Coating	Spray booth	PM Scrubber Venturi			22,926/m <sup>3</sup> /s	68.6	1	16kW/m <sup>3</sup> /s		E=50% for dpa< 3µmA. Δp = 90 cm W.C.									
												4,109/m <sup>3</sup> /s							
												7,840/m <sup>3</sup> /s							
Surface Coating	Spray booth	PM Scrubber Calvert Collision Scrubber			9,788/m <sup>3</sup> /s	87.5	2	7.1kW/m <sup>3</sup> /s		E=80% for dpa< 3µmA. Δp = 38 cm W.C.									
												2,435/m <sup>3</sup> /s							
												4,028/m <sup>3</sup> /s							
Surface Coating	Spray booth	PM Filter			15,905/m <sup>3</sup> /s	95.7	1	6.8kW/m <sup>3</sup> /s		E=93.2% for dpa< 3µmA. Air/cloth = 0.93 m/min.									
												2,078/m <sup>3</sup> /s							
												3,946/m <sup>3</sup> /s							

TABLE 12.5-1

CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

PROCESS	EMISSION SOURCE	PL CONTROL TECHNOLOGY	ANNUALIZED COSTS, \$	EFFY REL (%)	REL (%)	ENERGY USE	ENVIR IMPACT	REMARKS	REF
Surface Coating	Spray booth	PM Filter	12,514/m <sup>3</sup> /s	77.2	1	7.6kW/m <sup>3</sup> /s		E=63.8% for d <sub>pa</sub> < 3μmA. Air/cloth = 3.1 m/min.	
			1,874/m <sup>3</sup> /s						
			3,344/m <sup>3</sup> /s						
Surface Coating	Spray booth	PM Filter	15,268/m <sup>3</sup> /s	67.5	1	11kW/m <sup>3</sup> /s		E=48.4% for d <sub>pa</sub> < 3μmA. Air/cloth = 5.5 m/min.	
			2,337/m <sup>3</sup> /s						
			4,130/m <sup>3</sup> /s						

## SECTION 12

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SECTION 13  
INCINERATION

13.1 INTRODUCTION

Incineration of municipal wastes is not presently a major source of fine particle emissions in California. The U. S. Environmental Protection Agency (1980) states: "state and local regulations have generally tipped the economics of disposing of non-hazardous wastes in favor of land disposal". However, the practice of burning of municipal wastes as an energy source may soon increase. For this reason, CARB requested that municipal incineration be included in this report.

Industrial incinerators are used to burn a variety of industrial wastes. There is also increasing interest in heat recovery from industrial incineration. Wood waste boilers used in various wood products plants are an example of this.

Technically, wood waste boilers are not incinerators because the heat is recovered for a use. They are discussed in this section because the furnace operations are similar to those for municipal incineration.

13.2 MUNICIPAL INCINERATION  
13.2.1 Process Description

The purpose of municipal incineration is generally volume reduction. The dry residue from incineration has a volume 10 to 20% that of the charged waste. In addition, weight is reduced to 20 to 25% of the charged weight according to DeMarco et al. (1969).

The composition of municipal solid waste is influenced by the location, the season, economic conditions, and changing technology, according to Schweiger (1975). Because of the wide variation in waste characteristics, such as size, moisture content, chemical composition, and physical characteristics, refuse is not an ideal fuel.

To improve the operating conditions of the furnace, the waste is generally conditioned to some degree. Processes for waste preparation and resource recovery are presented by Schweige (1975).

A large variety of furnace designs are used in incineration. A general process description will be given here. More detailed furnace descriptions can be found in Niessen et al. (1970) and U. S. Environmental Protection Agency (1980).

Figure 13.2.1-1 shows one of the several types of furnaces which are used. The furnace consists of two or more refractory lined chambers. The waste is charged, through a chute, onto a traveling grate or hearth. The grate is designed to provide agitation of the bed to assure complete combustion.

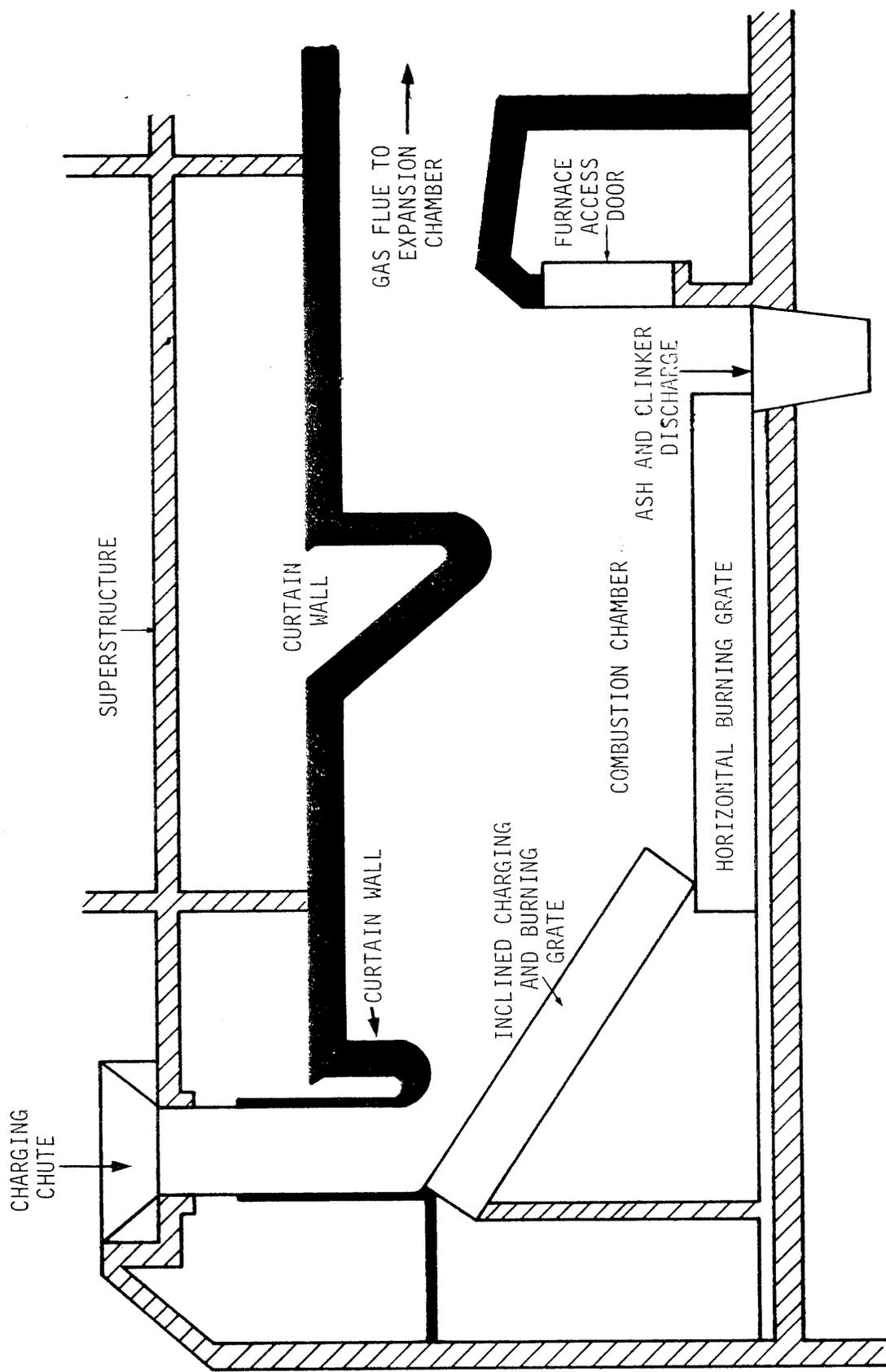


Figure 13.2.1-1. Rectangular incinerator furnace (DeMarco et al., 1969).

DeMarco et al. (1969) described two types of combustion which occur in the incinerator. Primary combustion consists of the drying, volatilization, and ignition of the fuel bed. Secondary combustion refers to the oxidation of gases and combustion of unburned wastes released from the bed by primary combustion.

The combustion air can be supplied under natural, forced or induced draft. Because mechanical draft incinerators, whether forced or induced, are more controllable than similar natural draft units, they are more efficient and emit fewer air contaminants, according to the U. S. Environmental Protection Agency (1980).

The residues from combustion generally pass through a water quench to cool them and reduce particle emissions. The residue should be carefully stored prior to disposal to prevent emissions of particles and leaching of water soluble compounds. Sanitary landfill methods are recommended for final disposal, according to DeMarco et al. (1969).

Certain types of incinerators can be used to burn sewage sludge as well as solid waste. Liquid wastes are usually sprayed into the incinerators. Schwieger (1975) described a system in which solid waste is converted to a liquid slurry prior to incineration.

Methods of incineration which deviate substantially from the previous description are reported by the U. S. Environmental Protection Agency (1980). These are: infrared incineration, molten salt incineration, fluidized bed incineration, and total incineration.

The recovery of heat from incineration is advantageous in terms of pollution control equipment requirements. According to DeMarco et al. (1969), when furnaces with water tube walls are used, the excess air requirements are 50-100% as compared to 150-200% for refractory lined furnaces. Heat exchangers which absorb heat from the exhaust gases also reduce the gas volume. The decrease in volume decreases the needed capacity of the air pollution control devices.

Exhaust gases from refractory lined furnaces are normally cooled to 315°C or less by water sprays, before they enter the air pollution control equipment. According to Fife (1972), this cooling is not needed for water tube incinerators.

### 13.2.2 Source Characteristics

Particle size distributions for incinerator emissions are shown in Figure 13.2.2-1. Table 13.2.2-1 shows chemical composition data for the particles. Other particle characteristics are shown in Table 13.2.2-2.

Gas characteristics are shown in Table 13.2.2-3. There are important differences in the combustion products of refuse and petroleum fuels. Refuse has a lower sulfur content and produces lower SO<sub>2</sub> emissions. Lead, zinc, and other metals are present in incinerator emissions in larger quantities than from combustion

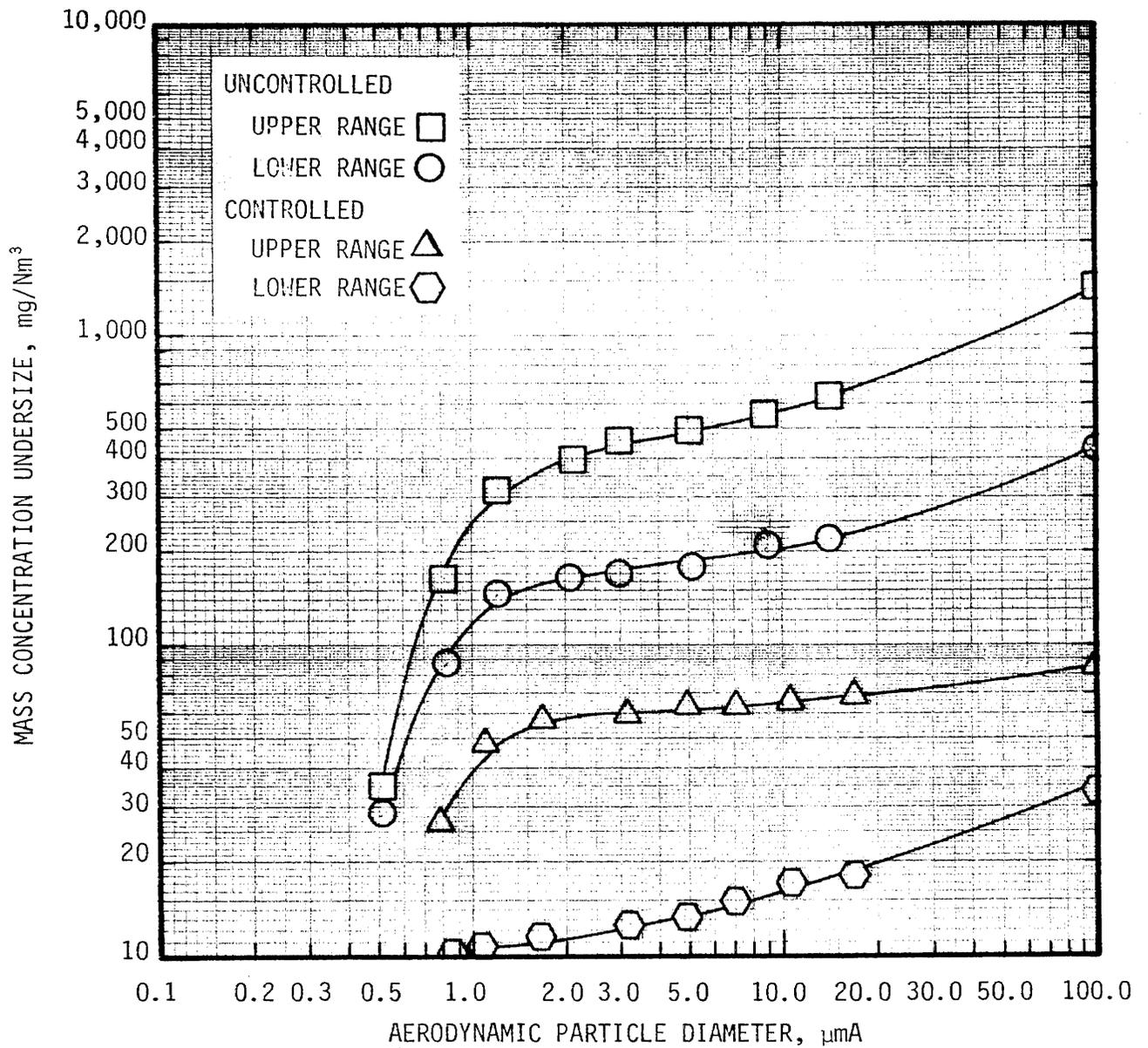


Figure 13.2.2-1. Particle size distribution from the effluent gases of controlled and uncontrolled incinerators (FPEIS).

TABLE 13.2.2-1. PARTICLE CHEMICAL COMPOSITION FOR MUNICIPAL INCINERATION<sup>a</sup>

<u>Component</u>	<u>Composition, Wt. %</u>
SiO <sub>2</sub>	31 - 45
Al <sub>2</sub> O <sub>3</sub>	12 - 17
Fe <sub>2</sub> O <sub>3</sub>	7 - 9
CaO	7 - 10
MgO	1.5 - 2.1
Na <sub>2</sub> O	6 - 8
SO <sub>3</sub>	2.6 - 3.7
P <sub>2</sub> O <sub>5</sub>	1 - 1.5
ZnO	1 - 1.5
Combustible (C, H)	0 - 30

<sup>a</sup>Niessen et al. (1970)

TABLE 13.2.2-2. PARTICLE CHARACTERISTICS FOR INCINERATION

<u>Process</u>	<u>Mass Concentration, mg/Nm<sup>3</sup></u>				<u>Particle Density g/cm<sup>3</sup></u>	<u>Particle Resistivity ohm-cm</u>
	<u>Total</u>	<u>Uncontrolled &lt;3 μm</u>	<u>Total</u>	<u>Controlled &lt;3 μm</u>		
Waste Incineration	500-2,000 <sup>a</sup> , <sup>b</sup>	150-500 <sup>a</sup>	30-100 <sup>a</sup> (Scrubber)	10-80 <sup>a</sup>	1.8-3.8 <sup>c</sup>	<10 <sup>6</sup> -10 <sup>9</sup> <sup>c</sup>

<sup>a</sup>FPEIS Data, Series 87, 1973

<sup>b</sup>Fife, 1972

<sup>c</sup>Vandegrift, 1970

TABLE 13.2.2-3. GAS CHARACTERISTICS FOR INCINERATORS

<u>Process</u>	<u>Production Rate, kg/s</u>	<u>Gas Flowrate Nm<sup>3</sup>/kg (unless otherwise noted)</u>	<u>Temperature °C</u>	<u>Chemical Composition, % vol, dry (unless otherwise noted)</u>
Waste Incineration	Municipal <sup>b,c,d</sup> 30-1,800	14-27 <sup>a,d</sup>	300-600 <sup>a</sup>	CO <sub>2</sub> 1.5-6 <sup>a,c,d</sup> O <sub>2</sub> 13-20 CO .02-.1 N <sub>2</sub> Balance dry H <sub>2</sub> O 5-9 (wet basis)

<sup>a</sup>Danielson, 1973

<sup>b</sup>U.S. Environmental Protection Agency, 1980

<sup>c</sup>Carotti and Smith, 1974

<sup>d</sup>Ongerth and Tucker, 1970

of petroleum products, according to data presented by Hall et al. (1979).

### 13.2.3 Control Technology

Particle emissions are affected by the air flow characteristics of the furnace. Fife (1972) reported that particle entrainment increases with increasing underfire air flow rates.

Scrubbers and ESP's are used to control incinerator emissions. Electrostatic precipitators have a lower pressure drop than scrubbers, and do not produce a wastewater stream or a steam plume. However, ESP's will not reduce gaseous emissions. Fife (1972) reported that ESP's have not been found suitable for incinerators which burn sewage sludge because the fly ash produced is sticky.

Scrubbers have an advantage in that they can control gaseous emissions such as HCl. Corrosion is a major problem, according to Fife (1972), but it can be overcome by proper material selection. Plume suppression methods, such as subcooling or reheating are sometimes required downstream from the scrubber.

Baghouses have not been commonly used on municipal incinerators due to temperature problems.

## 13.3 INDUSTRIAL INCINERATION

Incineration is used in industrial plants to reduce the volume and/or the toxicity of wastes, or for resource recovery. Combustion of waste for heat recovery is not classified as incineration. The U. S. Environmental Protection Agency (1980) reported that 50% of industrial incineration is for volume reduction, 29% is for resource recovery, and 21% is for toxicity reduction (based on data from Georgia, Illinois and Texas). The information for this section is from "Source Category Survey: Industrial Incinerators" by the U. S. Environmental Protection Agency (1980).

### 13.3.1 Process Description

The EPA report includes in the toxicity reduction category both toxic and hazardous wastes, such as combustible liquids, explosives, solvents, and substances containing hydrocarbons. Incineration for toxicity is predominate in chemical and petroleum industries.

Examples of resource recovery operations are: incineration of electric motor windings and wire for copper recovery, the incineration of photographic materials for silver recovery, the debonding of brake shoes, and the cleaning of steel drums by incineration of the residue adhering to the drum surface. Resource recovery incineration is predominant in the primary metal, electric machinery, transportation equipment, and instrument industries.

Incinerators operated by companies in the business of industrial waste disposal are also classified as industrial incinerators. These units are used almost exclusively for waste detoxification.

Capacities of industrial incinerators range from 1-2,830 kg/hr. Approximately 85% of the units have capacities under 454 kg/hr (1,000 lb/hr). Multiple chamber incinerators are generally used. One design is shown in Figure 13.3.1-1. The process description is similar to that for municipal incineration (Section 13.2.1). For more detailed information on different industrial sources, refer to the U. S. Environmental Protection Agency report (1980).

### 13.3.2 Source Characteristics

No size distribution data or chemical composition data was located for industrial incinerators. The composition of the feed for incineration will vary from industry to industry and also from plant to plant. The composition and level of emissions will vary with the material burned. Emission rates also vary with batch size, frequency of charging and the rate of auxiliary fuel use.

### 13.3.3 Control Technology

Afterburners are the most common control device used. The U. S. Environmental Protection Agency (1980) reported that afterburners were used on all the controlled industrial incinerators located in their survey.

Tests on wire, motor and brake show incinerators controlled by afterburners have shown particulate emission reduction in excess of 90%. However, it was not stated whether these were single or multiple chamber incinerators. Single chamber incinerators have much higher particle emissions than multiple chamber incinerators, due to incomplete combustion. Therefore, afterburners would show a greater efficiency on single chamber incinerators than on multiple chamber incinerators.

Scrubbers and baghouses are also used. Technologies now used for fossil fuel combustion, and those being developed, are applicable to industrial incineration. Fluidized bed combustion has been used for certain types of industrial wastes.

## 13.4 WOOD WASTE BOILERS

Wood industries such as lumber and paper mills, veneer, plywood, and particle board manufacturing, and furniture manufacturing produce wood wastes. In the past, these wastes have been incinerated in conical or "teepee" burners. The use of waste wood to produce steam or heat to be used in plant operations is becoming more common. Boubel (1977) reported 69 wood-fired boilers in California which burn over 1.2 million metric tons of

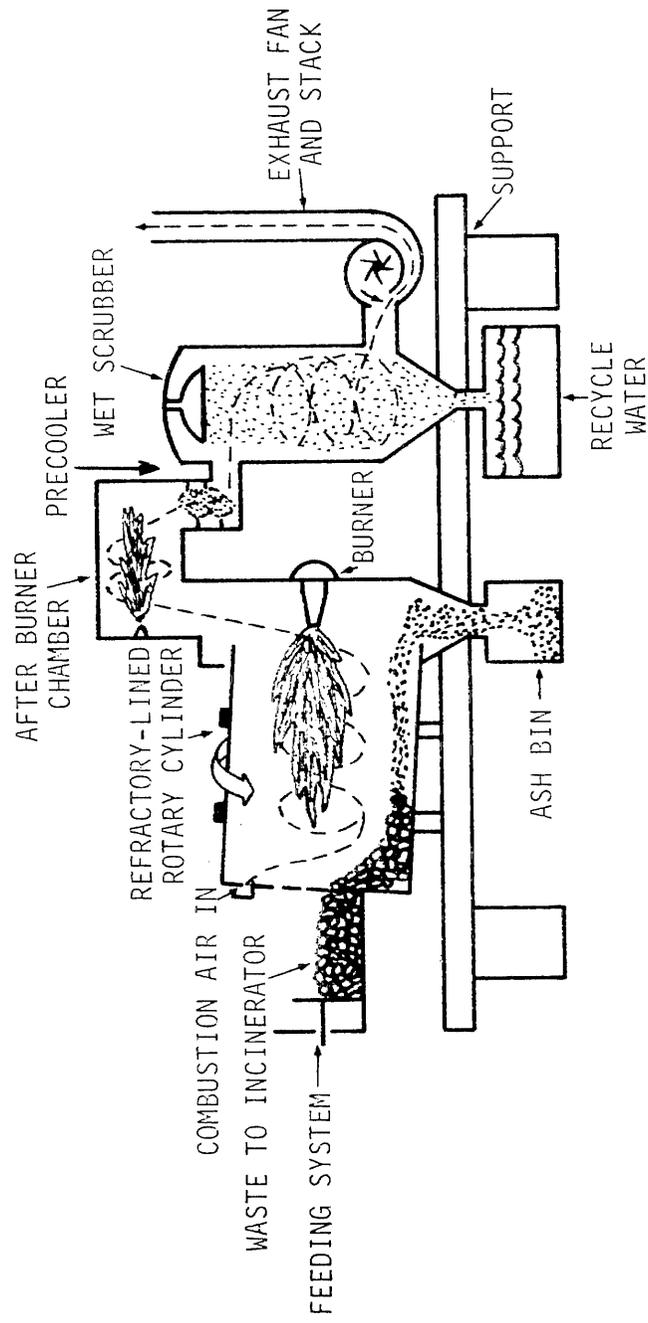


Figure 13.3.1-1. Rotary kiln incinerator.

wood each year. Boubel is the source of information for this section unless otherwise noted.

#### 13.4.1 Process Description

The wood waste that is used as fuel ranges from sanderdust, 2  $\mu\text{m}$  in diameter to bark, 10 cm in size. Normally the larger wood is reduced in size by machines known as wood "hogs" which gives rise to the term "hogged fuel boiler".

The wood waste often has a high moisture content due to process techniques and outdoor storage. Driers are used to reduce the moisture content to 25 to 35%. The drying operation can produce emissions of fine particles if the moisture content is reduced below 20%. If the wood is overheated, volatiles can be driven off and exhausted.

Boubel (1977) discussed several types of furnaces and boilers used to burn wood wastes. Figure 13.4.1-1 shows a package spreader-stoker furnace and boiler. The operating processes are similar to those for incineration. As with incineration, air flow and temperature should be carefully controlled for efficient combustion.

Wood waste boilers are usually designed to operate on at least one auxiliary fuel, such as oil or gas. This is to assure steam production when there is not enough wood to burn or the handling equipment breaks down.

Cinder reinjection is a technique used on wood-fired boilers to reduce the volume of solid waste by burning the carbon in the residue. In this method, the cinders are collected from cyclones located downstream of the heat exchanger. The cinders consist of fixed carbon, inorganic fly ash and other inorganic particles. The cinders are screened to remove heavier particles, and in the process they are broken into fine particles. These particles are reinjected into the furnace, however, they often pass through the combustion zone too quickly to burn and because of their fine size, they are emitted as air pollutants.

Boubel recommended that this practice be carefully evaluated. As he pointed out, if the furnace operates so inefficiently that large amounts of carbon remain in the residue, only 20-30% of the reinjected cinders will be burned. If the furnace is efficient, most of the reinjected cinder is inorganic. The volume of the collected residue is reduced by increasing air pollutants as well as by burning a portion of the remaining carbon. Boubel (1977) reported particle mass concentrations of 340  $\text{mg}/\text{Nm}^3$  when cinder is reinjected as compared to 275  $\text{mg}/\text{Nm}^3$  when the same boiler is operated without reinjection.

#### 13.4.2 Source Characteristics

Figure 13.4.2-1 shows a particle size distribution reported by Taback et al. (1979), for a hog fuel boiler which was controlled by a multicyclone. Chemical composition data for the

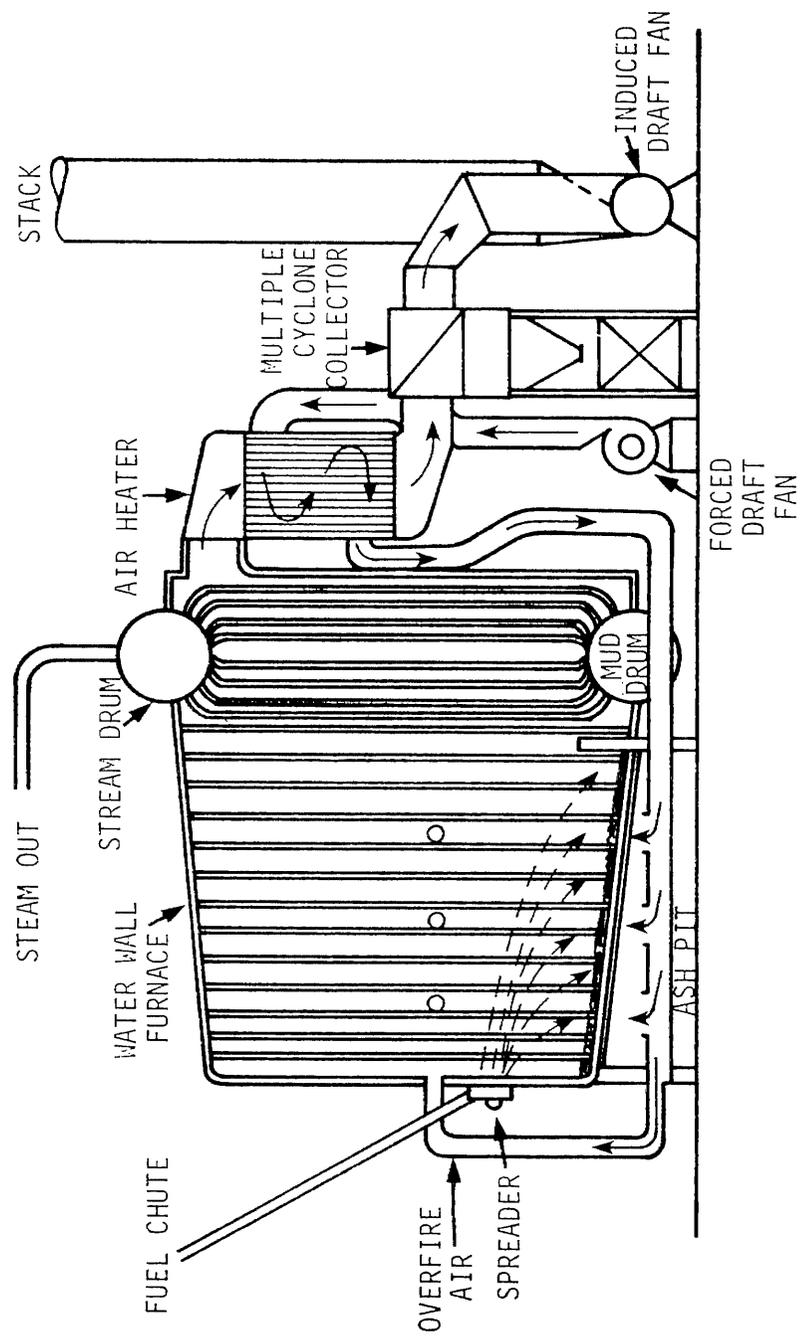


Figure 13.4.1-1. Wood waste boiler (Boubel, 1977).

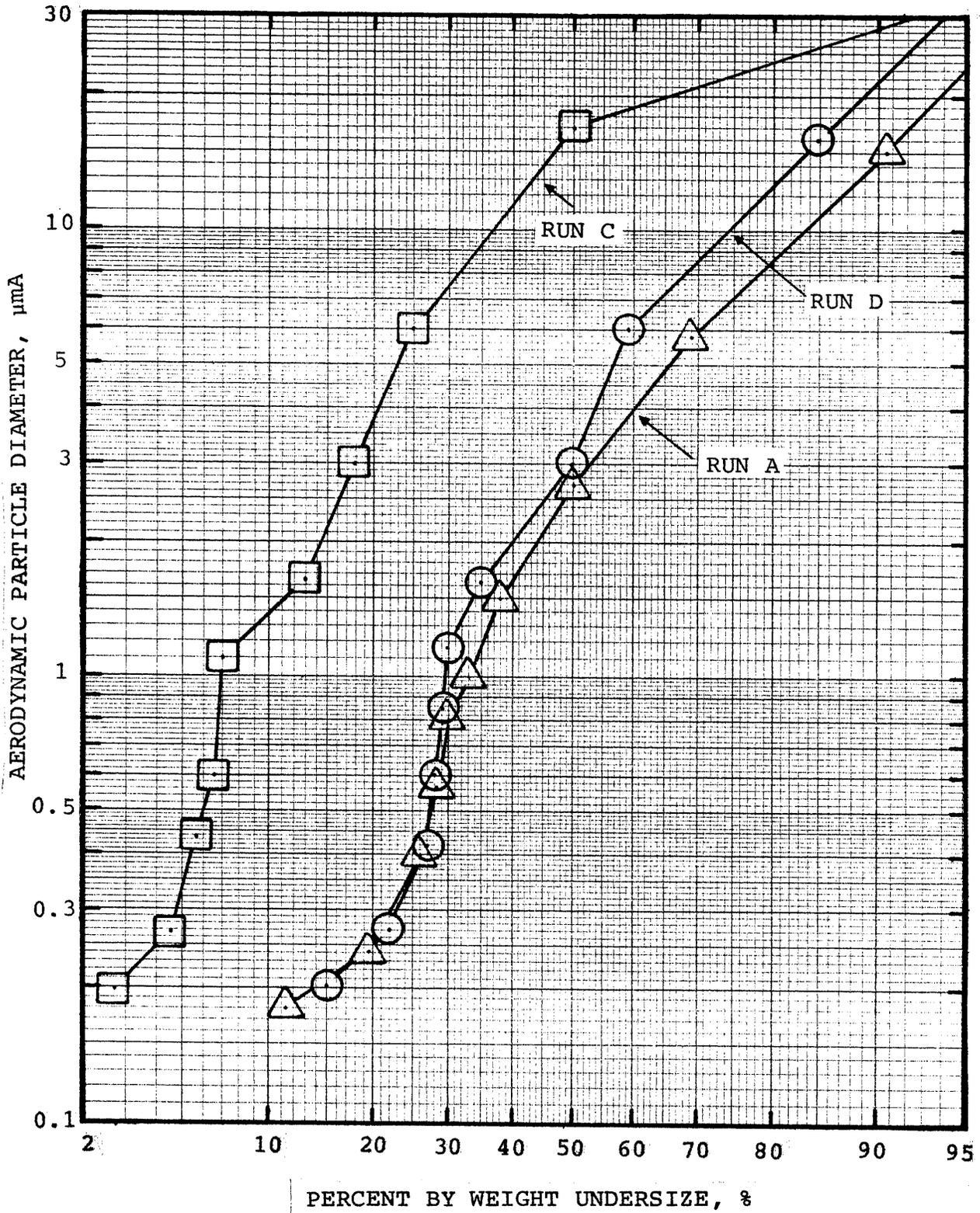


Figure 13.4.2-1. Particle size distribution from wood waste boiler (Hood, 1976).

particles are shown in Table 13.4.2-1.

Particle and gas characteristics for wood waste boilers are presented in Tables 13.4.2-2 and 13.4.2-3.

### 13.4.3 Control Technology

Cyclone control devices are commonly used on wood waste boilers. Multiple cyclones, which consist of 50-250 small diameter cyclones enclosed in a single box, give higher efficiencies than single large cyclones. For instance, multiple cyclones collect 10 micrometer particles with efficiencies over 95%. A single large cyclone would have efficiencies closer to 60% for the same size particles, according to Boubel.

Abrasive damage to the cyclones is common. Since multiple cyclones are enclosed, cyclones can be completely eroded before the operator is aware of it.

Wet scrubbers are also used and have the same advantages and disadvantages as were discussed in Section 13.2-3.

Granular bed filters, which use a bed of granular material to collect the particles, have been used. Tables 13.4.2-2 and 13.4.2-3 show data on their use.

ESP's are not commonly used, mainly due to variable particle resistivity and low particle resistivity. Baghouses are also uncommon due largely to fire hazard. Data for one application is shown in Tables 13.4.2-2 and 13.4.2-3.

### 13.5 CALCULATIONS

A list of performance calculations for incineration process emissions is presented in Table 13.5.1. The calculation results are summarized in Tables 13.5.2 and 13.5.3.

A duty factor of 0.70 was assumed for estimating the operating cost for control devices.

TABLE 13.4.2-1. WOOD WASTE BOILER PARTICLE  
ELEMENTAL ANALYSIS<sup>a</sup>

All Numbers in Weight Percent.

	<u>Composite</u>	<u>&lt;1 μm</u>	<u>1-3 μm</u>	<u>3-10 μm</u>	<u>&gt;10 μm</u>
Volatile Carbon	10	7	23	7	16
Carbon (less Volatile)	20	23	7	23	14
Silicon	10	10	10	10	10
Sulfates	3	3	2		
Chlorine	2	2			
Calcium	1	1		14	7
Iron	1		4	5	4
Potassium	1	1	3	6	3
Other (O <sub>2</sub> ,Na,Mg,Al)	52	53	51	35	46
<hr/>					
Total	100	100	100	100	100
Wt % of Composite in each size range	100	74	21	5	.3

<sup>a</sup>Taback et al.,(1979)

TABLE 13.4.2-2. WOOD WASTE BOILER PARTICLE CHARACTERISTICS

Process	Mass Concentration, mg/Nm <sup>3</sup>		Particle Density g/cm <sup>3</sup>	Particle Resistivity ohm-cm
	Uncontrolled Total	Controlled Total		
Hogged Fuel Boiler; Multiple Cyclone Control		0.27 <sup>a</sup>	0.26 <sup>a</sup>	
Hogged Fuel Boiler; Cyclone and Baghouse Control	2,800-3,270 <sup>b*</sup>	6.8-17.0 <sup>b</sup>		
Hogged Fuel Boiler and Dry Scrubber Control	1,380-1,990 <sup>b*</sup>	60-180 <sup>b</sup>		
Wood Waste Boiler; Low Energy Scrubber Control		93-175 <sup>b</sup>		

<sup>a</sup>Taback et al., (1979)

<sup>b</sup>Boube1 (1977)

<sup>c</sup>Hood (1976)

\*Concentration at Cyclone Outlet.

TABLE 13.4.2-3. WOOD WASTE BOILER GAS CHARACTERISTICS

Process	Production Rate	Gas Flowrate Nm <sup>3</sup> /kg (unless otherwise noted)	Temperature °C	Chemical Composition, % vol, dry (unless otherwise noted)
Hogged Fuel Boiler; Multiple Cyclone Control	0.3 kg fuel/s <sup>a*</sup>	3.3 Nm <sup>3</sup> /s <sup>a</sup>	200 <sup>a</sup>	CO <sub>2</sub> 4.3 <sup>a</sup> O <sub>2</sub> 16.6
Hogged Fuel Boiler; Cyclone and Baghouse Control		4.6-5.0 Nm <sup>3</sup> /s <sup>b</sup>	211 <sup>b**</sup>	CO <sub>2</sub> 12 <sup>b</sup>
Hogged Fuel Boiler; Cyclone and Dry Scrubber Control				CO <sub>2</sub> 12 <sup>b</sup>
Wood Waste Boiler; Low Energy Scrubber Control		20-28 Nm <sup>3</sup> /s <sup>b</sup>	70-85 <sup>b</sup>	

<sup>a</sup>Taback et al., (1979)

<sup>b</sup>Boube1 (1977)

\*Average dry weight.

\*\*Temperature at cyclone outlet.

TABLE 13.5-1. PERFORMANCE CALCULATIONS

Process	ESP	Pulse Charging ESP	Precharging ESP	Venturi	Calvert Collision Scrubber	Filter	Electrified Filter	F/C Scrubber	Charged Particle/Charged Drop Spray Scrubber
Municipal Incineration	X			X	X	X	X	X	X
Wood Waste Boiler	X			X	X	X	X		X

CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

SECTION:

INDUSTRY: Incineration

CAPITAL,  
OPERATING,  
ANNUALIZED EFFY REL

COSTS, \$ (%) (%) S USE IMPACT

PROCESS EMISSION SOURCE PL CONTROL TECHNOLOGY

Municipal Incinerator PM ESP 13,471/m<sup>3</sup>/s 72.0 1 2.2kW/m<sup>3</sup>/s E=50% for dpa<  
incineration 2,127/m<sup>3</sup>/s 3,709/m<sup>3</sup>/s 25m<sup>2</sup>/m<sup>3</sup>/s. SCA =  
Corona power =  
41w/m<sup>3</sup>/s.

Municipal Incinerator PM ESP 13,471/m<sup>3</sup>/s 87.5 1 3.4kW/m<sup>3</sup>/s E=75% for dpa<  
incineration 2,660/m<sup>3</sup>/s 4,242/m<sup>3</sup>/s 3μmA. SCA =  
25m<sup>2</sup>/m<sup>3</sup>/s.  
Corona power =  
336W/m<sup>3</sup>/s.

Municipal Incinerator PM ESP 24,189/m<sup>3</sup>/s 95.0 1 3.8kW/m<sup>3</sup>/s E=90% for dpa<  
incineration 3,296/m<sup>3</sup>/s 6,137/m<sup>3</sup>/s 3μmA. SCA =  
50m<sup>2</sup>/m<sup>3</sup>/s.  
Corona power =  
375W/m<sup>3</sup>/s.

Municipal Incinerator PM Scrubber 12,868/m<sup>3</sup>/s 96.8 2 9.6kW/m<sup>3</sup>/s E=90% for dpa<  
incineration Calvert 8,068/m<sup>3</sup>/s 52 cm W.C.  
Collision  
Scrubber  
10,162/m<sup>3</sup>/s

## CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

PROCESS	EMISSION SOURCE	PL CONTROL TECHNOLOGY	INDUSTRY:	SECTION:	ANNUALIZED COSTS, \$	EFFY REL (%)	REL (%)	ENVIR S	ENERGY USE	REMARKS	REF
Municipal incineration	Incinerator	PM Scrubber Venturi	Incineration		12,165/m <sup>3</sup> /s 6,586/m <sup>3</sup> /s 8,565/m <sup>3</sup> /s	92.0	1	1	7.2kW/m <sup>3</sup> /s	E=75% for dpa < 3µmA. Δp = 39 cm W.C.C.	
Municipal incineration	Incinerator	PM Scrubber Venturi			23,202/m <sup>3</sup> /s 10,730/m <sup>3</sup> /s 14,506/m <sup>3</sup> /s	96.8	1	1	16.9kW/m <sup>3</sup> /s	E=90% for dpa < 3µmA. Δp = 96 cm W.C.C.	
Municipal incineration	Incinerator	PM Scrubber Charged Part./ Charged Drop Scrubber				99.6	5	5		E=98.9% for dpa < 3µmA. 3-stage scrubber with QL/QG = 4 X 10 <sup>-3</sup> m <sup>3</sup> /m <sup>3</sup> per stage.	
Municipal incineration	Incinerator	PM Filter			27,459/m <sup>3</sup> /s 6,339/m <sup>3</sup> /s 9,564/m <sup>3</sup> /s	98.7	2	2	9.6kW/m <sup>3</sup> /s	E=99.6% for dpa < 3µmA. Air/cloth = 0.93 m/min.	

CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

PROCESS	EMISSION SOURCE	PL CONTROL TECHNOLOGY	INDUSTRY:	SECTION:	CAPITAL, OPERATING, ANNUALIZED EFFY REL COSTS, \$		ENERGY ENVIR S USE IMPACT		REMARKS	REF
					(%)	(%)	S			
Municipal incineration	Incinerator	PM Filter	Incineration		16,312/m <sup>3</sup> /s	96.6	2	8.4kW/m <sup>3</sup> /s	E=95% for dpa< 3µmA. Air/cloth = 3.1 m/min.	
					5,137/m <sup>3</sup> /s					
					7,053/m <sup>3</sup> /s					
Municipal incineration	Incinerator	PM Filter			17,818/m <sup>3</sup> /s	92.6	2	11kW/m <sup>3</sup> /s	E=86.7% for dpa< 3µmA. Air/cloth = 5.5 m/min.	
					6,105/m <sup>3</sup> /s					
					8,198/m <sup>3</sup> /s					
Municipal incineration	Incinerator	PM Filter Electro-statically Augmented Filter				99.97	5		E=99.92% for dpa< 3µmA. Full ESP power.	
Municipal incineration	Incinerator	PM Scrubber F/C Scrubber				96.8	3		E=90% for dpa< 3µmA. ΔP = 21 cm W.C.	

## CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

PROCESS	EMISSION SOURCE	PL CONTROL TECHNOLOGY	INDUSTRY:	SECTION:	CAPITAL, OPERATING, ANNUALIZED COSTS, \$	EFFY REL (%)	REL (%)	ENERGY ENVIR S USE	IMPACT	REMARKS	REF
Wood waste boiler	Hog fuel boiler	PM Scrubber Venturi	Incineration		23,179/m <sup>3</sup> /s	74.0	1	4.3kW/m <sup>3</sup> /s	E=50% for dpa< 3μmA. Δp = 22 cm W.C.		
					28,262/m <sup>3</sup> /s						
					32,034/m <sup>3</sup> /s						
Wood waste boiler	Hog fuel boiler	PM Scrubber Calvert Collision Scrubber			15,577/m <sup>3</sup> /s	90.0	2	4.9kW/m <sup>3</sup> /s	E=80% for dpa< 3μmA. Δp = 24 cm W.C.		
					28,222/m <sup>3</sup> /s						
					30,757/m <sup>3</sup> /s						
Wood waste boiler	Hog fuel boiler	PM Filter			43,686/m <sup>3</sup> /s	99.3	2	8.9kW/m <sup>3</sup> /s	E=99% for dpa< 3μmA. Air/cloth = 0.93 m/min.		
					19,899/m <sup>3</sup> /s						
					25,031/m <sup>3</sup> /s						
Wood waste boiler	Hog fuel boiler	PM Filter			36,108/m <sup>3</sup> /s	87.7	2	8.2kW/m <sup>3</sup> /s	E=77.1% for dpa< 3μmA. Air/cloth = 3.1 m/min.		
					18,997/m <sup>3</sup> /s						
					23,238/m <sup>3</sup> /s						

CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

PROCESS	EMISSION SOURCE	PL CONTROL TECHNOLOGY	CAPITAL, OPERATING, ANNUALIZED COSTS, \$	EFFY REL (%)	REL (%)	S	ENERGY USE	ENVIR IMPACT	REMARKS	REF	
											INDUSTRY:
Wood waste boiler	Hog fuel boiler	PM Filter	38,281/m <sup>3</sup> /s	79.1	2	10.9kW/m <sup>3</sup> /s	E=60.9% for dpa < 3µmA. Air/cloth = 5.5 m/min.				
			20,010/m <sup>3</sup> /s								
			24,507/m <sup>3</sup> /s								
Wood waste boiler	Hog fuel boiler	PM Filter	Electro-statically Augmented Filter	99.4	4		E=98.9% for dpa < 3µmA. Full ESP power. Air/cloth = 1.76 m/min.				
Wood waste boiler	Hog fuel boiler	PM Scrubber	Charged Part./Charged Drop Spray Scrubber	99.8	5		E=99.6% for dpa < 3µmA. 3-stage scrubber with QL/QG = 4 X 10 <sup>-4</sup> m <sup>3</sup> /m <sup>3</sup> .				
Wood waste boiler	Hog fuel boiler	PM ESP	16,006/m <sup>3</sup> /s	84.0	2	2.6kW/m <sup>3</sup> /s	E=75% for dpa < 3µmA. SCA = 25m <sup>2</sup> /m <sup>3</sup> /s. Corona power = 258 W/m <sup>3</sup> /s.				
			10,477/m <sup>3</sup> /s								
			12,357/m <sup>3</sup> /s								

CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

PROCESS	EMISSION SOURCE	PL CONTROL TECHNOLOGY	INDUSTRY:	SECTION:	CAPITAL, OPERATING, ANNUALIZED COSTS, \$	EFFY REL (%)	REL (%)	ENERGY USE \$	ENVIR IMPACT	REMARKS	REF
Wood waste boiler	Hog fuel boiler	PM ESP	Incineration		21,849/m <sup>3</sup> /s	94.0	2	2.9kw/m <sup>3</sup> /s		E=90% for dpa < 3µm, SCA = 50m <sup>2</sup> /m <sup>3</sup> /s. Corona power = 300 W/m <sup>3</sup> /s.	
					10,870/m <sup>3</sup> /s						
					13,437/m <sup>3</sup> /s						

## SECTION 13

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## SECTION 14

### WOOD MILLING AND WORKING

#### 14.1 PROCESS DESCRIPTION

Many manufacturing operations use wood working equipment. These include lumber mills, planing mills, furniture manufacturers, cabinet shops, and sash and door manufacturers. The particle emissions from wood working operations vary in size from submicron to chips and curls several inches long. Often these are handled in the same collection system.

Sanding operations produce the smallest particulate emissions of the various wood working operations. Hammer mills produce particulates covering a large size range, including fine particles. Other machines, such as saws, lathes, planers, borers, and jointers, produce particles which are generally larger than 10  $\mu\text{m}$  in diameter (Danielson, 1973).

Figure 14.1-1 shows the use of exhaust hoods on two saws. Emissions from other types of wood working equipment are collected in a similar manner.

The burning of wood wastes, either in an incinerator or a wood waste boiler, is also a source of particle emissions in wood products operations. Wood waste boilers are discussed in Section 13.

#### 14.2 SOURCE CHARACTERISTICS

Figure 14.2-1 shows size distributions for a wood sanding operation controlled by a cyclone upstream from a baghouse. The size distribution at the cyclone inlet was reported by Taback et al. (1979), as 87% by weight greater than 10 micrometers and 13% between 1 and 3 micrometers.

Figure 14.2-2 shows particle size distributions for the sawing operation depicted in Figure 14.1-1. Particle and gas characteristics are given in Tables 14.2-1 and 14.2-2.

#### 14.3 CONTROL TECHNOLOGY

Low efficiency cyclones are the most common control devices used on wood working exhaust systems (Danielson, 1973). Often the emissions from several pieces of equipment are controlled by one cyclone.

#### 14.4 CALCULATIONS

Filter, Venturi scrubber, and Calvert Collision scrubber were evaluated as fine particle control devices for wood sanders. Calculation results are shown in Table 14.4-1. Operating costs were calculated for 1 shift/day for the whole year.

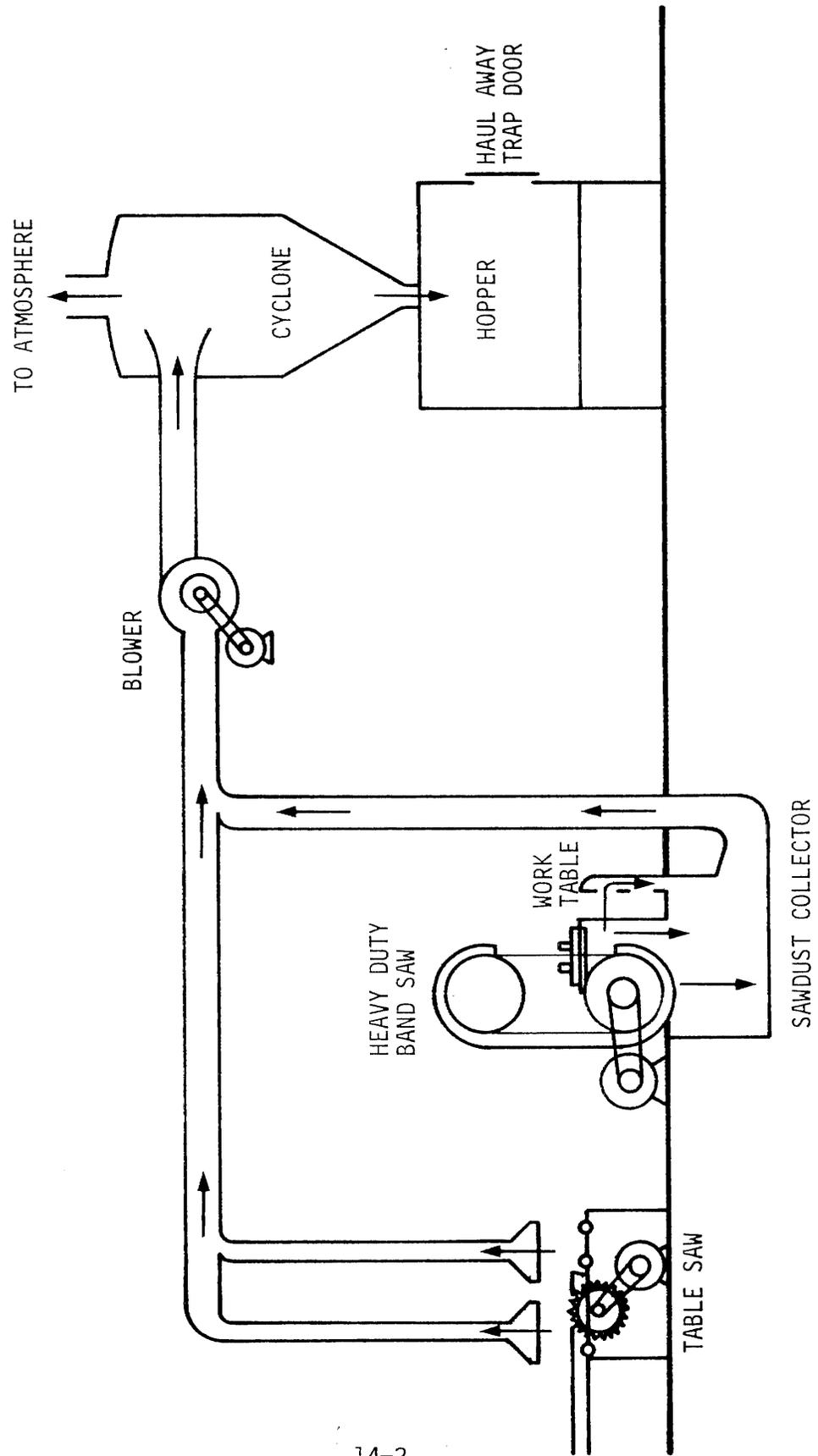


Figure 14.1-1. Wood sawing operation (Taback et al. 1979).

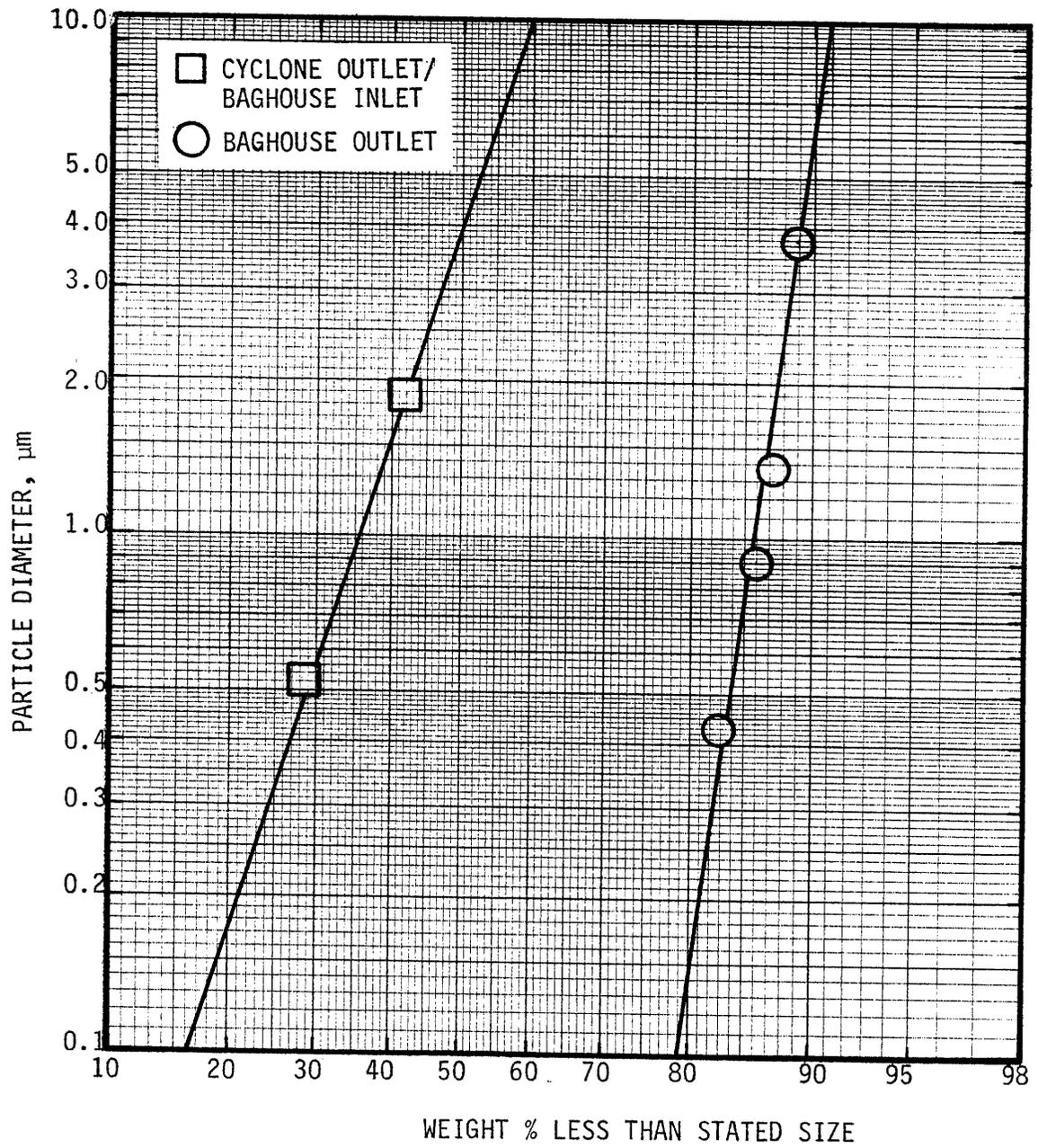


Figure 14.2-1. Particle size distributions for wood sander emissions (Taback et al. 1979).

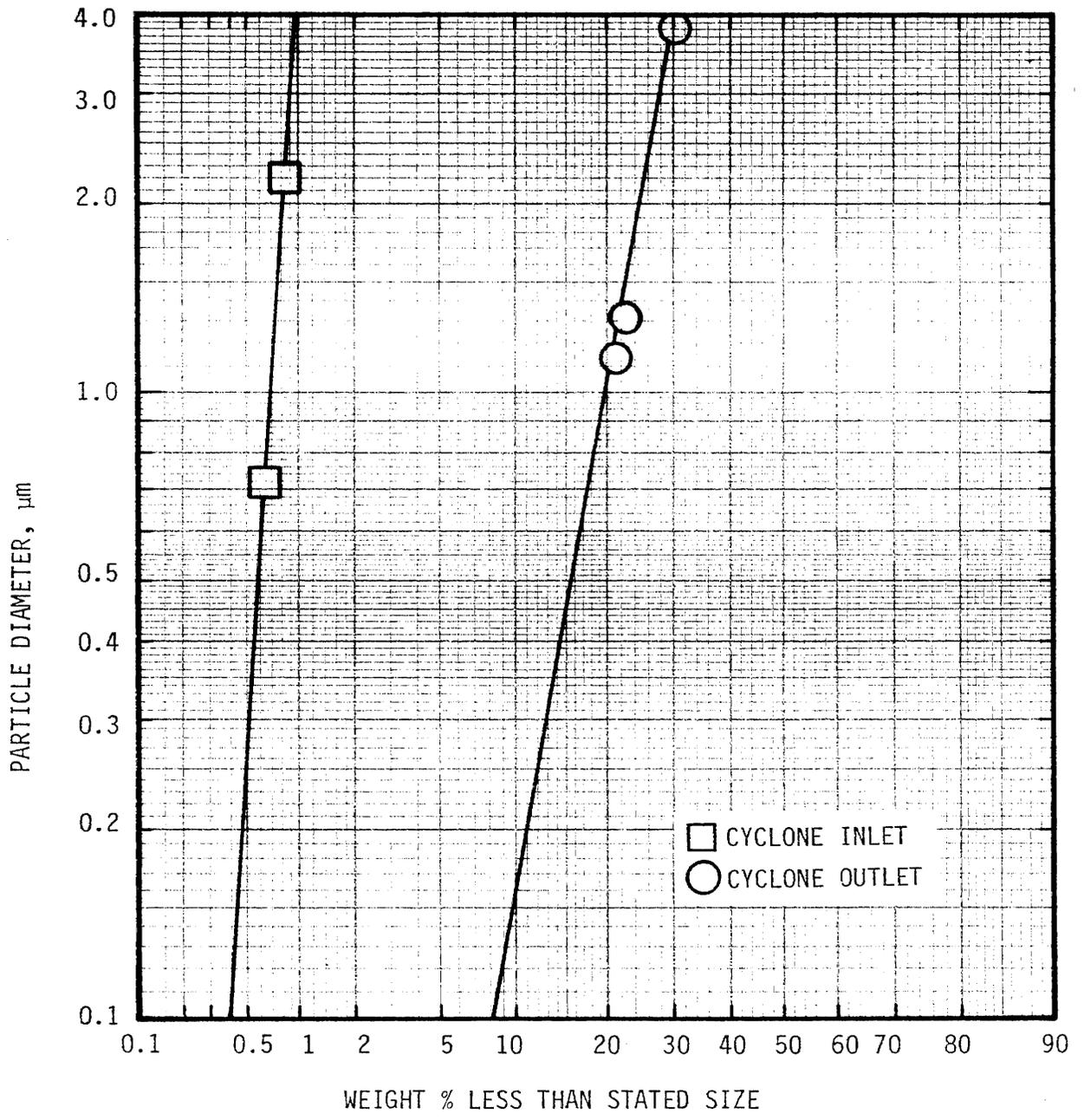


Figure 14.2-2. Particle size distributions for wood saw emissions (Taback et al. 1979).

TABLE 14.2-1. WOOD MILLING PARTICLE CHARACTERISTICS<sup>a</sup>

Mass Concentration, mg/Nm<sup>3</sup>

<u>Process</u>	<u>Uncontrolled</u>		<u>Controlled</u>		Particle Density g/cm <sup>3</sup>	Particle Resistivity ohm-cm
	<u>Total</u>	<u>&lt;3 μm</u>	<u>Total</u>	<u>&lt;3 μm</u>		
Wood Sander; Cyclone Control	2,120		40	20*		
Wood Sander; Cyclone and Baghouse			5	4*		
Wood Saw; Cyclone Control	830	7	7	2**		

<sup>a</sup>Taback et al., (1979)

\*Based on Figure 14.2-1.

\*\*Based on Figure 14.2-2.

TABLE 14.2-2. WOOD MILLING GAS CHARACTERISTICS<sup>a</sup>

<u>Process</u>	<u>Production Rate</u>	<u>Gas Flowrate Nm<sup>3</sup>/kg (unless otherwise noted)</u>	<u>Temperature °C</u>	<u>Chemical Composition, % vol, dry (unless otherwise noted)</u>
Wood Sander		120 Nm <sup>3</sup> /min	~20	
Wood Saw		190 Nm <sup>3</sup> /min	~20	

<sup>a</sup>Taback et al., (1979)

There are few fine particles from other wood working operations, such as sawing. Current control practice, i.e. with cyclones, is adequate for these operations.

TABLE 14.4-1

PAGE 1

## CONTROL TECHNOLOGY FOR STATIONARY SOURCES OF AIR POLLUTION

PROCESS	EMISSION SOURCE	PL CONTROL TECHNOLOGY	ANNUALIZED COSTS, \$	EFFY REL (%)	REL (%)	ENERGY USE	ENVIR IMPACT	REMARKS	REF	SECTION:
										INDUSTRY:
Wood milling	Wood sander	PM Scrubber Calvert Collision Scrubber	18,083/m <sup>3</sup> /s	98.8	2	2.8kW/m <sup>3</sup> /s	E=75% for dpa< 3µmA. Δp = 13 cm W.C.			
			17,488/m <sup>3</sup> /s							
			20,431/m <sup>3</sup> /s							
Wood milling	Wood sander	PM Scrubber Venturi	62,862/m <sup>3</sup> /s	76.0	2	29.4kW/m <sup>3</sup> /s	E=50% for dpa< 3µmA. Δp = 170 cm W.C.			
			22,694/m <sup>3</sup> /s							
			32,925/m <sup>3</sup> /s							
Wood milling	Wood sander	PM Filter	57,888/m <sup>3</sup> /s	96.0	2	6.7kW/m <sup>3</sup> /s	E=92% for dpa< 3µmA. Air/cloth = 0.91 m/min.			
			12,844/m <sup>3</sup> /s							
			19,644/m <sup>3</sup> /s							
Wood milling	Wood sander	PM Filter	54,624/m <sup>3</sup> /s	79.8	2	7.6kW/m <sup>3</sup> /s	E=57.8% for dpa< 3µmA. Air/cloth = 3.1 m/min.			
			12,615/m <sup>3</sup> /s							
			19,031/m <sup>3</sup> /s							

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PROCESS	EMISSION SOURCE	PL CONTROL TECHNOLOGY	ANNUALIZED COSTS, \$	EFFY REL (%)	REL (%)	ENERGY USE	ENVR IMPACT	REMARKS	REF	SECTION:
										INDUSTRY:
Wood milling	Wood sander	PM Filter	57,401/m <sup>3</sup> /s 13,063/m <sup>3</sup> /s 19,805/m <sup>3</sup> /s	72.3	2	10.5kW/m <sup>3</sup> /s	E=42.2% for dpa< 3µm. Air/cloth = 5.5 m/min.			Wood Milling and Working

## SECTION 14

### REFERENCES

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APPENDIX "A"  
CALCULATION METHODS

A.1 PERFORMANCE PREDICTION METHOD

The overall particle penetration of any device on a dust of any size distribution is

$$\begin{aligned}
 PE &= \int_0^{\infty} P_{td} f(d_p) dd_p \\
 &= \frac{1}{C_{Pt}} \int_0^{\infty} P_{td} dC_p
 \end{aligned}
 \tag{A-1}$$

where

- $\overline{Pt}$  = overall penetration, fraction
- $P_{td}$  = penetration for particles with diameter " $d_p$ ", fraction
- $f(d_p)$  = frequency distribution of particles
- $d_p$  = particle diameter,  $\mu\text{m}$
- $C_p$  = particle concentration,  $\text{g}/\text{cm}^3$
- $C_{Pt}$  = total particle concentration,  $\text{g}/\text{cm}^3$ .

Equation (A-1) can be solved by numerical integration methods, such as by trapezoid rule.

Equation (A-1) gives the overall penetration for the whole particle size spectrum, the following procedure is used to calculate the overall penetration for particles smaller than  $3\mu\text{m}$  diameter.

1. Construct a grade penetration curve, either from design equations or from experimental results.
2. Plot " $P_{td}$ " versus percent smaller than " $d_{pa}$ " (from cumulative particle size distribution curve).
3. Integrate the area under the curve of step (2). The result is the overall penetration.
4. To calculate the integrated penetration for particles smaller than  $3\mu\text{m}$  diameter. The area under the curve of step (3) from 0 to the percent undersize for  $d_{pa} = 3\mu\text{m}$  is obtained numerically. The integrated penetration for particles smaller than  $3\mu\text{m}$  diameter is equal to this area divided by the area obtained in step (3).

## A.2 COST ESTIMATES

The cost estimate includes capital cost and annualized cost.

### A.2.1 Capital Cost

Several methods of varying degrees of accuracy are available for estimating the capital costs of systems. These methods range from presenting overall installed costs on a per unit basis (such as \$/cfm) to detailed cost estimates based on design, layout, and contractor quotes. Cost on a unit basis provides a quick, order of magnitude estimate of the cost. The detailed cost estimate, which may take many months of engineering effort and require process and engineering flow sheets, plot plans, and equipment arrangement drawings, can produce accuracies of  $\pm 5\%$ . The technique used in this study is the "Lang" method which has generally been used for first-cut estimating purpose. The Lang method estimates the capital cost based on some established cost factors for direct and indirect installation costs as a function of known equipment costs. The accuracy of the Lang method is about  $\pm 20\%$ .

The capital costs of a pollution control system consists of the delivered equipment costs for the control device and all the auxiliary equipment and appurtenances plus direct and indirect costs of installation. Table A.2.1-1 shows the cost factors developed by Neveril et al. (1979) for installation costs of pollution control systems.

#### A.2.1.1 Purchased Equipment Costs

The purchased equipment costs represent the delivered costs of the control device, auxiliary equipment (such as fan and pump), instrumentation, tax, and freight. The costs of the control device and the auxiliary are estimated by first establishing the design and operating characteristics of the equipment then obtaining the cost from the equations and graphs presented in Sections 4 through 7. The estimated control device and auxiliary equipment costs represent flange-to-flange costs and include internals, electricals and controls. Instrumentation is not included because it is usually provided as an optional feature in most equipment costs. The typical cost factor for instrumentation can be considered as 10% of the equipment costs. Freight costs within the U.S. are generally 5% of the equipment cost. The purchased equipment costs, which includes the f.o.b. equipment cost, instrumentation, freight, and taxes, then becomes the basis for determining the direct and indirect installation costs. This is done by multiplying the appropriate factor shown in Table A.2.1-1 for each element by the purchased equipment cost.

### A.2.1.2 Cost of Control Device

The cost of the basic electrostatic precipitator, Venturi scrubber, and baghouse is presented earlier in Sections 4 through 6. The cost for SCAT, Calvert Collision Scrubber, charged spray scrubber, granular bed filter, and electrostatically augmented filter is estimated from material and labor costs in fabricating the control device.

### A.2.1.3 Auxiliary Equipment

The cost data in the following sections have been adjusted to 1981 fourth quarter U.S. dollars.

#### A.2.1.3.1 Fan

The fan size (and cost) are dependent on the gas flow rate and the developed pressure. The cost as a function of horse power is calculated according to the following equation (Viner and Sparks, 1981):

$$\text{Fan cost (\$)} = 300.9 (\text{Fan hp}) \quad (\text{A.2.1.3-1})$$

The equation for calculating fan brake horsepower is:

$$\text{Fan hp} = 1.886 \frac{Q_G (\Delta p) (\rho_G)}{\eta} \quad (\text{A.2.1.3-2})$$

where  $Q_G$  = volumetric flow rate,  $\text{Am}^3/\text{min}$

$\Delta p$  = pressure drop, cm W.C.

$\rho_G$  = gas density,  $\text{g}/\text{cm}^3$

$\eta$  = fan efficiency, fraction

Stenby et al. (1980) used  $\Delta p = 10.2$  cm W.C. (4" W.C.) for ESP's and 17.8 cm W.C. (7" W.C.) for bag houses. For Venturi and Calvert Collision scrubbers, the required " $\Delta p$ " from efficiency calculations can be used.

#### A.2.1.3.2 Screw Conveyors

Dust removal from bag houses and precipitators can be accomplished intermittently by manual means or continuously by screw conveyors. For applications having light dust concentrations, the collected dust is stored in the hoppers of the control device and periodically emptied through a valve for disposal by truck or local transport. For heavy dust loading, screw conveyors are generally used to remove the dust continuously as it is

Table A.2.1-1 Average Cost Factors for Estimating Capital Costs (Neveril et al., 1979).

	<u>Precipitator</u>	<u>Venturi Scrubber</u>	<u>Fabric Filter</u>
<u>Direct Costs</u>			
1) Purchased Equipment Costs			
a) Control device	As Req'd		
b) Auxilliary equipment	As Req'd		
c) Instruments and control	0.1		
d) Taxes	0.03		
e) Freight	0.05		
Total	1.00		
2) Installation Direct Costs			
a) Foundation and supports	0.04	0.06	0.04
b) Erection and handling	0.50	0.40	0.50
c) Electrical	0.08	0.01	0.08
d) Piping	0.01	0.05	0.01
e) Insulation	0.02	0.03	0.07
f) Painting	0.02	0.01	0.02
g) Site preparation	As Req'd		
h) Facilities and building	As Req'd		
Total	1.67	1.56	1.72
<u>Indirect Costs</u>			
3) Installation Indirect Costs			
a) Engineering and super- vision	0.2	0.10	0.10
b) Construction and field expense	0.2	0.10	0.20
c) Construction fee	0.1	0.10	0.10
d) Start up	0.01	0.01	0.01
e) Performance test	0.01	0.01	0.01
f) Model study	0.02		
g) Contingencies	0.03	0.03	0.03
Overall Total	2.24	1.91	2.17

collected. The cost of continuously removal equipment is based on the diameter of the screw conveyor and its overall length. The cost of a 30.5 cm (12") and a 20.3 cm (8") diameter screw conveyor can be estimated from the following equations (Neveril et al, 1979):

$$p_p = 1102.6 + 328.1 x \quad (\text{for } 30 \text{ cm dia.}) \quad (\text{A.2.1.3-3})$$

$$p_p = 933 + 319.4 x \quad (\text{for } 20.3 \text{ cm dia.}) \quad (\text{A.2.1.3-4})$$

where  $p_p$  = purchase price, \$  
 $x$  = conveyor length, m

#### A.2.1.3.3 Pump

Viner and Ensor (1981) gave the following equation for the cost of a pump with capacity up to 0.631 m<sup>3</sup>/s (10,000 gpm):

$$p_p = 28,270 (Q_L)^{0.457} \quad (\text{A.2.1.3-5})$$

where  $Q_L$  = liquid flow rate, m<sup>3</sup>/s

#### A.2.1.3.4 Duct

The cost of duct is estimated according to size, type, materials of construction, and plate thickness. Tables A.2.1.3-1 and A.2.1.3-2 present the prices for carbon steel and stainless steel straight duct and elbow. For "tees", the price is 1/3 the corresponding price of an elbow having the same diameter and thickness. For transitions, the price is 1/2 the corresponding elbow price based on the larger diameter (Neveril, 1979).

### A.2.2 Annual Operating Costs

The annual operating costs consists of direct and indirect operating costs and the capital charge. Table A.2.2-1 shows the basis for estimating the annual operating costs. The costs have been updated to December, 1981 U.S. dollars.

#### A.2.2.1 Indirect Operating Costs

The indirect operating costs include the cost of taxes, insurance, administration expenses, overhead, and capital charges. Taxes, insurance, and administration are collectively estimated at 4% of the capital costs while overhead charges can be considered as 80% of the labor charges for operation and maintenance of the system (Neveril, 1978). The annualized capital charges reflect the costs associated with capital recovery over the depreciable life of the system and can be determined as follows:

Table A.2.1.3-1 Straight Duct Price (Neveril et al., 1979)

Carbon Steel Straight Duct

<u>Thickness</u>	<u>Equation</u>
1.25 cm	$p_p = -18.67 + 573.46 \bar{d}$
0.95 cm	$p_p = -14.17 + 453.44 \bar{d}$
0.64 cm	$p_p = - 9.91 + 337.24 \bar{d}$
0.48 cm	$p_p = - 8.53 + 261.02 \bar{d}$
0.32 cm	$p_p = - 7.05 + 207.68 \bar{d}$

Stainless Steel Straight Duct

<u>Thickness</u>	<u>Equation</u>
1.25 cm	$p_p = -265.91 + 2751.18 \bar{d}$
0.95 cm	$p_p = -204.07 + 2069.09 \bar{d}$
0.64 cm	$p_p = -129.89 + 1436.55 \bar{d}$
0.48 cm	$p_p = -105.15 + 1095.54 \bar{d}$
0.32 cm	$p_p = - 20.41 + 729.72 \bar{d}$

$p_p$  = straight duct price, \$/m (December, 1981 U.S. dollars)  
 $\bar{d}$  = duct diameter, m

Table A.2.1.3-2 Elbow Duct Price (Neveril et al., 1979)  
 Price includes flanges.

Carbon Steel Elbow

<u>Thickness</u>	<u>Equation</u>
1.25 cm	$p_p = -24 + 1434.97 d + 1097.43 d^2$
0.95 cm	$p_p = -19 + 1225.32 d + 1028.84 d^2$
0.64 cm	$p_p = -12 + 1069.11 d + 548.71 d^2$
0.48 cm	$p_p = -14 + 973.29 d + 468.69 d^2$
0.32 cm	$p_p = 701 d + 402.39 d^2$

Stainless Steel Elbow

<u>Thickness</u>	<u>Equation</u>
1.25 cm	$p_p = 401 + 1860 d + 6401.7 d^2$
0.95 cm	$p_p = 293 + 1376.3 d + 4801.3 d^2$
0.64 cm	$p_p = 198 + 1120.8 d + 3338 d^2$
0.48 cm	$p_p = 183 + 1022.1 d + 2400.6 d^2$
0.32 cm	$p_p = 1105.7 d + 1607.3 d^2$

$p_p$  = elbow price, \$ (December, 1981 U.S. dollars)

$d$  = duct diameter, m

$$\text{Capital Recovery Cost} = (\text{capital costs}) \frac{i(1+i)^n}{(1+i)^n - 1} \quad (\text{A.2.2.1-1})$$

where  $i$  = annual interest rate, fraction  
 $n$  = capital recovery period

The average life of electrostatic precipitators and bag houses is about 20 years. The average life of Venturi scrubbers is about 10 years (Neveril et al., 1979). For average interest rates of 10% over a recovery period of 10 years, the annual capital charge is 16.28% of capital investment. It is 11.75% for a recovery period of 20 years.

#### A.2.2.2 Direct Operating Costs

Direct operating costs consist of direct expenses of labor and materials for operation and maintenance, the cost of replacement parts, utility costs, and waste disposal. The operating and maintenance labor costs depend on the duty factor of the plant or the number of shifts per year the control device is in operation. Table A.2.2-1 shows the labor required each shift for operation and maintenance.

The maintenance costs shown in Tables A.2.2-1 and A.2.2.2-1 are for general maintenance, such as replacing torn bags. For bag houses, in addition to this unscheduled bag replacement, bags are also replaced regularly according to bag life. Stenby et al. (1980) used a bag life for 2 years. Neveril et al. (1979) gave an average life of 1.5 years with a range of 0.3 to 5 years. In the present study, a bag life of 2 years is used.

##### A.2.2.2.1 Calculation of Electric Usage

The power requirements for the ESP transformer-rectifier (T-R), fan, ash removal system, hopper heater, and accessories are calculated from the following equations (Viner and Ensor, 1981).

$$\text{T-R power (kWh)} = \frac{\text{AIV (8760) (Duty factor)}}{0.6} \quad (\text{A.2.2.2-1})$$

$$\text{Fan (kWh)} = \frac{(8760) (\text{fan hp}) (0.746) (\text{Duty factor})}{\eta} \quad (\text{A.2.2.2-2})$$

Table A.2.2-1 Basis For Estimating Annual Operating Costs<sup>a</sup>  
(Neveril et al., 1979)

<u>Cost Component</u>	<u>Cost Factor</u>
<u>Direct Operating Costs</u>	
1. Operating Labor	
a. Operator	\$11.31/man-hour
b. Supervisor	15% of 1a
2. Maintenance	
a. Labor	\$12.45/man-hour
b. Material	100% of 2a
3. Replacement parts	As required
4. Utilities	
a. Electricity	\$0.062/kWh
b. Fuel Oil	\$0.26/l (\$1.00/gal)
c. Natural Gas	\$0.10/m <sup>3</sup> (\$2.85/1,000 ft <sup>3</sup> )
d. Water	\$0.040/m <sup>3</sup> (\$0.15/1,000 gal)
e. Steam	\$0.016/kg (\$7.25/1,000 lb)
f. Compressed air	\$0.001/m <sup>3</sup> (\$0.029/1,000 ft <sup>3</sup> )
5. Waste disposal	\$0.008-0.015/kg (\$7.2-14.4/ton)
<u>Indirect Operating Costs</u>	
6. Overhead	
7. Property Tax	
8. Insurance	
9. Administration	
10. Capital recovery cost	
<u>Credits</u>	
11. Recovered product	As required

Note: <sup>a</sup>December, 1981 U.S. dollars

$$\text{Hopper heater (kWh)} = (\text{no. of hopper}) (\text{heater power}) \\ (\text{duty factor}) (8760)$$

$$\text{Ash removal (kWh)} = (7.8 \times 10^{-3}) (8760) (A) (\text{duty factor})$$

$$\text{Accessories (kWh)} = (3.2 \times 10^{-3}) (8760) (A) (\text{duty factor})$$

where A = ESP plate area, m<sup>2</sup>  
 I = current density, A/m<sup>2</sup>  
 V = applied ESP voltage, kV  
 η = fan efficiency, fraction

The power requirements for the 1-R sets of the ESP are set by the operating point on the V-I curve. An assumed AC to DC conversion factor of 60% is used to calculate the total wattage. The number of hoppers required is determined by assuming a rate of 1 hopper for every 1,335 m<sup>2</sup> of ESP plate area. The heater power requirement is about 10-15 kW/hopper. The constant "8,760" in these equations is the number of hours in one year.

Equations for bag house requirements are derived from reports by Stenby et al. (1978) and Viner and Ensor (1981).

$$\text{Hopper heat (kWh)} = (\text{no. of modules})(\text{heater power}) \\ (8760)(\text{load factor}) \quad (\text{A.2.2.2-3})$$

$$\text{Ash removal(kWh)} = (0.538 \frac{\text{kW}}{\text{m}^3/\text{min}}) (8760 Q_G) (\text{duty factor}) \quad (\text{A.2.2.2-4})$$

$$\text{Accessories (kWh)} = (2.15 \times 10^{-3}) (8760A) (\text{duty factor}) \quad (\text{A.2.2.2-5})$$

$$\text{Reverse air fan (kWh)} = (0.008) (8760) (A) (\text{duty factor}) \quad (\text{A.2.2.2-6})$$

where Q<sub>G</sub> = gas flow rate, m<sup>3</sup>/min  
 A = bag area, m<sup>2</sup>

Stenby et al. (1978) reported power requirements of 15 kW/hopper for 16 modules and a total bag area of 1.01 x 10<sup>5</sup> m<sup>2</sup>. Therefore, 1 module contains 6,300 m<sup>2</sup>.

Power requirements for Venturi scrubbers are mainly due to blower and pump.

$$\text{Pump (kWh)} = (\text{pump hp}) (0.746) (8760) (\text{duty factor}) \quad (\text{A.2.2.2-7})$$

$$\text{fan (kWh)} = (\text{fan hp}) (0.746) (8760) (\text{duty factor}) \quad (\text{A.2.2.2-8})$$

Table A.2.2.2-1. Estimated Labor Hours Per Shift

Control Device	Operating Labor (man-hour/shift)	Maintenance Labor (man-hour/shift)
Fabric filters	2-4	1-2
Precipitators	0.5-2	0.5-1
Venturi scrubber	2-8	1-2

Neveril (1978) used a head of 30m (100 ft) for pump horse power calculations.

#### A.2.2.2.2 Disposal

The cost of waste disposal is \$0.008 to \$0.015/kg (Neveril et al., 1979). The amount of dust for disposal is determined as follows:

$$\text{kg dust} = C_p Q_G E (31.5) (\text{duty factor}) \quad (\text{A.2.2.2-9})$$

where  $C_p$  = inlet particle concentration,  $\text{m}^3/\text{min}$

$Q_G$  = gas flow rate,  $\text{m}^3/\text{min}$

$E$  = overall collection efficiency, fraction or percent

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