4.2.13 Rice Drying Process

A. Process Description--

Rice drying is a seasonal process that must be performed as soon as the raw rice is harvested. The rice must be taken to 1-2% moisture content to preserve it until it is consumed. Figure 4-50 shows the flow of rice through the dryer. The raw rice is conveyed to the top of hollow, double-wall cylindrical columns which are constructed of screen. The rice slowly moves down between the screen walls as warm air (∿120°F) passes from the center of the column through the rice to a large surrounding building. This building has six large, screen-covered, circular openings which vent the air back to the atmosphere. The openings are equipped with vacuum wands which rotate over the interior of the screen to remove chaff build-up.

The raw rice has 18-20% moisture initially. If it is dried too fast the rice will crack. Therefore after each pass through the dryer, the rice is stored until it reaches an equilibrium temperature and moisture content. The cycle is repeated until the rice reaches 1-2% moisture.

B. Particulate Test Set-up--

As shown in Figure 4-51, each of the six vent screens has the following features:

1. An area 18" in diameter at the center is solid sheet metal.
2. A 1" wide band 124" diameter is used for support.
3. Sixteen 1" wide bands used for support are evenly spaced over the circle to form pie shaped sections.
4. There is a large supporting screen with ∿1" hole space and 5/16" wire.

Taking the features into consideration, the flow area for each of the screens was calculated to be 118.4 ft^2. The velocity was measured by anemometer on each of the 32 sections of the screen as shown in Figure 4-51 for each of the six screens. One other problem complicated the calculation.

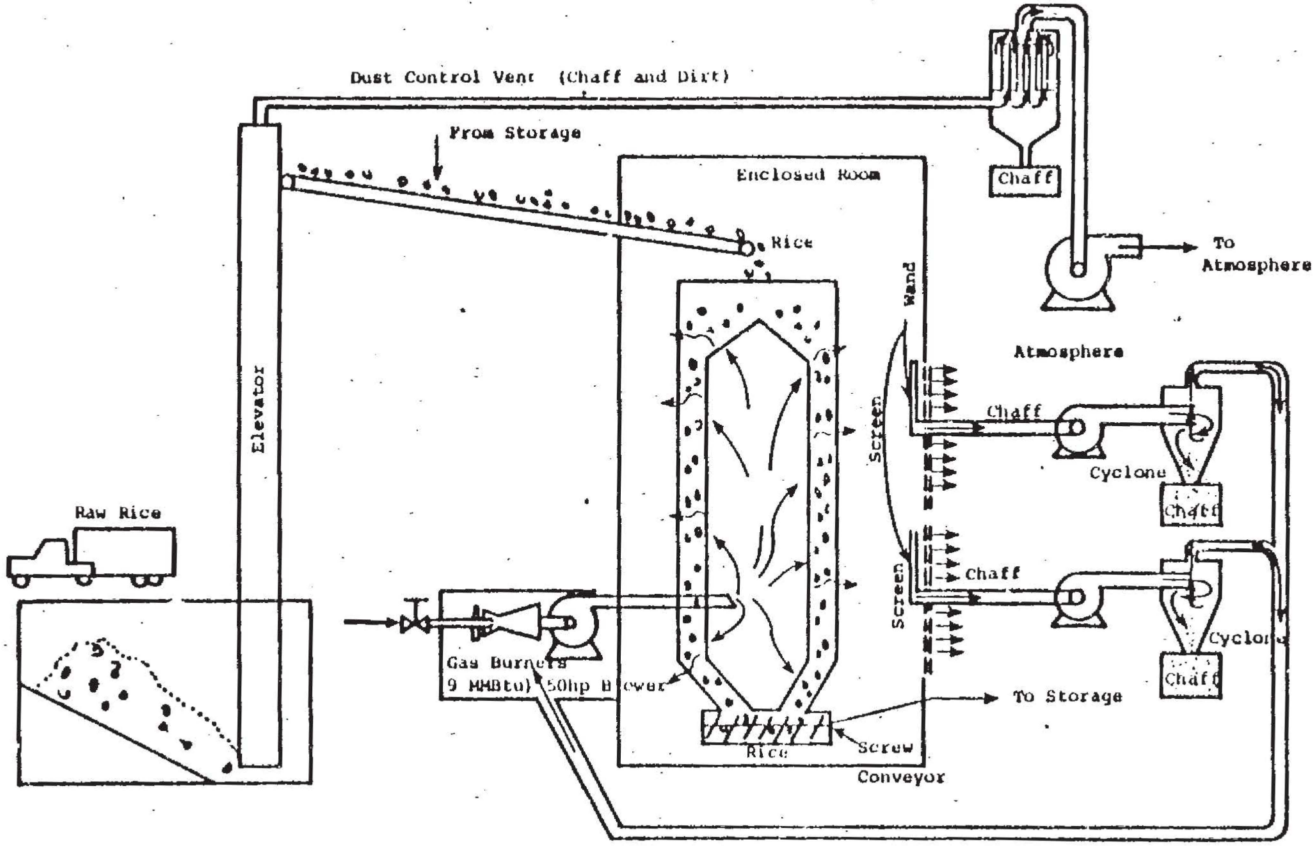
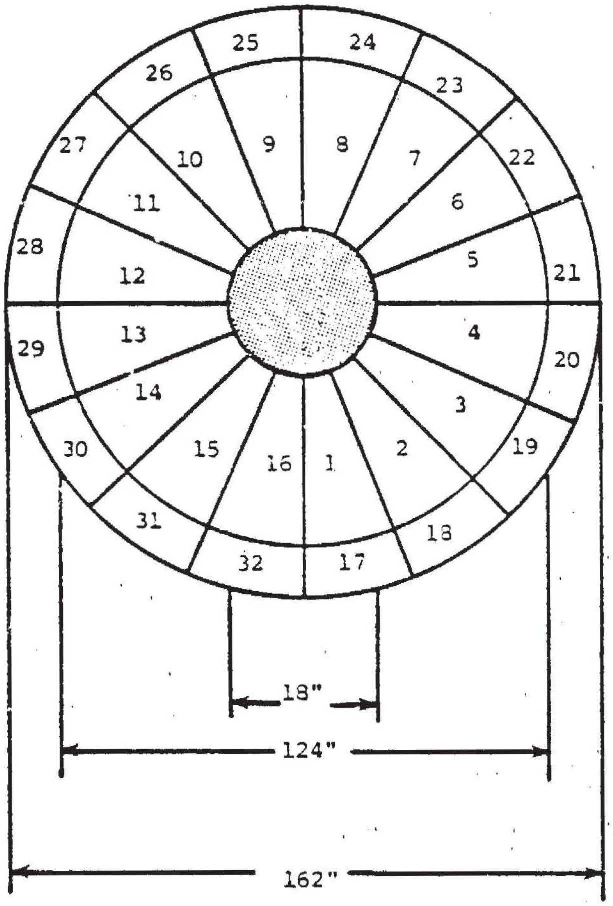


Figure 4-50. Rice dryer flow diagram (Test 4).



Center with no flow	=	1.76 ft^2
16 pie sections @ 5.13 ft^2	=	82.1 ft^2
16 trapezoid sections @ 3.81 ft^2	=	61.0 ft^2
Sub-total	=	143.1 ft^2
16 strips 1" wide x 64" long	=	-7.1 ft^2
1 strip 125" diameter	=	-2.7 ft^2
Large screen 1" squared (5/16" width wire) at 16.1 in^2/ft^2	=	-14.9 ft^2
Total area for flow for each screen	=	118.4 ft^2

Figure 4-51. Schematic of screen sections for rice dryer (Test 4).

Part of the screens had become clogged with chaff. For each section an estimate of the unclogged area was made. Thus to obtain the flow, in CFM, from the screens, the product of measured velocity X unclogged area (total area X estimated fraction unclogged) was summed for each of the 32 sections of the six screens.

The total flow from the screens was calculated to be 128,000 SCFM. The sample point was chosen where the flow was 11 ft/sec. A 1" nozzle was used with the larger SASS train and a 1/2" nozzle was used with the smaller Joy train.

C. Test Results--

The results of the tests (Test 4S and 4J) discussed in this section are listed in Table 4-1. Major elemental composition, sulfate, nitrate and carbon analysis were determined for all fractions of particulate catches which contained weight in excess of 100 mg. The details for these procedures are discussed in Section 3.2.2. Table 4-58 lists the results from this analysis.

D. Discussion of Results--

1. Particle size distribution--Figure 4-52 is a plot of particle size (μm) vs. accumulated weight percent, the latter plotted on a probability scale as explained in Section 3.2.3 B. Two answers are presented, one including the impinger catch, and the other ignoring it. Considering the nature of the exit air, it would seem that the effects of pseudo particulates would not be present. Therefore, the impinger catch was believed to be properly included in the measurements of the suspended particulates. The breakdown of the particle size distribution including the impinger catches is as follows:

	Percent of Particles			
	>10μm	10-3μm	3-1μm	<1μm
Test 4S	46	12	12	30
Test 4J	89	2	2	8

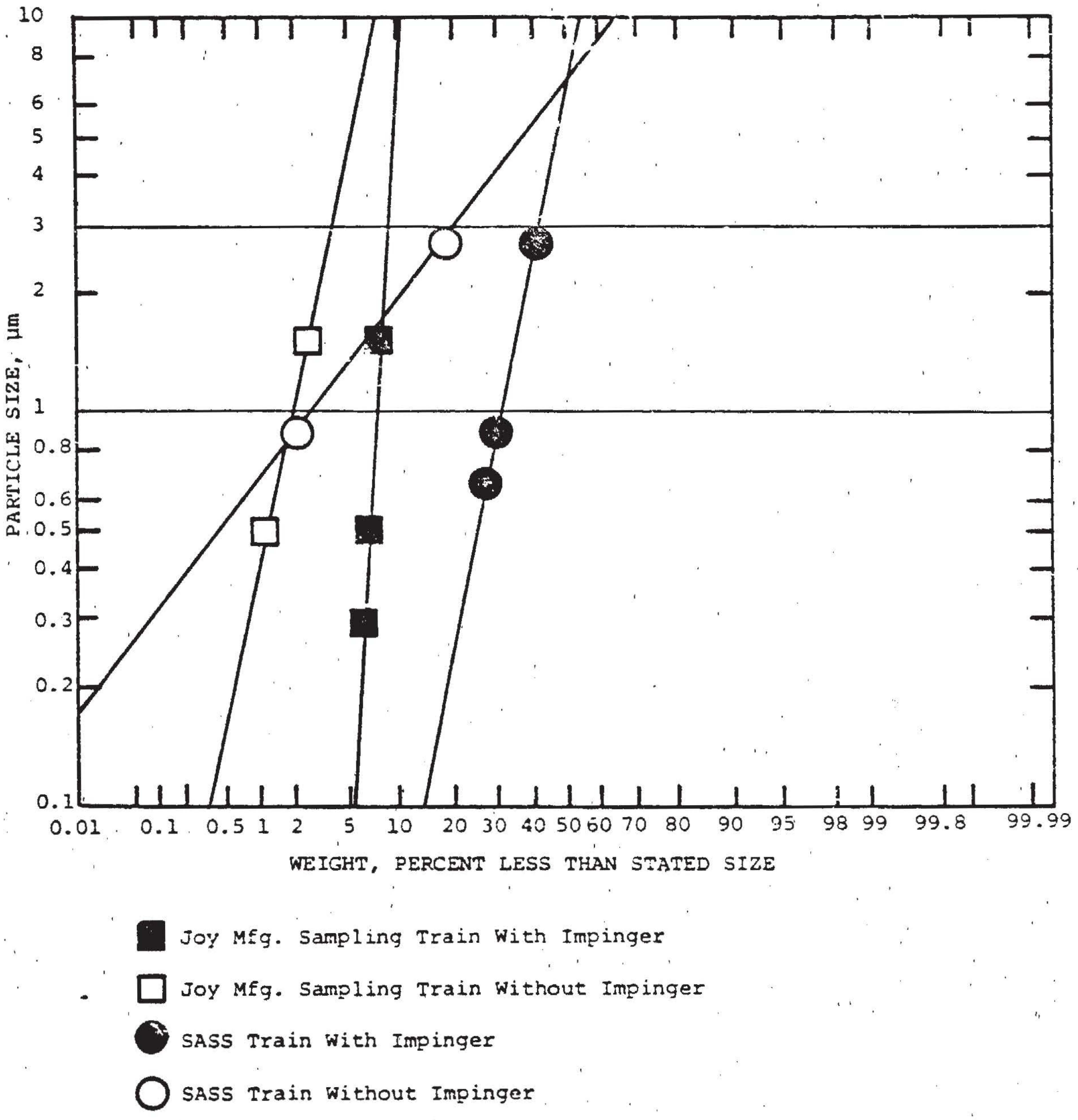


Figure 4-52. Particle size distribution (Test 4).

Since neither train could be sampled isokinetically, it is difficult to say which of the results are more correct. For developing emission profiles, the two distributions including the impinger were averaged.

2. Chemical composition--Table 4-58 lists the results from the chemical analysis of the particulate fraction for the tests (4J and 4S) discussed in this section. Silicon is the most abundant element, most likely in the form of SiO_2 from the field dust (approximately 70% SiO_2). XRF analysis for silicon is not as accurate as for other elements (see Section 3.2.2 B).

3. Emissions and emission factors--Emissions and emission factors can be listed with several different units. The following lists some of these emissions and factors.

	Test 4S	Test 4J
gr/DSCF	0.00935	0.0154
T/yr	3.5	5.8
lb/hr	10.03	16.5
lb/ton produced	0.1	0.16
lb/ton produced (Ref. 4-22)	0.3	0.3

TABLE 4-58. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR RICE DRYER (TEST 4)

	Joy	SASS		
SAMPLE #	10μm Cyclone 04J-2S	10μm Cyclone 04S-2S	3μm Cyclone 04S-3S	Impinger 04S-IC
WT. PERCENT OF CUT	74	56	11	9
XRF ANALYSIS				
Calcium	t	t	1.1	1.3
Chlorine	t	t		5.2
Chromium	t	t	t	t
Iron	t	t	3.7	5.1
Manganese	t	t	t	t
Nickel	t	t	t	t
Potassium	t	t	3.4	t
Silicon	10	12		
(Sulfur)			(<10)	(7.7)
Vanadium			t	
Zinc				t
TOTAL[1]	4	4	10	14
Sulfates, H_2O sol[2]	t	t	t	13
(Sulfur, from $SO_4^{=}$)[4]	(t)	(t)	(t)	(4)
Nitrate (H_2O sol)[2]			t	t
Total Carbon[3]	11	14	31	21
(Volatile Carbon)[3]	(11)	(13)	(29)	(21)
(Carbonates)[3]		t		
TOTAL ANALYZED	14	18	41	46
BALANCE	86	82	59	54
	100%	100%	100%	100%

t detected in concentration of <1%

[1] analyzed by x-ray fluorescence--Section 3.2.2 B

[2] analyzed by wet chemistry--Section 3.2.2 A

[3] analyzed by Oceanography carbon analyzer--Section 3.2.2 A

[4] calculated from sulfates (sulfur=sulfate/3) to compare with sulfur from XRF

[5] for values shown as X/Y, X is % of the element present and Y is the error (i.e. X% ± Y)

( ) not included in total--sulfur and sulfates are accounted for in sulfur XRF analysis and volatile carbon and carbonate are accounted for in total carbon

4.2.14 Carob Roasting

A. Process Description--

Carob roasting is a process very similar to coffee roasting. Carob, which is imported in the form of pods, must be cleaned, roasted, milled, and packaged before being sold. In a typical carob roasting operation (see Figure 4-53). the pods are freed of dust and chaff by dropping the pods into a current of air. The cleaned pods are then sent to a batch or continuous roaster. During the roasting, moisture is driven off, the pods swell, and chemical changes take place that give the roasted pods their color and flavor. When the pods have reached a certain color, they are quenched, cooled, and stored until they are ground in preparation for making carob candies.

B. Particulate Test Set-up--

Due to high temperatures encountered in sampling the stack gases from the after burner, there are no particulate data for the outlet of the after burner. The smaller sample train was used to sample the exhaust gas from the roaster to the after burner. The velocity profile in this duct is listed in Table 4-59. A 5/16" nozzle was used at Velocity Point #3.

C. Test Results--

The results of the test discussed in this section are listed in Table Elemental composition, sulfate, nitrate, and carbon analysis were determined for all fractions of particulate catches which contained weights in excess of 100 mg. The details for these procedures are discussed in Section 3.2.2. Table 4-60 lists the results from this analysis.

D. Discussion of Results--

1. Particle size distribution--Figure 4-56 is a plot of particle size (µm) vs. accumulated weight percent, the latter plotted on a probability scale as explained in Section 3.2.3 B. Two curves are presented, one including the impinger catch, and the other ignoring it. Considering the nature of the process, the material captured in the impinger is mostly condensibles from the

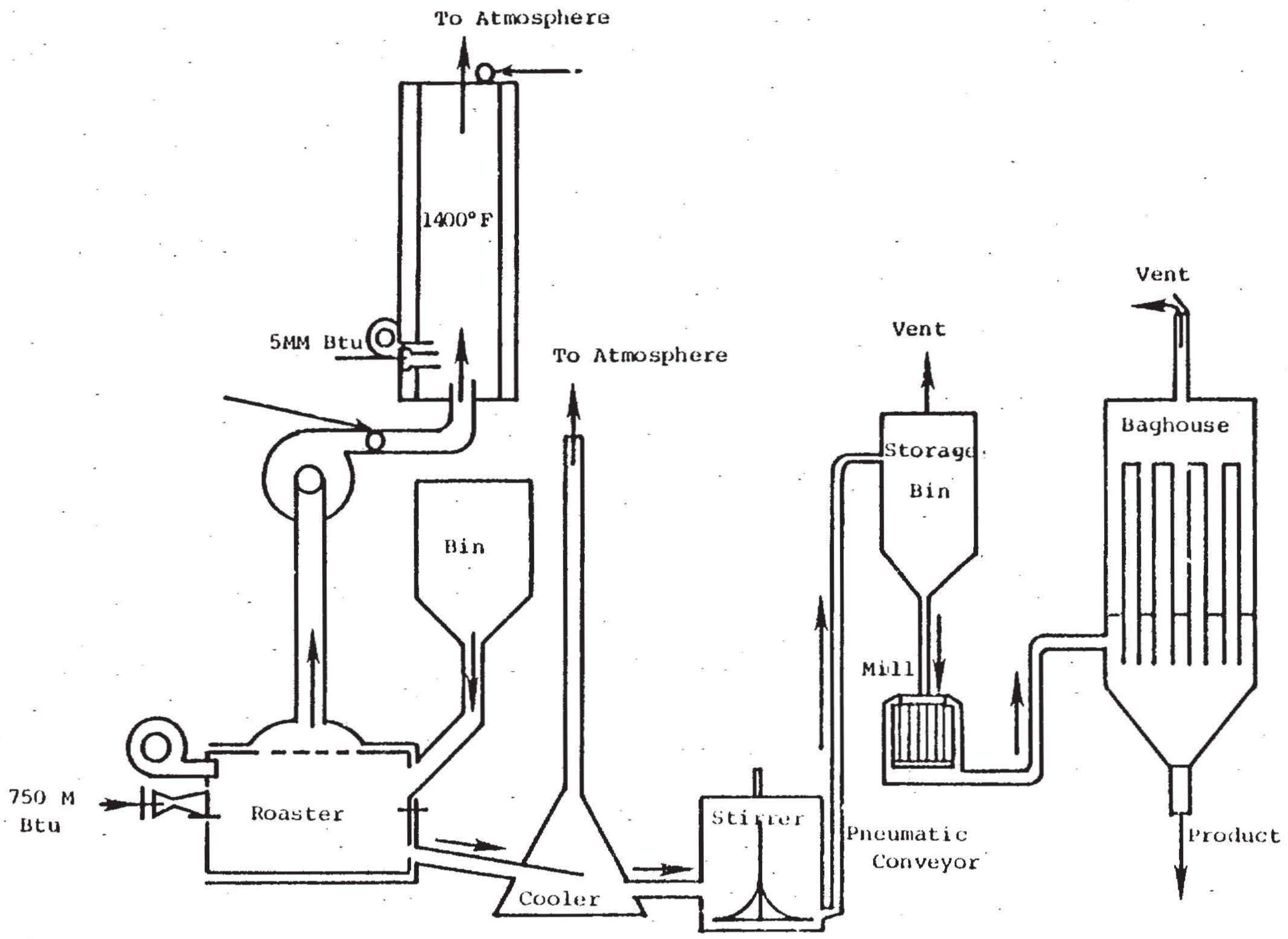
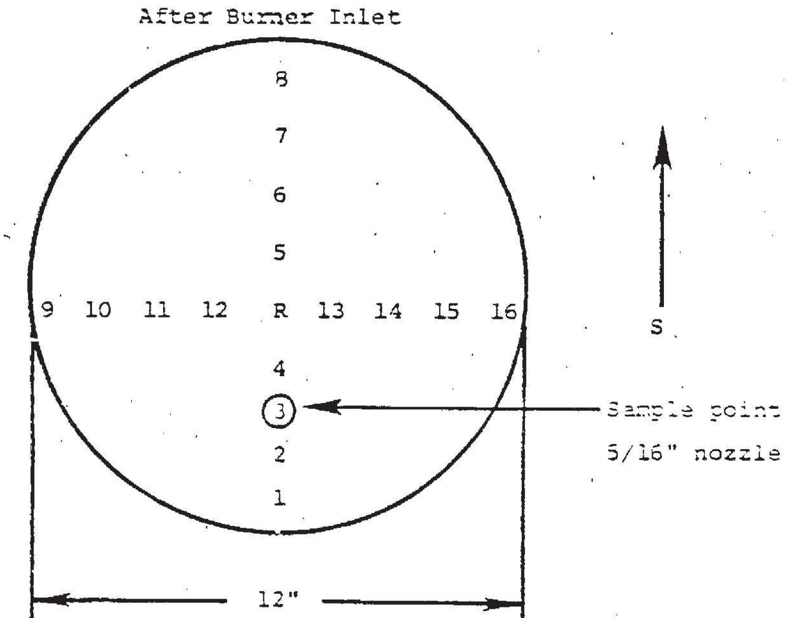


Figure 4-53. Food processing--carob roasting (Test 37)

TABLE 4-59. VELOCITY PROFILE--CAROB ROASTING (TEST 37)



Temperature: 86°F

Static Pressure: -1.9" H_2O

Distance from Edge of Duct	Velocity Point #	ft/sec	Point #	ft/sec
0.4"	1	40.6	9	40.6
1.25	2	38.9	10	38.9
2.3	3	39.5	11	35.8
3.8	4	38.3	12	38.9
6	R	38.9	R	38.9
8	5	40.6	13	39.5
9.7	6	41.7	14	38.9
10.7	7	41.7	15	40.6
11.6	8	41.7	16	41.7

Average 39.5 ft/sec
1773 SCFM

distillation that is occurring during the roasting. Therefore, the impinger catch was believed to be properly not included in the measurements of the suspended particulates. The breakdown of the particle size distribution with and without including the impinger catch is as follows:

	Percent of Particles			
	>10µm	10-3µm	3-1µm	<1µm
Without	97	0.5	0.5	2
With	38	1.0	1.0	60

However, due to the small amount of material collected in the three and one µm cyclones, it is felt that this distribution may not be representative and, also due to the high operating temperature of the sampling train oven (400°F), the sample may have been chemically changed or cooked in the cyclone. This would also account for the large weight in the impinger catch.

2. Chemical composition--Table 4-60 lists the results from the chemical analysis of the particulate fraction for the test discussed in this section. Carbon was found to be the most abundant elemental. All other elementals detected were in concentrations of less than one percent.

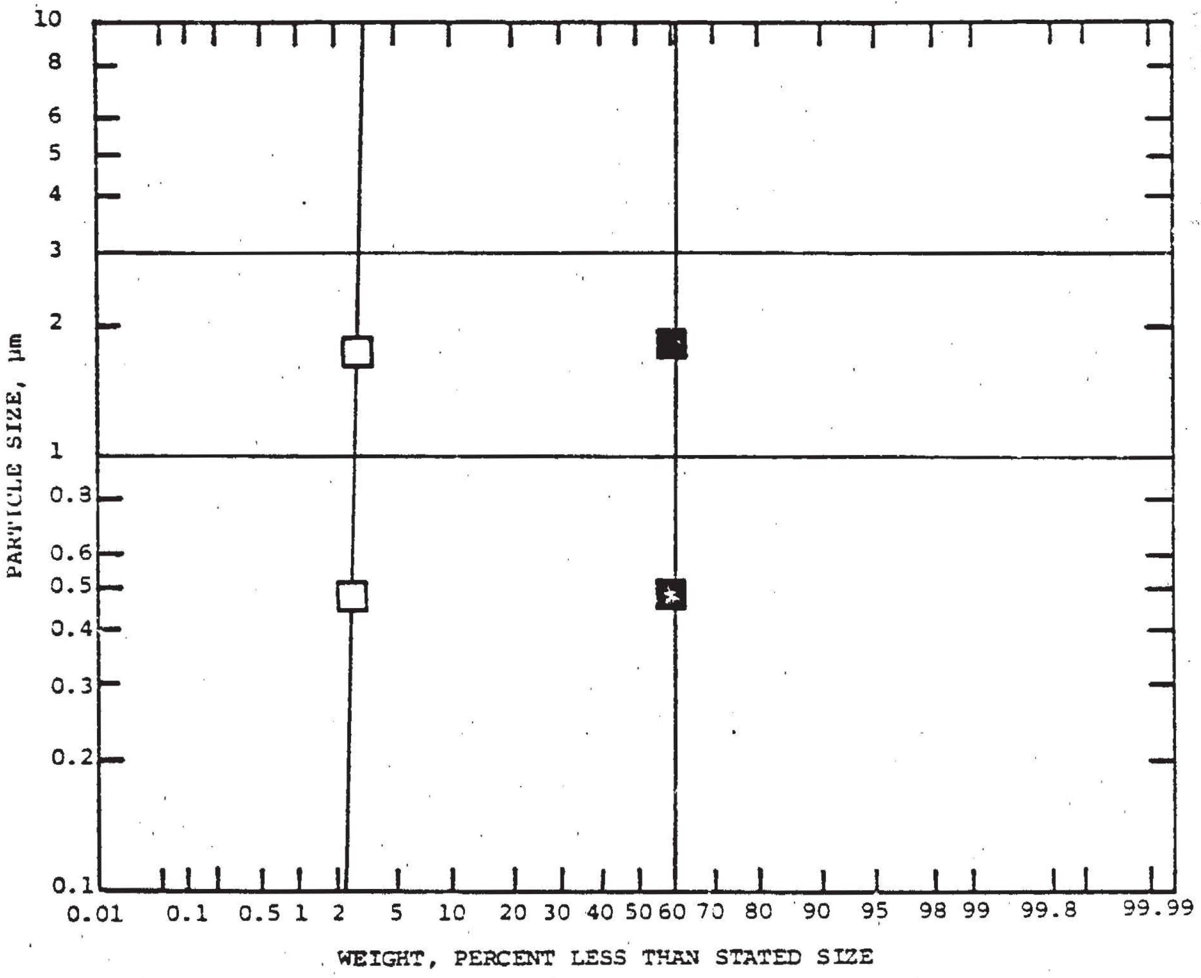
3. Emissions and emission factors--Emissions and emission factors can be listed with several different units. The following lists some of these emissions and factors.

	Uncontrolled
gr/DSCF	0.0711
T/yr	2.0
lb/hr	2.0
lb/ton produced	6.0
lb/ton produced (Ref. 25)	7.6

TABLE 4-60. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR CAROB ROASTING OPERATION (TEST 37)

SAMPLE #	Joy 10µm Cyclone 37J-2S	Joy Impinger 37J-IC
WT. PERCENT OF CUT	36	46
XRF ANALYSIS		
Calcium	t	
Iron	t	
Potassoum	t	
(Sulfur)	(<4)	(<2)
TOTAL[1]	2	
Sulfates, H_2O sol[2]		(t)
(Sulfur, from $SO_4^=$)[4]		t
Nitrate (H_2O sol)[2]	t	t
Total Carbon[3]	34	24
(Volatile Carbon)[3]	(33)	(22)
(Carbonates)[3]		
TOTAL ANALYZED	36	24
BALANCE	64	76
	100%	100%

t	detected in concentration of <1%
1	analyzed by x-ray fluorescence--Section 3.2.2 B
2	analyzed by wet chemistry--Section 3.2.2 A
3	analyzed by Oceanography carbon analyzer--Section 3.2.2 A
4	calculated from sulfates (sulfur=sulfate/3) to compare with sulfur from XRF
5	for values shown as X/Y, X is % of the element present and Y is the error (i.e. X% ± Y).
( )	not included in total--sulfur and sulfates are accounted for in sulfur XRF analysis and volatile carbon and carbonate are accounted for in total carbon



■ Joy Mfg. Sampling Train With Impinger

☐ Joy Mfg. Sampling Train Without Impinger

Figure 4-54. Particle size distribution for carob roasting operation (Test 37)

METAL FABRICATION

4.2.15 Steel Heat Treating

A. Process Description (Ref. 4-26)--

Heat treating involves the carefully controlled heating and cooling of solid metals and alloys for effecting certain desired changes in their physical properties. In general, the methods used to heat treat both ferrous and nonferrous metals are fundamentally similar. These methods include hardening, quenching, annealing, tempering, normalizing ferrous metals, and refining grain of non-ferrous metals. Also included in the category of heat treating are the various methods of case hardening steels by carburizing, cyaniding, nitriding, flame hardening, induction hardening, carbonitriding and siliconizing.

Figure 4-55 shows the type of heat treating equipment tested in this study. The steel to be treated is dipped into a tank of liquid salt at 1620°F until heat treatment is complete. Then it is quenched in water and dried in a natural gas flame. Particulate emissions from this type of heat treater are mostly caused by molten salt spray.

B. Particulate Test Set-up--

Two sampling trains were used simultaneously to sample the inlet and exit of the baghouse as shown in Figure 4-55. Table 4-61 lists the velocity profile in the inlet and outlet duct. A 3/8" nozzle was used at Velocity Point #3 with the smaller (Joy) sample train on the inlet duct and a 9/16" nozzle was used at Velocity Point #3 with the larger (SASS) sample train on the rectangular (42"x57") outlet duct. Due to one section of the baghouse being open to the atmosphere during the test, a higher flow was observed for the outlet than for the inlet duct.

C. Test Results--

The results of the tests discussed in this section are listed in Table

Elemental composition, sulfate, nitrate, and carbon analysis were determined for all fractions of particulate catches which contained weights in excess of 100 mg. The details for these procedures are discussed in Section 3.2.2.

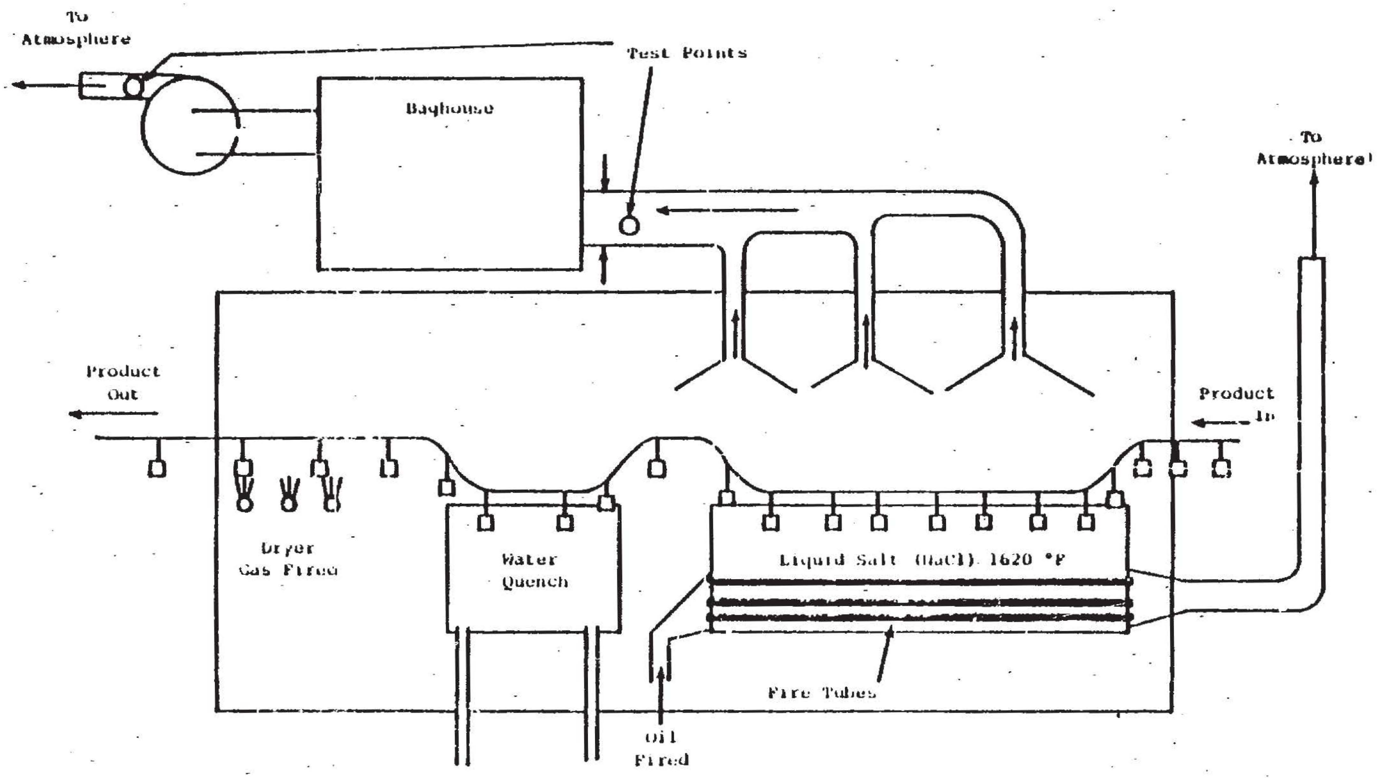
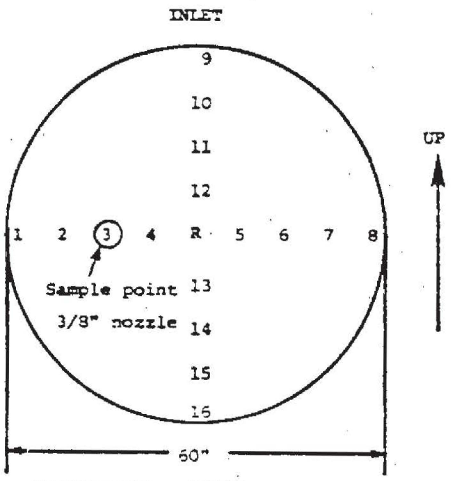


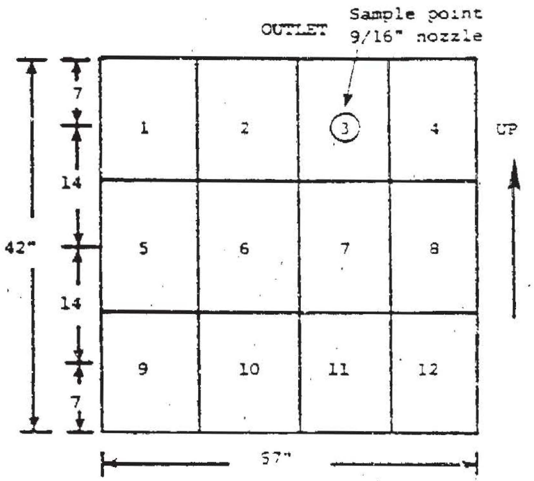
Figure 4-55. Steel heat treating process.

TABLE 4-61. VELOCITY PROFILE-STEEL HEAT TREATING (TEST 14)



Temperature: 175°F

Static Pressure: -0.25



Temperature: 126°F

Static Pressure: +0.2" H_2O

Distance from end of port	Velocity			
	Point #	ft/ sec	Point #	ft/ sec
4"	1	22.0	9	21.2
4-3/8	2	22.7	10	21.2
13-5/8	3	22.0	11	22.0
21-1/4	4	2.12	12	21.2
32	R	23.7	R	22.9
42-3/4	5	21.2	13	21.2
50-3/8	6	22.9	14	22.9
55-5/8	7	21.2	15	21.2
60	8	21.2	16	19.3

Average: 21.8 ft/sec

20994 SCFM

Distance from end of port	Velocity	
	Point #	ft/ sec
9	1	65.5
23-1/4	2	59.2
37-1/2	3	63.2
51-3/4	4	80.0
9	5	64.7
23-1/4	6	52.5
37-1/2	7	56.5
51-3/4	8	70.2
9	9	61.6
23-1/4	10	55.3
37-1/2	11	56.2
51-3/4	12	58.3

Average: 51.8 ft/sec

45791 SCFM

D. Discussion of Results--

1. Baghouse efficiency--The efficiency of a control device is defined as

$$\text{efficiency} = [(\text{mass out} - \text{mass in})/\text{mass in}] \times 100\%$$

using the emission mass rate in lb/hr for inlet and outlet,

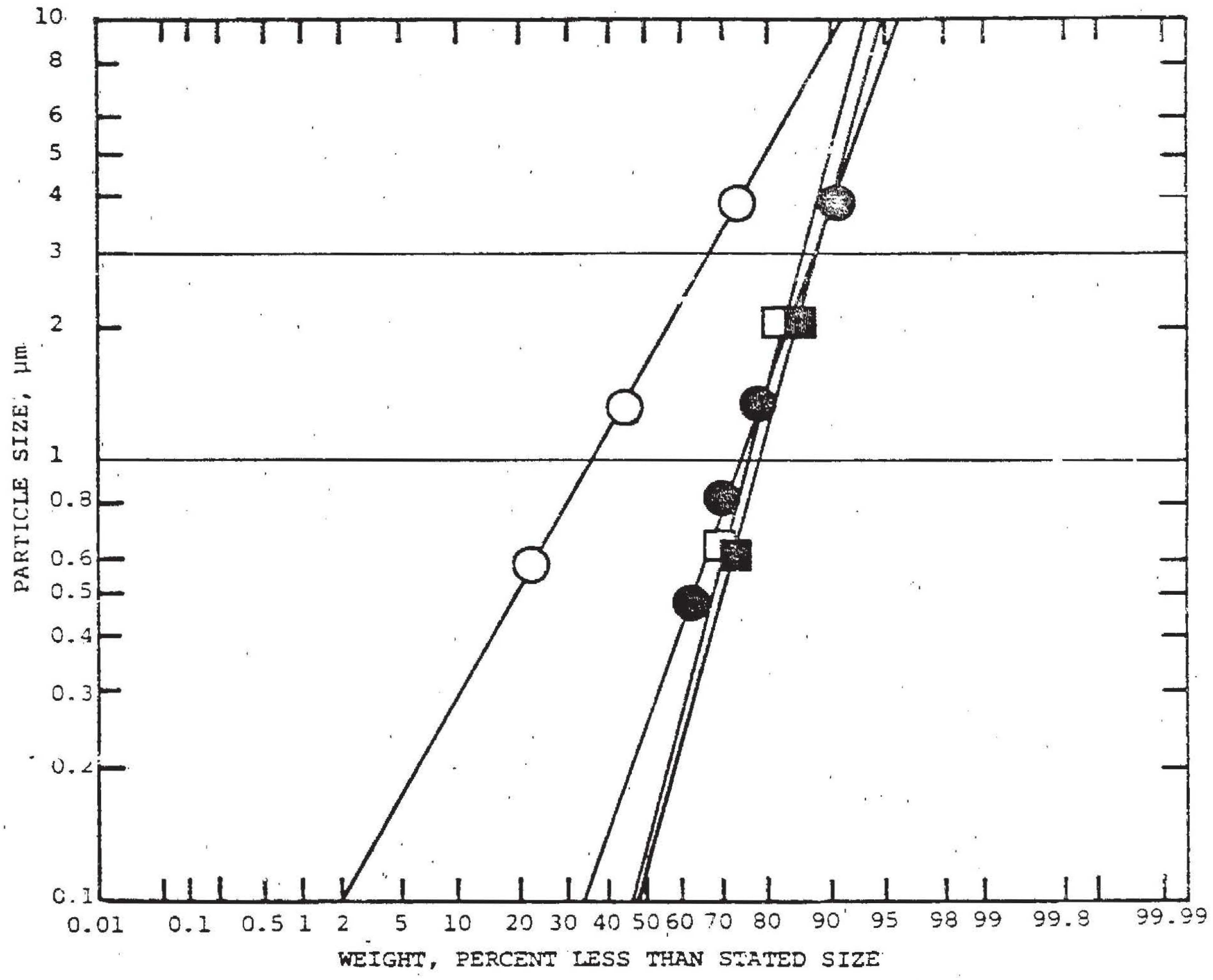
$$\text{efficiency} = [(10.5 - 1.1)/10.5] \times 100\% = 90\%$$

2. Particle size distribution--Figure 4-56 is a plot of particle size (µm) vs accumulated weight percent, the latter plotted on a probability scale as explained in Section 3.2.3 B. Two sets of curves are presented, one including the impinger catch and the other ignoring it. Considering that almost all the particulate material is caused from salt splash, it is believed that the impinger catch should be included in the measurements of the suspended particulates for size distribution. The breakdown of the particle size distribution including the impinger catch is as follows:

	Percent of Particles			
	>10µm	10-3µm	3-1µm	<1µm
Test 14J inlet	4	8	14	74
Test 14S outlet	5	7	10	76

The mean particle size based on the curves in Figure 4-56 is a 0.15µm for the inlet and about 0.25µm for the outlet. These are essentially the same values, considering the accuracy of the data. Normally the mean particle size should be higher for a baghouse inlet than the outlet. If mean particle size is the same, as in this case, it might indicate that there was a bag leak which might also explain the relatively low collection efficiency (90%) for a baghouse.

3. Chemical Composition--Table 4-62 lists the results from the chemical analysis of the particulate fraction for each of the tests discussed in this section. As would be expected, chlorine is the most abundant element in each particulate fraction. Potassium, sulfur, carbon, and barium are next abundant. Sulfates concentration dominated the impinger catch. Iron, nickel, molybdenum and manganese seemed a little high in the impinger catch. This



■	Joy Mfg. Sampling Train With Impinger	Inlet
☐	Joy Mfg. Sampling Train Without Impinger	
●	SASS Train With Impinger	Outlet
○	SASS Train Without Impinger	

Figure 4-56. Particle size distribution for steel heat treating operation (Test 14)

TABLE 4-62. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR STEEL HEAT TREATING (TEST 14)

	Inlet			Outlet
SAMPLE #	10µm Cyclone 14J-2S	3µm Cyclone 14J-3S	14µm Cyclone 14J-4S	Impinger 14S-IC
WT. PERCENT OF CUT	14	11	38	55
XRF ANALYSIS				
Barium	2/0.3	t	t	
Calcium				t
Chlorine	30/10	38/10	30/10	8.9/3
Chromium	t			1.7/0.2
Cobalt				t
Iron	t	t	t	9.3/1
Manganese				t
Molybdenum				t
Nickel				2.2/0.3
Potassium	10/3	14/5	13/4	t
(Sulfur)	(<6)	(<4)	(<2)	(15/5)
TOTAL	42	52	43	22
Sulfates, H_2O sol[2]	t	t	t	32
(Sulfur, from $SO_4^{=}$)[4]	(t)	(t)	(t)	(10.7)
Nitrate (H_2O sol)[2]		t	t	3.8
Total Carbon[3]	5	5	2.7	8.1
(Volatile Carbon)[3]	(5)	(5)	(1.37)	(6.6)
(Carbonates)[3]			t	
TOTAL ANALYZED	47	57	46	66
BALANCE	52	42	53	34
	100%	100%	100%	100%

t	detected in concentration of <1%
1	analyzed by x-ray fluorescence--Section 3.2.2 B
2	analyzed by wet chemistry--Section 3.2.2 A
3	analyzed by Oceanography carbon analyzer--Section 3.2.2 A
4	calculated from sulfates (sulfur=sulfate/3) to compare with sulfur from XRF
5	for values shown as X/Y, X is % of the element present and Y is the error (i.e. X% ± Y)
( )	not included in total--sulfur and sulfates are accounted for in sulfur XRF analysis and volatile carbon and carbonate are accounted for in total carbon

could be from stainless steel contamination, caused from sulfuric acid and hydrochloric acid attack. Potassium and barium tended to favor the larger particles. Nitrates in smaller sizes showed up mainly in the impinger catch.

4. Emissions and emission factors--Emissions and emission factors can be listed with several different units. The following lists some of these emissions and factors.

Units	Test 14J (inlet)	Test 14S(outlet)
gr/DSCF	0.0593	0.0028
T/yr	21.6	2.2
lb/hr	10.58	1.1
lb/ton processed	0.14	0.01

4.2.16 Abrasive Blasting

A. Process Description (Ref. 4-17)--

Abrasive blast cleaning is the operation of cleaning or preparing a surface by forcibly propelling a stream of abrasive material against the surface. Blast cleaning operations may be classified according to: (1) the abrasive material used, (2) the method of propelling the abrasive, and (3) the equipment used to control the abrasive stream or move the articles being cleaned into the abrasive stream.

The oldest and most widely used device to confine and control the blast is the blasting room (Figure 4-57) which consists of an enclosure with the operator inside manipulating the blast from a hose. Blasting rooms vary widely in their construction. One popular design is the all-steel, prefabricated room with floor grating and a completely automatic abrasive recovery system. These systems usually use specialized or other abrasives such as carbide and walnut shells and often have monorail conveyors, rail cars, or rotating tables to aid the operator in handling the objects, which are usually large and heavy. Figure 4-57 shows the blasting room setup tested on this program. The grit used was aluminum oxide (Al_2O_3) and the metal being blasted was heat treated stainless steel.

B. Particulate Test Set-up--

Two sampling trains were used simultaneously to sample the inlet and outlet of the baghouse. The inlet station was located on the horizontal duct (36" diameter) approximately five ft. from the baghouse. The rectangular outlet station (35" x 39") was located about 3 ft. above the blower. The velocity profile in both inlet and outlet ducts are listed in Table 4-63 The larger sample train was used on the outlet duct at velocity point #7 with a 5/8" nozzle, and the smaller sample train was used on the inlet duct at velocity point #3 with a 5/16" nozzle.

C. Test Results--

The results of the tests (Test 34J and 34S) discussed in this section are listed in Table 4-1. Elemental composition, sulfate, nitrate, and carbon analysis were determined for all fractions of particulate catches which contained weights in excess of 100 mg. The details for these procedures are discussed in Section 3.2.2. Table 4-64 lists the results of this analysis.

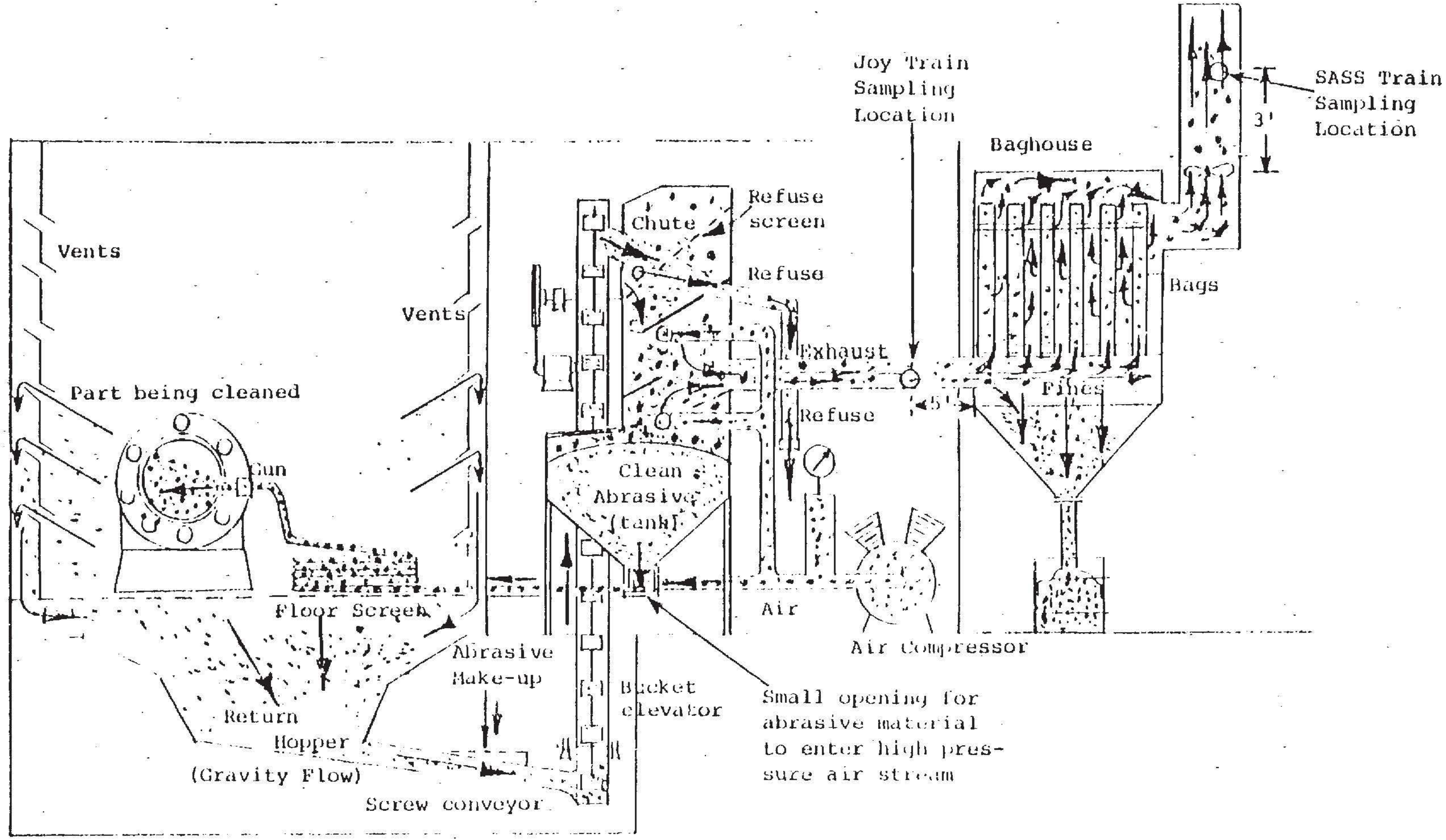
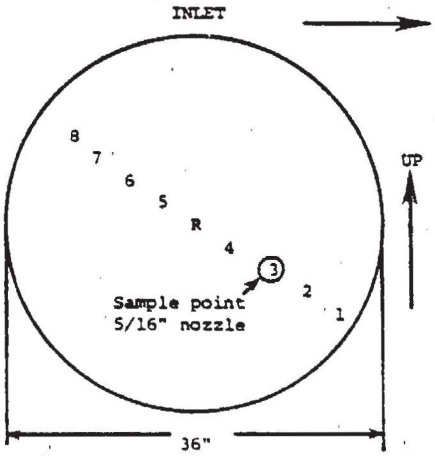


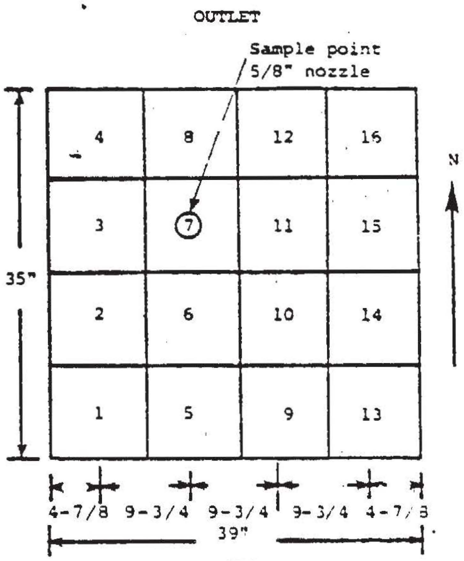
Figure 4-57. Abrasive blast metal cleaning.

TABLE 4-63. VELOCITY PROFILE FOR ABRASIVE BLASTING (TEST 34)



Temperature: 66°F

Static Pressure: -0.5" H_2O



Temperature: 72°F

Static Pressure: +2.1" H_2O

Distance from Edge of Duct (inches)	Velocity		Distance from Edge of Duct (inches)	Velocity			
	Point#	ft/sec		Point #	ft/sec	Point #	ft/sec
1-1/8	1	23.0	4-3/8	1	35.4	9	24.1
3-3/4	2	25.8	13-1/8	2	35.4	10	15.0
7	3	26.6	21-7/8	3	44.4	11	20.1
11	4	27.4	30-5/8	4	66.9	12	63.5
18	R	27.4	4-3/8	5	20.1	13	6.7
24-1/2	5	28.2	13-1/8	6	16.4	14	14.9
29	6	28.0	21-7/8	7	31.5	15	14.9
32-1/4	7	29.7	30-5/8	8	65.5	16	0
34-7/8	8	26.6					

Average: 27.1 ft/sec
11635 SCFM

Average: 29.6 ft/sec
16509 SCFM

TABLE 4-64. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR ABRASIVE BLASTING (Test 34)

SAMPLE #	10μm Cyclone 34J-2S	3μm Cyclone 34J-3S	1μm Cyclone 34J-4S
WT. PERCENT OF CUT	97	1.3	0.09
XRF ANALYSIS			
Chromium	t	t	t
Copper		<0.1	<0.1
Iron	t	18/2	15/2
Manganese	t	t	t
Molybdenum		t	t
(Sulfur)	(<3)	(<3)	(<4)
Titanium	t	2.3/0.3	2.6/0.3
Zirconium	t	t	t
TOTAL[1]	1.8	22	20
Sulfates, H_2O sol[2]		t	
(Sulfur, from $SO_4^=$)[4]		(t)	
Nitrate (H_2O sol)[2]	t	t	t
Total Carbon[3]	1.0		
(Volatile Carbon)[3]			
(Carbonates)[3]	t		
TOTAL ANALYZED	3	22	20
BALANCE (Primarily Al_2O_3)	97	78	80
	100%	100%	100%

t detected in concentration of <1%

[1] analyzed by x-ray fluorescence--Section 3.2.2 B

[2] analyzed by wet chemistry--Section 3.2.2 A

[3] analyzed by Oceanography carbon analyzer--Section 3.2.2 A

[4] calculated from sulfates (sulfur=sulfate/3) to compare with sulfur from XRF

[5] for values shown as X/Y, X is % of the element present and Y is the error (i.e. X% ± Y)

( ) not included in total--sulfur and sulfates are accounted for in sulfur XRF analysis and volatile carbon and carbonate are accounted for in total carbon

D. Discussion of Results--

1. Baghouse efficiency--Using the mass loading (lb/hr) for both inlet and outlet to the baghouse, the efficiency was calculated to be 99.9% from the equation: efficiency = [(mass out - mass in)/mass in] x 100%.

2. Particle size distribution--Figure 4-58 is a plot of particle size (μm) vs accumulated weight percent, the latter plotted on a probability scale as explained in Section 3.2.3B. Two sets of curves are presented, one including the impinger catch, and the other ignoring it. Considering that nearly all the particulate material in the ducts are aluminum oxide (Al_2O_3), it would seem that the effects of pseudo particulates would not be present. Therefore, the impinger catch was believed to be properly included in the measurements of the suspended particulates. The breakdown of the particle size distribution including the impinger catch is as follows:

	Percent of Particles			
	>10μm	10-3μm	3-1μm	≤1μm
Test 34J (inlet)	93	3.5	1.7	1.8
Test 34S (outlet)	14	6	6	74

The mean particle size for the inlet is >100μm and the mean size for the outlet is 0.6μm.

3. Chemical composition--Table 4-64 lists the results from the chemical analysis of the particulate fraction for the tests discussed in this section. Unfortunately, the most abundant species, aluminum oxide Al_2O_3, was not able to be detected by XRF analysis. Iron (iron oxide) found in the cyclones was significant in quantity (15-18%). Approximately 2% titanium and ~3% sulfur was detected. The titanium is attributed to residual materials from parts being grit blasted in that facility previously.

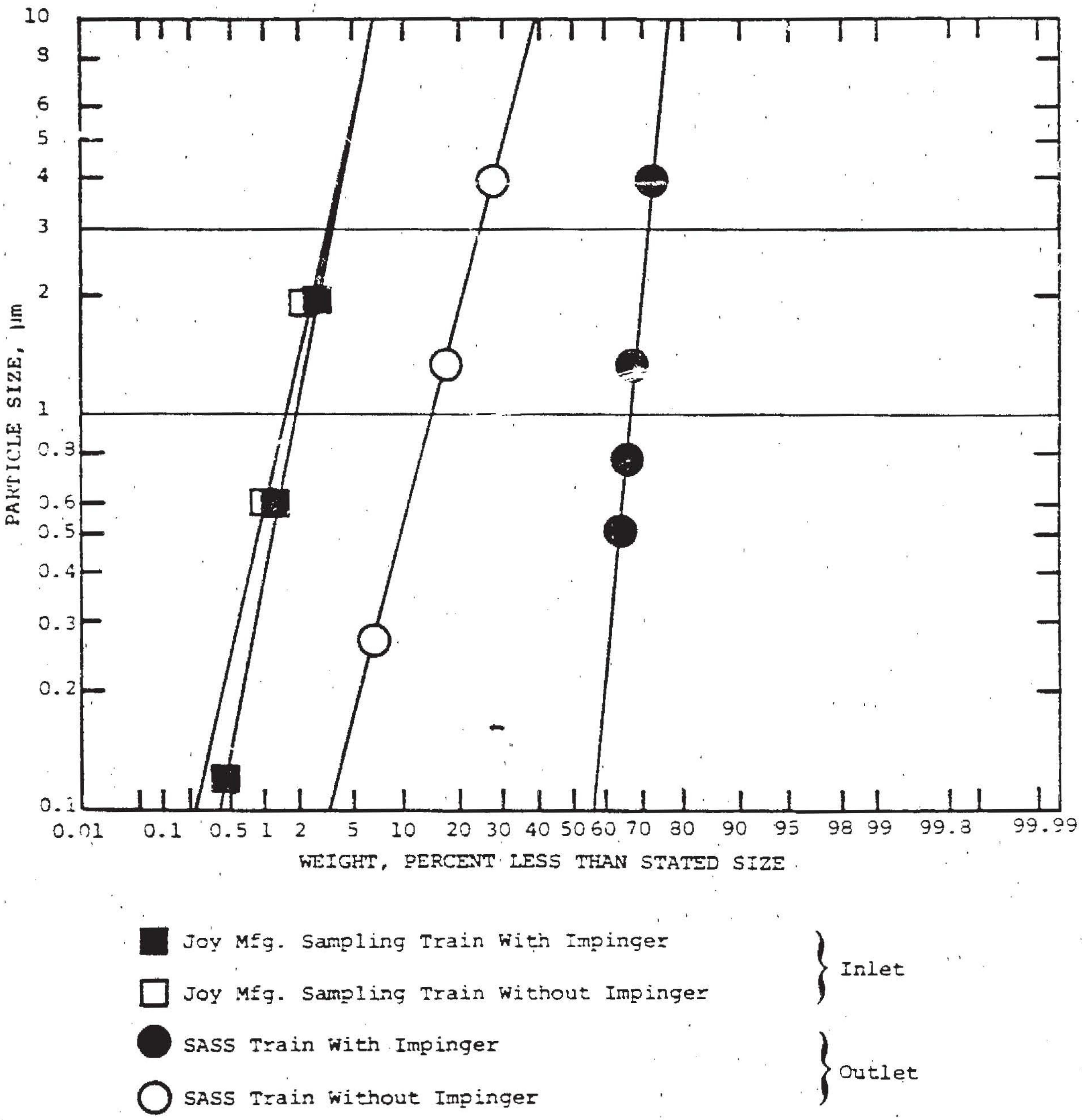


Figure 4-58. Particle size distribution for abrasive blasting (Test 34)

4. <u>Emissions and emission factors</u>--Emissions and emission factors can be listed with several different units. The following lists some of these emissions and factors.

	Test 34J (uncontrolled)	Test 34S (controlled)
gr/DSCF	1.922	0.0009
T/yr	99.4	0.07
lb/hr	191.2	0.125
lb/ton processed	1530	1.04

4.2.17 Aluminum Foundry (Reverberatory Furnace)

A. Process Description--

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

Reverberatory furnaces, as shown in Figure 4-59, of 20-50 ton holding capacity are common. Usually one heat is produced in a 24-hour period; however, the time per heat in different shops varies from four hours to as much as 72 hours. This type of furnace is commonly used to melt a variety of scrop. The materials charged, method of charging, size and design of the furnace, heat input, and fluxing, refining, and alloying procedures all have some influence on the time required to complete a heat. After the charge is completely melted, alloying ingredients are added to adjust the composition to required specifications. Large quantities of fluxes are added when scrap of small size and low grade is melted. The flux in some cases may amount to as much as 30% of the weight of scrap charged for the older type furnaces (Ref. 4-28). However, for the newer type of furnace tested here very little flux is used. The reverberatory furnace tested on this program is shown in Figure 4-59. It was producing aluminum for casting billet for extruding. The furnace had no emission controls. Premixed gas and air enter the furnace and produce a long rotating flame which melts the charged material. The combustion products (stack gas) are drawn up the stack by natural draft. Part way up the stack is an opening which allows airto be pulled in the gases. This partially cools the 1,500 °F stack gas. Also in this open section is an air damper which reduces the natural draft forces and thus help hold the heat in the furnace.

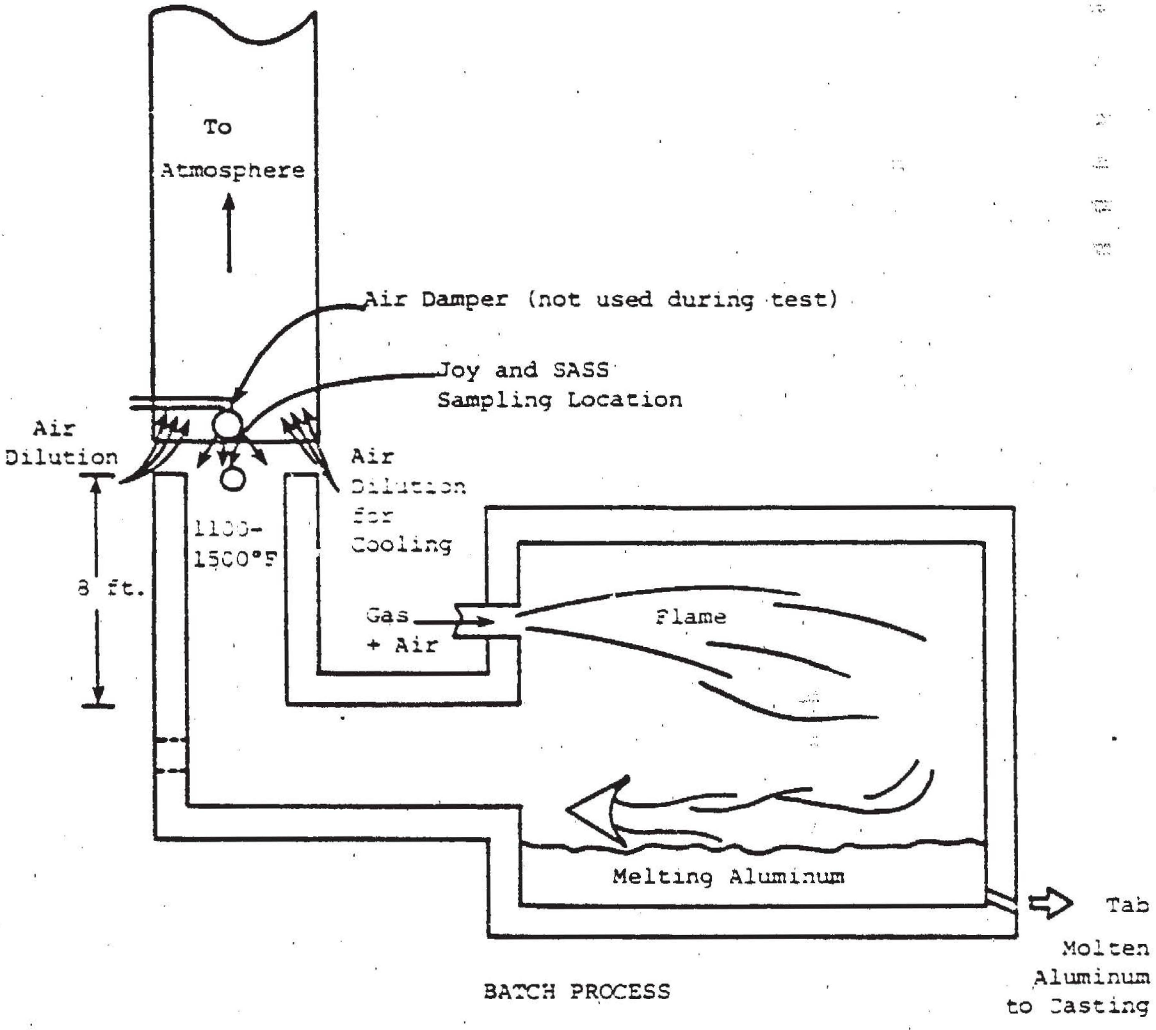


Figure 4-59. Thirty-five ton aluminum reverberatory melting furnace.

B. Particulate Test Setup--

Two sampling trains were used simultaneously to sample the stack gases at the same location to obtain an accuracy assessment of the two trains and to have more reliable data. The location of the test station was on the open (air dilution) section of the stack just below the air damper as shown in Figure 4-59. A 1-1/4" nozzle was used with the larger SASS train and a 3/4" nozzle was used with the smaller Joy train. The velocity profile in the stack for high firing and for low firing is listed in Table 4-65. There seemed to be some turbulence in this region. However, this was the only possible location for the test. The turbulence was caused from the flow of dilution collingair entering the stack. The air damper was not used during this test because it would have produced a more severe turbulence problem.

C. Test Results--

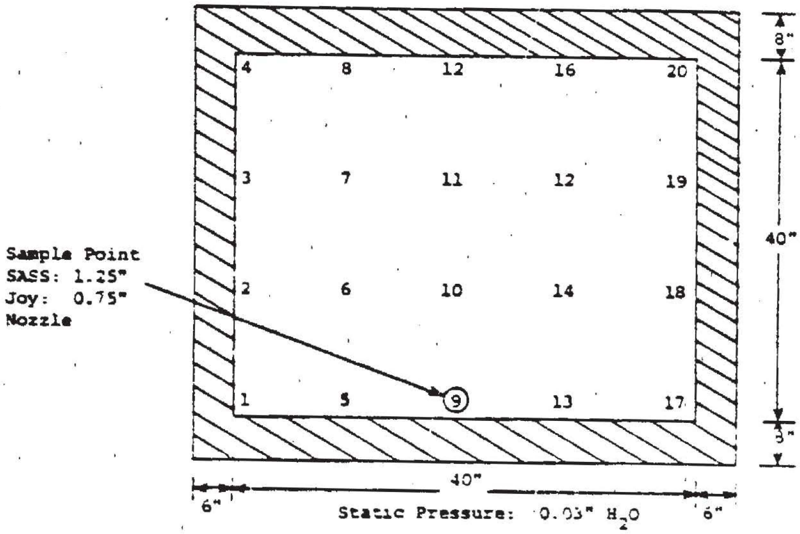
The results of the tests (Test 10S and 10J) discussed in this section, are listed in Table 4-1. Major elemental composition, sulfate, nitrate, and carbon analysis were determined for all fractions of particulate catches which contained weights in excess of 100 mg. The details for these procedures are discussed in Section 3.2.2. Table 4-66 lists the results from these analyses.

D. Discussion or Results--

1. Particle size distribution--Figure 4-60 is a plot of particle size (μm) versus accumulated weight percent, the latter plotted on a probability scale as explained in Section 3.2.3.B. Two sets of curves are presented, one including the impinger catch and the other ignoring it. Considering that about half the material collected was in the impinger, it would seem that the effect of pseudo particulates would be small. Therefore, the impinger catch was believed to be properly included in the measurements of the suspended particulates for particle size distribution. The breakdown of the particle size distribution, including the impinger catch, is as follows:

	Percent of Particles			
	>10 μm	10-3 μm	3-1 μm	<1 μm
Test 10S	5	4	5	86
Test 10J	9.5	3	2	86

TABLE 4-65. VELOCITY PROFILE FOR ALUMINUM REVERBERATORY FURNACE (TEST 10)



Distance From Edge of Duct (inches)	Point #	Velocity High Firing Ft/Sec (1456 °F)	 Low Firing Ft/Sec (1092 °F)
13	1	25.3	12.16
23	2	29.8	8.63
33	3	32.6	19.75
43	4	37.7	0
13	5	20.8	13.60
23	6	22.1	-7.81
33	7	29.8	0
43	8	26.9	18.04
13	9	17.9	14.59
23	10	21.3	-26.08
33	11	13.3	-18.38
43	12	18.8	0
13	13	19.7	13.00
23	14	20.0	16.70
33	15	0	21.80
43	16	13.3	25.50
13	17	16.6	22.30
23	18	12.0	18.38
33	19	0	21.05
43	20	0	21.05
	Average:	18.9	8.34
		3518 SCFM	2207 SCFM

TABLE 4-66. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR ALUMINUM FOUNDRY

SAMPLE #	SASS Impinger 10S-IC	SASS Filter 10S-5S
WT. PERCENT OF CUT	38	23
XRF ANALYSIS		
Calcium	3/1	2.6
Chlorine	11/4	
Chromium	t	
Copper		6.2
Iron	6/.7	
Manganese	t	
Nickel	t	t
Potassium	t	t
(Sulfur)	(6/2)	t
Zinc	t	t
TOTAL	23	10
Sulfates, H_2O sol[2]	17	t
(Sulfur, from $SO_4^=$)[4]	(5.6)	(t)
Nitrate (H_2O sol)[2]	t	
Total carbon[3]	13	t
(Volatile Carbon)[3]	(13	
(Carbonates)[3]		t
TOTAL ANALYZED	53	10
BALANCE	47	90
	100%	100%

t	detected in concentration of <1%
1	analyzed by x-ray fluorescence—Section 3.2.2 B
2	analyzed by wet chemistry--Section 3.2.2 A
3	analyzed by Oceanography carbon analyzer--Section 3.2.2 A
4	calculated from sulfates (sulfur=sulfate/3) to compare with sulfur from XRF
5	for values shown as X/Y, X is % of the element present and Y is the error (i.e. X% ± Y)
( )	not included in total—sulfur and sulfates are accounted for in sulfur XRF analysis and volatile carbon and carbonate are accounted for in total carbon

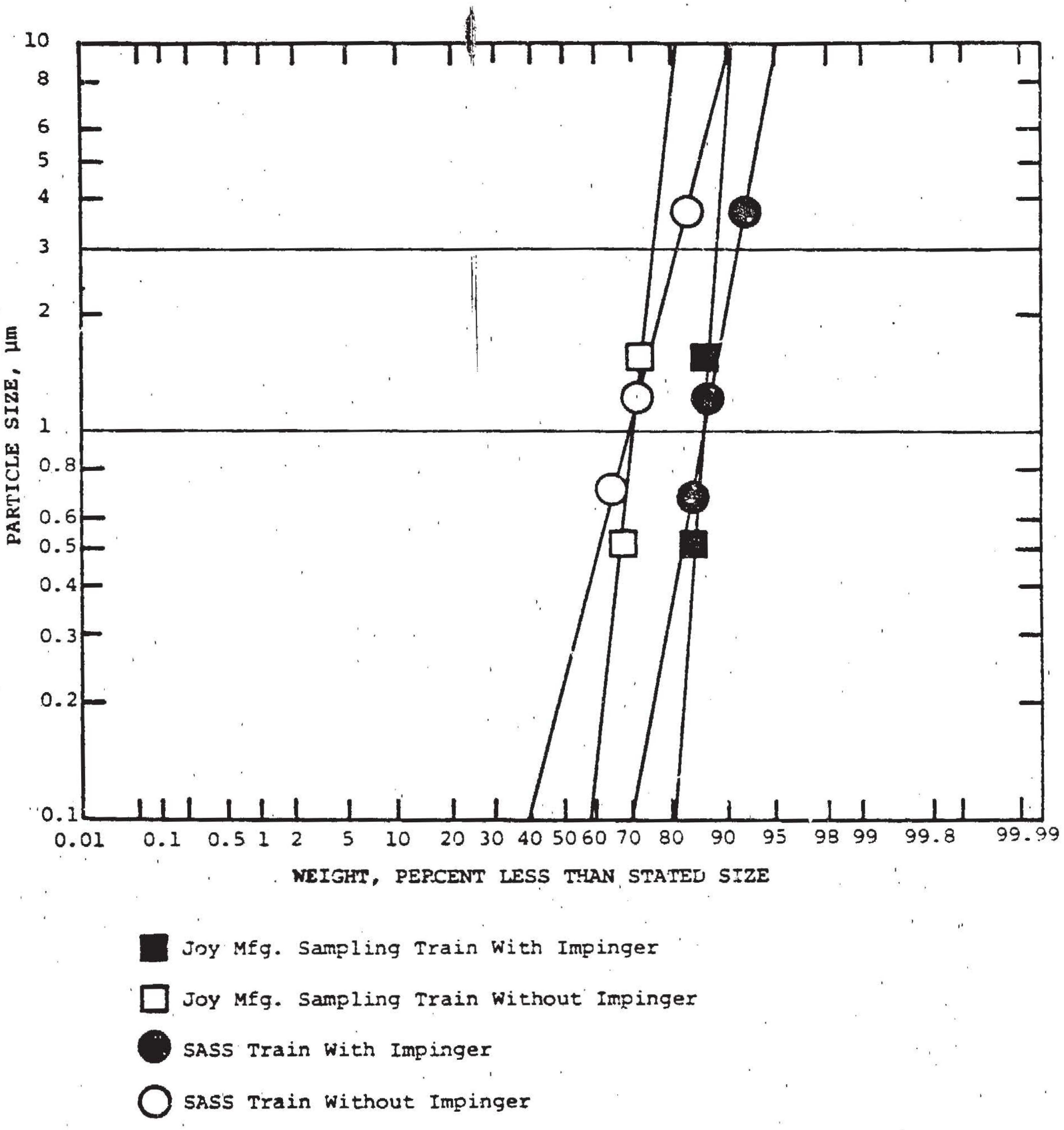


Figure 4-60. Particle size distribution for aluminum foundry (Test 10)

The mean particle size is <.1 μm for aluminum melting furnaces. In spite of the highly irregular flow conditions measured in the duct the particle size distribution measurement with the two different trains were surprisingly simil...

2. Chemical composition--Table 4-66 lists the results from the chemical analysis of the particulate fraction for each of the tests discussed in this section. Sulfates concentration is much higher in the impinger than on the filter. Carbon, iron, and chlorine were higher in the impinger than on the filter.

3. Emissions and emission factors--Emissions and emission factors can be listed with several different units. The following lists some of these emissions and factors:

Uncontrolled Emission (New type surface)	Test 10S	Test 10J
gr/DSCF	0.0026	0.0021
T/yr	0.17	0.14
lb/hr	0.072	0.058
lb/ton	0.02	0.02
(Old type surface)		
lb/ton (Ref. 4-29)	4.30	4.30

The new type of furnace is a method of control (process and equipment improvements). The data shows a 99% reduction of emissions with the new furnace. The emission factor used for the inventory was taken from AP-42 because nearly all of the furnaces in the Basin were of the older type.

4.2.18 Steel Production--Sinter Plant

A. Process Description--

The sinter operation is only a small part (about 5% of the emission) of the total production of steel. Figure 4-61 (Ref. 4-30) shows the basic flow diagram of iron and steel processes. Each of these operations can be done at the same location or done separately at different locations.

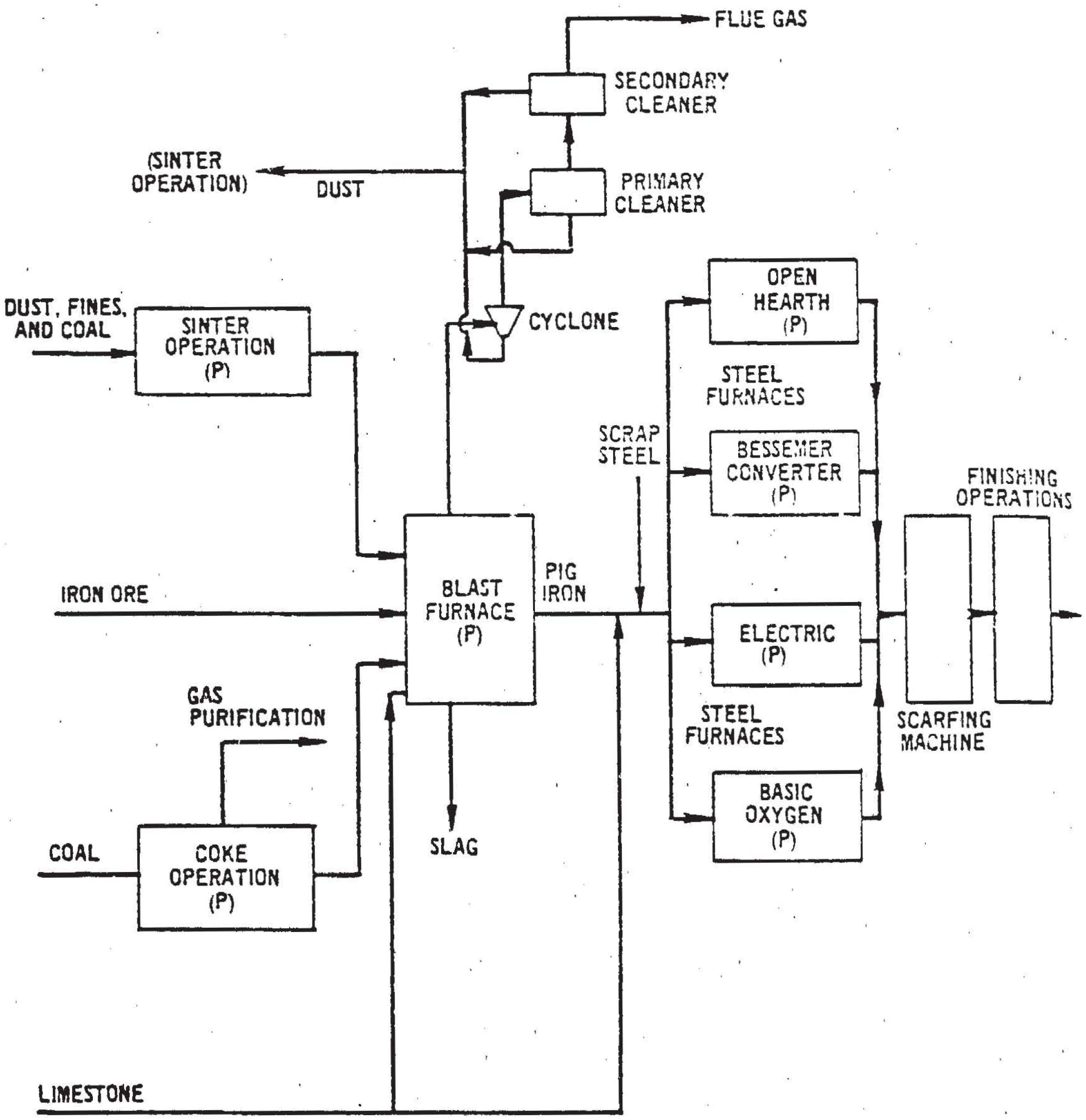
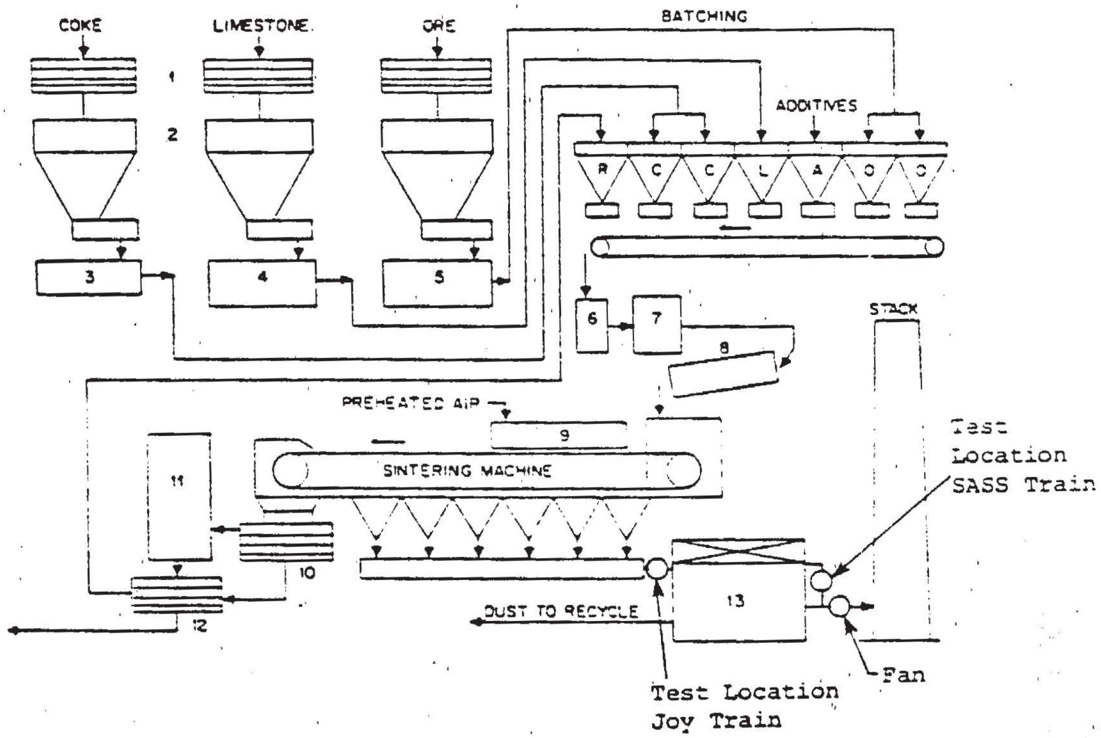


Figure 4-61. Basic flow diagram of iron and steel processes. (P) denotes a major source of particulate emissions.

Sinter is an agglomerate made from small particles of iron-bearing materials fused or fritted together at high temperature. In the sintering process this high tempbrature is achieved by burning carbon in the form of finely crushed coke in the sintering-machine feed mix. Flux can be added in the feed mix to eliminate flux charging partially or completely in the subsequent ironmaking operations. The flexibility of the process permits conversion of a variety of materials, including naturally fine ores; ore fines from screening operations, flue dust, and ore concentrates; and other iron-bearing materials of very small particle size into a granular, relatively coarse form well suited for the blast furnace. A continuous sintering process is shown in Figure 4-62 (Ref. 4-31). A traveling grate conveys a bed of ore fines, or other finely divided iron-bearing material, intimately mixed with approximately 5% of a finely divided coke. Near the head or feed end of the grate, the bed is ignited on the surface by gas burners, and as the mixture moves along the traveling grate, air is pulled down through the mixture to burn the fuel by downdraft combustion. As the grate moves continuously over the wind boxes toward the discharge end of the strand, the combustion front in the bed moves progressively downward. This creates sufficient heat and temperature (1313-1480 °C, 2400-2700 °F) to sinter the fine ore particles together into porous, coherent lumps. Sinter plants with production capacity of about 20,000 tons/day can be constructed. The unit tested on this program had production capacity of 5000 tons/day.

B. Particulate Test Set-up--

Two sampling trains were used simultaneously to sample the inlet and exit of the baghouse as shown in Figure 4-62. The inlet station was located on the horizontal underground section of the duct leading to the baghouse. A section 6" wide and 4' long was provided to sample the flue gases. Table 4-67 lists the velocity profile in the inlet and outlet ducts. The outlet duct was on the vertical section leading down to the fan. The inlet sample was taken at velocity point 6 (Table 4-67) with a 1/4" nozzle and the outlet sample was taken at velocity point R with a 1/2" nozzle. Note that the inlet flow is about 80% of the outlet flow.

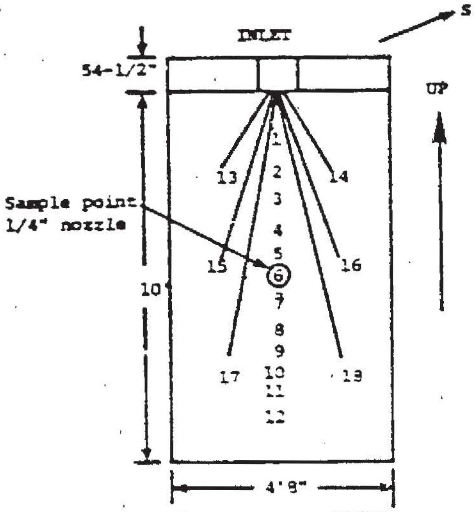


A = Additives
C = Coke fines
L = Limestone flakes
O = Ore fines
R = Return fines

1. Raw-material screens
2. Raw-material storage hoppers
3. Rod mill to reduce size of coke
4. Limestone crusher
5. Ore crusher
6. Mixing drum
7. Raw-sinter mixer
8. Rerolling drum
9. Burner hood
10. Sinter screening (hot)
11. Sinter cooler
12. Sinter screening (cold)
13. Baghouse

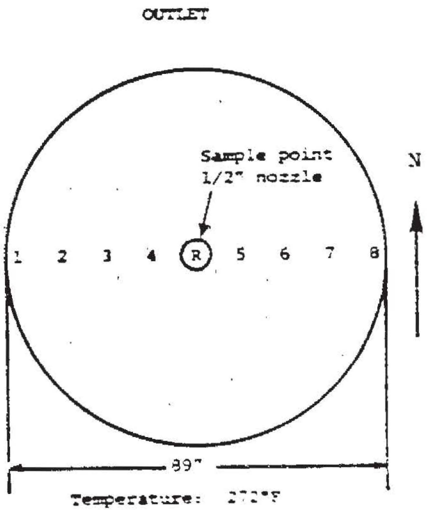
Figure 4-62. Continuous iron ore sintering process.

TABLE 4-67. VELOCITY PROFILE FOR TEST 26



Temperature: 360°F

Static Pressure: -12.8"H_2O



Temperature: 272°F

Static Pressure: -17.5"H_2O

Distance from end of port (inches)	Velocity	
	Point #	ft/sec
59	1	58.0
69	2	62.0
79	3	60.4
89	4	59.6
99	5	59.6
109	6	58.8
119	7	58.3
129	8	59.2
139	9	60.4
149	10	59.6
159	11	59.2
169	12	59.6
71	13	62.0
71	14	47.0
104	15	61.2
104	16	48.0
130	17	64.3
130	18	47.5

Average: 56.7 ft/sec

108,760 SCFM

Distance from end of port (inches)	Velocity	
	Point #	ft/sec
7	1	62.1
13	2	62.1
21	3	60.4
33	4	65.5
44	R	74.7
64	5	77.5
75	6	80.2
83	7	85.4
90	8	80.2

Average: 73.0 ft/sec

134,334 SCFM

The reason for this was that another sintering plant which usually feeds into the baghouse was down for repair. The duct from that other plant was disconnected from the baghouse and the opening in the baghouse wall was only partially closed. Therefore some fresh air was drawn in through the partially open duct.

C. Test Results--

The results of the tests (Test 26J and Test 26S) discussed in this section are listed in Table 4-1. Elemental composition, sulfate, nitrate, and carbonanalysis were determined for all fractions of particulate catches which contained weights in excess of 100 mg. The details for these procedures are discussed in Section 3.2.2. Table 4-68 lists the results from these analyses.

D. Discussion of Results--

1. Baghouse efficiency--The calculated efficiency for the baghouse based on the total particulate catch is 72.5%. Neglecting the impinger catch on both trains the efficiency is 97.8%. The EPA Method 5 ignores the impinger catch therefore the higher efficiency would apply -- whereas the SCAQMD includes the impinger catch and this method would indicate the lower value for efficiency.

2. Particle size distribution--Figure 4-63 is a plot of particle size (µm) vs. accumulated weight percent, the latter plotted on a probability scale as explained in Section 3.2.3B. Two sets of curves are presented, one including the impinger catch, and the other ignoring it. Considering the large amount ofmaterial collected in the impingers, it would seem that pseudo particulates would not significantly add to the total weight. Therefore, the impinger catch was believed to be properly included in the measurements of the suspended particulates from sinter plants for particle size distribution. The breakdown of the particle size distribution, not including the impinger catch, is as follows:

	Percent of Particles			
	>10µm	10-3 m	3-1 m	<1µm
Test 26J inlet	6	1.0	1.0	92
Test 26S outlet	2	1.2	1.4	95

The mean particle size for the inlet as well as the outlet is less than 0.1 µm.

TABLE 4-68. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR TEST 26

SAMPLE #	SASS 10µ Cyclone 26S-2S	Joy 10µ Cyclone 26J-2S	Joy Inlet 3µ Cyclone 26J-4S	Joy Inlet Filter 26J-5S	SASS Exit Filter 26S-5S	SASS Exit Impinger 26S-IC	Joy Inlet Impinger 26J-IC
WT. PERCENT OF CUT	3.0	5.2	12	43	3.5	91	12
XRF ANALYSIS							
Arsenic				t	t		
Bromine			t	t	t		
Cadmium			t	t	t		
Calcium	9.3/2	12/3	1.1/0.4			t	
Chlorine	4.9/2	8/3	14/5	23/10	30/10	17/4	16/5
Chromium	t	t				3.4/0.4	
Copper	t	t	1.6/0.4	1.2/0.2	1.6/0.2		
Cesium			t	t	t		
Iron	20/3	16/2	2/0.3	t	t	13	
Lead	t	2/0.3	13/2	12/2	11/2		
Manganese	t	t				t	
Molybdenum						t	
Nickel						1.9/0.3	
Potassium	3.1/1	5/2	9/4	16/5	20/7	t	t
Rubidium		t	t	t	t		
(Sulfur)	(17/5)	(18/8)				(15/5)	(16/5)
Titanium		t					
Zinc			t	t	t		
TOTAL[1]	40	45	43	55	65	24	17
Sulfates, H_2O sol[2]	8.23	6.01	2.12	1.40	7.46	22.81	25.49
(Sulfur, from $SO_4^{=}$)[4]	(2.74)	(2.0)	t	t	(2.49)	(7.60)	(8.50)
Nitrate (H_2O sol)[2]	t	t					
Total Carbon[3]	15		7	t	t	11	6
(Volatile Carbon)[3]	(12)		7			(10)	(6)
(Carbonates)[3]	t	1.67					
TOTAL ANALYZED	63	53	52	56	72	58	48
BALANCE	37	47	48	44	28	42	52
	100%	100%	100%	100%	100%	100%	100%

t	detected in concentration of <1%
1	analyzed by x-ray fluorescence--Section 3.2.2 B
2	analyzed by wet chemistry—Section 3.2.2 A
3	analyzed by Oceanography carbon analyzer--Section 3.2.2 A
4	calculated from sulfates (sulfur=sulfate/3) to compare with sulfur from XRF
5	for values shown as X/Y, X is % of the element present and Y is the error (i.e. X% ± Y)
( )	not included in total--sulfur and sulfates are accounted for in sulfur XRF analysis and volatile carbon and carbonate are accounted for in total carbon

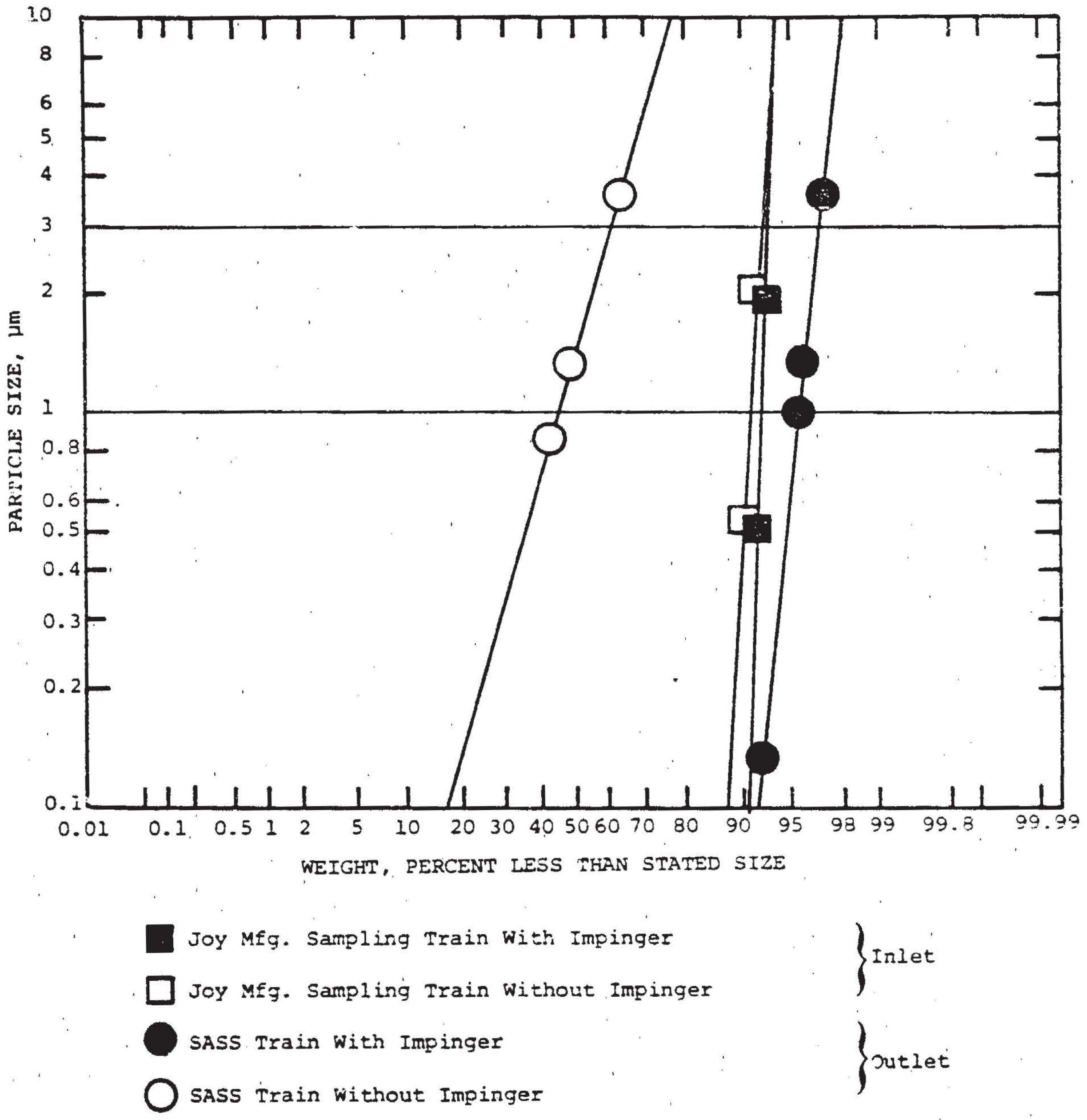


Figure 4-63. Particle size distribution for sinter plant (Test 26)

3. Chemical composition--Table 4-68 lists the results from the chemical analysis of the particulate fraction for each of the tests discussed in this section. Sulfates are most abundant in the impingers. Chlorine was detected in large concentration, 5-30% in all size fractions and had the largest concentration on the filters. Calcium was found primarily in the first cyclone. This indicates that the calcium is concentrated in large particles. Lead tends to concentrate in the 0.5 µm size range. Iron is in the form of larger particles, >10 µm. Potassium seems to follow the pattern of chlorine. Possibly the compound is KCl.

4. Emissions and emission factors--Emissions and emission factors can be listed with several different units. The following lists some of these emissions and factors.

Units	Uncontrolled Test 26J	Controlled Test 26S
gr/DSCF	0.205	0.0459
T/yr	709	195
lb/hr	170.4	46.82
lb/ton produced	3.4	1.0
lb/ton produced-AP-42 (Ref. 4-34)	22	0.67

4.2.19 Steel Production--Open Hearth Furnace

A. Process Description (Ref. 4-35 and 4-36)

In the open hearth process, a mixture of scrap iron, steel and pig iron is melted in a shallow rectangular basin, or "hearth," for which various liquid gaseous fuels provide the heat. Impurities are removed in a slag (see Figure 4-64).

Emissions from open hearths consist of particulates and small amounts of fluorides when fluoride-bearing ore, fluorspar, is used in the charge. The particulates are composed primarily of iron oxides, with a large portion in the 0 to 5 micrometer size range. The quantity of dust in the off-gas increases considerably when oxygen lancing is used.

The devices most commonly used to control the iron oxide and fluoride particulates are electrostatic precipitators which effectively remove

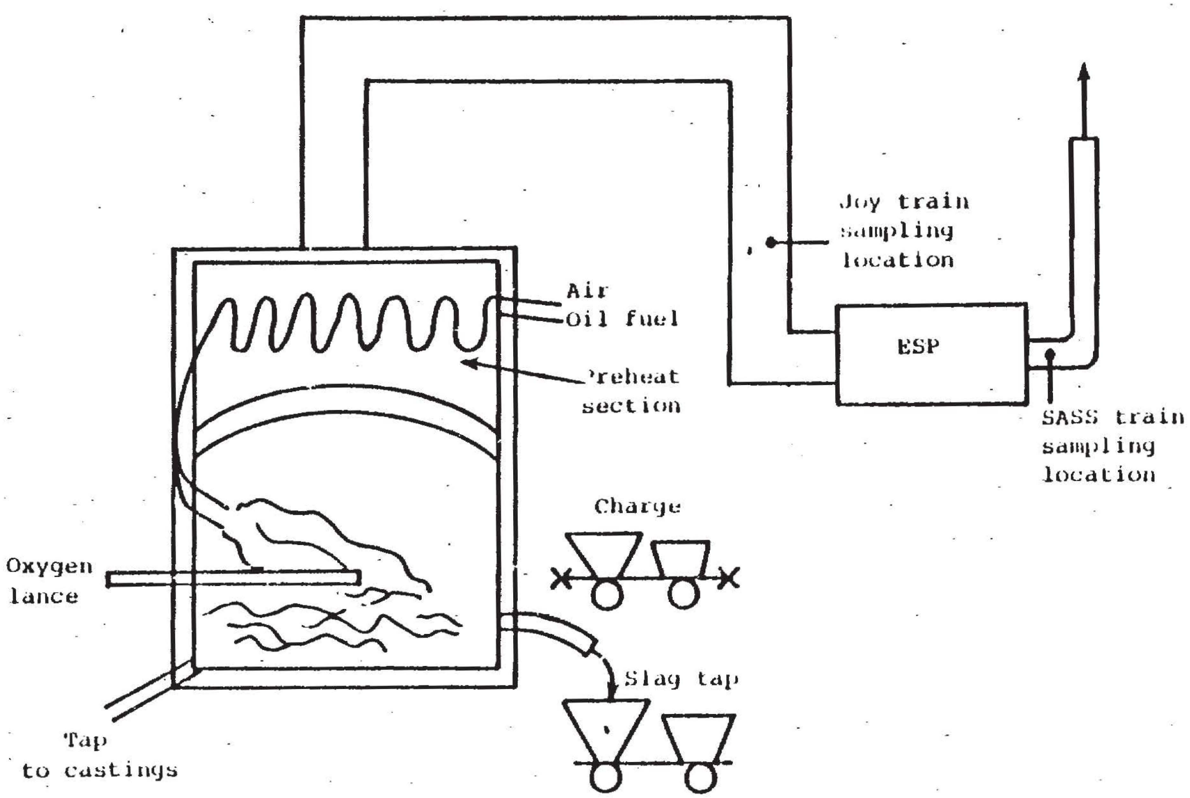


Figure 4-64. Open hearth furnace.

B. Particulate Test Set-up--

Two sampling trains were used simultaneously to sample the inlet and outlet of the electrostatic precipitator. The inlet station was located on the vertical duct leading upward to the ESP. The outlet station was located on the vertical duct leading down to the fan. The velocity profiles in the inlet and outlet ducts are listed in Table 4-69. Velocity points 8 and 16 on the inlet were not able to be measured due to the geometry of the port and pitot tube. A 1/2" nozzle was used at velocity point 12 on the inlet and a 9/16" nozzle was used at velocity point R on the outlet.

C. Particulate Test Results--

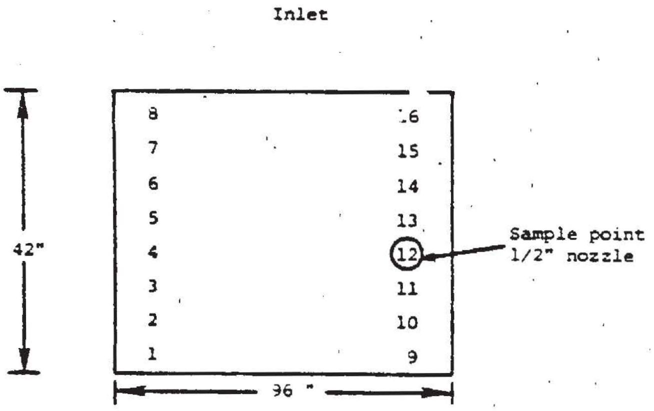
The results of the two tests (Tests 36S and 36J) discussed in this section are listed in Table 4-70 Elemental composition, sulfate, nitrate, and carbon analysis were determined for all fractions of particulate catches which contained weights in excess of 100 mg. The details for these procedures are discussed in Section 3.2.2. Table 4-72 lists the results from these analyses.

D. Discussion of Test Results--

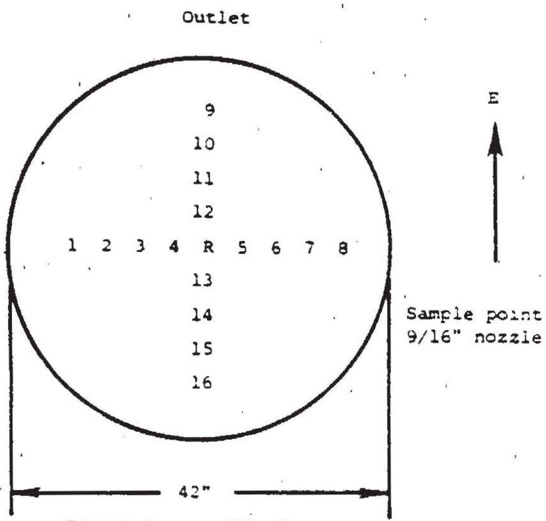
1. <u>Electrostatic precipitator efficiency</u>--The calculated efficiency for the ESP based on the total particulate catch is 84.2%. Neglecting the impinger catch on both trains the efficiency is 90.3%. The EPA Method 5 ignores the impinger catch; therefore, the higher efficiency would apply. Whereas, the SCAQMD includes the impinger catch method and indicates the lower value for the efficiency.

2. <u>Particle size distribution</u>--Figure 4-65 is a plot of particle size (μm) vs. accumulated weight percent, the latter plotted on a probability scale as explained in Section 3.2.3B. Two sets of curves are presented, one including the impinger catch, and the other ignoring it. Considering the large amount of material collected in the impinger, it would seem that the effects of pseudo particulates would be insignificant. Therefore, the impinger catch was believed to be properly included in the measurements of the suspended particulates from open hearth steel producing furnaces. The breakdown of the

TABLE 4-69. VELOCITY PROFILE FOR OPEN HEARTH FURNACE (TEST 37)



Temperature: 460 °F
Static Pressure: -4.2" H_2O



Temperature: 415 °F
Static Pressure: -4.2" H_2O

Distance from end of port (inches)	Velocity				Distance from end of port (inches)	Velocity			
	Point #	ft/sec.	Point #	ft/sec.		Point #	ft/sec	Point #	ft/sec.
5-5/8	1	27.3	9	25.3	4-3/8	1	55.3	9	50.5
10-7/8	2	27.3	10	25.3	7-3/8	2	59.7	10	63.8
16-1/8	3	28.3	11	25.3	12-1/4	3	61.8	11	69.6
21-3/8	4	24.3	12	23.1	16-1/2	4	63.8	12	69.6
26-5/8	5	23.1	13	23.1	24	R	63.8	R	67.7
31-7/8	6	24.3	14	14.6	31-5/8	5	63.8	13	22.5
37-1/8	7	23.1	15	14.6	36-3/4	6	63.8	14	22.5
43-3/8	8	20.7	16	14.6	40-5/8	7	63.8	15	22.5

Average: 22.68 ft/sec.
21,539 SCFM

Average: 54.2 ft/sec.
18,584 SCFM

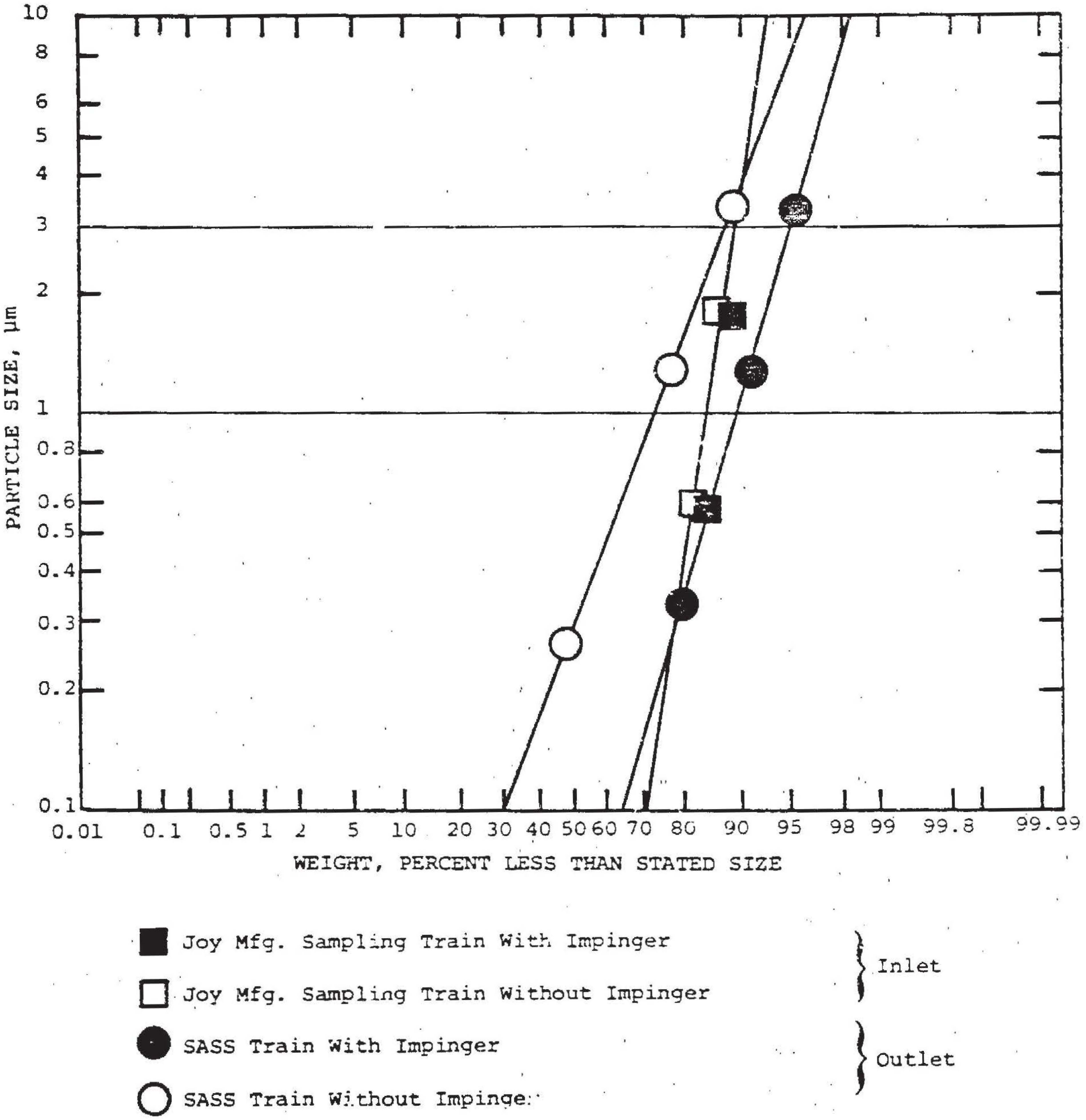


Figure 4-65. Particle size distribution for open hearth furnace (Test 36)

particle size distribution for the inout and outlet to the ESP including the impinger catch is as follows:

	Percent of Particles			
	>10μm	10-3 m	3-1μm	<1μm
Test 36J (inlet)	8.0	5.0	4	83.0
Test 36S (outlet)	2.2	3.8	7	87.5

The mean particle size for the ESP is <0.1 m for the inlet and outlet. This agrees with AP-42 as mentioned above in the Process Description.

3. Chemical composition of particulates--Table lists the results from the chemical analysis of the particulate fraction for the tests discussed in this section. Sulfates were found to be most abundant in each size cut. Carbon was detected in the high concentrations in the impinger fractions. Iron, potassium, and zinc were also found to have significant quantities in each size fraction.

4. Emissions and emission factors--Emissions and emission factors can be listed with several different units. The following lists some of these emissions and factors for these tests:

Units	Controlled Test 26S	Uncontrolled Test 26J
gr/DSCF	0.0366	0.206
T/yr	22.3	141.4
lb/hr	5.53	35.1
lb/ton produced	0.67	4.2
lb/ton produced (Ref. 4-37).	0.35	17.4

TABLE 4-70. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR TEST 36

SAMPLE #	SASS 1µm Cyclone 36S-4S	SASS Filter 36S-5S	SASS Impinger 36S-IC	Joy 10µm Cyclone 36J-2S	Joy 1µm Cyclone 36J-4S	Joy Filter 36J-5S	Joy Impinger 36J-IC
WT. PERCENT OF CUT	9.7	15	44	12	26	39	9.6
XRF ANALYSIS							
Calcium	t	1.2/0.5	t	2.2/0.4	t	t	t
Chromium	1.1/0.2	1.2/0.3	2.2/0.4	t	t	1.3/0.3	
Cooper	t	t	t	t	t	t	t
Iron	15/2	11/2	8.2/1	18/3	13/2	8.2/1	t
Lead	t	t		t	t	t	
Manganese	1.0/0/2	t	t	1.1/0.2	t	t	
Nickel	t	t	1.2/0.2	t	t	t	
Potassium	4.5/1	5.8/1		3.1, 0.6	4.3/1	6.1/1	t
(Sulfur)	(27/10)	(30/10)	(18/6)	(25/10)	(20/8)	(30/10)	(16/6)
Vanadium	t	t		t	t	t	
Zinc	11/2	8.9/1		9.0/1	9.3/1	7.4/0.8	t
TOTAL[1]	25	31	13	24	31	26	3
Sulfates, H_2O sol[2]	38	41	38	32	41	44	32
(Sulfur, from $SO_4^=$)[4]	(12.8)	(13.8)	(12.8)	(12.8)	(13.7)	(14.8)	(10.9)
Nitrate (H_2O sol)[2]	t	t	t	t	t	t	t
Total Carbon[3]	21		23				41
(Volatile Carbon)[1]	(21.82,		(21)				(32)
(Carbonates)[3]							
TOTAL ANALYZED	84	72	74	66	72	70	77
BALANCE	16	28	26	34	28	30	23
	100%	100%	100%	100%	100%	100%	100%

t detected in concentration of <1%

1 analyzed by x-ray fluorescence--Section 3.2.2 B

2 analyzed by wet chemistry--Section 3.2.2 A

3 analyzed by Oceanography carbon analyzer--Section 3.2.2 A

4 calculated from sulfates (sulfur=sulfate/3) to compare with sulfur from XRF

5 for values shown as X/Y, X is % of the element present and Y is the error (i.e. X% ± Y)

( ) not included in total--sulfur and sulfates are accounted for in sulfur XRF analysis and volatile carbon and carbonate are accounted for in total carbon

4.2.20 Boric Acid Production

A. Process Description (Ref. 4-38)--

Sulfuric acid is reacted with borax to produce boric acid and Glauber salt, (hydrated sodium sulfate, $Na_2SO_4 \cdot 10\ H_2O$). These products are then separated on a vacuum filter. The boric acid cake is redissolved, filtered, crystalized, centrifuged, dried, and screened. The Glauber salt follows a similar circuit except for an additional step of conversion to sodium sulfate. Figure 4-66 is a flow diagram of the process.

B. Particulate Test Setup--

Two sampling tains were used simultaneously to sample the inlet and outlet of the baghouse which controls the dust load from the boric acid dryers. The inlet station was located on the vertical section of the rectangular duct leading to the baghouse. The dry train was used on this station which was at least eight feet from the nearest bend or obstruction. The outlet station was located on the horizontal section of the duct about five feet ahead of the blower and 15 feet from the old baghouse. As shown in Figure 4-66, the flow from the dryers was spit into two parts which went to two baghouses operating in parallel. The outlet from the older of the two baghouses was tested with the SASS train. The velocity profile in the inlet duct to both units and in the outlet duct from the older baghouse is listed in Table 4-71. If it was assumed that the volumetric flow through both baghouses were the same, then the total flow from the baghouses would be 22,000 SCFM. This would compare 17,000 SCFM for the inlet and 22,000 SCFM for the outlet. This difference is due to leaks because the system is under negative pressure.

C. Test Results--

The results of the tests (Test 17S and Test 17J) discussed in this section are listed in Table 4-1. Elemental composition, sulfate, nitrate and carbon analysis were determined for all fractions of particulate catches which contained weights in excess of 100 mg. The details for these procedures are discussed in Section 3.2.2. Table 4-72 lists the results from this analysis.

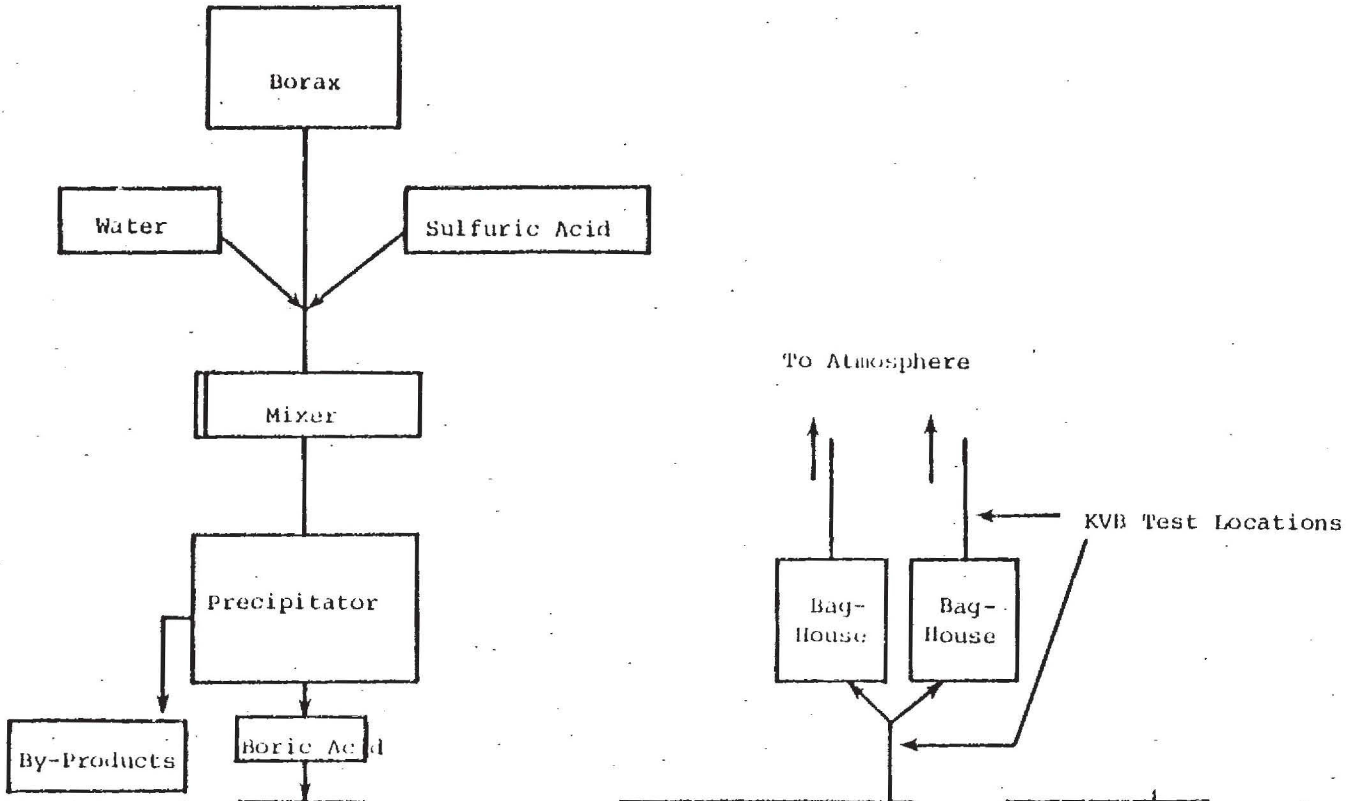
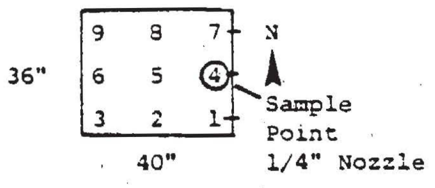
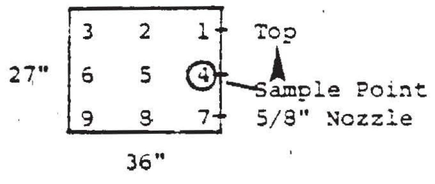


Figure 4-66. Boric acid production flow diagram.

TABLE 4-71. VELOCITY PROFILE FOR BORIC ACID PLANT (TEST 17)



Temperature - 150 °F
Static Pressure - 13" H_2O



Temperature - 130 °F
Static Pressure - 16" H_2O

Distance From End of Duct	Velocity		Distance From End of Duct	Velocity	
	Point No.	ft/sec		Point No.	ft/sec
13-1/4	1	46.4	6	1	30.1
19-3/4	2	44.5	18	2	32.3
33	3	33.9	30	3	30.6
13-1/4	4	38.9	6	4	32.3
19-3/4	5	38.1	18	5	31.2
33	6	37.9	30	6	33.9
13-1/4	7	28.1	6	7	28.9
19-3/4	8	14.7	18	8	34.4
33	9	38.9	30	9	31.2
	Average	34.8 ft/sec		Average	31.9 ft/sec
		17799 SCFM			11387 SCFM

TABLE 4-72. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR BORIC ACID (TEST 17)

	Impinger		10μm	
SAMPLE #	Inlet 17J-IC	Outlet 17S-IC	Inlet 17J-25	Outlet 17S-24
WT. PERCENT OF CUT	29	84	6	11
XRF ANALYSIS				
Chlorine	t	t		t
Chromium				
Iron		t		
(Sulfur)	(<2.0)	t	t	t
TOTAL[1]	t	t	t	1.3
Sulfates, H_2O sol[2]	1.96	t	t	2.20
(Sulfur, from $SO_4^=$)[4]	t	t	t	t
Nitrate (H_2O sol)[2]	t	t	1.48	2.43
Total Carbon[3]		4.0		
(Volatile Carbon)[3]		3.9		
(Carbonates)[3]			t	
TOTAL ANALYZED	2	4	2	6
BALANCE Probably HBO_3	98	96	98	94
	100%	100%	100%	100%

t detected in concentration of <1%

[1] analyzed by x-ray fluorescence--Section 3.2.2 B

[2] analyzed by wet chemistry--Section 3.2.2 A

[3] analyzed by Oceanography carbon analyzer--Section 3.2.2 A

[4] calculated from sulfates (sulfur=sulfate/3) to compare with sulfur from XRF

[5] for values shown as X/Y, X is % of the element present and Y is the error (i.e. X% ± Y)

( ) not included in total--sulfur and sulfates are accounted for in sulfur XRF analysis and volatile carbon and carbonate are accounted for in total carbon

D. Discussion of Results--

1. Baghouse efficiency--Using the total weight data (including the impinger catch) from both sampling trains for the inlet and exit to the baghouse, and assuming that the inlet stream was equally divided between the two baghouses (one baghouse was tested), the efficiency was calculated to be 98.7%. If only the solid weights (front half of sampling tain as used by EPA Method No. 5) are used, then the efficiency is calculated to be 99.6%

2. Particle size distribution--Figure 4-67 is a plot of particle size (μm) versus accumulated weight percent, the latter plotted on a probability scale as explained in Section 3.2.3B. Two sets of curves are presented, one including the impinger catch and the other ignoring it. Considering the large amount of material collected in the impinger, it would seem that the effect of pseudo particulates was insignificant. Therefore, the impinger catch was believed to be properly included in the measurements of the suspended particulates for size distribution, including the impinger catch, as follows:

PERCENT OF PARTICLES

	>10μm	10-3μm	3-1μm	<1μm
Uncontrolled (Test 17J)	15	0.1	0	84
Controlled (Test 17S)	10	0.5	0.5	89

The mean particle size for particles in the inlet and outlet ducts of the of the baghouse is <0.1μm including the impinger catch. If the impinger catch is not included (EPA method), then the mean particle for the inlet and outlet is >10μm.

3. Chemical composition--Table 4-72 lists the results from the chemical analysis of the particulate fraction for each of the tests discussed in this section. The most abundant species is other - boric acid. Boric acid, HBO_3, is not detected by XRF. The three percent of the elements that were detected are mainly sulfates.

4. Emission and emission factors--Emission and emission factors can be listed with several different units. The following lists some of these emissions and emission factors:

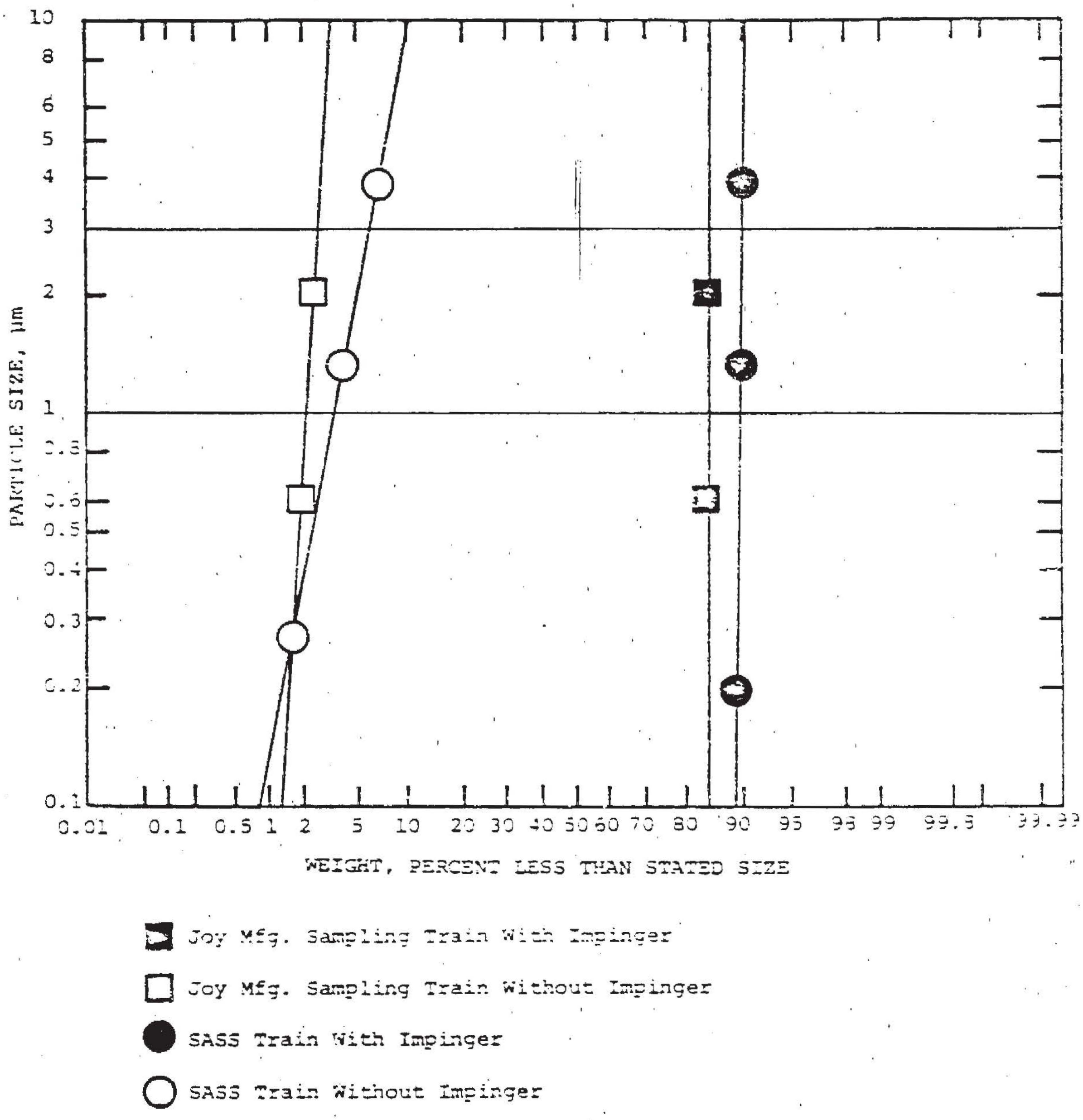


Figure 4-67. Particle size distribution for boric acid plant. (Test 17)

Units	Controlled Test 17S	Uncontrolled Test 17J
gr/DSCF	0.0237	0.6105
T/yr	9.74	387.0
lb/hr	2.23	88.7
lb/T	0.21	8.3

4.2.21 Chemical Fertilizer Plants

A. Process Description

Raw material is weighed, placed in a holding hopper, crushed in a hammer mill, then mixed and pressed into granules. The fertilizer is then dryed in a rotating drum-type drier and cooled in a similar rotating drum. The finished product is taken at this point and the smaller product is returned to the inclined mixers. The sources of particulates are the cyclone exits from the dryer, and the second bag house exit from the cooler, and the first baghouse exit from the weighing hopper. The inlet and exit of the second baghouse from the dryer was tested in this study. See Figure 4-68.

B. Particulate Test Setup--

Two sampling trains were used simultaneously to sample the inlet and exit of the baghouse. The inlet station was located on the horizontal duct (17 inch diamter) leading to the baghouse. This sation was about eight feet before the baghouse and at least four duct diameters to the nearest bend. Table 4-73 lists the velocity profile in the inlet and outlet ducts. The outlet station was located on the vertical section of the duct leading to the atmosphere of at least six duct diameters from the nearest bend or obstruction. The particulate sample was taken through a 7/16 inch nozzle on the inlet duct using the Joy train and through a 5/8 inch nozzle on the outlet duct using the SASS train.

C. Test Results--

The results of the test (Test 19J and Test 19S) discussed in this section are listed in Table 4-1. Elemental composition, sulfate, nitrate, and carbon analysis were determined for all fractions of particulate catches which contained weights in excess of 100 mg. The details for these procedures are discussed in Section 3.2.2. Table 4-74 lists the results from this analysis.

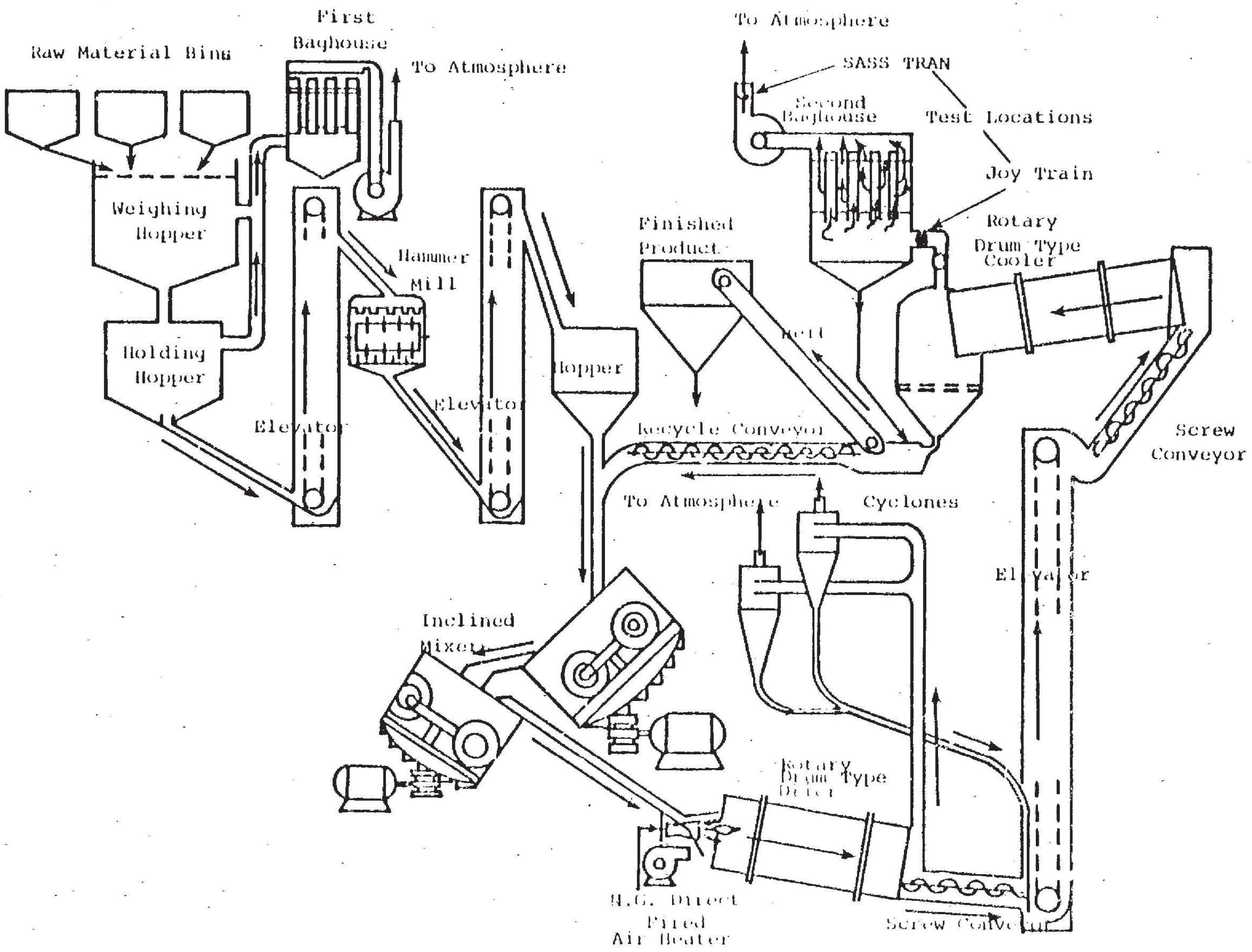
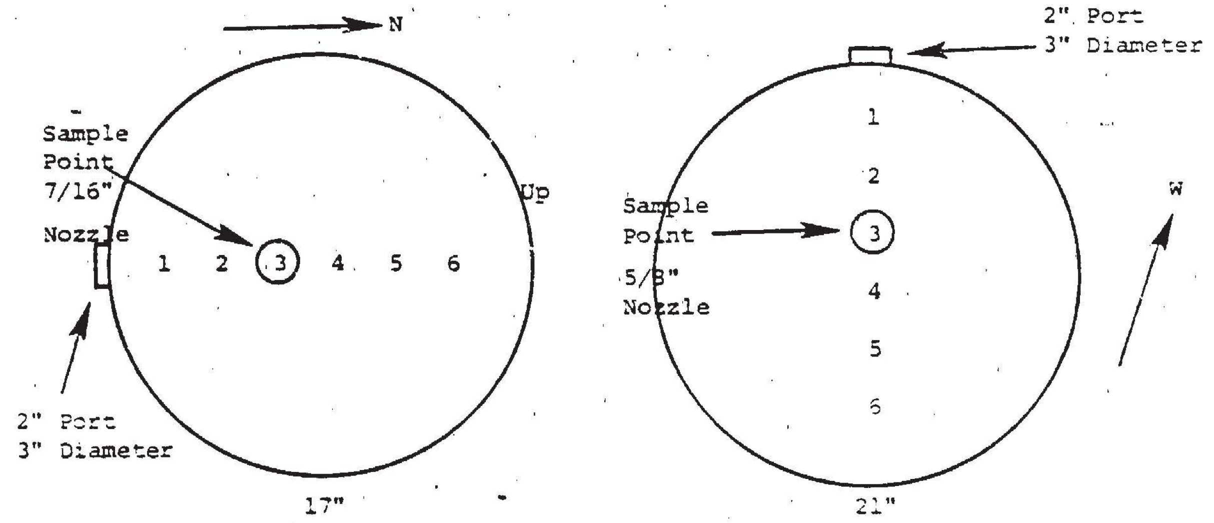


Figure 4-68. Chemical-fertilizer pelletizing.

TABLE 4-73. VELOCITY PROFILE FOR CHEMICAL FERTILIZER (TEST 19)



Temperature - 86 °F
Static Pressure - -0.16" H_2O

Temperature - 101 °F
Static Pressure - +0.56

Distance From End of Port	Velocity Point No.	Velocity ft/sec	Distance From End of Port	Velocity Point No.	Velocity ft/sec
2.8	1	22.4	3	1	43.4
4.5	2	22.4	5	2	40.2
7.0	3	23.8	8	3	38.6
10.5	R	22.4	12-1/2	R	37.2
14.0	4	20.9	17	4	37.2
16.5	5	22.4	20	5	37.2
18.2	6	25.9	22	6	37.2
	Average	23.0 ft/sec		Average	38.6 ft/sec
		2021 SCFM			4758 SCFM

TABLE 4-74 CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR CHEMICAL FERTILIZER PLANTS

SAMPLE #	Impingers Inlet 19J-IC	 Outlet 19S-IC	10um-Cyclone 19J-25
WT. PERCENT OF CUT	1	92	99
XRF ANALYSIS			
Calcium	t	t	2.2/0.4
Chlorine	4.5/1	11/3	5/2
Cobalt	t		
Iron			t
Potassium	t	t	5.2/1
(Sulfur)	(2.1/0.8	(<2)	(8.1/3)
Zinc			t
TOTAL[1]	6	13	37
Sulfates, H_2O sol[2]	5.0	2.9	8.1
[Sulfur (from $SO_4^=$)][4]	(1.68)	(1.0)	(2.7)
Nitrate (H_2O sol)[2]	t	1.0	t
Total Carbon[3]	34	11.3	10.3
(Volatile Carbon)[3]	31	10.7	9.2
(Carbonates)[3]	--	t	t
TOTAL ANALYZED	45	27	55
BALANCE	55	73	45
	100%	100%	100%

---

t detected in concentration of <1%

[1] analyzed by x-ray fluorescence--Section 3.2.2 B

[2] analyzed by wet chemistry--Section 3.2.2 A

[3] analyzed by Oceanography carbon analyzer--Section 3.2.2 A

[4] calculated from sulfates (sulfur=sulfate/3) to compare with sulfur from XRF

[5] for values shown as X/Y, X is % of the element present and Y is the error (i.e. X% ± Y)

( ) not included in total--sulfur and sulfates are accounted for in sulfur XRF analysis and volatile carbon and carbonate are accounted for in total carbon

D. Discussion of Results--

1. Baghouse efficiency--Using the total weight data (includes impinger catch) from both sampling trains for the inlet and outlet to the baghouse, the efficiency was calculated to be 99.1%

2. Particle size distribution--Figure 4-[illegible]9 is a plot of particle size (μm) versus accumulated weight percent, the latter plotted on a probability scale as explained in Section 3.2.3B. Two sets of curves are presented, one including the impinger catch, and the other ignoring it. Considering the nature of the gas stream, it would seem that the material collected in the impinger would be attributed to very fine particles and not to pseudo particulates. Therefore, the impinger catch was believed to be properly included in the measurements of the suspended particulates from chemical fertilizer plants for particle size distribution. The breakdown of the particle size distribution, including the impinger catch, is as follows:

PERCENT OF PARTICLES

	>10μm	10-3μm	3-1μm	<1μm
Baghouse Inlet (Test 19J)	98.6	0.2	0	1.2
Baghouse Outlet (Test 19S)	4.0	1.0	1.0	94.0
Uncontrolled (Ref. 4-39 4-40)	95	3.0	1.0	1.0

The mean particle size for the particles entering the baghouse was greater than 10μm and the mean size leaving the baghouse was less than 0.1μm. This shows that the baghouse is very efficient for removing large particles.

3. Chemical composition--Table 4-74 lists the results from the chemical analysis of the particulate fraction for each of the tests discussed in this section. Ureau and Phosporus were primarily the most abundant, although not detected by XRF. Sulfates and carbon were next in abundance, followed by potassium and chlorine.

4. Emissions and emission factors--Emissions and emission factors can be listed with several different units. The following lists some of these emissions and emission factors:

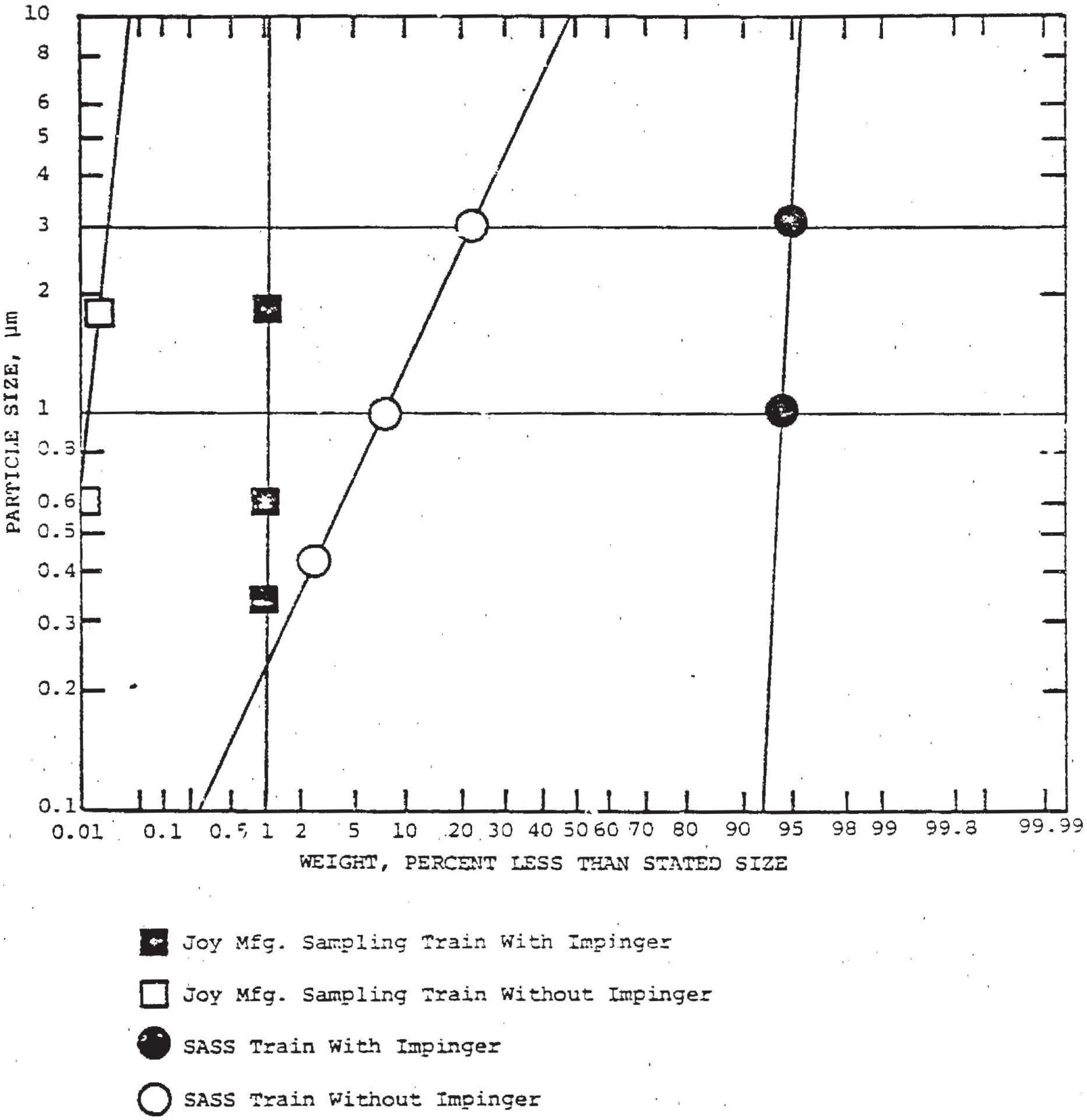


Figure 4-69. Particle size distribution for chemical fertilizer plants. (Test 19)

Units	Controlled	Uncontrolled
gr/DSCF	0.0028	0.72
T/yr	0.1	12.2
lb/hr	0.11	12.6
lb/ton produced	0.02	2.0
lb/ton produced (Ref. 4-37)	0.4	80.0

4.2.22 Paint Spray Booths - Automobile

A. Process Description

In spraying operations, a coating from a supply tank is forced, usually by compressed air, through a "gun" which is used to direct the coating as a spray upon the article to be coated. Many spraying operations are conducted in a booth or enclosure vented by a fan to protect the health and safety of the spray gun operator by ensuring that explosive and toxic concentration levels of solvent vapors do not develop.

Figure 4-70 shows a typical type of paint spray booth commonly used.

B. Particulate Test Setup

1. Test 27 - water base enamels-- Two sampling trains were used simultaneously on the same stack to sample one of six stacks exhausting the paint spray booth from an automotive assembly plant. The sampling station was located on the vertical section of the stack at least eight duct diameters from the nearest bend or obstruction. The velocity profile in the duct is listed in Table 4-75. Also listed in Table 4-75, is the average flow, SCFM, for each of the six stack exhausting the spray booth. The total flow for the spray booth exhaust is 95,000 SCFM. A 5/8 inch nozzle was used with the larger SASS train at Velocity Point R and a 5/16 inch nozzle was used with the smaller Joy train, also at Velocity Point R.

2. Test 31 - oil base enamel-- Two sampling trains were used simultaneously on the same stack to sample one of four stacks exhausting the paint spray booth from the automotive assembly plant. The sampling station was located on the vertical section of the stack at least four duct diameters from the nearest bend or obstruction.

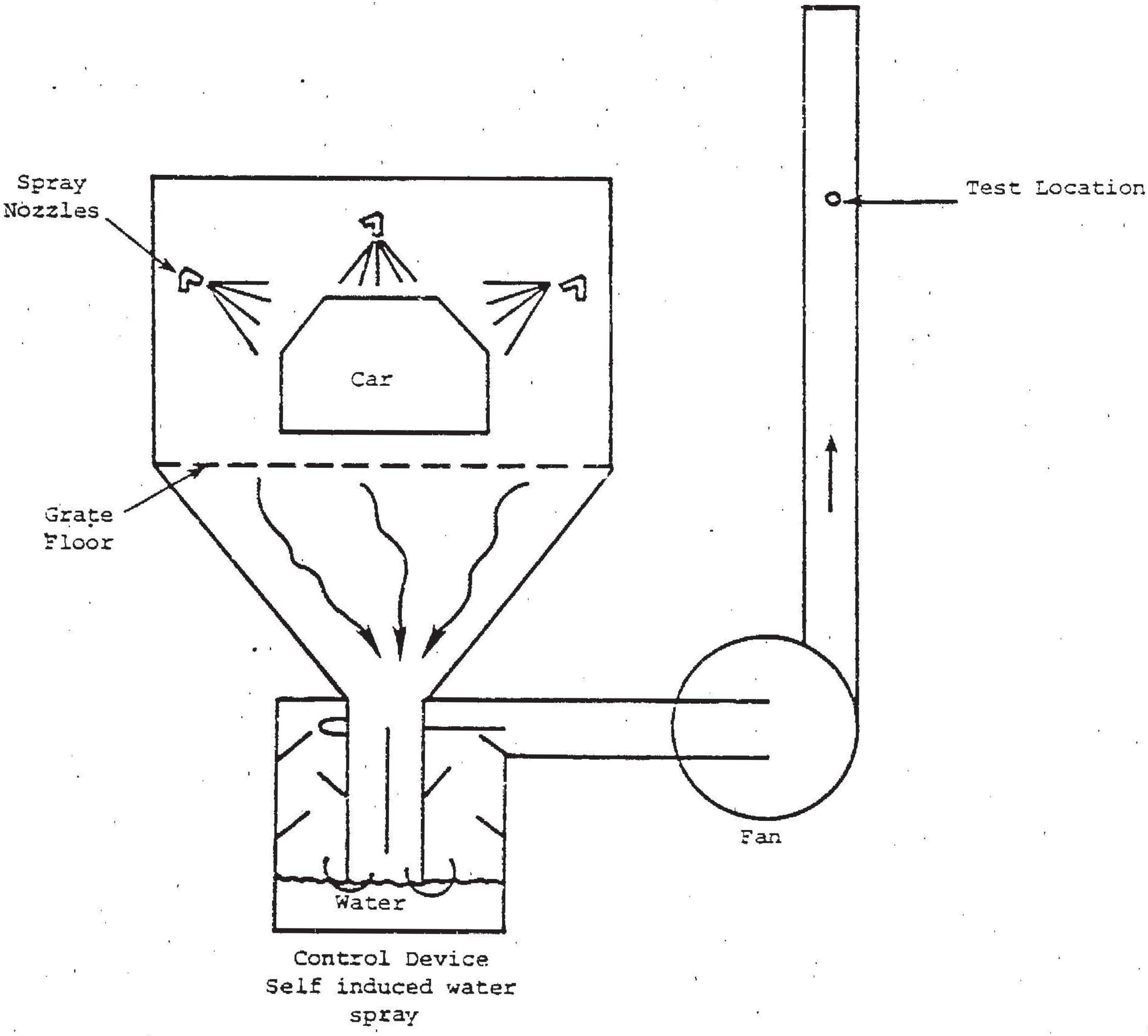
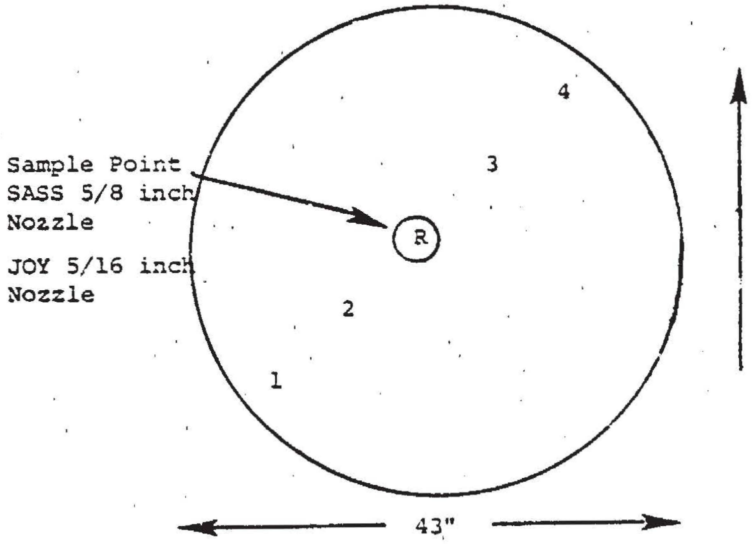


Figure 4-70. Automotive spray booth.

TABLE 4-75. VELOCITY PROFILE FOR SPRAY BOOTH, TEST 27 (WATER BASE)

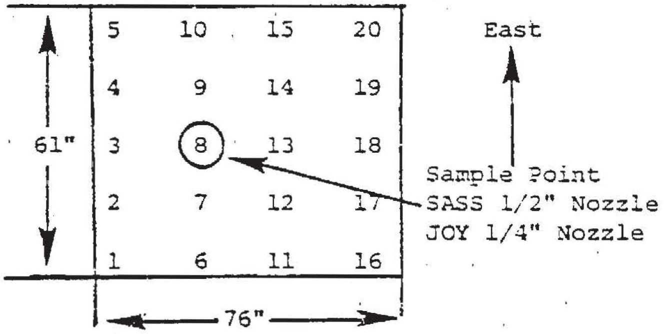


Temperature - 67 °F
Static Pressure - +0.1" H_2O

Stock No. 1
One of Six Stacks

Distance From Edge of Duct	Point No.	Velocity ft/sec	Stack No.	Average ft/sec	Flow SCFM
2.7	1	23.2	1	25.3	15215
10.75	2	30.5	2	20.0	11805
21.5	R	29.4	3	33.5	19920
32.25	3	24.9	4	25.1	14925
40.3	4	20.8	5	27.9	16570
Stack No. 1 Average 25.3 ft/sec 15215 SCFM			6	26.4	15975
				Total	95000 91400 DSCF/min

TABLE 4-76. VELOCITY PROFILE FOR PAINT SPRAY EXHAUST, TEST 31 (OIL BASE)



Temperature - 70 °F
Static Pressure - +0.2" H_2O

Stack No. 1 of four stacks

Distance From Edge of Duct	Point No.	Velocity ft/sec	Point No.	ft/sec
6"	1	52.0	11	52.6
18	2	51.0	12	46.4
30	3	54.9	13	43.7
42	4	46.0	14	43.0
54	5	49.6	15	42.3
6"	6	55.5	16	60.8
18	7	50.8	17	49.6
30	8	48.4	18	42.3
42	9	42.3	19	40.3
54	10	41.5	20	49.0
			Average	48.5 ft/sec 79,992 SCFM

Stack No.	Flow
1	80,000
2	69,000
3	42,200
4	49,000
Average	240,200 SCFM/235,400 DSCFM

The velocity profile in the duct is listed in Table 4-76. Also listed in Table 4-76 is the average flow, SCFM, for each of the four stacks exhausting the spray booth. The total flow for the spray booth exhaust is 240,000 SCFM. A 1/2 inch nozzle was used with the larger SASS train at velocity point No. 8 and a 1/4 inch nozzle was used with the smaller Joy train, also at Velocity Point No. 8.

C. Test Results

The results of the tests (Test 27S, 27J, 31S, 31J) discussed in this section are listed in Table 4-1. Elemental composition, sulfate, nitrate and carbon analysis were determined for all fraction of particulate catches which contained weights in excess of 100 mg. The details for these procedures are discussed in Section 3.2.2. Table 4-77 lists the results from this analysis. Because of the small particle loading in the exhaust stream, both tests failed to yield sufficient sample for chemical analysis. See Section

D. Discussion of Results

1. Particle size distribution-- Figure 4-71 and 4-72 are plots of particle size (μm) versus accumulated weight percent, the latter plotted on a probability scale as explained in Section 3.2.3B. Two sets of curves are presented for each test, one including the impinger catch and the other ignoring it. Considering that about 50% of the material was in the impinger catches, it would seem that it should be counted in the particle size distribution. However, most of the material is from condensed solvent. This is indicated by the large fraction of organic matter, between 25% and 50%, found in the impinger. Therefore, the impinger catch was believed to be properly not included in the measurements of the suspended particulates from paint spray booths for particle size distribution. The breakdown of the particle size distribution taken from Figure 4-71 and 4-72, not including the impinger catch, is as follows:

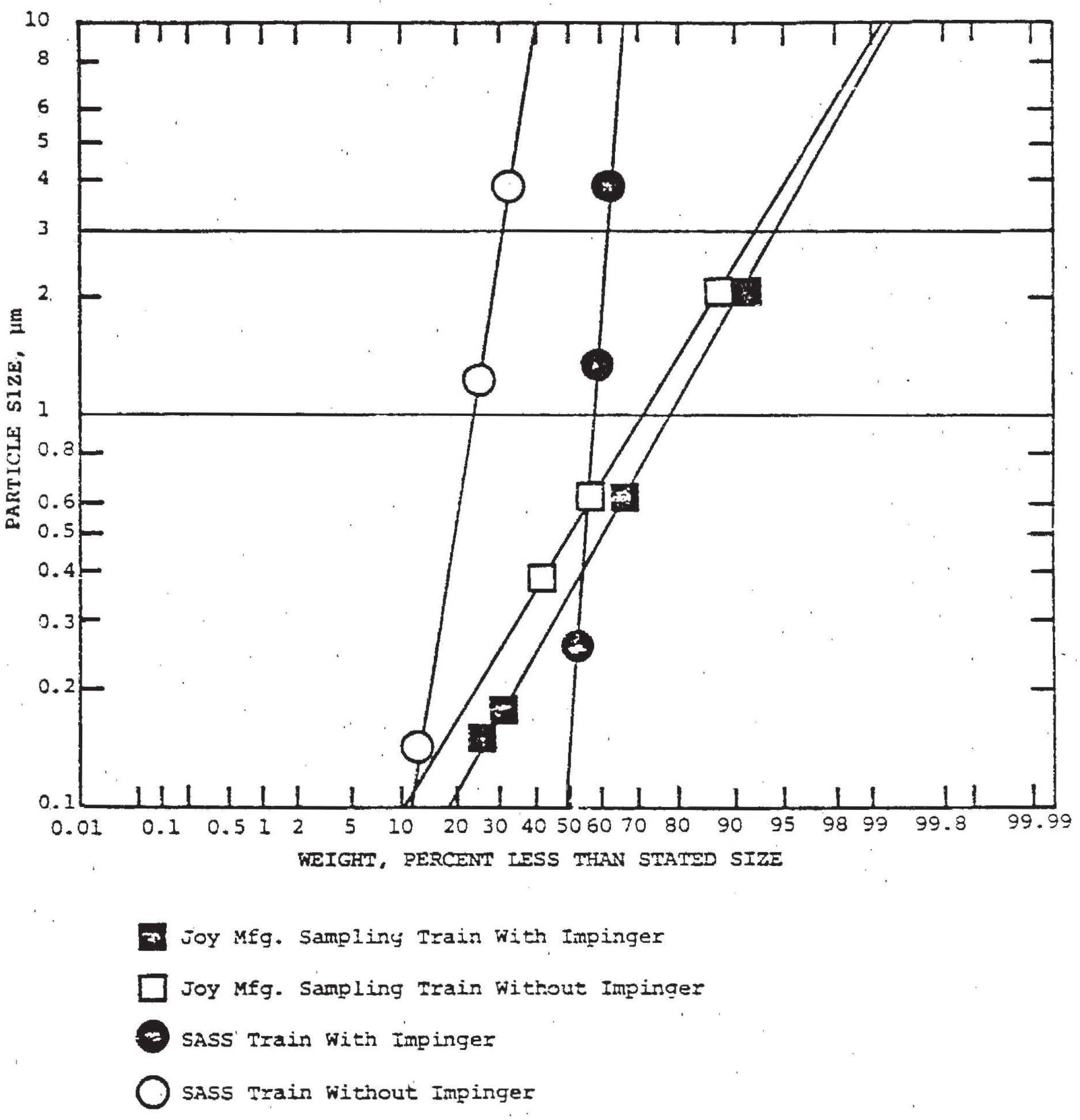


Figure 4-71. Particle size distribution for spray booth (Test 27). (Water Base)

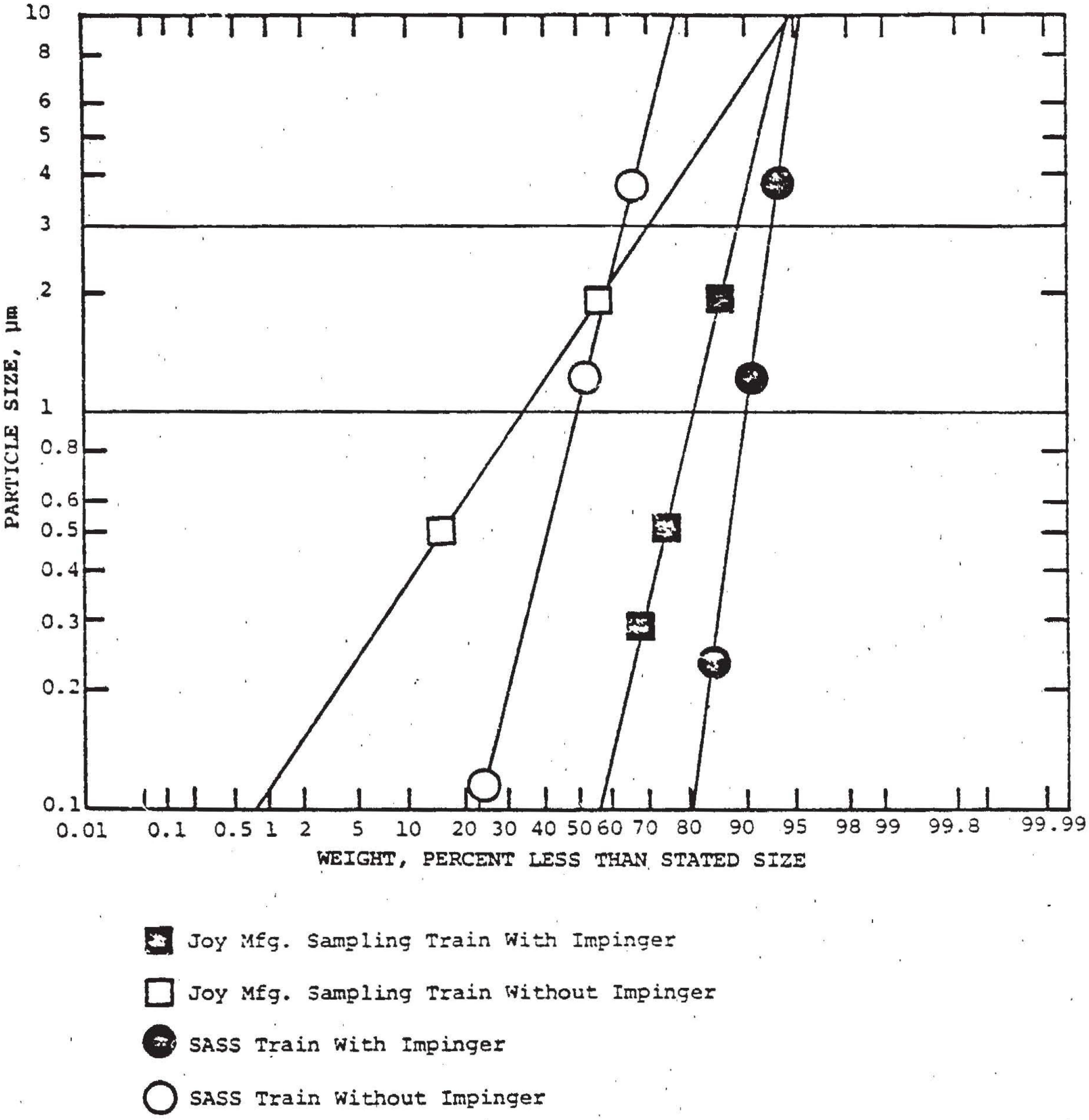


Figure 4-72. Particle size distribution for spray booth (Test 31). (Oil Base)

PERCENT OF PARTICLES

		>10µm	10-3µm	3-1µm	<1µm
Test 27S		60	8	8	24
Test 27J		1	6	21	72
Test 31S		22	13	15	50
Test 31J		5	23	36	36
	Average	22	16	17	45

The mean particle size is about 1µm.

2. Chemical composition-- Table 4-77 lists the results from the chemical analysis of the particulate fraction for each of the tests discussed in this section. However, the only sample with sufficient mass for chemical analysis was the 10 µm cyclone cut on Test 27S. Even this sample had insufficient mass for carbon analysis. Of the elements detected, sulfur was most abundant; titanium and iron were next. It is believed that about 50 to 60% of the material is carbon and most of the remaining is oxygen.

3. Emissions and emission factors-- Emissions and emission factors can be listed with several different units. The following lists some of these emissions and factors based on the total flow from the sum of the stacks in each test.

Units	Test 27S (WB)	Test 27J (WB)	Test 31S (OB)	Test 31J (OB)
gr/DSCF	.0037	.0033	.0025	.0028
T/yr	5.8	5.1	6.9	7.8
lb/hr	2.9	2.6	5.0	5.7

4.2.23 Wood Processing

Milling, molding, resaw (cross cut and ripping) and sanding are the most common types of wood processing operations in the Basin. Two of these types were tested by KVB and are discussed in this section. These are (1) sanding operation of veneer section for door manufacturing, and (2) resaw operation where large beams and planks are reduced to boards for sale at various building supply facilities.

TABLE 4-77. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR PAINT SPRAY BOOTHS

SAMPLE #	10μm - Cyclone (Water Base) 27S-2S
WT. PERCENT OF CUT	22
XRF ANALYSIS	
Calcium	t
Iron	t
(Sulfur)	(<4)
Titanium	2.7/0.3
TOTAL[1]	4
Sulfates (H_2O sol)[2]	1.88
(Sulfur (from $SO_4^{=}$))[4]	t
Nitrate (H_2O sol)[2]	t
Total Carbon[3]	-- Not Enough
(Volatile Carbon)[3]	-- Sample for Analysis
(Carbonates)[3]	--
TOTAL ANALYZED	6
BALANCE	94
	100%

t detected in concentration of <1%

1 analyzed by x-ray fluorescence--Section 3.2.2 B

2 analyzed by wet chemistry--Section 3.2.2 A

3 analyzed by Oceanography carbon analyzer--Section 3.2.2 A

4 calculated from sulfates (sulfur=sulfate/3) to compare with sulfur from XRF

5 for values shown as X/Y, X is % of the element present and Y is the error (i.e. X% ± Y)

( ) not included in total--sulfur and sulfates are accounted for in sulfur XRF analysis and volatile carbon and carbonate are accounted for in total carbon

A. Process Description--

1. Sanding operation (Test 30)-- Figure 4-73 is a schematic drawing of the sanding operation's particulate control system tested. Sawdust is picked up in the hooded section over the belt sander where the veneer section is being sanded. The sawdust is transported from the hood to a cyclone which removes large particles, then to a baghouse which removes the finer particles to prevent them from entering the atmosphere.

2. Resawing operation (Test 39)-- Figure 4-74 shows the flow of sawdust from a typical resaw operation. The sawdust generated from the rapping plank is pneumatically conveyed to a cyclone where the wood particles are collected and the air returned to the atmosphere.

B. Particulate Test Setup--

1. Sanding operation--Three sampling trains (Method 5, Joy Train and SASS Train) were used simultaneously to sample the inlet and exit of the cyclone baghouse. The inlet station to the cyclone was located about eight feet from the inlet. The cyclone outlet/baghouse inlet station was located about three feet from the the baghouse inlet. The baghouse outlet station was located at the top of the duct leading to the atmosphere. The velocity profiles of each of these are listed in Table 4-78. The velocity in the baghouse exit was determined using an anemometer because of the low velocity distributed over both exits.

2. Resaw operations--Two sampling trains (Joy Train and SASS Train) were simultaneously to sample the inlet and exit of the cyclone. The inlet station was located on the horizontal duct about nine feet from the inlet to the cyclone. The outlet station was located on top of the cyclone at its exit. The velocity in the center of the cyclone outlet is listed in Table 4-79. Note that the velocity in the center of the cyclone outlet is negative (i.e., the flow is reversed) and the velocity at the edges is the highest. This is normal for cyclones.

C. Test Results--

The results of the tests (Tests 30S, 30J, 30 No. 5, 39S, and 39J) discussed in this section are listed in Table 4-1. Major elemental composition sulfate, nitrate, and carbon analysis were determined for all fractions of

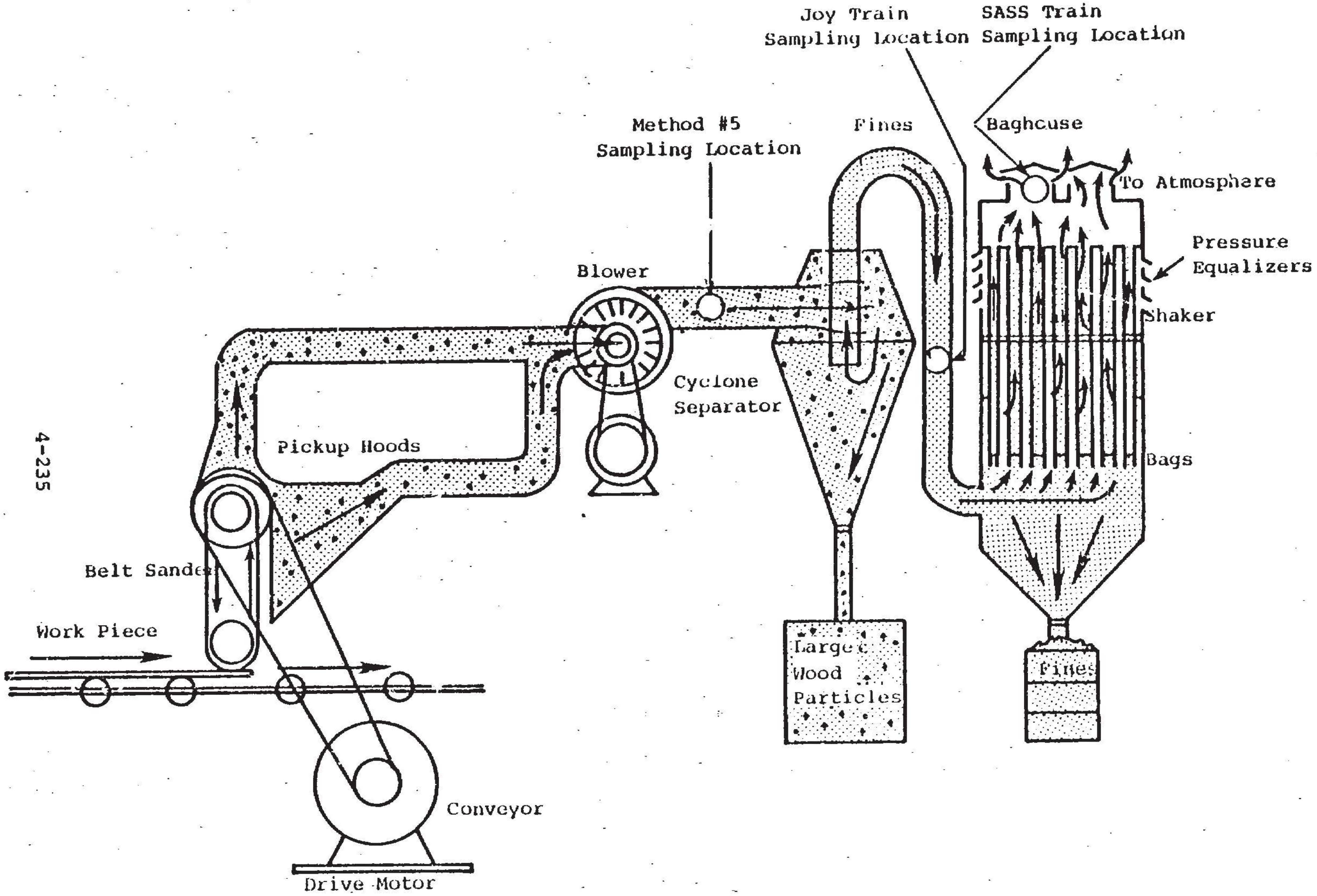


Figure 4-73. Wood sanding with particulate controls. KVB 5806-783

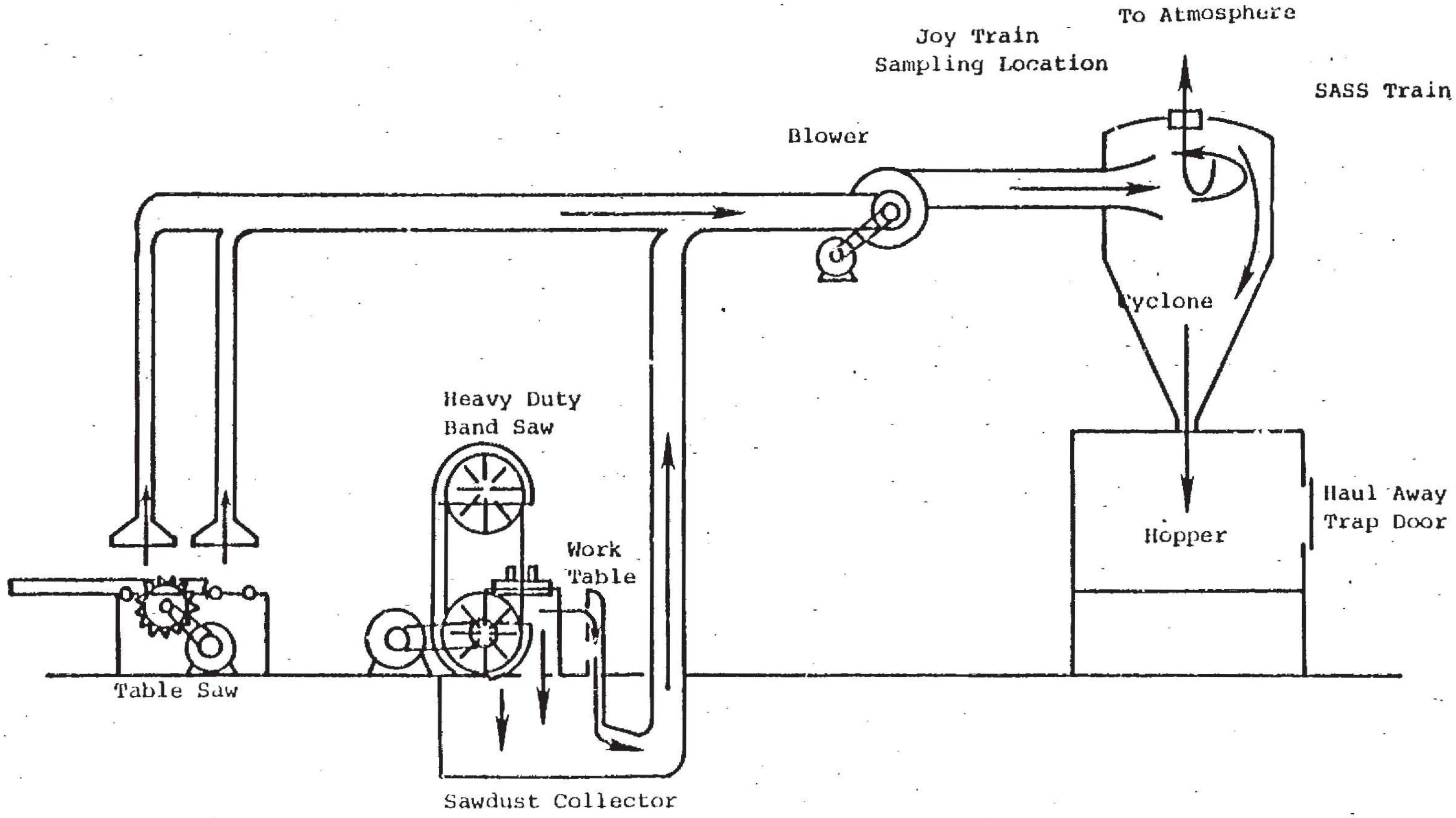
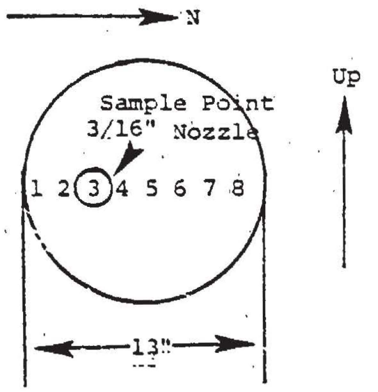


Figure 4-74. Wood resawing with particulate controls.

TABLE 4-78. VELOCITY PROFILE FOR WOOD SANDING OPERATION (TEST 30)

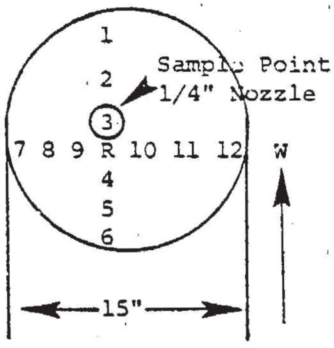
Cyclone Inlet



Temperature - 73 °F
Static Pressure - +5.5" H_2O

Distance From Edge of Duct	Velocity	
	Point No.	ft/sec
0.4"	1	61.4
1.4"	2	63.2
2.5"	3	70.2
4.5"	4	76.3
6.5"	R	79.2
9.0"	5	73.3
10.5"	6	67.0
11.6"	7	63.5
12.5"	8	56.8
Average		70.0
		4384 SCFM

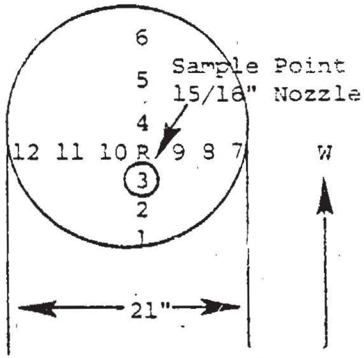
Cyclone Outlet
Baghouse Inlet



Temperature - 78 °F
Static Pressure - +2.1" H_2O

Distance From Edge of Duct	Velocity	
	Point No.	ft/sec
5/8"	1	38.0
2-1/4	2	30.1
4-3/8	3	31.6
7-1/2	R	33.6
10-1/2	4	52.5
12-3/4	5	51.7
14-3/8	6	45.6
5/8	7	27.7
2-1/4	8	36.8
4-3/8	9	36.8
7-1/2	R	33.6
10-1/2	10	23.3
12-3/4	11	24.2
14-3/8	12	32.9
Average		58.6
		4180 SCFM

Baghouse Outlet
One of Two

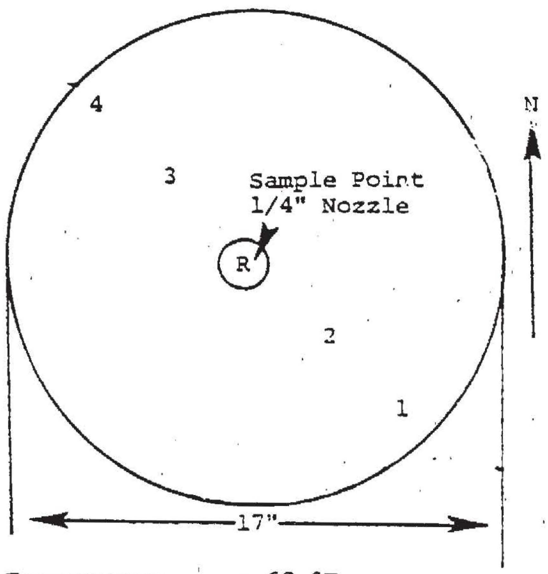


Temperature - 79 °F
Static Pressure - Ambient

Distance From Edge of Duct	Velocity	
	Point No.	ft/sec
0.1"	1	15
3.0"	2	15
6-1/8"	3	15
10.5"	R	15
14.88"	4	15
18.0"	5	15
20.0"	6	15
0.9"	7	15
3.0"	8	15
6-1/8"	9	15
10-5"	R	15
14.88"	10	15
18.0"	11	15
20.0"	12	15
Average	15	
		4206 SCFM

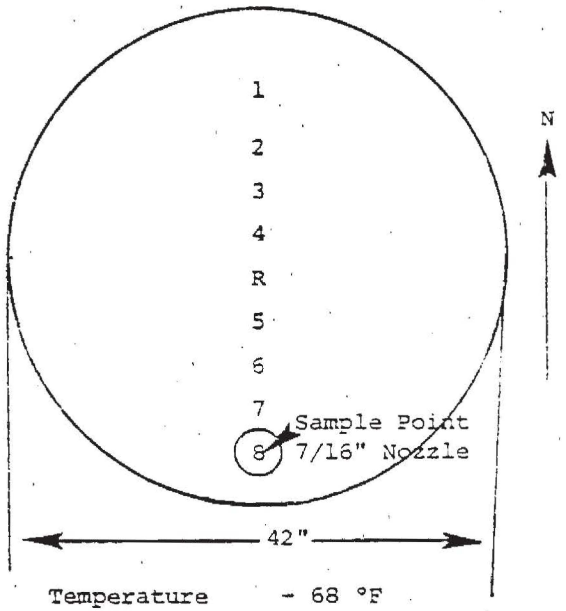
TABLE 4-79. VELOCITY PROFILE FOR WOOD RESAW OPERATION (TEST 39)

Cyclone Inlet



Temperature - 68 °F
Static Pressure - +0.2" H_2O

Cyclone Outlet



Temperature - 68 °F
Static Pressure - 0.1" H_2O

Distance From Edge of Duct	Point No.	Velocity ft/sec
1.5	1	66.6
4.25	2	69.9
8.5	R	69.9
12.75	3	73.0
15.5	4	76.0
	Average	71.8
		6703 SCFM

Distance From Edge of Duct	Point No.	Velocity ft/sec
1.4	1	53.7
4.4	2	42.1
8.0	3	13.3
13.5	4	0
21.0	R	-23.2
28.5	5	0
33.8	6	13.3
37.6	7	44.2
41.4	8	70.4
	Average	26.2
		6546 SCFM

particulate catches which contained weights in excess of 100 mg. The details for these procedures are discussed in Section 3.2.2. Table 4-80 lists the results from this analysis for Tests 30 and 39.

D. Discussion of Results

1. Efficiency of particulate control equipment

a. Sanding operation

Using the solid weight data (does not include impinger catch) from both inlet and outlet of the cyclone and inlet and outlet to the baghouse, the efficiency was calculated to be 98.4% for the cyclone and 96.3% for the baghouse. Therefore, the overall efficiency of the system is 99.94%. Using the total catch including the impinger catch the efficiency is 98.2% for the cyclone, 86.9% for the baghouse and for overall efficiency of 99.8%.

b. Resaw operation

Using the solid weight data, the efficiency of the cyclone was calculated to be 99.2%, and using the total catch the efficiency is 99.1%.

2. Particle size distribution

Figures 4-75 and 4-76 are plots of particle size (μm) versus accumulated weight percent, the latter plotted on a probability scale as explained in Section 3.2.3B. Two sets of curves are presented, one including the impinger catch and the other ignoring it. Considering the nature of the gas stream, it would seem that the effects of pseudo particulates would be present. Therefore, the impinger catch was believed to be properly included in the measurements of the suspended particulates. The breakdown of the particle size distribution, including the impinger catch, is as follows:

PERCENT OF PARTICLES

	>10μm	10-3μm	3-1μm	<1μm
Sanding:				
Test 30S (Baghouse outlet)	8	3	3	86
Test 30J (Baghouse inlet / Cyclone outlet)	42	10	12	36
Test 30 No. 5 (cyclone inlet)	87		13	
Resaw:				
Test 39S (Cyclone outlet)	60	11	9	20
Test 39J (Cyclone inlet)	99	0.3	0.3	0.7

TABLE 4-80. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR WOOD PROCESSING

SAMPLE #	SASS 10µm Cyclone 39S-2S	JOY 10µm Cyclone 39J-2S	Method 5 Cyclone 30-5-2S
WT. PERCENT OF CUT	55	68	87
XRF ANALYSIS			
Calcium	t	t	t
(Sulfur)	(<2)	(<3)	(<2)
TOTAL[1]	t	t	t
Sulfates, (H_2O sol)[2]	t	-	-
(Sulfur (from $SO_4^=$)[4]	(t)	-	-
Nitrate (H_2O sol)[2]	t	t	-
Total Carbon[3]	61	42	41
(Volatile Carbon)[3]	(58)	(39)	(35)
(Carbonates)[3]	-	-	t
TOTAL ANALYZED	61	42	41
BALANCE	39	58	59
	100%	100%	100%

t detected in concentration of <1%

[1] analyzed by x-ray fluorescence--Section 3.2.2 B

[2] analyzed by wet chemistry--Section 3.2.2 A

[3] analyzed by Oceanography carbon analyzer--Section 3.2.2 A

[4] calculated from sulfates (sulfur=sulfate/3) to compare with sulfur from XRF

[5] for values shown as X/Y, X is % of the element present and Y is the error (i.e. X% ± Y)

( ) not included in total--sulfur and sulfates are accounted for in sulfur XRF analysis and volatile carbon and carbonate are accounted for in total carbon

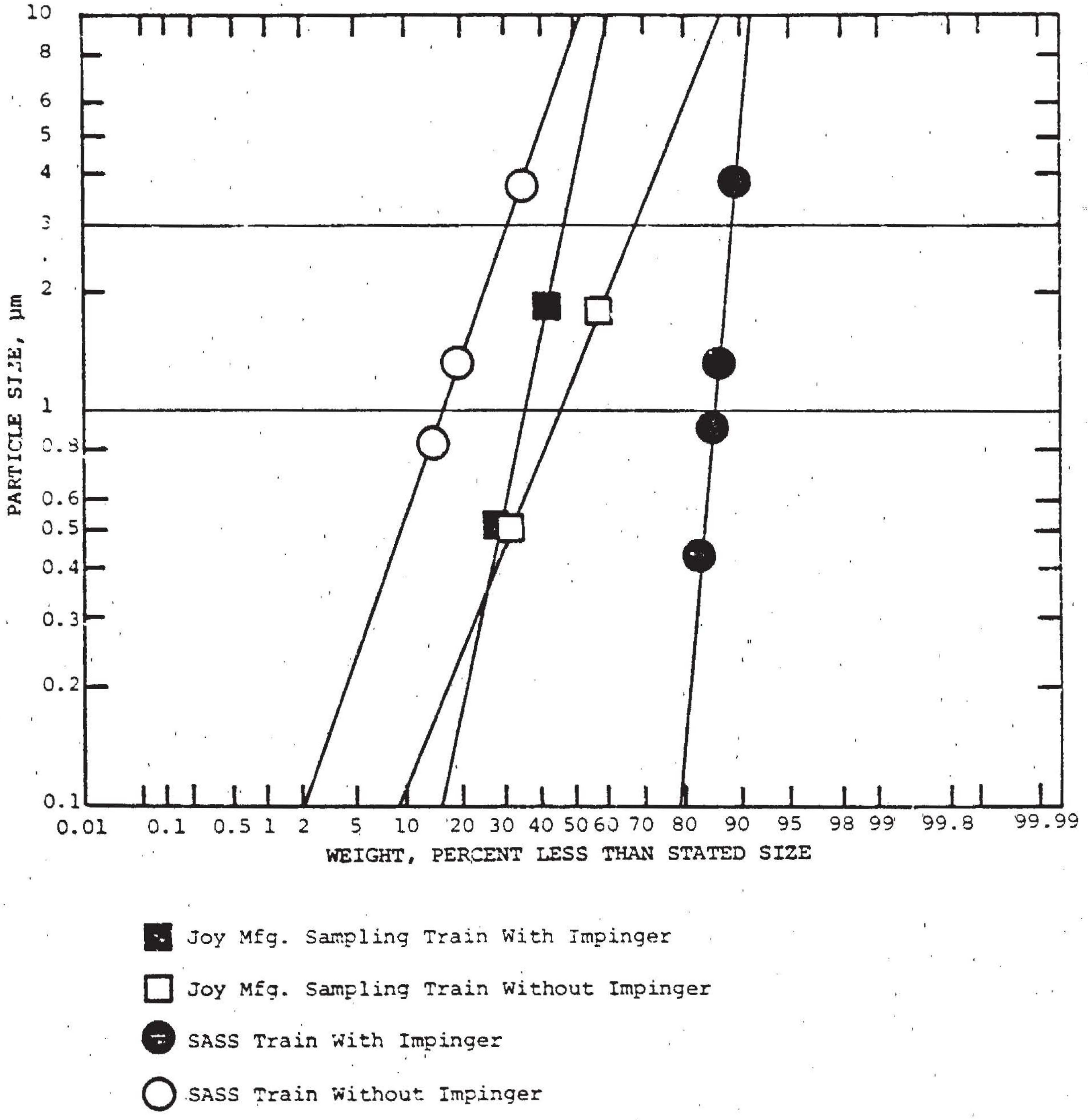


Figure 4-75. Particle size distribution for wood sanding operation (Test 30).

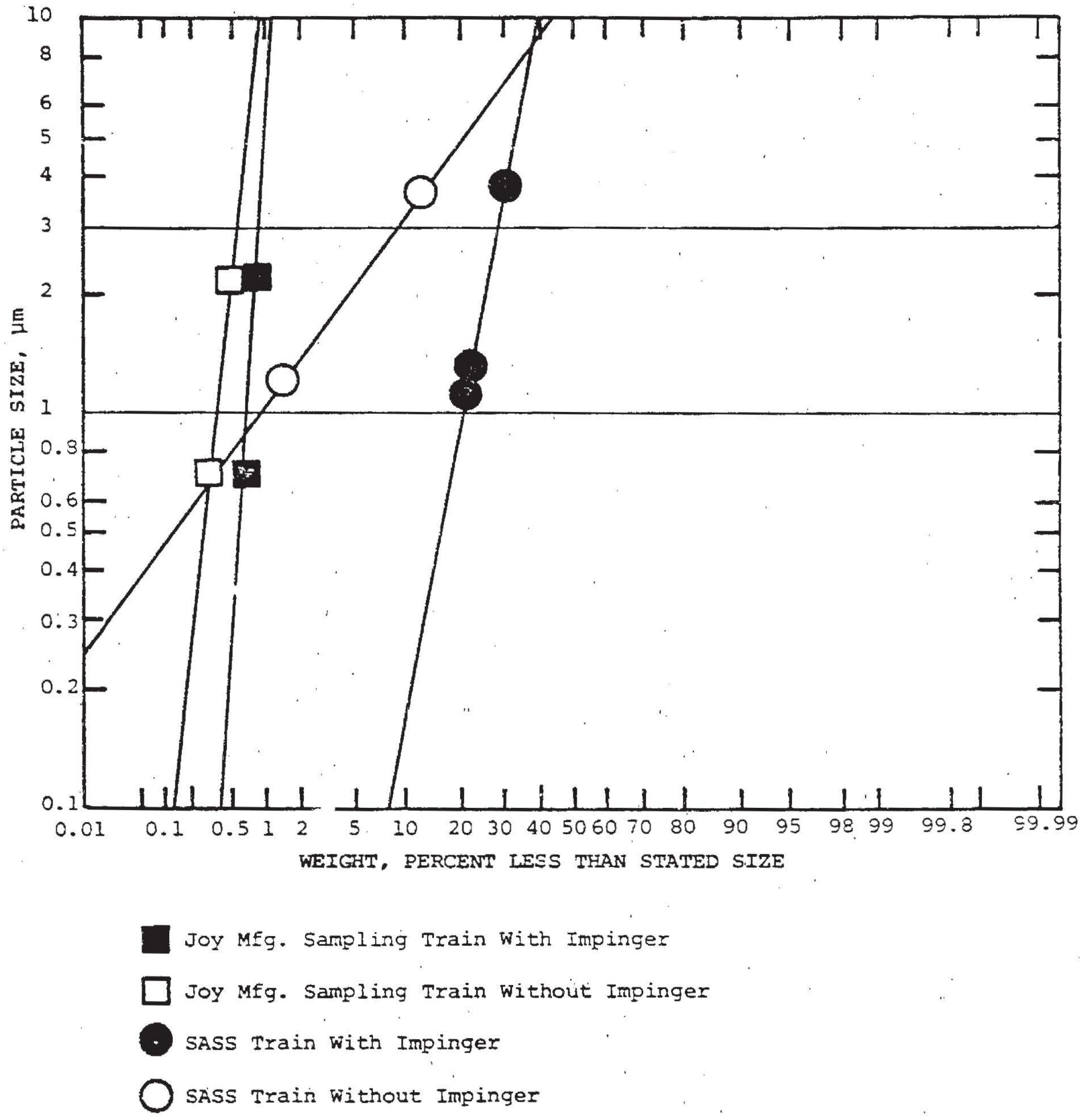


Figure 4-76. Particle size distribution for wood Resawing operation (Test 39).

Figure 4-76 is the size distribution plot for the resaw operation. Note: The particle size for uncontrolled wood operations is 85 to 99% >10μm, and for that controlled with cyclone is 20 to 36% <1μm, and baghouse control is 86% <1μm.

3. Chemical composition-- Table 4-80 lists the results from the chemical analysis of the particulate fraction for each of the tests discussed in this section. The chemical composition for both resaw and sanding operations is very similar. As expected the most abundant species is carbon in the form of volatile carbon. A few other elements were detected in trace quanitities only. The small amount of detected is attributed to the chemical bound sulfur in the wood.

4. Emissions and emission factors-- Emissions and emission factors can be listed with several different units. The following lists some of these emissions and factors.

	Uncontrolled		Cyclone Controlled		Baghouse Controlled
Units:	30-5	39J	30J	39S	30S
gr/DSCF	0.931	0.366	0.0168	0.003	0.002
T/yr	36.5	21.0	0.6	0.2	0.1
lb/hr	35.1	20.0	0.6	0.2	0.08
lb/hr (Ref. 4-42)	--	--	0.2/30	0.03/24	9.2/30

4.2.24 Refinery Process Heaters

A. Process Description (Ref. 4-43)

Refinery oil heaters usually are likely to be fired with a variety of refinery by-product fuels, both gaseous and liquid. A typical vertical, cylindrical refinery heater similar to that tested for particulates in this study is shown in Figure 4-77. The unit tested was used for heating and was fueled with natural gas.

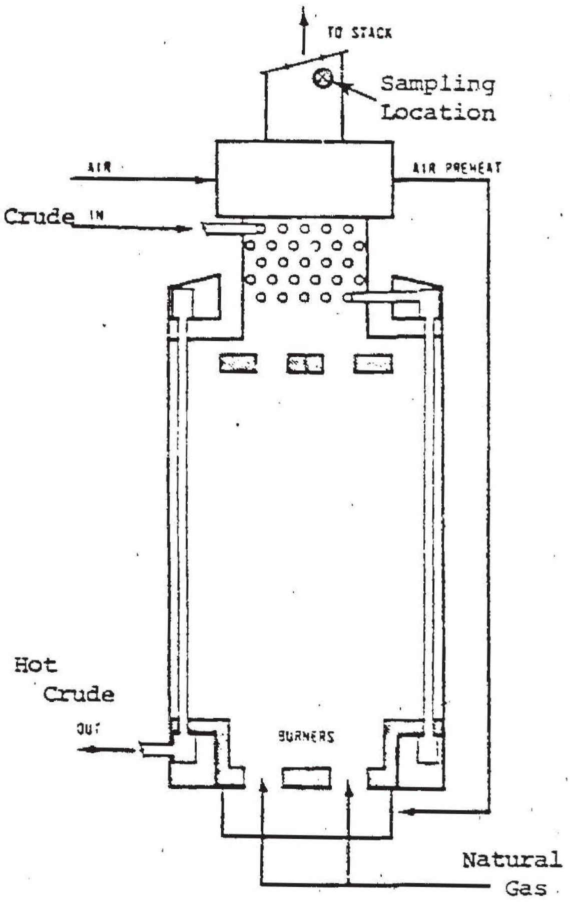


Figure 4-77. A vertical cylindrical refinery heater. (Ref. 4-43)

B. Particulate Test Setup--

Due to the accessability of the test station, only the larger SASS train was used at this test site. The sampling station was located on the vertical section of the exhaust stack about five feet above the preheat air section. The sampling port was approximately eight feet above the steel catwalk which was about 70 feet above ground level. The velocity profile in the stack at this location is listed in Table 4-81. The particulate sample was taken at Velocity Point 2 with a 1-1/4 inch nozzle. The fuel for the process heater was natural gas.

C. Test Results--

The results of the test (Test 40S) discussed in this section are listed in Table 4-1. Elemental composition, sulfate, nitrate, and carbon analysis were determined for all fraction of particulate catches which contained weights in excess of 100 mg. The details for these procedures are discussed in Section 3.2.2. Table 4-82 lists the results from this analysis.

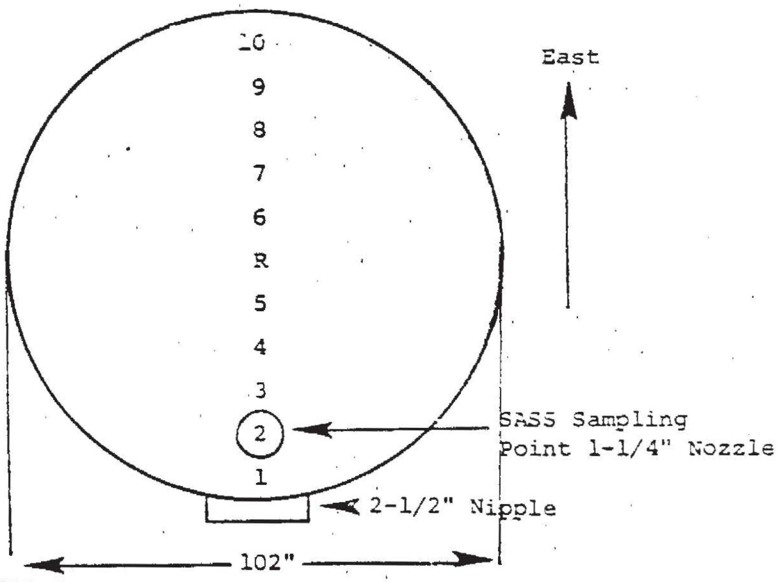
D. Discussion of Results--

1. Particle size distribution-- Figure 4-78 is a plot of particle size (µm) versus accumulated weight percent, the latter plotted on a probability scale as explained in Section 3.2.3B. Two curves are presented, one including the impinger catch, and the other ignoring it. Considering the large amount of material (over 80%) collected in the impinger it would seem that the effect of pseudo particulates would be insignificant. Therefore, the impinger catch was believed to be properly included in the measurements of the suspended particulates from refinery process heaters. The breakdown of the particle size distribution taken from Figure 4-78, including the impinger catch, is as follows:

PERCENT OF PARTICLES

	>10µm	10-3µm	3-1µm	<1µm
Test 40S	4.5	2	1.5	91

TABLE 4-81. VELOCITY PROFILE FOR PROCESS HEATER (TEST 40S)



Temperature - 460 °F
Static Pressure - -0.95" H_2O

Distance From End of Port	Point No.	Velocity ft/sec
4-5/8	1	16.5
10-7/8	2	12.7
17-1/4	3	12.7
25-5/8	4	10.4
37-5/8	5	10.4
53-1/2	R	7.4
69-3/8	6	7.4
81-3/8	7	16.5
89-3/4	8	16.5
96-1/8	9	16.5
102-1/4	10	15.2
	Average	13.4 ft/sec 18900 SCFM

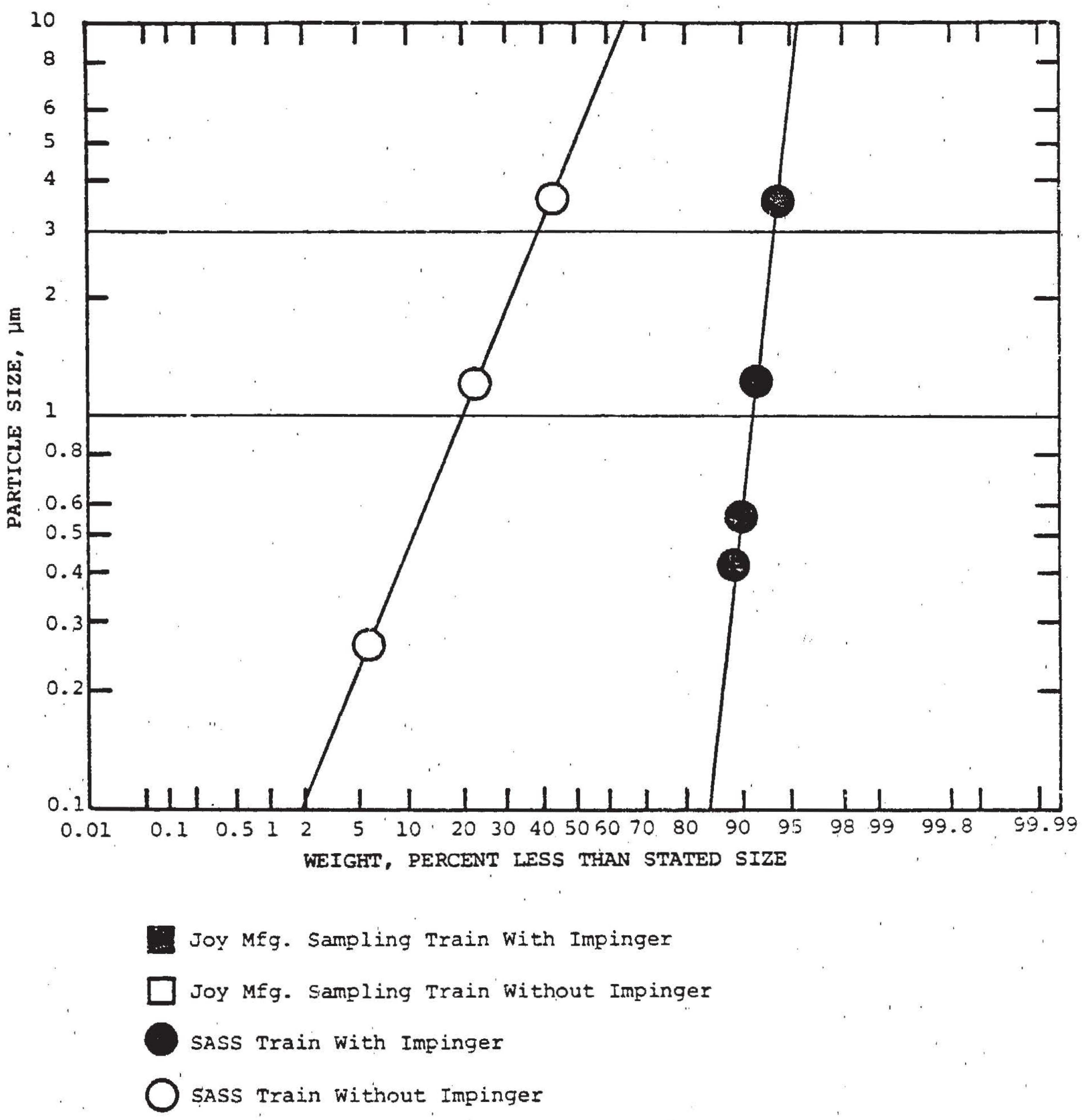


Figure 4-78. Particle size distribution for refinery process heater (Test 40).

2. Chemical composition-- Table 4-82 lists the results from the chemical analysis of the particulate fraction for the test discussed in this section. The only fraction with enough sample for chemical analysis was the impinger catch. Sulfates are most abundant in this sample. Carbon and calcium are next and all other elements are in trace (<1%) amounts.

3. Emissions and emission factors-- Emissions and emission factors can be listed with several different units. The following lists some of these emissions and factors:

	Test 40S
gr/DSCF	0.00424
T/yr	2.6
lb/hr	0.59
lb/MMBtu	0.0066
lb/Million ft^3 Burned	9.0
lb/Million ft^3 Burned (Ref. 4-44)	20

4.2.25 Catalytic Cracking

A. Process Description (Ref. 4-45)--

In the cracking operation, large molecules are decomposed by heat, pressure, and catalysis into smaller, lower-boiling molecules. Simultaneously, some of the molecules combine (polymerize) to form larger molecules. Products of cracking are gaseous hydrocarbons, gasoline, gas oil, fuel oil, and coke.

In fluidized bed catalytic cracker, finely powdered catalyst is lifted into the reactor by the incoming heated oil charge, which vaporizes upon contact with the hot catalyst. Spent catalyst settles out in the reactor, is drawn off at a controlled rate, purged with steam, and lifted by an air stream into the regenerator where the deposited coke is burned off.

Particulate emission from these units are in the combustion gases and from catalyst fines that may be discharged by vents on the catalyst

TABLE 4-82. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR REFINERY PROCESS HEATERS

(Natural Gas Fuel)

SAMPLE #	SASS Impinger 40S-IC
WT. PERCENT OF CUT	81
XRF ANALYSIS	
Calcium	5.2/1
Chromium	t
Cobalt	t
Iron	t
Nickel	t
Selenium	t
(Sulfur)	(20/7)
Zinc	t
TOTAL[1]	9
Sulfates, H_2O sol[2]	47
(Sulfur, from SO_4)[4]	16
Nitrate (H_2O sol)[2]	t
Total Carbon[3]	7
(Volatile Carbon)[3]	(7)
(Carbonates)[3]	-
TOTAL ANALYZED	62
BALANCE	38
	100%

---

t detected in concentration of <1%

1 analyzed by x-ray fluorescence--Section 3.2.2 B

2 analyzed by wet chemistry--Section 3.2.2 A

3 analyzed by Oceanography carbon analyzer--Section 3.2.2 A

4 calculated from sulfates (sulfur=sulfate/3) to compare with sulfur from XRF

5 for values shown as X/Y, X is % of the element present and Y is the error (i.e. X% ± Y)

( ) not included in total--sulfur and sulfates are accounted for in sulfur XRF analysis and volatile carbon and carbonate are accounted for in total carbon

handling system on the FCC Units. Control measures commonly used on regenerators consist of cyclones and electrostatic precipitators to remove particulates and energy-recovery combustors to reduce carbon monoxide emissions. The latter process, called a CO boiler, recovers the heat of combustion of the CO to produce refinery process steam. The exhaust of a CO boiler was sampled for fine particulates on this program.

B. Particulate Test Setup

The only available sampling ports were located downstream of the CO boiler. The sampling station was located in a vertical section of the tapered stack at a diameter of 96 in. The sampling port was 30 ft. downstream of the exhaust gas inlet to the ESP stack and 30 ft. below the stack exist. The velocity profile in the stack is listed in Table 4-83. The particulate sample was taken at traverse point four with a one inch nozzle.

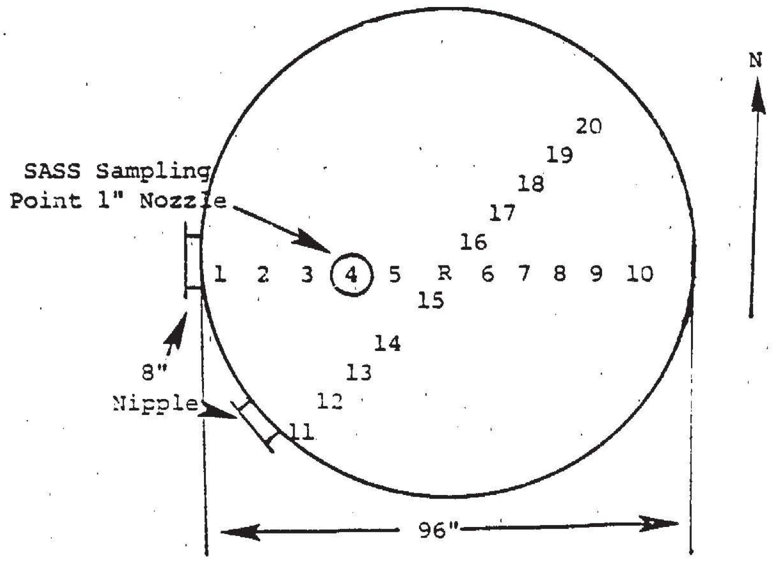
C. Test Results

The results of the test (Test 41S) discussed in this section are listed in Table 4-1. Elemental composition, sulfate, nitrate, and carbon analysis were determined for all fractions of particulate catches which contained weights in excess of 100 mg. The details for these procedures are discussed in Section 3.2.2. Table 4-84 lists the results from this analysis.

D. Discussion of Results--

1. Particle size distribution--Figure 4-79 is a plot of particle size (μm) versus accumulated weight percent, the latter plotted on a probability scale as explained in Section 3.2.3 B. Two curves are presented, one including the impinger catch, and the other ignoring it. Considering that about 25% of the total catch was in the impinger and the nature of the flue gases, it would seem that the effect of pseudo particulates was present. Therefore, the impinger catch was believed to be properly not included in the measurements of the suspended particulates from CO boilers - FCC units for particle size distribution. The breakdown of the particle size distribution taken from Figure 4-79, not including the impinger catch, is as follows.

TABLE 4-83. VELOCITY PROFILE FOR CO BOILER EXHAUST (TEST 41S)



Temperature - 565 °F
Static Pressure - +0.5" H_2O

Distance From Edge of Port	Velocity			
	Point No.	ft/sec	Point No.	ft/sec
10-1/8	1	13.5	11	21.8
15-7/8	2	13.5	12	29.9
21-7/8	3	11.0	13	27.9
29-3/4	4	27.0	14	24.4
41	5	27.0	15	25.6
56	R	28.0	R	27.9
71	6	27.0	16	25.6
82-1/4	7	22.0	17	18.9
90-1/8	8	22.0	18	15.5
96-1/8	9	11.0	19	13.4
101-7/8	10	11.0	20	10.9
			Average	20.4 ft/sec
				31399 SCFM

TABLE 4-84. CHEMICAL COMPOSITIION OF PARTICULATE SAMPLES IN PERCENT FOR CO BOILER - FCC UNIT

SAMPLE #	10µm Cyclone 41S-2S	1 µm Cyclone 41S-4S	Filter 41S-5S	Impinger 41S-IC
WT. PERCENT OF CUT	25	4.3	1.7	24
XRF ANALYSIS				
Lanthanum	t	t	t	
Cesium	1.1/0.2	1.1/0.2	1.6/0.4	
Arsenic			t	
Paseodymium	t	t		
Neodymium	t	t	t	
Calcium			15/6	
Iron	t	1.1/0.2	1.3/0.3	t
Silicon	20	20		
(Sulfur)	(8)	(3)	(8)	19/7
Titanium	t	t	t	
TOTAL[1]	24	24	20	t
Sulfates, H_2O sol[2]	6.8	1.6	5.1	54.4
(Sulfur (from $SO_4^{=}$)[4]	(2.2)	t	(1.7)	(15.0)
Nitrate (H_2O sol)[2]				
Total Carbon[3]				4.59
(Volatile Carbon)[3]				(3.41)
(Carbonates)[3]				
TOTAL ANALYZED	31	26	25	59
BALANCE	69	74	75	41
	100%	100%	100%	100%

t	detected in concentration of <1%
1	analyzed by x-ray fluorescence—Section 3.2.2 B
2	analyzed by wet chemistry—Section 3.2.2 A
3	analyzed by Oceanography carbon analyzer--Section 3.2.2 A
4	calculated from sulfates (sulfur=sulfate/3) to compare with sulfur from XRF
5	for values shown as X/Y, X is % of the element present and Y is the error (i.e. X% ± Y)
( )	not included in total—sulfur and sulfates are accounted for in sulfur XRF analysis and volatile carbon and carbonate are accounted for in total carbon

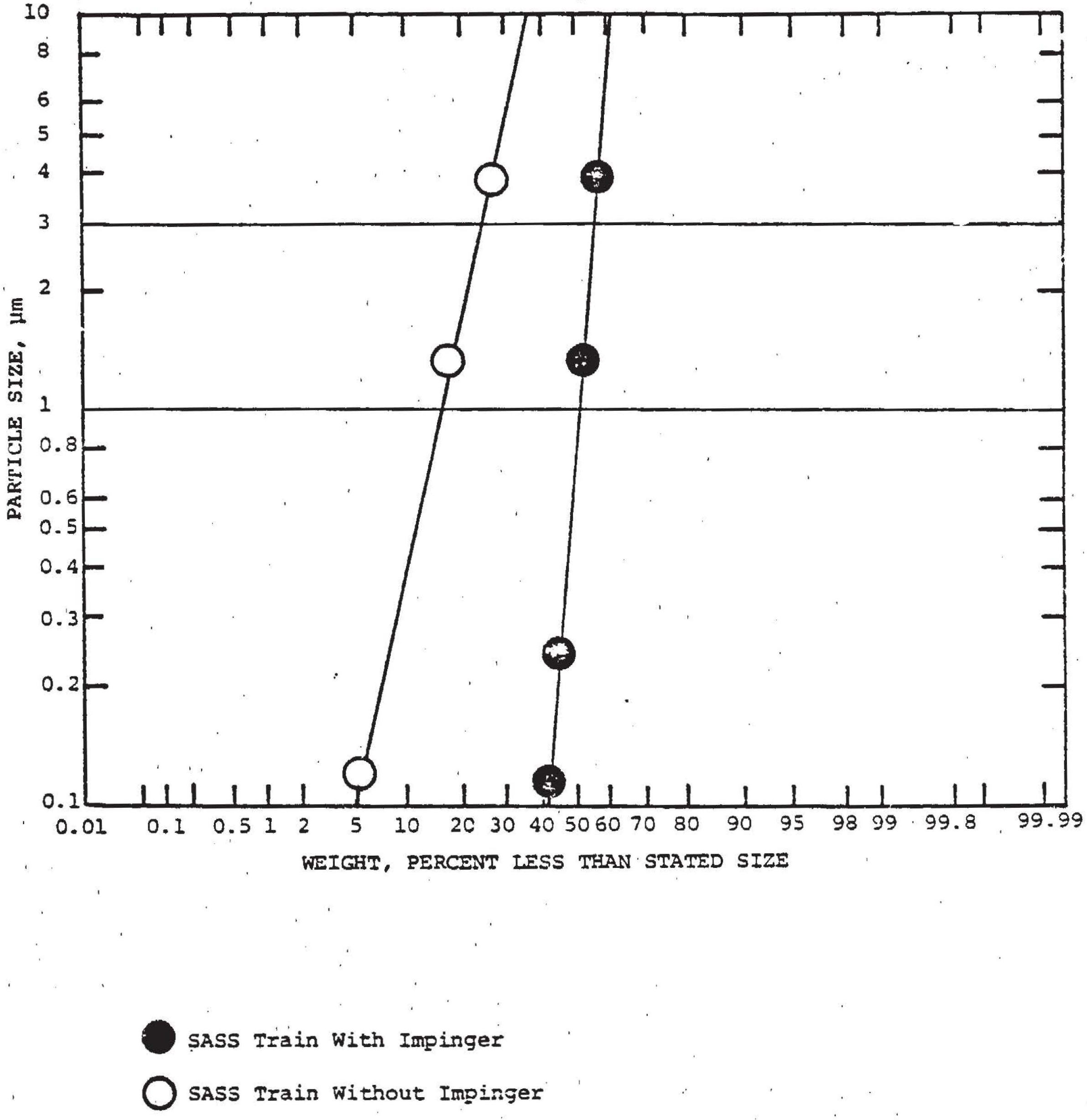


Figure 4-79. Particle size distribution for CO boiler - FCC Unit. (Test 41)

PERCENT OF PARTICLES

	>10μm	10-3μm	3-1μm	<1μm
Test 41S	63	12	9	16

The mean particle size, not including the impinger catch, was about 30μm. If the impinger catch is included, the mean size was about 1μm.

2. Chemical composition--Table 4-84 lists the results from the chemical analysis of the particulate fraction for each of the tests discussed in this section. Sulfates dominated in the impinger catch and was about ten fold less in the other fraction of the particulate catch. Silicon was high: 20% in the cyclone catches. Calcium was the most abundant element on the filter. Some unusual elements (lanthanum, cerium, praseudymium, neodymium) were detected in concentrations between 0.5 to one percent for the solid fraction of the catch.

3. Emissions and emission factors--Emissions and emission factors can be listed with several different units. The following chart lists some of these emissions and factors:

Units	Test 41S
gr/DSCF	0.055
T/yr	62.33
lb/hr	14.84
lb/1000 bbls fresh feed	32
lb/1000 bbls fresh feed (Ref. 4-45)	45

4.2.26 Alfalfa Dehydration

An alfalfa dehydrating plant produces an animal feed from alfalfa. (Ref. 4-46) The dehydration and grinding of alfala that produces alfalfa meal is a dusty operation most commonly carried out in rural areas.

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

Sources of dust emissions are the primary cyclone, the grinders, and the air-meal separator. Overall dust losses have been reported as high as 7% (Ref. 4-47), but average losses are around 3% by weight of the meal produced (Ref. 4-48). The use of a baghouse as a secondary collection system can greatly reduce emissions. KVB attempted to conduct alfalfa dehydrator tests for several months during the Phase II test program. Several scheduled tests were cancelled due to equipment failure. Therefore the data presented in this section are those taken by the Imperial County Air Pollution Control office. The results of the tests are listed in Table 4-85. The EPA Method #5 was used to obtain TSP data and an Andersen impactor was used to determine the particle size distribution. Figure 4-80 is a plot of particle size (µm) vs accumulated weight percent, the latter plotted on a probability scale as explained in Section 3.2.3 B. The breakdown of the particle size distribution taken from Figure 4-80 which does not include the impinger catch, is as follows.

	Percent of Particle			
Alfalfa Dehydration	>10µm	10-3µm	3-1µm	<1µm
Test 1	68	6	6	20
Test 2	76	6	4	14

The mean particle size is about 60µm.

TABLE 4-85. ALFALFA DEHYDRATION TEST RESULTS

	Measured Emissions		
Test No.	1	2	Average
Date of Test	11-18-76	11-18-76	
Duration of Test, minutes	60	60	60
Process Weight Rate, lbs/hr	20,000	20,000	20,000
Gas Flow Rate, SCFM (DRY)	9908	9616	9762
Stack Gas Temp., °F	185	183	184
CO_2 % by vol.	1	1	1
O_2 % by vol.	20	20	20
CO % by vol.	0	0	0
H_2O % by vol.	20	17	18.5
Particulate Concentration, gr/scf	0.11	0.11	0.11
Particulate Weight, lbs/hr	9.02	9.78	9.4

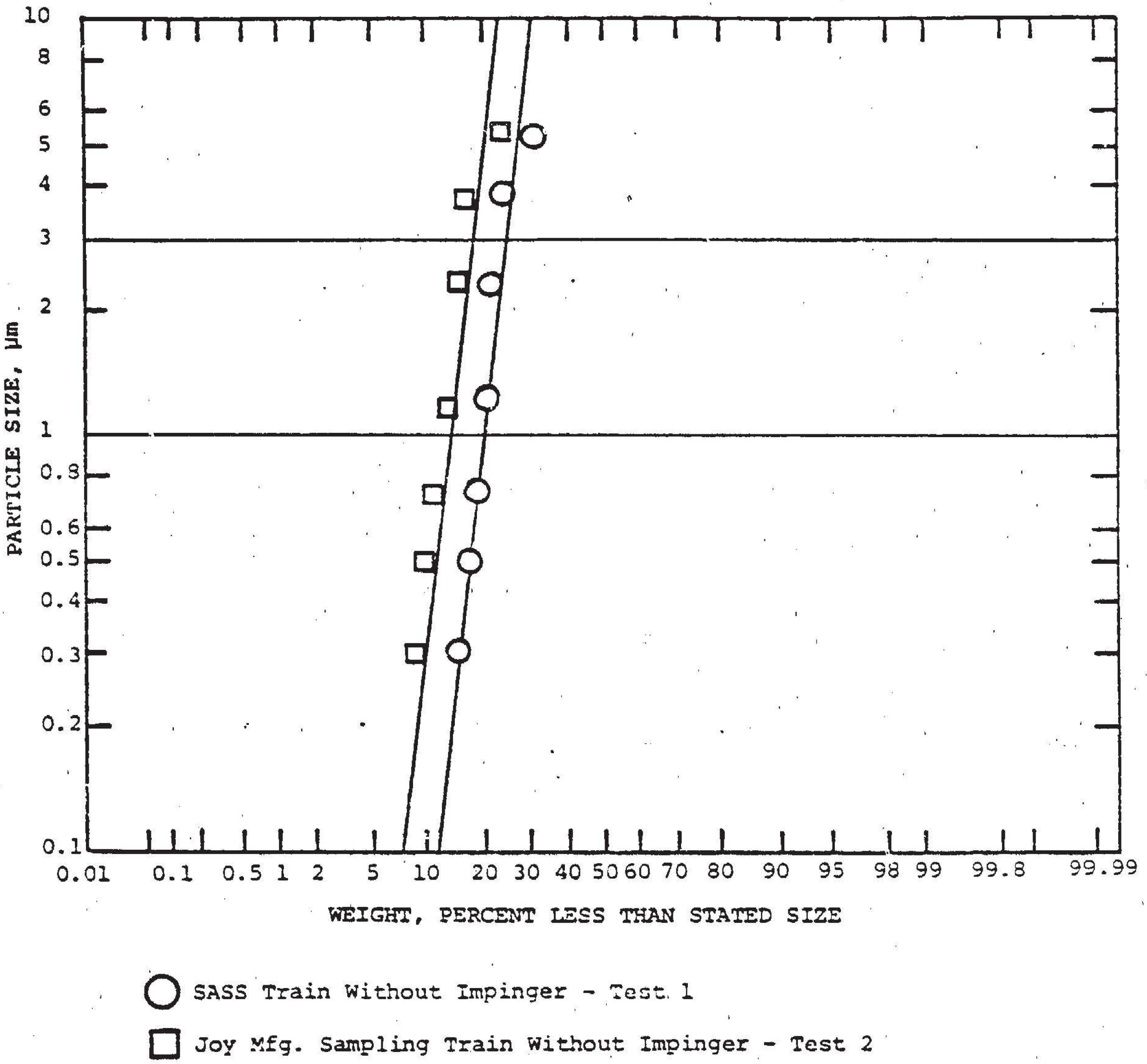


Figure 4-80. Particle size distribution for alfalfa dehydration.

4.2.27 Cotton Ginning Operations

The primary function of a cotton gin is to take raw seed cotton and separate the seed and the lint. A large amount of trash is found in the seed cotton, and it must also be removed. The problem of collecting and disposing of gin trash is two-fold. The first problem consists of collecting the coarse, heavier trash such as burrs, sticks, stems, leaves, sand, and dirt. The second problem consists of collecting the finer dust, small leaf particles, and fly lint that are discharged from the lint after the fibers are removed from the seed. From 1 ton (0.907 MT) of seed cotton, approximately one 500-pound (226-kilogram) bale of cotton can be made. (Ref. 4-60).

KVB attempted to conduct cotton gin tests for several months during the Phase II test program. Several scheduled tests were cancelled due to equipment failure. Therefore the data presented in this section are those taken by EPA - Region 9.

Several sources of particulate were sampled on the same gin by the EPA. The results of these tests are presented in Table 4-86.

TABLE 4-86. COTTON GIN TEST RESULTS

Test	A Unclean Notes	B #1 and #2 Incliner Clears	C Unloading and Dryer	D Unloading Separator	E Condensor & Basket Catch	F Note Cleaner	G #2 Lint Cleaner	H #1 Lint Cleaner	I #2 Lint Cleaner	J Batter Condensor
Flow Rate ACFH	630,000	850,000	721,000	350,500	345,000	143,500	823,660	1,080,000	780,000	1,494,860
Moisture %	0.035	03.3	0.8	0.19	0.35	0.93	0.28	2.0	1.24	1.63
Temperature °F	82	144	115	69	69	71	74	81	76	82
Emission GR/DSCF	0.043	0.0106	0.047	0.102	0.0097	0.087	0.031	0.088	0.041	0.023
Total lb/m	3.82	10.97	4.38	5.05	0.49	1.78	3.63	12.99	4.41	4.61
Front half lb/hr	3.78	10.72	4.34	4.99	0.36	1.71	3.35	11.86	4.41	3.64

4.3 PARTICULATE CONTROL EQUIPMENT EFFICIENCIES

Eleven simultaneous tests were done using the larger SASS train on the control equipment exit and the smaller train on the inlet, to evaluate the efficiency of the control equipment. Eight of these were baghouses, two were electrostatic precipitators, and one was a cyclone. The percentage efficiency for each of these was calculated from the following equation:

$$\text{efficiency} = \frac{wt_{in} - wt_{out}}{wt_{in}} \times 100$$

Table 4-87 summarizes the efficiency of the control equipment tested by KVB in this study. Two values are listed for the efficiency, one of which includes the weight from impinger catch in the calculation (SCAQMD method), and the other which ignores it (EPA method).

An interesting way to evaluate efficiency is to determine the efficiency as a function of particle size. Using the particle size distribution curves and the grain loading for the inlet and outlet for each test with control equipment, the efficiency can be calculated at each particle size from the following equation:

$$\text{efficiency (size)} = \frac{[(\text{wt in})\ (\text{\% of particle between size A and B}) - (\text{wt out})\ (\text{\% of particle between size A and B})] \times 100}{(\text{wt in})\ (\text{\% of particle between Size A and B})}$$

The results of this calculation for each of the control equipment tests are listed in Table 4-88. Figure 4-81 is a plot of the efficiency vs particle size for baghouses. Note that the efficiency increases as the size increases. This is in agreement with the literature (Ref. 4-49 to 4-52). Figure 4-82 is a plot of the efficiency vs particle size for ESP and a cyclone. The efficiency of the cyclone decreases as particle size increase (Ref. 4-53 to 4-58). The efficiency of ESP's goes through a minimum between 0.1 and 2μm (Ref. 4-59).

TABLE 4-87. CONTROL EQUIPMENT EFFICIENCY

Test #	Process Type	Control Type	Efficiency	
			Impinger Catch Included	Impinger Catch Not Included
30	Wood Sanding	Baghouse	86.9	96.3
29	Asphalt Batch	"	99.9	99.9
34	Abrasive Blasting	"	99.9	99.9
26	Sintering	"	77.6	97.8
19	Chemical Fertilizer	"	99.6	99.1
17	Boric Acid	"	96.1	98.7
14	Steel Heat Treating	"	95.2	90.0
8	Brick Grinding	"	99.5	99.8
20	Glass Mfg.	ESP	83.0	98.2
36	Steel Open Hearth Furn.	"	82.2	90.3
39	Wood Resawing	Cyclone	99.1	99.2

TABLE 4-88. SIZE EFFICIENCY CALCULATION RESULTS

Test	Percent of Particles 10-3μm	3-1μm	1-0.1μm	gr/DSCF	Control Type	Industrial Type
39J in	0.5	0.3	0.3	0.366	Cyclone	Wood Resaw
39S out	10	9	11.5	0.00317		
Efficiency	82.7	74	66.3			
30J	4	12	20	0.0168	Baghouse	Wood Sanding
30S	3	3	7	0,0022		
Efficiency	90.2	96.7	95.4			
29J	18	18	26	11.483	Baghouse	Asphalt Batch Plant
29S	6	4	7	0.00776		
Efficiency	99.98	99.98	99.98			
34J	3.5	1.7	1.6	1.922	Baghouse	Steel Sand-blasting
34S	6	6	12	0.00088		
Efficiency	99.92	99.8	99.7			
26J	1	1	2	0.205	Baghouse	Sinter Plant
26S	1.2	1.4	3	0.0459		
Efficiency	73.1	68.6	66.4			
20J	0.4	0.5	1.9	0.0364	ESP	Glass Mfg.
20S	0.6	1	2	0.00617		
Efficiency	74.6	66.1	82.2			
19J	0.2	0.01	0.2	0.7154	Baghouse	Chemical Fertilizer
19S	1	1	2	0.0028		
Efficiency	98	60.8	96.1			
17J	1	0.01	1	0.6105	Baghouse	Boric Acid Mfg.
17S	0.5	0.5	1	0.0237		
Efficiency	98.1	94.1	96.12			
14J	7	10	30	0.0593	Baghouse	Steel Heat Treating
14S	8	14	41	0.00283		
Efficiency	94.55	93.3	93.5			
8J	0.85	0.3	0.14	1.169	Baghouse	Brick Mfg.
8S	4	4	8	0.00641		
Efficiency	97.4	92.7	68.7			
36J	3	4	11	0.206	ESP	Steel Open Hearth Furn.
36S	3.8	7	23	0.0366		
Efficiency	77.5	68.9	64.1			

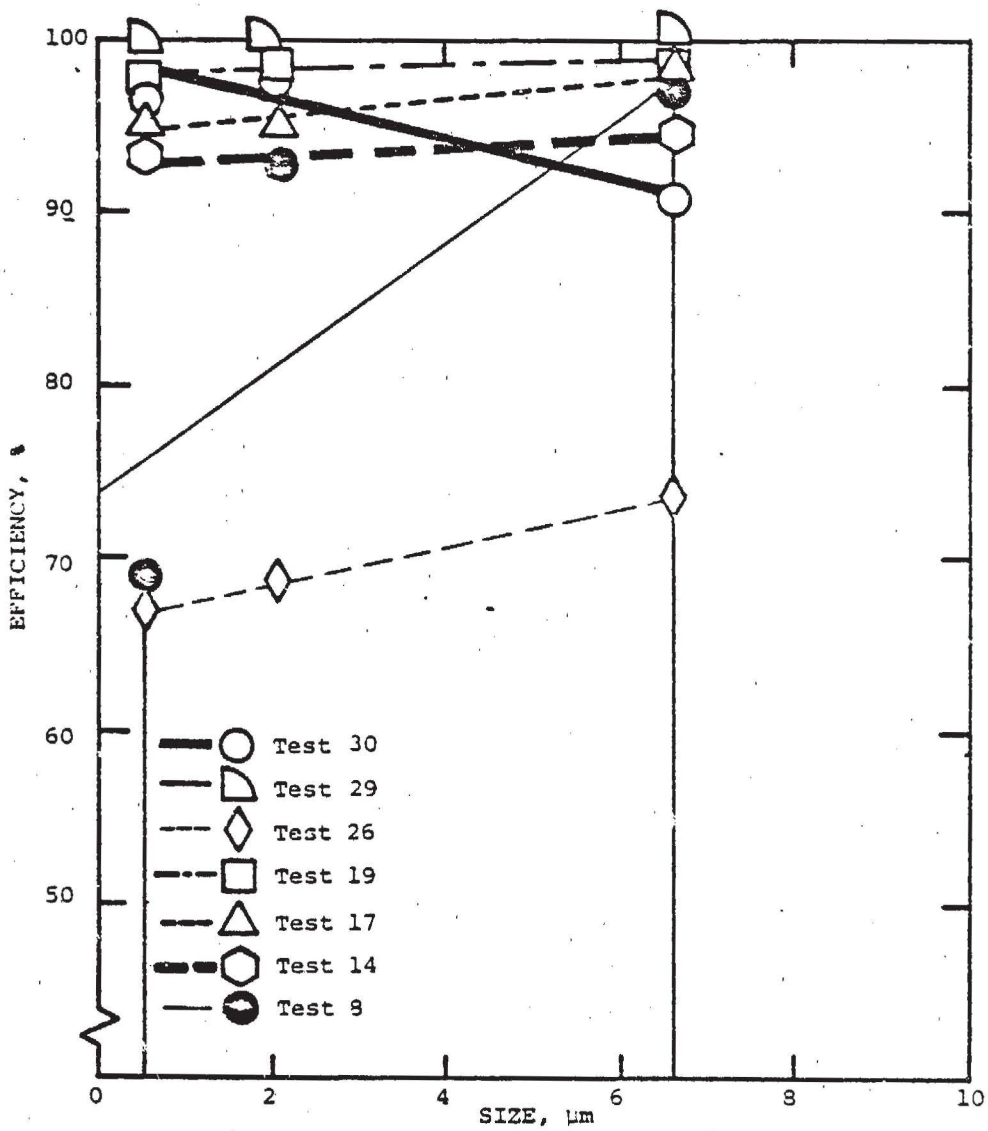


Figure 4-81. Baghouse size includes Impinger.

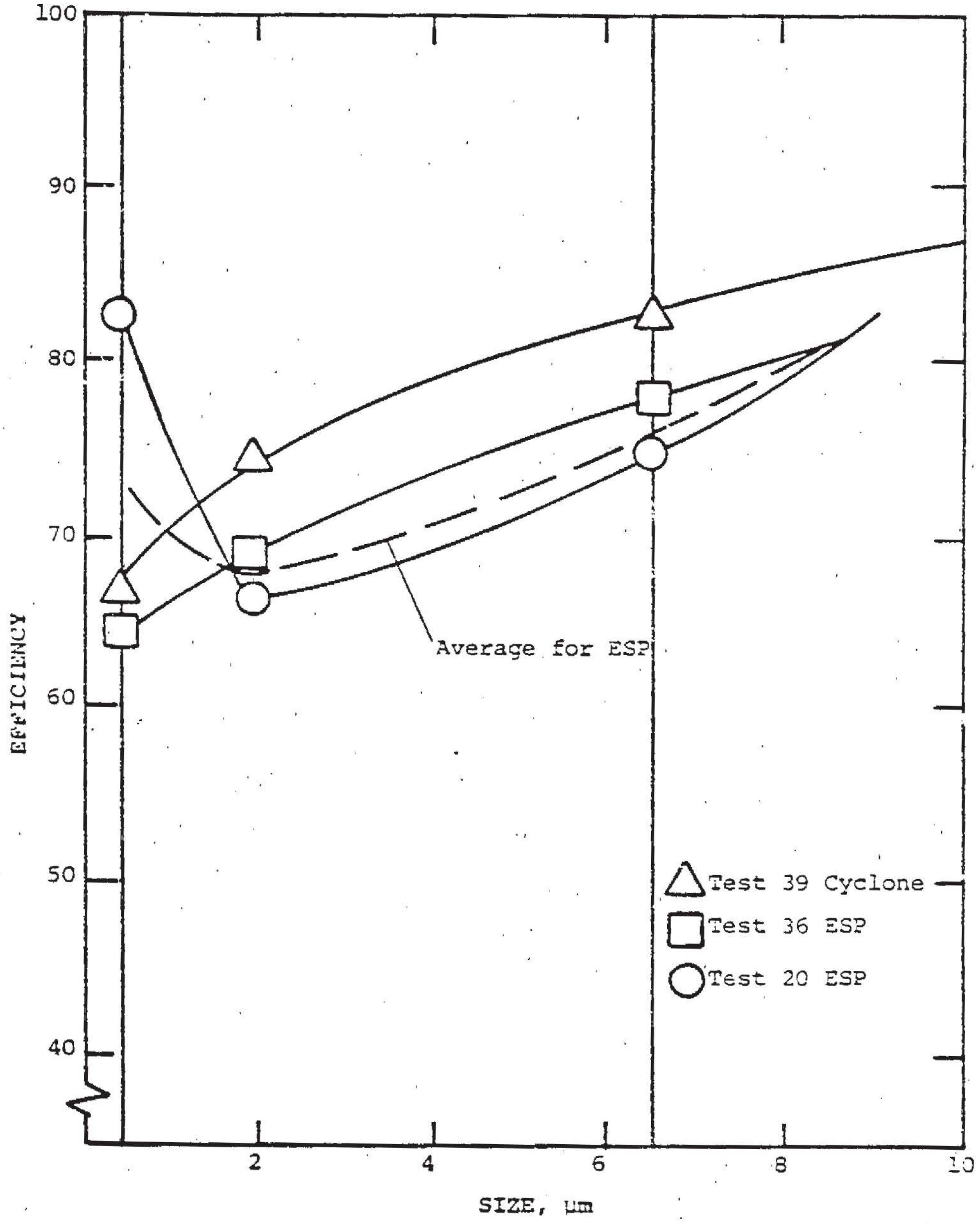


Figure 4-82. Cyclone and electrostatic precipitator efficiency curve.

SECTION 4.0

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SECTION 5.0

PARTICULATE EMISSION CONTROL TECHNOLOGY

INTRODUCTION

The removal of particulate matter from gas streams to reduce emissions to environmentally acceptable levels can be accomplished in a wide variety of ways. This section describes various types of particulate control equipment and includes suggested areas of applications as well as estimates of their performance and costs.

The selection of the most appropriate particulate control device is usually based on the size of the particulate matter which must be removed from the gas stream. Figure 5-1 illustrates the normal areas of application from a particle size standpoint, relative to particle size, for the following types of particulate control devices:

- Settling Chambers
- Momentum Separators
- Cyclones
- Spray Towers
- Tray and Packed Towers
- Venturi Scrubber
- Fabric Filters
- Electrostatic Precipitators

Table 5-1 is a generalized rating of these devices for various applications in the opinion of the authors.

An analysis of Figure 5-1 indicates that successful control of virtually all particulate emissions can be achieved by selecting the appropriate emission control device.

It is important to note that accurate information regarding the size distribution, grain loading, physical properties and removal requirements is essential to selecting the proper control device.

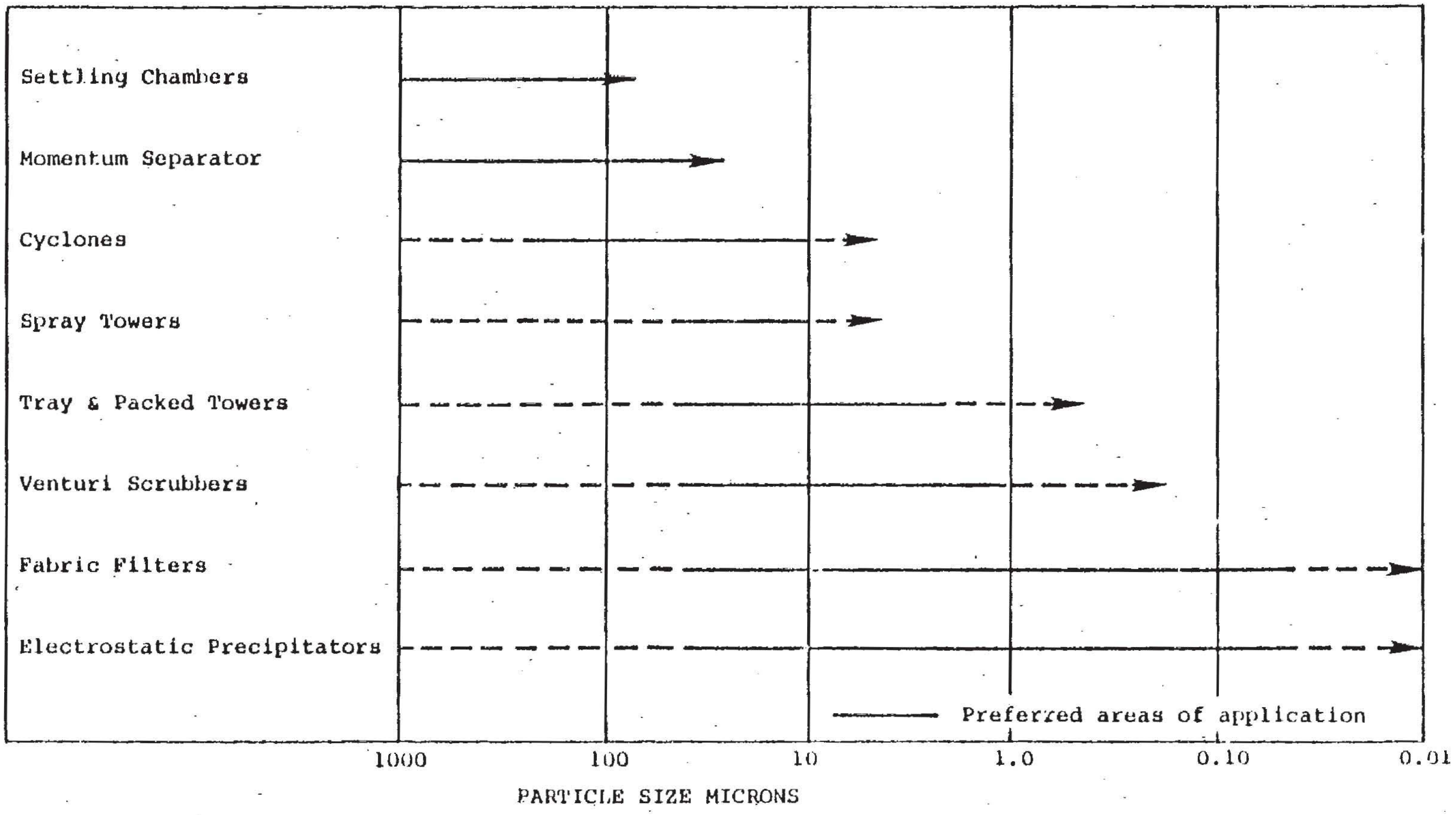

Figure 5-1. Areas of application for particulate control devices (Ref. 5-2).

TABLE 5-1. APPLICATION TABLE

Industry Type	Settling Chamber *	Cyclones *	Multiclones	Packed Columns	Spray Towers	Venturi Scrubbers	Filters (Baghouses)	ESP	Other
COMBUSTION OF FUELS									
Utility Boilers	P	NU*	G	NU	G	NB/B	NB	B	
Industrial Boilers	P	NU*	G	NU	G	NB	NB/B	B/NB	
Waste Incinerators	P	NU	G	NU	G	NG/B	NU	B	
MINERALS									
Cement Plant	P	G	G	NU	G	NU	B/NB	B	
Gypsum	P	-	-	-	-	-	B/NB	B	
Brick Grinder	P	G	G	-	-	G	B	-	
Glass Plants	NU	NU	-	-	-	N/B	B	B	
Asphalt	P	P	G	-	-	NB	B	NB	
FOOD & AGR.									
Cotton Gin	-	-	B	-	-	-	B		
Alfalfa Dehydrator	-	-	G	-	-	-	B	B	Incinerator
Rice Dryer	-	-	G	-	-	-	B	-	
METALLURGICAL									
Steel	P	NU	G	NU	NU	G	B/NB	NB/B	
Aluminum	-	NU	-	-	-	G	B/NB	B	
Lead	P	NU	G	NU	NU	G	B	NB	
CHEMICAL									
Fertilizer	-	-	-	-	G	B	NB	-	
Soap	-	-	-	-	-	-	B	-	
ORGANIC SOLVENT USE									
Spray Booth	NU	NU	NU	B	NB	G	NU	NU	Incineration
Wood Processing	NU	NU	NU	B	NB	G	NU	NU	
PETROLEUM									
FCC Unit	P	G	G	NU	NU	G	NU	G	
Heaters	-	-	-	-	-	-	B/NB	B	

* - Not used as primary pollutant removal devices
NU - No data available
B - Best
NB - Next to best
G - Good
P - Poor

This section has been prepared as a guide to introduce users to various types of control devices, to aid in understanding their capabilities and to serve as a general reference regarding their application.

There are many variables like disposal methods, potential for recycle, and variability of particulate characteristics to name but a few, which influence the selection of particulate removal devices that are beyond the scope of this report. Users must consider each application on an individual basis in order to select the most appropriate particulate control device.

5.1 METHODS OF CONTROL

5.1.1 Settling Chambers and Momentum Separators

A. Settling Chambers--

1. Settling chambers represent the simplest device available for particulate collection. They normally include nothing more than a low velocity region in the gas handling system where gravitional forces cause larger particles to settle out from the moving gas stream.

In these devices gravitational forces are sometimes augmented by directing the gas stream to impart a downward momentum to the particles to improve particulate collection. Figure 5-2 illustrates a typical settling chamber.

2. Settling chambers rely on gravitational forces for particulate separation. Since these forces are proportional to the weight of the particle, larger high density particles will be acted on by the large separating forces. The major force inhibiting collection is aerodynamics drag. This force is proportional to the cross sectional area of the particle and its velocity relative to the gas stream. With the exception of large particles which are readily collected, most particles quickly attain terminal velocity in the settling chamber. This velocity is reached when the gravitational forces are just balanced by the drag forces. It is this velocity which determines whether a particle will be collected. If the particle falls quickly enough while in the settling chamber to reach the hopper before it reaches the chamber outlet it will be collected, if it does not, it will pass through the chamber uncollected.

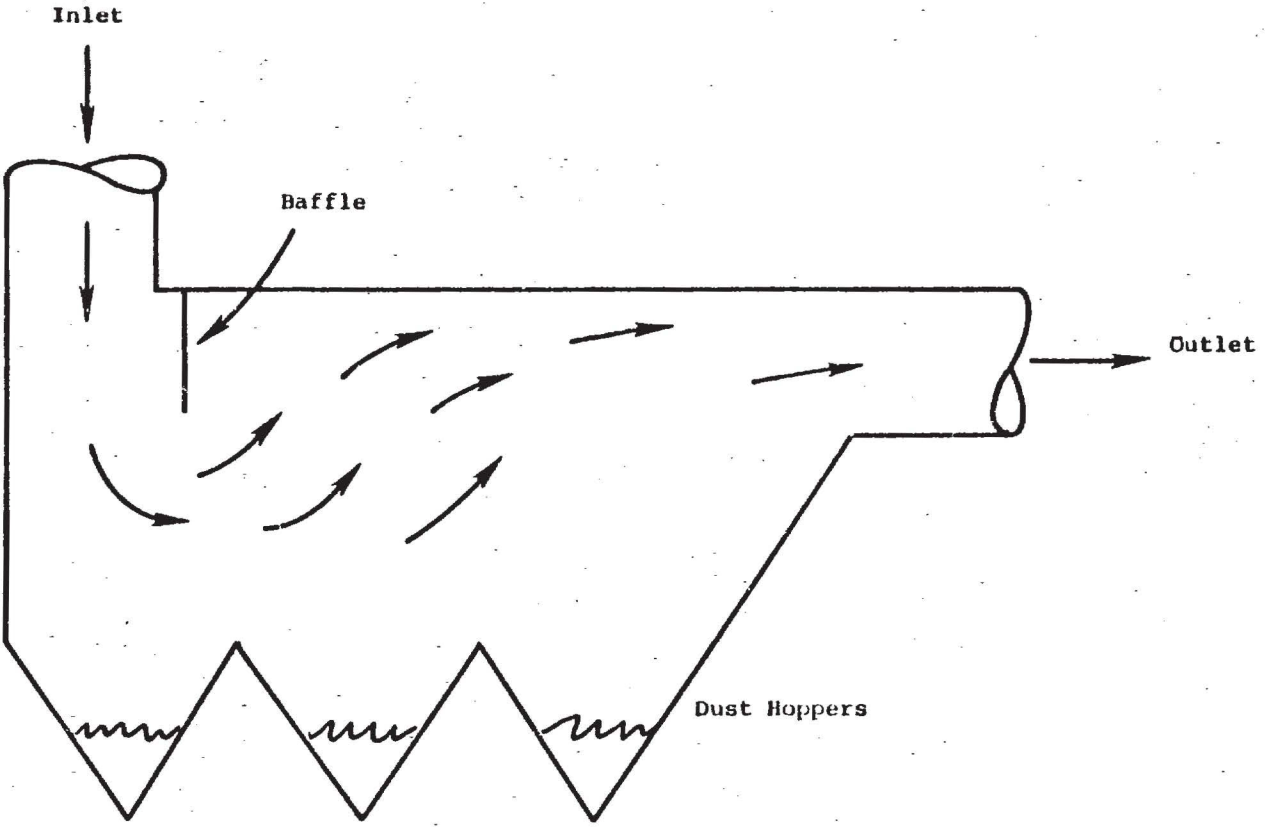

Figure 5-2. Settling chamber. (Ref. 5-J)

In theory particles as small as 5 microns, the size where suspension by Brownian motion takes on significance, could be collected in settling chambers. However, economic and space considerations limit efficient collection in settling chamber sizes to particles above 80 microns.

3. Other factors which also influence separation in settling chambers include chamber dimensions, gas density and gas viscosity.

The most important factors are gas velocity and chamber dimensions since these can be selected for a given application whereas all of the others are essentially fixed.

Figure 5-3 illustrates typical settling chamber collection efficiency and shows the effect of particle density on collection.

Maintaining a uniform velocity is critical to achieving good collection efficiency since eddies or areas of high velocity cause poor settling and result in unnecessary carryover of particles.

In addition, overall and local velocities must be maintained below the reentrainment velocity for the particular dust being collected to prevent pickup from the hopper. The reentrainment velocity is a function of the particle size and density as well as the tendency of collected particles to agglomerate.

4. The main problems associated with the operation of settling chambers are maintaining uniform gas velocity and avoiding plugging in the hoppers. The first problem can be virtually eliminated by proper settling chamber design coupled with good upstream and downstream duct layouts. The second problem can be controlled by designing hoppers with adequate slope, adding insulation and heat tracing to prevent condensation and adding hopper vibrators to aid in discharging collected dust. Where agglomeration and bridging are severe, the hopper should be discharged continuously.

B. Momentum Separators

1. Separators relying solely on momentum in which the gas stream impinges on the surface of a collector operate at substantially higher efficiencies than settling chambers. There are numerous configurations using this principle; one is illustrated in Figure 5-4.

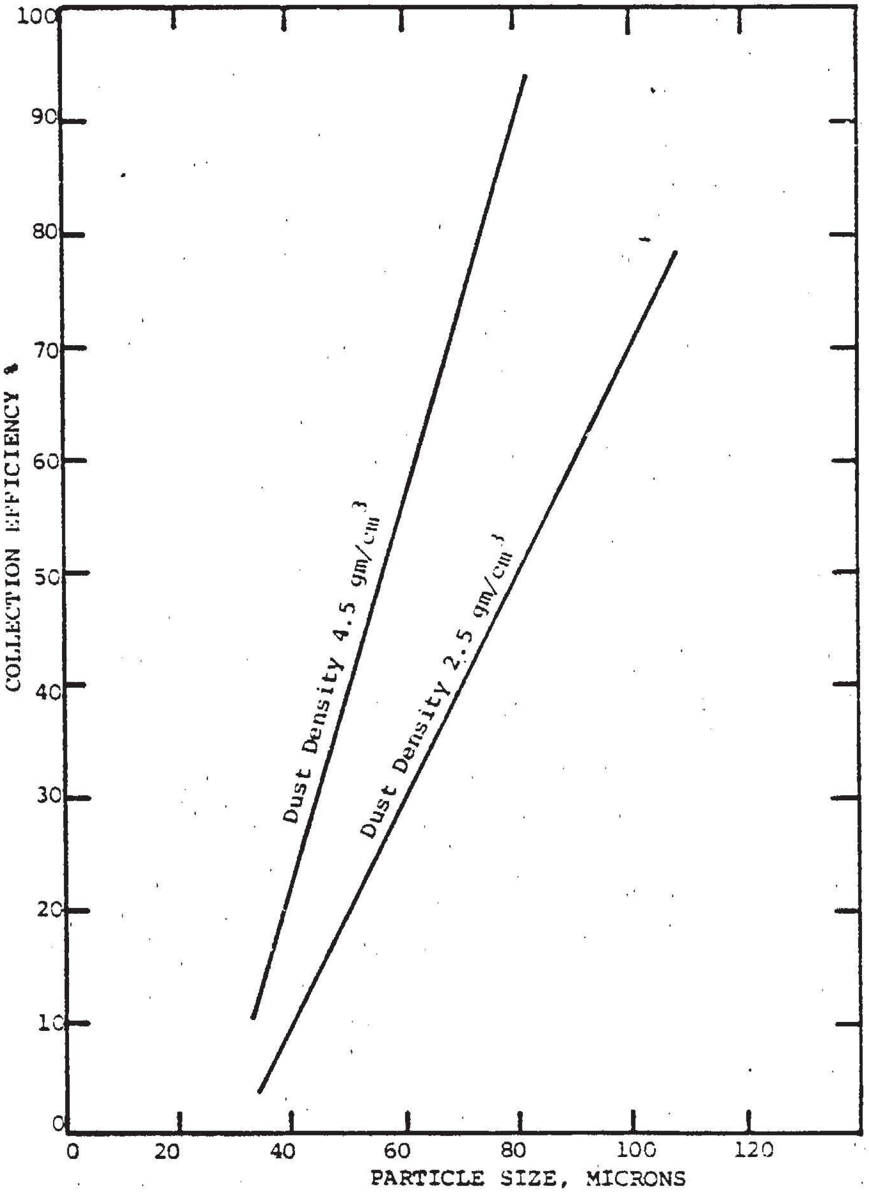

Figure 5-3. Typical settling chamber collection efficiency. (Ref. 5-1)

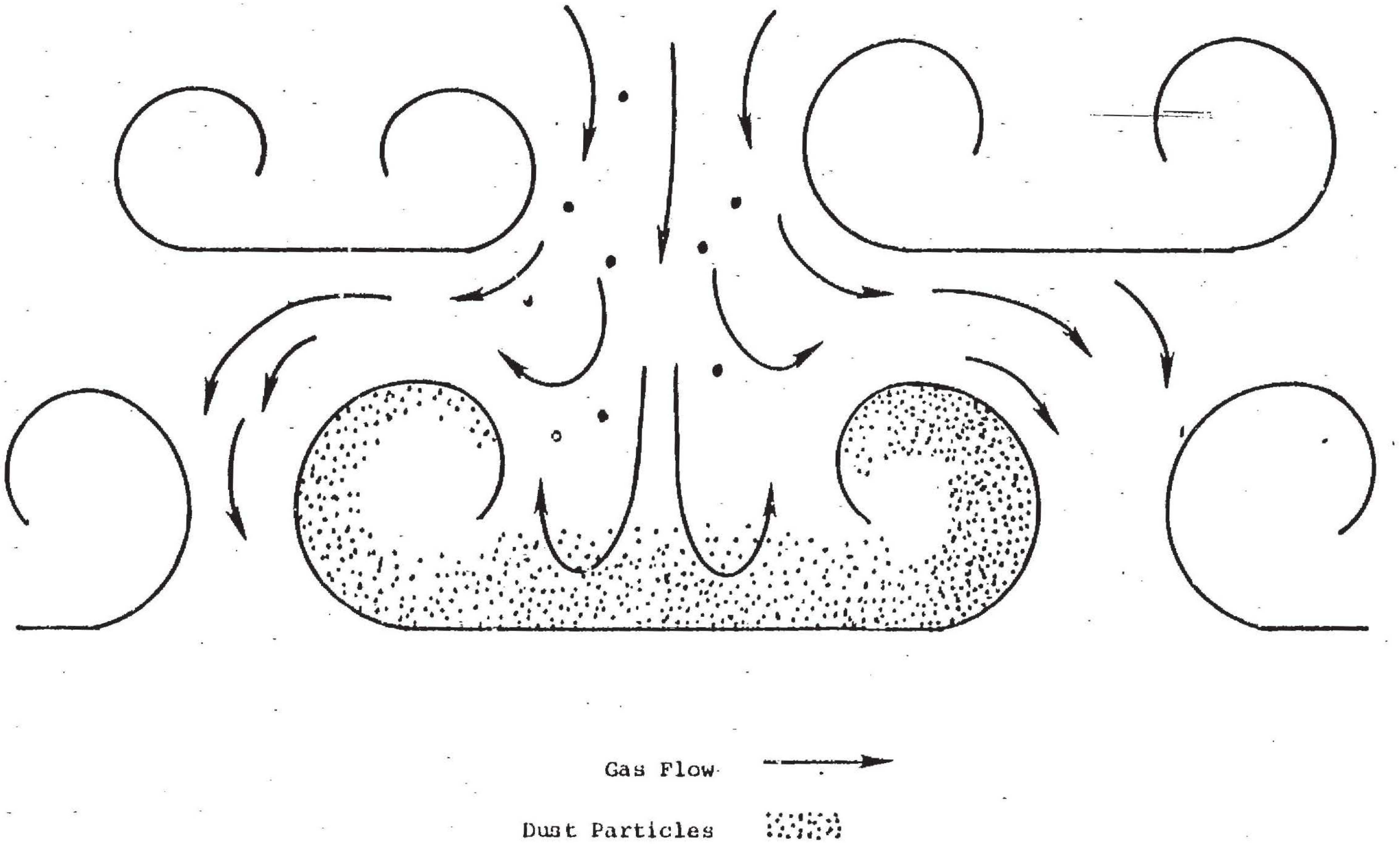

Figure 5-4. Momentum separator (Ref. 5-1).

2. In momentum separators particles which are carried along by the gas stream are separated when the gas stream is forced to make sharp change in direction. Factors which control separation are: (1) the weight and size of the particles, (2) velocity of the particles, (3) geometry of the separator, (4) gas density and velocity, and (5) the drag forces acting on the particles as the gas stream abruptly changes direction. High gas velocities and relatively high density particles favor separation, small lower density particles which tend to follow changes in gas flow patterns are not readily collected.

3. Collection in momentum separators is controlled by particle size and density, the geometry of the separating device and gas density and viscosity.

Figure 5-5 illustrates typical momentum separators collection efficiency as a function of particle size.

4. In momentum separators high velocities can cause excessive wear if the dust is abrasive and reentrainment can occur if dust removal is not adequate. The same precautions outlined above should be taken to avoid plugging problems.

5.1.2 Cyclones

A. Cyclones or centrifugal separators are devices which use centrifugal forces to separate particles from gas streams.

All cyclones consist of a device to induce a spinning motion to the gas and a means of removing the particles separated from the gas stream.

One of the most common configurations is the reverse flow cyclone illustrated in Figure 5-6. In this configuration gas which enters the cyclone tangentially is spun through several revolutions as it flows down the outer wall of the cyclone where the dust is separated before reversing its flow path and traveling up the center of the cyclone and out the top. The dust which was spun out to the wall, drops to the bottom of the cyclone where it is withdrawn.

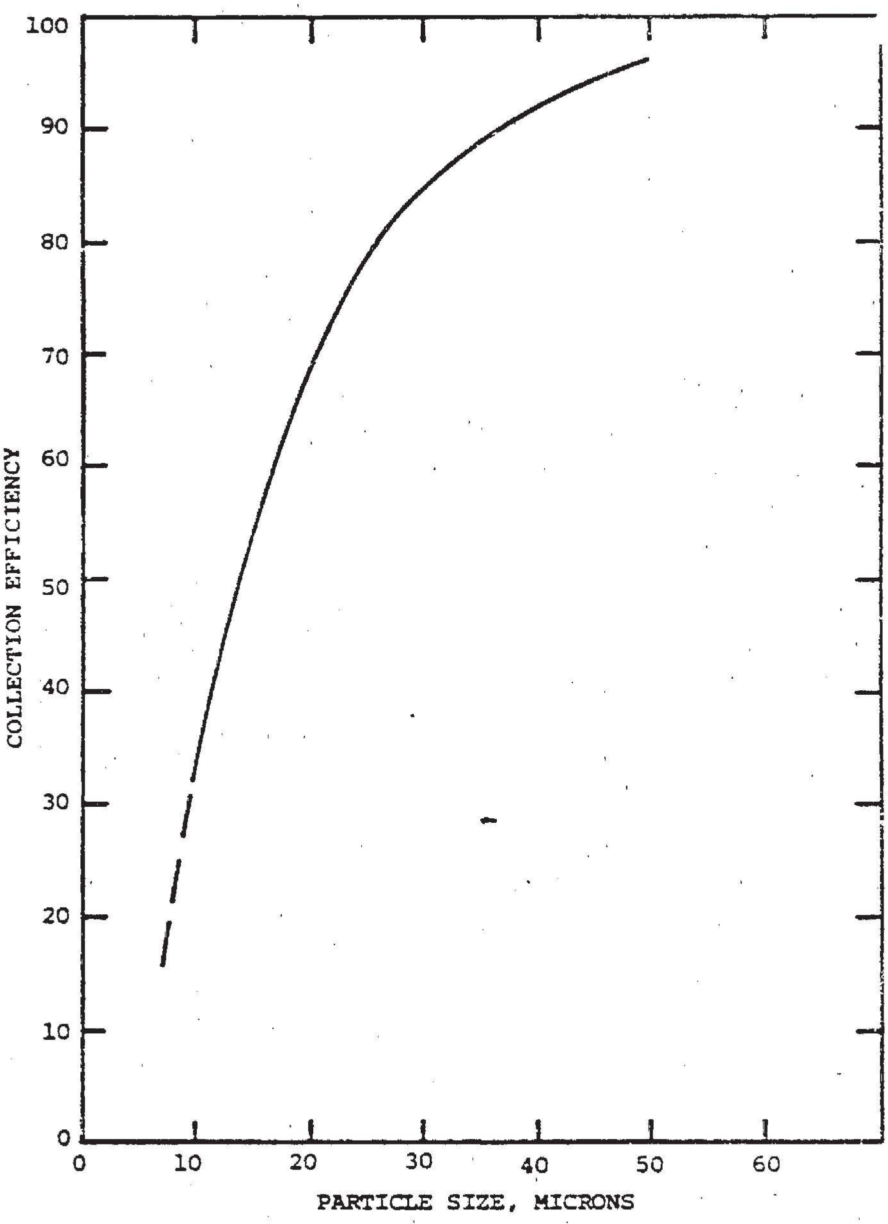

Figure 5-5. Typical momentum separator collection efficiency. (Ref. 5-1)

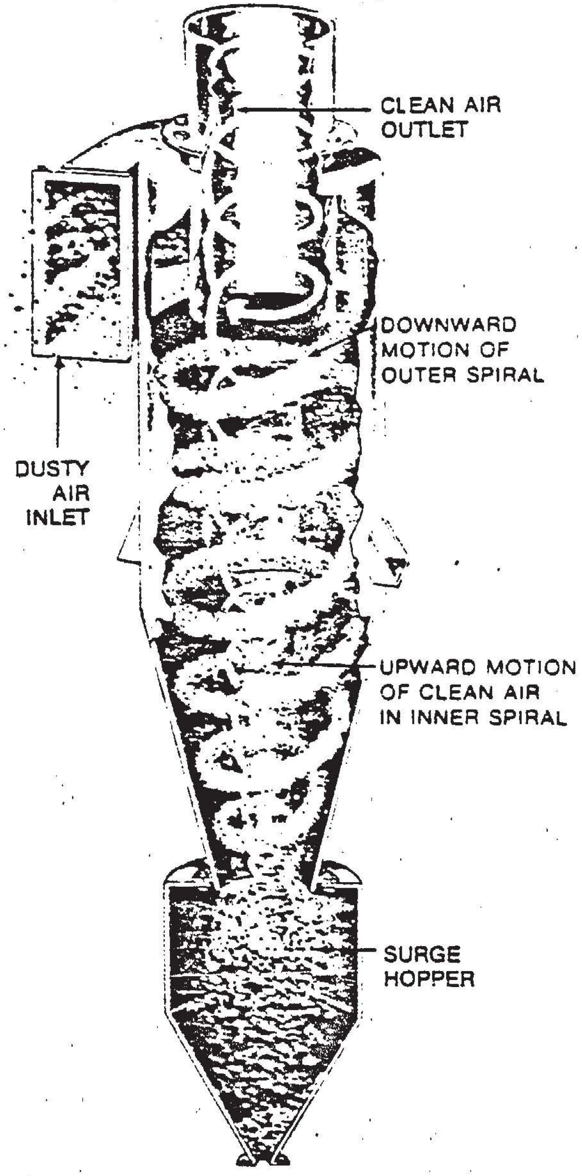

Figure 5-6. Reverse flow cyclone (Research-Cottrell).

B. The centrifugal forces created by spinning the gas stream in cyclones are often many times greater than the gravitational forces acting in settling chambers, therefore, cyclones can separate smaller particles than settling chambers in much smaller sized equipment. There is a substantial price in the form of pressure drop which must be paid for in the improvement in particle collection. Most cyclones require a pressure drop of 1 to 5 in w.c. for efficient operation.

The centrifugal force acting on a particle in the gas stream is proportional to the square of the velocity of the spinning gas and inversely proportional to the diameter of the cyclone.

$$F \approx \frac{V^2}{D} \qquad (1)$$

As in the other types of collectors, aerodynamic drag forces acting on the particles counteract the separating forces and limit collection.

C. An examination of Equation (1) above reveals that high velocities and small diameters increase separating forces thereby improving particle collection.

High efficiency collectors operate at high velocities and therefore higher pressure drops. They include a multiplicity of small diameter cyclones mounted in a common housing.

D. As in other collectors, particles which exhibit low aerodynamic drag relative to their size are collected more easily.

Figure 5-7 illustrates collection efficiency for a typical multicyclone operating at approximately 2-3 in w.c. pressure drop. As indicated in Figure 5-7, particles as small as 5 microns in diameter can be collected efficiently in this type of cyclone.

E. The problems most often associated with cyclones are erosion and reentrainment of dust due to high velocities and plugging of the hoppers where collected dust accumulates. The same precautions to overcome plugging, outlined previously for settling chambers, can be applied to cyclones. The

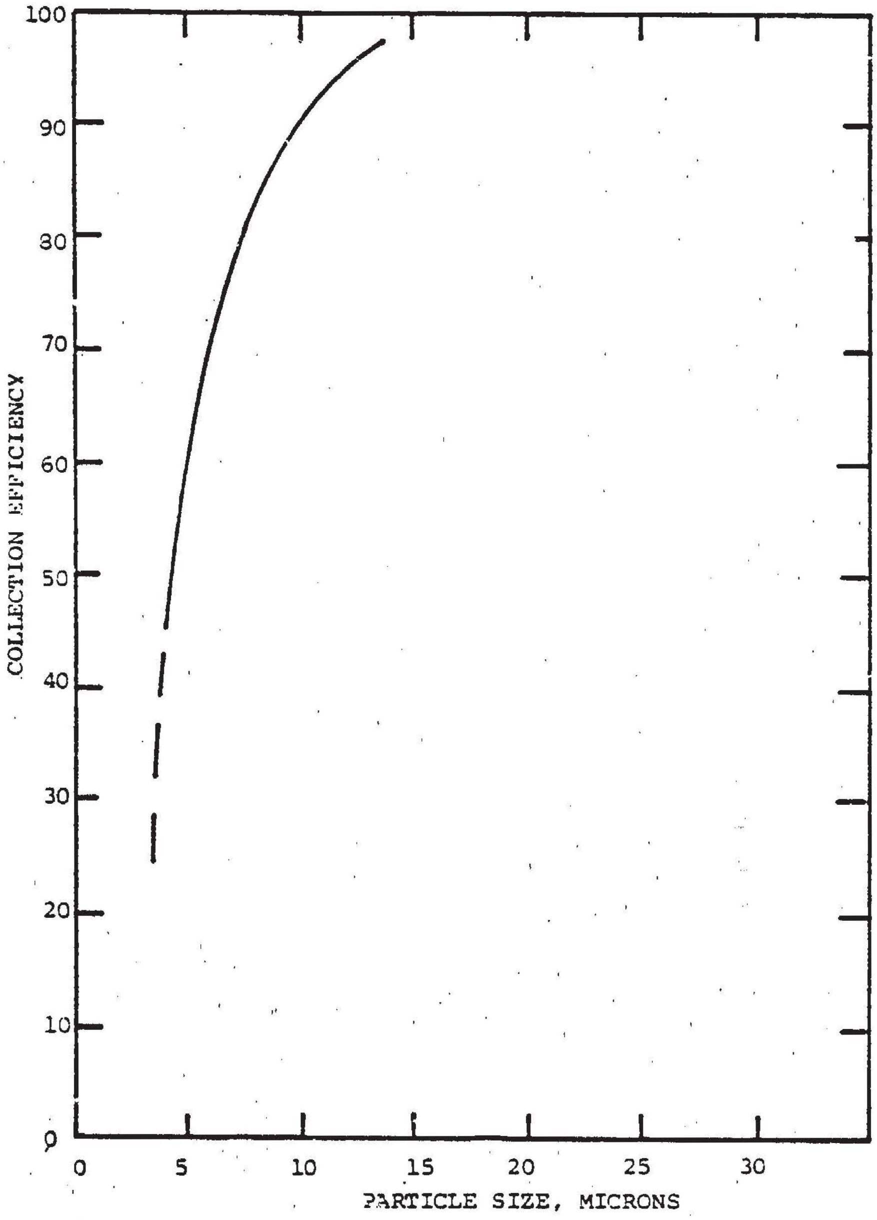

Figure 5-7. Typical multi-cyclone collection efficiency. (Ref. 5-1)

abrasion associated with high velocities and abrasive dust can be overcome by employing wear resistant materials and by using a precollector to remo coarse particles upstream from the cyclones.

5.1.3 Wet Scrubbers

Wet scrubbers can be divided into two basic categories: those designed for gas absorption and those designed for particulate removal. As convenient as these categories might be, they do not adequately depict actual scrubber behavior since all scrubbers remove some particulate matter while simultaneously absorbing constituents from the gas stream. When gas absorption is the primary objective, chemical reagents are often added to the scrubbing liquor.

A. Spray Towers--

Spray towers are the simplest type of wet scrubber; their primary function is coarse particulate collection. Since these scrubbers operate at relatively low gas velocities, some particulate settling will occur. In addition, in many scrubbers there is a sufficient difference in velocity between gas and scrubbing liquor droplets to collect some particles by interception and inertial impaction.* Finally, even submicron particles which move about in the gas stream via Brownian diffusion are collected when they contact droplets of scrubbing liquor.

1. A typical spray tower as illustrated in Figure 5-8 includes a gas inlet area where the wet-dry tower occurs, a quenching zone where gas cooling begins, the main gas-scrubber liquor contacting zone, the liquor spray manifold or manifolds and a mist elimination zone.

Gas containing dust particles enters the bottom portion of the scrubber where it makes contact with scrubbing liquor coming from the spray nozzles. The gas then passes through the mist eliminator on to the gas outlet.

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*These concepts are discussed in more detail in Section 5.1.3(C) Venturi Scrubbers.

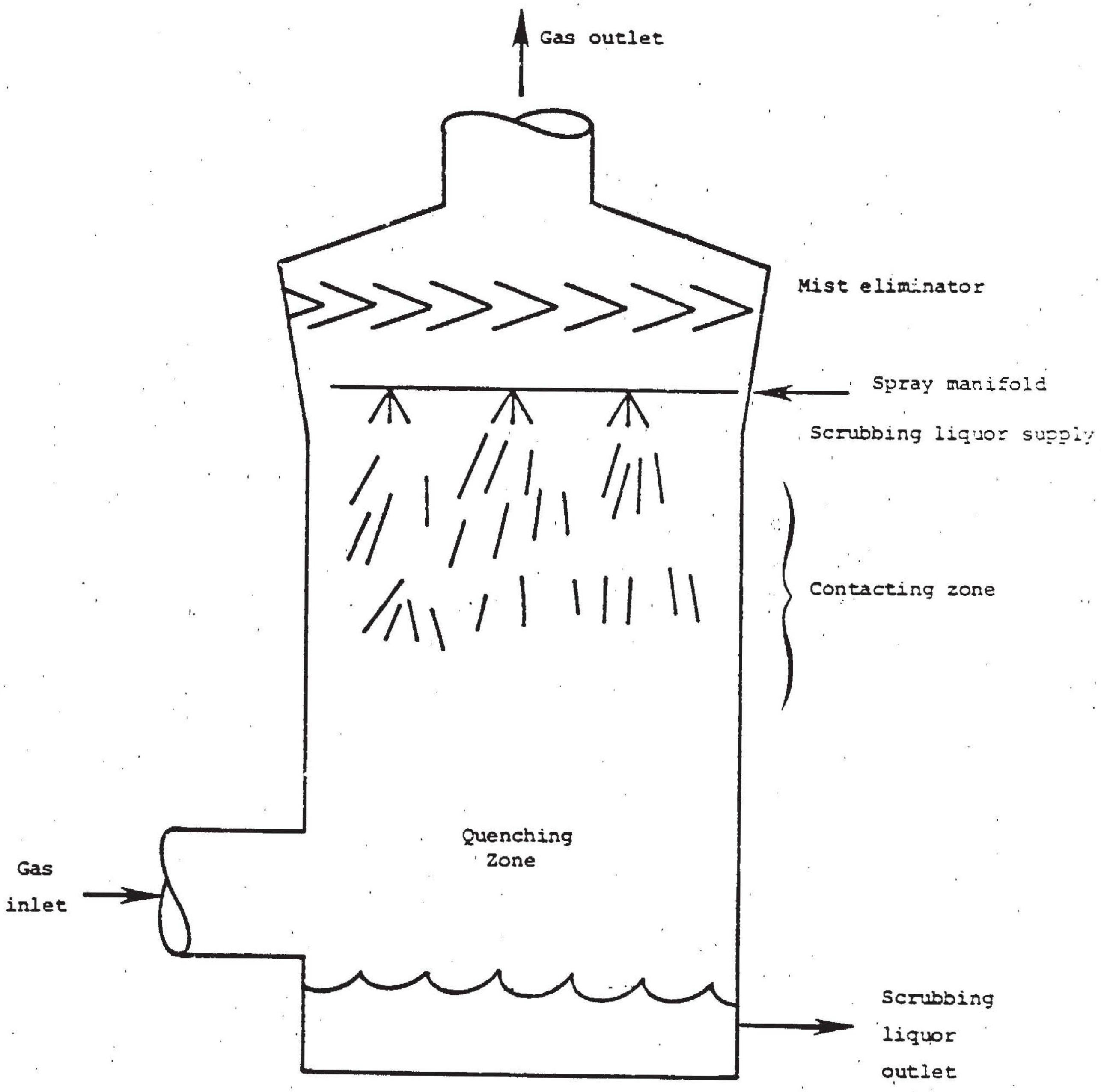

Figure 5-8. Typical spray tower.

The use of spray nozzles with appropriate manifolds is the most common method of creating droplets of scrubbing liquor in spray towers. The selection of spray nozzles is critical to successful operation. The scrubbing liquor must be uniformly distributed throughout the scrubber and the droplets which are produced must be large enough for gravitational forces to prevent aerodynamic drag forces from carrying them along with the gas.

Since all spray nozzles produce a range of different sized droplets, there are always some small droplets which will be swept along with the gas stream. It is usually necessary to prevent these droplets from leaving the scrubber, therefore, a mist eliminator is required.

There are many types of mist eliminators used in spray towers. The most common types use the principles of momentum separation described earlier. Figure 5-9 illustrates a typical Chevron type mist eliminator. Once the mist droplets are collected in the mist eliminator, they coalesce and drop off the lower edges in droplets large enough to fall down through the gas stream.

2. Investigations of particulate collection in spray towers has shown that there is an optimum droplet size for collecting particles from gas streams via inertial impaction and interception. These investigations have also shown that this droplet size is essentially independent of the size of the dust particles to be collected. For droplets composed mainly of water in gases similar to air the optimum droplet is approximately 800 microns in diameter.

An 800 micron water droplet has a terminal velocity in the air of approximately 10 ft/sec. However, spray nozzles designed to produce a mean droplet size of 800 microns produce substantial numbers of smaller droplets, therefore a maximum velocity of 4 to 5 ft/sec is usually selected. The use of larger droplets permits higher gas velocities, but the loss in collection efficiency, at least above 10 microns, can be offset by increasing scrubber liquor flow rates.

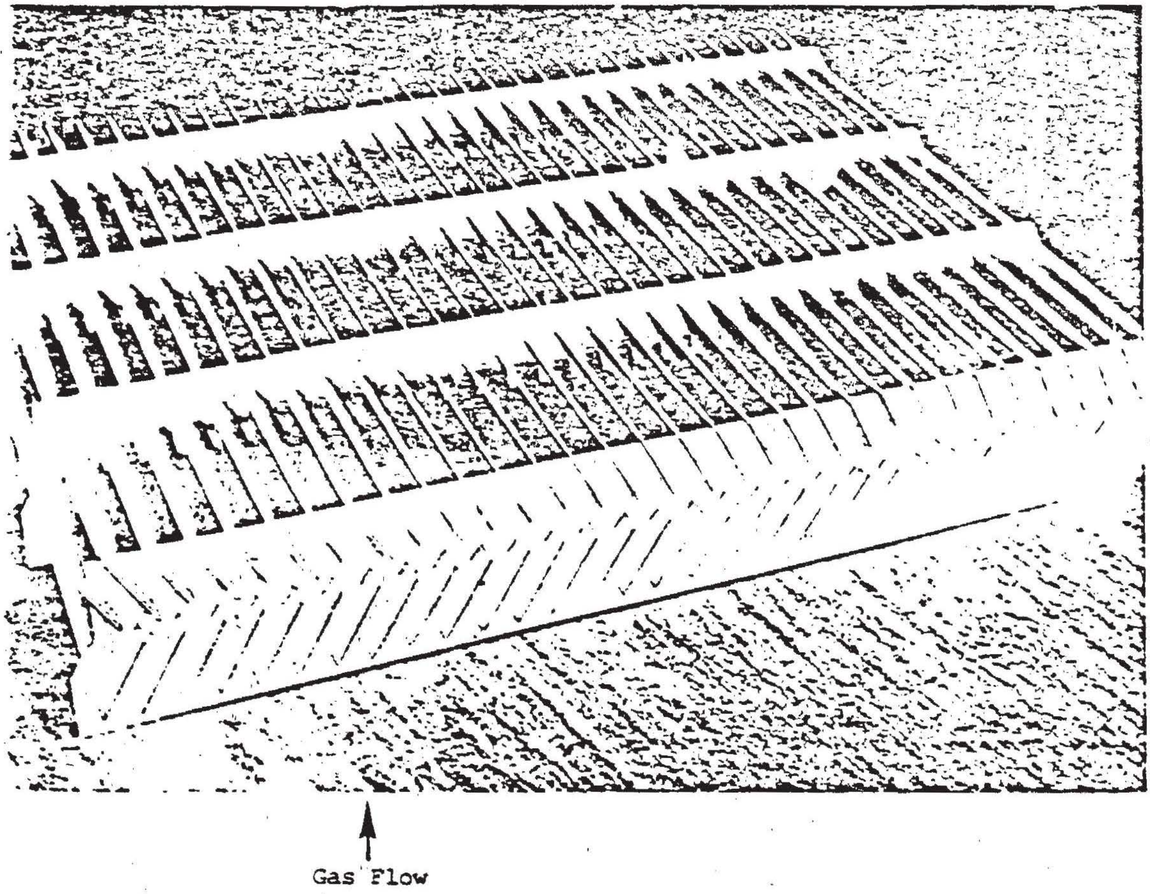

Figure 5-9. Chevron type mist eliminator (Munters Corp.).

3. The main factors which affect the particulate collection efficiency of spray towers are particle size distribution, scrubber liquor droplet size distribution and scrubber liquor to gas ratio. Figure 5-10 illustrates the theoretical collection efficiency of different sized particles for single droplets falling through air. Curves for 800 and 2000 micron droplets are presented.

The overall collection efficiency in a spray tower is essentially the aggregate of the collection of each of the droplets. Since this is so, increasing the number of droplets relative to the gas volume treated will increase the overall collection. Figure 5-11 illustrates the effect of increasing liquid rates on particulate removal in a typical spray tower.

4. The most common types of problems associated with spray towers are droplet carryover, wet-dry line solids buildup and corrosion, and spray nozzle erosion and plugging.

Droplet carryover can be controlled by the proper selection of scrubber gas velocity, spray nozzles and mist eliminator. Selecting the proper gas velocity and spray nozzle will minimize the amount of droplets carried upward by the gas stream and proper selection of the mist eliminator will result in a virtually droplet-free gas stream leaving the spray tower.

All scrubbers handling hot gas streams have a common potential source of problems in the area where the hot gas first contacts the scrubbing liquor.

The problems in this area are almost universally associated with inadequate irrigation of the scrubber shell in this area causing alternate wetting and drying and resulting in accumulation of particulate matter and corrosion of the scrubber shell. Usually supplemental spray nozzles to irrigate this area and the selection of adequate materials of construction will prevent difficulties.

In most spray towers scrubbing liquor is recirculated. This often results in the recirculation of substantial quantities of solids through the spray nozzles. If the particles are large or tend to agglomerate, spray nozzles can become plugged.

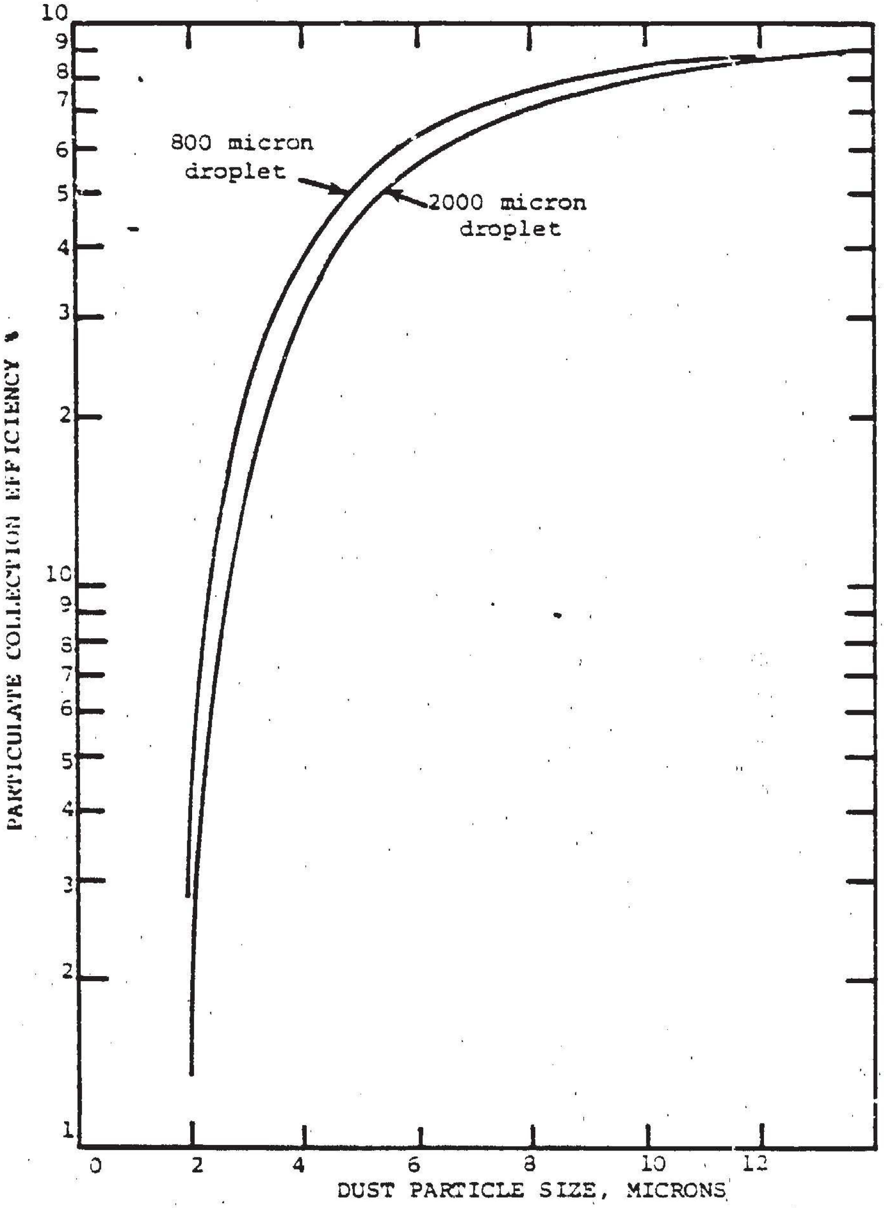

Figure 5-10. Theoretical collection efficiency for various sized droplets in a spray tower. (Ref. 5-1)

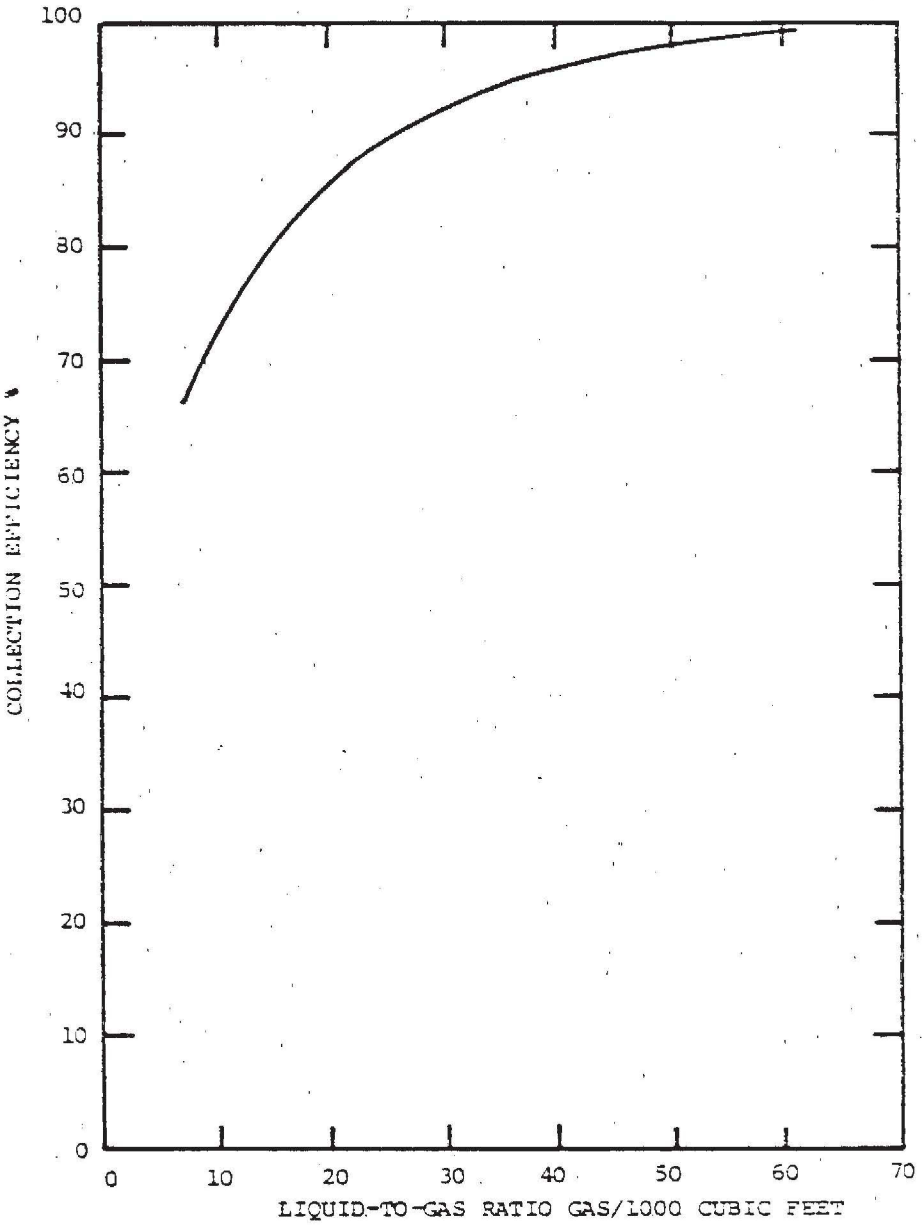

Figure 5-11. The effect of liquid-to-gas ratio on particulate collection in a spray tower. (Ref. 5-1)

The selection of nozzles with sufficiently large orifices to avoid plugging is usually not possible due to the fact that large nozzles produce large drops which may not produce adequate particulate collection or gas cooling. In this situation, some type of coarse screening device must be installed in the scrubber liquor recirculation loop or a precollector to remove these particles must be installed upstream of the scrubber.

The presence of solids in the recirculated liquor causes another problem, i.e., erosion of the nozzles. In time this results in enlarged nozzles, orifices and larger liquor droplets which cause scrubber performance to deteriorate. Using impingent or swirl type spray nozzles made of an abrasion and corrosion resistant material will usually result in a satisfactory service life. However, where excessively abrasive solids are present, nozzles should be operated at low pressure drops (15 psig maximum) even if there is some scrubber efficiency penalty to minimize downtime and costs for replacement of worn nozzles.

B. Tray and Packed Towers--

This class of equipment includes towers with a gas/liquid contacting medium which is continuous, i.e., packing or is comprised of discrete contacting units, i.e., trays.

This equipment is usually designed for gas/liquid mass transfer. In general these designs operate at relatively high gas velocities and are resistant to plugging.

1. The different types of tray and packed tower scrubbers used successfully for particulate removal are: (1) the floating bed scrubber (a packed device), (2) impingent plate, (3) valve tray, and (4) sieve tray scrubbers.

The floating bed scrubber illustrated in Figure 5-12 uses a bed of lightweight spheres retained between two grids for particulate collection. This bed is suspended by the gas flow and particulate collection occurs via inertial impaction, interception, momentum separators, gravity and diffusion. Scrubbing liquor which is sprayed in coarse droplets uniformly across the top of the suspended spheres to irrigate the bed washes out the collected solids thereby avoiding plugging in the bed.

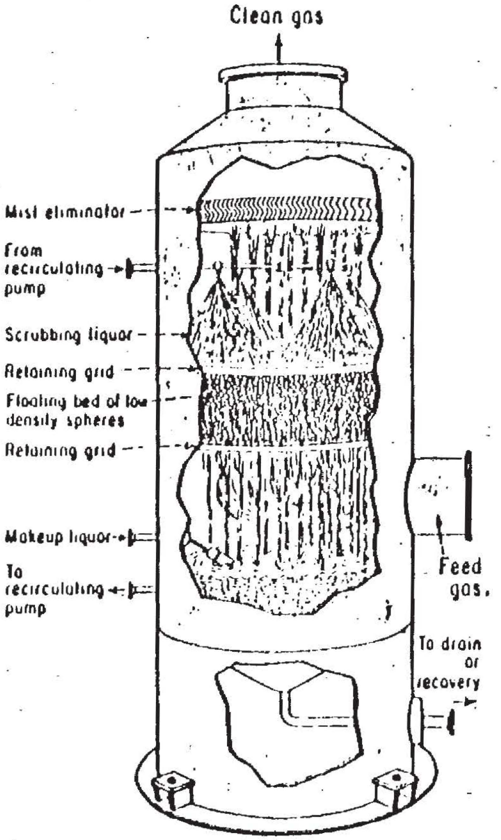

Figure 5-12. Floating-bed scrubber (Ref. 5-1).

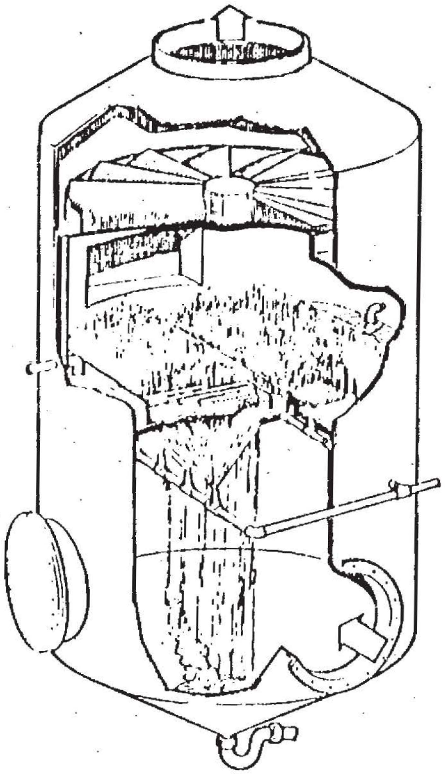

Figure 5-13. Impingement plate scrubber (Impinjet) (Ref. 5-1).

This type of scrubber normally operates at about 7 inches w.c. pressure drop and has been used successfully in fly ash and other applications.

Impingement, valve and sieve tray towers illustrated in Figure 5-13 all rely on the creation of high velocity jets in the openings of the trays to promote particulate collection. Each tray operates at a pressure drop of approximately 2 inches w.c.; they are often used in groups of two or more to increase overall collection efficiency. The hydraulic design of these devices is critical to minimize the possibility of plugging. Adequate irrigation of the plates is essential.

2. In essence, all of the packed and tray towers used for particulate collection rely primarily on inertial impaction and interception which are described in Section 5.1.3(C) for particulate collection. However, other mechanisms make significant contributions to overall particulate removal. Diffusion contributes substantially to collection of particles less than 0.5 microns in diameter and condensation effects, which increase the actual size of particles prior to collection, are often very important factors in these scrubbing processes. The differences among these scrubbers lie in: (1) the methods used to create droplets of scrubbing liquor, (2) the relative velocity between these droplets and the dust particles in gas streams, and (3) the means employed to handle solids in the scrubbing liquor to prevent plugging or excessive wear.

Since there are many types of packed and tray scrubbers, further details regarding their principles of operation are beyond the scope of this survey.

3. Since these scrubbers are designed primarily on the basis of collection by inertial impaction, their performance is controlled by the gas velocity through the various spaces, holes, slots, etc. in the scrubber. As a general rule, the higher the gas velocities, the higher the pressure drop and the higher the overall collection efficiency.

4. In addition to the types of problems outlined in Section 5.1.3(A)(4) above on spray towers, these scrubbers, with the exception of the floating bed device, must contend with the problem of solids settling in poorly agitated areas on the trays. Here again the use of a screening device or a precollector will substantially reduce the likelihood of settling problems due to large particles. The trays must be leveld and liquor distribution must be designed and controlled to maintain adequately high liquor velocities over the entire tray with and without gas flow.

C. Venturi Scrubbers--

1. This category of scrubbers includes a wide variety of devices which are often used to absorb gaseous pollutants and cool gas streams in addition to removing particulate matter.

The major components of a venturi scrubber include a venturi with a converging section, a high velocity throat and a diverging section, a means of introducing scrubbing liquor into the throat area and a device (usually a cyclonic mist eliminator) to collect the droplets of scrubbing liquor and collected particles from the gas stream. These components are illustrated in Figure 5-14.

A venturi throat cross sectional area is usually adjustable to compensate for gas flow variations or changes in particle size distribution. This is necessary since a venturi relies almost totally on gas stream pressure drop for atomization of scrubbing liquor and the pressure drop is dependent upon gas velocity in the throat.

2. Inercial impaction is the predominant mechanism for particulate collection in venturi scrubbers.

In this mechanism collection occurs when dust particles which are carried along by the gas stream impact on a droplet of scrubbing liquor. This impact occurs when the dust particles, because of their mass, have too much momentum to follow the gas stream as it diverges to flow around the droplets of scrubbing liquor. Figure 5-15 illustrates the path of the dust particles and the gas around a droplet of scrubbing liquor.

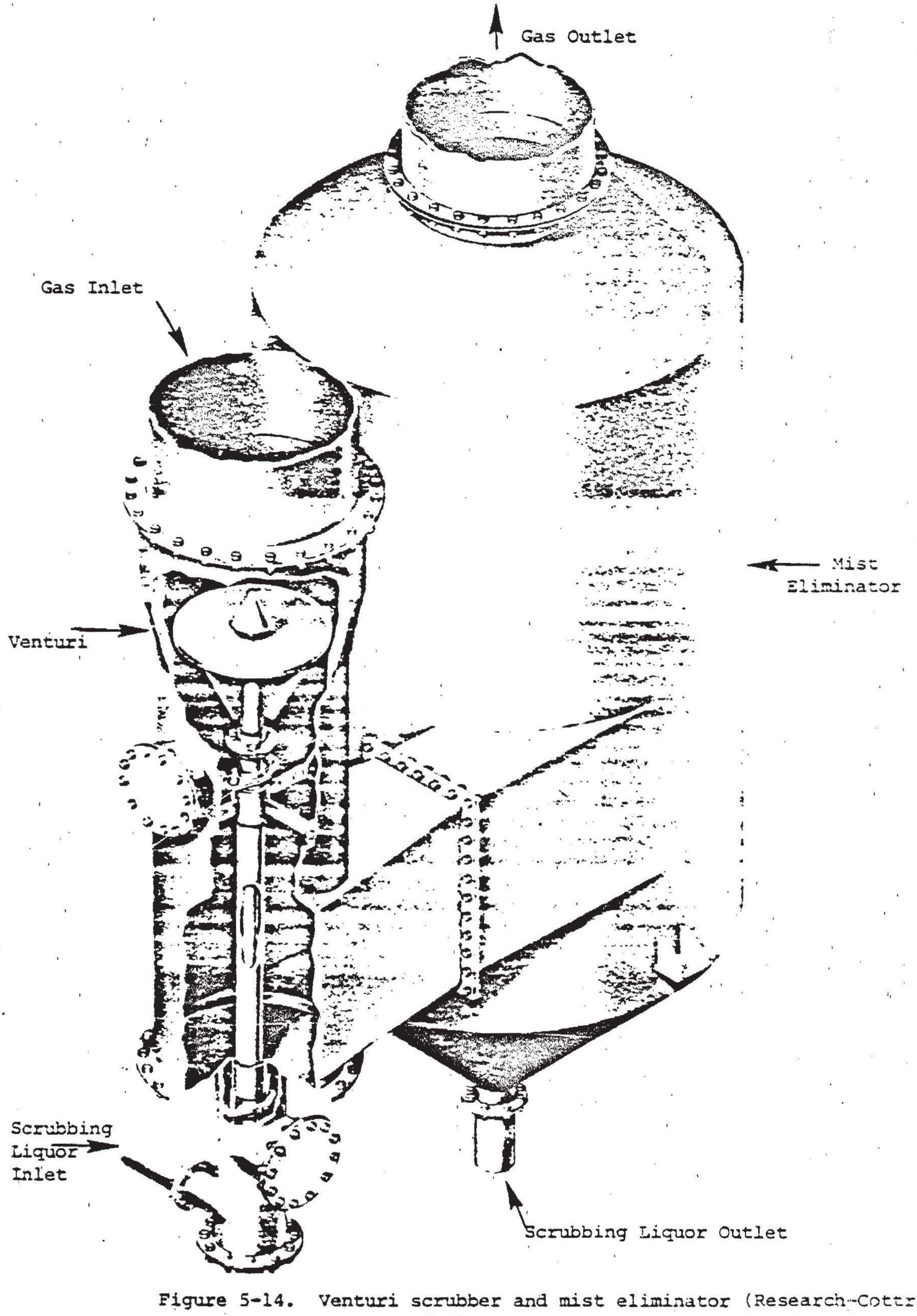

Figure 5-14. Venturi scrubber and mist eliminator (Research-Cottrell).

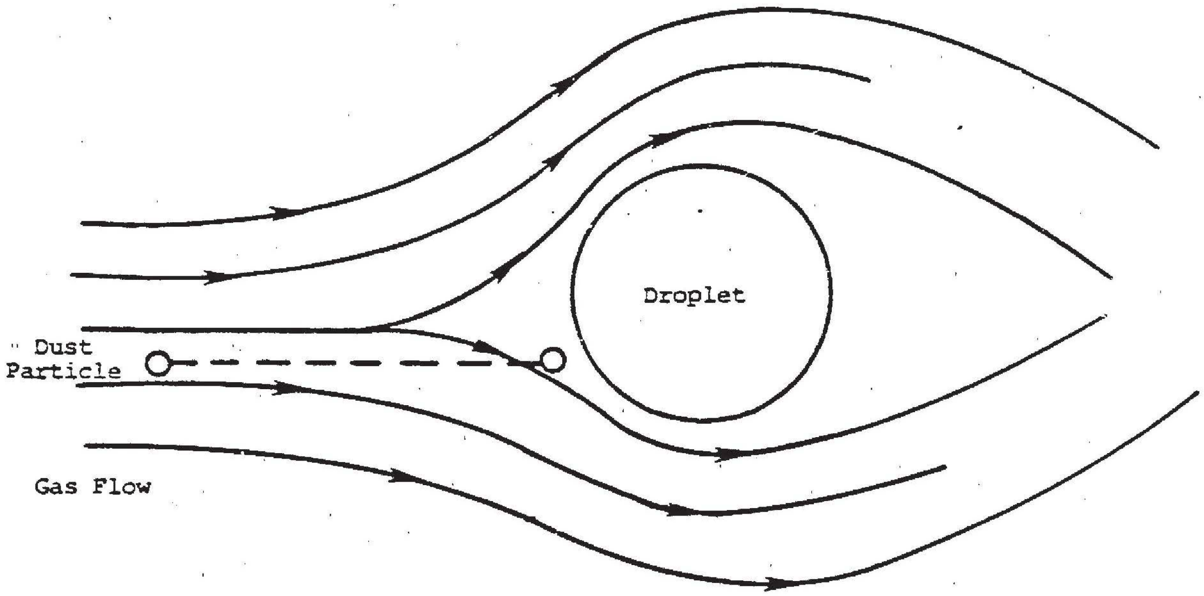

Figure 5-15. Path of dust particles (Ref. 5-1).

The collection efficiency of a venturi scrubber for a given sized particle is often estimated by using a model with the following form:

$$\text{Efficiency} = 1 - \exp\left[-K(L/G)(\Psi)^{1/2}\right] \tag{2}$$

where K is a system related parameter

L/G is the scrubbing liquor-to-gas ratio in gallons per 100 ACF of gas

$$\Psi = \frac{C\, d_p\, D_p^2\, V^2}{18\mu\ D_L} \tag{3}$$

where C is the Cunningham correction factor

D_p is the particle density

d_p is the particle diameter

V is the throat velocity

μ is the gas viscosity

D_L is the scrubbing liquor droplet diameter

The overall efficiency is estimated by summing up the efficiencies for each particle size in the inlet particle size distribution.

The normal range of liquid-to-gas ratios is 2 to 15 gallons per 1000 ACF; throat velocities are generally 200 to 400 ft per second.

3. The factors that effect particulate collection efficiency in venturi scrubbers include liquid-to-gas ratio, venturi throat velocity, particle size distribution and particle density.

In general, increasing the liquid-to-gas ratio increases collection efficiency up to ratios of 10 to 12. However, the venturi pressure drop increases somewhat as this ratio is increased.

Gas velocity in the venturi throat is the most important factor influencing collection efficiency. Even submicron particles can be collected at sufficiently high throat velocities. However, this ability to collect submicron particles comes at a high price since the pressure drop and therefore the power requirement increases as the square of the gas velocity.

The effect of particle size distribution on performance is simply this: efficient collection of small particles requires high throat veloci. s. If there are substantial amounts of submicron material which must be collected, very high throat velocities are required and pressure drops well over 50 in. w.c. may be required. The application of venturi scrubbers to remove particulate below 0.4 to 0.5 microns is generally not economical if the removal efficiencies required for these small particles are above 90%.

The density of the particles, i.e., the effect of density or the aerodynamic behavior of the particles has a significant effect on collection efficiency. High density, solid particles are relatively easy to collect while low density or fluffy particles like soot require very high throat velocities for efficient collection.

The collection efficiency for both moderate and high energy venturi scrubbers is illustrated in Figure 5-16.

4. The main problems associated with venturi scrubbers include erosion in the venturi throat and diffuser, plugging of the scrubbing liquor supply liner and carryover from the mist eliminator.

Since the throat velocity in a venturi scrubber is several hundred feet per second and scrubbing liquors often contain abrasive solids, erosic is a common problem. In applications where very high pressure drops are required, the throat and diffuser are often lined with a highly abrasion resistant material like alumina or silicon carbide. In addition, coarse particles can be removed from the scrubber liquor prior to recirculating it to the venturi throat to reduce erosion. This will also reduce the possibility of plugging the scrubber liquor supply liner. Maintaining the solids content of the scrubber liquor below 10 to 15% and maintaining uniform line velocities will also help to avoid plugging problems.

Proper design of the mist eliminator downstream from the venturi scrubber is essential to achieving high particulate collection efficiency. If the small droplets of scrubbing liquor from the venturi are not completely removed in the mist eliminator, unacceptable particulate emissions will occur because these droplets contain the particulate matter collected in the venturi.

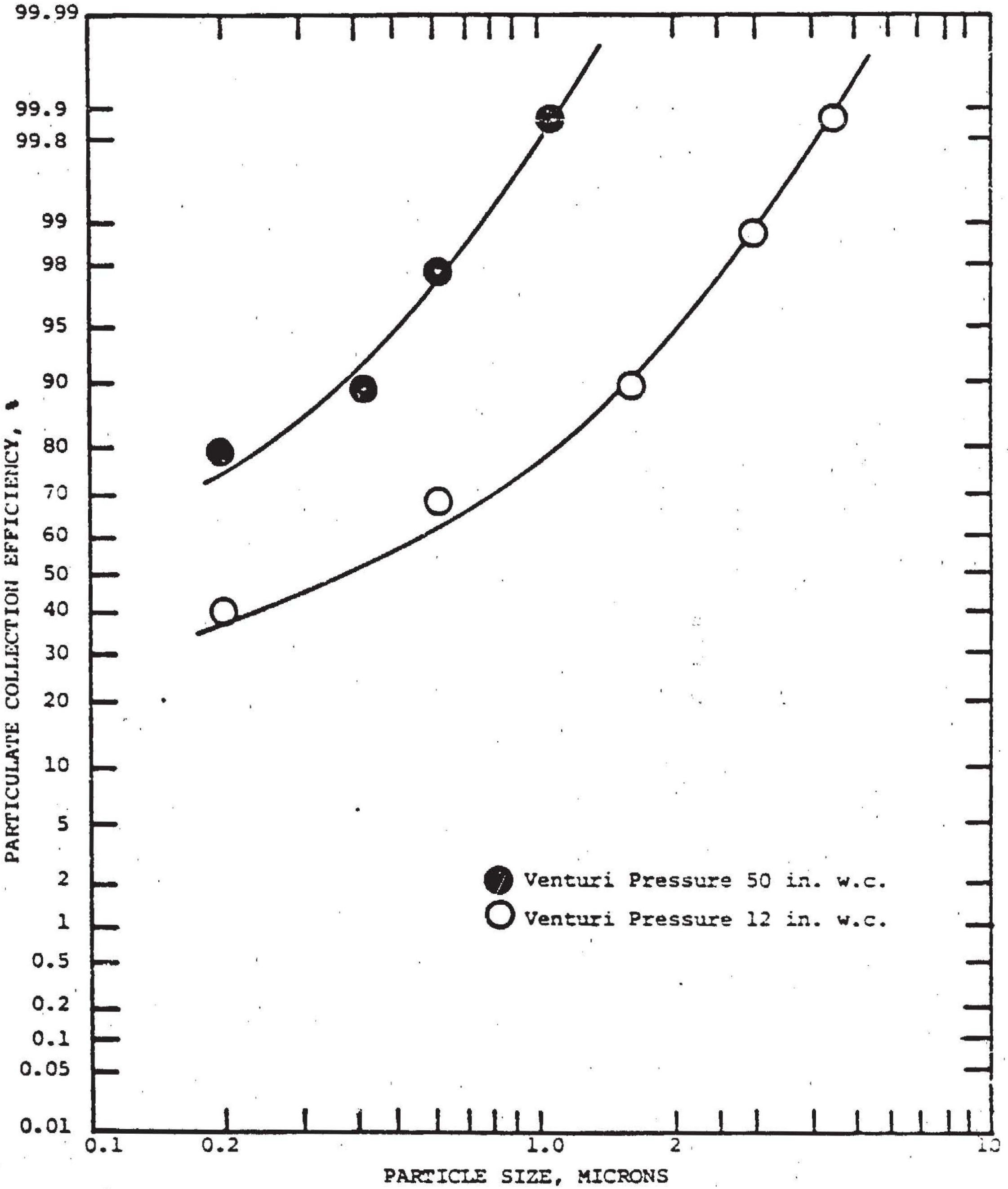

Figure 5-16. Typical venturi scrubber particulate collection efficiency (Research-Cottrell).

Since there are many different mist eliminators used, a detailed discussion is beyond the scope of this report. However, a cyclonic mist eliminator is the most common used in combination with venturi scrubbers. In these mist eliminators good performance can be assured by using conservative spin velocities (70 ft/sec max.) or conservative spin height, superficial gas velocities under 9 ft/sec and adequate sample level controls to prevent scrubber liquor from rising into the gas inlet.

5.1.4 Fabric Filters

Although fabric filters have been used for many years in a wide range of industrial applications, they were rarely used in large installations solely for control of emissions. With increasingly tighter emission limitations and the availability of fabric media with good life at relatively high temperatures, fabric filters are being used in areas once dominated by electrostatic precipitators. Today, if gas temperatures are below 500 °F and 99+% particulate removal is needed, fabric filters should be considered.

A. The basic components of a fabric filter or baghouse, as they are often called, include a suitable filter medium usually in the form of cylindrical bags, a gas tight enclosure for the bags, a mechanisms for cleaning accumulated dust from the bags, and a means for removing the accumulated dust from the device. A typical fabric filter is illustrated in Figure 5-17.

A gas stream containing particulate matter enters the fabric filter housing and enters either the inside or outside of the filter bags. As the gas stream passes through the filter bag and the dust layer accumulating on its surface, the dust particles are removed. A combination of collecting methods including inertial impaction, settling diffusion and electrostatic attraction contribute to particulate removal.

There are two modes of collection possible in a fabric filter, i.e., collection on the inside or outside of the bag. When collection occurs inside the bag, a woven fabric is normally used at relatively low gas rates, i.e., 1.5 to 3.5 $ft^3/min\ ft^2$. Woven fabrics are available in a wide range of materials and operation at temperatures up to 500 °F are possible.

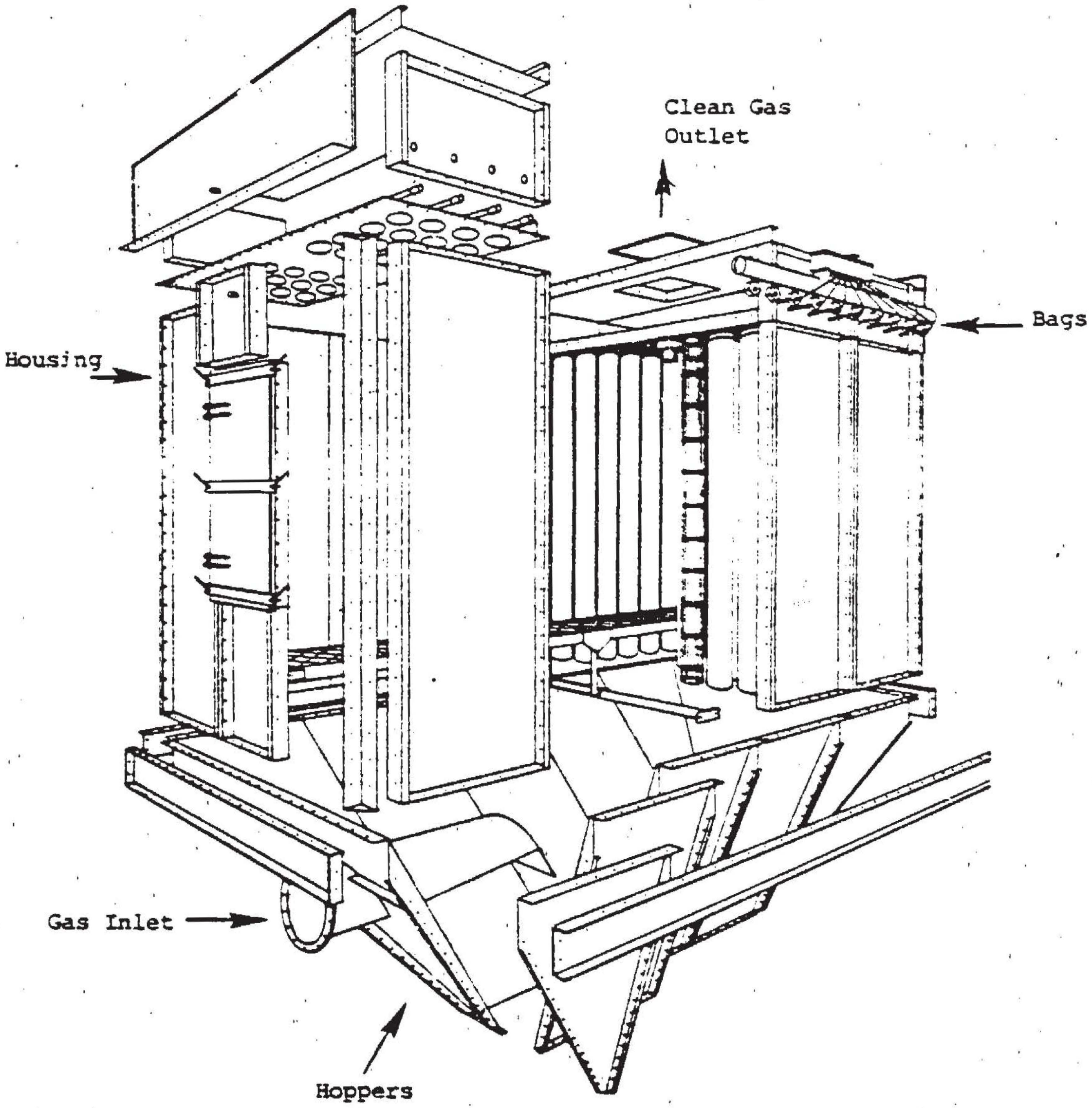

Figure 5-17. Typical pulse jet fabric filter (Research-Cottrell).

Felt fabrics are generally used when collection occurs on the outside of the bag. Since the pressure outside the bag is greater than that inside in this mode of operation, a support is necessary to prevent the bag from collapsing. Gas rates between 5 and 15 cfm/ft^2 are normal for outside collection applications.

Maximum gas temperatures are generally limited to 375 °F due to the types of felt materials available. In addition to the above, the choice between inside and outside collection affects housing and hopper design as well as the method chosen for cleaning. Mechanical shaking is suitable for either inside or outside collection. Reverse air cleaning, where a part of the clean gas is recycled backwards through the bags, is used for inside collection. Pulse jet cleaning, where a burst of high pressure clean gas is sent through the bags is used for outside collection. Cleaning cycles are initiated as needed to maintain the pressure drop across the bags at an acceptable level, usually in the range of 2 to 6 in. w.c. This minimization of cleaning cycles helps to maximize bag life.

The dust dislodged from the bags during the cleaning cycle collects in a hopper before removal via a rotary valve screw conveyor or other suitable device.

B. The selection of the best fabric filter medium for a given application is governed by the temperature of the gas stream and the nature of the dust.

Exotic materials like metal or ceramic cloth which can operate at temperatures above 550 °F are prohibitively expensive. Therefore as a matter of practicality fabric filters have an upper temperature limit of 550 °F.

It is important to note that gas temperatures above 550 °F do not automatically preclude use of fabric filters. If the gas stream can be cooled below this temperature by heat exchange, evaporative cooling or dilution with cool air, a fabric filter can be used.

The other major factor influencing fabric selection is the abrasive qualities of the dust.

Certain materials which are hard and have sharp angular shapes tend to produce rapid wear of the fabric. This tendency can be minimized by lowering filtration rates and minimizing the number of cleaning cycles. It is also important to remember that coarse dusts tend to be more abrasive than fine ones. The selection of cloth is usually left to the supplier as is the filtration rate. The manufacturer selection can be checked by comparing it with the normal fabric and filtration rate used in similar applications.

Table 5-2 lists common fabrics and some of their relevant characteristics. Many of these fabrics can be knitted into seamless bags. This eliminates leaking and breakage which often occurs along the long seam in the bag.

C. Fabric filters are basically simple devices which take advantage of a number of particulate collection mechanisms. Particles are removed as the gas flows through the fabric filter medium by one or more of the following mechanisms:

1. Inertial impaction
2. Diffusion to the surface of an obstacle because of Brownian diffusion
3. Direct interception because of finite particle size
4. Sedimentation
5. Electrostatic phenomena

D. Parameters that are important in fabric filtration system design include air-to-cloth ratio and pressure drop. Each of these factors is discussed briefly below.

A major factor in the design and operation of a fabric filter, the air-to-cloth (A/C) ratio is the ratio of the quantity of gas entering the filter (cfm) to the surface area of the fabric (ft^2). The ratio is therefore expressed as cfm/ft^2 or sometimes also as filtering velocity (ft/min). In general, a lower ratio is used for filtering of gases containing small particles or particles that may otherwise be difficult to capture. Selection of the ratio is generally based on industry practice or the recommendation of the filter manufacturer.

TABLE [illegible]-2. FABRIC CHARACTERISTICS

Material	Temperature Limits		Fabric Type Woven = W Felt = F	Abrasion Resistance	Resistance to Chemicals			Relative Fabric Cost
	Normal	Maximum			Acids	Alkali	Organic Acids	
Cotton	180	225	W	Good	Poor	Good	Good	1
Wool	200	250	W	Good	Fair	Poor	Fair	2
Nylon (Polyamide)	200	25	F	Excellent	Poor	Good	Fair	2.1
Orlon Polyacrylonitride	240	275	W	Good	Good	Fair	Good	2.1
Polyester	275	325	W/F	Excellent	Good	Good	Good	2.7
Polypropylene	200	250	F	Excellent	Excellent	Excellent	Excellent	2.7
Nomex (Polyamide)	425	500	F	Excellent	Fair	Good	Excellent	6.9
Fiberglass	550	600	W	Poor-Fair	Excellent	Poor	Excellent	2.3
Teflon	450	500	W/F	Fair	Excellent	Excellent	Excellent	4.0

(Ref. 5-3)

Pressure drop in a fabric filter is caused by the combined resistances of the fabric and the accumulated dust layer. The resistance of the fabric alone is affected by the type of cloth and the weave; it varies directly with the air flow. The permeability of various fabrics to clean air is usually specified by the manufacturer as the air flow rate (cfm) through 1 ft^2 of fabric when the pressure differential is 0.5 in. H_2O in accordance with the American Society for Testing and Materials (ASTM). At normal filtering velocities the resistance of the clean fabric is usually less than 10 percent of the total resistance. The spaces between the fibers are usually larger than the particles that are collected. Thus the efficiency and the pressure drop of a new filter are initially low. After a coating of particles is formed on the surface, the collection efficiency improves and the pressure drop also increases. Even after the first cleaning and subsequent cleaning cycles, collection efficiency remains high because the accumulated dust is not entirely removed.

The pressure drop through the accumulated dust layer has been found to be directly proportional to the thickness of the layer. Resistance also increases with decreasing particle size. Maximum pressure drop on existing utility fabric filters is 5 to 6 in. w.c.

Particulate collection in fabric filters even for submicron particles is very good. Overall efficiencies well over 99% are possible for a wide variety of particles. Figure 5-18 illustrates fabric filter collection efficiency as a function of particle size.

E. Various cleaning methods are used to remove collected dust from fabric filters to maintain a nominal pressure drop of 2 to 6 in. w.c. Mechanical shaking or reversed air flow are generally used to force the collected dust off the cloth.

Many mechanical shaking methods are in use. High-frequency agitation can be very effective, especially with deposits of medium to large particles adhering rather loosely. In such cases, high filtering velocities can be used and higher pressure drops can be tolerated without danger of blinding (blocking or clogging) the cloth.

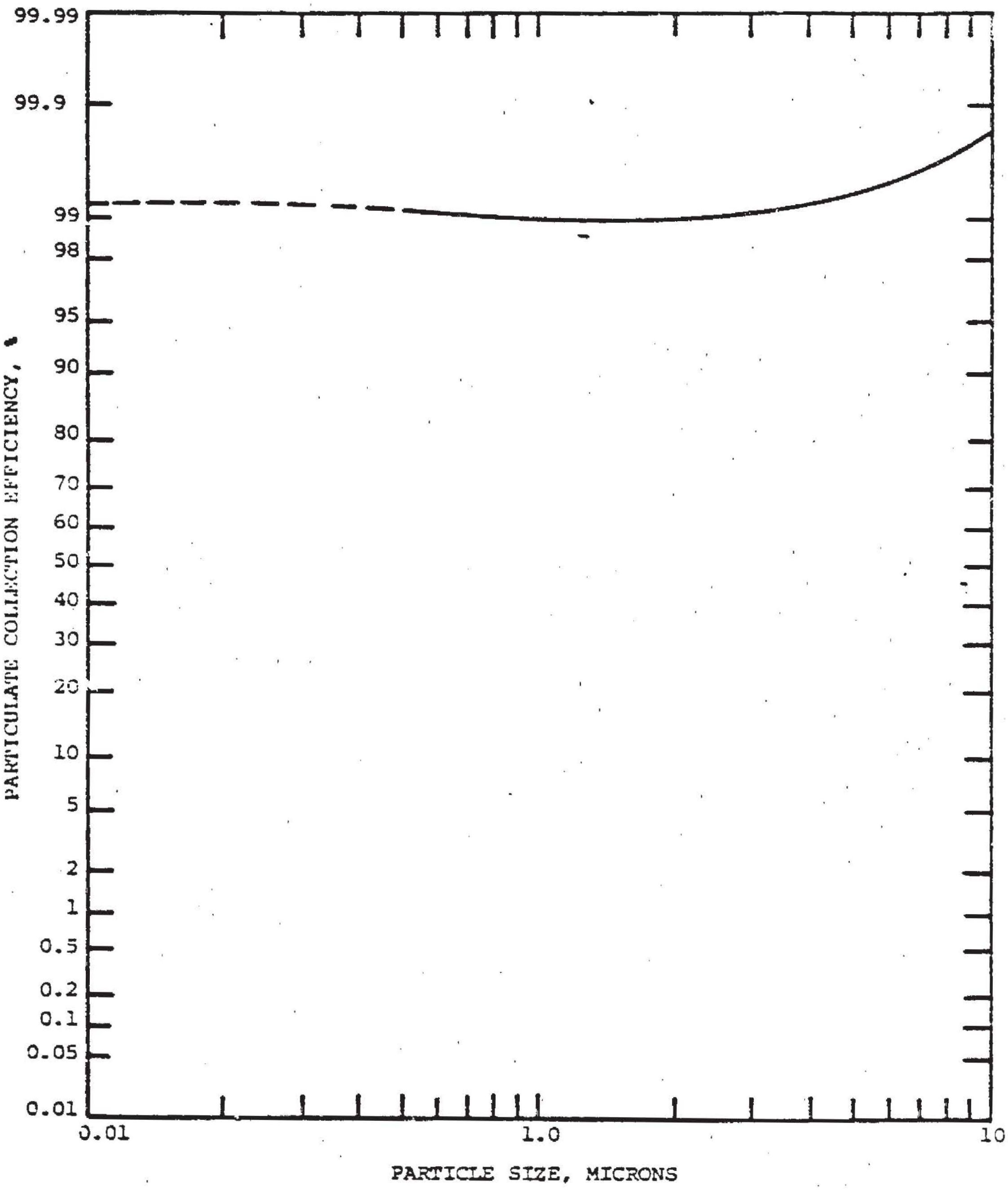

Figure 5-18. Fabric filter particulate collection efficiency (Ref. 5-4).

In an alternative cleaning method, an intermittent pulse jet of high-pressure air (100 psi) is directed downward into the bag to remove the collected dust. In some designs the air is introduced at lower pressures, but these systems may require a greater quantity of cleaning air. Felted fabrics are used in conjunction with the pulse-jet cleaning method. A qualitative comparison of cleaning methods is given in Table 5-3.

A normal cleaning cycle is actuated by a pressure transducer near the inlet to the induced-draft fan when the pressure drop across the bags exceeds about 4 in. w.c. The use of compartments, i.e., groups of bags with individual sets of cleaning controls, permits continuous operation and particulate removal.

During operation each compartment is cleaned in the following manner:

1. The gas inlet damper to the compartment closes, shutting off the flow of "dirty" flue gas to this compartment.
2. The collapse damper opens, allowing a reverse flow of "clean" flue gas from the outlet flue to be pulled through the bags, partially collapsing and thus cleaning the bags.
3. The collapse damper closes.
4. The gas inlet damper opens, returning the compartment to the filtering mode.

So that no sizable portion of the total fabric will be out of service for cleaning at any given time, the time required for cleaning should be a small fraction of the time required for dust deposition. With shake cleaning equipment, for example, a common cleaning-to-filtration time ratio is 0.1 or less. With a ratio of 0.1, 10 percent of the compartments in the baghouse are out of service at all times during operation. Therefore, the frequency of cleaning should be designed to minimize this ratio.

TABLE 5-3. COMPARISON OF FABRIC FILTER CLEANING METHODS

Cleaning Method	Uniformity of Cleaning	Bag Attrition	Equipment Ruggedness	Type Fabric	Filter Velocity	Apparatus Cost	Power Cost	Dust Loading
Shake	Average	Average	Average	Woven	Average	Average	Low	Average
Rev. Air	Good	Low	Good	Woven	Average	Average	Med. Low	Good
Pulse-jet	Average	Average	Good	Felt, Woven	High	High	High	V. high
Vibrating, rapping	Good	Average	Low	Woven	Average	Average	Med. Low	Average

(Ref. 5-3)

F. The normal problems associated with fabric filters include poor control of gas temperature resulting in overheated bags which fail prematurely, impingent of coarse particles on the bags which causes perforation, inadequate clearance between bags which results in excessive wear at contact points, condensation on bags during startup, or operation which results in a sticky cake which cannot be removed from the bags.

The selection of a fabric which is chemically attacked by constituents in the gas or in the particles, excessive pressure during the cleaning cycle which can cause the bags to tear or burst, and cleaning the bags too frequently which substantially reduces bag life.

In addition to the above, the problems of handling the dust collected in the hoppers must be considered.

5.1.5 Electrostatic Precipitators

A. Electrostatic precipitators (ESPs) are one of the simplest, most reliable and economical devices available for particulate removal. These devices operate at very low pressure drops and require minimal amounts of power for charging, rapping and dust removal.

A typical ESP incorporates an electrode arrangement consisting of positive grounded collecting plates and thin section negative discharge wires spaced approximately 5-6 inches apart. A high voltage (approximately 30 KV) DC charge is imposed on the negative element and an electrical field is set up between the two electrodes. The dust particles pass between the elements and are charged and transported to the electrode of opposite polarity. Periodically, the precipitated material must be removed from the electrodes; this is accomplished by vibrating or rapping the plate to dislodge the dust. Figure 5-19 shows the basic components involved and Figure 5-20 gives an idea of the arrangement of a typical full size precipitator.

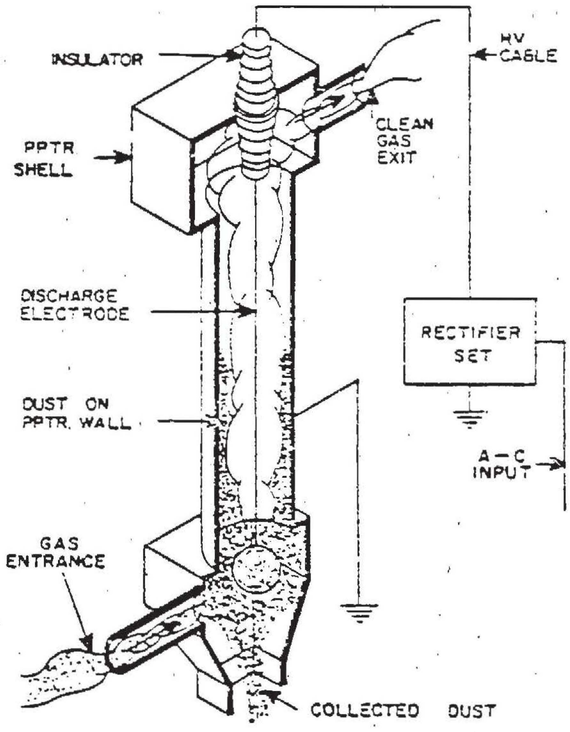

Figure 5-19. Typical precipitation process (courtesy of Research-Cottrell).

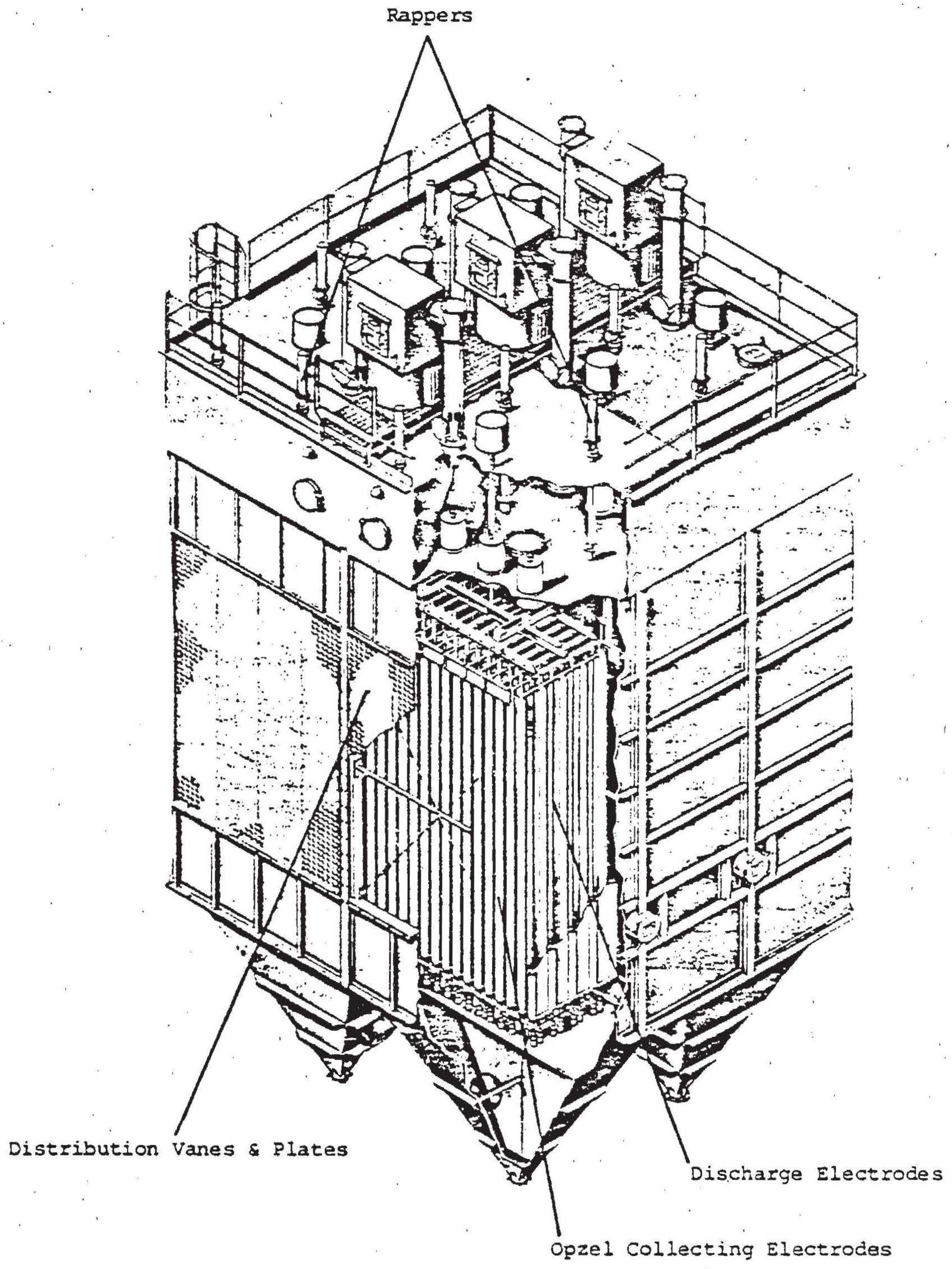

Figure 5-20. Typical full-size electrostatic precipitator (Research-Cottrell)

B. Historically, precipitator sizing has been based on use of the Deutsch equation where

$$\text{Efficiency} = 1 - \exp\left(-\frac{A}{V} w\right) \tag{4}$$

e = Base of Natural Logarithms
A = Collecting Electrode Area (square feet)
V = Gas Flow Rate (cubic feet/second)
w = Migration Velocity (feet/second)

The designer must solve for "A". The parameter "w", migration velocity, is derived from an equation which takes into account the electrical field strength at the collecting surface and the discharge electrode, particle size of the dust, and gas viscosity. Basically, selection of this value reflects the expertise of the designer and the company's experience in the particular application. In essence, the following three values have been those considered of primary importance in sizing a precipitator:

Face Velocity - expressed in feet per second (the speed at which the gas travels through the precipitator). This determines the frontal area of the box.

Migration Velocity - expressed in cm/second or feet/second. This is the speed at which the dust particle travels toward the plate under the influence of the electrical field. As mentioned, selection of this value has been based on experience.

Aspect Ratio - the ratio of the length of the precipitator to its height. (A unit with 30 foot high fields and 36 feet of treatment has an aspect ratio of 1.2). For high (99+%) efficiency, a minimum aspect ratio of 1 is considered necessary.

C. There are many factors which affect ESP efficiency. The following are the more important ones: gas distribution, rapping electrical sectionalization, gas sneakage, dust removal and the stability of the high voltage sytem.

Gas Distribution - Careful attention must be given to the flue arrangement conveying gases to and from the precipitator as well as to the design of the transitions. Nothing will downgrade the performance of a unit as effectively as maldistribution.

Rapping - Cleanliness of precipitator collecting surfaces and discharge electrodes is essential to proper performance. The manufacturer must provide adequate rapping equipment to keep the system clean. As a general rule, at lease one rapper per 2000 square feet of collecting surface and per 3000 lineal feet of discharge wire should be provided.

Electrical Sectionalization - Theoretically, the most efficient precipitator would be one in which each individual discharge electrode has its own power supply in order to maximize power input. This is obviously impractical. However, it is practical and advisable to have the precipitator divided into a number of separately energized electrical sections which can be individually isolated. This practice not only allows, to some extent for variations and stratification in temperature, dust loadings, etc., but it renders a smaller section of the precipitator vulneralbe to external malfunctions such as dust removal problems.

Gas Sneakage - Loss of efficiency can result from gas by-passing the electrostatic zone in a precipitator. This can occur between the end plates and the shell, over the top of the electrical fields, or in the hoppers. On high efficiency units, design provisions are made to provide such potential problems areas with proper sealing and baffling.

Dust Removal - Inadequately designed or under-sized dust removal systems can cause precipitator damage and loss of efficiency. Dust build-up in hoppers can cause damage to precipitator internals by distorting the lower high tension framework, bowing discharge electrodes and causing accelerated failure. Moreover, ash build-up in the hoppers increases possibility of dust re-entrainment and loss of efficiency.

Stability of High Voltage System - The efficiency of a precipitator is a direct function of the power input. Any condition which affects power input adversely should be avoided in the basic design of the precipitator. Proper alignment and stability of the high voltage system is essential.

Todays high efficiency ESPs are very effective collection devices for fine particles. Figure 5-21 illustrates typical collection efficiency as a function of particle size.

D. Rappers--

Removal of particulate matter collected on the plates in ESPs is accomplished by rapping the plates to dislodge the dust. The wires can also be cleaned in this manner.

There are three types of rapping devices in general use today: drop hammers, magnetic or pneumatic impulse rappers, and electromagnetic vibrators. Impulse rappers are used most often on the collecting electrodes or plates because the frequency and intensity of rapping can be adjusted to optimize performance. Charging electrodes are most often cleaned with vibrators.

Plate rapping is performed in either of two modes, i.e., in line with the plate or across the plate. In general, rapping across the plate produces higher levels of accelerations in the plates for a given energy input and results in more thorough cleaning of the plates. The interval between rapping operations is also an important factor in ESP performance. Rapping too often results in unnecessary reentrainment and a decrease in particulate collection efficiency, while overly long rapping cycles result in the buildup of excessively thick layers of insulating dust which also reduces particulate collection.

The optimum rapping cycle in a given ESP installation must be established for each field in the precipitator; fine tuning after startup is almost always required to maximize particulate collection efficiency.

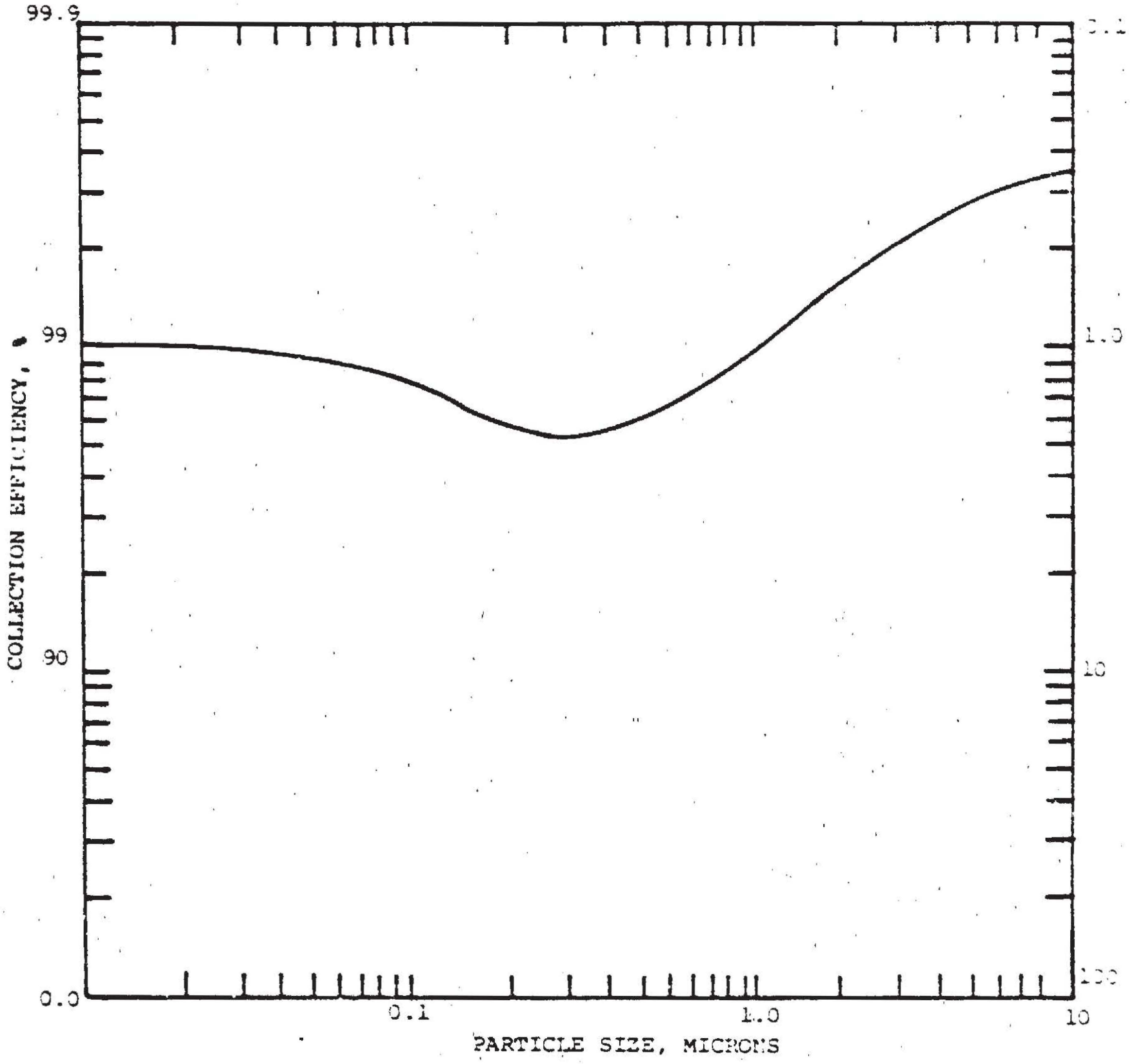

Figure 5-21. ESP collection efficiency (Research-Cottrell).

E. There are several problems that can arise which will substantially reduce ESP performance. The following are the most common encountered with fuel burning equipment:

Gas Volume - A precipitator is a volumetric device. Any increase in boiler load which results in excessive flow through the precipitator will cause a loss of efficiency. For example, a precipitator designed for 3 feet/second face velocity and an efficiency of 99% will drop to 96.5% if the the velocity increases to 4 feet/second (0.33% increase in load).

Temperature - A change in operating temperature may also have an effect on precipitator efficiency. The resistivity of fly ash (ability of the dust particle to be charged) varies greatly in the temperature range 200-400 °F. Ignoring the effects of temperature on gas volume the impact of temperature on efficiency would be (assuming 99% guarantee at 325 °F):

200 °F	99.9+%
325 °F	99%
400 °F	99.5%

Figure 5-22 is a typical fly ash temperature vs. resistivity curve. Bearing in mind that as resistivity increases efficiency decreases it can be seen that there is benefit to be derived in operating below or above the 300-350°F level.

Fuel - Any significant change in the type of fuel being fired will have an effect on the performance of a precipitator. For example, a change from a 2% sulfur bituminous coal to a 0.5% sulfur subbituminous western coal can result in a design efficiency of 99.5% dropping to 90% (or less). It has also been demonstrated that other chemical constituents (such as sodium oxide) in the ash can have an effect on performance by reducing bulk resistivity. It is, therefore, advisable that adequate attention be paid to the fuel as related to its impact on precipitator performance. Ash analysis should be submitted to the manufacturer, if it is available and the unit designed for the worst expected fuel.

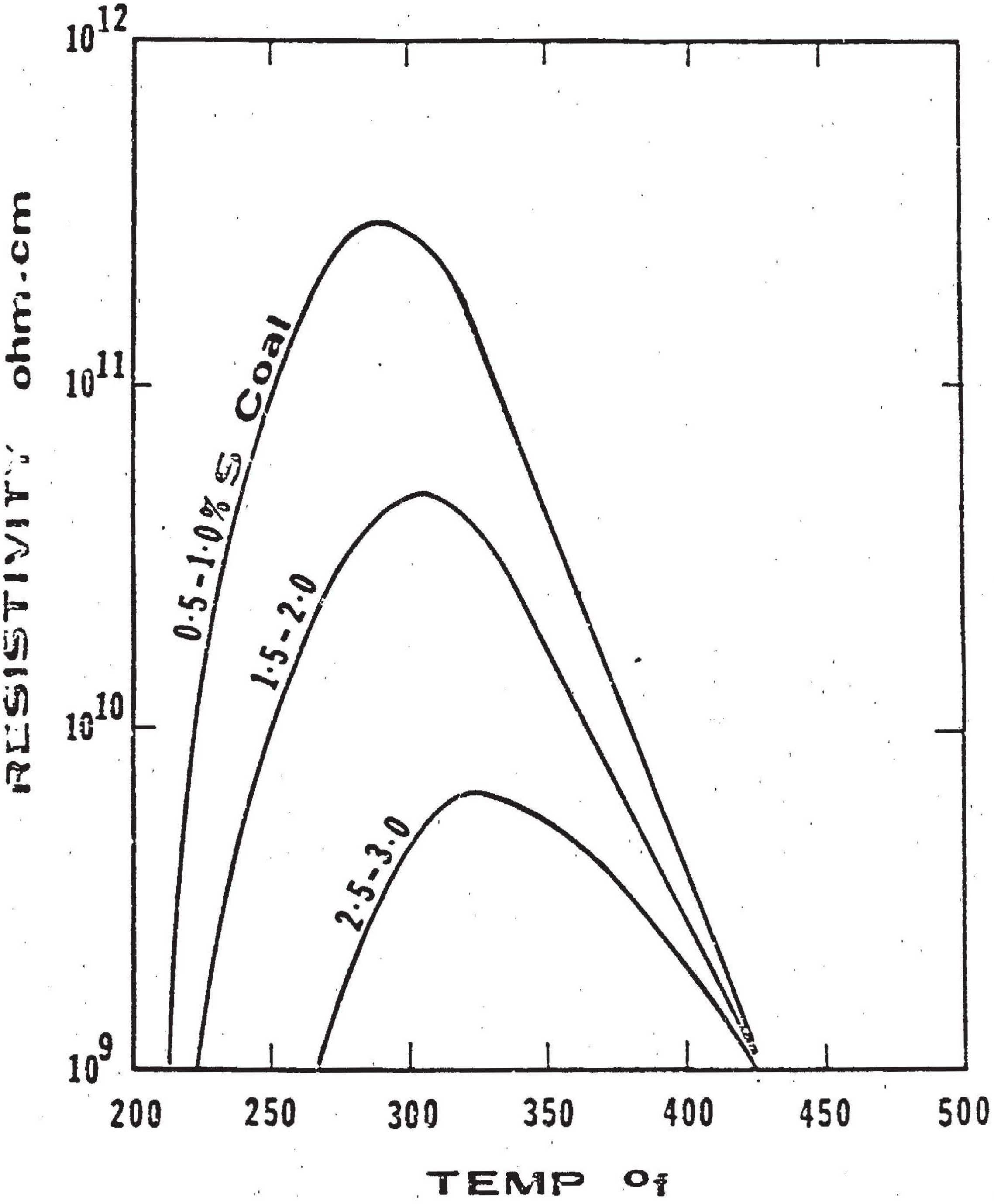

Figure 5-22. Typical fly ash temperature vs. resistivity curve. (Research-Cottrell)

Inlet Loading - The effect of increased dust loading is somewhat obvious. Since a precipitator is designed to remove a certain percentage by weight of the entering material, all things being equal, an increase of 50% at the inlet will result in the same increase at the outlet. Therefore, if a fuel change involves an increase in percentage ash one can expect a corresponding increase at the outlet with greater opacity resulting.

Carbon - Variations in firing practice or coal pulverization which affect the quantity of combustible materials in the fly ash also have an impact on precipitator performance. Carbonaceous materials are readily charged in a precipitator, but lose their charge quickly and are readily reentrained. Not only is the carbon particle very conductive, it is large and light compared to the other constituents making up fly ash. Precipitators on stoker fired boilers, where combustible content may be 25 to 50 percent, are more conservatively sized and employ lower face velocity than a P.C. fired unit firing the same fuel.

The above are the major variables which impact precipitator performance and should be considered if a deterioration in performance is to be avoided.

5.2 COST OF PARTICULATE CONTROL

The cost of particulate control equipment is governed primarily by the volume of gas to be treated, the size distribution of the particles to be removed, and the overall removal efficiency required.

In addition, the chemical and physical characteristics of the gas stream and the particulate matter may require special design features and use of special corrosion, abrasion, or temperature resistant materials.

Where applicable the necessity for considering these extraordinary measures will be noted and their impact on system cost will be indicated.

The particle size indicated on the following cost curves is the size that is collected at the 90% efficiency level. Exceptions to this are noted on the figure.

The installed costs used in this report are the costs that an owner would pay to a contractor to install that piece of equipment and all typical auxiliary equipment necessary for a turnkey ready to operate installation. These costs include the equipment purchase price and the contractor's fees for designing, supervising, and installing the equipment. But these are not the total costs to the owner. In addition to these direct costs are such indirect costs as the engineering and management time necessary to recognize the problem; find alternative solutions; select equipment and contractor; supervise the construction and integration with the plant; company lost revenues for the time the plant is inoperative while the equipment is being installed; changes elsewhere in the plant due to the new control equipment; and the company's general and administrative expenses (bookkeeping, accounting, legal, etc.) associated with these expenditures. These indirect items can add 50% to 100% additional cost to the owner.

5.2.1 Cost Basis

Each of the five major categories of particulate removal equipment has a particular set of factors which dictate performance capabilities and cost. The factors for each category are described below. The cost factors are based on a particular base sized module and a base particulate loading. The effects of scaleup and variations in particle loading on costs are defined for each category of equipment.

The cost figures are based on equipment and labor prices escalated to a 1978 basis and include, where applicable, equipment supports, access ladders and platforms, insulation, instrumentation, painting, wiring, lighting, piping, foundations and interconnecting ductwork, and appropriate onsite waste handling equipment. Waste disposal costs are not included. The cost data were derived from equipment offerings and estimates prepared by Research-Cottrell* during 1977 and 1978.

There are many variables which affect the installed cost of these types of systems. These include factors such as labor rates, productivity, climatic conditions, weather patterns, local construction code requirements,

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*Research-Cottrell, Bound Brook, NJ is the country's largest manufacturer of emission control equipment.

freight and site conditions. The range of the cost data presented in the figures in the following sections in an attempt to define the affect of these types of variables on installed costs.

5.2.2 Cost Data

A. Settling Chamber and Momentum Separators--

Factors Dictating Cost: Figure 5-23

1. Gas Volume
2. Particle Size Distribution

Basic Size Module - 100,000 ACFM

Basic Particulate Loading - 5 gr per SCF

Scaleup: Cost x $(\text{Actual Gas Flow}/100{,}000\ \text{ACFM})^{0.6}$

Particulate Loading Variation: Cost x $(\text{Actual Loading}/5\ \text{gr per SCF})^{0.1}$

The following example illustrates the use of the cost curves.

Settling Chamber:

Gas Volume: 250,000 ACFM
Particulate Loading: 8 gr/SCF
Particle Size to be Collected: 40 microns and larger

Basic System Cost for 40 micron Particles from Figure 5-23: $27,000/39,000

Gas Volume Multiplier: $(250{,}000/100{,}000)^{0.6} = 1.73$

Particulate Loading Multiplier: $(8.0/5.0)^{0.1} = 1.05$

Actual System Cost: 1.05 x 1.73 x ($27,000/$39,000) = $49,000/$71,000

The selection of a final actual system cost from the above range requires that a judgment be made on the basis of the site specific factors cited above.

Note 1. Since settling chambers and momentum separators are rarely used as primary collection devices, the cost data for this category of particulate collection equipment is based on their incremental cost assuming that onsite waste handling equipment has been included in the cost for the primary collection device.

Note 2. Scaling of size and loading should not exceed a factor of 5 of the bases, e.g., 20,000 - 500,000 ACFM.

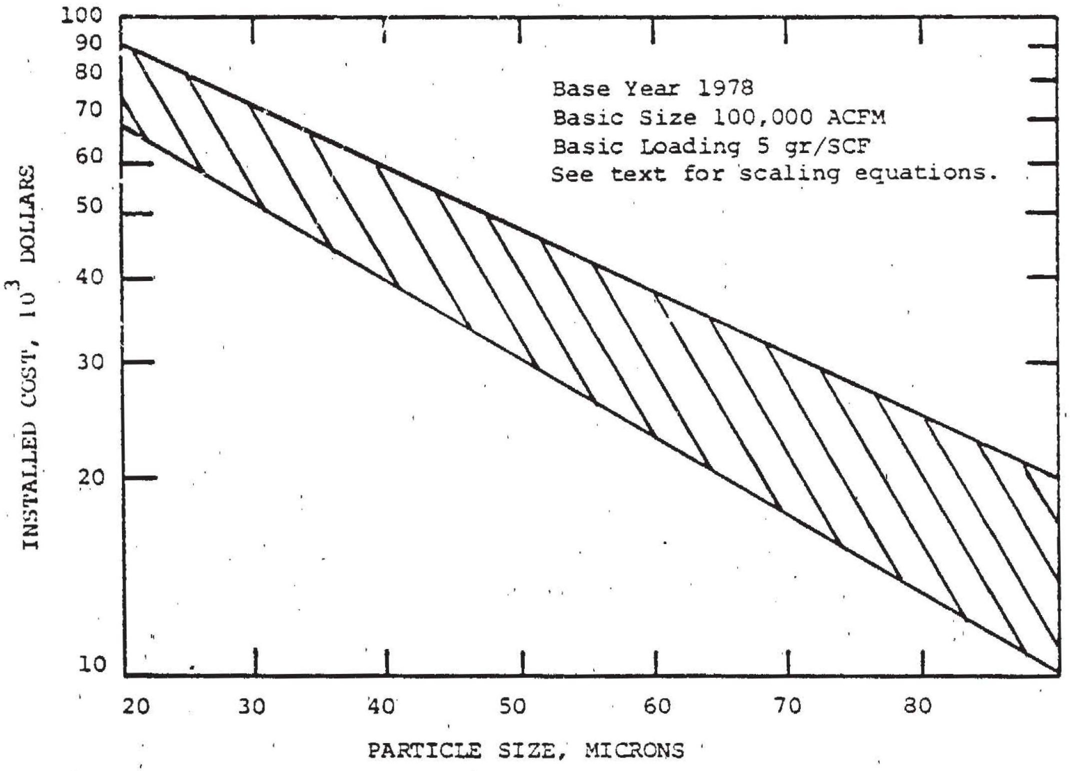

Figure 5-23. Settling chamber and momentum separator cost data.

B. Cyclones--(Figure 5-24)

Factors Dictating Cost:

1. Gas Volume
2. Particle Size Distribution
3. Abrasion Requirements

Basic Size Module: 100,000 ACFM

Basic Particulate Loading: 5 gr SCF

Scaleup: Cost x (Actual Gas Flow/100,000)$^{0.9}$

Particulate Loading Variation:

Cost x (Actual Loading/5 gr per SCF)$^{0.1}$

Abrasion Factor: For abrasive materials use higher end of cost range.

Materials of Construction: Carbon Steel

Nominal pressure drop: 3 I.W.C.

Note 1. Scaling of size and loading should not exceed a factor of 5 of the bases, e.g., 200,000 - 500,000 ACFM

Note 2. In cases where cyclones are used as the primary collection device, the upper range on Figure 5-24 should be used and the following scaleup equation used:

Scaleup: Cost x (Actual Gas Flow/100,000)$^{0.75}$

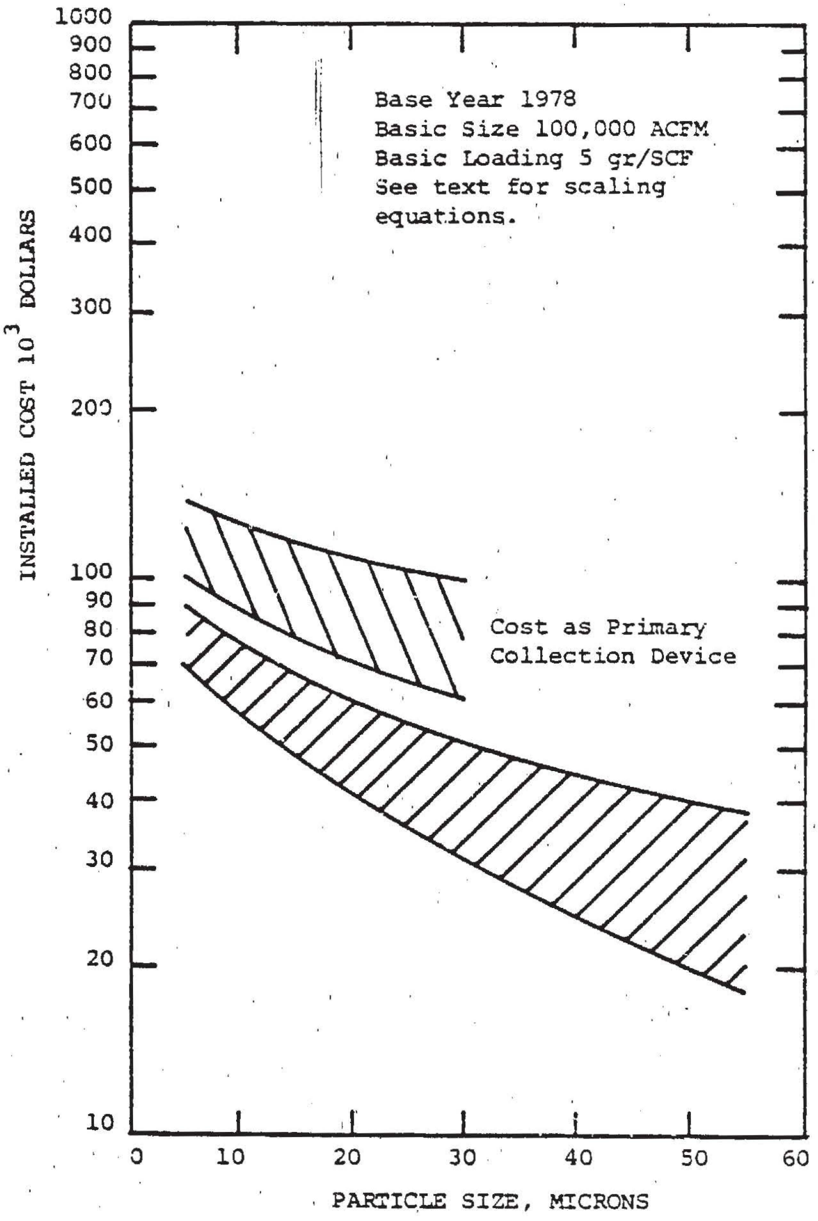

Figure 5-24. Cyclone and multi-cyclone cost data.

C. Wet Scrubber--

1. Spray, Tray, and Packed Towers including auxiliary equipment. Figure 5-25.

Factors Dictating Cost:

1. Gas Volume
2. Liquor-to-gas ratio

Basic Size Module: 100,000 ACFM

Basic Particulate Loading: 5 gr/SCF

Basic Liquor-to-gas ratio: 30 gal. per 1,000 ACF

Scaleup: Cost x $(\text{Actual Gas Flow}/100{,}000)^{0.6}$

Particulate Loading Variation:

Cost x $(\text{Actual Loading}/5 \text{ gr SCF})^{0.15}$

Liquor-to-gas Ratio Variation:

Cost x $[(\text{Actual L/G})/30 \text{ gal. per } 1{,}000 \text{ ACF}]^{0.25}$

Materials of Construction: 316 LSS (stainless steel)

Nominal Pressure Drop:

Spray Towers: 2 to 4 I.W.C.

Tray and Packed Towers: 8 to 12 I.W.C.

Note: Scaling of size and loading should not exceed a factor of 5 of the bases, e.g., 20,000 - 500,000 ACFM

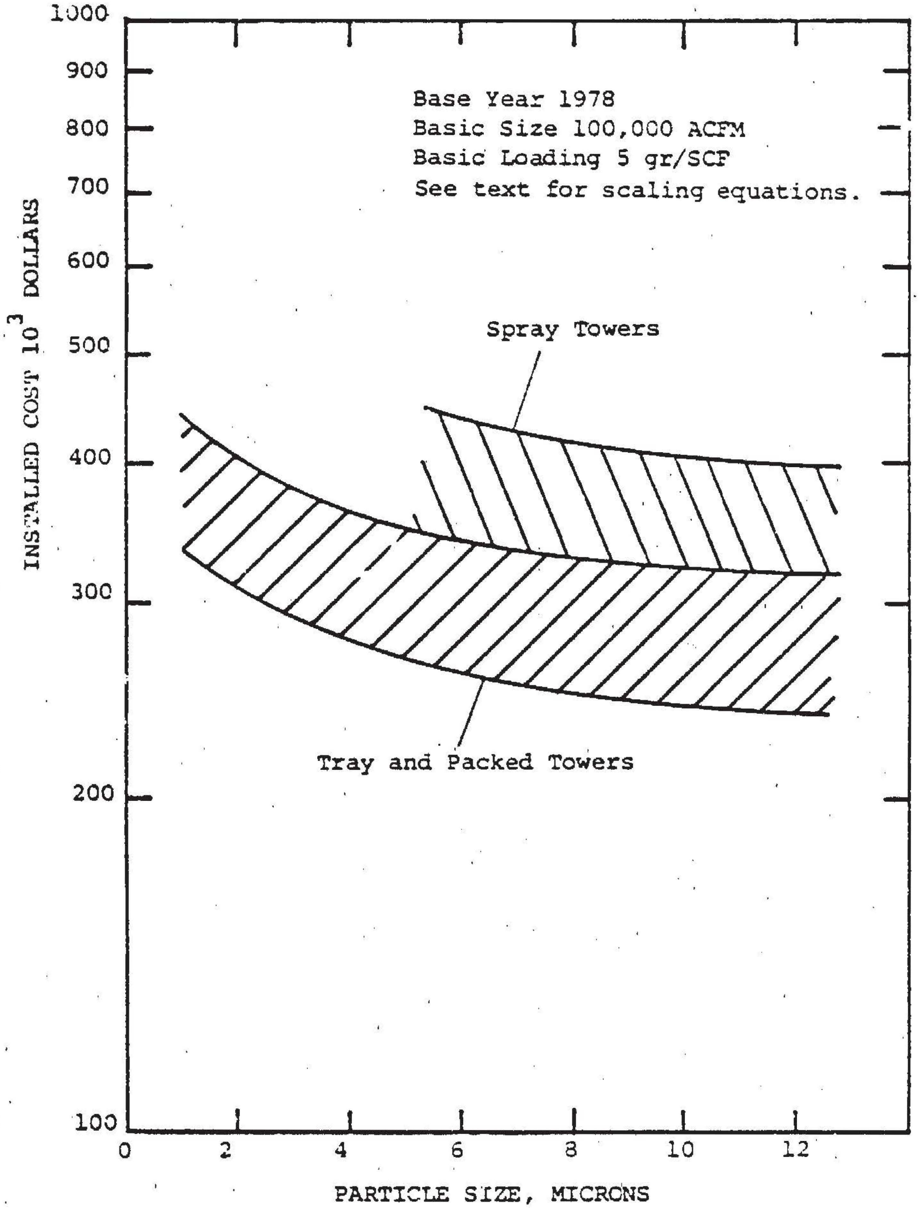

Figure 5-25. Wet scrubber spray, tray and packed tower cost data.

2. Venturi Scrubbers including auxiliary equipment, Figure 5-26

Factors Dictating Cost:

1. Gas Volume

Basic Size Module: 100,000 ACFM

Basic Particulate Loading: 5 gr per SCF

Basic Liquor-to-gas ratio: 6 gal. per 1,000 ACF

Scaleup: Cost x (Actual Gas Flow/100,000)$^{0.6}$

Particulate Loading Variation:

Cost x (Actual Loading/5 gr per SCF)$^{0.15}$

Liquor-to-gas Ratio Variation:

Cost x [(Actual L/G)/6 gal. per 1,000 ACF)$^{0.1}$

Materials of Construction: 316 LSS (stainless steel)

Nominal Pressure Drop

Low Efficiency: 8-10 I.W.C. for collection of particles above 1 µm

Medium Efficiency: 25 I.W.C. for collection of particles between 0.5 and 1 µm

High Efficiency: 50 I.W.C. for collection of particles below 0.5 µm

Note: Scaling of size and loading should not exceed a factor of 5 of the bases, e.g., 20,000 - 500,000 ACFM

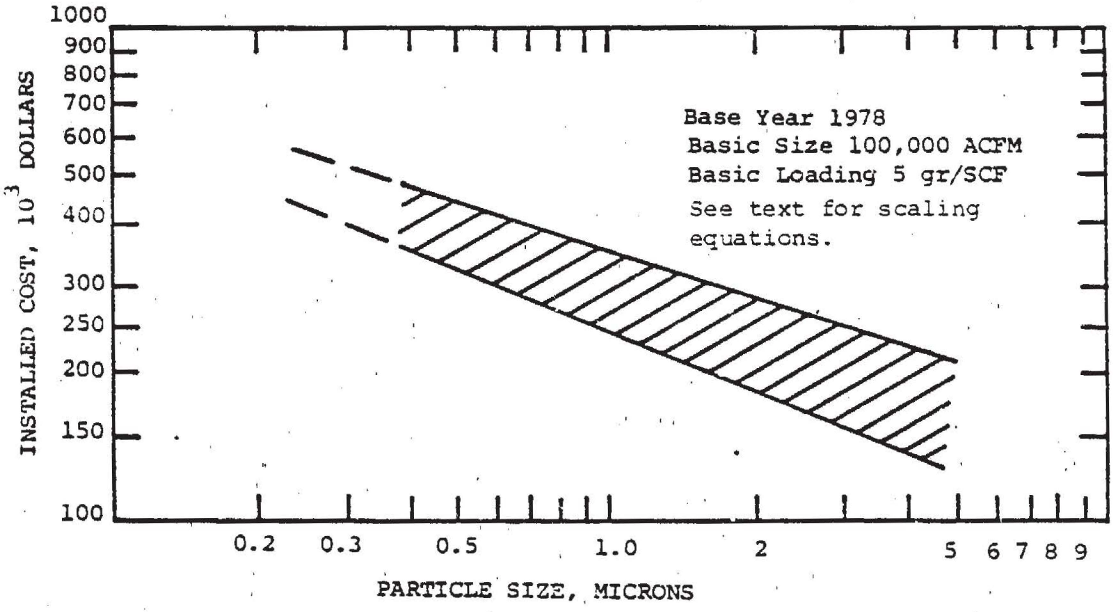

Figure 5-26. Venturi scrubber cost data.

D. Fabric Filters--(Figure 5-27)

Factors Dictating Cost:

1. Gas Volume
2. Gas Temperature
3. Selection of A/C ratio

Basic Size Module: 100,000 ACFM

Basic Particulate Loading: 5 gr/SCF

Basic Gas Temperature: 350 °F

Basic Gross A/C Ratio: 2 $ft^3/min\ ft^2$

Scaleup: Cost x $(\text{Actual Gas Flow}/100{,}000\ \text{ACFM})^{0.9}$

Particulate Loading Variation:

Cost x $(\text{Actual Loading}/5\ \text{gr SCF})^{0.1}$

Gas Temperature Variation: 0.95 x cost + 0.05 x cost (Relative Cost of Fabric/2.3)*

Gross A/C Ratio Variation: $\text{Cost x}\left(\frac{2\ ft^3/min\ ft^2}{\text{Actual A/C ratio}}\right)^{0.9}$

Materials of Construction: Carbon steel

Nominal Pressure Drop: 4-6 I.W.C.

Note: Scaling of size and load should not exceed a factor of 5 of the bases, e.g., 20,000 - 500,000 ACFM

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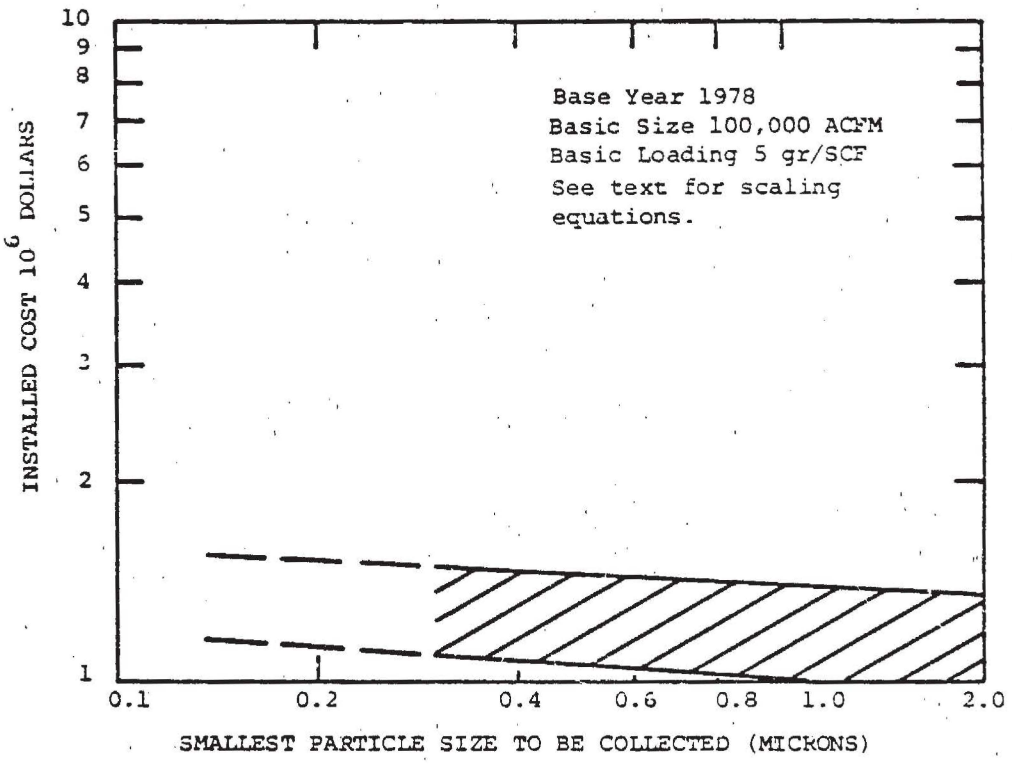
*See Table 5-1 in Section 5.1.4(B) for relative fabric cost data.



Base Year 1978
Basic Size 100,000 ACFM
Basic Loading 5 gr/SCF
See text for scaling equations.

Figure 5-27. Fabric filter cost data. NOTE: 99+% overall collection efficiency.

E. Electrostatic Precipitators—(Figure 5-28)

Factors Dictating Cost:

1. Gas Volume
2. Particulate Loading
3. Particulate Resistivity

Basic Size Module: 100,000 ACFM

Basic Particulate Loading: 5 gr/SCF

Basic Particulate Resistivity: up to 10^9 ohm-cm

Scaleup: Cost x $(\text{Actual Gas Flow}/100{,}000\ \text{ACFM})^{0.9}$

Particulate Loading Variation:

Cost x $(\text{Actual Loading}/5\ \text{gr SCF})^{0.1}$

Particulate Resistivity Variation:

Cost x $(\text{Actual Resistivity}/10^9\ \text{ohm-cm})^{0.15}$

Note: Scaling of size and loading should not exceed a factor of 5 of the bases, e.g., 20,000 - 500,000 ACFM

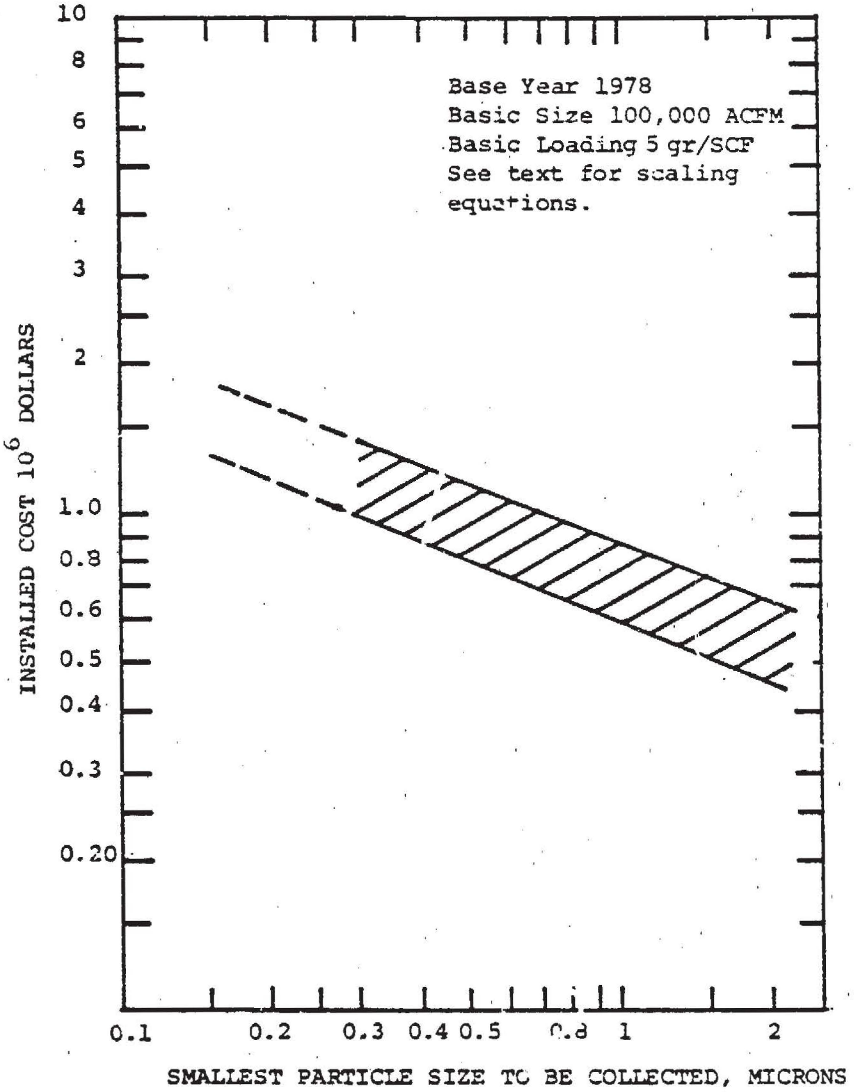


Figure 5-28. Electrostatic precipitator cost data. NOTE: 99% overall collection efficiency.

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50272-101

REPORT DOCUMENTATION PAGE

1. REPORT NO. ARB-R-A6-191-30-79-94

2.

3. Recipient's Accession No.

4. Title and Subtitle Fine Particle Emissions From Stationary and Miscellaneous Sources in the South Coast Air Basin - Final Report

5. Report Date February 1979

6.

7. Author(s) H.J. Taback, A.R. Brienza, J. Macko, N. Brunetz

8. Performing Organization Rept. No. KVB 5806-783

9. Performing Organization Name and Address
KVB, Inc.
17332 Irvine Blvd.
Tustin, CA 92680

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C) ARB A6-191-30
(G)

12. Sponsoring Organization Name and Address
Air Resources Board
State of California
P.O. Box 2815
Sacramento, CA 95812

13. Type of Report & Period Covered Final

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

The report presents results of a program to characterize fine particulate emissions from stationary and miscellaneous sources in the California South Coast Air Basin. Point source emissions were sampled using an EPA Source Assessment Sampling System, which divides the particulate matter into four size ranges: >10, 3-10, 1-3, and <1μm. These samples were analyzed to determine elemental composition (by x-ray fluorescence); sulfates and nitrates (by wet chemistry); and carbon content (by carbon analyzer) in the forms of volatile, carbonate and total carbon. Data for the area source particulate samples in the same size range were obtained from the literature.

From these data, emission profiles were developed for 81 of the 135 Source Classification Codes which are found in the Basin. The profiles provide composition data for each size category. Approximately 66 percent of the particulate matter emitted from point sources was in the fine (<10μm) size range. These emissions amounted to 83 tons per day (tpd), with combustion of fuels being the predominate application category. The area source fine particulate emissions totalled 385 tpd. These data are presented in tabulated and gridded (by 10km) formats. A discussion of control technology emphasizes costs and efficiencies.

The emission profiles are presented in the Appendix.

17. Document Analysis a. Descriptors

Air Pollution	Dust
Aerosols	Particle Size
Sulfates	
Nitrates	

b. Identifiers/Open-Ended Terms

Stationary Sources
Suspended Particulate Matter
Particle Size Distribution

c. COSATI Field/Group

18. Availability Statement
Release Unlimited. Available from National Technical Information Service 5285 Port Royal Rd. Springfield, VA 22161

19. Security Class (This Report) unclassified

20. Security Class (This Page)

21. No. of Pages 582

22. Price PC A25/MF A01

(See ANSI-Z39.18)

See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

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