3.2.2 Analysis Methods

All of the particulate samples obtained for any of the catches that had a weight of 100 mg or greater were sent to Armament Systems Corporation,* Anaheim, California, for elemental composition and to Rockwell International Air Monitoring Center (AMC), Newbury Park, California, for sulfate, nitrate, and carbon analysis.

A. Elemental Analysis--

1. X-ray fluorescence--During the mid 1960's, solid state devices (energy dispersive spectometers) were developed which absorb X-ray radiation emitted by a sample and generate voltage pulses whose magnitudes are proportional to the energy of the absorbed X-rays. With the aid of a multichannel analyzer, these pulses can be separated according to their size. Since each atom generates a series of X-rays with specific energies, the energy spectrum accumulated in a multichannel analyzer has peaks which specify the elements present. With proper calibration, the integrated intensity of these responses can be related to the concentrations of the observed elements in the analyzed sample.

(See ASTM STP485, Energy Dispersive X-ray Analysis: X-ray and Electron Probe Analysis, 1971).

Special sample preparation procedures and laboratory techniques were used with energy dispersive spectrometers to generate low ppm detectability for all chemical elements heavier than potassium in solids. The laboratory analysis included the following procedural steps:

(1) A representative sample was coarsely sieved and the remaining material was thoroughly mixed before a 10-50 mg aliquot was taken.

(2) The sample was then dried and degreased if necessary.

(3) 20 to 50 mg of this material were combined with a binder and pressed into a thin pellet for analysis.

A Picker X-ray generator was used to provide photons which excited the prepared pellet. The tube X-rays were filtered in two different modes to provide essentially monochromatic photons of 17 and 35 KeV which were used to fluoresce the sample. This optimized the sensitivity for elements with atomic numbers 19-39 plus 57-83, and 40-56, respectively. Prior to analysis, an absorption measurement was made on the target according to the method of Giaque

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* Formerly Analex Corp.

and Jaklevic (Ref. 3-25). This was required for elements with atomic numbers 19-30. This measurement enabled proper comparison with NBS standard reference materials and EPA standard reference samples. Each pellet was then fluoresced and the spectrum was accumulated. The responses were corrected for absorption effects, properly integrated and compared to standards to obtain the final elemental concentrations. To insure accuracy, comparisons were made on a periodic basis with whatever data were available from other analytical methodologies in addition to the normal calibration routine.

Although X-ray fluorescence is not normally used to detect silicon and sulfur, atomic numbers 14 and 16 respectively, Armament Systems was requested to report these elements when they felt their analysis could produce a meaningful result. Those results are reported but should be used with some reservation concerning their accuracy.

2. Atomic Adsorption (AA)--A few samples were randomly chosen for AA analysis to compare with the results of the XRF analysis. Atomic Adsorption analysis was done by Rockwell AMC. The procedure is as follows:

Five to ten milligrams of solid particulate or 1" circle from the filters was treated with a mixture of hydrofloric acid and nitric acid to completely dissolve any silicates present. The mixture was taken to dryness so that all silicones were driven off as SiF_6. The remaining solids were resuspended in 10% nitric acid. Before diluting to volume, a flame buffer of lanthanum was added, so that the final matrix used for AA was 10% nitric and 0.5% lanthanum. Then flame analysis was performed.

B. Chemical Analysis--

Each sample received was placed in a desiccator for a minimum period of 24 hours. The samples which contain large particulates were then ground with a mortar pestle until they were homogeneous.

1. Water soluble sulfate ($SO_4^=$) analysis--Three samples were randomly chosen to test relative extraction efficiency for recovery of total sulfate, by a) 0.01 M carbonate extraction, b) water extraction, and c) carbonate fusion extraction. Duplicate and triplicate samples were analyzed to give an indication of precision. The results are discussed in Section 3.3.2. The 0.01 M carbonate extraction method was chosen for all $SO_4^=$ analysis. The three procedures are given below:

a) 0.01 M Carbonate Extraction--A 10mg portion of solid sample or a 1" diameter circle punched from filter samples was reflux extracted in a 0.01 M carbonate, .0036 M acetate buffer (pH 4.5) for one hour. The hot extract solution was then filtered through Whatman #41 filter paper and diluted to a final volume of 50 ml. Colorimetric analysis was performed using the methylthymol blue (MTB) method. The detection limits were 1.0 μg/ml (0.5% by weight solid).

The MTB method of sulfate determination is based on the spectral difference which exists in basic solutions (pH 12.5-13.0), between the barium complex of MTB and the free MTB. At his pH the barium complex is blue and the free MTB is brownish-red. (abosrbs light at 460mm). Thus, the color of solutions containing both the free MTB and the barium complex of MTB, monitored colorimetrically at 460 nm, is the measure of the amount of sulfate in the sample because the reaction of sulfate with MTB-Ba^{++} results in equivalent amounts of free MTB.

b) Water Extraction--The procedure used for water extraction was the same as the 0.1 M carbonate extraction except water replaced the 0.01M carbonate solution.

c) Carbonate Fusion Extraction--In this method sodium and potassium carbonates were melted with the sample to convert all insoluble $SO_4^=$ to soluble forms.

Procedure-- 5-10 mg of substance, finely ground, was mixed with 40-50 ml of a mixture of equal parts of anhydrous sodium and potassium carbonates, in a platinum crucible. The sample was first heated for 5 minutes gently, then to fusion, maintaining the mass in the fused state for 30 minutes. When no further bubbles of carbon dioxide were formed, it was heated as strongly as possible for another 10 minutes. It was allowed to cool, causing the mass to congeal as a layer around the walls of the crucible. (It was easier to extract the mass afterwards if it had as large a surface as possible.) The crucible was then filled one-third with water and heated gently. The solid was then detached. If it did not respond to this treatment, the crucible was placed in a beaker of water and heated until the solid was disintegrated.

The hot extract solution was then filtered through Whatman #41 filter and diluted to a final volume of 50 ml. Colorimetric analysis was performed using the MTB method discussed above.

2. Nitrate (NO_3^-) Analysis--A portion of the 50 ml hot extract solution (from $SO_4^=$ analysis, section 3.2.2, A.1.a. above) was filtered for the analysis of nitrate. Calorimetric analysis was performed using the Cd reduction-diazo dye method. The detection limit was 0.50 µg/ml (0.25% by weight solid).

The nitrate extracted from the solid and filter samples was reduced to nitrite by a copperized-cadmium reductor column and was reacted with sulfanilamide in acidic solution to form a diazo compound. This compound then coupled with N-1-naphthylenediamine dihydrochloride to form a reddish-purple azo dye which was determined spectrophotometrically at 560 nm.

C. Carbon Analysis--

A carbon analyzer made by Oceanography International was used for the carbon analysis. Using this instument, carbon in the sample was converted to CO_2, which was analyzed using a Horiba NDIR detector. Three different techniques were used to analyze the samples. Using the direct injection technique, microliter quantities (up to 100 µg) of sample were injected onto a filament for programmed heating at 150 °C and then at 800 °C. This filament is in a sealed system with O_2 flowing first over the filament, then through a furnace kept at 800 °C, and finally to the NDIR detector.

Samples were sometimes analyzed by the ampule technique. Using this technique, samples were sealed in a glass ampule with oxidizing solution and heated at 150 °C for at least eight hours. The ampules were then cooled and and placed in the analyzer. The tip of the ampule was broken and nitrogen gas flushes all CO_2 from the ampule to the NDIR detector.

Carbonate in solution was analyzed using a closed vial containing acid solution. There was a continuous flow of nitrogen through the solution of this vial and to the NDIR detector. Up to 1 ml of sample was injected through a septum into the acid solution of the vial.

Most of the samples on this program were analyzed for volatile carbon and total carbon by the direct injection techniques. Five ml of final ground particulates were suspended in 10 ml of carbonate free water. Up to 100 µg of these suspended particulates were injected onto the injection filament for programmed heating. "Volatile" carbon was the carbon which either vaporizes or is oxidized as the filament is heated at 150 °C for 200 seconds. "Non-volatile" carbon is determined as the filament is heated to 800 °C for 80 seconds.

Inorganic carbon was determined on particulate samples by injecting 1.0 ml of the suspended particulate into acid solution in a closed vial. Carbon dioxide was purged from the acid and to the detector by a flow of nitrogen through the acid solution.

Filter samples were analyzed for inorganic and for total carbon using the ampule technique. For inorganic analysis, a 1 cm circle was punched from the filter and placed in a glass ampule. The ampule was then purged of atmospheric carbon and sealed in a flame. Inorganic carbon was determined by breaking the ampule in a closed system, adding 2.0 ml 5% v/v phosphoric acid, and purging the carbon dioxide to the detecting system. For total carbon analysis, another 1 cm circle was punched from the filter and placed in a glass ampule. One ml 6% v/v phosphoric acid and two ml water are added to the ampule and the ampule is then allowed to sit for 30 minutes. Three ml of saturated potassium persulfate were added and the ampule was purged of carbon dioxide and sealed in a flame. Several ampules were then placed in a pressure vessel and heated for eight hours at 150 °C to allow oxidation of organic carbon. The ampules were cooled and analyzed by breaking the ampule in a sealed system and purging the carbon dioxide to the detection system.

D. Analysis for the Organic Content of the Impinger Catch--

Sample processing was divided into two operations: (1) determining the amount of water condensed in the impingers, and (2) determining the total weight of particulate matter collected by the impingers.

The total volume of liquid contained in the impingers was carefully measured. The difference between this volume and the initial volume of distilled water was recorded as the condensate volume. When small amounts of condensate were obtained, each impinger was weighed (to the nearest 0.1 g) before and after the test. A small correction was made for particulate matter.

The impingers and associated tubing were carefully rinsed with small portions of distilled water, the liquid and washings being kept in a beaker or flask. The inner walls of the sampling probe and tubing were washed and the washings kept separate. All of the inner surfaces of each of the cyclones and tubing were washed and processed separately, after the solid material had been transferred to tared vials. Any tar-like or organic material in the equipment or tubing was washed out with minimum amounts of reagent grade acetone or methyl chloroform and added to the aqueous portion. All washing was done in a counter-current manner, using each portion of water or solvent to wash each impinger successively in a direction opposite to the sample gas travel, in order to conserve liquid volume and avoid excess use of organic solvent.

The organic material was removed from the aqueous by extraction with an organic solvent, and the solvent extract was evaporated at room temperature. The combined liquid and washings (usually a volume of about 2-3:1) from the impinger train, were transferred to a separatory funnel and extracted with five 25-ml portions of reagent grade methyl chloroform per 500 ml of water. About 25 shakings were made for each extraction. The two liquids were allowed to separate as much as possible after each extraction, and care was taken not to include any water in the solvent extract that was drained from the lower portion of the funnel after each extraction. Larger volumes of solvent were used if the aqueous volume was much greater than 500 ml. Since methyl chloroform vapors are toxic all operations were conducted in a well ventilated or hooded location.

Finally, the aqueous fraction was evaporated to dryness and residue weighed as described below:

The small beaker was evaporated just to dryness at 105 °C in a constant temperature electric oven, cooled in a desiccator for one-half hour, and weighed on an analytical balance to the nearest 0.1 mg. The difference from the tare weight of the beaker was recorded as the weight of particulate matter collected by the impingers. Determination of dissolved solids was made on each batch of distilled water used and a correction for this blank applied to each sample.

The solvent containing the dissolved organic fraction of the particulate matter was placed in 250-ml conical flask and the solvent evaporated by a stream of dry air. The flask was equipped with a two-holed cork stopper. A short glass outlet tube was connected to a vacuum line. An inlet glass tube, drawn out to about 1 mm in diameter at the tip, was placed at a point just above the surface of the liquid. The vacuum was regulated to draw a jet of air over the surface of the solvent and promote fast evaporation. The inlet air passed through a large-diameter drying tube filled with a desiccant such as Drierite. The flask was kept slightly above room temperature in a water bath to prevent slowing of the evaporation process. The discharge air from the vacuum pump or aspirator was hooded to a ventilation system to remove the toxic vapors.

When the solvent evaporated to 15 ml or less, the liquid was transferred to a tared 50-ml beaker, using small amounts of solvent. The beaker was placed under a small bell jar (such as Corning No. 7880) with an arrangement for drawing a stream of dry air over the surface of the liquid at room temperature, in the manner described in the preceding paragraph. The evaporation was continued until all of the solvent had evaporated and only an oil or resin remained. A halide leak detector (such as one manufactured by Prest-O-Lite) was used to determine when all the chlorinated solvent had evaporated. The sampling tube of the detector was held above the residue in the beaker and the color of the small acetylene flame over a copper grid observed. If any halogen was present as a vapor, the flame would be colored more or less bright blue or green; otherwise the flame was almost a nonluminous blue-biolet. This test is sensitive to a few parts per million. In the rare event that the particulate matter contained volatile organic halides, a series of weighings were necessary in order to determine when all the solvent had been evaporated.

The beaker was placed in a desiccator for one-half hour and weighed on an analytical balance to the nearest 0.1 mg. The difference from the tare weight represented the weight of solvent-soluble particulate matter collected by the impingers. (Only relatively high boiling point organic compounds--over 320 °F boiling point--were retained during the evaporation of the chlorinated solvent.) (The lower boiling point organic compounds, e.g., aldehydes, ketones, organic acids, would not be held.) There should be negligible blank weight from the evaporation of the pure solvent. The weights of the solvent and aqueous residues are added to give the total particulate matter collected by the impingers. Due to the tar-like consistency of the sample it was not possible to obtain further chemical analyses (i.e., XRF, sulfate, nitrate, and carbon).

3.2.3 Data Reduction

A. Data Sheets and Data Work sheets--

This section deals with the description and use of the various types of data sheets that were used to document each field test. Also in this section are explanations of the calculation used for the reduction of the data to the form given in Table 4-1.

The following is a list of data sheet and work sheet forms used throughout the field test portion of this program and discussed in this section. These forms are listed below and a copy is presented in Section 3.4.

5806-6	Test Preparation and Plant Visit
5804-7	Gas Velocity Data
5804-5	SPOT Monitoring Data by Draeger
5806-2	Meter Sheet
5804-4	Water Vapor and Gas Density Calculations
5806-3	Engineering Process Field Report
60-3	Mobile Laboratory Data--only used on sources that were being monitored.

60-33	Control Room Data
5804-1	Statement of Process Weight
5806-1	Particulate Emission Calculation
5806-10	Extraction of Impinger Water
5806-8	Solid Cyclone and Filter Catch
5806-7	Particulate Emission Boil down Sheet
5806-9	Particulate Summary Sheet
5804-8	Laboratory Test Request
5806-A	Size Distribution Work Sheet #1
5806-B	Size Distribution Work Sheet #2
5806-C	Particle Size Distribution
5806-D	Chemical Composition of Particulate Samples
5806-E	X-ray Fluorescence Analysis Results
5806-F	Sulfate and Nitrate Analysis Results
5806-G	Carbon Analysis Results

Careful selection of the test sites was made by using the preliminary inventory data. When several test sites were selected for a particular industrial type from the inventory data, then phone calls were made to each plant until cooperation was obtained from at least one plant. A plant visit was scheduled to inspect the equipment and determine the best location for test set-up (if test could be conducted at all). The field test director or project engineer would then visit the plant and use Form 5806-6 (page 1-3) Section 3.4, to acquire the information needed to plan and prepare for the source sampling of particulates.

On the day of the field test, the order of events was as follows:

1. The field test director would clear the test area with the proper personnel and safety people.
2. The test crew would begin unloading equipment, while the field test director would check the stack (pollution source) for toxic matters with a Draeger tube whenever toxic matter might be present. These data are recorded on Form 5804-5, Section 3.4.

3. While test equipment was being set up, a velocity traverse was taken of the stack or ducts (sometimes at both inlet and exit to a control device if these were to be tested.) The velocity data were recorded and calculated on Form 5804-7, Section 3.4. The equation used to calculate velocity was:

   $$\text{velocity (ft/sec)} = 2.9\ [(\text{vel. head in } H_2O)(\text{Temp } ^\circ K)]^{1/2}$$

4. Water vapor in the gas stream was determined by using an Orsat and/or Fryrite (O_2 and CO_2) or sling psychrometer. These data were recorded and calculated on Form 5804-4, Section 3.4.

5. The field test director calculated a proper nozzle diameter using the nomograph technique discussed in Section 3.2.1 B or the equation given in the same section.

6. As the test crew would complete the last details of the set-up, the field test director would check with the control room to assure a normal operation of the equipment being tested.

7. The test crew would wait for the field test director's approval before starting the test. The initial meter readings were recorded on the meter sheet, Form 5806-2, Section 3.4.

8. During the test interval, the test crew would record data on the meter sheet every 15 minutes, and the field test director would record process observations and data on Forms 5806-3, 60-3, 60-33, and 5804-1 in Section 3.4.

9. At the end of the test, the crew would record the final reading and carefully load the equipment for transporting.

The next day at the KVB lab facility, the test crew would unload the samples from the van and begin the tasks of weighing, extracting, and evaporating the liquids. The order of events was as follows:

1. Initial weight for solid catches (particulates caught in the cyclones and filter containers) were obtained before the field test. The material in the cyclone was carefully transferred to tared vials, dessicated, and weighed. These data were recorded on Form 5806-8, Section 3.4. Weight data for the filter also were recorded at this time.

2. The amount of water in the impinger was measured and recorded on the meter sheet, Form 5806-2, Section 3.4. The water was then transferred to a separatory funnel and extracted with methyl chloroform. This procedure is discussed in Section 3.2.2 C. The data were recorded and calculated on Form 5806-10, Section 3.4.
3. The impinger water was then evaporated. Also water washes of the cyclones and probe were evaporated. These data and calculations were recorded on Form 5806-7, Section 3.4.
4. At this point, the weights of all samples were recorded on the weight summary sheet, Form 5806-9 (Section 3.4) and the data turned over to the project engineer.

The project engineer would review the weight summary sheets and decide on the samples to be sent for XRF analysis and SO_4, NO_3, and carbon analysis. Only samples with weights of 100 mg or larger could be sent for these analyses, due to the limited amount of sample necessary for determinations. He would use Form 5804-8 (Section 3.4) to record samples sent for analysis.

The project engineer would use the various forms discussed above to calculate the parameters given on Form 5806-1, Section 3.4. He would also use the data to determine the size distribution curve. Calculations and plots were recorded on Forms 5806-A, 5806-B, and 5806-C, Section 3.4. The correction for temperature and flow for the D_{50} cut size for each cyclone was performed using the data discussed in Section 3.2.3-C. Also refer to Section 3.2.3-B for the explanation of the size distribution plots.

When the project engineer received analysis data for samples completed by 1) XRF--Form 5806-E (Sect. 3.4)--major elements, 2) sulfates and nitrates--Form 5806-F (Sect. 3.4), and 3) total carbon, volatile carbon, carbonates--Form 5806-G (Sect. 3.4), he would check the results and enter the data on Form 5806-D (Sect. 3.4) for each field test. This form allowed for easy comparison between the different size fractions for each test and also for assessments of the two trains when they were used simultaneously.

B. Particle Size Distribution--

In general, the particle sizes will have a normal or Gaussian distribution. Plotting the particle size distribution in μm, against the cumulative weight percent on log-normal probability paper, yields a straight line (Refs. 3-5 to 3-8).

Each source sample for TSP was broken down into the following fractions:

1. Probe Catch--assumed to have sizes of particles evenly distributed over total range.
2. First Cyclone Catch--contained all particles larger than the D_{50} calibrated cut size for this cyclone (9.2 μm for SASS and 8.3 μm for Joy)
3. Second or Middle Cyclone Catch--contained only particles of the D_{50} calibrated cut size for this cyclone (3.8 μm for SASS and 1.9 μm for Joy).
4. Third or Small Cyclone Catch--contained only particles of the D_{50} calibrated cut size for this cyclone (1.3 μm for SASS and 0.6 μm for Joy).
5. Filter Catch--contained all particles of sizes less than the D_{50} calibrated cut size of third cyclone but greater than the porosity of the filter (porosity of the filter is questionable but is estimated at 0.01 μm).
6. Impinger Catch--contained aerosols which were vapor through the 400 °F filter and had condensed in the impinger, and submicron particles less than 0.01 μm. However, pseudo particulates [particles formed after the filter, e.g., $SO_3 + 3H_2O \rightarrow H_2SO_4 \cdot 2H_2O$ and $2NH_3 + SO_3 + H_2O \rightarrow (NH_4)_2SO_4$] may add to the weight of this fraction.

The weight fraction of the probe catch was not used to define the size distribution, because this fraction contained particles of unknown sizes. The weights, in mg, of the remaining fractions were listed on the

"Size Distribution Work Sheet #2 (Table B)--impinger catch not included, and on the "Size Distribution Work Sheet #1" (Table C)--impinger catch included (Sect. 3.4). Only the data from the second and third cyclones from these work sheets were used to determine the straight line on a log-normal probability plot (corrected size, µm vs weight percent less than stated size). Figure 3-28 illustrates the construction of this function. The first cyclone was not used in generating the particle size distribution since it would catch particles above its D_{50} cut point. This material could only be characterized as being above the cut point, i.e. the effective first cyclone catch diameter could not be determined. Corrections of the D_{50} calibrated cut sizes are discussed in Section 3.2.3-C.

The sizes of particles contained in the filter catch and in the impinger catch were determined using the straight line and the weight percent less than stated size for these fractions.

This line was also used to determine the percent of particles of sizes greater than 10 µm, 3 - 1 µm, and less than 1 µm.

Size distribution plots for each of the industrial types tested are discussed in Section 4.0.

C. D_{50} Cut Size Corrections for Flow Rate and Temperature--

Temperature and flow rate corrections were needed for samples where the temperatures and/or flow rates were not maintained at the designed conditions (i.e., 4 and 1 SCFM and 400 °F). Varying from the designed conditions was necessary for certain sources (1) to protect the chemical makeup of the sample (i.e., agricultural samples), (2) for safety (e.g., chemical fertilizers), or in a few cases, were the result of inadvertent variation of temperatures and flow rates during the sampling time.

Correction curves for temperature and flow rate on the D_{50} cut size were derived using the data obtained from the "Development and Laboratory Evaluation of a Five-Stage Cyclone System" (Ref. 3-21.). A summary of these data is shown in Table 3-2.

Temperature Corrections--In Figure 3-29, the temperature is plotted against the cyclone D_{50} cut points, µm, at a flow rate of 1.0 acfm and a particle density of 1.00 gm/cm^3. It is noted that when the data are extra-

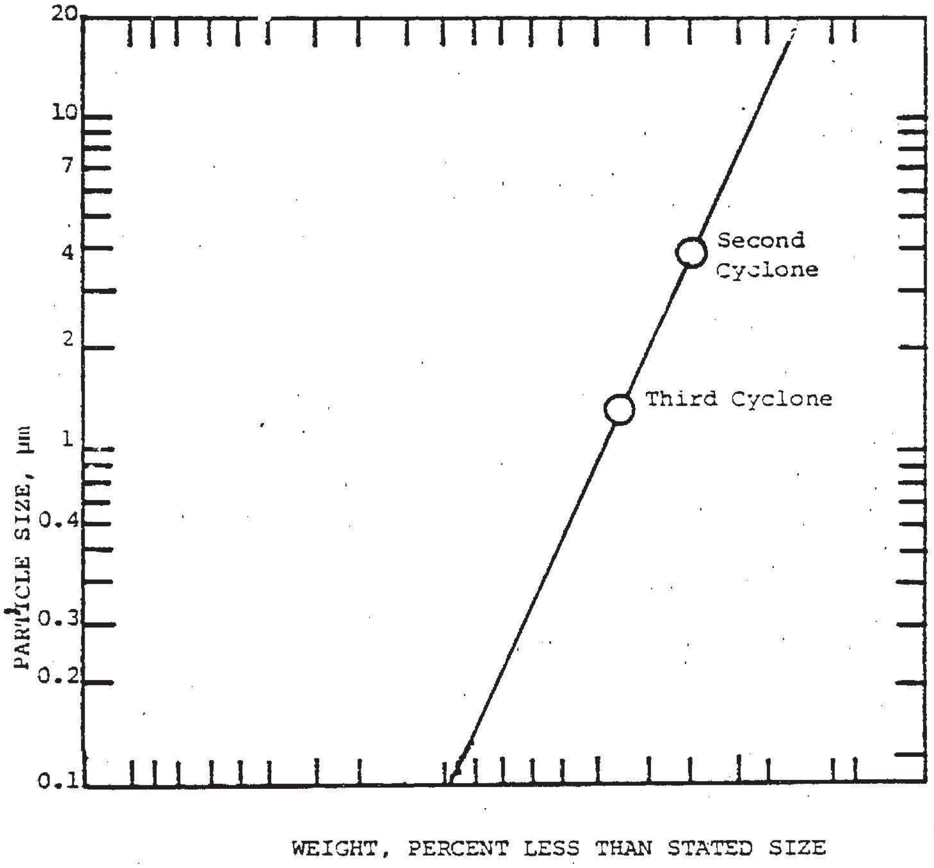

Figure 3-28. Illustration of particle size distribution construction.

TABLE 3-2. LABORATORY CALIBRATION OF THE FIVE-STAGE CYCLONES D_{50} CUT POINTS

Cyclone		I		II		III			IV		V	
Particle Density (gm/cm^3)		2.04	1.00	2.04	1.00	2.04	1.35	1.00	1.05	1.00	1.05	1.00
Flow l/min	Temp °C	Cyclone D_{50} Cut Points Micrometers										
7.1	25								2.5	(2.5)	1.5	(1.5)
14.2	25	5.9	(8.4)	2.4	(3.5)	(1.7)	2.1	(2.4)	1.5	(1.5)	0.85	(0.87)
28.3	25	3.8	(5.4)	1.5	(2.1)	0.95	-	(1.4)	0.64	(0.65)	0.32	(0.32)
28.3	93	4.4	(6.3)	2.3	(3.3)	1.2	-	(1.8)				
28.3	204	6.4	(9.1)	2.9	(4.1)	1.9	-	(2.8)				

D_{50} cut points enclosed in parentheses are derived from the experimental data using Stoke's Law.

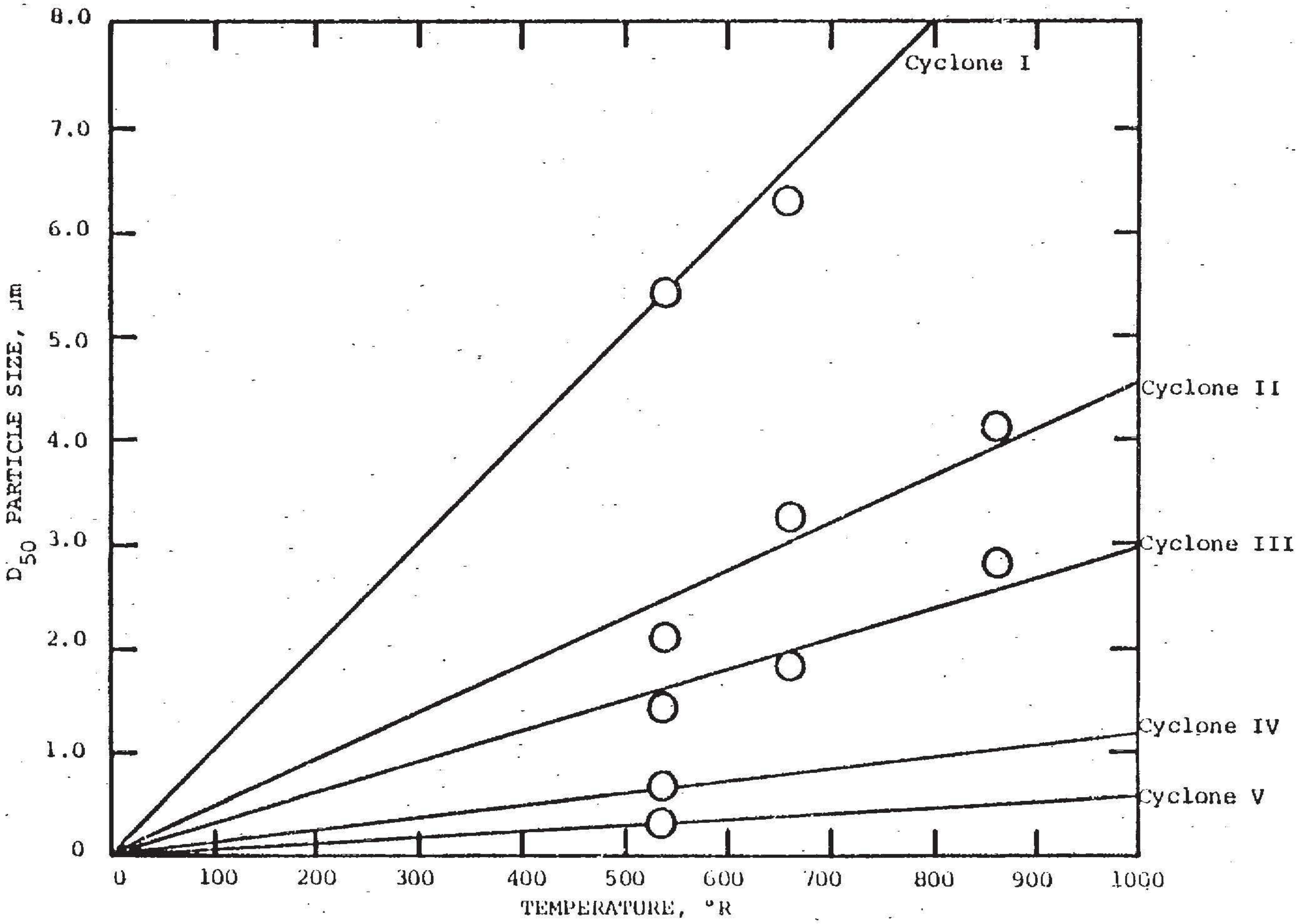

Figure 3-29. D_{50} particle size, μm vs temperature °R at flow rate of 1.0 acfm and 1.00 gm/cm^3.

polated to low temperatures, the D_{50} cut points approach zero as the temperature approaches absolute zero. With this information, a temperature correction curve can be drawn for any D_{50} cut size at the calibration temperature of any cyclone. Simply draw a line between absolute zero and the coordinate of the D_{50} cut size and the calibration temperature. The corrected D_{50} cut size is read on the line at the operation temperature of the cyclones. The calibrated D_{50} cut points for the small cyclones are plotted this way in Figure 3-30.

Flow Rate Corrections--The D_{50} cut point, µm, and the flow rate, acfm, from Table 3-2, are plotted on log-log paper in Figure 3-31. Observe that the slope of the line for each of the cyclone plots is about -0.85. If it is assumed that the slope is the same over the range of flow rates used in this study, then a flow rate correction curve can be obtained for the small cyclones. The flow rate correction curves for both sets of cyclones are shown in Figure 3-32.

Example of a temperature and flow rate correction

SASS Train Data:	V_s, sample volume DSCF	912
	V_w, water collected SCF (vapor)	96
	t, sampling time, min.	240
	T_o, oven/cyclone temperature, °R	660

Calculate the wet actual flow rate at the cyclones, wacfm, as follows:

$$\text{flow rate at cyclones} = \frac{(V_s + V_w)}{t} \times \frac{T_o}{520}$$

$$= \frac{(912 + 96)}{240} \times \frac{660}{520}$$

$$= 5.33 \text{ wacfm}$$

First go to Figure 3-32. Read the D_{50} cut point for each of the cyclones where the correction line crosses the flow rate, 5.33 acfm

10 µ cyclone - 11.5
3 µ cyclone - 4.6
1 µ cyclone - 1.6

} these values are corrected for flow rate only

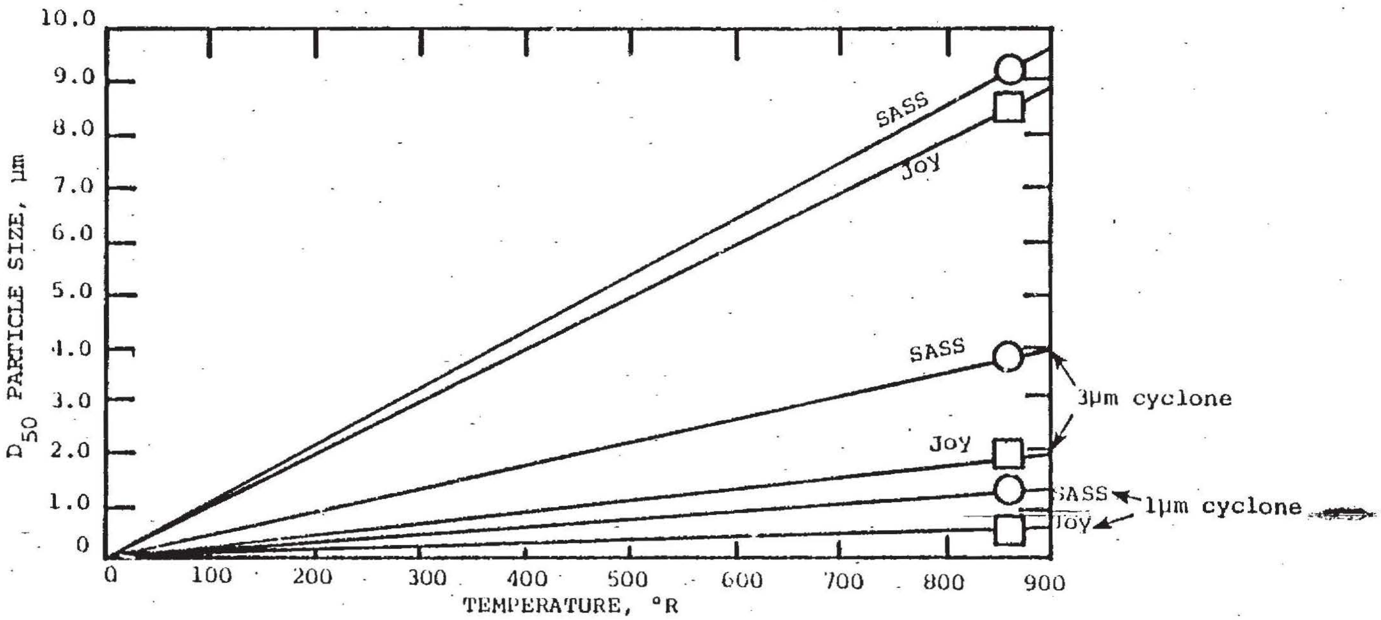

Figure 3-30. Temperature correction curves for the six cyclones used in the program.

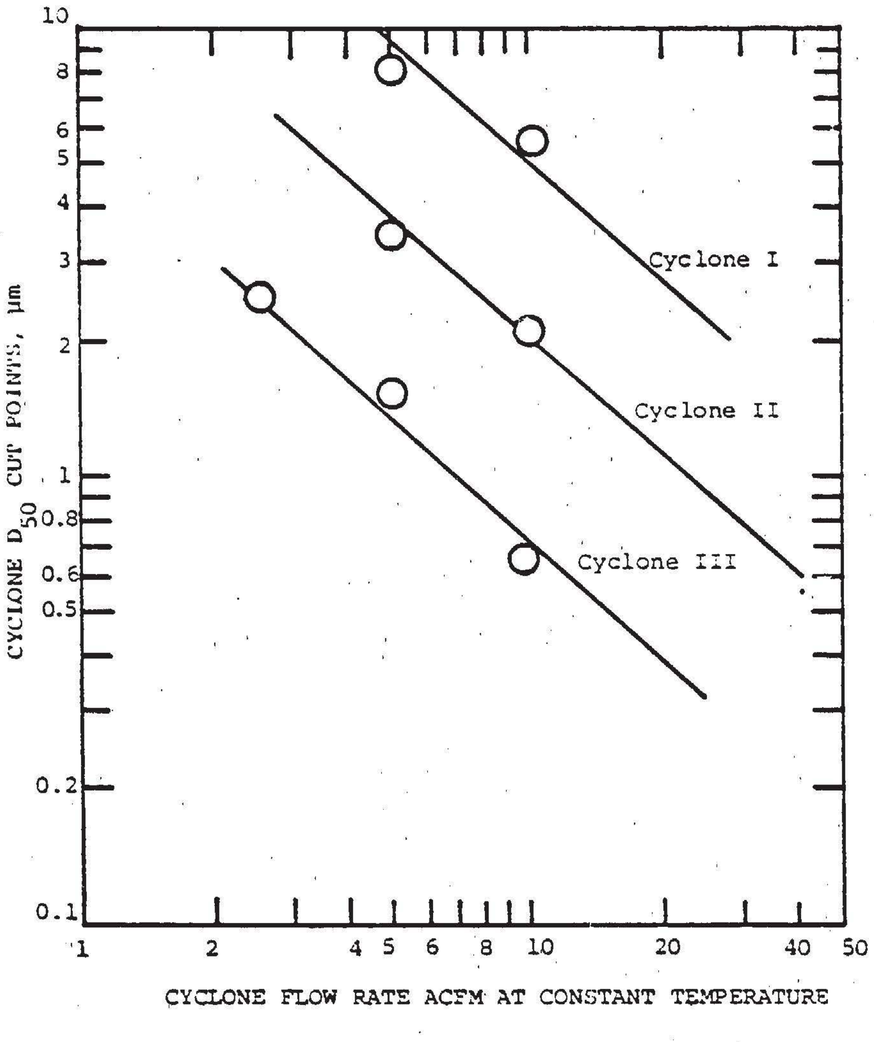

Figure 3-31. Cyclone flow rate vs D_{50} cut point for small cyclones.

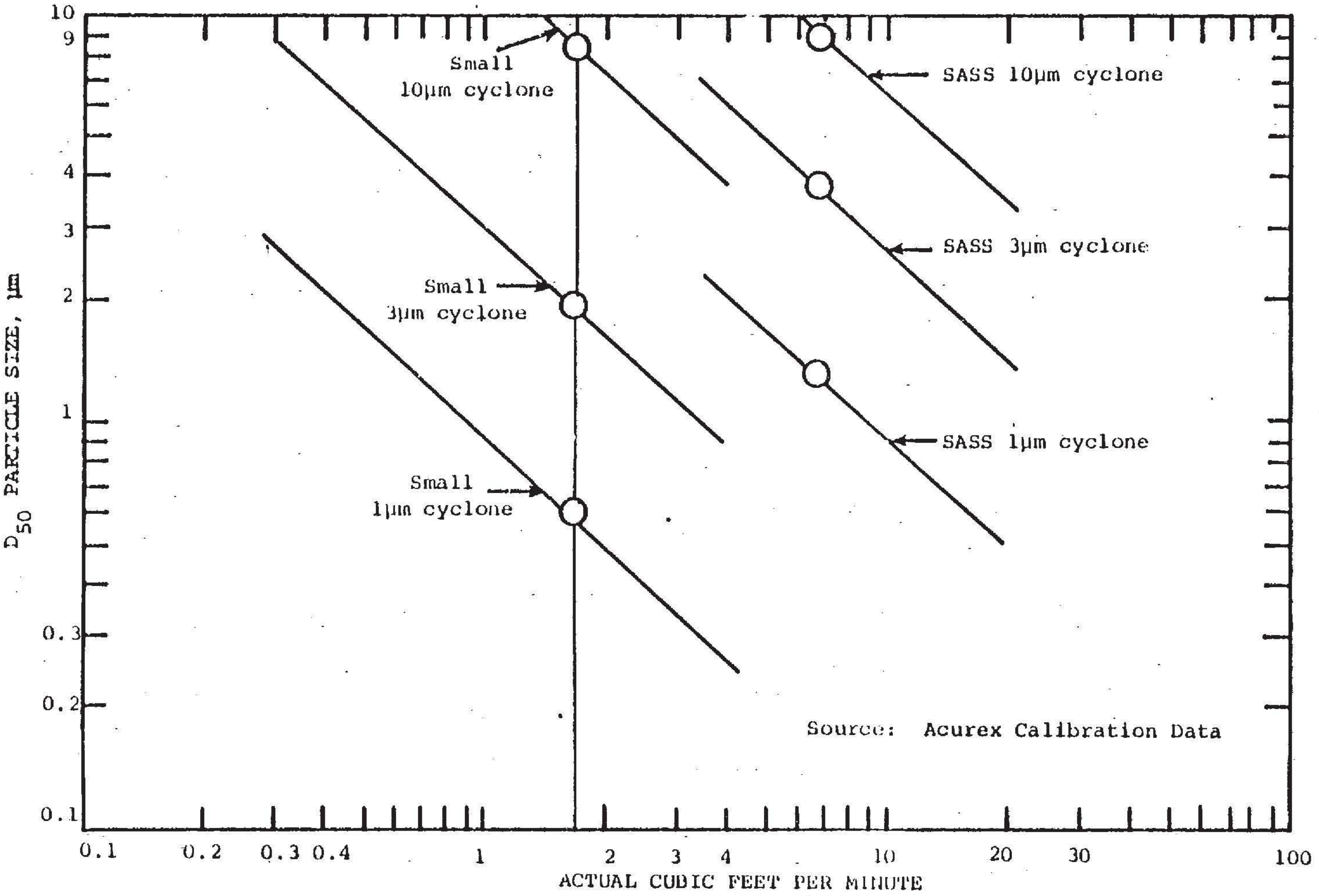

Figure 3-32. Cyclone flow rate vs D_{50} cut point for small and SASS cyclones.

Now go to Figure 3-30. Place a dot for each of the flow rate corrected values above on the 860 °R line. Then draw a line from the dot to absolute zero and read the temperature corrected D_{50} cut point at the oven/cyclone temperature 660 °R.

SASS		Flow Rate Corrected		Flow Rate and Temperature Corrected
10μ cyclone	→	11.5	→	8.9μm
3μ cyclone	→	4.6	→	3.5μm
1μ cyclone	→	1.6	→	1.3μm

The above procedure is repeated for the small cyclones.

3.3 QUALITY CONTROL

A comprehensive quality control program was conducted as an integral part of the particulate emission field tests. The program featured:

1. Calibration of cyclone at 400 °F and 4 scfm for the SASS train and 1 scfm for the Joy train.
2. Laboratory quality assurance procedures.
3. Concurrent samples taken from the same source with separate but identical trains for precision checks.
4. Calibrations of field test instruments with standard methods and frequent response-factor calibrations of laboratory instruments.

3.3.1 Cyclone Calibration

This section contains discussion taken from EPA 600/7-78-018, February 1978, "Source Assessment Sampling System: Design and Development" (Ref. 3-1).

The calibration of the SASS cyclones has been underway almost continuously since the development of the SASS. Initial efforts were conducted by Southern Research Institute using a Vibrating Orifice Aerosol Generator. Later calibration tests were performed by Acurex using a different method involving dispersions of polydisperse aluminum spheres. Results have been obtained with both methods that are reasonably consistent and are believed to represent the actual performance of the cyclones.

The object of the various cyclone calibration tasks was to determine the cyclone efficiency curve; from that curve can be obtained a commonly used figure-of-merit for the cyclone called the D_{50} cut diameter. Figure 3-33 illustrates these concepts. The efficiency of particle collection is plotted against the particle diameter. For each particle diameter, therefore, the effectiveness of the cyclone is determined. For example, Figure 3-33 shows that for this particulate (fictitious) device, if a large number of 2.5 µm diameter particles are introduced, 17.5% will be collected and 82.5% will pass through uncollected. The particle diameter at which half of the particles collected is the D_{50} cut diameter; Figure 3-33 shows the D_{50} cut diameter of that device to be 3.0 m. The D_{50} cut diameter, often abbreviated to "cut size", is commonly used as a rough indication of the collection cut-off of a cyclone.

Note that Figure 3-33 expresses particle diameters as aerodynamic particle diameters. It is important to distinguish aerodynamic diameters from physical diameters. The physical diameter is the dimension of the particle obtained by physical measurement, for example, with a microscope and reticle. For nonsymmetrical particles, the physical diameter of a given particle may have several different values, depending on the measurement axis chosen. The aerodynamic diameter (sometimes called the Stokes diameter) is defined as the diameter of the equivalent spherical particle of unit specific gravity having the same terminal settling velocity as the particle in question. The advantages of using the aerodynamic diameter to characterize the particles used for cyclone calibration are two-fold. First, each particle is uniquely characterized, independent of any choice of physical dimension. Second, and more important, since the basic cyclone separation mechanism depends on Stoke's Law, measuring particle diameter in terms of Stoke's Law behavior assures that calibration data will be valid over wide ranges of particle size, shape, and density.

A. Polydisperse Powder Cyclone Calibration Method--

From the size distribution data, it should have been possible to construct a cyclone efficiency vs particle size curve for the particle size range of the test dust. When this was attempted, it became apparent that

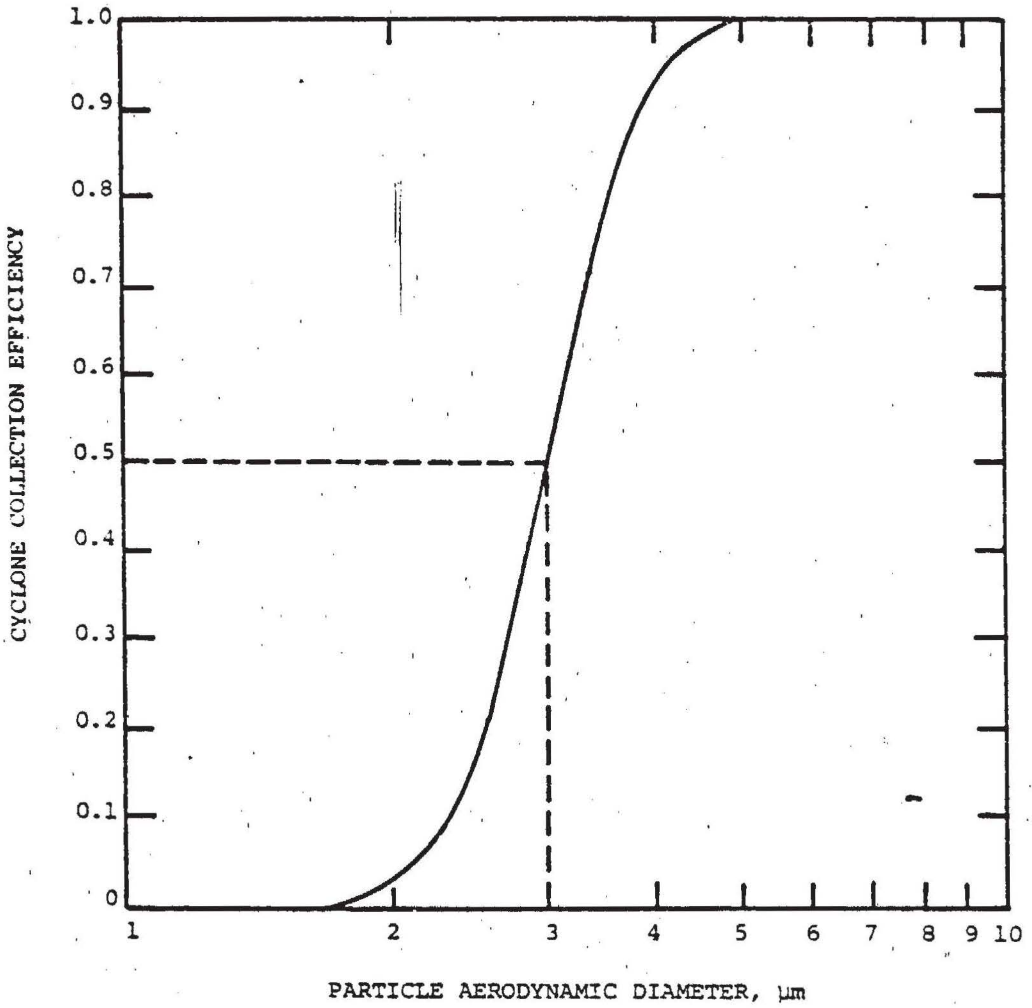

Figure 3-33. Typical cyclone fractional efficiency curve.

the experimental results were inconsistent, and in some cases, contradictory. For several experiments, for example, the mass median size of the cyclone cup catch was smaller than the feed material; the filter catch mass median diameter was even smaller. This result is clearly impossible unless the test dust is changing its characteristics during the test.

There is some evidence that the latter explanation is the cause of the unexpected test results. Figures 3-34, 3-35, and 3-36 are scanning electron micrographs of the feed, cyclone cup, and filter fractions. respectively, from a calibration run with the small cyclone. The magnification is 3000X. It is qualitatively apparent that the cyclone cup fraction is smaller than the feed fraction, as indicated by the X-ray Sedograph measurements. The most interesting point, however, is the appearance of the particles. The test dust particles (Figure 3-34) are generally smooth and show cleavage planes. The particles collected by the cyclone (Figure 3-35), however, are very rough and pitted, and seem to be rounded off. The filter fraction largely consists of very small particles that are not evident in the test dust. All of this seems to indicate that the test dust has been eroded and reduced in average size somewhere in the calibration apparatus. As velocities in the dust cloud outlet tube and heater are kept deliberately high (near sonic) to avoid reagglomeration of the dust, it is suspected that particle-particle contact in this region is causing the erosion. The hardness and frangibility of the test dust undoubtedly is also a major factor.

B. Cyclone Calibration Results--

The calibrated aerodynamic D_{50} cut points for the three KVB (ARB) SASS cyclones without the swirl busters are 9.2, 3.8, and 1.3 µm for the large, middle, and small cyclones, respectively. The calibration curves are given in Figure 3-37. The calibration results of the KVB SASS cyclone set agree well with the calibration results of the EPA SASS cyclone set as compared in Figure 3-38.

The calibrated aerodynamic D_{50} cut points for the three KVB (ARB) Joy cyclones are 8.3, 1.9, and 0.6 µm for the large, middle, and small cyclones, respectively. The calibration curves are given in Figure 3-39. The solid lines are the results of the calibration by Acurex and the broken line (— · —) is the result of Southern Research Institute (SoRI) calibration data on a similar cyclone set. The dashed line (---) is an assumed projection.

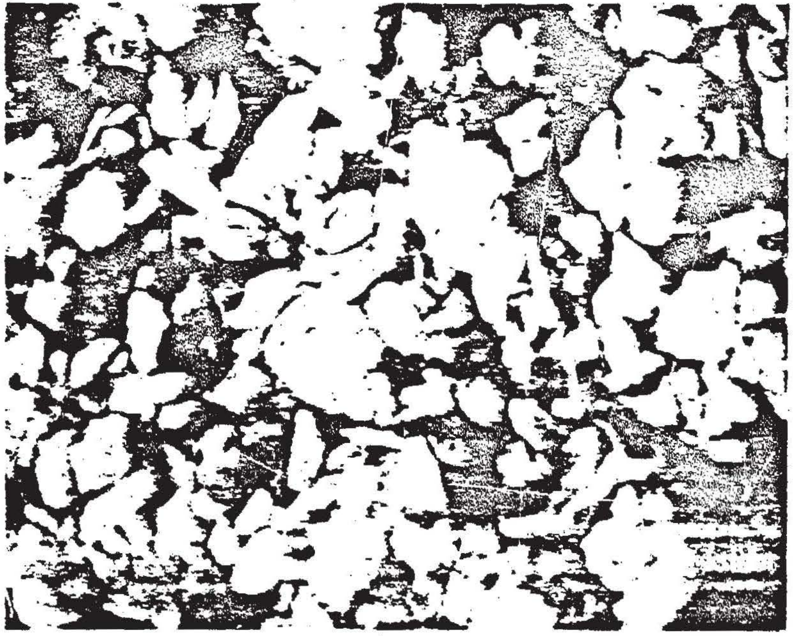

Figure 3-34. SiO_2 test dust.

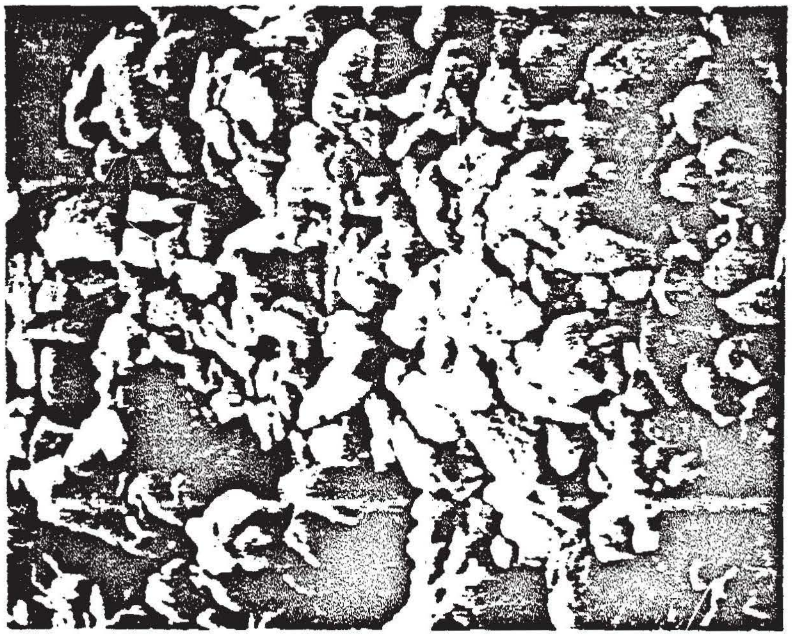

Figure 3-35. SiO_2 -- small dust cyclone cup catch.

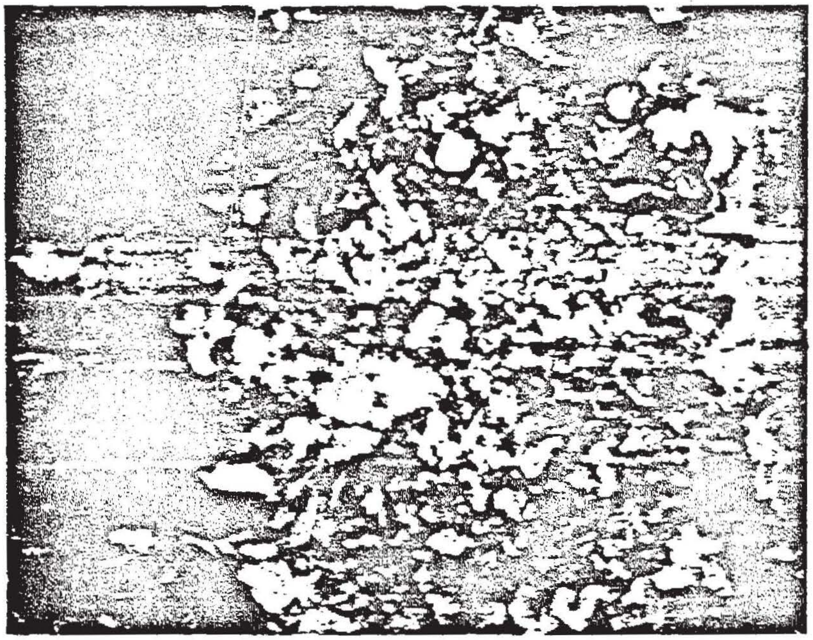

Figure 3-36. SiO_2 test dust -- small cyclone filter catch.

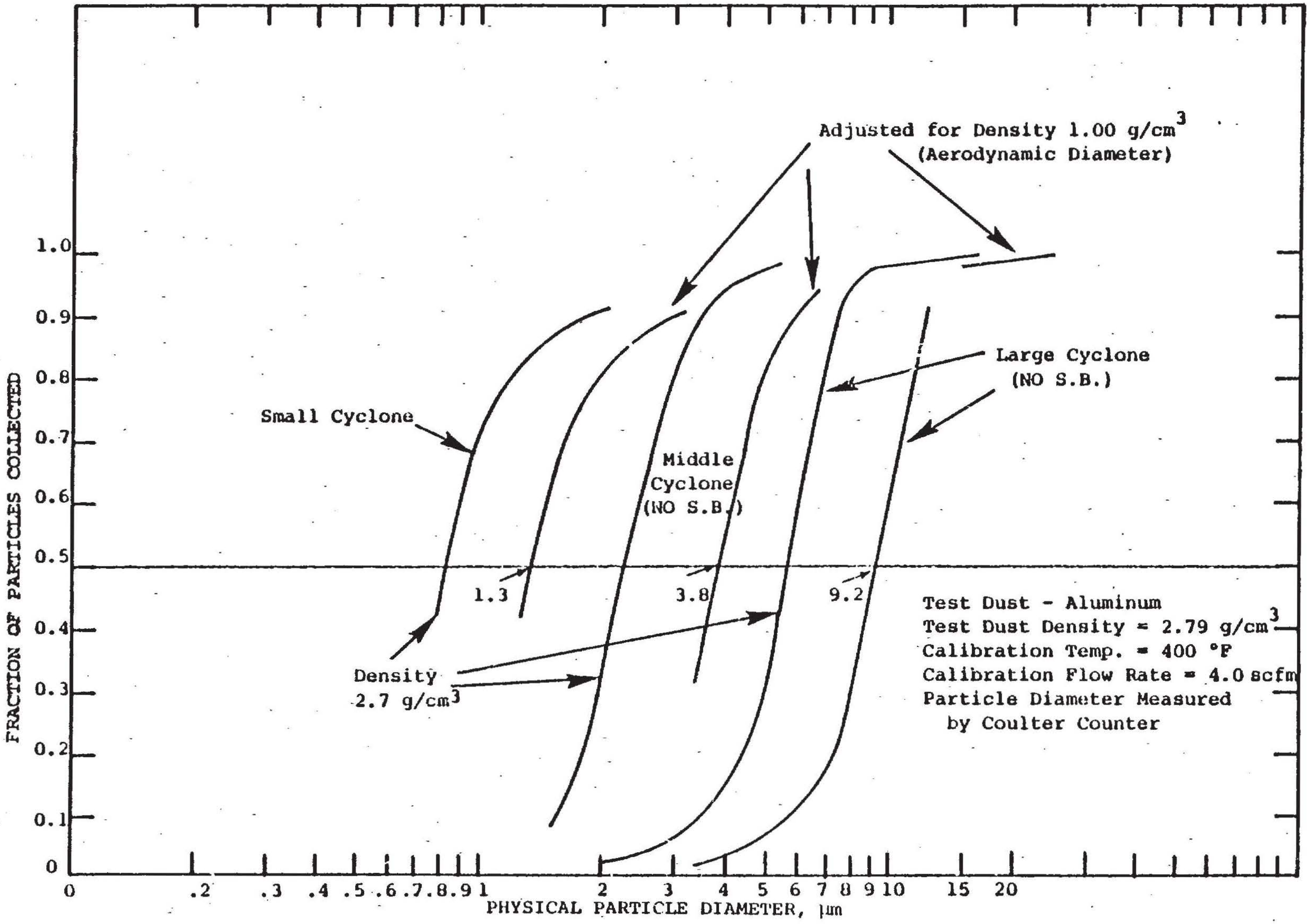

Figure 3-37. Cyclone calibration, KVB (ARB) SASS cyclones.

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	D50 Cut Diameters, µm			
	KVB		EPA	
Cyclone	Physical	Aerodynamic	Physical	Aerodynamic
Large[a]	5.61	9.2	6.20	10.2
Medium[a]	2.30	3.8	2.18	3.6
Small	0.81	1.3	1.05	1.7

[a] Swirl busters removed

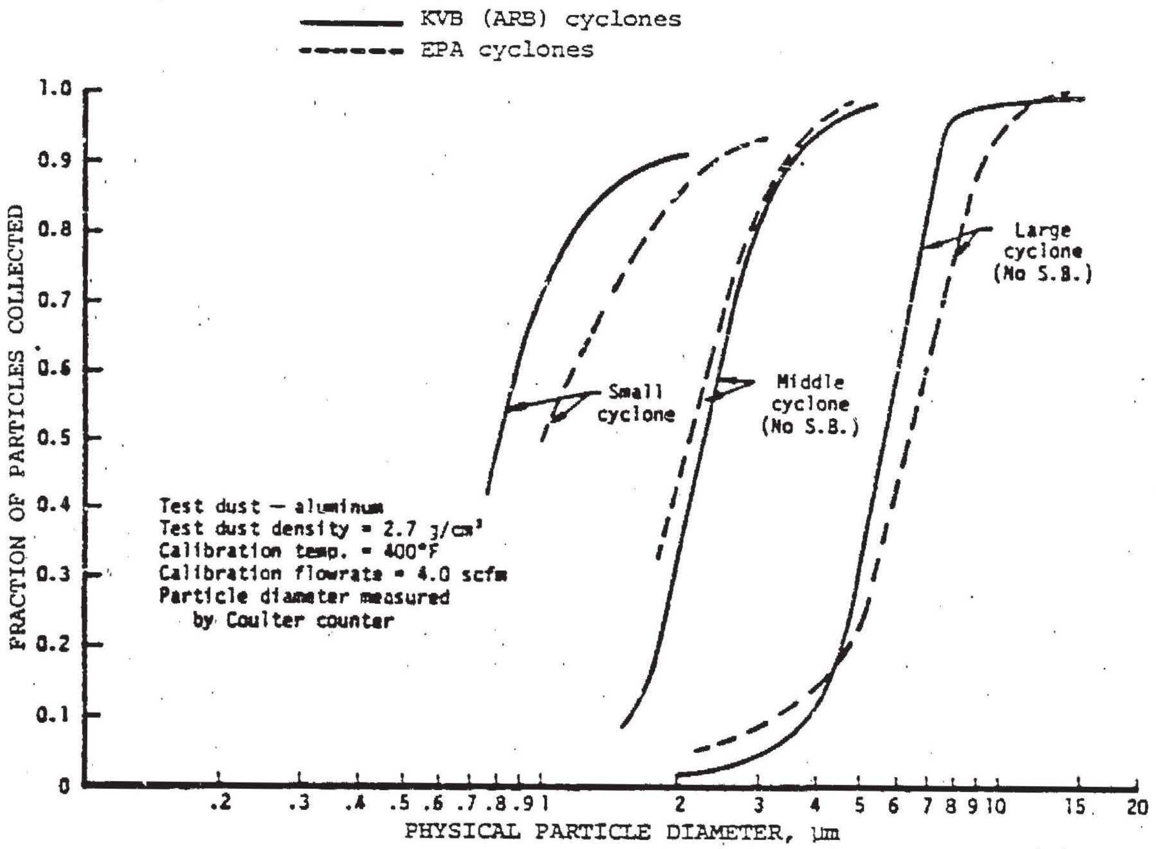

Figure 3-38. Comparison - calibration results for two sets of SASS cyclones.

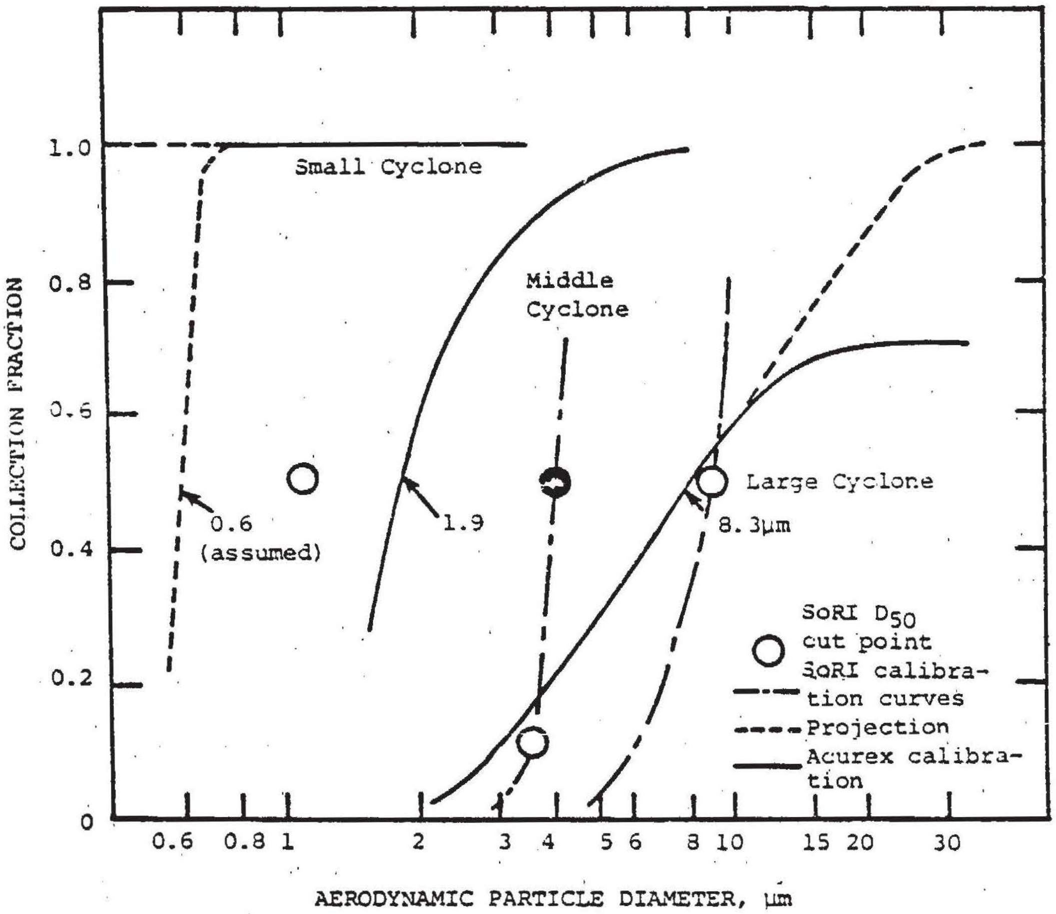

Figure 3-39. Calibration results, KVB 1 cfm cyclone.

The calibration results (curves) from Acurex for the KVB Joy cyclone set entails some questions:

1. Why does the small cyclone calibration curve stay at 100%?

Answer: The small cyclone collected 100% of all of the particle, in the size range of the calibration. The smallest particles were between 0.6 - 0.7μm. Therefore the collection efficiency curve was assumed (as shown in Figure 3-39) and the D_{50} cut point was taken from this curve to be 0.6μm.

2. Why does the calibration curve for the large cyclone taper off at 70% collection efficiency?

Answer: Dr. D. Blake, Acurex, admits that the curve looks strange (nothing like he has even seen before), and said that 30% of the large particles in the size range (15-30μm) of the calibration dust got through the cyclone somehow. However, he could not explain how the large particles could do this and that there might have been an error in the calibration but he could not trace it. Therefore the dashed line is an assumed projection of what the curve should be.

3. Why are the two calibration curves different for the middle cyclone which has the same physical dimensions?

Answer: At first it was thought that possibly the physical dimensions of the two cyclones were different. Both SoRI and KVB remeasured the critical dimensions for their cyclone. However, no detectible difference in the cyclone dimensions was found. Blake of Acurex suggested that the calibration method was different and would give different results, i.e. Acurex's calibration method used a grain loading of 1.0-1.5 gr/DSCF whereas SoRI's method used a grain loading of 0.0001-0.001 gr/DSCF.

3.3.2 Laboratory Quality Assurance Program

A. Rockwell Air Monitoring Center--

The importance of applying quality assurance control practices to laboratory procedures was recognized very early by chemists; several texts of analytical chemistry devote chapters to this subject. Essentially, the purpose of quality assurance is to answer the question of whether data generated by an analytical procedure can be regarded as typical samples from a single population of data. If such data can be so regarded, statistical control can be assumed. The most commonly used method of determining accurate representation consists of control charts. Control charts are sequential plots of various quality characteristics. For example, qualities shown might be a day-to-day plot of the average content of copper (Cu) in an ore, the normality of a standard solution, the calibration parameters of an instrument, etc. Control charts give a continuous record of the quality characteristic and trends in data. Also, sudden lack of precision can be made evident and causes may be sought by use of the charts. The necessity of comprehensive quality assurance techniques in air quality data generated either in the field or in the laboratory are very well known and have been recognized widely. No study can be considered complete without the application of some type of quality assurance procedure.

To ensure the quality of the results of the sulfate, nitrate, carbon and metal analysis by AA the following procedures are routinely incorporated into the analysis of each sample:

Parameter	Method	QA Measure
1. Mass Determination	Analytical Balance	Calibration checked daily against a standard weight.
A. Sample	Analytical Balance	10% are reweighed
B. Blank	Analytical Balance	10% are reweighed
2. $SO_4^=$, NO_3^-, & NH_4^+	Technicon Auto-Analyzer II	Calibrated daily against standard solutions. Control checks per tray of 40 samples. 1. Extract from previous tray 2. Blank extract 3. Standard solution 4. Duplicate exposed strips
3. Metals (Pb^{++})	Atomic Absorption	Calibration check daily against standard solutions. Control checks per run 1. Two repeat extract. 2. Two blank extracts (one spiked) 3. Two standard solutions 4. Two duplicate exposed strips
4. Carbon	Oceanography Intl.	1. Calibrated daily against standard solutions 2. Control checks every 10 samples 3. 10% variations are re-analyzed

TABLE 3-3. REDUNDANT SAMPLING RESULTS

	Test #	TSP, Including Impinger Catch, gr/DSCF			% Std Deviation
		SASS Train	Joy Train		
	2	0.0285	0.0278		1.73
	4	0.0093	0.0154		34.92
	7	0.0427	0.0200		51.2
	10	0.0026	0.0021		15.04
	16	0.0263	0.0199		19.59
	21	0.0092	0.0071		18.22
	22	0.0109	*		
	35	0.0594	0.0649		6.26
	38	0.0170	0.0136		15.7
	25	0.0075	0.0078		2.77
	27	0.0037	0.0033		8.08
	31	0.0025	0.0028		8.00
KVB Boiler	1	0.0672	0.0896	(Test 3 Method 5 0.066)	20.2
	3	0.051	0.0365		23.43
Same Utility Boiler	11	0.0091	0.0078		10.88
	12	0.0072	0.0085		15.23
	13	*	0.0088		
	23	*	0.0084		
	24	0.0112	0.0144		17.68
	32	0.0124	0.0086		25.59
	33	0.0132	0.0133		0.53
				Average	16.4

*TSP data known to be in error.

10 samples for carbon analysis
9 " " sulfate analysis
7 " " nitrate analysis
4 " " XRF analysis for elements
3 " " atomic absorption analysis to compare with XRF

Table 3-4 lists the results for redundant carbon analysis. For each set of replicate analyses the percent of the standard deviation ($\%\sigma$) on the mean was calculated. The average of these values is 18%. Therefore, the precision of the carbon analysis is ± 20%, to be conservative. Table 3-5 lists the results for redundant sulfate and nitrate anlaysis. The average of $\%\sigma$ for sulfate analysis is 3.0. Again being conservative, the precision of the sulfate analysis is ±5%. A conservative average for the nitrate analysis is ±30%. Table 3-6 lists the results for the redundant XRF analysis of the metals. In all cases listed the results agree with the repeat analysis within the error limit stated for each element.

Table 3-7 lists the results for the chemical composition of the particulate samples, comparing the XRF analysis with the AA analysis. For solid particulate samples (cyclone and filter catches) there is good agreement between the two methods of analysis.

C. Blank Runs on the Sampling Trains--

Twice during Phase II (the field testing part of the program), both sampling trains were treated as though a sample has been taken, although the sampling train has never left the lab. These were called blank runs. The objectives for the blank runs were:

1) Determine if any material was being left in the trains from the previous test.
2) Evaluate the techniques of the technician used in the lab.
3) Determine if material was being transferred from the methyl chloroform to the water or vice versa during the extraction of the impinger condensate.

TABLE 3-4. REDUNDANT CARBON ANALYSIS

Sample No.	Total Carbon, %	% Standard Deviation	Volatile Carbon, %	% Standard Deviation
8J-2S	1. < 2	---	< 2	
	2. < 2	---	< 2	
1S-4S	1. 85.3	7.8	---	
	2. 74.1		---	
	3. 81.4		---	
1S-3S	1. 67.7	14.0		
	2. 72.5		---	
	3. 69.1		---	
	4. 51.0		---	
	5. 74.7		---	
1S-2S	1. 43.7	19.1	---	
	2. 29.7		---	
	3. 39.7		---	
2S-4S	1. 85.8	2.9	---	
	2. 82.4		---	
3S-4S	1. 79.7	1.7	---	
	2. 77.8		---	
3S-2S	1. 31.8	32.0	---	
	2. 50.4		---	
19J-2S	1. 11.2	9.7	10.2	11.6
	2. 9.5		8.1	
	3. 9.5		9.0	
30-5-2S	1. 48.6	17.0	46.6	20.5
	2. 60.7		56.9	
	3. 39.5		36.8	
	4. 50.4		49.0	
	5. 41.4		35.4	
	6. 41.4		35.4	
26J-2S	1. 5.7		2.3	
	2. 5.9	48.5	1.1	34.7
	3. < 2		< 2	

Average 18%

TABLE 3-5. REDUNDANT SULFATE AND NITRATE ANALYSIS

Sample No.	Sulfate, %	% Standard Deviation	Nitrate, %	% Standard Deviation
12S-IC*	1. 15.8	4.8	---	---
	2. 16.8		---	---
	3. 17.4		---	---
11S-IC*	1. 15.8	1.1	---	---
	2. 16.1		---	---
2S-4S	1. 6.2	0.2	0.07	18.3
	2. 6.0		0.12	
1S-3S**	1. 3.5	1.3	0.19	77.1
	2. 3.1		0.46	
3S-4S**	1. 3.6	0.28	0.09	0
	2. 3.5		0.09	
19J-2S	1. 8.2	4.4	0.42	67.0
	2. 8.7		0.15	
8J-2S	1. 0.06	18.1	0.02	12.9
	2. 0.09		0.05	
29J-2S	1. ND	0	ND	0
	2. ND		ND	
30-5-2S	1. ND	0	ND	0
	2. ND		ND	
	Average	2.9	Average	25.0

ND = Not Detected

*Tests 1 and 12 were performed on the same utility boiler at the same sampling location.

**Tests 1 and 3 as above.

TABLE 3-6. ELEMENT COMPOSITION OF PARTICULATE SAMPLES BY XRF ANALYSIS IN PERCENT FOR REDUNDANT ANALYSIS

Sample Number	29J-2S	Repeat 29J-2S	19J-2S	Repeat 19J-2S	8J-2S	Repeat 8J-2S	30-5-2S	Repeat 30-5-2S
	t	t						
Calcium	1.9/0.3	1.9/0.3	2.2/0.4	1.7/0.5	t	t		
Chlorine			5/2	6.7/2				
Chromium	t	t						
Iron	4.3/0.5	4.0/0.5	0.87/0.1	0.8/0.1	2.4/3	2.2/0.2		
Manganese	t	t						
Potassium	1.5/0.2	1.6/0.3	5.2/1	3.8/1	1.2/0.1	0.9/0.1		
Silicon	>11	>10			17/4	15/4		
Sulfur	<3	<2	8.1/3	7/3			2	t
Titanium	t	t			t	t		
Zinc			t	t				

2/01 reads 2 ± 0.1

TABLE 3-7. XRF VS AA FOR ELEMENT COMPOSITION OF PARTICULATE SAMPLES IN PERCENT

	23S-2S (10µ in Cyclone)		26J-4S (1µ in Cyclone)		11S-5S (Filter)	
Sample Number	XRF	AA	XRF	AA	XRF	AA
Calcium	1.1/0.3	t	1.1/0.4	1.17	12.2/1.0	13.5
Chlorine			14/5	31		
Cobalt					t	t
Copper			1.6/0.4	1.4		t
Iron	3.4/0.4	2.1	2/0.3	2.2	4.9/0.06	4.1
Lead	t	t	13/2	12.4		t
Nickel	2.5/0.3	1.2			10.6/1.1	8.4
Potassium		t	9/4	1.8	t	t
Vanadium	t	t		t	2.1/0.3	1.5
Zinc	t	t	t		t	t

t denotes <1.0%

Where values indicated as x/y x is the measured percent composition and y is the percent variation.

In both cases for the Joy and SASS blank runs, the filters and cyclone wash residues showed no significant weight gain. The probe wash residues had a gain in weight for an average of about 1.5 mg. If it is assumed that this gain is material left in the probe from the previous test, then it can be said that less than 2% of the matter collected in the probe remains in the probe. The impinger condensates were extracted as normal. Normally, the distilled water when boiled dry leaves a residue of 0.006% of the water weight. After the distilled H_2O was subjected to methyl chloroform extraction, the residue was reduced to approximately 0.004%. Although this result is interesting, it has no effect on the results of the field test samples.

3.3.4 Equipment Maintenance and Calibration

Analytical Balance--One of the most important tools used in measuring fine particulates is the analytical balance. To assure the quality of the work, KVB's analytical balance was serviced and certified at the beginning of the program and half way through it.

Dry-gas Meter--The dry gas meter is another critical instrument used. The dry gas meters used in the sampling trains were checked against one another and against a recently calibrated dry-gas meter four times through the course of the program (once every two months).

Pitot Tubes--The pitot tubes used with the probes and those used to measure stack velocities were checked once a month in a clean air stream against a calibrated standard type pitot tube to check the pitot correction factors. Also the magnehelic gauges which are used to measure the pressure drop across the pitot tube were checked against a draft gauge.

Thermocouples--The thermocouples and pyrometers and thermometers used for the particulate program were checked once a month against constant boiling liquids.

Vacuum Leaks--Vacuum leaks in the sampling system were checked for as part of the sampling procedure for each test.

SECTION 3.4

FORMS

This section contains the forms referred to in Sections 3.1 through 3.3.4.

KVB

TEST PREPARATION AND PLANT VISIT

RESULTS	Test: firm ___	on date ______	hr ______
	tentative ___		

Firm Name ______________________________

Address ______________________________

Person Contacted Name ______________________________

Title ______________________________

Process Product ____________________

Equipment to be Tested ____________________ APCD Permit __________

Size ____________________

Make ____________________

Control Equipment, if any ____________________ APCD Permit __________

Size ____________________

Make ____________________

Process Material Information (quantitative, qualitative, source) __________

____

Process Weight Availability ______________________________

____

Operating Schedule of Equipment, cycle, type ______________________________

____

Operating Schedule of Plant ______________________________

____

Plant Personnel Schedule (Shifts) ______________________________

____

Process Specifics ______________________________

____

Process Control Location ______________________________

Access ______________________________

Process Typicity (Representative of Normal Operation): __________

____

Annual Process Time Rate: hr/day ______ day/week __________

wks/year ____________________

Process Diagram, Drawings Availability ______________________________

Plant Entry and Exit ______________________________

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Plant Restrictions in Access ______________________________

____

Vehicle Access ______________________________

Parking ______________________________

Plant Safety Requirements ______________________________

____

Plant Engineering and Maintenance Engineering Help During Test __________

Their Liaison, Name: ______________________________

Equipment Access ______________________________

Operator Access (in Charge) ______________________________

Operator's Permission (by Company Policy) to Supply Information __________

____

Operational Fluke Indicators of Down, Start-up, Stop, etc: __________

Revisit Contact, Name ______________________________

Title ______________________________

Test Documentation Photo Permit ______________________________

Test Synchronization with Plant Running ______________________________

____

(if overtime by test crew on rigging, take-down, etc.)

Communication to Outside ______________________________

____

Emergency Procedures, if any, Designated: ______________________________

____

TEST SETUP

Best Location of Test Stations ______________________________

Source Geometry: Shape ______________________________

Diameter ______________

Height ______________

Test Area Access at Height ______________________________

through ______________________________

Test Holes Size ______________________________

Height Above Level Area ______________________________

Width of Platform ______________________________

General Space Availability ______________________________

____

Estimate of Source: Temperatures, Inlet ____________
Outlet ____________

IN		OUT
____________	gas velocity	____________
____________	gas toxicity	____________
____________	emission load	____________
____________	noise	____________
____________	dust	____________

Equipment Hauling to Test Area ____________

____

Electricity Availability: 30A, 60A, 110 V each ____________ at Distance ______

____________ to be assisted in hook-up by ____________

Water Availability ____________

Cleanup Availability ____________

Nearest Source of ICE Machine at ____________

DATE: ____________ BY ____________

KVB, INC.

KVB

Sample Code__________ __________ __________ __________

Firm and Unit______________________________

Test No. ____________________ Page F-________

Sampling Station ______________________________Date ___ ________

GAS VELOCITY DATA Vel (ft/sec)=$2.9\sqrt{\Delta P\,(°K)}$

Time Start ____ Point	Vel.Head In. H_2O	Temp. °F	Vel. Ft/Sec.	Vel.Head In.H_2O	Temp. °F	Vel. Ft/Sec.	Vel.Head In.H_2O	Temp. °F	Vel. Ft/Sec.
Finish									

A. Average Velocity(Traverse)Ft/Sec ________________

B. Av. Velocity(Ref. Point) Ft/Sec ________________

C. Flue Factor A/B ________________

D. Pitot Correction Factor________________

E. Gas Density Correction Factor________________

F. Corrected Vel., AxDxE, Ft/Sec ________________

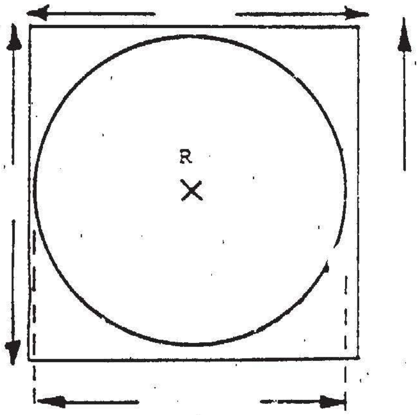
or BxCxDxE, Ft/Sec ________________

G. Area of Flue, Sq. Ft. ________ ________

H. Average Flue Temp., °F ________ ________

I. Flow Rate, FxGx60, CFM ________________

J. Flow Rate, 520 x I/(H+460), SCFM ________________



KVB

Sample Code ________ ________ ________

Firm Name and Unit ____________________________

Test No. ____________ Page D-2 ________

Sampling Station ____________________ Date ________

SPOT MONITORING DATA BY DRAEGER OR TLV SNIFFER

			CONCENTRATION		
INSTRUMENT USED	FUNCTIONAL DATA	COMPOUND NAME	ppm	Grs/SCF	Lbs/Hour

9/76

KVB 5804-5

KVB

LOCATION ____________________
UNIT ____________ FUEL ____________
OPERATORS ____________________
Train type: ________

TEST NUMBER ________
DATE ________
AMBIENT TEMPERATURE, °F ________
METER VOL. (START/END) ____/____

Page ____
Of ____

Fuel Analysis (% By Weight)

C = H = S = O =
N = CO_2 = H_2O =
ASH = INERT =
DENSITY = HHV =

Nomograph Setup

P_{meter}= C =
P_{stack}= T_{stack}=
T_{meter}= ΔP =
$\Delta H_@$ = Noz (Ideal)=
% H_2O = Noz (Actual)=
Y =

Imp.	Vol. (End)		Vol. (Start)		ΔVol. (ml)
#1		−		=	
#2		−		=	
#3		−		=	
				Total	
#4 (Silica Gel)	g (End)		g (Start)		Δ grams
		−		=	
			Total Vol. H_2O		ml

Filter# ________

Particulate Wts
Filter ________ mg
Acetone ________ mg
Total ________ mg

1	11	21	31	41	51	61	71
Sampling Time Per Point, Min.	Particulate Wt., mg	Condensate Vol., ml	Fuel Flow gal/hr	Load MW	C_{pitot}	Stack Press. In.Hg-Gauge	Barometric Pressure
3-91							

1 11 21 31 41 51 61

Sample Point	Time	METER CONDITIONS			TEMPERATURES, °F							O_2,%	Vac.
		ΔP_s	ΔH	Meter Reading	Stack	Probe	Oven	Impingers In	Impingers Out	Meter In	Meter Out		

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Av. Av.
Av.

TEST RESULTS

Test Averages:
ΔP_s = ______ T_{stack} = ______ °F
ΔH = ______ T_{meter} = ______ °F
Sample Vol.= ______ Ft^3

Percent O_2 = ______
$MW_{stack\ gas}$ = ______ (~28
Velocity = ______ ft/se
Total Sample Time = ______ min.
ISOKINETICS = ______ %

Particulate Emissions

______ lbs/10^6 BT

COMMENTS:

KVB

Sample Code ________ ________ ________ ________

Firm and Unit ________________________

Test No. ________________________ Page ________

Sampling Station ________________________ Date ________

WATER VAPOR AND GAS DENSITY CALCULATIONS

Percent Water Vapor in Gases

A. Gas Pressure at Meter, In. Hg (Absolute) ________________

B. Vapor Pressure of Water at Impinger Temp., In. Hg ________________

C. Volume of Metered Gas, Cu. Ft. ________________

D. Volume of Water Vapor Metered, BXC/A, Cu.Ft. ________________

E. Volume of Water Vapor Condensed, Cu.Ft.* ________________

F. Total Volume of Water Vapor in Gas Sample, D+E, Cu.Ft. ________________

G. Total Volume of Gas Sample, C+E, Cu.Ft. ________________

H. % Water Vapor in Sampled Gas, 100 x F/G ________________

* See D on sampling train data sheet

Gas Density Correction Factor

Component	Volume Percent X	Moisture Collection X	Mol.Wt.=	Weight Per Mole Wet Basis
Water		1.0	18.0	
CarbonDioxide	Dry Basis		44.0	
CarbonMonoxide	Dry Basis		28.0	
Oxygen	Dry Basis		32.0	
Nitrogen + Inerts	Dry Basis		28.2	

Average Molecular Weight ________

J. Density of Gas Referred to Air = $\frac{\text{Av.Mol.Wt.}}{28.95}$ = ________________

K. Gas Density Correction Factor = $\sqrt{\frac{1.00}{J}}$ = ________________

KVB Test No.

KVB

page No.

ENGINEERING PROCESS FIELD REPORT

Co. Name:
Date
Address
APCD permit No
Source of particulates
Type
Point of observation
Pt. of discharge
weather
wind
time from
to
Co. Process or Plt. engr.

TIME		Interval		% opacity or Rngm	color	Process observation
		min	sec.			

COLOR
B = black
W = white
___ = ___
___ = ___

Total time of discharge of opacity

signature ______________________

KVB

Test No.______to_______

Test Engr._____________

K V B. INC.

MOBILE LABORATORY DATA

Test Number________________________________ Date____________________________

Unit Number________________________________ Owner____________________________

Fuel_______________________________________ Location____________________________

Capacity (k#/hr)________________________________ Identification____________________________

Furnace Type________________________________ Burner Type____________________________

1. Test Number					
2. Load (k#/hr) or Btu/hr					
3. Flue Diameter (ft)					
4. Probe Position					
5. Process Rate					
6.					
7. Water Content (% vol.)					
8. Oxygen (%)					
9. NOx(hot line) reading/@3% O_2(ppm)					
10. NO(hot line) reading/@3% O_2(ppm)					
11. NO_2(hot line) reading/@3% O_2(ppm)					
12. NOx dry @ 3% O_2(hot line)ppm					
13. NO dry @ 3% O_2 (hot line)(ppm)					
14. NO_2 dry @ 3% O_2 (hot line)(ppm)					
15. Carbon Dioxide (%)					
16. Carbon Monoxide (ppm) uncor./cor.					
17. Hydrocarbon (ppm)					
18. Sulfur Trioxide (ppm)					
19. Sulfur Dioxide (ppm)					
20. Total Particulate (g/Mcal)					
21. Total Particulate (lb/Mbtu)					
22. Smoke Number					
23. NO(cold line)reading/dry @3%(ppm)					
24.					
25. Atmos. Temp. (F°/C°)					
26. Dew Point Temp. (F°/C°)					
27. Atmos. Pressure(in.Hg)					

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KVB

Test No. ______________

Engr. ______________

CONTROL ROOM DATA

Test Number ______________ Date ______________

Unit Number ______________ Owner ______________

Fuel ______________ Location ______________

Capacity (K#/hr) ______________

Furnace Type ______________ Burner Type ______________

1. Test Number					
2. Load (K#/hr)					
3. Control Method Auto/Hand					
4. Staged Air Port Open					
5.					
6. Oxygen/Air Level (%)					
7. Drum Pressure (psig)					
8. Final Steam Press/Temp(psig/°F)					
9. Fuel-Air Ratio Setting					
10. Feedwater Press/Temp(psig/°F)					
11. Air Flow Primary/Secondary( )					
12. Air Temp Primary/Secondary(°F)					
13. Fan Setting FD/ID					
14. Register Setting (%open C.C.)					
15. Fuel Flow (lb/hr)*					
16. Fuel Press/Temp (psig/°F)					
17. Fuel Atomization Press (psig)					
18. Pressure Furnace/Windbox (iwg)					
19. Smoke Meter					
20. Stack Temp. (°F)					
21. Boiler Outlet Press (iwg)					
22. Boiler Outlet Temp. (°F)					
23. Air Heater Inlet Temp.(°F)					
24. Air Heater Outlet Temp. (°F)					
25. Windbox Temperature (°F					
26.					
27.					
28.					

***Fuel flow in lb/hr needed for efficiency calculation.**

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4/76

KVB

Sample Code ________ ________ ________ ________

Tested by: ______________________________

Date ______________

STATEMENT OF PROCESS WEIGHT OR VOLUME

Firm Name ______________________________

Address ______________________________

DATA ON OPERATING CYCLE TIME:

Start of Operation, Time ______________

End of Operation, Time ______________

Elapsed Time, Minutes ______________

Idle Time During Cycle, Min. ______________

Net Time of Cycle, Minutes ______________

DATA ON MATERIAL CHARGED TO PROCESS DURING OPERATING CYCLE:

Material	______________	Weight	______________	lbs, gal
Material	______________	or	______________	lbs, gal
Material	______________	Volume	______________	lbs, gal
Material	______________		______________	lbs, gal
Material	______________		______________	lbs, gal
Material	______________		______________	lbs, gal
Material	______________		______________	lbs, gal
		Total:	______________	

Signature ______________________________

Title ______________________________

9/76

KVB 5804-1

PARTICULATE EMISSION CALCULATIONS

Test No.__________ Date____________ Location______________________ Engr.__________

Unit No.__________ Fuel______________ Load____________________________________

Pitot Factor, Fs______________ Barometric Pressure, P_{bar}____________in. Hg

Tot. Liquid Collected, V_{1c}__________ml Total Particulate, M_n__________m gm

Velocity Head, ΔP________ iwg Stack Temp., Ts________°R Stack Area, As________ft^2

Sample Volume, Vm________ft^3 Stack Press., Psg________iwg Excess O_2, XO_2%__________%

Orifice Press. Diff., H__________iwg Stack Gas Sp. Gravity, Gs__________n.d.

Sample Time, θ________min Nozzle Dia., Dn__________in. Meter Temp., T_m__________°R

*1. Sample Gas Volume $Vm_{std} = 0.0334\ Vm(P_{bar} + H/13.6)\ \frac{520}{T_m}$ __________ SCF

2. Water Vapor $Vw_{std} = 0.0474\ V_{1c}$ __________ SCF

3. Moisture Content Bwo = Eq. 2/(Eq. 1 + Eq. 2) __________ N.D.

4. Concentration a. $C = 0.0154\ Mn/Vm_{std}$ __________ grains/DSCF

b. $C = 2.205 \times 10^{-6}\ Mn/Vm_{std}$ __________ lb/DSCF

c. $C = \text{Eq. 4b} \times 16.018 \times 10^3$ __________ grams/DSCM

5. Abs. Stack Press. $Ps = (P_{bar} \times 13.6) + Psg$ __________ in. w abs.

6. Stack Gas Speed $Vs = 174\ Fs\ \sqrt{\Delta P Ts}\ \sqrt{\frac{407}{Ps} \times \frac{1.00}{Gs}}$ __________ ft/min

7. Stack Gas Flow Rate @ 60°F a. $Qsw = \text{Eq. 6} \times As \times \frac{520}{Ts} \times \frac{Ps}{407}$ __________ WSCF/min

b. Qsd = Eq. 7a x (1. - Eq. 3) __________ DSCF/min

8. Material Flow Ms = Eq. 7b x Eq. 4b x 60 __________ lb/hr

9. XO_2 factor $XO_2f = 2090/(20.9 - XO_2\%)$ __________ N.D.

10. Emission a. E = Eq. 4b x Fe x Eq. 9 __________ lb/MMBtu

b. E = Eq. 4c x Fm x Eq. 9 x 1000 __________ ng/joule

11. % Isokinetic $I = \dfrac{14077 \times Ts\,(Vm_{std} + Vw_{std})}{\theta \times Vs \times Ps \times Dn^2}$ __________ %

	Oil	Gas	Coal
Fe SC Feet/10^4 Btu	92.2	87.4	98.2
Fm SC Meters/10^4 joules	0.002475	0.002346	0.002636

Data Sheet 5806-1

* Omit $\frac{520}{T_m}$ if dry gas meter is temp. compensated

KVB

EXTRACTION OF IMPINGER WATER

Extraction Date ______________

Test Number ______________ Engineer ______________

Sampling Type: ________ SASS Train ________ Joy Train

Vol. of Impinger Water ______________ ml

Vol. of methyl chloroform per extraction ______________ ml

Times of extractions ______________

Amb Temperature ______________ °F

Sample No. ______________

Sep. No. ______________

Tared Beaker No.		Tared Beaker No.		Tared Beaker No.	
Final wt. (g)					
Initial (g)					
Increase (g)					
* Tare					
wt. (g)		Methyl Chloroform Blank Residue g/200cc			
- Residue (g)		Residue Total (g)			
Organics (g)					

REMARKS: ______________

KVB

TEST NO. ____________________ TRAIN ____________________

ENGINEER ____________________

SOLID CYCLONE CATCH

	10µ	3µ	1µ	TARE	TARE
Cont. No.					
Final Wt. (g)					
Initial Wt. (g)					
Inc. (g)					
± Tare					
Part. Wt. (g)					

FILTER CATCH

	SAMPLE FILTER NO.	TARED FILTER NO.	TARED FILTER NO.
Final Wt. (g)			
Initial Wt. (g)			
Inc. (g)			
± Tare			
Part. Wt. (g)			

REMARKS: ____________________

KVB

DATE ______________

LABORATORY TEST REQUEST

PROGRAM: C.A.R.B. ORGANIC COMPOUND EMISSION INVENTORY

TEST: FIRM NAME ______________

ADDRESS ______________

UNIT TESTED ______________

DATE OF TEST ______________

PROCESS MATERIAL ______________ EMISSION TYPE ______________

REMARKS ______________

TEST CODE ______________ ______________

SAMPLE CONTAINER		SOURCE OF SAMPLE	SAMPLING TIME	SAMPLING DURATION	SAMPLE VOLUME	
NO.	TYPE				CC.	CU.FT.

DELIVERY DATE ______________ BY (SIGNATURE) ______________

RECEIVED BY ______________

ANALYSIS COMPLETED BY ______________ DATE ______________

PROJECTED DATA TRANSFER DATE ______________

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5804-8

White - originator Pink - receipt

Yellow - lab Blue - attached to results

KVB

SIZE DISTRIBUTION WORK SHEET #1

Test No.____________________ Company______________________________

	mg	%	Weight % Less Than Stated Size	Uncorrected Size, um	Corrected Size, um
SASS					
10 µ cyclone			100%	9.2	
3 µ cyclone				3.8	
1 µ cyclone				1.3	
Filter					
Impinger					
Total		100%	0%		
Oven Temperature (°R)					
Flow Rate Through Cyclones (wacf/min)					
JOY					
10 µ cyclone			100%	8.4	
3 µ cyclone				1.9	
1 µ cyclone				0.6	
Filter					
Impinger					
Total		100%	0%		
Oven Temperature (°R)					
Flow Rate Through Cyclones (wacf/min)					

KVB 5806-A
Rev. 3/7/78

KVB

SIZE DISTRIBUTION WORK SHEET #2

Test No.__________________ Company____________________________

	mg	%	Weight % Less Than Stated Size	Uncorrected Size, μm	Corrected Size, μm
SASS					
10 μ cyclone			100%	9.2	
3 μ cyclone				3.8	
1 μ cyclone				1.3	
Filter					
Total		100%	0%		

	mg	%	Weight % Less Than Stated Size	Uncorrected Size, μm	Corrected Size, μm
JOY					
10 μ cyclone			100%	8.4	
3 μ cyclone				1.9	
1 μ cyclone				0.6	
Filter					
Total		100%	0%		

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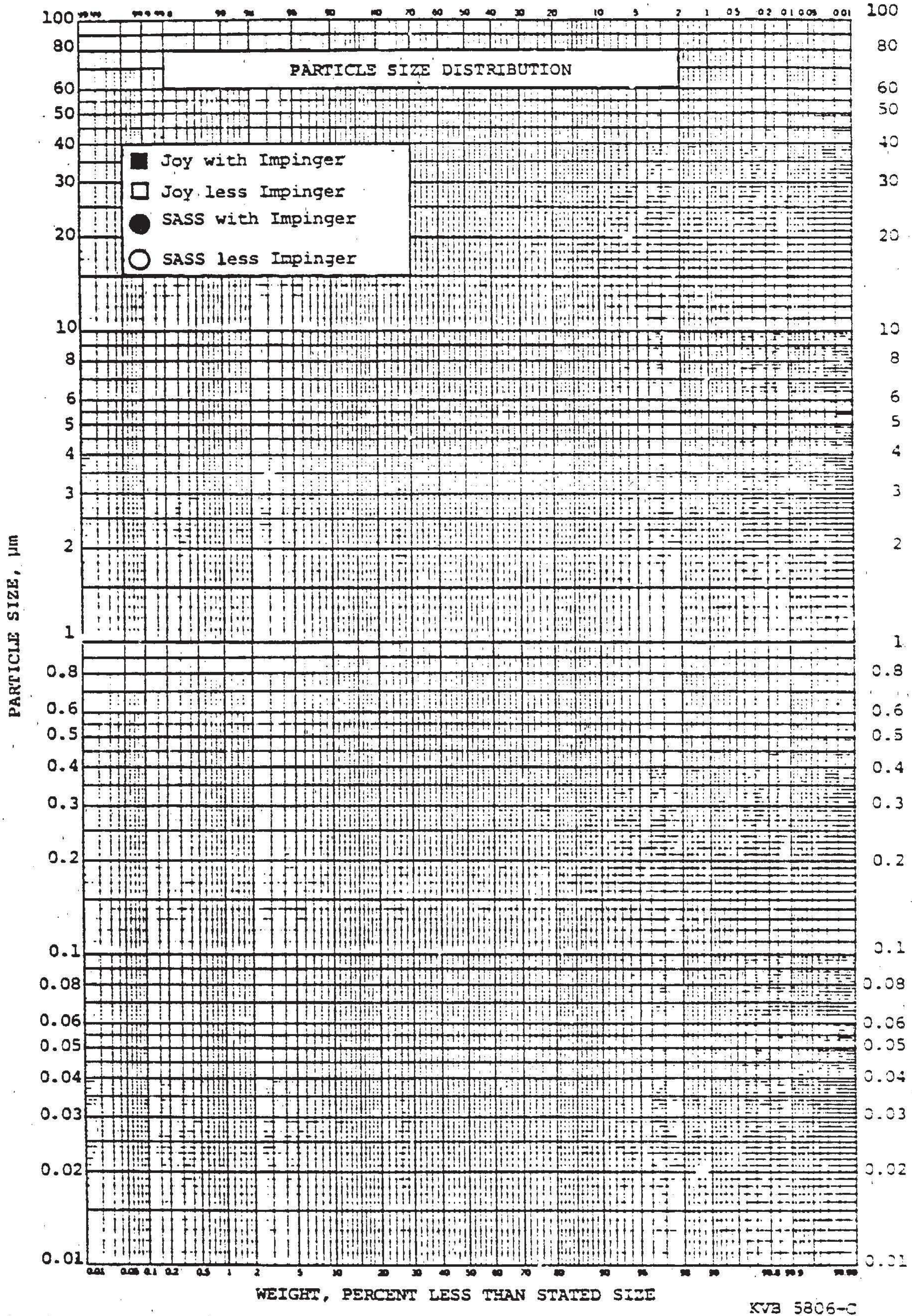
Test ____________



KVB 5806-C

CHEMICAL COMPOSITION OF PARTICULATE SAMPLES
IN PERCENT

Sample Number							
Percent of Cut							
Aluminum							
Antimony							
Arsenic							
Barium							
Bismuth							
Bromine							
Cadmium							
Calcium							
Chlorine							
Chromium							
Cobalt							
Copper							
Gallium							
Indium							
Iodine							
Iridium							
Iron							
Lead							
Manganese							
Mercury							
Molybdenum							
Nickel							
Niobium							
Osmium							
Palladium							
Phosphorus							
Platinum							
Potassium							
Rhenium							
Rubidium							
Ruthenium							
Scandium							
Selenium							
Silicon							
Silver							
Strontium							
Sulfur							
Tantalum							
Tin							
Titanium							
Tungsten							
Vanadium							
Yttrium							
Zinc							
Zirconium							
Sub Total Elements*							
Sulfates (H_2O sol)							
Sulfur (from $SO_4^=$)							
Nitrate* (H_2O sol)							
Total Carbon*							
Volatile Carbon							
Carbonates							
Sub Total							
Other*							
Total							

* Sum of listings with '*' equal 100 percent

ANALEX, INC.

712-C North Valley Street, Anaheim, California 92801 (714) 533-4780

Prepared for: ____________________

____

Date: ____________

P.O.# ____________

Lab Run # __________

Sample Label: ____________________

Concentrations are in __________

Aluminum __________
Antimony __________
Arsenic __________
Barium __________
Bismuth __________
Bromine __________
Cadmium __________
Calcium __________
Cesium __________
Chlorine __________
Chromium __________
Cobalt __________
Copper __________
Gallium __________
Germanium __________
Gold __________
Hafnium __________

Indium __________
Iodine __________
Iridium __________
Iron __________
Lead __________
Manganese __________
Mercury __________
Molybdenum __________
Nickel __________
Niobium __________
Osmium __________
Palladium __________
Phosphorus __________
Platinum __________
Potassium __________
Rhenium __________
Rhodium __________

Rubidium __________
Ruthenium __________
Scandium __________
Selenium __________
Silicon __________
Silver __________
Strontium __________
Sulfur __________
Tantalum __________
Tellurium __________
Thallium __________
Tin __________
Titanium __________
Tungsten __________
Vanadium __________
Yttrium __________
Zinc __________
Zirconium __________

( ) qualitative estimate

* detected (<0.1% concentration)

\ not detected

KVB1 DATA

FIELD DATA

ANALYTICAL DATA

KVB NUMBER mL TAKEN	SO4 YG/ML %	NO3 YG/ML %	CODE

KVB2 DATA

FIELD DATA

ANALYTICAL DATA

KVB [illegible]ER mg T[illegible]	CO3 YG/ML %	VC YG/ML %	TC YG/ML %	CODE

REFERENCES

SECTION 3.0

3-1. Blake, D. E., "Source Assessment Sampling System: Design and Development," EPA-600/7-78-018, February 1978.

3-2. Smith, W. B. and Wilson, R. R., "Development and Laboratory Evaluation of a Five-Stage Cyclone System," EPA-600/7-78-008, January 1978.

3-3. Federal Register, Vol. 36, pp. 22394 to 22396, November 25, 1971.

3-4. Giaque and Jaklevic, "Rapid Quantitative Analysis by X-Ray Spectrometry," Advances in X-Ray Analysis, Vol. 15, p. 164-175, Plenum Press, New York, NY, 1971.

3-5. Dixon, W. J., "Introduction to Statistical Analysis," McGraw-Hill, Inc., Ch. 5, 1969.

3-6. "Control of Particulate Emissions," EPA Training Course 413, Section 9.

3-7. Stockham, J. D. and Fochtman, E. G., "Particle Size Analysis," Ann Arbor Science Publishers, Inc. Ch. 2, 1977.

3-8. Hesketh, H. E., "Fine Particles in Gaseous Media," Ann Arbor Science Publishers, Inc., Ch. 1, 1977.

3-9. Smith, W. B., et al., "Technical Manual: A Survey of Equipment and Methods for Particulate Sampling in Industrial Process Streams," EPA-600/7-78-043, March 1978.

-10. Blake, D. E., Cyclone Calibration report, January 1978, Acurex/Aerotherm.

SECTION 4.0

PARTICULATE TEST RESULTS

4.1 TEST PROGRAM

During this program, 41 source tests were conducted at 25 different locations. This section is a report of each of these tests describing the source, discussing circumstances of the test, and presenting and analyzing the test results. The following sub-sections are grouped together according to the type of general industrial process.

Fuel Combustion
Mineral Products
Food and Agriculture
Metal Fabrication
Metallurgical
Organic Solvent Use
Chemical
Wood Operation
Petroleum Operation

The field tests were run to obtain particulate emission data for the industrial types listed above. The distribution of the tests is shown in Figure 4-1. Of the completed field tests, 21 tests were run with simultaneous sampling with the larger SASS train and the small Joy train (as discussed in Section 3.2.1 A) for accuracy assessment. Eleven tests were run as simultaneous sampling of both trains (one on the inlet and the other on the outlet) to evaluate the efficiency of the particulate control equipment. Seven tests were run using only the SASS train, and two tests were run using only the Joy train.

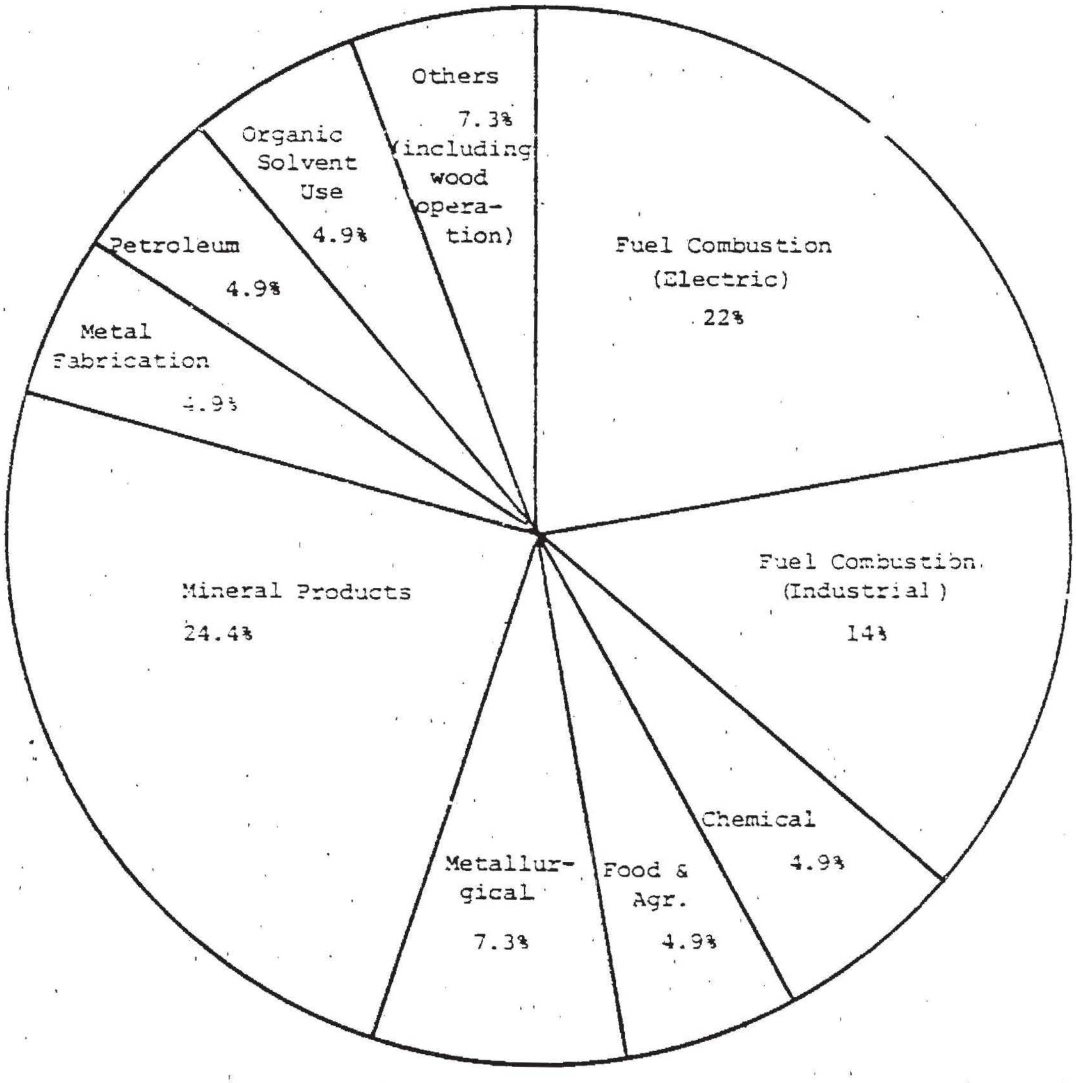


Figure 4-1. Distribution of field tests (total 41 tests)

4.2 SUMMARY OF TEST RESULTS

The key results of all field tests are summarized in Table 4-1. The results for each test have been listed on two consecutive pages. For example, results from Test 01S begin on the first line of the industrial boiler section on the first page of the table and continue on the first line of the second page. The following is a brief explanation of each of the entries in the Table 4-1:

1) Application Categories--Combustion of Fuel, Food and Agriculture, Metal Fabrication, etc.; general classification of the source type tested.
2) Company/Industry Type--Type of source tested. Specific names of plants tested are not included in the report.
3) Test Number--A unique number assigned by KVB which identifies the location, test procedure and test results.
4) Date of Test
5) Sample Volume--Volume of gas sample taken during test [Dry Standard Cubic Feet (DSCF) and Wet Standard Cubic Feet (WSCF)].
6) Sample Flow Rate--[Wet Standard Cubic Feet per Minute (WSCFM)]. This is the flow rate of gas that has passed through our sampling equipment.
7) Temperature °F--Shown are the temperatures of the stack, the dry gas meter used to measure the sample volume taken, and the oven in which the three cyclones plus filter were housed.
8) Percent Isokinetic--The amount that the sampling stream velocity varies fron stack gas velocity. Over 100% means the sampling stream was faster than the stack gas stream.
9) Particulate Weights, mg--These are the weights of particulates collected in probe, 10μm cyclone, 3μm cyclone, 1μm cyclone, the filter, and the impinger. The impinger catch is broken down into two parts, the organic fraction and the nonorganic fraction.

10) Stack Flow Rate--Dry Standard Cubic Feet per Minute (DSCFM). This is the exhaust gas velocity measured at the sample location

11) Excess O_2--This is the oxygen concentration in the exhaust gas measured at the sampling location. Combustion Sources.

12) CO_2--This is the carbon dioxide concentration in the exhaust gas measured at the sampling location. Combustion Sources.

13) Sampling Time--The time taken in minutes to complete the source sample.

14) Plant Operation Time--This is the number of hours the plant or equipment sampled is operated in one year.

15) Emissions--These are factors related to the device type tested.

gr/DSCF	- Grains per dry standard cubic feet
T/yr	- Tons per year
lb/hr	- pounds per hour
lb/MMBtu	- pounds per million Btu

16) Particle Size Distribution, Percent of Particles--Distribution into size ranges; greater than 10 microns, 3 to 10 microns, 1 to 3 microns and less than 1 micron. This table includes the impinger catch as part of the total suspended particulate (TSP) as directed by the ARB (EPA Method 5 does not include the impinger catch in the measurement of TSP. The SCAQMD includes the impinger catch in their methods. Results with and without the impinger catch are presented in the detailed discussions in Section 4.2).

The percent of particles >10μm, 3-10μm, 1-3μm, <1μm are taken from the size distribution curves (weight percent less than stated versus particle size, μm, on log-normal paper) presented in Section 4.2.

17) Control--If the inlet and exit to a control device were sampled, the type of control device (i.e., baghouse, cyclone, etc.) and efficiency is listed. Where a control device was tested, the measured control efficiency ($\frac{\text{Input - Output}}{\text{Input}}$ x 100 percent) is indicated.

TABLE 4-1. SUMMARY OF FIELD TEST RESULTS

Company/Industry Type	Test No.	Date	Sample Vol. DSCF	Sample Vol. WSCF	Sample Flow Rate WSCFM	Temperature, °F Stack	Temperature, °F Meter	Temperature, °F Oven	% Isokin.	Particulate Weights, mg Probe Catch	10µm Cyclone	3µm Cyclone	1µm Cyclone	Filter Catch	Impinger H2O/Org.	Total
FUEL COMBUSTION																
Industrial Boiler	01S	9/13 1977	589	645	3.2	514	99	400	114		630.8	244.0	143.6	565.	836 160.5	2580.2
	01J	9/13 1977	32	35	1.01	500	94	400	99.5		79.5	8.9	11.2	19.5	44.2 20.9	184.2
	02S	9/15 1977	917	101	3.72	515	106	401	138	54.2	256.3	234.9	349.1	275.6	390.9 139.1	1700.
	02J	9/15 1977	81	90	.97	500	85	400	91	22.1	36.8	15.1	4.0	15.4	39.2 11.9	146.
	03S	9/20 1977	570	625	3.47	516	101	400	122	63.7	268.8	116.7	126.9	277.	1014.4 30.8	1838.
	03J	9/20 1977	49	56	.93	500	88	369	79	26.4	36.7	3.1	3.5	18.7	24.1 4.3	116.
	03#5	9/20 1977	62	70	1.17	500	100	305	99	36	-	-	-	124.4	63 43.6	267
	03A	9/20 1977	15	17	1.10	512	80	-	98	3.4 @ 7.5µm	3.4 @ 5.0µm	3.0 @ 3.5µm	1.2 @ 1.1µm	3.3	- -	14.3
	16S	12/12 1977	807	883	3.68	450	88	401	118	20.2	34.6	9.6	6.3	100.1	883.6 10.5	1065.1
	16J	12/12 1977	229	263	1.10	450	100	400	119	2.8	2.7	3.1	8.2	24.2	87.0 1.0	129.0
IC Engine	07S	10/20 1977	634	762	3.2	412	91	400	88	13.2	8.4	2.8	1.3	29.8	1618.4 82.9	1756.8
IC Engine	07J	10/20 1977	207	243	1.156	412	90	396	103	5.5	3.6	1.4	1.2	1.2	192.7 62.7	268.3
IC Engine	15J	12/7 1977	227	240	1.00	720	78	400	93	17.0	26.5	9.2	35.3	89.9	142.6 143.8	484.3
Wood Boiler	05S	10/13 1977	418	451	5.66	305	106	388	124	30.0	126.2	514.8	100.0	146.7	2168.2 1041.4	4327.

(Continued)

TABLE 4-1 (Continued).

Test No.	Stack Flow Rate DSCFM	Excess O_2	CO_2	Sampling Time, min.	Plant Operation Time hr/yr	Emissions				Particle size distribution, Percent of Particles				Control		Remarks
						gr/DSCF	T/yr	lb/hr	lb/MMBtu	<10μm	10μm	3-1μm	<1μm	Type	Efficient	
FUEL COMBUSTION																
01S	552	2.2		202.5		0.0672		0.120	0.0990	17	10	11	63	None		
01J	431	2.2		35		0.0896		0.111	0.1322	15	5	4	56	"		
02S	520	2.5		272		0.0285		0.128	0.043	8	11	15	66	"		
02J	520	2.5		92		0.0278		0.124	0.042	13	9	12	65	"		
03S	476	2.5		180	-	0.051		0.210	0.077	11	6	7	76	"		
03J	476	2.5		60		0.0365		0.149	0.549	36	4	2	58	"		
03HS	476	2.4		60		0.066		0.270	0.099	-	20	20	-	"		
03A	473	2.5		15		0.0179		0.073	0.0270	-	-	-	-	"		
16S	8181	8.37	9.0	240	8736	0.0203	6.2	1.43	0.0431	2.5	0.8	0.8	96	"		
16J	8181	8.37	9.0	240	8736	0.0087	2.7	0.61	0.0184	0.7	0.9	1.4	97	"		
07S	247	2.1	14.0	240	8736	0.0427	0.4	0.0900	0.0600	0.6	.15	0.35	99.1	None		
07J	247	2.1	14.0	211.2	8736	0.0200	0.2	0.0424	0.0281	0.8	0.4	0.6	98.4	"		
15J	5248	12.5	3.7	240	6570	0.0303	4.5	1.36	0.0995	4	2	2	92	"		1450 kW
05S	5966	16.6	4.1	130	8736	0.159	15.7	8.17	0.214	0.3	4.45	4.45	74	None		

KVB 5806-783

(Continued)

TABLE 4-1 (Continued).

Company/Industry Type	Test No.	Date	Sample Vol. DSCF	Sample Vol. WSCF	Sample Flow Rate WSCFM	Temperature, °F Stack	Temperature, °F Meter	Temperature, °F Oven	% Isokin.	Particulate Weights, mg Probe Catch	10μm Cyclone	3μm Cyclone	1μm Cyclone	Filter Catch	Impinger H_2O/Org.	Total
Utility Boiler #1	11S	1/14 1978	943	1027	4.3	275	91	436	158	29.5	28.3	13.9	10.6	98.4	325.7 50.4	556.8
Utility Boiler	11J	1/14 1978	223	245	1.02	275	81	389	164	11.7	14.4	3.4	2.6	24.8	26.1 29.6	112.6
"	12S	1/16 1978	915	996	4.1	284	94	392	155	31	31.2	25.3	9.6	96.8	215.7 19.4	429.0
"	12J	1/16 1978	222	244	1.01	275	81	389	156	3.6	14.3	2.6	2.7	24.6	25.7 10.4	83.9
"	13S*	1/18 1978	1406	1533	4.2	281	82	388	149	92.2	19.8	64.8	3.0	183.4	2107.8 0	2471.0
"	13J	1/18 1978	300	336	1.06	273	77	345	132	4.0	3.5	0	0.9	29.8	122.2 10.2	170.6
"	23S*	1/24 1978	899	977	4.24	297	80	390	76	157.1	35.6	29.2	5.7	116.9	1174.3 167.2	1686.0
"	23J	1/24 1978	194	214	0.93	290	80	355	87	10.6	10.9	1.2	3.6	25.5	47.3 6.5	105.6
"	24S	1/26 1978	946	1024	4.2	222	111	400	77	30.4	41.7	3.4	1.4	96.8	495.0 17.4	686.1
"	24J	1/26 1978	212	233	0.98	220	95	299	88	18.5	5.8	1.5	0.9	24.5	106.6 40.9	198.7
"	32S	3/6 1978	772	852	4.1	295	84	377	92	49.7	26.9	6.7	3.4	64.5	407.5 62.4	621.1
"	32J	3/6 1978	778	851	1.03	292	79	351	92	83.3	5.5	35.1	11.4	68.0	195.9 34.4	433.6
"	33S	3/8 1978	883	981	4.1	286	75	385	100	73.9	52.6	28.4	6.9	108.3	427.1 60.0	757.2
"	33J	3/8 1978	227	249	1.06	286	79	383	101	21.1	19.4	3.8	7.0	29.5	60.1 54.9	195.8

*Bad data; not included in subsequent analyses

KVB 5806-783
(Continued)

TABLE 4-1 (Continued).

Test No.	Stack Flow Rate DSCFM	Excess O_2	CO_2	Sampling Time, min.	Plant Operation Time hr/yr	Emissions				Percent of Particles				Control		Remarks
						gr/DSCF	T/yr	lb/hr	lb/MMBtu	>10μm	10μm	3-1μm	<1μm	Type	% Efficient	
11S	833730	4.8	10.0	240	8736	0.0091	284	65.0	0.0154	1.0	2.5	2	91.5	None		472 MW
11J	833730	4.8	10.0	240	8736	0.0078	243	55.6	0.0132	9	3	10	78	"		
12S	898170	5.9	10.0	240	8736	0.0072	242	55.5	0.0130	4	5	7	84.0	"		476 MW
12J	898170	5.9	10.0	240	8736	0.0058	196	44.8	0.0105	5	3	8	80.0	"		
13S*	913230	6.2	10.5	360	8736	0.0271	928	212.4	0.050	0.1	0.9	3	95.5	"		472 MW
13J	913230	6.2	10.6	316	8736	0.0088	299	68.5	0.0162	2	0	0	98	"		
23S*	849434	6.4	10.5	230.5	8736	0.0289	921	210.8	0.0554	1.5	1.3	2.2	95	None		450
23J	849434	6.4	10.5	229.6	8736	0.0084	268	61.3	0.0161	10	1.0	1.5	87.5	"		
24S	481018	6.5	10.0	240	8736	0.0112	202	46.2	0.0214	5	1	1	93.0	"		238
24J	481018	6.5	10.0	240	8736	0.0144	259	49.3	0.0275	5.5	0.5	0.6	96.5	"		
32S	79598	4.75	10.2	206.9	8736	0.0124	369	84.5	0.0211	3.5	1.5	1	94	"		453
32J	79598	4.75	10.2	828.5	8736	0.0086	256	58.7	0.0147	0.1	0.7	4	95	"		
33S	85504	6.0	10.7	240	8736	0.0132	423	96.9	0.0244	4	4	5	87	"		455
33J	85504	6.0	10.7	238.6	8736	0.0133	427	97.7	0.0246	8	2	2	88	"		

*Bad data; not included in subsequent analyses

TABLE 4-1 (Continued).

ompany/Industry Type	Test No.	Date	Sample Vol.		Sample Flow Rate	Temperature, °F			%	Particulate Weights, mg						
			DSCF	WSCF	WSCFM	Stack	Meter	Oven	Isokin.	Probe Catch	10µm Cyclone	3µm Cyclone	1µm Cyclone	Filter Catch	Impinger H₂O/Org.	Total
Utility Boiler #2	21S	1/16 1978	774	853	4.6	274	76	399	150	60.6	4.3	4.8	1.9	50.9	271.6 66.6	460.7
"	21J	1/16 1978	157	177	1.00	275	72	382	131	11.2	1.2	0.6	0.9	12.2	45.9 0.4	72.4
"	22S	1/18 1978	1138	1233	4.38	225	83	381	111	18.0	7.3	37.3	9.8	82.7	619.0 34.1	808.2
"	22J*	1/18 1978	250	277	0.994	225	83	370	100	8.4	2.0	1.7	2.8	19.5	33.0 8.4	75.8

*Bad data; not included in subsequent analyses

TABLE 4-1 (Continued).

Test No.	Stack Flow Rate DSCFM	Excess O_2	CO_2	Sampling Time, min	Plant Operation Time hr/yr	Emissions gr/DSCF	Emissions T/yr	Emissions lb/hr	Emissions lb/MMBtu	Percent of Particles >10μ	Percent of Particles 10-3μ	Percent of Particles 3-1μ	Percent of Particles <1μ	Control Type	Control % Efficient	Remarks
21S	170394	7.0	9.8	105	8736	0.0092	130.2	29.8	0.022	.15	0.75	1.6	97.5	None		174 MW
21J	170394	7.0	9.8	176	8736	0.0071	100.9	23.1	0.017	1.2	0.6	0.7	97.5	"		
22S	215124	8.0	9.5	281	8736	0.0109	88.6	20.3	0.024	2.1	1.1	5.8	91	"		90 MW
22J*	215124	8.0	9.5	279	8736	0.0046	37.7	8.6	0.0099	1.4	1.1	1.5	96	"		

*Bad data, not included in subsequent analyses

TABLE 4-1 (Continued).

Company/Industry Type	Test No.	Date	Sample Vol DSCF	Sample Vol WSCF	Sample Flow Rate DSCFM	Temperature, °F Stack	Temperature, °F Meter	Temperature, °F Oven	% Isokin.	Particulate Weights, mg Probe Catch	10μm Cyclone	3μm Cyclone	1μm Cyclone	Filter Catch	Impinger H₂O/Org.	Total
MINERAL																
Gypsum	6S	10/18 1977	385	507	4.83	414	104	404	131	32.3	565.5	506.4	80.2	33.6	145.0 32.5	1395.5
Brick	8S	11/3 1977	699	701	4.91	85	95	202	94	15.5	130.9	12.8	1.7	1.6	39.5 89.0	291.0
Brick	8J	11/3 1977	115	117	0.98	75	89	205	51	105.4	8581.5	14.9	5.2	2.5	3.5 0	8713.0
Cement	9S	11/7 1977	942	985	3.99	365	94	395	132	31.5	98.5	124.9	34.3	19.5	32.6 1.4	342.7
Cement	18S	12/16 1977	940	992	4.13	381	92.3	398	89.5	35.4	145.9	185.1	53.8	27.6	151.7 6.9	606.4
Glass	20S	1/12 1978	990	1062	5.14	420	89.7	389	145	5.6	7.3	4.1	5.4	12.7	359.[illegible] 2.1	396.5
Glass	20J	1/12 1978	194	217	0.97	1001	76	374	90	7.5	5.6	2.4	111.1	264.7	56.0 9.4	457.5
Glass	28S	2/16 1978	325	361	3.6	819	93	397	81	75.4	13.3	12.1	34.7	947.6	191.5 19.1	1293.7
Glass	35S	3/16 1978	370	410	3.7	835	100	380	94	48.4	90.2	49.0	82.3	938.4	192.7 16.7	1425.7
Glass	35J	3/16 1978	170	186	0.94	835	118	397	110	54.4	24.0	16.9	256.9	181.0	134.1 47.9	715.6
Fiberglass	38S	3/28 1978	915	963	3.8	154	104	399	105	13.2	7.6	2.2	3.1	120.8	820.0 43.9	1011.4
Fiberglass	38J	3/28 1978	230	241	0.96	154	103	379	101	11.3	1.4	1.4	3.5	30.8	141.0 13.7	203.7
Asphalt Roofing	25S	1/31 1978	991	996	4.15	130.8	94	388	102	25.6	19.3	18.7	5.1	2.2	1.4 349.7	485.0
Asphalt Roofing	25J	1/31 1978	234	239	0.99	139	85	249	109.5	8.8	3.1	1.4	1.7	0	11.9 91.2	118.1
Batch	29S	2/21 1978	834	931	3.9	175	92	400	113	18.3	261.2	15.2	8.7	15.0	65.2 17.0	420.0
Batch	29J	2/21 1978	76	92	0.85	186	86	244	100	804.7	10931.6	10928.3	2182.9	12112.1	3.1 3.6	50966.[illegible]

TABLE 4-1 (Continued).

Test No	Stack Flow Rate DSCFM	Excess O_2	CO_2	Sampling Time, min.	Plant Operation Time hr/yr	Emissions gr/DSCF	Emissions T/yr	Emissions lb/hr	Emissions lb/MMBtu	Percent of Particles <10μm	Percent of Particles 10μm	Percent of Particles 1μm	Percent of Particles <1μm	Control Type	Control % Efficient	Remarks
MINERAL																
6S	4508	19.0	0.5	105	8736	0.0558	9.4	2.16	NA	12	31.5	14	22			
8S	6435	Air	--	145.2	2475	0.00641	0.4	0.354	NA	44	4	4	48	Bag-house	99.8	Baghouse Exit
8J	2139	Air	--	120	2475	1.169	26.6	21.5	NA	98.6	0.85	0.30	0.15	"	99.8	Inlet
9S	121524	14.2	7.2	240	7728	0.00560	22.6	5.85	NA	8.0	32	40	20	Not	Tested	Fuel - gas
16S	146121	14.3	10.4	240	7728	0.0099	48	12.47	NA	8.0	24	34	34.0	Not	Tested	Fuel - coal
20S	34959	12.7	5.8	240	8736	0.00617	8.0	1.88	NA	1.4	0.6	1	97	ESP	98.24 solids only	ESP Outlet
20J	27484	12.3	5.9	223	8736	0.0364	37	8.59	NA	0.5	0.4	0.5	98.6	ESP	98.24	ESP Inlet
28S	13670	8.6	6.5	90.1	8400	0.0612	30.2	7.19	NA	0.6	0.7	1.3	97.4	None		
35S	11888	11.0	8.0	100	8400	0.0594	25.5	6.00	NA	4.2	3	4	88	None		
35J	11888	11.0	8.0	180	8400	0.0649	27.8	6.63	NA	1.2	1.3	2	95	None		
38S	65779	20.0	0.5	240	8736	0.0170	84.0	19.24	NA	0.6	0.2	0.2	98.9	Water curtain	Not Tested	Emissions given for both ducts
38J	65779	20.0	0.5	240	8736	0.0136	67.2	15.4	NA	0.2	0.2	0.4	99.2			
25S	45349	6.4	0.4	240	7072	0.00754	10.4	2.94	NA	2.3	2.8	4	91	Mist Eliminator	Not Tested	
25J	44697	6.4	0.4	240	7072	0.0079	10.5	2.98	NA	0.55	0.2	0.3	99	"	"	
29S	65089	18.2	3.5	210	720	0.00776	1.56	4.34	NA	60	6	4	30	Bag-house	99.9	
29J	58557	17.4	2.0	90	720	11.485	079.9	777.5	NA	--	--	--	--			

TABLE 4-1 (Continued).

Company/Industry Type	Test No.	Date	Sample Vol DSCF	Sample Vol WSCF	Sample Flow Rate WSCFM	Temperature, °F Stack	Temperature, °F Meter	Temperature, °F Oven	% Isokin.	Particulate Weights, mg Probe Catch	10µm Cyclone	3µm Cyclone	1µm Cyclone	Filter Catch	Impinger H₂O/Org.	Total
FOOD AND AGRICULTURE																
Rice	4S	10/11 1977	973	996	5.00	87	100	202	117	37.5	327.8	64.9	7.6	1.0	57.6 94.3	590.7
Rice	4J	10/11 1977	190	197	0.99	86	91	205	116	36.6	141.1	2.2	1.0	0.7	6.8 1.9	190.3
CARACOA	37S				Lost	Sample	Due	To	High	Temperature						
CARACOA	37J	3/23 1978	232	241	0.99	115	101	400	122	180.3	384.9	1.0	8.1	2.1	319.3 174.1	1069.8
METAL FABRICATION																
Heat Treat Steel	14S	11/29 1977	762	772	4.06	139	114	397	84	16.5	12.5	14.8	9.7	10.2	59.6 16.8	140.1
Heat Treat Steel	14J	11/29 1977	178	180	0.97	180	117	391	97	59.2	96.7	73.7	261.8	147.2	10.2 36.2	685.0
Sand Blast Steel	34S	3/14 1978	936	941	4.0	75	103	399	100	0.2	14.2	3.1	1.0	1.2	13.2 20.4	53.3
Sand Blast Steel	34J	3/14 1978	164	164	1.03	66	85	351	117	61.3	19852.8	262.4	186.6	17.3	5.8 60.3	20446.5
METALLURGICAL																
Aluminum Foundry	10S	11/10 1977	1220	1341	4.30	1141	105	404	81	57.0	12.1	8.4	5.1	47.0	51.1 27.7	208.4
Aluminum Foundry	10J	11/10 1977	334	303	1.22	1141	97	382	69	12.0	4.1	1.0	4.0	6.6	2.2 15.7	45.8
Sinter Plant	26S	2/2 1978	954	1023	4.2	229	87	376	108	35.1	85.1	36.7	14.1	100.3	2345.2 224.5	2841.0
Sinter Plant	26J	2/2 1978	206	223	0.99	245	82	339	122	727.8	142.1	20.9	319.3	1180.4	160.4 135.9	2735.1
Open Hearth Steel	36S	3/21 1978	698	181	3.8	422	107	402	93	373.1	70.3	66.1	161.0	251.1	722.8 16.0	1660.4
Open Hearth Steel	36J	3/21 1978	170	189	0.90	486	101	403	98	227.9	268.9	99.1	585.2	883.3	165.0 54.0	2283.4

TABLE 4-1 (Continued).

Test No.	Stack Flow Rate DSCFM	Excess O_2	CO_2	Sampling Time, min.	Plant Operation Time hr/yr	Emissions				Percent of Particles				Control		Remarks
						gr/DSCF	T/yr	lb/hr	lb/MMBtu	>10μm	10μm	1-1μm	<1μm	Type	% Efficient	
FOOD AND AGRICULTURE																
4S	124901	16	--	199.2	700	0.00935	3.5	10.03	NA	46	12	12	30	--	screens not tested	
4J	124901	16	--	198.9	700	0.0154	5.8	16.5	NA	89	2	1	8	--	--	
37S														after lost	burner test	
37J	1620	Air	--	233	2000	0.0711	2.0	2.0	NA	41	1	1	57	--	--	
METAL FABRICATION																
14S	45196	Air	--	190	4080	0.00283	2.2	1.10	--	4	8	14	74	Bag-house	90%	Exit
14J	20767	Air	--	190	4080	0.0593	21.6	10.58	--	5	7	10	76	Bag-house	90%	Inlet
34S	1662	Air	--	233	1040	0.00088	0.07	0.125	--	23	6	6	74	Bag-house	99.9	Baghouse Exit
34J	11577	Air	--	159	1040	1.922	99.4	191.2	--	93	3.5	1.7	1.8			Baghouse Inlet
METALLURGICAL																
10S	3180	5.7	6.8	314.1	4774	0.00263	0.17	0.072	NA	5	4	5	86	None		
10J	3180	5.7	6.8	304.1	4774	0.00211	0.14	0.058	NA	9.5	3	2	86			
26S	118760	16.3	4.4	240	8320	0.0459	195	46.82	NA	2	1.2	1.4	95	BH	97.8 solids only	Baghouse Exit
26J	96855	15.8	5.0	225	8320	0.205	709	170.4	NA	6	1	1	92	BH	97.8 solids only	Baghouse Inlet
36S	17551	9.5	10.5	181	8064	0.0166	22.3	5.51	--	2.[illegible]	3.8	7	87.5	ESP	84.2	ESP Exit
36J	19798	8.5	11.5	177	8064	0.206	141.4	35.08	--	8	3	4	82		90.3 solids only	EST Inlet

TABLE 4-1 (Continued).

ompany/Industry Type	Test No.	Date	Sample Vol.		Sample Flow Rate WSCFM	Temperature, °F			% Isokin.	Particulate Weights, mg						
			DSCF	WSCF		Stack	Meter	Oven		Probe Catch	10µm Cyclone	3µm Cyclone	1µm Cyclone	Filter Catch	Impinger H2O/Org.	Total
ORGANIC SOLVENT USE																
Spray Booth	27S	2/14 1978	800	817	4.1	68	88	234	103	76.7	41.5	5.2	7.6	8.1	9.0 44.5	192.6
Spray Booth	27J	2/14 1978	189	197	0.99	68	83	231	106	11.0	2.0	4.9	8.1	0.8	6.0 7.1	39.9
Spray Booth	31S	2/28 1978	945	956	3.99	71	90	249	102	49.8	6.6	2.8	6.2	4.8	21.2 60.9	152.3
Spray Booth	31J	2/28 1978	235	239	0.99	71	86	260	104	20.4	3.0	2.8	1.1	0	4.0 11.7	43.0
CHEMICAL																
Boric Acid	17S	12/14 1977	948	966	4.03	132	111	400	95	70.5	153.8	5.5	3.6	2.6	1213.7 10.4	1460.1
Boric Acid	17J	12/14 1977	50	52	0.95	136	95	370	231	1301.5	114.2	0.6	1.5	0.8	569.2 11.9	1999.7
Fertilizer Plant	19S	1/5 1978	956	975	5.02	118	90	198	113	3.4	8.1	1.6	0.5	0.3	148.2 11.4	173.5
Fertilizer Plant	19J	1/5 1978	196	201	1.03	147	85	202	91	27.5	8980.9	0.4	0.5	0.7	81.1 22.7	9113.8
WOOD PROCESSING																
Sanding	30S	2/24 1978	765	773	4.01	78	94	80	94	13.4	10.1	2.6	0.8	2.2	24.8 55.4	109.3
Sanding	30J	2/24 1978	125	126	1.05	78	75	76	82	49.6	32.3	21.3	23.8	0.7	3.9 4.2	135.8
Sanding	30 #5	2/24 1978	64	69	1.01	77	78	78	130	235.4	1365.3	--	--	23[illegible].6	18.2 4.5	3854.0
Resawing	39S	3/31 1978	977	988	4.17	75	83	66	108	41.0	110.9	14.5	--	1.9	13.0 19.9	201.2
Resawing	39J	3/31 1978	93	98	0.83	75	92	70	59	699.1	1504.7	2.3	4.5	--	1.5 5.3	2217.4
PETROLEUM																
Heaters	40S	4/4 1978	916	1044	3.8	460	88	407	117	21.6	14.8	5.6	4.4	1.5	147.3 57.2	252.4
FCC Unit	41S	4/18 1978	861	962	4.01	525	98	388	91	1293.6	758.5	93.1	132.5	52.8	684.5 63.3	3078.

(Continued)

TABLE 4-1 (Continued).

Test No.	Stack Flow Rate DSCFM	Excess O_2	CO_2	Sampling Time, min.	Plant Operation Time hr/yr	Emissions gr/DSCF	Emissions T/yr	Emissions lb/hr	Emissions lb/MMBtu	Percent of Particles <10μm	Percent of Particles 10μm	Percent of Particles 3-1μm	Percent of Particles <1μm	Control Type	Control % Efficient	Remarks
ORGANIC SOLVENT USE																
27S	91400	Air	--	199	4000	0.00171	5.8	2.91	NA	32	5	5	59	--		
27J	91400	Air	--	199	4000	0.00325	5.1	2.56	NA		4.4	15		--		
31S	235,400	Air	--	240	2750	0.00248	6.9	5.0	NA	5	2.5	3	90			
31J	235,400	Air	--	240	2750	0.00282	7.8	5.7	NA	5	6	8	81			
CHEMICAL																
17S	10948	20.9	--	240	8736	0.0237	9.74	2.23	--	10	0.5	0.5	89	BH	97.5	Baghouse Exit
17J	16903	20.9	--	55	8736	0.6105	389	88.7	--	15	1	0	84	BH	97.5	Inlet
19S	4688	Air	--	151	2000	0.00280	0.1	0.11	--	4	1	1	94	BH	99.1	Baghouse Exit
19J	1979	Air	--	195	2000	0.7154	12.2	12.16	--	98.6	0.2	0	1.2	BH	99.1	Inlet
WOOD PROCESSING																
30S	4179	Air	--	192.3	2080	0.0022	0.1	0.078	NA	8	3	3	86	BH	96.3	Baghouse Exit
30J	4206	Air	--	120	2080	0.0168	0.6	0.601	NA	37	4	12	36	--		Baghouse Inlet, Cyclone Exit
30 #5	4384	Air	--	70	2080	0.931	36.5	35.05	NA	--	--	--	--	Cyclone	98.4	Cyclone Inlet
39S	6546	Air	--	240	2080	0.00317	0.2	0.2	--	60	11	9	20	Cyclone	99.0	Cyclone Outlet
39J	6701	Air	--	120	2080	0.366	21	20.0	--	99	0.3	0.3	0.7	*	99.0	Cyclone Inlet
PETROLEUM																
40S	16216	3.9		240	8736	0.00424	2.6	0.59	0.0062	4.5	2	1.5	91	None		
41S	31399	0.9	10.7	240	8400	0.055	62.33	14.84	--	62	5	5	52	ESP	Not Tested	

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4.2.1 KVB Boiler Tests

KVB set out to accomplish several objectives for the first few tests performed on the KVB boiler. These objectives were as follows:

1. To check out the test crew and to check out the equipment.
2. Determine the time involved for completing the tests (i.e. set-up time, test time, tear down time, turn around time, lab analysis time).
3. Determine the accuracy and precision of the total particulate collection.
4. Determine the accuracy and precision of the size distribution.
5. Determine the effect of fuel sulfur on TSP and size distribution.
6. Check out elemental and chemical analysis procedures of subcontractor laboratories at Armament Systems (X-ray, fluorescence) and Rockwell AMC (sulfates, nitrates, and carbon).
7. Determine data reduction method for listing raw data (data sheets) and methods for calculating and plotting data (Section 3.2.3).
8. Use the data to develop profiles and emission factors for industrial boilers.
9. Determine if SO_2 would cause a weight change on the filters (i.e. pseudo particulates).

Due to the amount of effort involved in performing particulate tests using both the SASS and Joy train, three test runs were designed to accomplish the above objectives.

Two fuels were chosen with different sulfur contents but with similar characteristics--especially carbon, hydrogen, ash content and composition and heating value. These fuels were a No. 6 fuel oil with 0.28% sulfur and a Wilmington crude oil with 1.35% sulfur. The fuel analysis results of these two fuels are shown in Table 4-2.

Test 01 and Test 03 were done with both Joy and SASS trains running simultaneously using the high sulfur Wilmington crude at same boiler setting.

TABLE 4-2. FUEL OIL CHARACTERISTICS[a]
(Test 01, 02, & 03)

	No. 6 Fuel Oil	Test 01 & 03 Wilmington Crude
API Gravity	23.0	22.6
Heating Value (HHV, Btu/lb)	19150[b]	18,810
Viscosity, SUS@100°F	324.	80
Flash Point, °F	245	--
Water & Sediment, %	0.12	--
Carbon Residue, % (Ramsbottom)	3.44	--
Copper Strip Corrosion	S.T.[c]	--
Carbon, %	86.61	86.26
Hydrogen, %	12.25	11.81
Nitrogen, %	0.24	.59
Sulfur, %	0.28	1.35
Ash, %	0.016	0.017
Oxygen, % by difference	0.60	0
Asphaltenes, %	0.58	4.96
Vanadium, ppm	15.	61
Iron, ppm	12	16
Nickel, ppm	12	26
Calcium, ppm	12	0.11
Magnesium, ppm	7.8	0.29
Sodium, ppm	12	ND
Silicon, ppm	15	0.24
Manganese, ppm	0.18	0.11
Aluminum, ppm	3.2	0.41
Barium, ppm	1.0	0.92
Lead, ppm	<1.2	0.20
Tin, ppm	0.11	0.14
Molybdenum, ppm	0.027	ND
Copper, ppm	0.059	0.004
Zinc, ppm	0.54	0.75
Titanium, ppm	0.086	0.32
Cobalt, ppm	0.66	1.1
Potassium, ppm	Trace	ND
Chromium, ppm	0.042	0.12
Strontium, ppm	0.082	Trace
Boron, ppm	ND	ND
Phosphorus, ppm	ND	ND
Cadmium, ppm	ND	ND

(a) All fuel analysis preformed by Truesdail Laboratories

(b) Estimated from API gravity [$Q_v = 22,320 - 3,780 (sg)^2$] (Ref. 3)

(c) Slight tarnish

(d) None detected

These two tests were exact repeats and were used to determine the precision of the sampling trains for TSP and size distribution. For Test 03, a Method 5 and an Andersen impactor were simultaneously used in addition to the SASS and Joy trains to determine the accuracy of the sampling trains for the TSP and size distribution. Test 01 was used to check out the test crew and equipment and determine the times involved for the different operations of the test. Test 02 was run with the low sulfur No. 6 fuel oil at the same boiler conditions as for Test 01 and 03.

Test 01, 02, and 03 were used to determine the effect of fuel sulfur content on TSP and size distribution (discussed in subsequent sections). All three were used to 1) evaluate the methods of analysis for major elemental composition and chemical content (discussed in Section 3.2.2), and 2) determine data sheet need for data reduction and method for data reduction and size distribution plots (discussed in Section 3.2.3). For test 01 a back-up filter was used to determine if SO_2 was adding weight to the filter.

A. Test Facility--KVB 80 HP boiler--

The KVB combustion laboratory has a 5,000,000 Btu/hr Scotch dry-back boiler having a combustion chamber three feet in diameter and eleven feet in length, with air supply up to 650 °F and 1 psig. Flue gas recirculation of up to 35% into the combustion air is possible. This unit, as shown schematically in Figures 4-2, 4-3 and 4-4, is equipped to fire nearly any type of gaseous, liquid, or solid fuel. The boiler, its flues, and the locations of its four sampling ports are shown schematically in Figure 4-5. The sampling ports are located in the vertical flue section on the right.

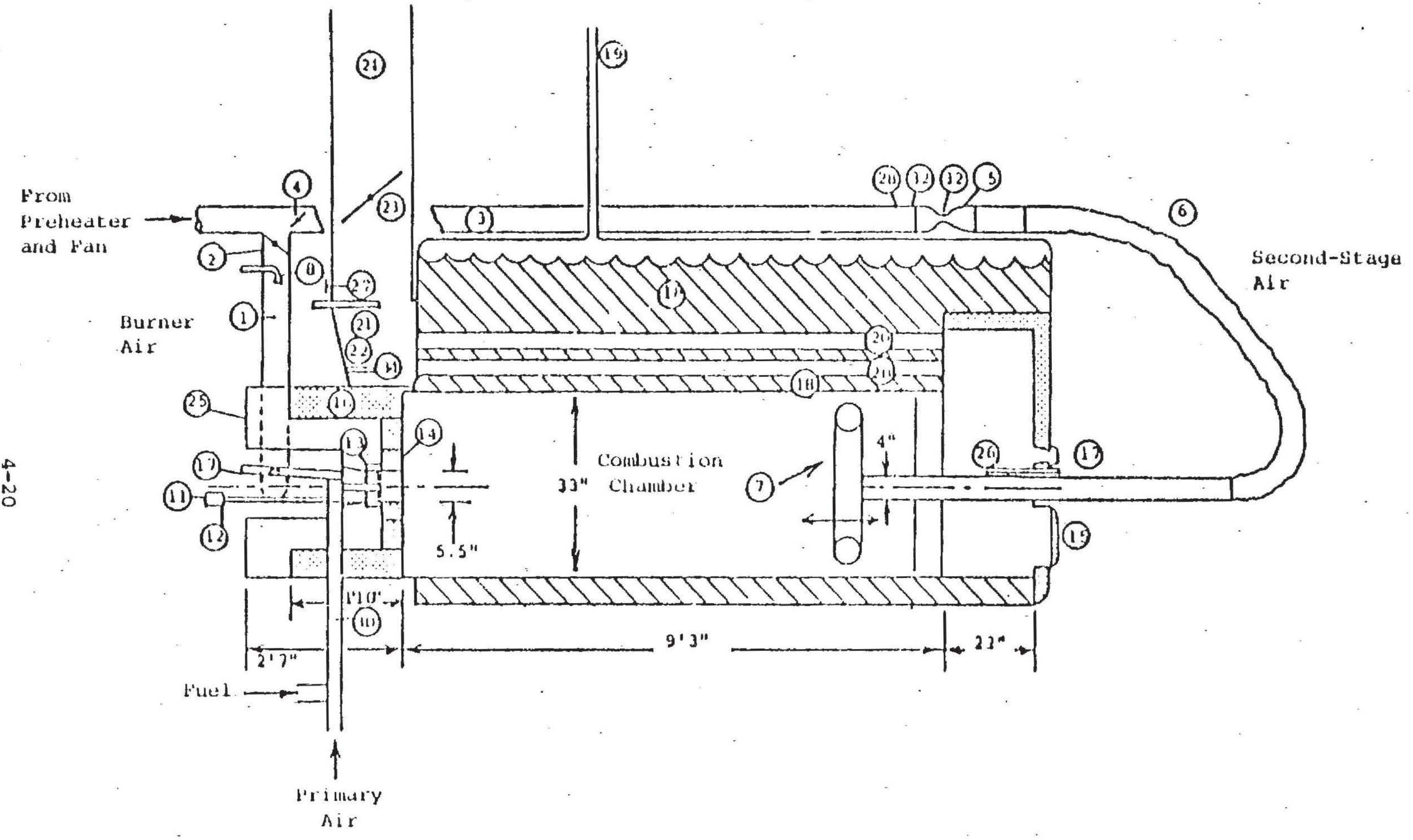

Figure 4-2. Schematic of 80 horsepower boiler.

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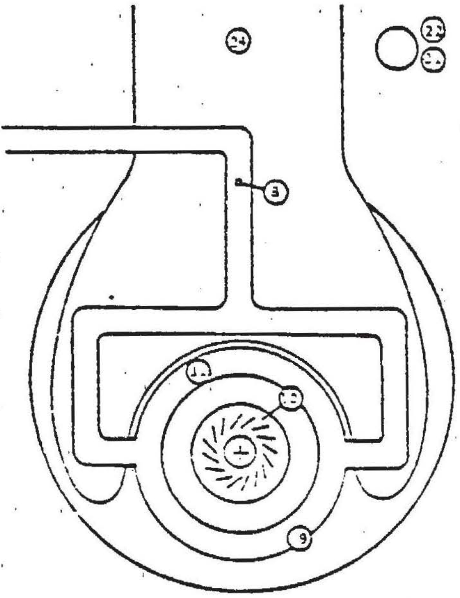


Figure 4-3. Cross section through windbox

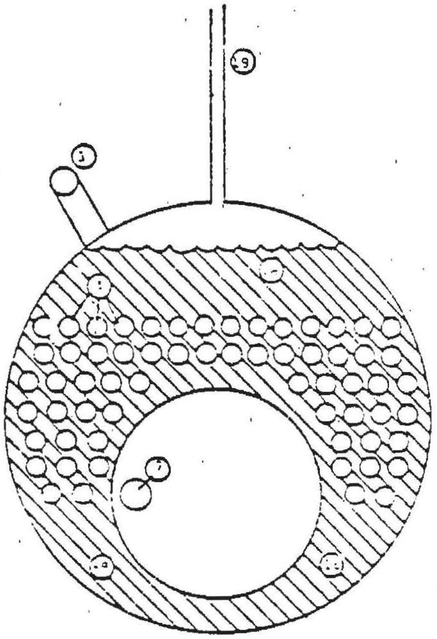


Figure 4-4. Cross section through firebox

LEGEND FOR FIGURES 4-3 and 4-4

1. **Primary Air Duct**
2. **Primary Air Valve**
3. **Staged Air Duct**
4. **Staged Air Valve**
5. **Staged Air Venturi**
6. **Staged Air Flexible Hose**
7. **Staged Air Injection Torus and Inlet Pipe, Variable Position**
8. **Water Injection Nozzle**
9. **Burner Support Cylinder**
10. **Air Register**
11. **Flame Detector**
12. **Ignitor**
13. **Burner**
14. **Ceramic Quarl - 5-1/2" Throat Diameter**
15. **Observation Door**
16. **Fire Brick 25" Inside Diameter**
17. **View Ports**
18. **Water Wall of Scotch Boiler**
19. **Steam Vent**
20. **Fire Tubes (62 With Diameter 2-7/8")**
21. **Recirculation Gas Duct**
22. **Recirculation Gas Venturi (not shown)**
23. **Damper**
24. **Stack**

Temperatures:

25. **Windbox**
26. **Hot End**
27. **Stack**
28. **Second Venturi**
29. **Recirc. Venturi (not shown)**
30. **Primary Air (not shown)**

Pressures:

31. **Windbox**
32. **Secondary Venturi**
33. **Recirc. Venturi (not shown)**

Gas Sample:

34. **Stack**

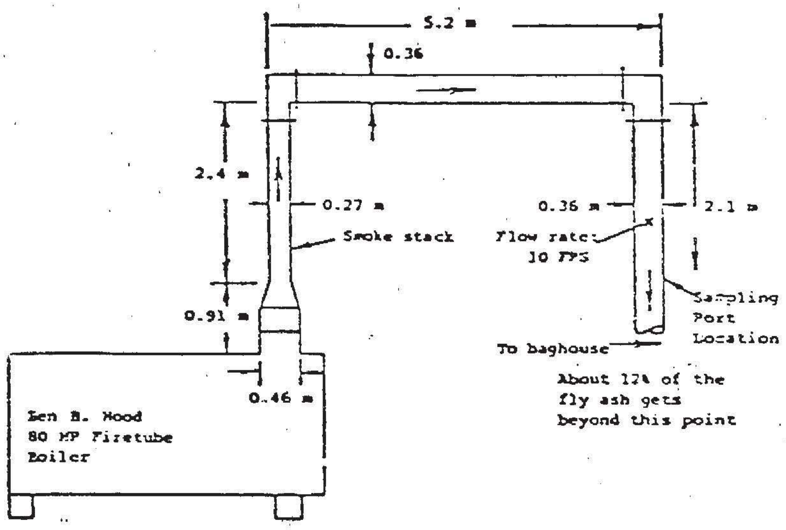


Figure 4-5. KVB test boiler installation

Instrumentation is available in the Combustion Laboratory for measuring fuel and air flows, temperatures (by thermocouple), and the concentrations of NO, CO, O_2, unburned hydrocarbons in the flue gas, and particulates.

B. Particulate Test Set-up--

A velocity traverse of the stack flow was measured before each test at two locations six feet and eight feet above the transition section of the boiler exhaust plenum and nine feet below the top of the stack on a straight section. The velocity profile obtained is listed in Table 4-3. A 3/4 inch nozzle for the SASS train was positioned 4 inches into the stack at the 6 ft. height and a 3/8 inch nozzle for the Joy train was positioned 6 inches into the stack at the 8 ft. height. A 3/8 inch nozzle was also used for the Method 5 test and for the Andersen impactor test at the same location as the Joy train.

Test 01 ran from 11:00 AM to 3:00 PM on 9/13/77
Test 02 ran from 10:00 AM to 2:00 PM on 9/15/77
Test 03 ran from 11:00 AM to 2:00 PM on 9/20/77

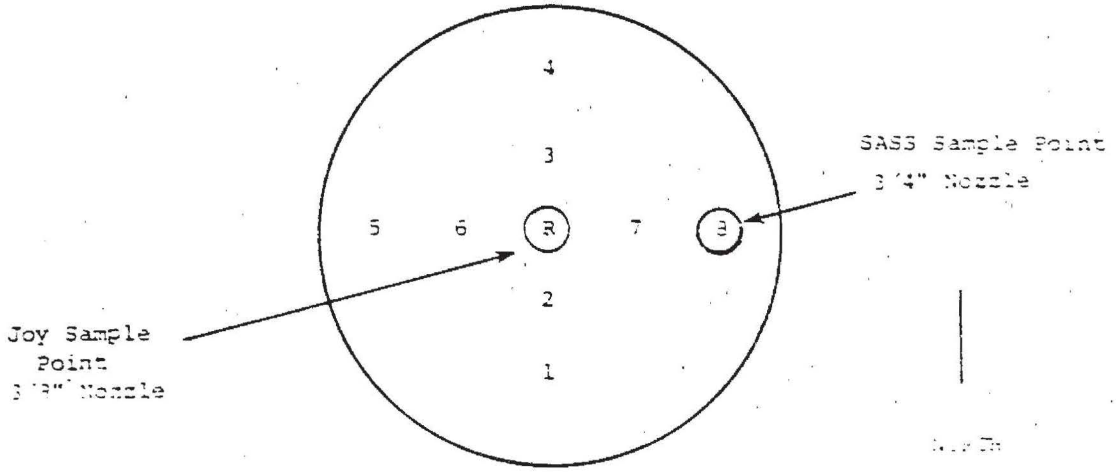
C. Particulate Test Results--

The results of the tests (Test 01, 02, and 03) 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. Tables 4-4, 4-5, and 4-6 list the results from this analysis.

D. Discussion of Results--

1. The objective of checking out the test crew and equipment was well met. The crew executed the test in a routine fashion which was excellent performance considering this was only the first test. The equipment in general performed very well. A few malfunctions were encountered with the SASS train's temperature controllers. These were

TABLE 4-3. VELOCITY PROFILE IN KVB BOILER STACK



Distance from Edge of Duct	Point #	Velocity ft/sec	Point #	Velocity ft/sec
0.9	1	25.8	5	21.1
2.8	2	24.7	6	22.4
5.5	R	24.7	R	24.7
8.2	3	24.7	7	25.8
10.1	4	24.7	8	25.8

sent back to Acurex for repairs. Also it was found that the original filter design for the Joy train was too small. It did not have a large enough surface area to collect particulates for four hours without clogging the filter. A filter holder similar to and the same size as the SASS filter was manufactured and located in the Joy oven (discussed in Section 3.2.1 A-2). The length of time involved for the different parts associated with the test was determined as follows:

		man x hours
prepare trains for test	8 man hours	2x4
set up equipment for test	12 " "	4x3
take stack sample	16 " "	4x4
tear down equipment	8 " "	4x2
process samples (KVB lab)	32 " "	2x16
analysis turn around	30 days Armament Systems, 30 days Rockwell Total 60 days	
Total man hours per test =	76	

2. <u>Accuracy and precision of the total particulate collection and size distribution</u>--Simultaneous tests were done to compare the total paticulate collection and size distribution using the SASS train, the small cyclone train, the current method 5 procedure and an Andersen cascade impactor. The data from these tests (Test 01S, 01J, 02S, 02J, 03S, 03J, 03#5, 03A) are given in Table 4-1 along with the data from all the field tests.

The emissions obtained from the different methods used in Test 03 were compared to estimate the accuracy. Also compared were the size distribution curves for these tests. The curves are shown in Figures 4-6, 4-7, and 4-8 and the emission in gr/DSCF are as follows:

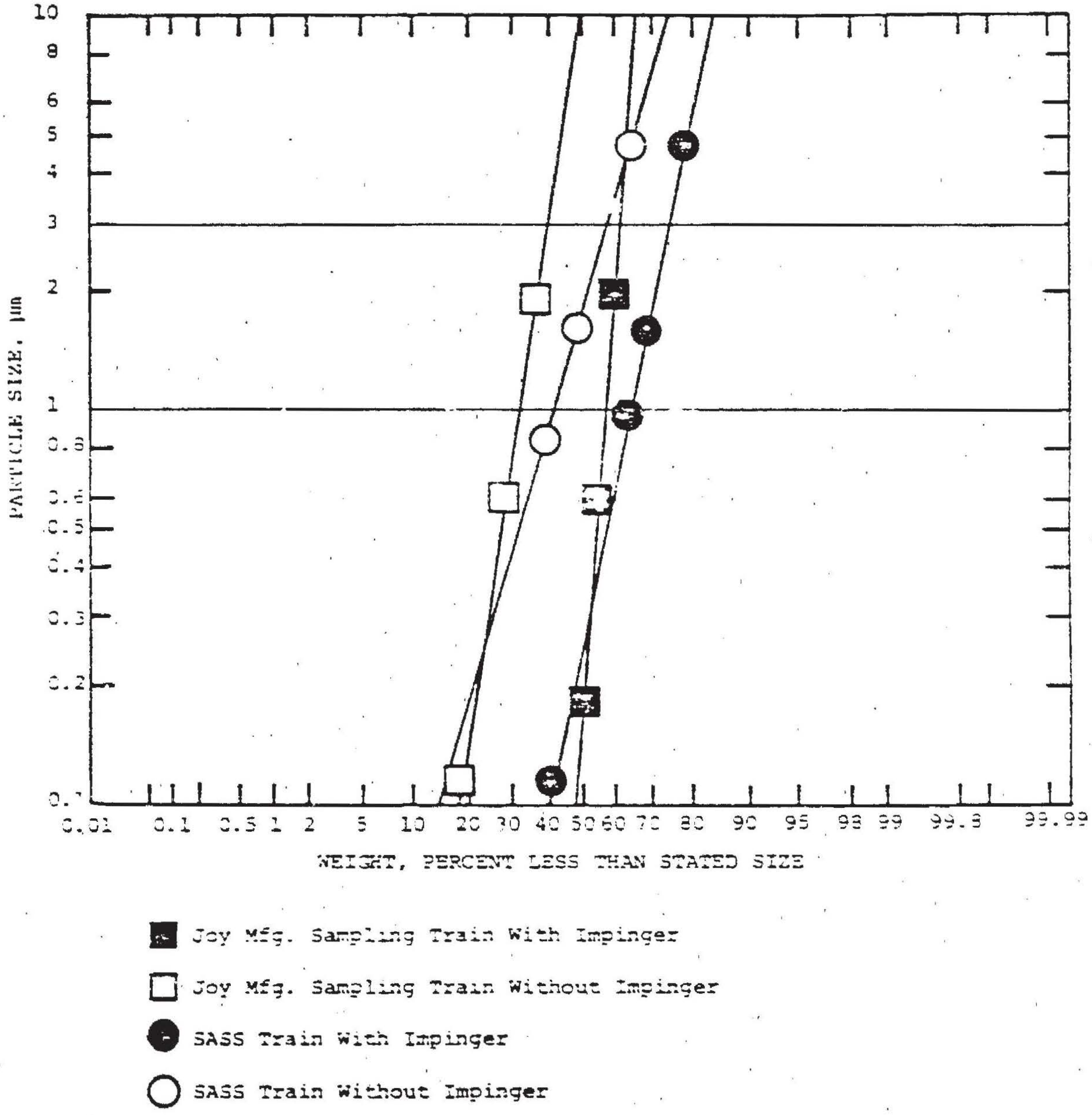


Figure 4-6. Particle size distribution (Test 01).

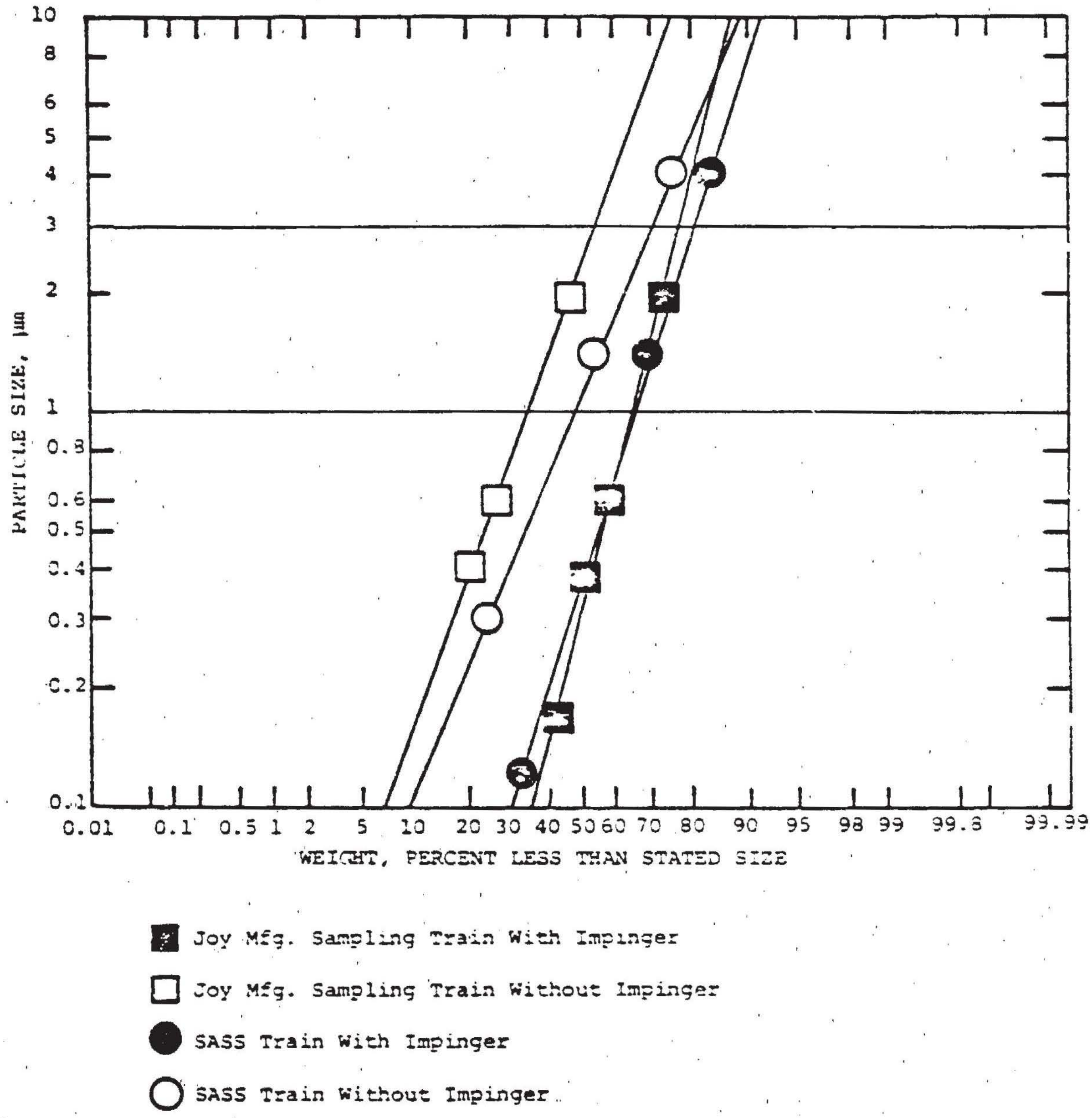


Figure 4-7. Particle size distribution (Test 02).

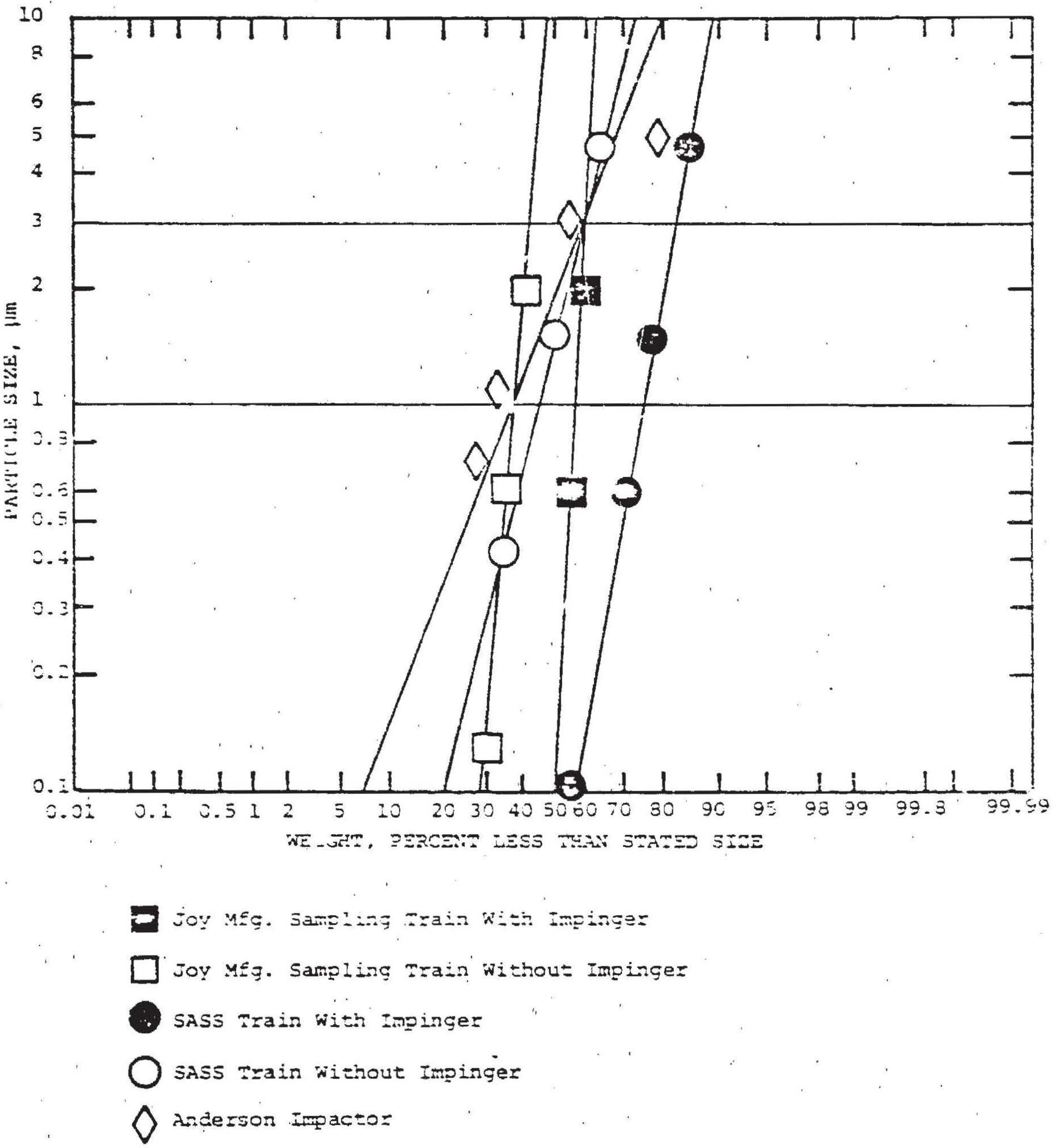


Figure 4-8. Particle size distribution (Test 03)

Test #	Method of Collection	gr/DSCF Particulate Emmission		% of particles *			
				Less than 10µm		Less than 1µm	
		With Imp.	w/o imp	With imp.	w/o imp.	With imp.	w/o imp.
03S	SASS	.0510	.0229	89	74	76	47
03J	Joy	.0365	.0276	64	50	58	38
03#5	Method 5	.0660	.0396	—	—	--	--
03A	Andersen impactor	-	≠	—	80	—	38
	mean	.0512	.0300	76	68	67	41
	stand dev	.0148	.0086	18	16	13	5
	% stand dev	29	29	23	23	19	13

* Taken from curves in Figure 4-8

≠ TSP not determined for Andersen sampler

The reason for the two listings--one including impinger catch and one not including impinger--has something to do with psuedo particulates and is discussed in detail in Section 3.2.3 H. Also the EPA Method 5 does not include the impinger, whereas the SCAQMD and ARB methods do.

Based on the results from the above data (Test 03) the accuracy of the sampling trains for the TSP seems to be ±30%, and the accuracy of the size distribution curves is also ±30%. The ±30% comes from a conservative percent of standard deviation for each of the test methods.

The precision of the data was determined using the data from repeat tests, Test 01 and 03. These data are as follows:

Test #	Particulate emission, gr/DSCF		% of particles less than*			
			10µm		1µm	
	With imp.	w/o imp.	with imp.	w/o imp.	with imp.	w/o imp.
03S	.0510	.0229	89	74	76	47
03J	.0365	.0276	64	50	58	38
01S	.0674	.0414	84	74	63	40
01J	.0896	.0579	65	48	56	30
mean	.0611	.0374	75	61	63	39
stand dev, σ	.0228	.0157	13	14	9	7
% σ	37	42	17	24	14	18

* taken from

Both the SASS train and the Joy train data for the two repeat tests were used to determine a mean, standard deviation and % of the standard deviation from the mean. The TSP in gr/DSCF from the above list shows that the SASS data falls close to the mean and is within the ±40%. The TSP for the two Joy runs is not as good as the SASS runs. This may be due to the small sample size (as a result of clogging of the filter and an early end to the test). Six repeat utility boiler tests were done during the field test program. The results of these tests are discussed in Section 4.2.4 and show that the precision for the Joy train is about ±40%σ which is consistent with the result obtained here.

The precision of the size distribution curves is around ±20%σ from these data and about ±10%σ from the utility boiler tests discussed in Section 4.2.4. The agreement from SASS run to SASS run and from Joy run to Joy run is very close.

3. Chemical Composition of the Particulate Collection

Each of the five fractions (10μm cyclone, 3μm cyclone, 1μm cyclone, impinger, and filter catch) for Test 01, 02, and 03 were analyzed for major elements by x-ray fluorescence and for $SO_4^=$, NO_3^-, total carbon, inorganic carbon, and volatile carbon. These results are given in Tables 4-4, 4-5, 4-6.

Tables 4-7, 4-8, and 4-9 list the comparison of elementals from the fuel ash to the elemental from the particulate catch. The last column lists the 10^{-4} lb/hr of elements that would be emitted from the fuel ash (calculated from fuel flow rate x ppm of elements in oil). The first five columns are the 10^{-4} lb/hr of elements that are emitted from each fraction of the particulate catch (calculated from lb/hr of particulates x cut % of total x elemental % of cut). The next column is the sum of the 10^{-4} lb/hr for each cut. The next column is the lb/hr x 10^{-4} for each element normalized to 100% if the five fraction columns did not total 100%. This column can be compared to the last column for each element. The sum of the last column can be compared to the total particulate catch, and it should always be less than the total catch.

TABLE 4-4. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR INDUSTRIAL BOILERS (TEST 01)

Sample #	10µm Cyclone 01S-2S	3µm Cyclone 01S-3S	1µm Cyclone 01S-4S	Filter 01S-1C	Impinger 01S-5S
PERCENT OF CUT	24.4	9.5	5.6	21.9	32.4
XRF ANALYSIS					
Calcium			t	t	t
Chromium	0.36	t	t	t	
Cobalt				t	t
Iron	1.0	t	1.5	t	3.3
Nickel	0.55	t	2.0		5.3
Potassium					t
(Sulfur)	(6.4)	(5.6)	(6.5)	(11.0)	8.6
Vanadium	0.3	t	1.1		4.4
Sulfates, H_2O sol[2]	3.6	3.5	5.0	35	23
(Sulfur, from $SO_4^=$)[4]	(2.1)	(1.4)	(2.2)	(3.7)	(2.8)
Nitrate (H_2O sol)[2]	t	t	t	NA	0
Total Carbon[3]	37	70	80	4.3	6.0
(Volatile Carbon)[3]	(t)	(t)	(t)	(3.1)	(0)
(Carbonates)[3]	(t)	(t)	(t)	(t)	(NA)
TOTAL ANALYZED	42	74	90	39	42
BALANCE	58	26	10	61	58
	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

TABLE 4-5. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR INDUSTRIAL BOILERS (TEST 02)

Sample #	10µm Cyclone 02S-2S	3µm Cyclone 02S-3S	1µm Cyclone 02S-4S	Impinger 02S-IC	% Filter 02S-5S
PERCENT OF CUT	15.0	13.8	20.5	23.0	16.2
XRF ANALYSIS					
Calcium	t	t	3.3	t	t
Cobalt					t
Iron	t	t	1.3	t	2.5
Nickel	t	t	t	t	3.8
Potassium					t
(Sulfur)	(2.6)	(3.1)	(5.5)	(31)	(19.3)
Vanadium		t	t		1.7
TOTAL^1	t	t	4.6	t	8.0
Sulfates, H_2O sol^2	1.8	1.9	6.2	63	60
(Sulfur, from $SO_4^=$)^4	(0.9)	(1.0)	(7.8)	(10.5)	(6.4)
Nitrate (H_2O sol)^2	t	t	t		
Total Carbon^3	59	93	84	-	3.6
(Volatile Carbon)^3	(58)	(92)	(82)	-	-
(Carbonates)^3	(t)	(t)	1.51	-	
TOTAL ANALYZED	61	95	95	63	72
BALANCE	39	5	5	37	28
	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

TABLE 4-6. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR INDUSTRIAL BOILERS (TEST 03)

Sample #	10µm Cyclone 03S-17	3µm Cyclone 03S-18	1µm Cyclone 03S-12	Impinger 03S-6b	Filter 03S-47
PERCENT OF CUT	14.2	6.2	6.7	53.4	14.6
XRF ANALYSIS					
Calcium		t	t	1.5	8
Chromium					t
Cobalt				t	1.1
Iron	t	t	1.7	4.9	t
Nickel	t	t	2.2	9.0	5
Potassium				t	
(Sulfur)	(4.5)	(3.4)	(6.4)	(11.8)	(13)
Vanadium	t	t	1.3	6.8	
TOTAL[1]	t	t	5.2	22	14
Sulfates, H_2O sol[2]	2.0	1.8	3.5	47	25
(Sulfur, from $SO_4^=$)[4]	(1.5)	(1.1)	(2.1)	(4.0)	(4.7)
Nitrate (H_2O sol)[2]	t	t	t	-	
Total Carbon[3]	44	62	79	5.9	4.7
(Volatile Carbon)[3]	(t)	(t)	(t)	-	4.0
(Carbonates)[3]	(t)	(t)	(t)	-	(t)
TOTAL ANALYZED	46	64	88	75	44
BALANCE	54	36	12	25	56
	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

TABLE 4-7. MASS BALANCE FOR TEST 01

TEST 01	183.5 lb/hr fuel flow; 0.0312 lb/hr ash generated; 0.318 lb/hr TSP collected						
Fraction	10 µm Cyclone	3 µm Cyclone	1 µm Cyclone	Filter	Impinger	Sum/Total[1]	Fuel Analysis
% Fraction	24%	9.5%	5.6%	22%	39%	100%	Ash=0.017%
Units	10^{-4} lb/hr	10^{-4} lb/hr	10^{-4} lb/hr	10^{-4} lb/hr	10^{-4} lb/hr	10^{-4} lb/hr	10^{-4} lb/hr
Vanadium	2.3	1.2	2.0	31		36	110
Iron	7.8	2.4	2.7	23	3.4	39	29
Nickel	4.3	2.1	3.5	37	1.2	48	48
Calcium			0.19	3.3	3.6	7.0	0.2
Magnesium	0.78	0.3	0.18	0.7	1.2	3.2	0.53
Sodium							--
Silicone							0.44
Manganese	0.78						0.2
Aluminum							0.44
Barium		0.3	0.18	0.7		1.2	0.72
Lead							0.36
Tin							0.25
Molybdenum	0.78						--
Copper	0.78				1.2	2.0	0.056
Silver							0.007
Zinc	0.78	0.3	0.18	0.7	1.2	3.2	1.4
Titanium	0.78		0.12	0.7		1.6	0.59
Cobalt	0.78	0.3	0.18	0.98	8.0	10	2.0
Chromium	2.8	0.48	0.3		1.2	4.8	0.22
Strontium							--
Potassium				2.3		2.3	--
Sulfur	50	17	12	60	150	(200)	25000
Sulfate	28	10	9.9	160	440	140	
Nitrate	0.62	1.4	0.57			2.6	
Total Carbon	290	210	140	42	53	740	
Vol. Carbon							
Carbonate	1.2	0.78	0.27			(2.2)	
					Total	1038 x 10^{-4} lb/hr	
					TSP	3180 x 10^{-4} lb/hr	

(1) Compare total column with fuel analysis column

TABLE 4-8, MASS BALANCE FOR TEST 02

TEST 02 — 183 lb/hr of fuel; 0.0291 lb/hr ash generated; 0.128 lb/hr TSP collected

Fraction % Fraction Units	10 µm Cyclone 15% 10^{-4} lb/hr	3 µm Cyclone 14% 10^{-4} lb/hr	1 µm Cyclone 21% 10^{-4} lb/hr	Filter 16% 10^{-4} lb/hr	Impinger 31% 10^{-4} lb/hr	Sum* 97% 10^{-4} lb/hr	Total[1] 100% 10^{-4} lb/hr	Fuel Analysis Ash=0.016% 10^{-4} lb/hr
Vanadium	0.19	0.28	2.1	3.5		6.1	0.6	27
Iron	0.88	0.85	3.4	5.3	3.2	14	14	22
Nickel	0.38	0.58	2.5	8.0	0.52	12	12	8.4
Calcium	0.38	1.2	8.7	0.48	3.0	14	15	22
Magnesium								14
Sodium								22
Silicone								27
Manganese	0.19	0.18	0.26		0.4	1.0	1.1	0.33
Aluminum								5.9
Barium	0.19	0.18	0.53			0.90	0.93	1.8
Lead			0.26		0.4	0.71	0.73	2.2
Tin								0.2
Molybdenum	0.19	0.18	0.26	0.21	0.4	1.2	1.3	0.05
Copper	0.19	0.18	0.26	0.21	0.4	1.2	1.3	0.11
Silver	0							0.01
Zinc	0.19	0.18	0.26	0.42	0.4	1.3	1.5	0.99
Titanium					0.4	0.4	0.41	0.16
Cobalt	0.19	0.18	0.26	0.43	0.56	3.3	3.4	1.2
Chromium	0.27	0.18	0.26	0.21	0.52	1.4	1.5	0.08
Strontium		0.18	0.26		0.4	0.84	0.87	0.15
Potassium			0.26	1.0		1.3	1.3	--
Sulfur	5.0	5.5	14	65	77	170	170	5100
Sulfate	3.5	3.4	17	130	240	390	400	
Nitrate	0.19	0.18	0.26			0.63	0.65	
Total Carbon	110	160	220	7.8		390	410	
Vol. Carbon								
Carbonate	0.41	1.0	4.0			5.4	(5.6)	

Total 880 x 10^{-4} lb/hr

TSP 1280 x 10^{-4} lb/hr

---

(1) Compare total column with fuel analysis column

* Probe catch not analyzed

TABLE 4-9. MASS BALANCE FOR TEST 03

TEST 03	181 lb/hr of fuel burned; 0.0312 lb/hr generated; 0.210 lb/hr TSP collected*							
Fraction % Fraction	10 µm Cyclone 14%	3 µm Cyclone 6.2%	1 µm Cyclone 6.7%	Filter 15%	Impinger 55%	Sum* 97%	Total[1] 100%	Fuel Analysis Ash=0.017%
Units	10^{-4} lb/hr	10^{-4} lb/hr	10^{-4} lb/hr	10^{-4} lb/hr	10^{-4} lb/hr	10^{-4} lb/hr	10^{-4} lb/hr	10^{-4} lb/hr
Vanadium	0.38	0.46	1.8	21		23	24	
Iron	1.3	0.71	2.4	15	10	30	31	
Nickel	0.98	0.77	3.1	28	1.9	34	36	
Calcium		0.13	0.28	4.5	92	97	100	
Magnesium								
Sodium								
Silicona								
Manganese	0.30	0.13		0.31	1.2	1.9	2.0	
Aluminum								
Barium		0.13	0.14	0.31	1.2	2.0	2.1	
Lead				0.31		0.31	0.32	
Tin								
Molybdenum	0.30	0.13	0.14	0.31	1.2	2.0	2.1	
Copper	0.30	0.13	0.14		1.2	1.6	1.7	
Silver								
Zinc	0.30	0.13	0.14		1.2	1.6	1.7	
Titanium	0.30	0.13	0.14	0.31		0.88	0.91	
Cobalt	0.30	0.13	0.14	0.62	13	14	14	
Chromium	0.30	0.13	0.14		2.9	3.5	3.6	
Strontium	0.30		0.14	0.31	1.2	1.9	2.0	
Potassium				1.9		1.9	2.0	
Sulfur	13	4.4	9.0	36	150	200	200	
Sulfate	5.8	2.3	4.9	140	290	440	460	
Nitrate	0.15	0.09	0.14			0.38	0.39	
Total Carbon	130	80	110	18	54	390	410	
Vol. Carbon					47	47	(49)	
Carbonate	0.30	0.30	0.35			1.1	(1.1)	
						Total	1141 x 10^{-4} lb/hr	
						TSP	2100 x 10^{-4} lb/hr	

(1) Compare total column with fuel analysis column
* Probe catch not analyzed

The value of sulfur from XRF analysis can be compared to the value of sulfate ($SO_4^{=}/S = 96/32 = 3$). Divide the sulfate lb/hrx10^{-4} by the sulfur lb/hrx10^{-4}; the quotient should be about 3.0. Tables 4-4, 4-5 and 4-6 are in the general form of an emission profile for these sources. The development of emission profiles is discussed in detail in Section 2.3.2.

4. The effect of sulfur content in fuel on size distribution and on total particulates--Goldstein and Siegmund (Ref. 4-1) pointed out that the fuel sulfur content is directly proportional to the ash plus asphaltene content of the fuel. Their data are shown by the line in Figure 4-9; the circle represents the KVB high sulfur fuel used for Tests 01 and 03, and the triangle represents that for the low sulfur fuel used for Test 02. Goldstein and Siegmund (Ref. 4-1) also determined that the particulate emissions are proportional to the fuel sulfur content. Their data are represented by the line in Figure 4-10. The KVB data are as noted.

The particulate emissions obtained by KVB for the three boiler tests follow this relationship. The particle size distribution is affected by the sulfur content of the fuel (Ref. 4-1). The lower sulfur fuel tends to produce a larger percentage of smaller particles than the higher sulfur fuel. KVB's data agrees with this. Figure 4-11 shows the particle size distribution for Goldstein's and KVB's data.

5. A recent study (Ref. 4-2) shows that different types of filter paper would gain weight when exposed only to SO_2 and water. For Test 01, SASS, a back-up Reeve Angel filter was used in series with the SASS train filter. The first filter would collect all filterable particulates and the second Reeve Angel 934AH filter would only see very small particles, SO_2, and flue gases. The Reeve Angel filter was desiccated and weighed in the usual way after the test. It was found that the Reeve Angel paper did not change in weight.

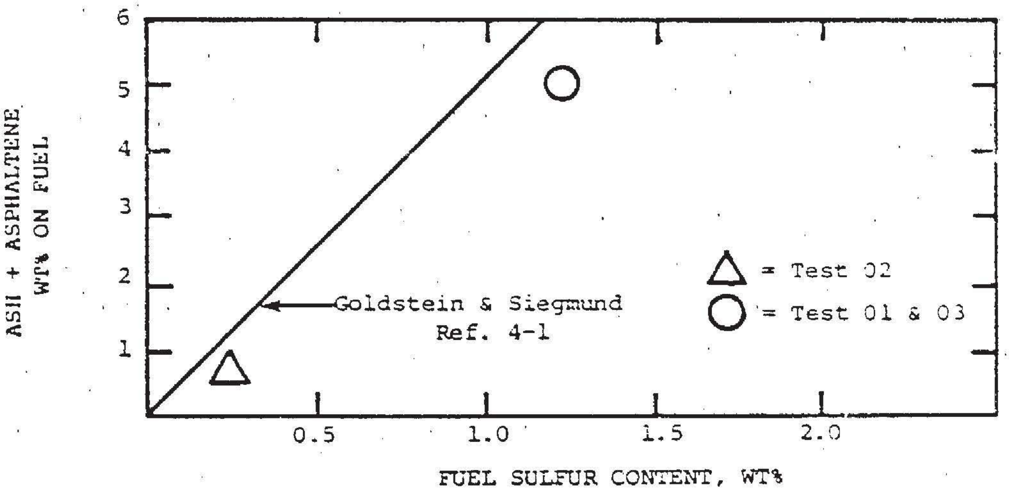


Figure 4-9. Ash + asphaltenes vs fuel sulfur.

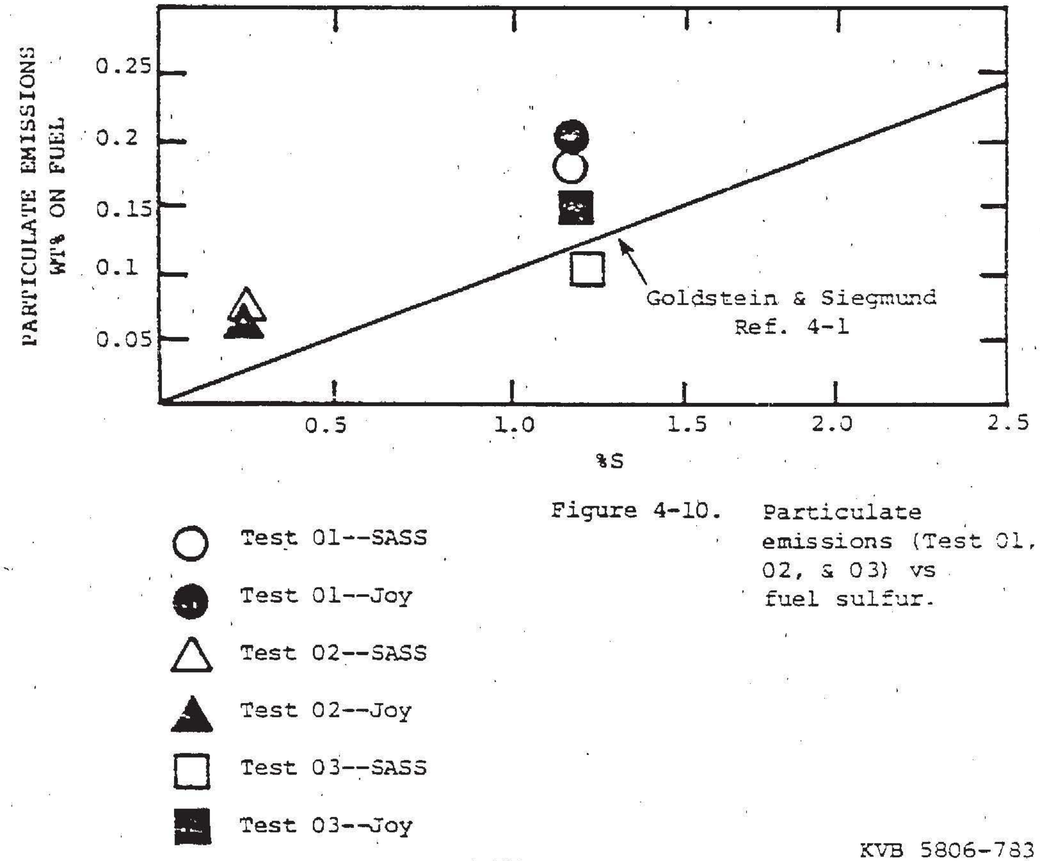


Figure 4-10. Particulate emissions (Test 01, 02, & 03) vs fuel sulfur.

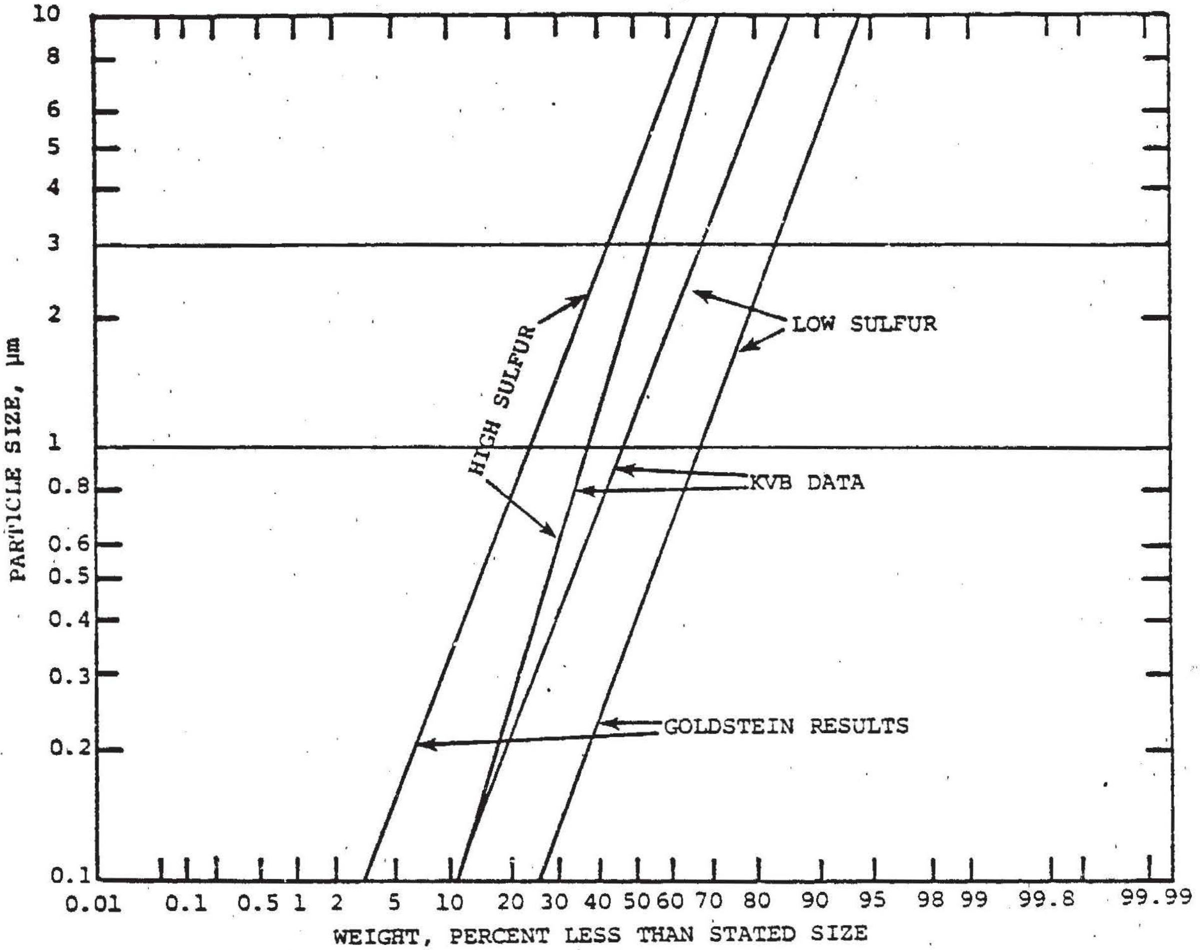


Figure 4-11. Particle size distribution for high fuel sulfur-low fuel sulfur comparison.

Also a test was designed as described below to determine any weight change. A gas stream of 831 ppm SO_2 from a gas cylinder was passed first through a Gelman AE filter paper, next through a Reeve Angel 934AH filter paper, and finally the volumes of gas were measured on a dry gas meter. Over 15 scf of gas was passed over the filters. The filters were processed in the normal way (desiccate and weigh). Neither the Gelman nor the Reeve Angel paper showed any weight change. Based on the data in Ref. 4-2, the Reeve Angel filters were used throughout the program.

4.2.2 #2 Fuel Oil-Fired Industrial Boiler

A. Process Description (Ref. 4-3)--

Boilers, heaters, steam generators, and similar combustion equipment fired with #2 fuel oil are used in commerce and industry to transfer heat from combustion gases to water or other fluids. The only significant emissions to the atmosphere from this equipment in normal operation, regardless of the fluid being heated or vaporized, are those resulting from the burning of fossil fuels. Differences in design and operation of this equipment can, however, affect production of air contaminants.

A boiler or heater consists essentially of a burner, firebox, heat exchanger, and a means of creating and directing a flow of gases through the unit. All combustion equipment--from the smallest domestic water heater to the largest power plant steam generator--includes these essentials. Most also include some auxiliaries. The number and complexity of auxiliaries tend to increase with boiler size. Larger combustion equipment often includes flame safety devices, soot blowers, air preheaters, economizers, superheaters, fuel heaters, and automatic flue gas analyzers.

The industrial boiler tested was a Babcock & Wilcox type H Stirling boiler as shown in Figure 4-12. It has a heating surface of 4950 ft^2, a design pressure of 160 lb. It was built in 1946.

B. Particulate Test Setup--

Two sampling trains were used simultaneously to sample the exhaust gases of the boiler. The sampling station was located on the vertical section of the stack above the roof, at least 6 duct diameters from the nearest disturbance. The velocity profile in the stack is shown in Table 4-10. However, the velocity in the stack varied as the load varied to meet the steam demand of the plant. The steam demand varied from 10,000 to 28,000 lb/hr during the sampling time. This was a typical type of operation. The fuel for the boiler was low sulfur No. 2 fuel oil. The results of the fuel analysis is listed in Table 4-12.

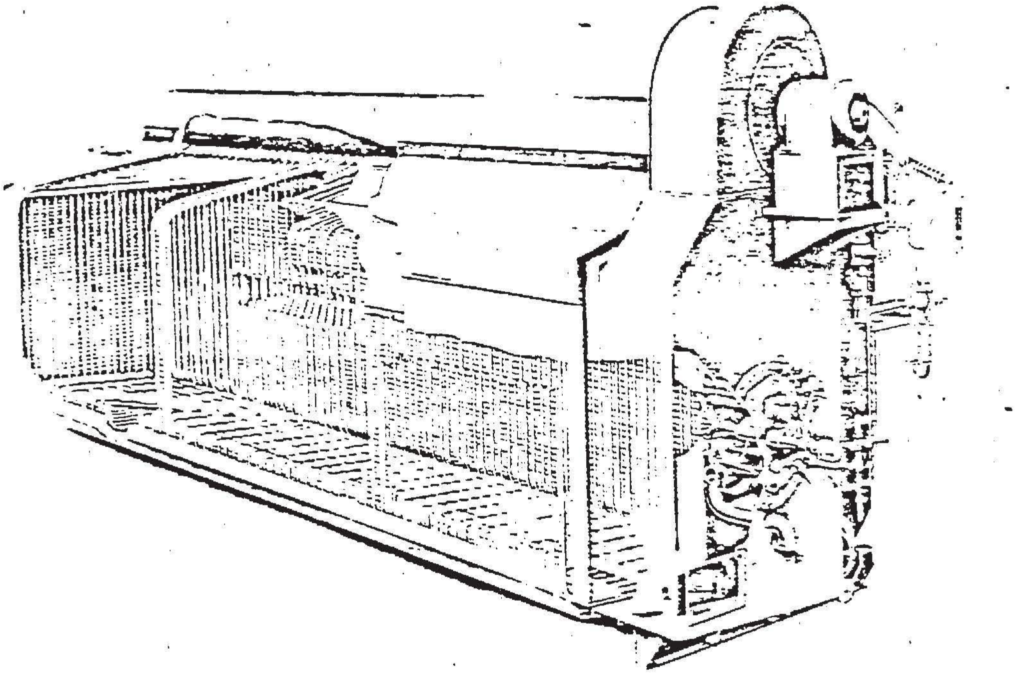
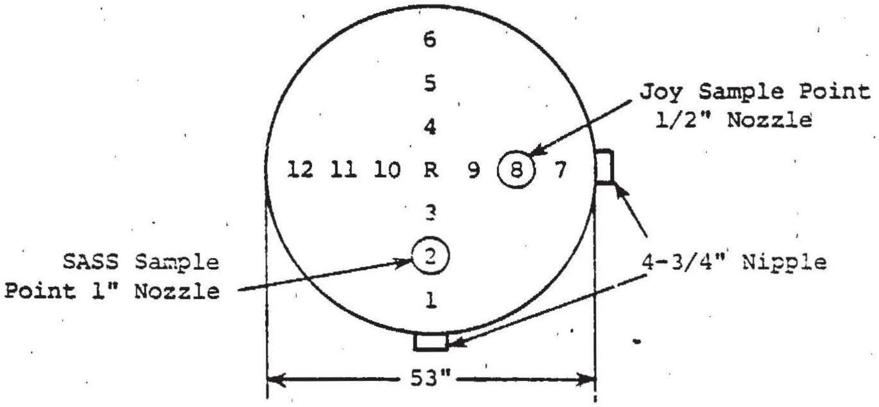


Figure 4-12. An industrial water tube boiler (The Babcock & Wilcox Co., New York).

TABLE 4-10. VELOCITY PROFILE FOR INDUSTRIAL BOILER (TEST 16)



Temperature	515 °F
Static Pressure	0.6 in. H_2O
Steam Load	18-22,000 lb/hr

Distance From End of Port,* inches	Velocity			
	Point No.	ft/sec	Point No.	ft/sec
7-1/8	1	20.1	7	18.6
12-1/2	2	22.8	8	21.5
20-3/8	3	20.1	9	20.1
31-1/4	R	18.6	R	18.6
42-1/8	4	17.0	10	18.6
50	5	17.0	11	18.6
55-3/8	6	18.6	12	18.6

* Includes 4-3/4" nipple length

Average 18.8 ft/sec
9170 SCFM

C. Test Results--

The results of the tests (16J and 16S) discussed in this section are listed in Table 4-1. Elemental compositions, 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. An analysis of fuel composition was also performed.

D. Discussion of Results--

1. Particle Size Distribution--Figure 4-13 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 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 would be insignificant. Therefore, the impinger catch was believed to be properly included in the measurements of the suspended particulates from industrial boilers for particle size distribution. The break-down of the particle size distribution, taken from Figure 4-13 including the impinger catch, is as follows:

	Percent of Particles			
	>10 um	10 - 3 um	3 - 1 um	<1 um
Test 16J	0.7	0.9	1.4	97
Test 16S	2.5	0.8	0.8	96

2. Chemical Composition--Table 4-11 lists the results from the chemical analysis of the particulate fraction for each of the tests discussed in this section. Sulfates are the most abundant species found in the particulate catches. Carbon, iron and nitrates are next in order. All other elements detected were found in concentrations less than 1%.

Using the results from the XRF analysis and the fuel analysis results (Table 4-12) a mass balance was determined for each train for the elements. This is listed in Table 4-13. The rate of elements (10^{-4}xlb/hr) calculated from the ash content is compared to the total of the elements detected in

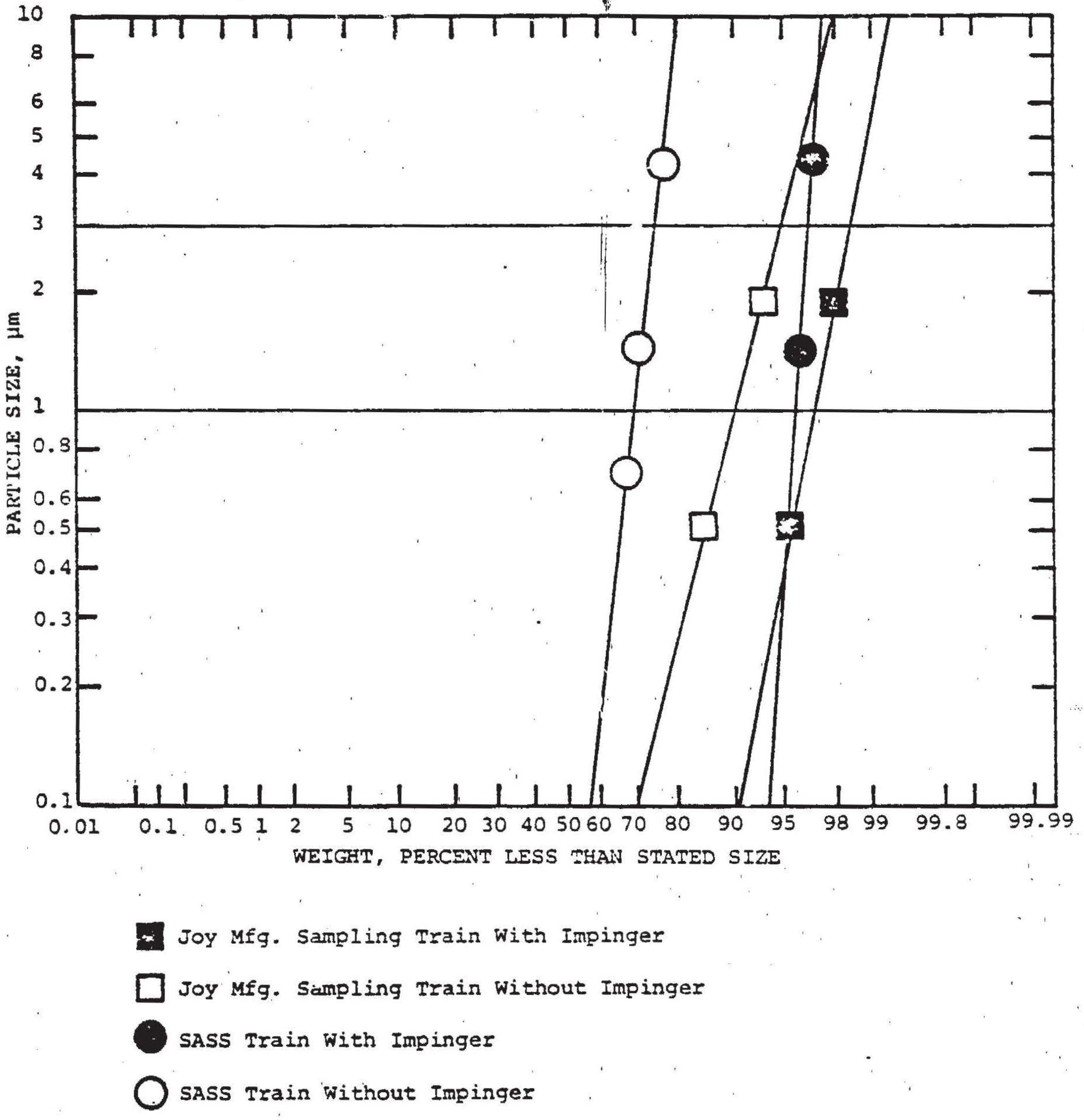


Figure 4-13. Particle size distribution for industrial boiler (Test 16).

TABLE 4-11. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR TEST 16

SAMPLE #	SASS Impinger 16S-IC	Joy Filter 16J-5S	Joy Impinger 16J-IC	SASS Filter 16S-5S
PERCENT OF CUT	84	19	68	9.4
XRF ANALYSIS				
Calcium				2.2/0.5
Chromium	t			
Iron	2/0.3	3.9/0.5		2.7/0.3
Lead		t		t
Nickel	t			
Sulfur	(18/6)	(24/10)	(18/6)	(11/3.1)
Zinc		t		t
TOTAL[1]	2.0	3.9		4.9
Sulfates, H_2O sol[2]	32	30	14.3	17.5
(Sulfur, from $SO_4^=$)[4]	(10.7)	(9.9)	(4.8)	(5.8)
Nitrate (H_2O sol)[2]	4.10	0.12	0.26	
Total Carbon[3]	20	16	13	5.4
(Volatile Carbon)[3]	(17.84)		(9.0)	
Carbonates)[3]	--	--	--	--
TOTAL ANALYZED	58	49	28	28
BALANCE	42	51	72	72
	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

TABLE 4-12. FUEL ANALYSIS RESULTS TEST NO. 16--#2 FUEL OIL

by Truesdail Laboratories, Inc.

Carbon, %	86.63
Hydrogen, %	12.96
Sulfur, %	0.38
Ash, %	0.001
Heat of Combustion:	
Gross Btu/lb	19,470
Net Btu/lb	18,290

The results of the spectrographic analysis of the ash are as follows:

	Percent in Ash
Iron	48
Silicon	6.0
Boron	0.55
Manganese	0.29
Magnesium	0.39
Lead	1.7
Nickel	0.85
Aluminum	1.0
Calcium	0.71
Copper	0.23
Silver	0.006
Sodium	< 1.3
Zinc	0.47
Titanium	0.061
Cobalt	0.080
Chromium	0.035

TABLE 4-13. MASS BALANCE ELEMENTS FOR INDUSTRIAL BOILER (TEST 16)

1098 lb/hr fuel flow; 0.01 lb/hr particulate from ash; 1.43 lb/hr particulate from SASS, 0.61 lb/hr particulate from Joy

	SASS					JOY			
Collector % TSP Collected Units of Table	Impinger 84% 10^{-4} lb/hr	Filter 9.4% 10^{-4} lb/hr	Sum 93.4% 10^{-4} lb/hr	Total[1] 100% 10^{-4} lb/hr	Fuel Analysis 10^{-4} lb/hr	Impinger 68.2% 10^{-4} lb/hr	Filter 18.3% 10^{-4} lb/hr	Sum 87% 10^{-4} lb/hr	Total[1] 100% 10^{-4} lb/hr
Bromine	t		t	t		t	44.7	t	t
Iron	240	36.2	276	295	53	t		49	56
Nickel	53		53	56	t	t		t	t
Calcium	5	29.5	42	45	t	5		5	t
Magnesium					t				
Silicon					6.6				
Manganese	t		5	t	t	t		t	t
Aluminum					t				
Lead		t	t	t	2	t	t	t	t
Molybdenum	t		t	t					
Copper	t		t	t	t	t		t	t
Silver					t				
Zinc	5	5	5	5	t	5	5	5	t
Cobalt	t		t	t	t	t		t	t
Chromium	55		55	59	t	t		t	t
Potassium						t		t	t
Sulfur[2]	2162	141	2303	(2465)	4200	749	275	1024	(1177)
Cadmium	t		t	t		t		t	t
Sulfate	3875	235	4110	4400		595	339	934	1073
Nitrate	492		492	527		10.8	1.4	12.2	14
Total Carbon	2362	164	2526	2704		541	400	941	1081
Volatile Carbon	2140		2140	(2300)		374		374	(430)
Selenium	t		t			t	t	t	t
			Total Accounted for by Analysis	8,091				Total Accounted for by Analysis	2,654
			Total Catch (i.e. TSP)	14,300				Total Catch (TSP)	6,100

[1] Values in "Total" column are obtained by dividing values in "Sum" column by the % TSP collected for the "Sum" column. This accounts for material collected in the probe and in other collectors not analyzed.

[2] "Sulfur" value listed is from XRF analysis. "Sulfate" vlaue is from wet chemical analysis and includes the sulfur plus the oxygen in the sulfate value. Theoretically the "sulfur" value should equal 1/3 of the "sulfate" value.

( ) Not included in the total.

each sampling train. Comparison of the mass rate of the elements (lb/hr) for the Joy train with that of the fuel is reasonable. However, the SASS train comparison indicates that there was some iron contamination in the sample. It is believed that this contamination was caused by oxidation of the nozzle. Several weeks after the test, rust was detected on the nozzle used for Test 16S.

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

Units	Test 16S*	Test 16J	Frederiksen (Ref. 4-4) No. 25	Frederiksen (Ref. 4-4) No. 26
gr/DSCF	0.02	0.0087	0.0071	0.010
T/yr	6.2	2.7	2.9	4.3
lb/hr	1.43	0.61	0.67	0.97
lb/MMBtu	0.043	0.018	0.02	0.029
lb/1000 gal Burned	10.0	4.3	4.7	6.8
lb/1000 gal Burned, (Ref. 4-5)	2.0	2.0	2.0	2.0
% wt on fuel	0.13	0.058	0.064	0.093

* Results suspected to be in error--see Section 4.2.2 D2

Also the emission follows the Goldstein relation (Ref. 4-1) of emission vs % S, see Figure 4-10, Section 4.2.1 (i.e. the point 0.38% sulfur fuel ash particulate emission of 0.058% on fuel is on Goldstein's line).

4.2.3 Wood Waste Boiler

Sawdust, wood chips, and bark are used as fuel in boilers of lumber sawmills. These wood waste boilers have replaced nearly all of the conical (or teepee) burners formerly used to dispose of what was considered a waste product. The steam generated by the wood waste burners is typically used to heat the kilns in which the fresh-cut lumber is cured. The wood waste is collected at various processing stations, and delivered into a large silo-like hopper. The waste is dampened to a 60 to 70% water content to prevent ignition. The waste is fed from the hopper into the boiler at a controlled rate to meet steam demand.

A. Boiler Description

The unit tested was a Wellons Hog Fuel Boiler, consisting of the following components:

1. Babcock and Wilcox watertube boiler, 3952 ft^3 heating surface, 160 psig rated, and 125 psig operating.
2. Wellons Double Cell Type Furnace, with refractory lining, water cooled grates, 5'6" inside diameter.
3. Wellons Posi-Flo Storage Bin, 32000 ft^3 capacity, with automatic feed system to furnace.
4. Wellons Multi-Cone Collector, with 35 8" collector tubes.
5. Hagan Pneumatic Controls.
6. Three ft diameter, 40 ft high stack.

The rated steam load is 27,000 lb/hr maximum, 15,000 lb/hr average. It is operated continuously all year round. Fuel feed rate is 4500 lb/hr maximum, 2500 lb/hr average dry weight. The average heating value of the fuel is 8500 Btu/lb dry weight, and the ash content is 2% or less of the dry weight. The annual wood consumption is approximately 11,000 ton/year dry weight.

The unit is shown in Figure 4-14 which includes a step-by-step description of the process operations. Note that near the top of the conveyor the unit contains a sawdust screen which extracts the sawdust which contains 75% water and blows it with 600 °F exhaust gas through a cyclone which removes approximately 15% of the water before returning the sawdust to the surge bin.

B. Particulate Test Setup

A three inch diameter port was made in the three foot diameter stack located midway up the 30 ft high stack, 15 ft above the induced draft fan located at the base of the stack. Table 4-14 presents the velocity profile in the stack, which was slightly unusual due to the asymmetric flow caused by the induced draft fan. A 0.75 diameter nozzle was used with the SASS train probe which was inserted 24 inches into the stream from the test port. Sampling occurred continuously from 12:00 noon to 2:10 pm, on October 13, 1977. Sampling rate was 6.5 ACFM ± 5% at 400 °F ± 10 °F. Total volume of gas sampled was 455 SCF. The test was stopped due to a clogged filter.

C. Test Results

The following lists the actual weight collected in milligrams, mg and weight % of total for each fraction of the total catch:

	mg	Weight % of Total
Probe	30	1
Large Cyclone - 9.2 µm	126	3
Medium Cyclone - 3.8 µm	515	12
Small Cyclone - 1.3 µm	100	2
Filter	347	8
Impinger water	2170	50
Impinger extract	1041	24
Total:	4330	100

LEGEND: Fuel is conveyed ① to the storage bin ②..Posi-flo agitator ③ works its way around the feed-out cone, eliminating bridging or arches which occur along the cone side; fuel feeds down the agitator to the feed-out augers ④ which maintain a constant level of fuel over the conveyor chain ⑤..The conveyor chain, feed-out augers and agitator operate only as necessary to keep a constant supply of fuel in the metering surge bin ⑥ whose variable speed augers are governed by the combustion controls to match the steam loading on the boiler. The fuel passes through a screen (6a) which seperates the sawdust from the chips. The sawdust is heated and passes through a cyclone (6b) where the water in the sawdust is reduced by 10 to 15% and the sawdust is introduced into the surge bin. The furnace feed auger ⑦ delivers a metered amount of fuel to the Wellons Cyclo-blast high temperature furnace cells where wood fuel gasification and carbon combustion occurs in a small controlled pile on Wellons Water-cooled Grates ⑧..Discharged grate cooling water is returned to the boiler feedwater system, conserving heat. Preheated primary combustion air is introduced under the grates, secondary and tertiary combustion air is injected through directional ports in the furnace walls above the fuel pile. Completion of combustion takes place in chamber ⑨ where radiant energy is directed to the radiant section of the boiler ⑪..Ash and entrained matter fall into the dropout chamber ⑩.. Combustion gasses pass through a convection section of the boiler and on through a multiclone collector ⑬.. Particulate passes through a rotary seal ⑭ to a dump box ⑮.. Stack gasses pass through a combustion air preheater ⑯.. The forced draft air from fan ⑳ circulates through the air preheater and is metered to the furnace through linear flow dampers ㉑ for proper fuel combustion. Stack gasses leave the air preheater, pass through an induced draft damper ⑰ which maintains a preset controlled pressure in the boiler combustion chamber...Final journey of the stack gasses is through the induced draft fan ⑱ and out the exhaust stack ⑲ to atmosphere. Steam energy discharges through outlet ⑫ to process.

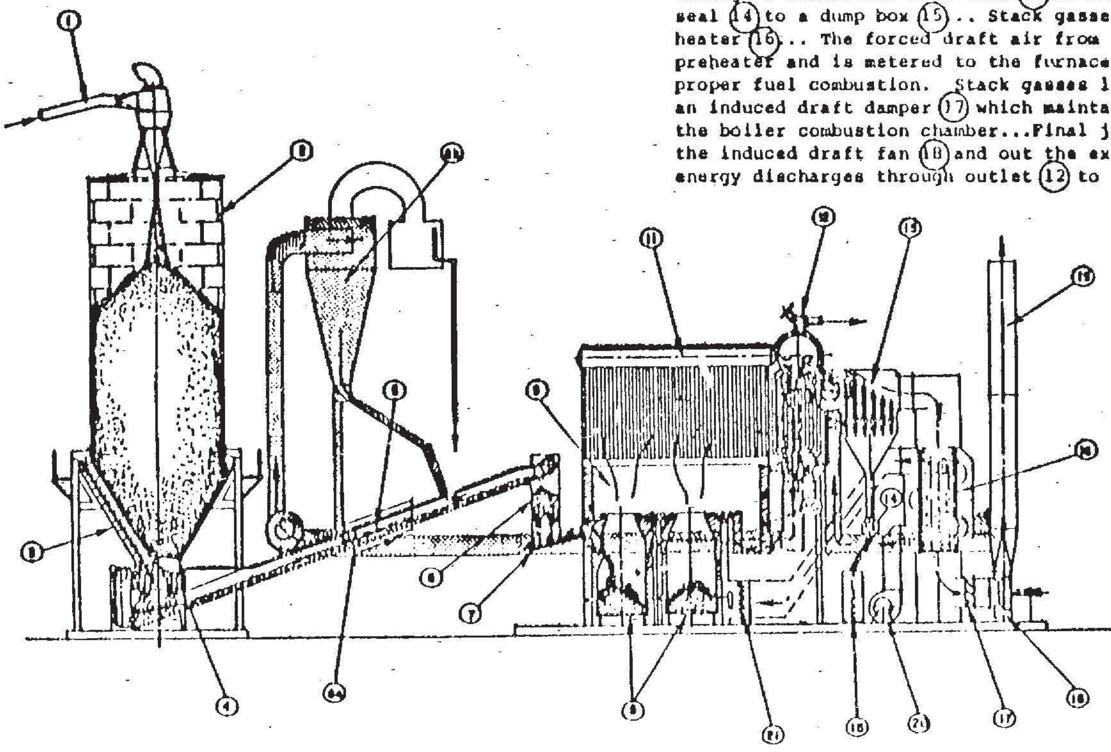
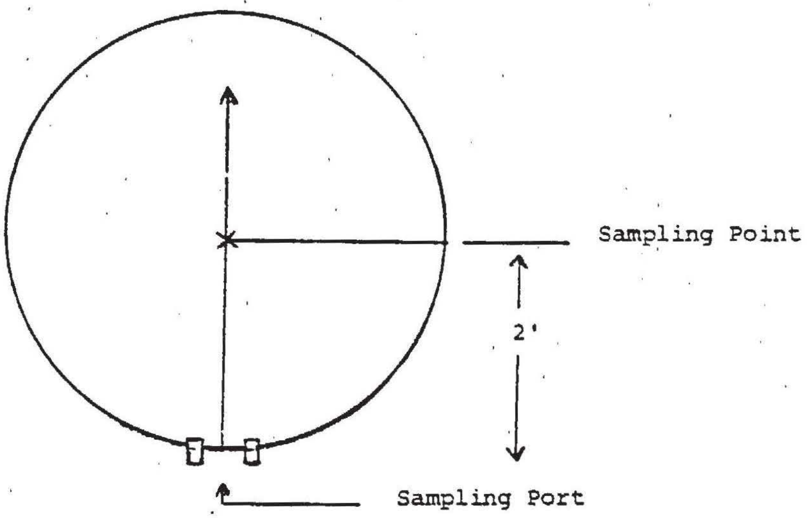


Figure 4-14. Wood chip and sawdust boiler.

TABLE 4-14. WOOD WASTE BOILER - STACK VELOCITY PROFILE (TEST 5)



Distance from Port Entrance, in.	Velocity Head, in. H_2O		in ft/sec
1.2	0.05	=	14.9
3.8	0.08	=	18.8
6.8	0.12	=	23.1
11.2	0.10	=	21.1
17.5	0.12	=	23.1
23.8	0.16	=	26.7
28.2	0.20	=	29.8
31.3	0.21	=	29.8
33.9	0.20	=	29.8
	0.132	=	at 754 °R = 24.2 ft/sec
	Average		Average Velosity

The impinger water had turned a dark amber color by the end of the test. Later it was determined that 75% of the particulate was caught in the impinger. In Table 4-15 the results of XRF analysis of the various particulate samples are summarized. For each sample caught in the traps, as indicated, the percentage of each element is presented with the error indicated after the slash, i.e., 1.2/0.01 means 1.2% ± 0.01%.

The results of the test 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 4-15 lists the results from this analysis.

The sulfate, nitrate, and carbon analyses results are also summarized in Table 4-15.

D. Discussion of Results--

1. Particle Size Distribution -- Figure 4-15 is a plot of particle size vs. 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 collected in the impinger (over three grams), it would seem that the effects of pseudo particulates would be negligible. Therefore, the impinger catch was believed to be properly included in the measurement of total suspended particulates from this waste wood boiler. Therefore the breakdown of particle size distribution is as follows:

	%
> 10 μm	1
3 - 10 μm	3
1 - 3 μm	16
< 1 μm	80

TABLE 4-15. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR WOOD WASTE BOILER (TEST 5)

SAMPLE #	10µm Cyclone 5S-2S	3µm Cyclone 5S-3S	1µm Cyclone 5S-4S	Filter 5S-5S	Impinger 5S-IC
Percent of Cut	3	12	2	8	50
XRF ANALYSIS					
Barium	t	t	t	t	
Calcium	6.5/1	14/2	10/2	3.3/0.4	t
Chlorine				2/0.4	2/0.8
Iron	4.2/0.5	4.6/0.3	3.6/0.4	t	
Manganese	t	t	t	t	t
Potassium	2.6/0.3	5.5/0.5	2.4/0.3	9.3/1.5	
Silicon	10	10			
(Sulfur)		(3.1/0.7)	(<3)	(3.8/1.5)	(2.1/0.7)
Tantalum	t	t			
Zinc			t	t	
Total Elements[1]	23	34	16	15	2.0
Sulfates, H_2O sol[2]	t	1.2	2.3	7.0	2.4
(Sulfur, from $SO_4^=$)[4]	(t)	(t)	(t)	(2.3)	(t)
Nitrate (H_2O sol)[2]	t	t		t	
Total Carbon[3]	30	30	t	23	7.0
(Volatile Carbon)[3]	(15.6)	(7.4)	(t)		(7.0)
(Carbonates)[3]	(3)	(6.5)	(t)	(t)	
TOTAL ANALYZED	53	65	18	45	11
BALANCE	47	35	82	55	89
	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

2. Chemical Composition--Table 4-15 lists the results from the chemical analysis of the particulate fraction for tests discussed in this section. Carbon was found to be most abundant followed by potassium, calcium, iron and carbonates.

3. Emission Factors--Based on this test alone, the following emission factors can be calculated at 4.3% CO_2 and 16.6% O_2.

0.15	grams TSP/Dry SCF Exhaust Gas
20×10^{-6}	lb TSP/Dry SCF Exhaust Gas
0.3	grams TSP/Dry SCF Exhaust Gas
7	lb TSP/hr of operation
30	Ton TSP/yr of operation
1	lb TSP/Ton of dry wood waste
0.5	lb TSP/Ton of stored wood waste (wet)
0.7	lb TSP/Ton of steam produced.

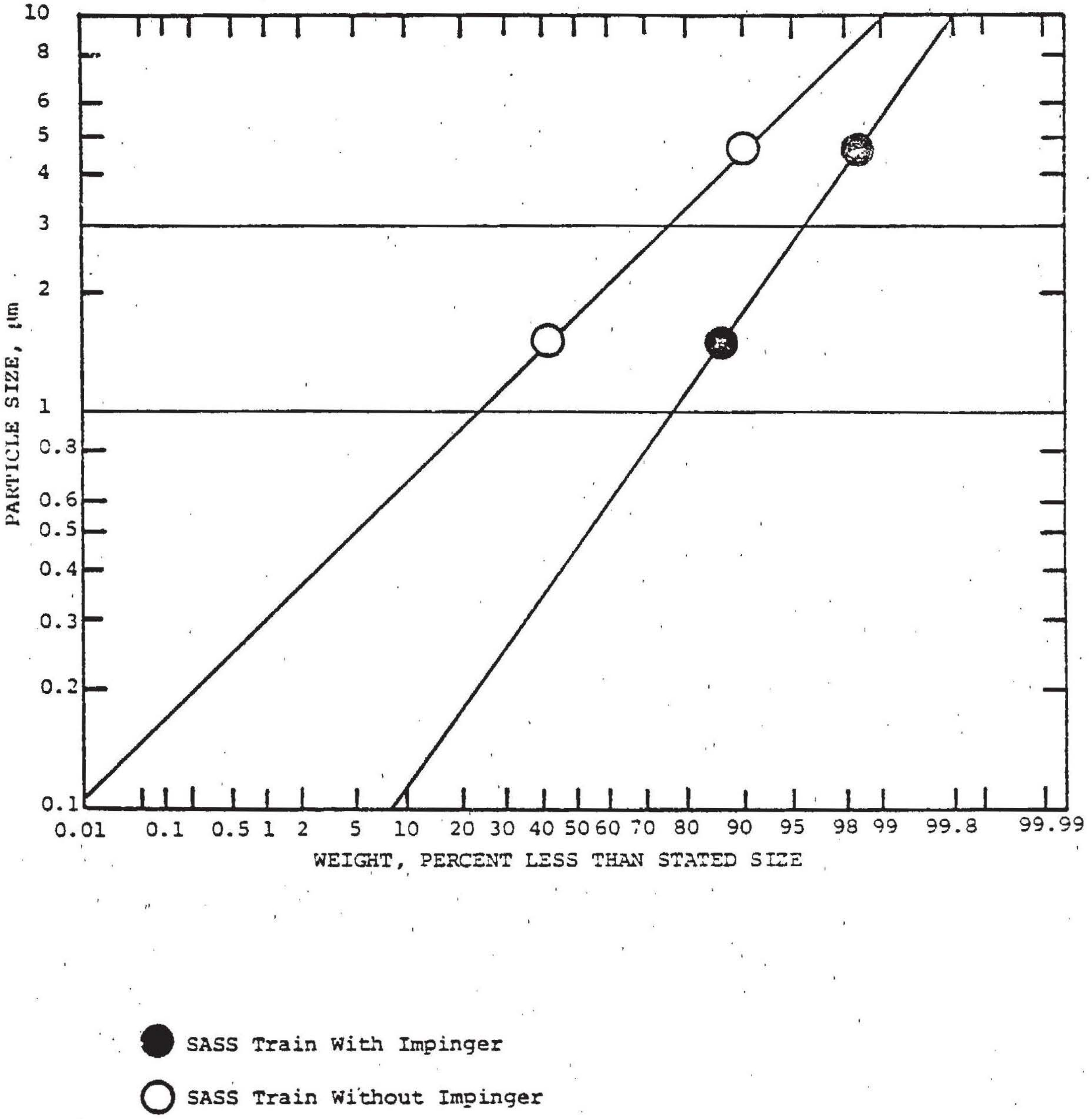


Figure 4-15. Particle size distribution for wood waste boiler (Test 05).

4.2.4 Utility Boilers

A. Boiler Description--

1. Boiler 1--The first utility boiler tested was an opposed face-fired B&W supercritical 480 MW steam generator with 32 gas and residual oil burners. The unit operates at a supercritical pressure of approximately 3500 psig; the first water pass is through a division wall which divides the furnace in half. The feedwater pumps control the steam pressure. The firing rate is adjusted to maintain a 1000°F superheat temperature. The control of reheat temperature at 1000°F is accomplished by flue gas proportional dampers, reheat spray, and hopper flue gas recirculation. Full load for this unit is 480 MW and the current minimum load is 180 MW.

2. Boiler 2--The second utility boiler tested was a face-fired, balanced draft, 180 MW steam generator with 16 gas and residual oil burners. The unit operates at a supercritical pressure of approximately 1800 psig and the first water pass is through a division wall which divides the furnace into halves. The feedwater pumps control the steam pressure and the firing rate is adjusted to maintain a 1000°F superheat temperature. The control of reheat temperature at 1000°F is accomplished by flue gas proportional dampers, reheat spray, and hopper flue gas recirculation. Full load for this unit is 180 MW and the current minimum load is 80 MW.

B. Particulate Test Set-up--

Two sampling trains were used simultaneously for each of the particulate tests performed on utility boilers in order to have redundant tests for accuracy determination. Tests 11, 12, and 13 were planned as identical tests to determine precision. These three tests were performed on a clean boiler. Test 23 was run at the same condition and on the same boiler but after the boiler had been operating for a period of time long enough to be considered a dirty boiler (>12 weeks). Test 24 was conducted on a dirty boiler under low load conditions. Tests 32 and 33 were performed at high load and dirty boiler condition; repeats of Test 23. However, for Test 32 the two sampling trains were run with equal sample volumes. This required over 13 hours of sampling time for the smaller Joy train. Tests 21 and 22 were performed on the second boiler at high and low load, respectively. The following comparisons can be made.

High load vs low load	Boiler 1
High load vs low load	Boiler 2
Boiler 1 vs Boiler 2	
Clean Boiler vs Dirty Boiler	
Repeats: Tests 11, 12 and 13; Tests 23, 32, and 33	
Joy vs SASS for each test	

1. Boiler 1--The sampling stations for Boiler 1 were located on the vertical section of the steel-lined, reinforced concrete stack about 100 ft above ground level, and about 10 ft above the location where the gases enter the stack (see Figure 4-16). The internal diameter of the stack was 270". Because of the large diameter of the stack, a velocity traverse was not possible. Velocity was measured up to 50" into the stack from the north and from the east. However, the stack flow rate was determined from fuel combustion calculations because a complete velocity profile was not obtained. Table 4-16 lists the stack flow rate for each test and sample train along with sample location, average stack velocity, ft/sec, during the test, nozzle diameter, stack temperature, static pressure of the stack, and boiler load.

2. The sampling station for Boiler 2 was located on the lower of two 12' x 12' horizontal ducts leading to the base of the concrete stack (see Figure 4-16). This station was about 50' above ground level and on the straight section of the duct about 40 ft downstream from the nearest bend and about 15 ft from where the flow enters the concrete stack. Because of the large diameter of the stack, a velocity traverse was not possible. Velocity was measured up to 50" into the stack from the west on the lower of the two ducts. However, the stack flow rate was determined from fuel combustion calculations because a complete velocity profile was not obtained. The particulate test set-up data are also given in Table 4-16.

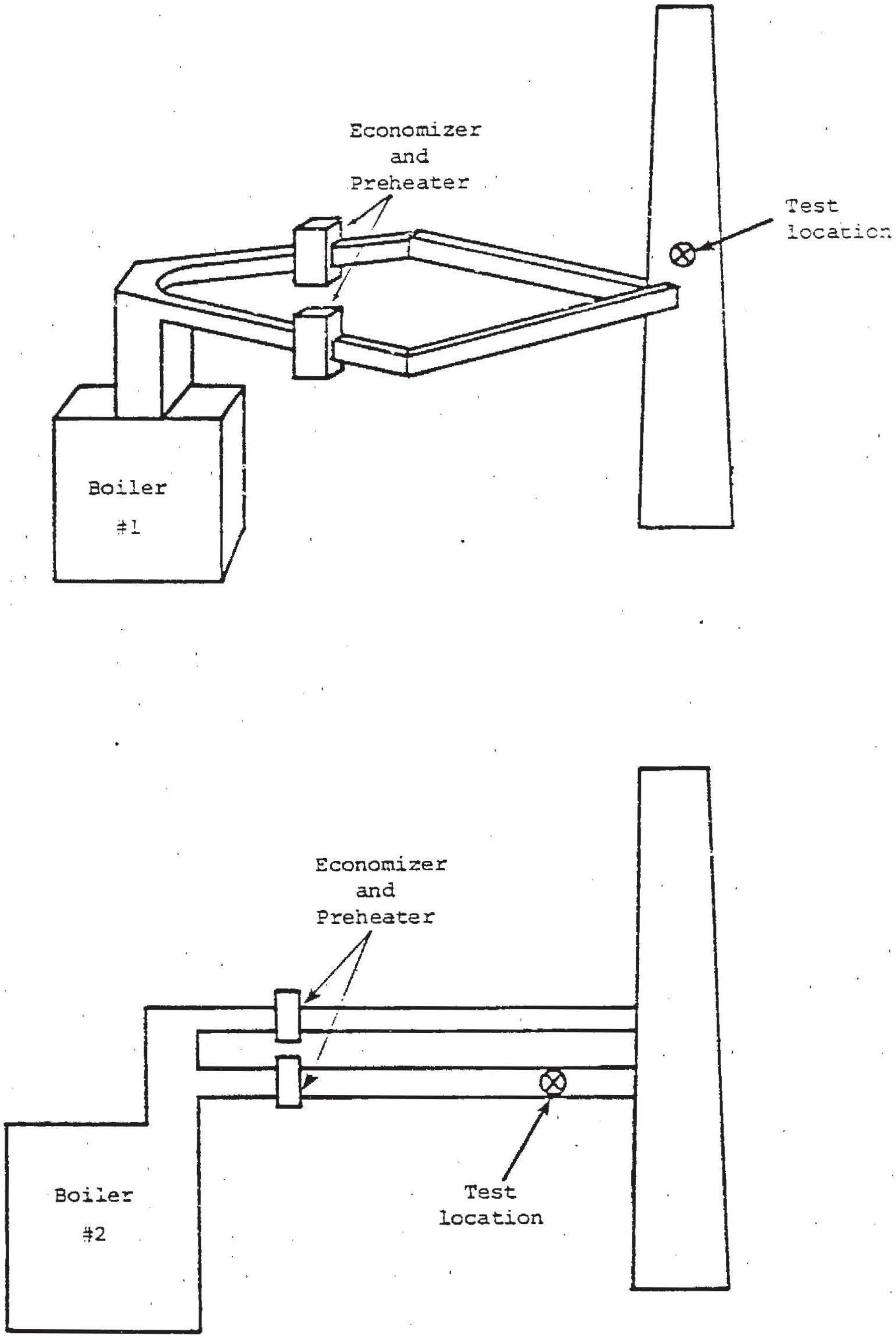


Figure 4-16. Flue gas flow from utility boilers.

TABLE 4-16. PARTICULATE TEST SET-UP DATA FOR UTILITY BOILERS

		Sample Location								
Test #	Train	Distance From internal wall, inches	From Direction	Velocity ft/sec At Test Point	Nozzle Diameter inches	Stack Temperature °F	Static Pressure Inches of Water	Stack Flow Calculated DSCFM	Load MWW	Boiler
11S	SASS	34	North	78.0	3/8	275	+1.0	833,730	472	1
11J	Joy	34	East	42.1	1/4	275	+1.0	833,730	472	1
12S	SASS	34	North	80.1	3/8	284	+1.0	898,170	276	1
12J	Joy	34	East	54.6	1/4	275	+1.0	898,170	276	1
13S*	SASS	34	North	88.6	3/8	281	+1.0	913,230	472	1
13J	Joy	34	East	30.8	1/4	273	+1.0	913,230	472	1
23S*	SASS	34	North	76.1	9/16	297	+1.0	849,434	450	1
23J	Joy	34	East	47.0	5/16	290	+1.0	849,434	450	1
24S	SASS	34	North	46.1	11/16	222	+1.3	481,018	238	1
24J	Joy	34	East	23.0	7/16	220	+1.3	481,018	238	1
32S	SASS	34	East	51.7	5/8	295	+1.0	795,981	453	1
32J	Joy	34	East	51.7	1/4	292	+1.0	795,981	453	1
33S	SASS	34	East	45.0	5/8	286	+1.0	855,043	455	1
33J	Joy	34	East	45.0	5/16	286	+1.0	855,043	455	1
21S	SASS	53	West	32.9	5/8	274	-0.8	378,394	174	2
21J	Joy	65	West	32.9	5/16	275	-0.8	378,394	174	2
22S	SASS	53	West	15.6	1.0	222	-0.75	215,124	90	2
22J*	Joy	65	West	15.6	1/2	225	-0.75	215,124	90	2

*Bad data; not included in subsequent analyses

C. Test Results--

The results of the eight valid tests for Boiler #1 and for Boiler #2 (Tests 11-13, 21, 22, 24, 32, 33) 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 weight in excess of 100 mg. The details for these procedures are discussed in Section 3.2.2. Tables 4-17 to 4-24 list the results from these analyses. A fuel analysis for each test is presented in Table 4-25. Using the results of the particulate and fuel analyses a material balance of elements was made, these are listed in Tables 4-26 to 4-33. Particle size distribution curves for each test are given in Figures 4-17 to 4-25

D. Discussion of Results--

1. Particle size distribution--Figures 4-17 to 4-25 are plots 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 for each test, one including the impinger catch, and the other without it. The EPA Method 5 (Ref. 4-6) does not include the impinger catch. However, the local agency (SCAQMD) does include the impinger catch. Also considering the large amount of material collected in the impinger, it would seem that the effects of pseudo-particulates would be small. Therefore, the impinger catch was believed to be properly included in the measurements of the suspended particulates from utility boilers for particle size distribution. The breakdown of the particle size distribution taken from Figures 4-17 to 4-25, including the impinger catch, is as follows:

TABLE 4-17. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR UTILITY BOILERS (TEST 11)

SAMPLE #	SASS Impinger (inorganic) 11S-IC	SASS Filter 11S-5S
PERCENT OF CUT	58	18
XRF ANALYSIS		
Barium		t
Calcium		12/1.6
Cobalt		t
Iron	t	4.9/0.06
Nickel	t	10.6/1.1
Potassium		t
(Sulfur)	(12/4)	(3.3/5)
Titanium		t
Vanadium		2.1/0.3
TOTAL[1]	2.2	27
Sulfates, H_2O sol)[2]	15	35
(Sulfur, from $SO_4^=$)[4]	(4.9)	(11.8)
Nitrate (H_2O sol)[2]		
Total Carbon[3]	8.8	5.9
(Volatile Carbon)[3]	(7.7)	
(Carbonates)[3]	--	t
TOTAL ANALYZED	26	68
BALANCE	74	32
	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

TABLE 4-18. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES FOR UTILITY BOILERS (TEST 12)

SAMPLE #	SASS Impinger (inorganic) 12S-IC	Joy Filter 12J-5S	SASS Filter 12S-5S
WT. PERCENT OF CUT	50	29	23
XRF ANALYSIS			
Barium		t	
Bismuth			t
Calcium			18/1.2
Chromium	t		
Cobalt			t
Iron	1/0.4	1.2/0.3	4.2/0.05
Lead		t	
Nickel	t	6.5/0 8	11/1.1
Potassium			t
(Sulfur)	(9.7/2)	(30)	(37/6.5)
Titanium			t
Vanadium		t	1.6/0.32
Zinc		t	t
TOTAL[1]	1.0	8.0	35
Sulfates, H_2O sol[2]	16	41	40
(Sulfur, from $SO_4^=$)[4]	(5.3)	(14)	(13)
Nitrate (H_2O sol)[2]			
Total Carbon[3]	14	20	9.5
(Volatile Carbon)[3]	(13)		
(Carbonates)[3]			
TOTAL ANALYZED	31	69	85
BALANCE	69	31	15
	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

TABLE 4-19. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR UTILITY BOILERS (TEST 13)*

SAMPLE #	SASS 3µm Cyclone 13S-3S	SASS Impinger (inorganic) 13S-IC	SASS Filter 13S-5S	Joy Impinger (inorganic) 13J-IC
PERCENT OF CUT				72
XRF ANALYSIS				
Calcium				t
Chromium				
Iron				t
Nickel				
Potassium				
(Sulfur)				(18/6)
Vanadium				
Zinc				t
TOTAL[1]				t
Sulfates, H_2O sol[2]				21
(Sulfur, from $SO_4^=$)[4]				(6.9)
Nitrate (H_2O sol)[2]				t
Total Carbon[3]				28
(Volatile Carbon)[3]				(23)
(Carbonates)[3]				
TOTAL ANALYZED				49
BALANCE				51
				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

* Test 13S invalid

TABLE 4-20. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR UTILITY BOILERS (TEST 21)

SAMPLE #	SASS Filter 21S-5S	SASS Impinger (inorganic) 21S-IC
WT. PERCENT OF CUT	11	59
XRF ANALYSIS		
Iron	1/0.2	t
Nickel	1.4/0.2	
Selenium		t
(Sulfur)	(6.2/2)	(19/4)
Vanadium	t	
TOTAL^1	1.4	t
Sulfates, H_2O sol^2	55	31
(Sulfur, from $SO_4^=$)^4	(18.3)	(10.4)
Nitrate (H_2O sol)^2	t	t
Total Carbon^3	9.1	9
(Volatile carbon)^3		(6)
(Carbonates)^3		
TOTAL ANALYZED	65	40
BALANCE	35	60
	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

TABLE 4-21. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR TEST 22*

SAMPLE #	SASS Filter 22S-5S
WT. PERCENT OF CUT	10
XRF ANALYSIS	
Iron	3.5/0.4
Nickel	4.8/0.5
(Sulfur)	(27/10)
Vanadium	1.3/0.2
TOTAL[1]	10
Sulfates, H_2O sol[2]	67
(Sulfur, from $SO_4^=$)[4]	(22)
Nitrate (H_2O sol)[2]	t
Total Carbon[3]	7.5
(Volatile Carbon)[3]	
(Carbonates)[3]	
TOTAL ANALYZED	84
BALANCE	16
	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

* Test 22J invalid

TABLE 4-22. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR TEST 24

SAMPLE #	SASS Filter 24S-5S	SASS Impinger (inorganic) 24S-IC	Joy Impinger (inorganic) 24J-IC
WT. PERCENT OF CUT	14	72	54
XRF ANALYSIS			
Barium	t		
Calcium		t	t
Chromium		t	
Iron	2.2/2.3	2.5/0.3	t
Lead	t		
Nickel	6.6/0.8	t	
(Sulfur)	(26/10)	(22/7)	(30/10)
Vanadium	t		
Zinc	t		
TOTAL[1]	9	3	t
Sulfates, H_2O sol[2]	48	24	25
(Sulfur, from $SO_4^{=}$)[4]	(16)	(8.1)	(8.5)
Nitrate (H_2O sol)[2]			
Total Carbon[3]	12	25	13
(Volatile Carbon)[3]			12
(Carbonates)[3]			t
TOTAL ANALYZED	69	53	50
BALANCE	31	47	50
	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

TABLE 4-23. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR TEST 32

SAMPLE #	SASS Impinger (inorganic) 32S-IC	Joy Filter 32J-5S
WT. PERCENT OF CUT	66	16
XRF ANALYSIS		
Barium		t
Calcium	t	8.6/3
Chromium	t	
Cobalt		t
Iron	t	1.9/0.3
Lead		t
Nickel	t	7.9/0.9
Selenium	t	
(Sulfur)	(15/5)	(25/10)
Vanadium		t
Zinc	t	t
TOTAL[1]	t	18.4
Sulfates, H_2O sol[2]	24	59
(Sulfur, from $SO_4^=$)[4]	(7.9)	(20)
Nitrate (H_2O sol)[2]		
Total Carbon[3]	18	t
(Volatile Carbon)[3]	(9)	
(Carbonates)[3]		
TOTAL ANALYZED	42	77
BALANCE	58	23
	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

TABLE 4-24. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR TEST 33

SAMPLE #	SASS Filter 33S-5S	Joy Impinger (inorganic) 33S-IC
WT. PERCENT OF CUT	14	31
XRF ANALYSIS		
Barium	t	
Calcium	10/3	t
Chromium		t
Cobalt	t	
Iron	3.6/0.5	1.2/0.2
Nickel	6.3/0.7	t
Selenium		t
(Sulfur)	(30/10)	(16/5)
Vanadium	t	
Zinc	t	t
TOTAL[1]	20	2
Sulfates, H_2O sol[2]	59	23
(Sulfur, from $SO_4^=$)[4]	(20)	(7.8)
Nitrate (H_2O sol)[2]		
Total Carbon[3]	t	20
(Volatile Carbon)[3]		(20)
(Carbonates)[3]		
TOTAL ANALYZED	79	45
BALANCE	21	55
	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

TABLE 4-25. FUEL ANALYSIS RESULTS OF UTILITY BOILER #6 FUEL OIL

	Test* 21 & 22	Test* 23	Test* 24	Test* 32	Test* 33	Test† 11	Test† 12	Test† 13
Carbon, %	86.86	86.68	86.50	86.24	86.09	86.39	86.35	86.34
Hydrogen, %	12.51	12.59	12.62	12.72	12.61	12.93	12.97	13.02
Sulfur, %	0.20	0.20	0.19	0.22	0.20	0.22	0.22	0.22
Ash, %	0.012	0.015	0.012	0.011	0.013	0.014	0.009	0.007
Moisture, %	0.12	0.12	0.12	0.26	0.70	0.05	0.2	0.05
Nitrogen, %	--	--	--	0.23	0.23	0.19	0.21	0.24
Oxygen, %	--	--	--	0.32	0.16	0.25	0.25	0.16
Heat of Combustion:								
Gross Btu/lb	19,310	19,280	19,250	19,260	19,250	19,278	19,287	19,255
Net Btu/lb	18,170	18,130	18,100	18,100	18,100	--	--	--
Alphaltenes, %	0.44	0.63	0.58	0.66	0.56	--	--	--
<u>Metals in % of Ash</u>								
Vanadium	3.9	2.8	4.1	9.0	8.2	1.93	2.78	3.00
Iron	19	14	11	10	15	3.14	4.33	3.00
Nickel	8.3	11	12	12	9.8	9.3	14.4	12.43
Sodium	13	13	15	9.2	8.6	4.79	5.11	5.86
Calcium	5.5	4.4	4.8	4.5	3.6	0.79	1.00	1.00
Silicon	1.2	2.8	2.2	2.0	2.2	2.0	3.33	2.29
Aluminum	0.43	1.1	0.61	3.5	6.1	0.86	1.89	1.57
Barium	0.31	0.57	0.41	0.42	0.42	0.86	1.22	1.24
Boron	0.051	0.016	0.018	0.011	<0.008	0.01	0.02	0.02
Magnesium	2.5	3.6	2.8	4.2	3.8	1.79	2.44	2.57
Manganese	0.11	0.28	0.13	0.13	0.16	0.08	0.12	0.12
Lead	0.43	0.85	0.70	0.58	0.42	0.29	0.54	0.37
Tin	0.11	0.26	0.35	0.16	0.19	0.58	1.08	1.57
Chromium	0.067	0.22	0.11	0.15	0.19	0.07	0.06	0.05
Titanium	0.34	0.17	0.25	0.065	0.084	0.11	0.14	0.14
Copper	0.055	0.77	0.092	0.11	0.08	0.14	0.17	0.10
Silver	0.0024	0.0044	0.0023	0.0023	0.0024	t	t	t
Zinc	1.5	1.0	1.2	0.57	0.21	0.23	0.41	0.30
Cobalt	0.28	0.31	0.31	0.47	0.42	0.44	0.47	0.59
Strontium	0.11	0.11	0.12	0.075	0.073	0.10	0.09	0.09
Molybdenum	--	--	--	0.023	0.024	0.13	0.12	0.06

* Truesdail Laboratories Inc.
† E. W. Saybolt & Co., Inc.

TABLE 4-26. MASS BALANCE FOR TEST 11

218,755 lb/hr fuel flow; 30.627 lb/hr particulate from ash; 65.03 lb/hr particulate from SASS

Fraction % Fraction Units	SASS Filter 18% lb/hr	SASS Impinger 68% lb/hr	Sum 86% lb/hr	Total[1] 100% lb/hr	Fuel Analysis Ash=0.014% lb/hr
Vanadium	0.24		0.24	0.28	0.83
Iron	0.58	0.08	0.66	0.77	1.35
Nickel	1.26	0.02	1.28	1.49	3.98
Calcium	1.45	0.01	1.46	1.70	0.37
Magnesium					0.77
Sodium					2.05
Silicon					0.86
Manganese		0.01	0.01	0.01	0.03
Aluminum					0.37
Barium	0.03		0.03	0.03	0.37
Lead	0.01	0.01	0.02	0.02	0.13
Tin					0.25
Molybdenum		0.01	0.01	0.01	0.06
Copper	0.01	0.01	0.02	0.02	0.06
Silver		0.01	0.01	0.01	0.0002
Zinc	0.03	0.01	0.04	0.05	0.10
Titanium	0.03	0.01	0.04	0.05	0.05
Cobalt					0.19
Chromium		0.02	0.02	0.02	0.03
Strontium	0.01	0.01	0.02	0.02	0.04
Potassium	0.05	0.01	0.06	0.07	
Sulfur	3.94	1.71	5.65	(6.57)[2]	481.3
Bromine		0.01	0.01	0.01	
Sulfate	4.19	2.11	6.3	7.33	
Nitrate	--	--			
Total Carbon	0.70	1.25	1.95	2.27	
Vol. Carbon	--	1.1	1.1	(1.28)[2]	
Carbonate	0.01	--	0.01	(0.01)[2]	
Cadmium		0.01	0.01	0.01	
Rubidium		0.01	0.01	0.01	
Selenium		0.01	0.01	0.01	
Arsenic	0.01		0.01	0.01	
Gallium	0.01		0.01	0.01	
			Total	14.21	
			TSP	65.03	

---

1 Compare total column with fuel analysis column

2 Not included in summation

TABLE 4-27. MASS BALANCE FOR TEST 12

220,497 lb/hr fuel flow; 19.84 lb/hr particulate from ash; 55.5 lb/hr particulate from SASS; 44.8 lb/hr particulate from Joy. t < 0.1 lb/hr.

	SASS					Joy	
Fraction % Fraction Units	Filter 23% lb/hr	Impinger 55% lb/hr	Sum 78% lb/hr	Total[1] 100% lb/hr	Fuel Analysis Ash=0.009% lb/hr	Filter 29% lb/hr	Total[1] 100% lb/hr
Vanadium	0.2		0.2	0.26	0.5	0.1	0.34
Iron	0.53	0.30	0.83	1.1	0.77	0.16	0.55
Nickel	1.4	t	1.4	1.9	2.58	0.85	2.9
Calcium	2.23	t	2.2	2.8	0.18		
Magnesium		t	t	t	0.44		
Sodium					0.91		
Silicone					0.6		
Manganese					0.02		
Aluminum					0.34	t	t
Barium		t	t	t	0.22	0.5	0.17
Lead	t	t	t	t	0.10	0.02	0.07
Tin					0.19		
Molybdenum					0.02		
Copper		t	t	t	0.03		
Silver		t	t	t	0.0001		
Zinc	0.04	t	t	0.06	0.07	0.02	0.07
Titanium	0.04	t	t	t	0.03		
Cobalt	0.04	t	t	t	0.08	t	t
Chromium		0.13	0.13	0.17	0.01		
Strontium	t		t	t	0.02		
Potassium	0.08	t	t	t			
Sulfur	4.71	2.95	7.7	(9.9)[2]	485	3.94	(13.5)[2]
Bromine		t	t	t			
Sulfate	5.02	4.9	9.9	12.7		5.38	18.36
Nitrate							
Total Carbon	1.19	4.3	5.5	7.1		2.68	9.1
Vol. Carbon		4.0	4.0	(5.1)[2]			
Carbonate							
Cadmium		t	t	t			
Selenium		t	t	t			
Bismuth	0.04		0.04	0.05			
Gallium	t		t	t			
			Total	26.0		Total	31.6
			TSP	55.5		TSP	44.8

---

[1] Compare total column with fuel analysis column

[2] Not included in summation

TABLE 4-28. MASS BALANCE FOR TEST 13

219,003 lb/hr fuel flow; 15.33 lb/hr particulate from ash; 68.5 lb/hr particulate from Joy

Fraction % Fraction Units	Joy Impinger 78% lb/hr	Joy Total[1] 100% lb/hr	Fuel Analysis Ash=0.007% lb/hr
Arsenic			
Vanadium			0.32
Iron	0.15	0.19	0.32
Nickel	0.05	0.06	1.33
Calcium	0.06	0.08	0.11
Magnesium			0.23
Sodium			0.63
Silicone			0.25
Manganese	0.05	0.06	0.012
Aluminum			0.17
Barium			0.13
Lead	0.05	0.06	0.04
Tin			0.17
Molybdenum			0.006
Copper	0.05	0.06	0.01
Silver			0.00007
Zinc	0.05	0.06	0.03
Titanium			0.02
Cobalt	0.05	0.06	0.06
Chromium	0.05	0.06	0.005
Strontium			0.009
Potassium	0.05	0.06	
Sulfur	9.59	(12.4)[2]	482
Rubidium			
Sulfate	10.94	14.1	
Nitrate	0.10	0.13	
Total Carbon	14.88	19.2	
Vol. Carbon	12.23	(15.8)[2]	
Carbonate	—		
Bromine	0.05	0.06	
Selenium	0.05	0.06	
Gallium			
	Total	34.3	
	TSP	68.5	

---

[1] Compare total column with fuel analysis column

[2] Not included in summation

TEST 4-29. MASS BALANCE FOR TEST 21

85,316 lb/hr fuel flow; 10.25 lb/hr particulate from ash; 29.8 lb/hr particulate from SASS

Fraction % Fraction Units	SASS Filter 11% lb/hr	SASS Impinger 73% lb/hr	Sum 84% lb/hr	Total[1] 100% lb/hr	Fuel Analysis Ash=0.012% lb/hr
Boron					0.005
Arsmic	0.003		0.003	0.003	
Vanadium	0.01		0.01	0.01	0.40
Iron	0.03	0.08	0.11	0.13	1.95
Nickel	0.05	0.02	0.07	0.08	0.85
Calcium	0.003		0.003	0.003	0.56
Magnesium					0.26
Sodium					1.33
Silicone					0.12
Manganese		0.02	0.02	0.02	0.01
Aluminum					0.04
Barium					0.03
Lead	0.003		0.003	0.003	0.04
Tin					0.01
Molybdenum		0.02	0.02	0.02	
Copper		0.02	0.02	0.02	0.005
Silver					0.0002
Zinc	0.003	0.02	0.023	0.03	0.15
Titanium					0.03
Cobalt	0.003	0.02	0.023	0.03	0.03
Chromium		0.02	0.02	0.02	0.006
Strontium	0.003	0.02	0.023	0.03	0.01
Potassium	0.003	0.02	0.023	0.03	
Sulfur	0.21	4.16	4.37	(5.17)[2]	1.71
Selenium	0.003	0.08	0.083	0.1	
Sulfate	1.81	6.82	8.63	10.21	
Nitrate	0.01	0.03	0.04	0.05	
Total Carbon	0.30	1.97	2.27	2.69	
Vol. Carbon	--	1.31	1.31	(1.55)[2]	
Carbonate	--	--			
Bromine		0.02	0.02	0.02	
Zirconium		0.02	0.02	0.02	
			Total	13.5	
			TSP	29.8	

---

1 Compare total column with fuel analysis column

2 Not included in summation

TABLE 4-30. MASS BALANCE FOR TEST 22

43,174 lb/hr fuel flow; 5.18 lb/hr particulate from ash; 20.2 lb/hr particulate from SASS

Fraction % Fraction Units	SASS Filter 10% lb/hr	Sum 10% lb/hr	Total[1] 100% lb/hr	Fuel Analysis Ash=0.012% lb/hr
Boron				0.002
Arsenic	0.002	0.002	0.02	
Vanadium	0.03	0.03	0.29	0.20
Iron	0.07	0.07	0.69	0.98
Nickel	0.10	0.10	0.98	0.43
Calcium				0.28
Magnesium				0.13
Sodium				0.67
Silicone				0.06
Manganese	0.002	0.002	0.02	0.005
Aluminum				0.02
Barium				0.02
Lead	0.002	0.002	0.02	0.02
Tin				0.005
Copper				0.002
Silver				0.0001
Zinc	0.002	0.002	0.02	0.08
Titanium				0.02
Cobalt	0.002	0.002	0.02	0.01
Strontium				0.005
Sulfur	0.56	0.56	(5.49)[2]	86
Selenium	0.002	0.002	0.02	
Sulfate	1.38	1.38	15.53	
Nitrate	0.0004	0.0004	0.004	
Total Carbon	0.15	0.15	(1.47)[2]	
Vol. Carbon	—			
Carbonate	—			
		Total	17.6	
		TSP	20.2	

---

[1] Compare total column with fuel analysis column

[2] Not included in summation

TABLE 4-31. MASS BALANCE FOR TEST 24

115,238 lb/hr fuel flow; 13.63 lb/hr particulate from ash; 46.2 lb/hr particulate from SASS; 59.3 lb/hr particulate from Joy

Fraction % Fraction Units	SASS Filter 14% lb/hr	SASS Impinger 75% lb/hr	SASS Sum 89% lb/hr	SASS Total[1] 100% lb/hr	Fuel Analysis Ash=0.012% lb/hr	Joy Impinger 74% lb/hr	Joy Total 100% lb/hr
Boron					0.002		
Bromine	0.006	0.03	0.036	0.04			
Vanadium	0.055		0.055	0.06	0.57		
Iron	0.143	0.86	1.003	0.09	1.52	0.12	
Nickel	0.43	0.16	0.59	0.66	1.66	0.04	0.05
Calcium		0.12	0.12	0.14	0.66	0.13	0.18
Magnesium					0.39		
Silicone					0.30		
Manganese	0.006	0.03	0.036	0.04	0.02	0.04	0.05
Aluminum					0.08		
Barium	0.009		0.009	0.01	0.06		
Lead	0.008	0.03	0.038	0.04	0.10	0.04	0.05
Cadmium		0.03	0.03	0.03	0.05		
Molybdenum		0.03	0.03	0.03			
Copper		0.03	0.03	0.03	0.013	0.04	0.05
Silver		0.03	0.03	0.03	0.0003		
Zinc	0.016	0.03	0.46	0.05	0.17	0.04	0.05
Titanium					0.03		
Cobalt					0.04	0.04	0.05
Chromium		0.21	0.21	0.24	0.02	0.04	0.05
Strontium		0.03	0.03	0.03	0.02		
Potassium		0.03	0.03	0.03			
Sulfur		7.59	7.59	(8.55)[2]	220	13.18	(17.79)[2]
Selenium	0.006	0.03	0.036	0.04		0.04	0.05
Sulfate	3.11	8.41	11.52	12.97		11.2	15.11
Nitrate	—	—				—	
Total Carbon	0.8	8.63	9.43	10.62		5.71	7.71
Vol. Carbon	—	1.04	1.04	(1.17)[2]		5.27	(7.11)[2]
Carbonate	—	—				0.09	(0.12)[2]
			Total	26.3		Total	23.4
			TSP	46.2		TSP	59.3

1 Compare total column with fuel analysis column
2 Not included in summation

TABLE 4-32. MASS BALANCE FOR TEST 32

210,857 lb/hr fuel flow; 23.19 lb/hr particulate from ash; 84.5 lb/hr particlate from SASS; 58.7 lb/hr particulate from Joy.

t < 0.1 lb/hr

Fraction % Fraction Units	SASS Impinger 76% lb/hr	SASS Filter 10% lb/hr	Sum 86% lb/hr	Total[1] 100% lb/hr	Fuel Analysis Ash=0.011% lb/hr
Boron					0.003
Vanadium		0.09	0.09	0.1	2.09
Iron	0.47	0.09	0.56	0.65	2.32
Nickel	0.11	0.73	0.84	0.98	2.78
Calcium	0.13	0.79	0.92	1.12	1.04
Magnesium					0.97
Sodium					2.13
Silicone					0.46
Manganese	t		t	t	0.03
Aluminum					0.81
Barium		t	t	t	0.1
Lead		t	t	t	0.13
Tin					0.94
Molybdenum	t		t	t	0.005
Copper	t		t	t	0.03
Silver					0.0005
Zinc	t	t	t	t	0.13
Titanium					0.015
Cobalt	t	t	t	t	0.11
Chromium	0.11		0.11	0.13	0.03
Strontium	t		t	t	0.017
Cadmium	t		t	t	
Sulfur	9.6	2.3	11.9	(13.9)[2]	464
Selenium	0.13		0.13	0.15	
Sulfate	15.2	5.4	20.5	24.0	
Nitrate	13.3		13.3	15.5	
Total Carbon	11.5		11.5	13.4	
			Total	56	
			TSP	84.5	

---

1 Compare total column with fuel analysis column

2 Not included in summation

TABLE 4-33. MASS BALANCE FOR TEST 33

209,055 lb/hr fuel flow; 27.18 lb/hr particulate from ash; 96.9 lb/hr particulate from SASS; 97.7 lb/hr particulate from Joy.

Fraction % Fraction Units	SASS Impinger 64% lb/hr	SASS Filter 14% lb/hr	Sum 78% lb/hr	Total [1] 100% lb/hr	Fuel Analysis Ash=0.013% lb/hr
Boron					0.002
Arsenic		0.01	0.01	0.01	
Vanadium		0.01	0.01	0.01	2.2
Iron	0.7	.49	1.19	1.51	4.1
Nickel	0.1	0.87	0.97	1.23	2.7
Calcium	0.09	1.4	1.13	1.44	1.0
Magnesium					1.0
Sodium					2.3
Silicone					0.6
Manganese	0.06		0.06	0.08	0.04
Aluminum					1.7
Barium	0.06	0.09	0.15	0.19	0.1
Lead	0.06	0.01	0.07	0.09	0.1
Tin					0.05
Molybdenum	0.06		0.06	0.08	0.006
Copper	0.06		0.06	0.08	0.02
Silver					0.0006
Zinc	0.1	0.05	0.15	0.19	0.05
Titanium					0.02
Cobalt	0.06	0.02	0.08	0.1	0.1
Chromium	0.2		0.02	0.03	0.05
Strontium		0.01	0.01	0.01	0.02
Sulfur	10	4.2	14.2	(18.06) [2]	420
Bromine	0.06		0.06	0.08	
Sulfate	14.54	8.14	22.68	28.84	
Nitrate	12.63	7.37	20.0	25.44	
Total Carbon	12.47	—	12.47	15.86	
Vol. Carbon	12.47	—	12.47	(15.86) [2]	
Carbonate	—	—			
Cadmium	0.06		0.06	0.08	
Selenium	0.07		0.07	0.09	
			Total	75.5	
			TSP	96.9	

[1] Compare total column with fuel analysis column

[2] Not included in summation

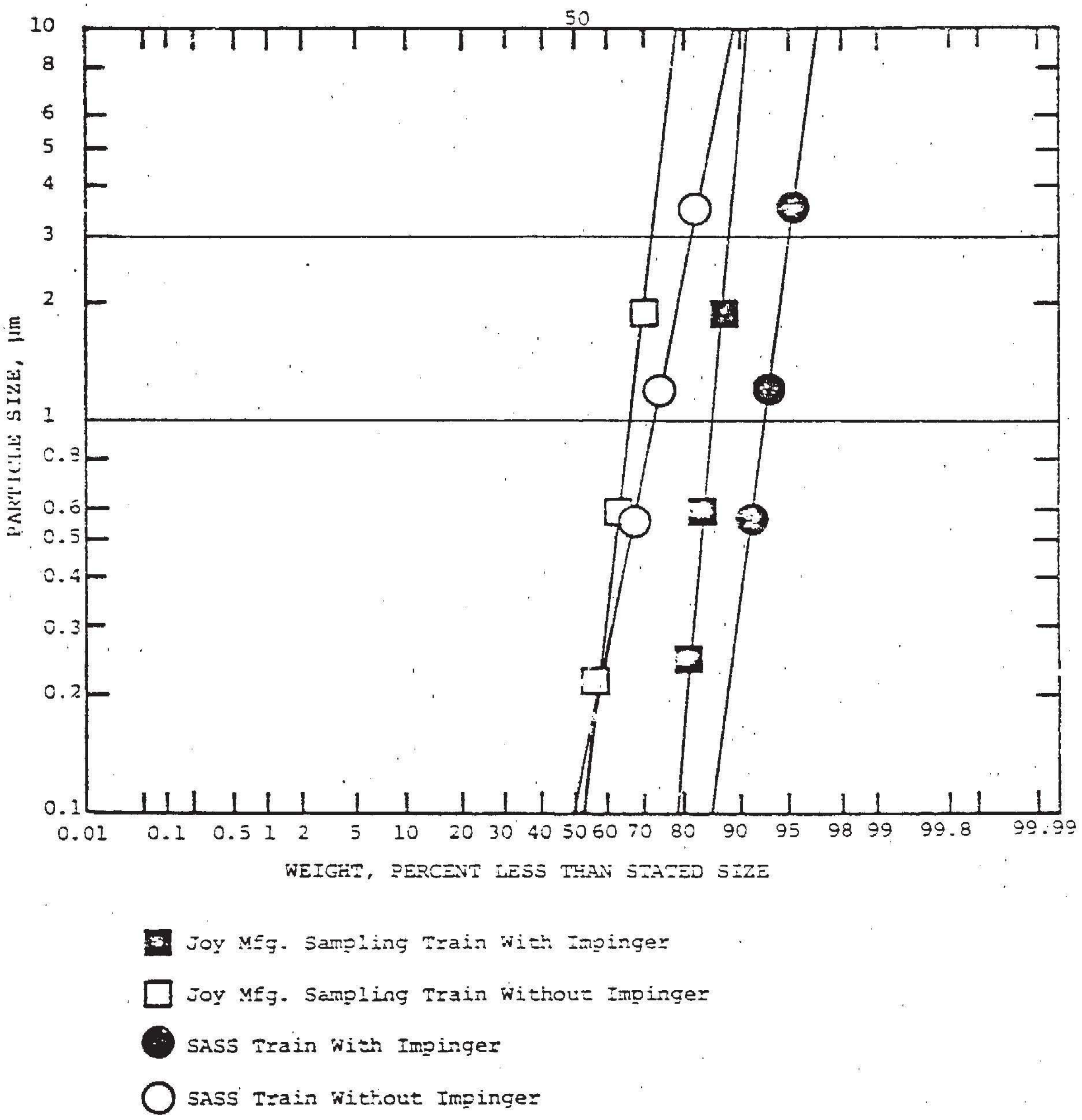


Figure 4-17. Particle size distribution for utility boilers (Test 11).

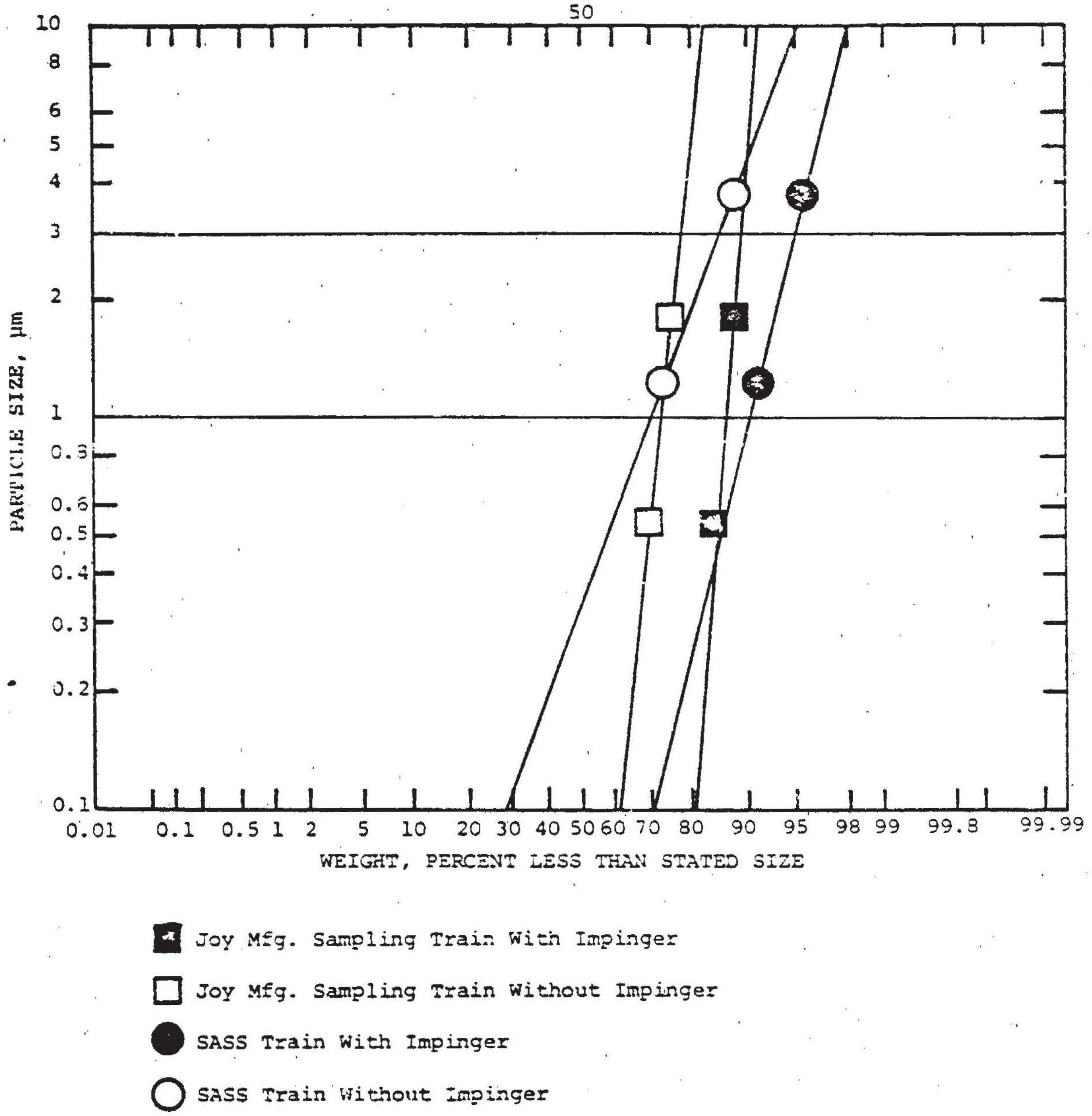


Figure 4-18. Particle size distribution for utility boilers (Test 12).

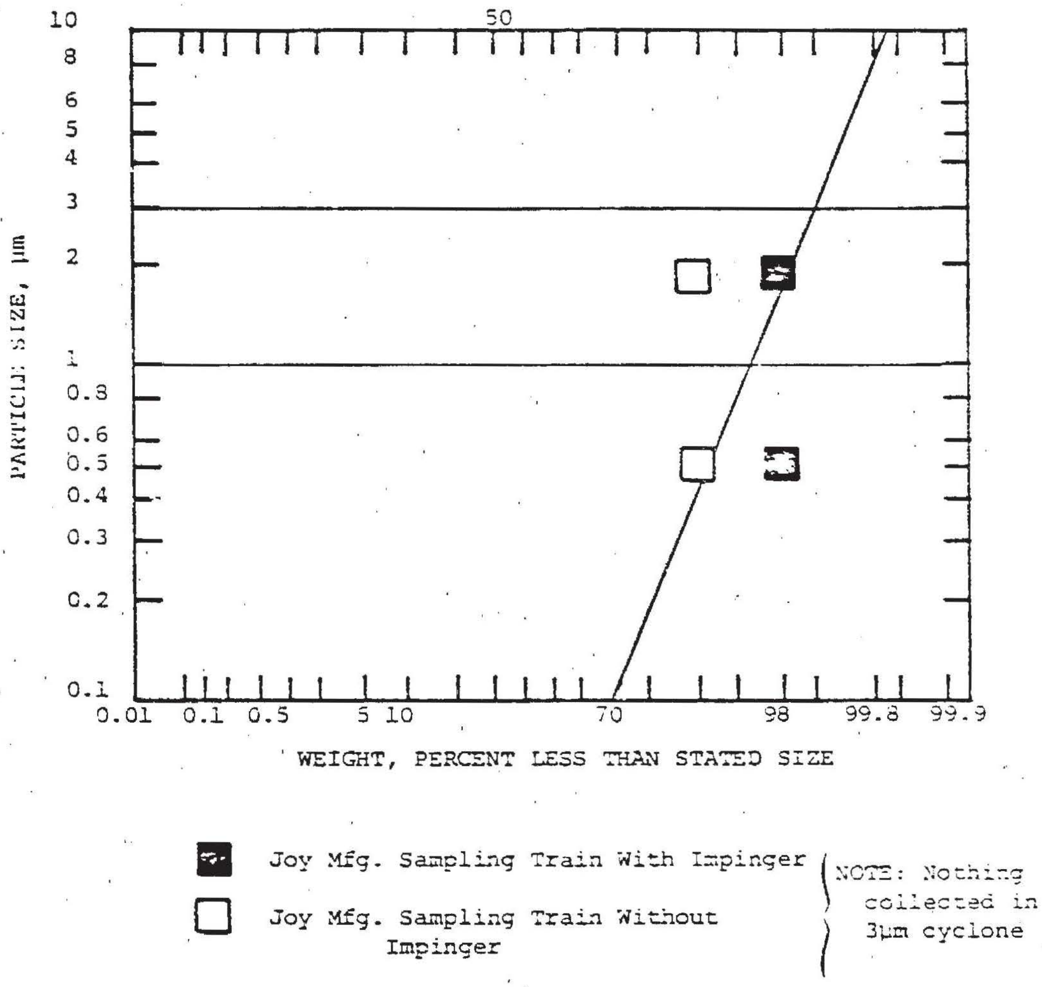


Figure 4-19. Particle size distribution for utility boilers (Test 13).

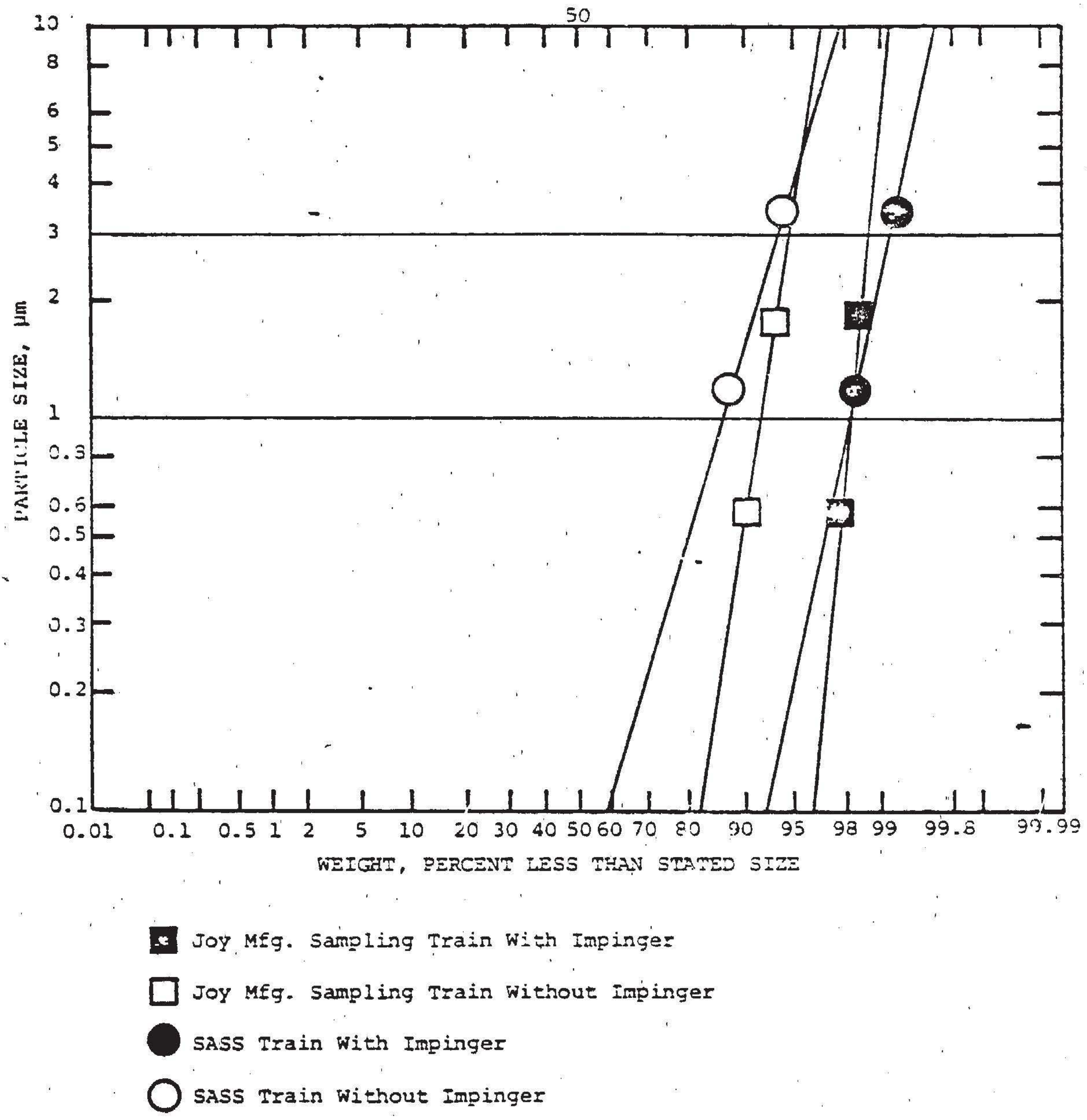


Figure 4-20. Particle size distribution for utility boilers (Test 21).

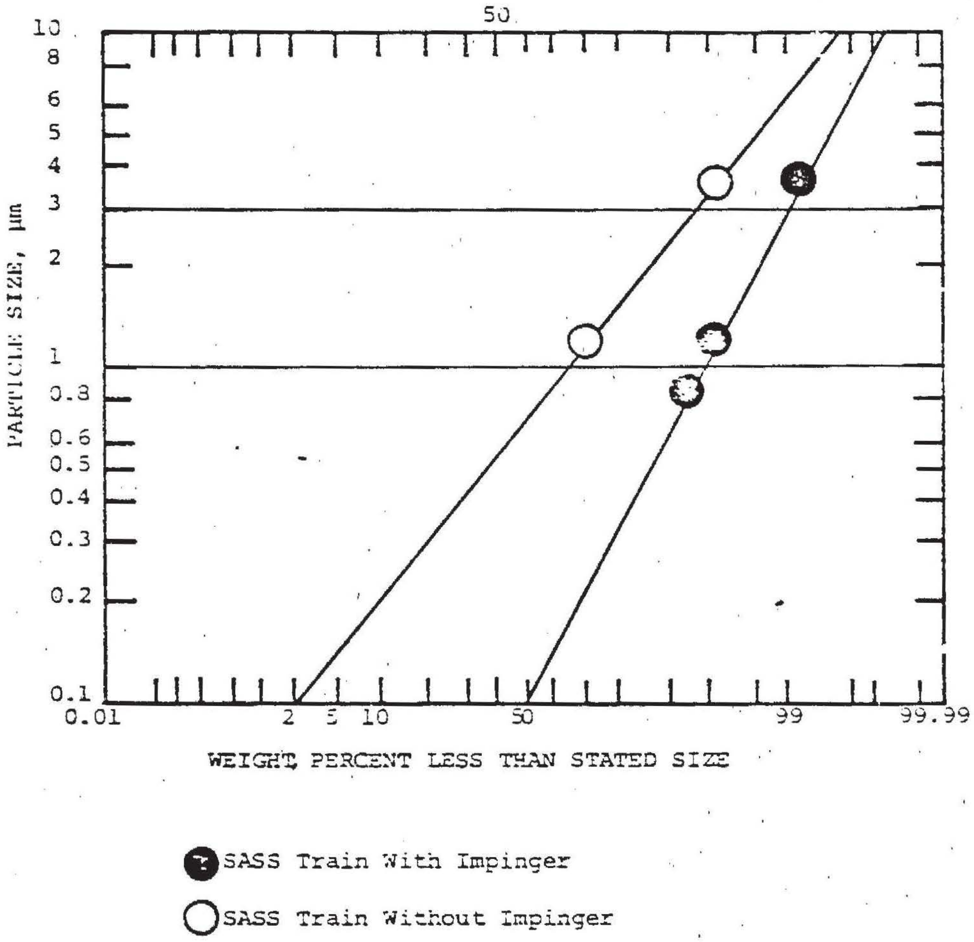
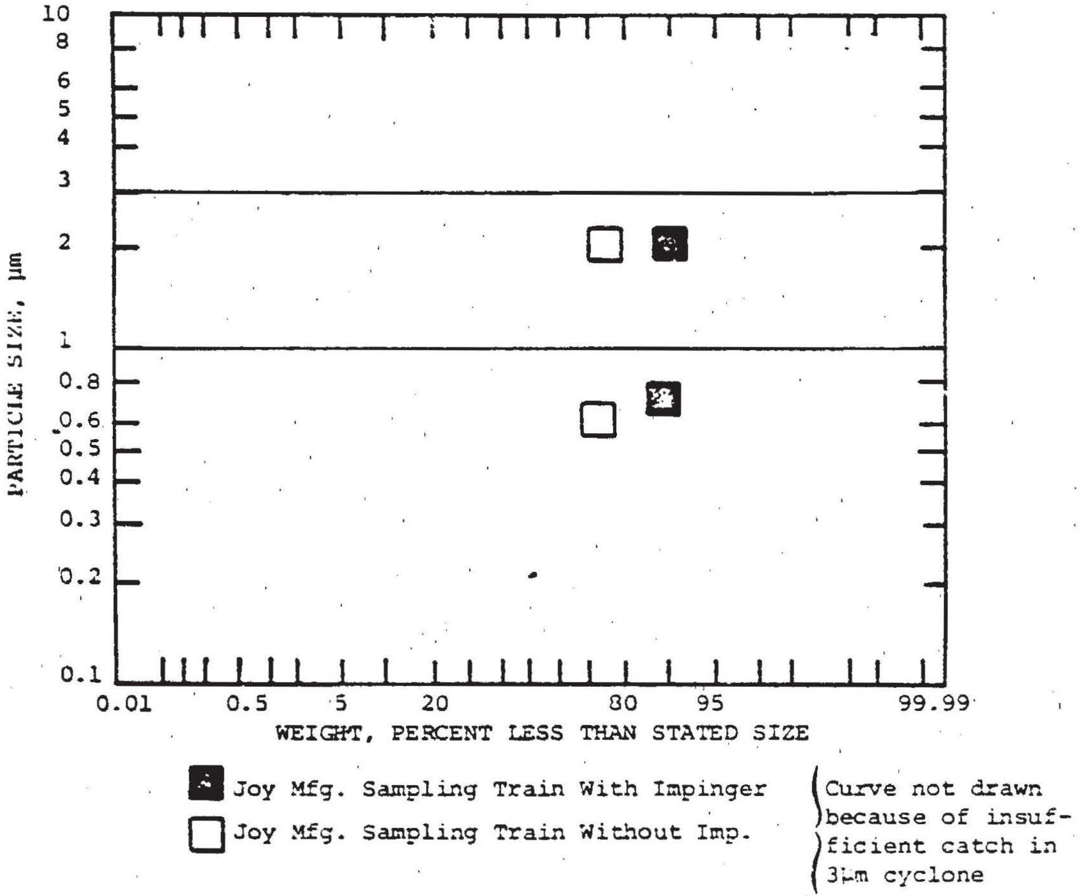


Figure 4-21. Particle size distribution for utility boilers (Test 22).



Curve not drawn because of insufficient catch in 3μm cyclone

Figure 4-22. Particle size distribution for utility boilers (Test 23).

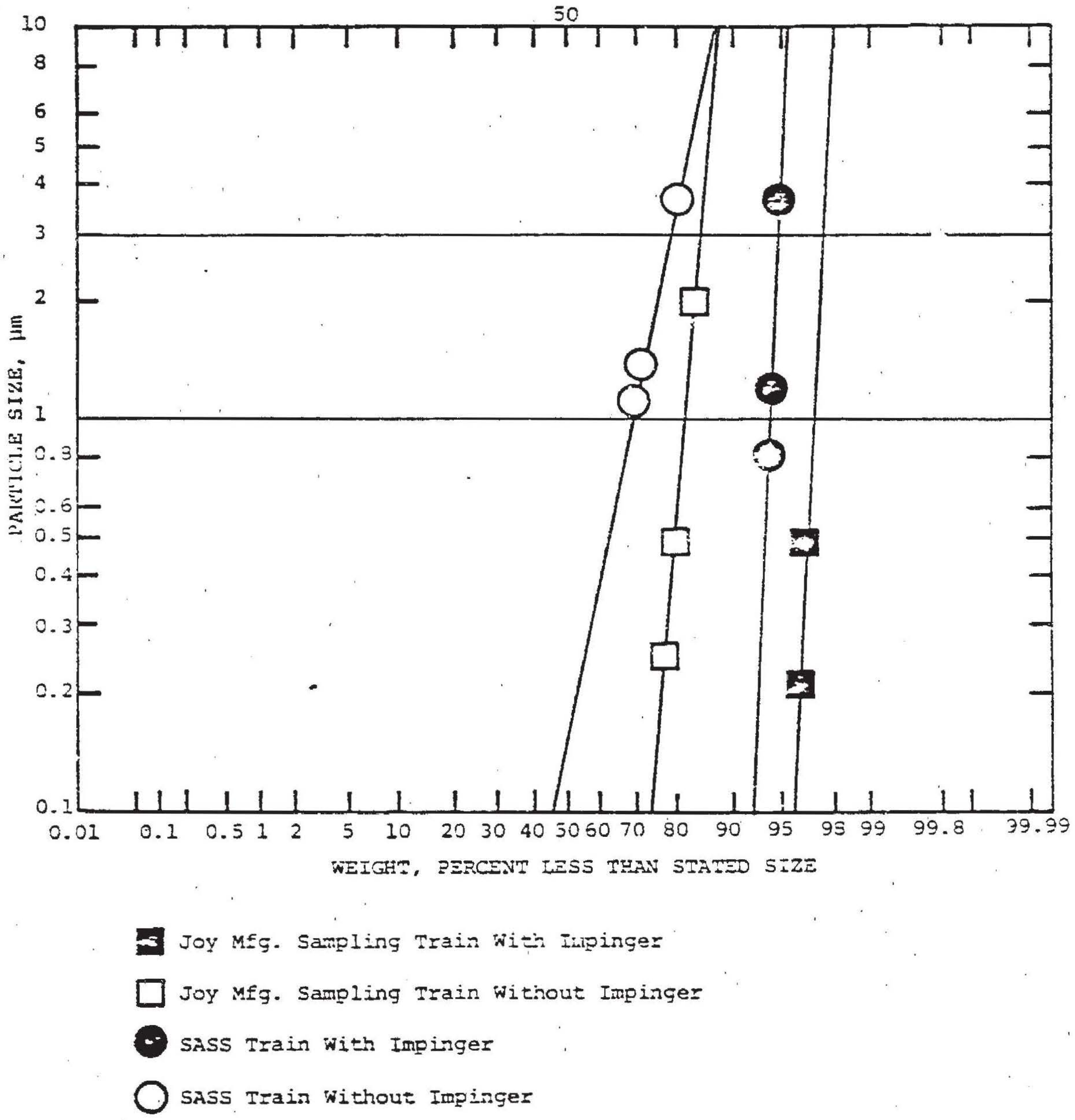


Figure 4-23. Particle size distribution for utility boilers (Test 24).

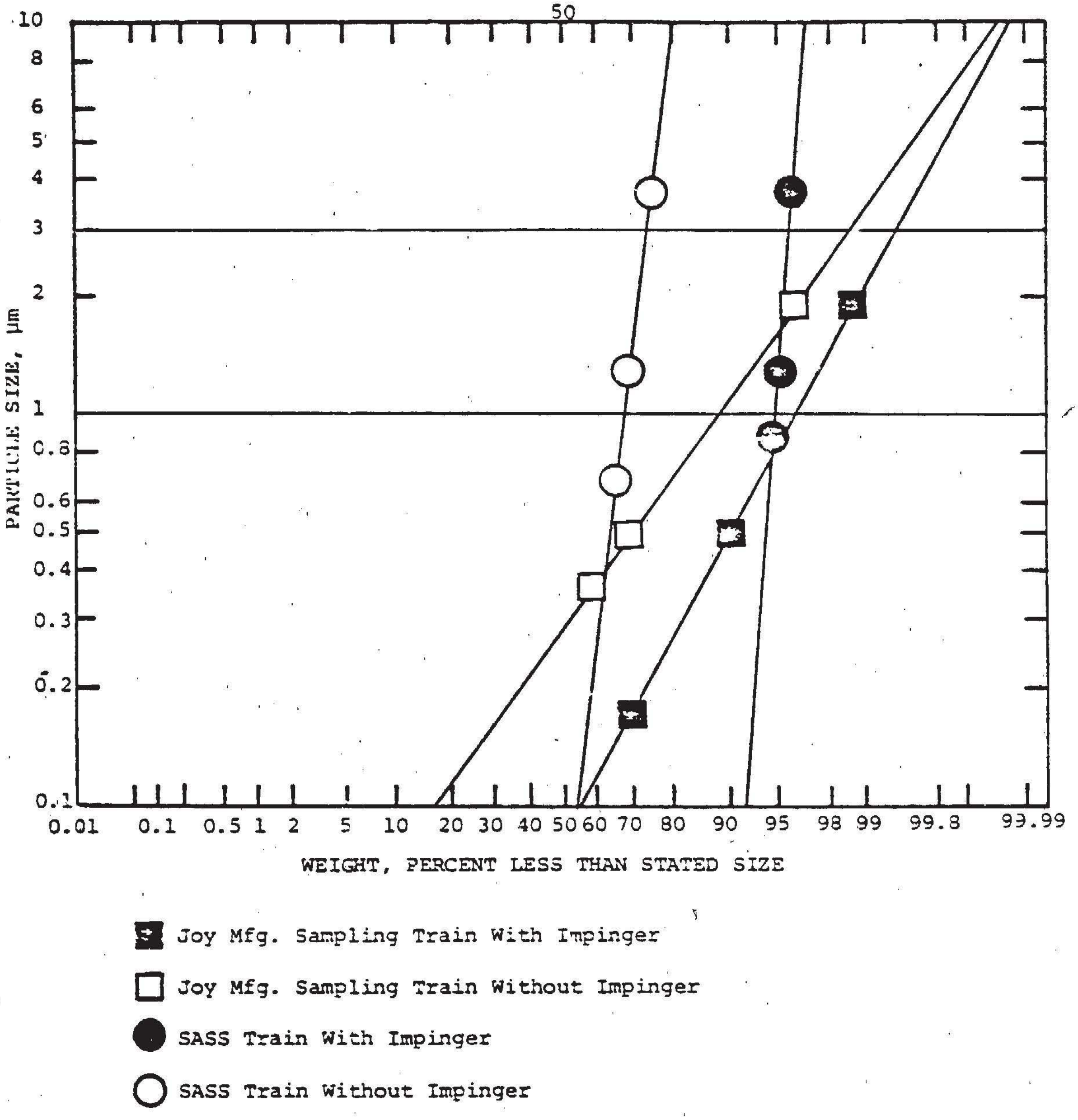


Figure 4-24. Particle size distribution for utility boilers (Test 32).

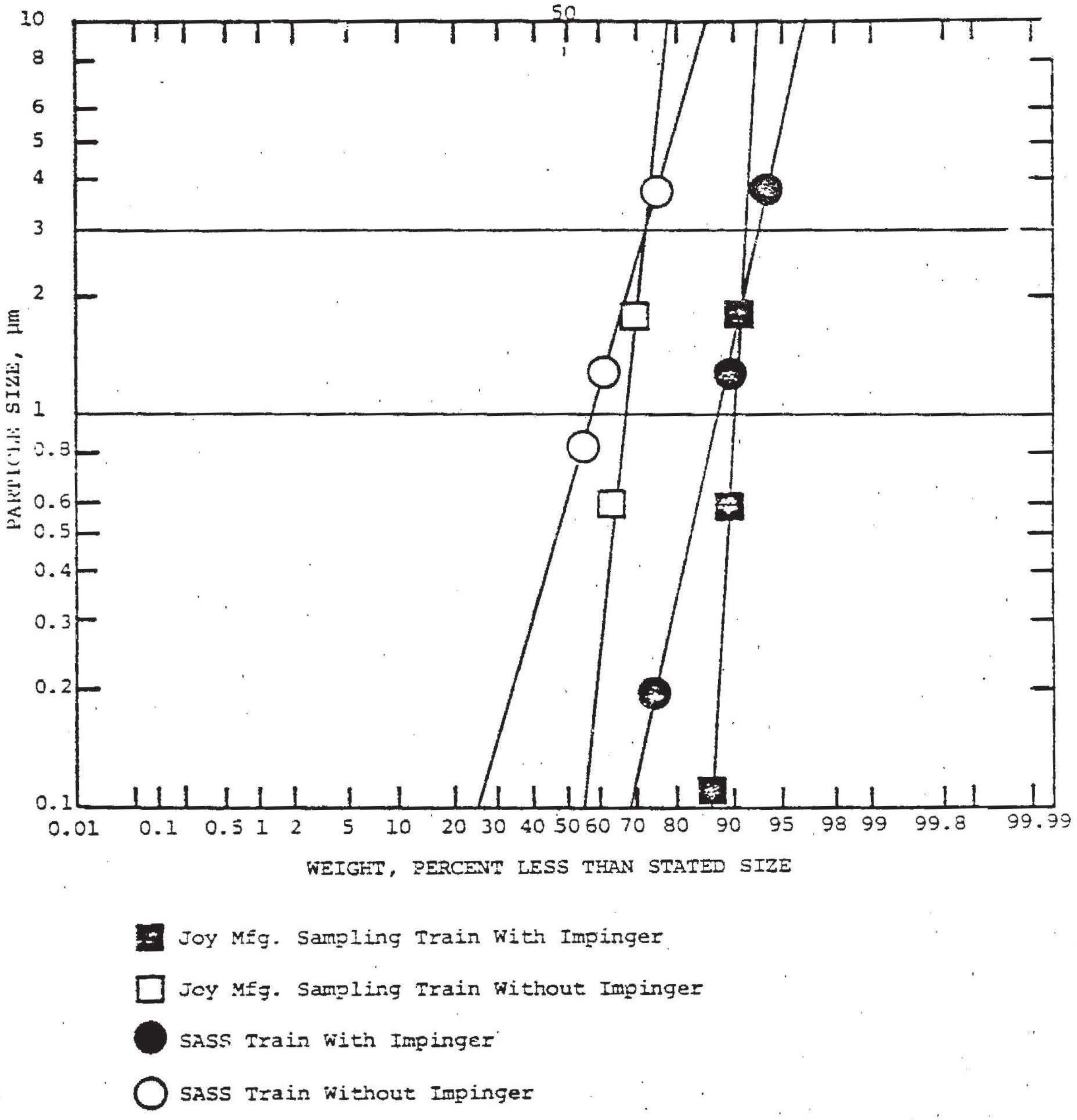


Figure 4-25. Particle size distribution for utility boilers (Test 33).

Test No.	Weight Percent of Particles* >10μm	 10-3μm	 3-1μm	 <1μm
11S	3	2	1	94
11J	9	3	3	85
12S	2	3	5	90
12J	9	3	3	85
13J	2	0	0	98
23J	8	1	1	90
24S	5	0.5	0.5	94
24J	2	0.5	0.5	97
32S	3	1	1	95
32J	0.1	0.9	3	96
33S	4	4	5	87
33J	8	1	1	90
21S	0.3	0.7	1	98
21J	0.9	0.4	0.7	98
22S	0.1	0.9	4	95
Mean*	4	1	2	93

For two of the tests (13J, 23J), the amount of matter collected in the middle cyclone was so small that when plotted on the size distribution curve it would appear to give a vertical line. For this reason the line for these two tests were not drawn. Care must be taken when projecting the size distribution curve to outside the range of 1-10 m. This is outside the range of the data and when projections are made the error in doing so is greatly increased.

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*Taken from Figure 4-26

Figure 4-26 is the particle size distribution range determined for the 18 utility boiler tests. The area between the solid lines is the particle size distribution range with the impinger catch, and the area between the dashed lines is without the impinger catch. The mean particle size including the impinger catch (i.e. particle size at the 50% point) is less than 0.1 µm.

3. Particulate mass balance (elements in ash vs. elements in particulate catch)--The mass of each element in the ash of the fuel going into the atmosphere as particulates (second law of thermodynamics). Table 4-26 lists the results of the fuel analysis for each of the fuels burned for each utility boiler particulate test. To calculate the mass rate of each element from the fuel analysis, the following equation was used:

$$(\text{element }\%/100) \times (\text{ash}\%/100) \times (\text{lb/hr of fuel burned}) = \text{lb/hr of element}_{\text{IN}}$$

Chemical Composition

Tables 4-17 to 4-24 present the chemical composition for the various utility boiler tests. In each case the primary constituents of the particulate matter was found to be sulfates ranging from 20 to 50% by weight. The sulfur determined by XRF should be 1/3 of the percent of the sulfates determined by wet chemistry. The table shows sulfur based on the sulfate analysis and on the XRF analysis. The agreement is fair, sometimes the XRF value is higher and other times the sulfate value is higher. The sulfate value is the more reliable determined by accurate wet chemistry techniques. The XRF method for sulfur is only approximate because sulfur is on the low limit of the XRF sensitivity. the next largest constituent is total carbon averaging approximately 10% although values vary from 1 to 83%. The values reported are the average of two determinations and several apparent others were retested and confirmed.

The other elements detected in measurable quantities are iron, nickel, and to a lesser extent calcium. Traces of the following metals were also found: barium, cobalt, selenium, potassium, titanium, vanadium, and zinc.

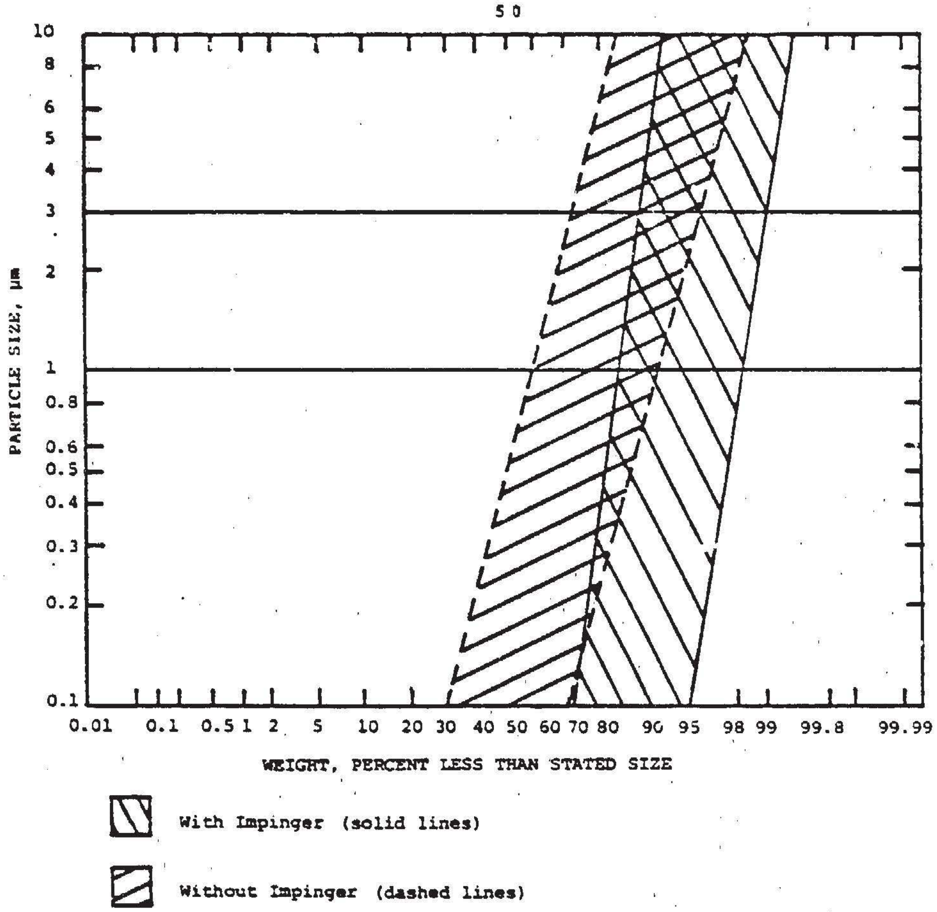


Figure 4-26. Summary of particle size distribution for utility boilers (15 tests).

The results of this calculation for each element are listed in the left column in Table 4-26 to Table 4-33 for each test. To calculate the mass rate of each elemental from the chemical analysis of the particulate catches the following equation was used:

$$\left(\frac{\text{element } \%}{100}\right) \times \left(\frac{\% \text{ fraction}}{100}\right) \times (\text{particulate emission lb/hr})$$

$$= \text{lb/hr of element (out) for each fraction}$$

The mass rate, lb/hr of each element for the fractions are added and the percentage of the fractions are added. The sum of each element is divided by the sum of the fractions (decimal equivalent) to give the total mass rate, lb/hr, of elements going out the stack. These are listed in Table 4-26 to Table 4-33.

In some cases, as in Tests 12 and 24, both SASS and Joy sampling trains had at least one fraction with large enough samples for chemical analysis. Thus a mass balance was done for each sampling train.

4. <u>Emissions and emission factors</u>--Emissions and emission factors can be listed for several different units. The list below shows some of these emissions and factors.

	Emissions				
Test #	gr/DSCF	T/yr	lb/hr	lb/MMBtu	lb/1000 gal burned
11S	0.0091	284	65.03	0.0154	2.29
11J	0.0078	243	55.6	0.0132	1.96
12S	0.0072	242	55.5	0.0130	1.94
12J	0.0058	196	44.8	0.0105	1.56
13S*	0.0271	928	212.4	0.050	7.47
13J	0.0088	299	68.5	0.0162	2.41
23S*	0.0285	921	210.3	0.0554	8.04
23J	0.0084	268	61.3	0.0161	2.34
24S	0.0112	202	46.2	0.0214	3.55
24J	0.0144	259	49.3	0.0275	4.57
32S	0.0124	369	84.5	0.0211	3.09
32J	0.0086	256	58.7	0.0147	2.14
33S	0.0132	423	36.9	0.0244	3.56
33J	0.0133	427	97.7	0.0246	3.59
21S	0.0092	130	29.8	0.022	2.77
21J	0.0071	101	23.0	0.017	2.13
22S	0.0109	87	20.2	0.023	3.70
22J*	0.0046	38	8.6	0.0099	1.57
Average	0.0098	252	57.1	0.0185	2.77

* Not included in the average (bad data)

The average emission factor for these tests is 2.77 lb/1000 gal. However, this value is about half the emission factor that the SCAQMD uses in the EIS system. This is because EIS system has not been updated since the new low sulfur (0.25%) regulation has been in effect. Figure 4-27 plots the emission factor vs fuel sulfur contents. Particulate emission data from several sources have been obtained to generate this plot. The relationship from AP-42 (Ref. 4-7, top line) which uses only the front half of the particulate catch (does not include impinger catch) seems to be high compared to the obtained data. The relationship given by SCAQMD (Ref. 4-8) which is for the total catch (impinger catch included) seems correct for high sulfur fuel, but seems too high for lower sulfur fuels. The relationship given by Goldstein and Sigmond (Ref. 4-1) seems to fit most of the data presented here. What is the emission factor for the 0.25% sulfur fuel? The average of the 15 KVB/ARB tests was 2.77 lb/1000 gal and the average of six other particulate tests was 2.9 lb/1000 gal. The emission factor is suggested to be 3.0 lb/1000 gal.

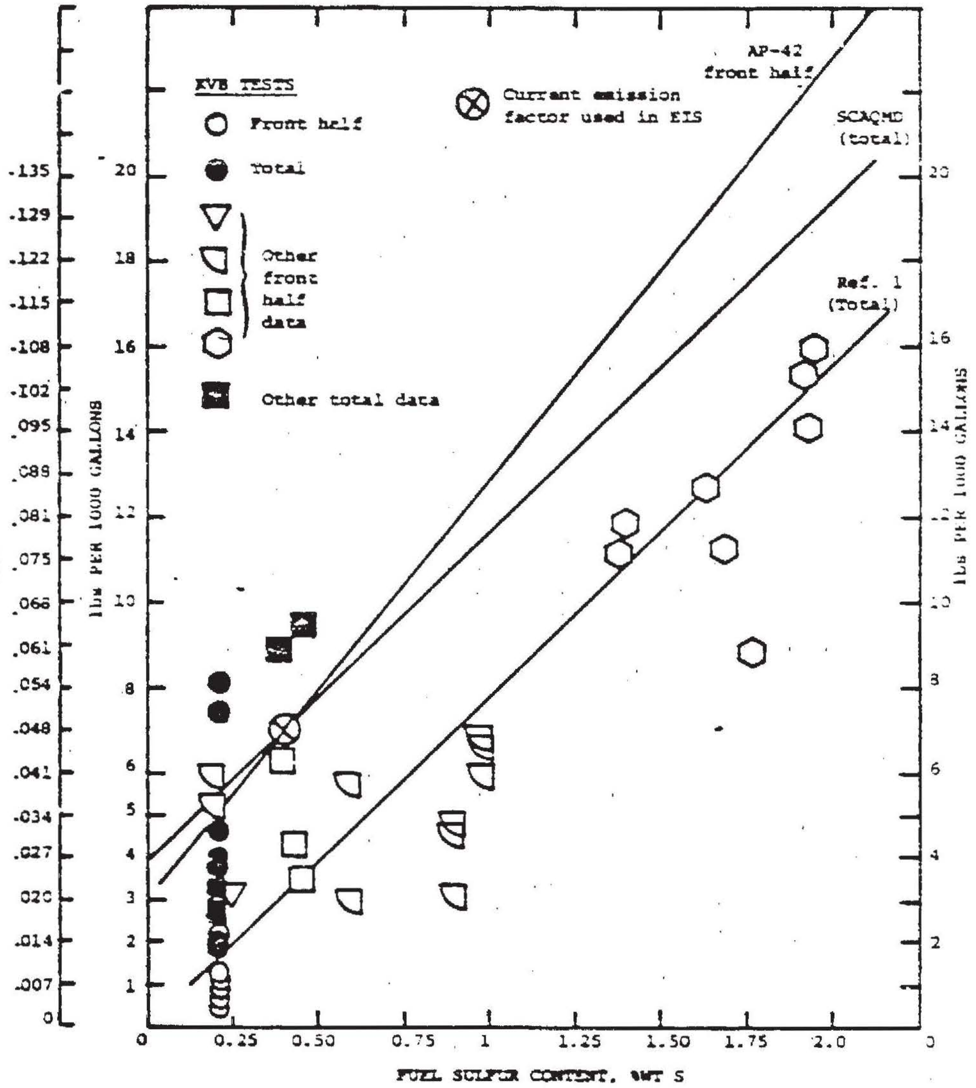


Figure 4-27. Emission factors as a function of fuel sulfur content for utility boilers.

4.2.5 Internal Combustion Engines

A. Process Description--

The internal combustion engines, for this study, are in general, large, heavy-duty, general utility reciprocating engines. These are generally used to generate electric power, to pump gas or other fluids, or to compress air for pneumatic machinery.

1. The function of the IC engine in Test 7 is to pump fluids. This is a Climax, gas fueled, reciprocating engine. The fuel was digested gas from a waste disposal operation.

2. The function of the IC engine in Test 15 is to generate electric power. This 2400 hp, turbocharged, diesel-fueled (EMD) engine was manufactured by Electro Motive Division, General Motors Corporation.

B. Particulate Test Set-up--

1. Test 7, IC engine with digester gas fuel--Two sampling trains were used simultaneously at the same location on the exhaust duct of the IC engine. This sampling station was on the vertical section of the duct (5-1/8" diameter) leading to the atmosphere, at least six duct diameters from the nearest bend. The velocity profile in this duct is listed in Table 4-34 The particulate sample was taken through a 9/16" nozzle for the larger SASS train at Velocity Point 6 and through a 5/16" nozzle for the smaller Joy train at Point 7.

2. Test 15, IC engine with #2 diesel fuel--Only the smaller Joy train was used to sample particulates from this source. The sampling station was located on the vertical section of the duct (18-3/4" diameter) leading to the muffler (see Figure 4-28). The velocity profile in the duct is listed in Table 4-35. The particulate sample was taken through a 1/4" nozzle at Velocity Points 1, 3, and 8 for 80 minutes each.

C. Particulate Test Results--

The results of the tests (Test 7 and Test 15) discussed in this section are listed in Table 4-1. Elemental composition, sulfate, nitrate, and

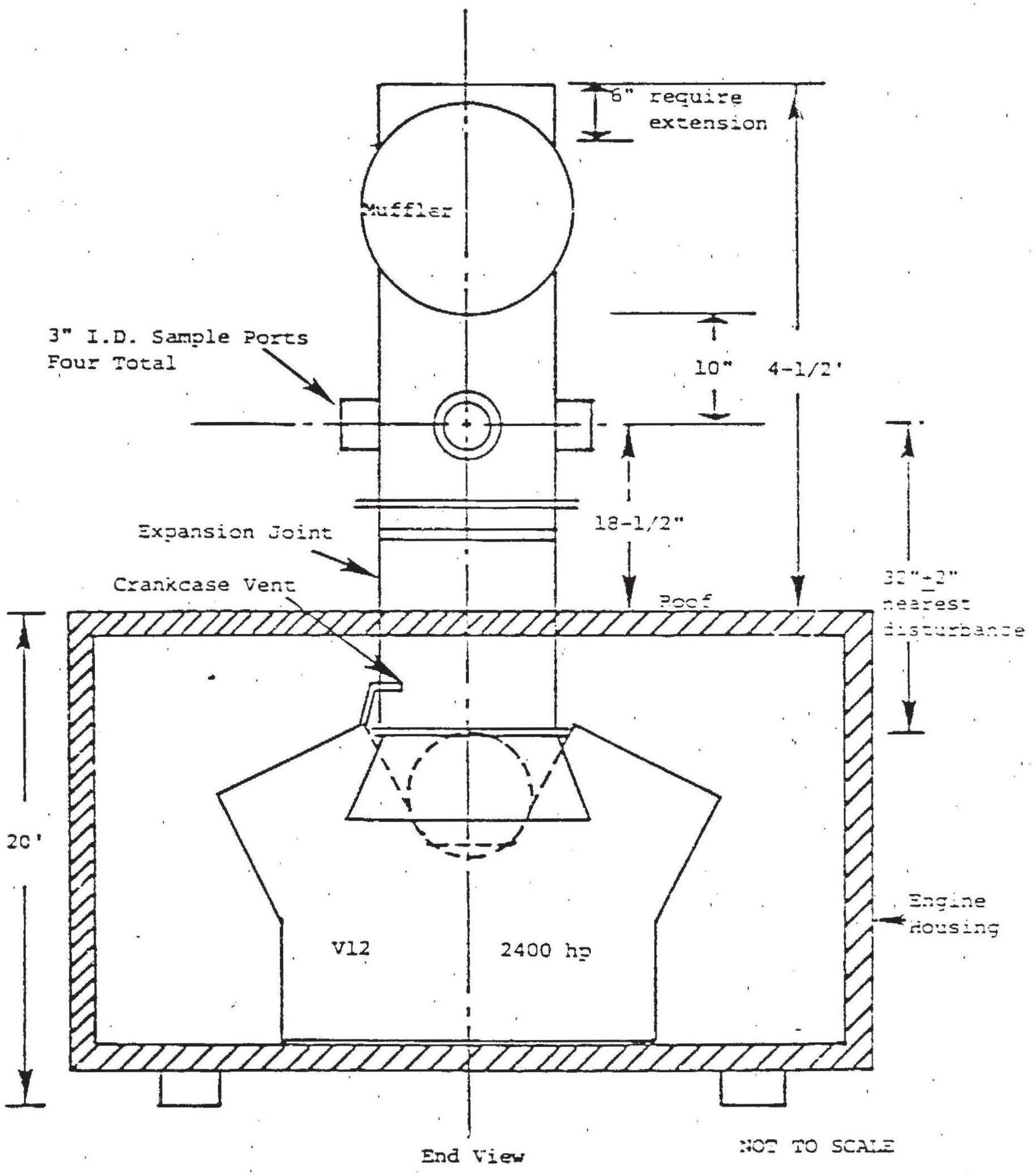
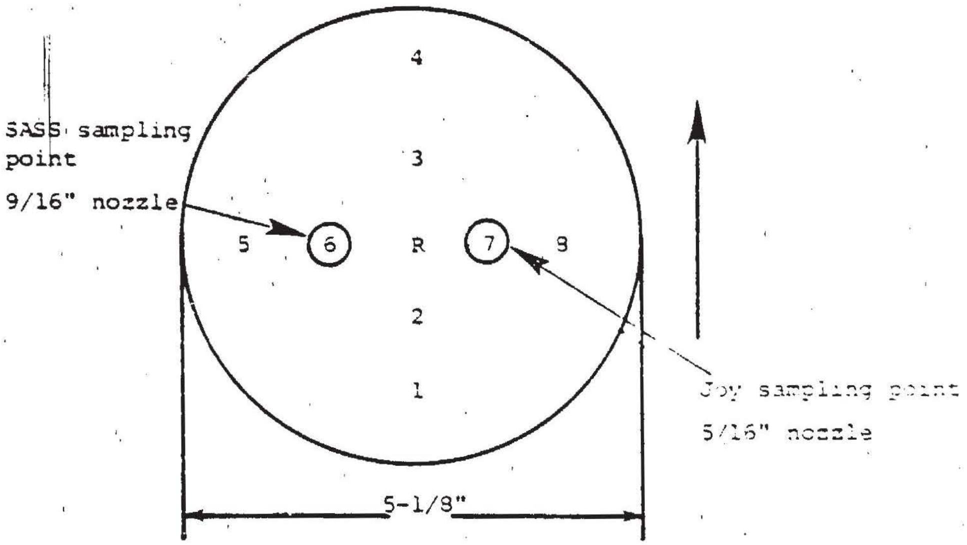


Figure 4-28. Schematic of IC engine (Test 15).

TABLE 4-34. VELOCITY PROFILE FOR INTERNAL COMBUSTION ENGINE (TEST 7)



Temperature: 412°F

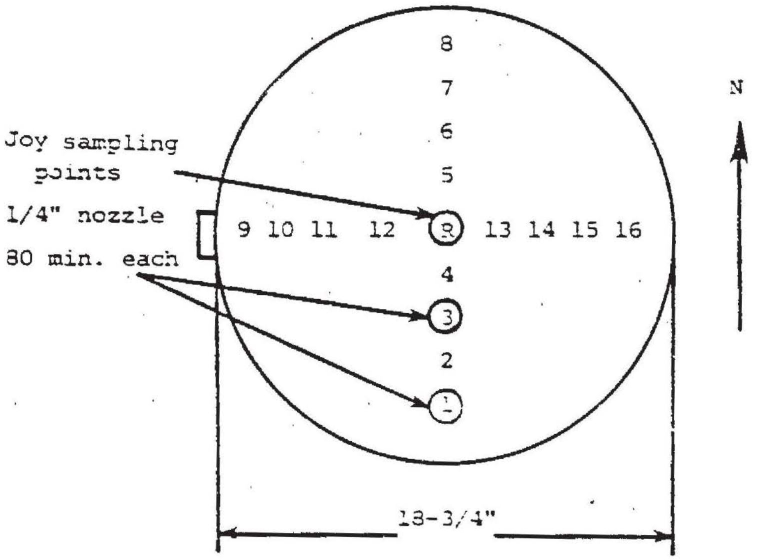
Static Pressure: 0.1" H_2O

Distance from end of duct	Velocity			
	Point #	ft/sec	Point #	ft/sec
0.3"	1	48.4	5	46.9
1.3"	2	47.7	6	59.3
2.6"	R	58.1	R	61.2
3.9"	3	59.3	7	60.6
4.8"	4	58.7	8	60.0

Average: 56.0 ft/sec

285 SCFM

TABLE 4-35. VELOCITY PROFILE FOR IC ENGINE
(TEST 15)



Temperature: 520°F

Static Pressure: +4-1/2" H_2O

Distance from internal wall	Velocity			
	Point #	ft/sec	Point #	ft/sec
0.6"	1	137	8	97
2.0	2	134	9	81
3.7	3	142	10	72
6.0	4	131	11	77
9.4	R	102	R	93
12.7	5	102	13	93
15.1	6	118	14	104
16.8	7	134	15	113
18.1	8	137	16	116

Average: 108 ft/sec

5508 SCFM

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. Tables 4-36 and 4-37 list the results from these analyses.

D. Discussion of Results--

1. Particle size distribution--Figure 4-29 is a plot 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 large amount of material 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 IC engines. The breakdown of the particle size distribution taken from Figure 4-29 including the impinger catch, is as follows:

	Percent of Particles			
	>10µm	10-3µm	3-1µm	<1µm
Test 7S (digester gas)	0.6	0.15	0.35	99.1
Test 7J (digester gas)	0.8	0.4	0.6	98.4
Test 15J (#2 diesel oil)	4	2	2	92

Note that the size of particle appears to be smaller for IC engines burning digester gas than for IC engines using #2 diesel fuel.

2. Chemical composition--Tables 4-36 and 4-37 list the results from the chemical analysis of the particulate fraction for each of the tests discussed in this section. For Test 7, sulfates and carbon are most abundant, followed by chlorine. The fuel analysis of the diesel oil used for Test 15 is listed in Table 4-40. For Test 15, sulfates and carbon are most abundant followed by calcium 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.

Units	Fuel--Digester Gas Test 7S	Fuel--Digester Gas Test 7J	Fuel--#2 Diesel Oil Test 15J
gr/DSCF	0.04	0.02	0.03
T/yr	0.4	0.2	4.5
lb/hr	0.09	0.04	1.4
lb/MMBtu	0.06	0.03	0.1
lb/1000 gal burned	--	--	8
lb/1000 gal burned (Ref. 1)	--	--	13
lb/million ft^3	11.5	5	--

4.2.6 Portland Cement Manufacturing

A. Process Description (Ref. 4-10 to 4-12)--Portland cement manufacture accounts for about 98% of the cement production in the United States. The more than 30 raw materials used to make cement may be divided into four basic components: lime (calcareous), silica (siliceous), alumina (argillaceous), and iron (ferriferous). Approximately 3200 pounds of dry raw materials are required to produce one ton of cement. Approximately 35% of the raw material weight is removed as carbon dioxide and water vapor. As shown in Figure 4-30, the raw materials undergo separate crushing after the quarrying operation, and when needed for processing, are proportioned, ground, and blended using the dry process.

In the dry process, the moisture content of the raw material is reduced to less than 1% either before or during the grinding operation. The dried materials are then pulverized into a powder and fed directly into a rotary kiln. Usually, the kiln is a long, horizontal, steel cylinder with a refractory brick lining. The kilns are slightly inclined and rotate about the longitudinal axis. The pulverized raw materials are fed into the upper end and travel slowly to the lower end. The kilns are fired from the lower end so that the hot gases pass upward and through the raw material. Drying, decarbonating, and calcining are accomplished as the material travels through a heated kiln, finally burning to incipient fusion and forming the clinker. The clinker is cooled, mixed with about 5% gypsum by weight, and ground to the final product fineness. The cement is then stored for later packaging and shipment.

(Ref. 4-9)

TABLE 4-36. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR IC ENGINES (TEST 7)

SAMPLE #	SASS Filter 07S-5S	SASS Impinger 7S-IC	Joy Impinger 7J-IC
PERCENT OF CUT	2	92	72
XRF ANALYSIS			
Calcium	2	t	t
Chlorine	7.2		
Potassium	<2		
(Sulfur)	(5.2)	(7.9)	(22)
Zinc	t		
TOTAL[1]	13.0	t	t
Sulfates, H_2O sol[2]	6.3	43	48
(Sulfur, from SO_4^-)[4]	(2.1)	(14.5)	(16)
Nitrate (H_2O sol)[2]		t	4.1
Total Carbon[3]	8.4	22	20
(Volatile Carbon)[3]		(18)	(14.5)
(Carbonates)[3]			
TOTAL ANALYZED	28	65	72
BALANCE	72	35	28
	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

TABLE 4-37. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR IC ENGINES (TEST 15)

SAMPLE #	Joy Filter 15J-5S	Joy Impinger Organics 15J-IO	Joy Impinger Condensate 15J-IC
PERCENT OF CUT	18.5	25.4	31.9
XRF ANALYSIS			
Calcium	4.7		t
Chlorine		t	
Iron			t
Potassium	t		t
Silicon		t	
(Sulfur)	(5.3)	(t)	(19)
Vanadium	t		
TOTAL[1]	5	t	t
Sulfates, H_2O sol[2]	8.2	÷	20.4
(Sulfur, from $SO_4^=$)[4]	(2.7)	÷	(7)
Nitrate (H_2O sol)[2]		÷	
Total Carbon[3]	5.34	÷	1.14
(Volatile Carbon)[3]		÷	t
(Carbonates)[3]		÷	(1.0)
TOTAL ANALYZED	19	3	21
BALANCE	81	97	79
	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

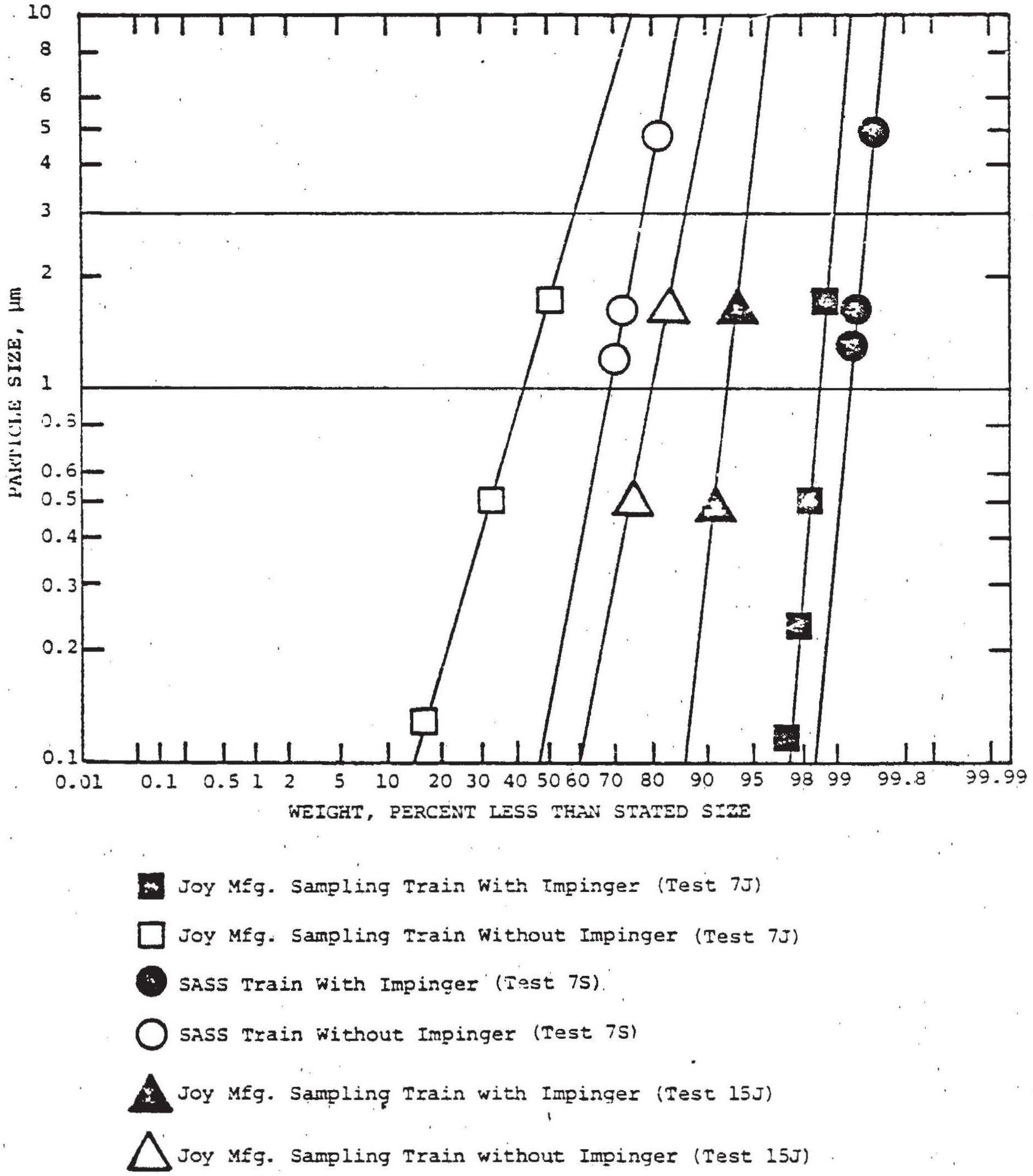


Figure 4-29. Particle size distribution for IC engines (Test 07)

B. Particulate test set-up--

Two tests were done on the same cement kiln operating at approximately the same conditions, and at the same position on the stack downstream of the baghouse at about 100 ft above ground level on the straight section leading to the atmosphere. Natural gas was used as the fuel source for the first test, Test 9, and coal was used for the second test, Test 18. The velocity profiles in the stack for the two tests are listed in Table 4-39 Velocity points greater than 72 inches were not able to be measured for Test 9 and velocity points greater than 121 inches were not able to be measured even with the pitot tube extension for Test 18. Note that for Test 18, coal firing, the mean velocity in the stack is somewhat higher than the gas fired Test 9. This is as expected, considering the additional air needed to stoichiometrically combust the coal to produce the same Btu value as natural gas for operating the process. For both tests the SASS sampling train was used with a 5/8" nozzle at Velocity Point #4.

C. Particulate Test Results--

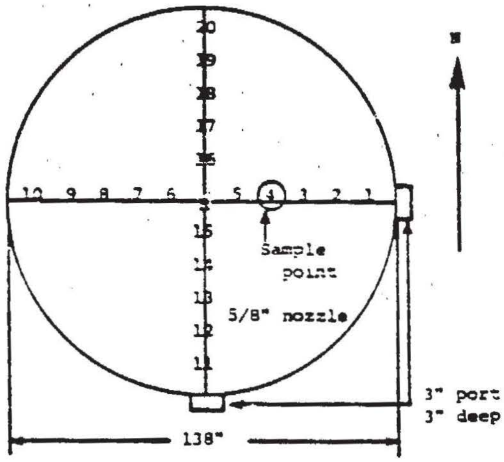
The results of the two tests discussed in this section are listed in Table 4-1. Major elemental composition, sulfate, nitrate and carbon analysis were determined for all fractions of particulate catches which contained weights in excess of 100 mg. The details for these procedures are discussed in Section 3.2.2. Tables 4-40 and 4-41 list the results from this analysis.

D. Discussion of Results--

1. Particle size distribution--Figure 4-31 is a plot of particle size (um) 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. The size distribution curve for both tests ignoring the impinger catch are identical. However, when the impinger catch is included the curve shifts to the right; more so for the coal firing than gas. The breakdown of the particle size distribution including the impinger taken from Figure 4-31 is as follows:

	Percent of Particles			
	>10um	10-3um	3-1um	<1um
Test 9, gas fired	8	32	40	20
Test 18, coal fired	8	24	34	34

TABLE 4-39. VELOCITY PROFILE FOR CEMENT MANUFACTURING



	Test 9	Test 18
Temperature	365°F	375
Static Pressure	-0.1"H_2O	+0.2
Fuel	Gas	Coal

Distance from End of port	Velocity Point #	Test 9 Velocity ft/sec	Test 18 Velocity ft/sec
6"	1	31.1	41.5
14-3/8	2	31.1	42.7
23	3	32.6	43.2
34-3/8	4	32.6	4.15
50-1/2	5	30.3	39.7
72	R	31.1	37.8
93-1/2	6	--	39.7
109-5/8	7	--	43.2
121	8	--	42.7
6"	11	32.6	46.0
14-3/8	12	36.8	47.0
23	13	34.8	44.4
34-3/8	14	34.1	43.2
50-1/2	15	31.1	41.5
72	R	31.1	38.4
93-1/2	16	--	39.0
109-5/8	17	--	39.7
121	18	--	39.0
	Average	32.8 ft/sec	40.2 ft/sec
		128760 SCF	154514 SCF

TABLE 4-40. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR GAS FIRED CEMENT KILN (Test 9)

SAMPLE *	10µm Cyclone 9S-2S	3µm Cyclone 9S-3S	Filter 09S-5S
PERCENT OF CUT	28.7	36.5	
XRF ANALYSIS			
Calcium	27/3	22/3	16.1/3
Chromium	t	t	
Iron	1.2/0.1	t	t
Potassium	1.4/0.3	1.5/0.3	2.4/0.4
(Sulfur)	(2.2/0.6)		(2.4/0.4)
Titanium			t
TOTAL[1]	30	24	19
Sulfates, H_2O sol[2]	1.26	1.68	4.27
(Sulfur, from $SO_4^=$)[4]	(0.42)	(0.56)	(1.42)
Nitrate (H_2O sol)[2]	t	t	t
Total Carbon[3]	16	19	
(Volatile Carbon)[3]	(3.22)	(2.66)	
(Carbonates)[3]	(8.79)	(8.10)	
TOTAL ANALYZED	47	45	23
BALANCE	53	55	77
	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

TABLE 4-41. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR COAL FIRED CEMENT KILN (TEST 18)

SAMPLE #	1µm Cyclone 18S-4S	10µm Cyclone 18S-2S	3µm Cyclone 18S-3S	Impinger 18S-IC	Filter 18S-5S
PERCENT OF CUT	8.9	24.1	30.5	26.2	4.6
XRF ANALYSIS					
Calcium	22/6	17/4	20/6	t	22/7
Iron	1.2/2	1.1/2	t	t	1.7/0.2
Nickel				t	
Potassium	1.5/0.4	1.1/0.3	1.6/0.5		1.5/0.5
(Sulfur)	(<3)	(2.7/0.7)	(5.2/0.2)	(40/10)	(4.9/2)
TOTAL[1]	25	20	22	2	25
Sulfates, H_2O sol[2]	1.82	3.8	3.2	70	6.4
(Sulfur, from $SO_4^=$)[4]	(t)	(1.25)	(1.06)	(23)	(2.1)
Nitrate (H_2O sol)[2]	t	t	t	3.2	
Total Carbon[3]	10	9.8	11.4	4.1	4.7
(Volatile Carbon)[3]	(4)	(4.1)	(4.7)	3.9	
(Carbonates)[3]	(6.8)	(7.4)	(8.5)		(4.4)
TOTAL ANALYZED	37	34	37	80	36
BALANCE	63	66	63	20	64
	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

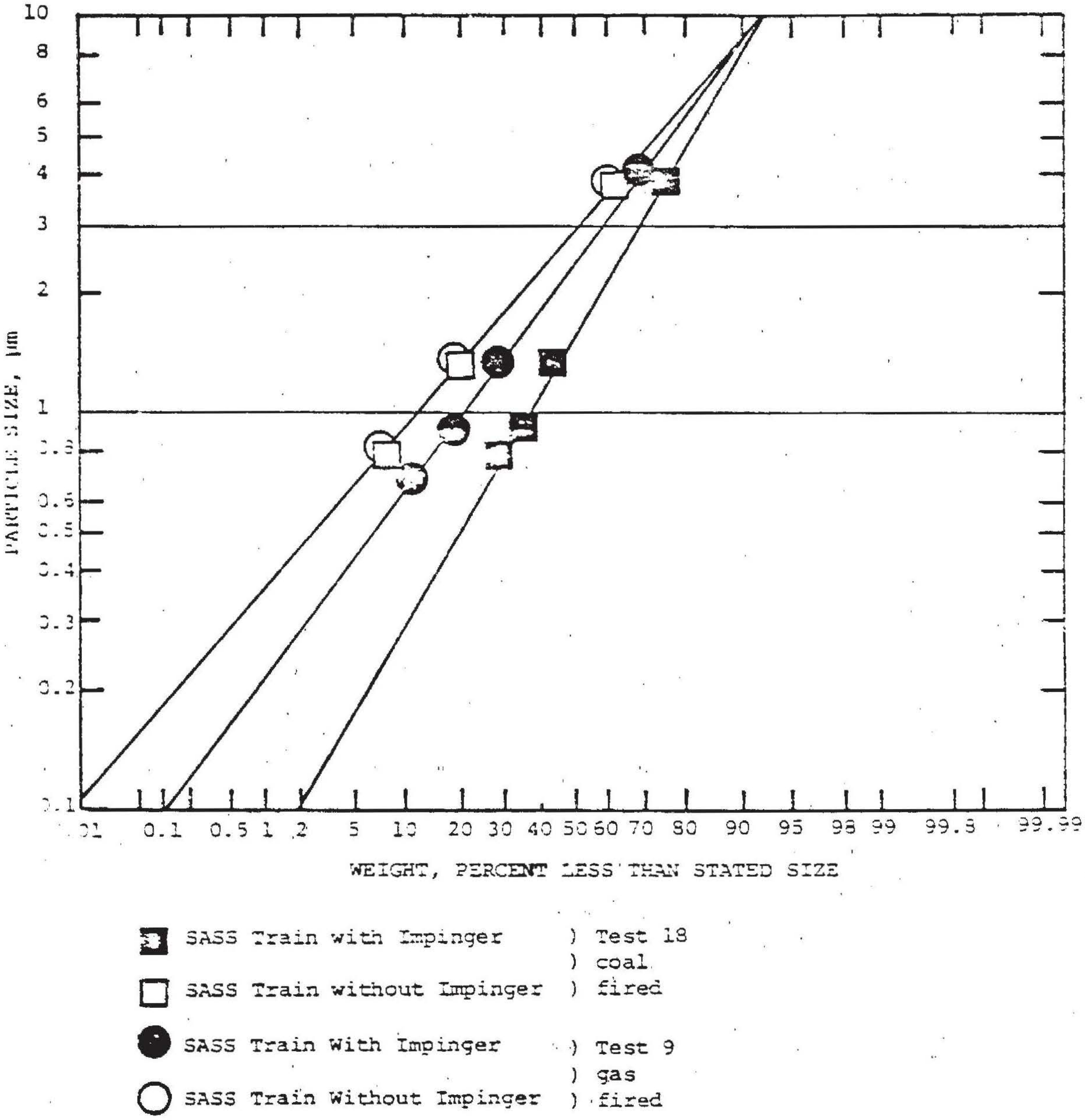


Figure 4-31. Particle size distribution for cement manufacturing (Test 09).

The mean particle size, including the impinger, for Test 18 is 15μm and 23μm for Test 9; ignoring the impinger catch it is 27μm for both tests. These results are similar to other size distribution data available in the literature (Ref. 4-13 and 4-14).

2. Chemical Composition-- Tables 4-40 and 4-41 list the results from the chemical analysis of the particulate fraction for each of the tests discussed in this section. Calcium is the most predominant species, as one would expect. Carbon is second most abundant. Its origin is most likely from the uncombusted fuel. The concentration of carbon is slightly more for coal firing than natural gas firing. Sulfate is third most abundant and tends to concentrate in the impingers. As expected, sulfate concentration is higher for coal firing than gas firing, due to higher sulfur content of the fuel. Nitrates also tend to end up in the impinger. Iron and potassium are in the range of 1% of the total particulates. All other elements listed were detected in trace 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 based on these two tests alone.

	Test 9 (gas)	Test 18 (coal)
gr/DSCF	0.0056	0.0099
T/yr	22	48
lb/hr	5.9	12.5
lb/ton produced	0.21	0.43
lb/bbl produced	0.041	0.084

4.2.7 Calcination of Gypsum

Gypsum is a mineral that occurs in large deposits throughout the world. It is hydrated calcium sulfate, with the formula $CaSO_4 \cdot 2H_2O$. When heated slightly, the following reaction occurs:

$$CaSO_4 \cdot 2H_2O \rightarrow CaSO_4 \cdot 1/2\ H_2O + 1\text{-}1/2\ H_2O(g);\ \Delta H = +19,700\ \text{cal.}$$

If the heating is at a higher temperature, gypsum loses all of its water and becomes anhydrous calcium sulfate or "anhydrite." Calcined gypsum can be made into wall plaster by the addition of filler materials such as asbestos, wood pulp, or sand. Without additions, it is plaster of paris and is used for making casts and for plaster.

A. Description (Ref 4-15)--

The usual method of calcination of gypsum consists of grinding the mineral and placing it in a large calciner which holds about ten tons of gypsum. The temperature is raised to about 350°F with constant agitation to maintain a uniform temperature. The materials in the kettle, commonly known as "plaster of paris" and called "first-settle plaster by the manufacturers, may be withdrawn and marketed at this point, or it may be heated further to 400°F to give a material known as "second-settle plaster." First-settle plaster is approximately the half hydrate, $CaSO_4.1/2\ H_2O$, and the second form is anhydrous. Practically all of the gypsum plaster sold is in the form of first settle plaster mixed with sand or wood pulp. The second form is used in the manufacture of plasterboard and other gypsum products. Gypsum may be calcined also in rotary kilns similar to those used for limestone. Figure 4-32 is a schematic of the calcinator which was tested for this study.

B. Test Set-up--

The best location for the sampling of particulate was at the baghouse exit, through a 3" test port located in the stack 3 ft above the roof (see Figure 4-32). The velocity profile in the stack is listed in Table 4-42 A one-inch nozzle was used to sample the particulate laden gases from Velocity Point 3. The KVB objective was to sample one complete batch. However, due to a minor difficulty of electrical power consumption for the sampling train the tail end of one batch and the front end of the next batch were sampled to approximate one complete batch time.

C. Test Results--

The results of this test (Test 06S) discussed in this section are listed in Table 4-1. Major elemental composition, sulfate, nitrate and

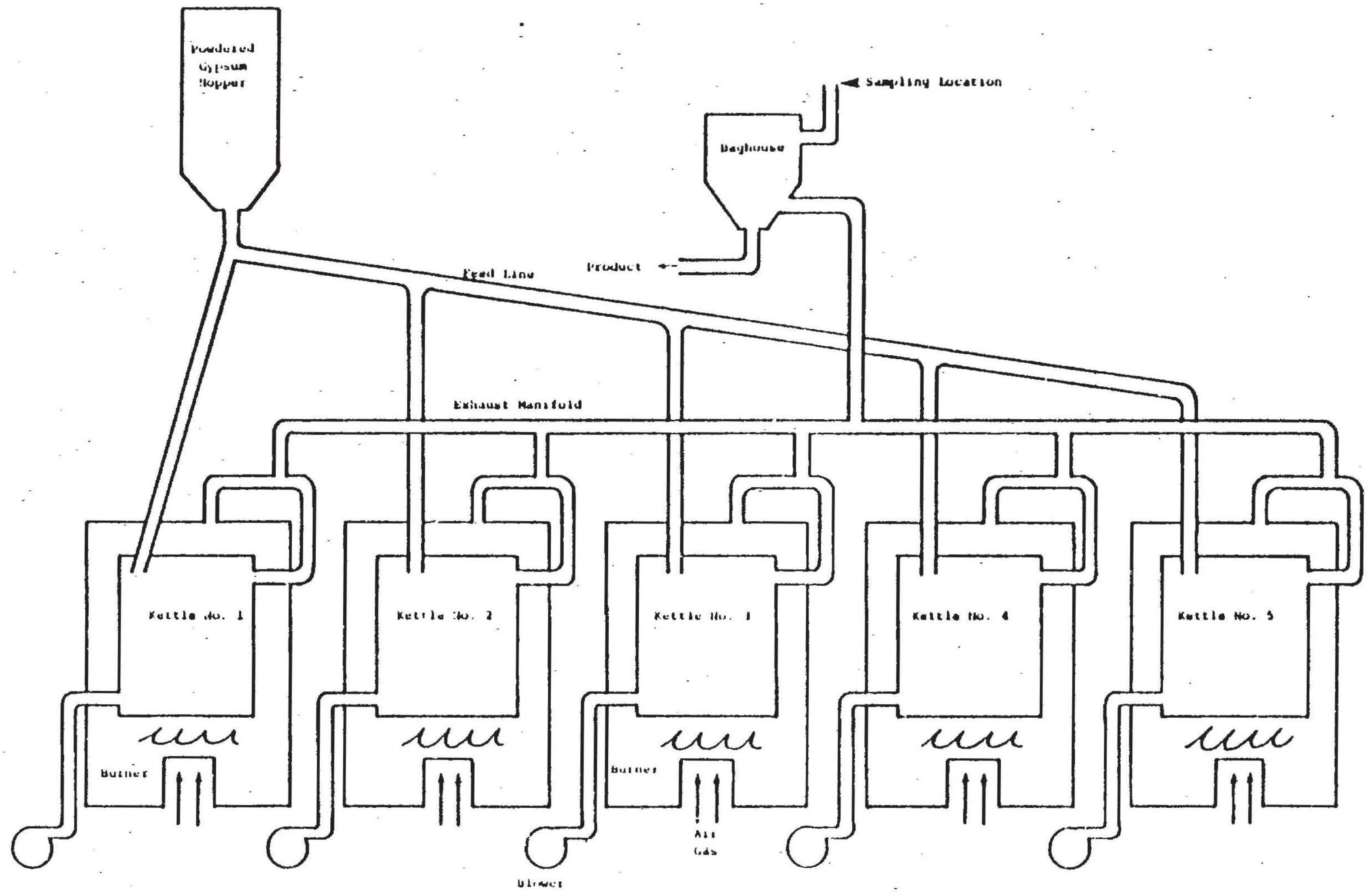
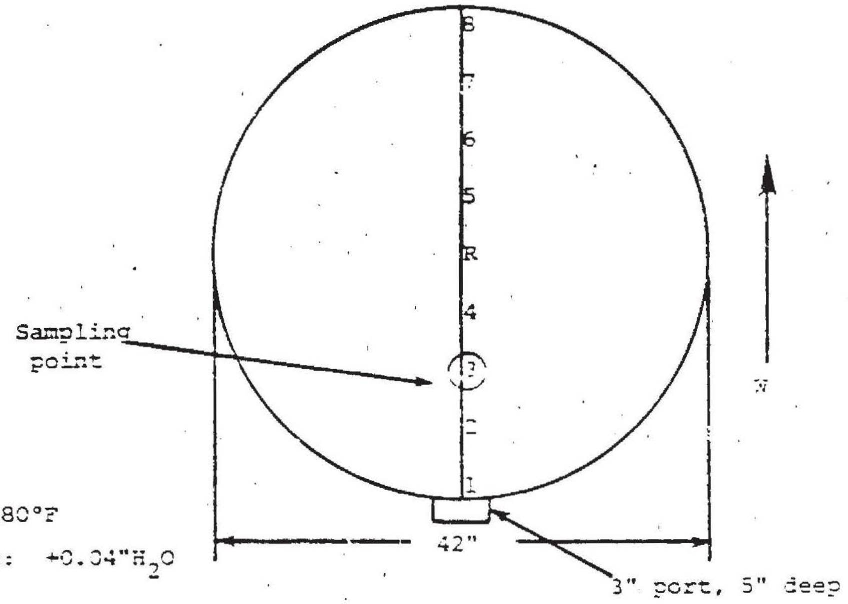


Figure 4-32. Gypsum calcining operation.

KVB 5806-783

TABLE 4-42. VELOCITY PROFILE FOR GYPSUM CALCINATION (TEST 6)



Temperature: 380°F

Static Pressure: +0.04"H_2O

Distance From End of Port	Velocity Point #	Velocity ft/sec
6-3/8	1	14.1
9-3/8	2	18.6
13-1/4	3	17.2
18-1/5	4	18.6
26	R	18.6
33-1/2	5	17.2
38-7/8	6	15.7
42-5/8	7	14.1
45-5/8	8	14.1
Average	-	16.4

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 4-43 lists the results from these analyses.

D. Discussion of Results--

1. Particle size distribution--Figure 4-33 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 small amount (18% by wt.) of material collected in the impinger, it would seem that the effects of pseudo particulates would be present. 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 not including the impinger catch, taken from Figure 4-33, is as follows:

% by weight	>10µm	10-3µm	3-1µm	<1µm
impinger not included	6	44	43	7

The particle size distribution curve, Figure 4-33, indicates that the mean particle size is 3.0µm. This size of particle has the greatest potential health effects.

2. Chemical Composition--Table 4-43 lists the results from the chemical analysis of the particulate fractions. Sulfates are the most predominant species present along with calcium, and seem to be evenly distributed over the entire size range. This is as expected. Gypsum is calcium sulfate. Iron was also found in each fraction in concentrations of around 0.3-1.2%. All other elements have low concentrations, 0.1% or less. Carbonates were found in the cyclone catches and not in the impinger or filter catches. The volatile carbon found in the impinger catch (34%) seems to be wrong, because there is no volatile carbon detected in the first and second cyclones and on the filter catches. We believe that possible methyl chloroform from the organic extraction of the impinger water may have contaminated this fraction.

TABLE 4-43. CHEMICAL COMPOSITION IN PERCENT FOR GYPSUM CALCINATOR (TEST 6)

SAMPLE #	10µm Cyclone 06S-2S	3µm Cyclone 6S-3S	Filter 6S-3S	Impinger 6S-IC	1µm Cyclone 6S-4S
PERCENT OF CUT	40	36	2	10.5	5.7
XRF ANALYSIS					
Calcium	10.0	8.8	13.0	5.9	15
Chlorine			t		
Iron	t	t	1.25	t	t
Potassium		t		t	t
Strontium	t	t	t	t	t
(Sulfur)	(1.0)	(8.6)	(22)	(18)	(30)
TOTAL[1]	10	9.7	15	7	15
Sulfates, H_2O sol[2]	62	57	12	41	61
(Sulfur, from $SO_4^=$)[4]	(20)	(19)	(4.12)	(13)	(20)
Nitrate (H_2O sol)[2]	t	t		t	t
Total Carbon[3]	1.67	t	1.10	38	t
(Volatile Carbon)[3]				(35)	(0.04
(Carbonates)[3]	t	t			t
TOTAL ANALYZED	74	57	28	86	76
BALANCE	26	43	72	14	24
	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

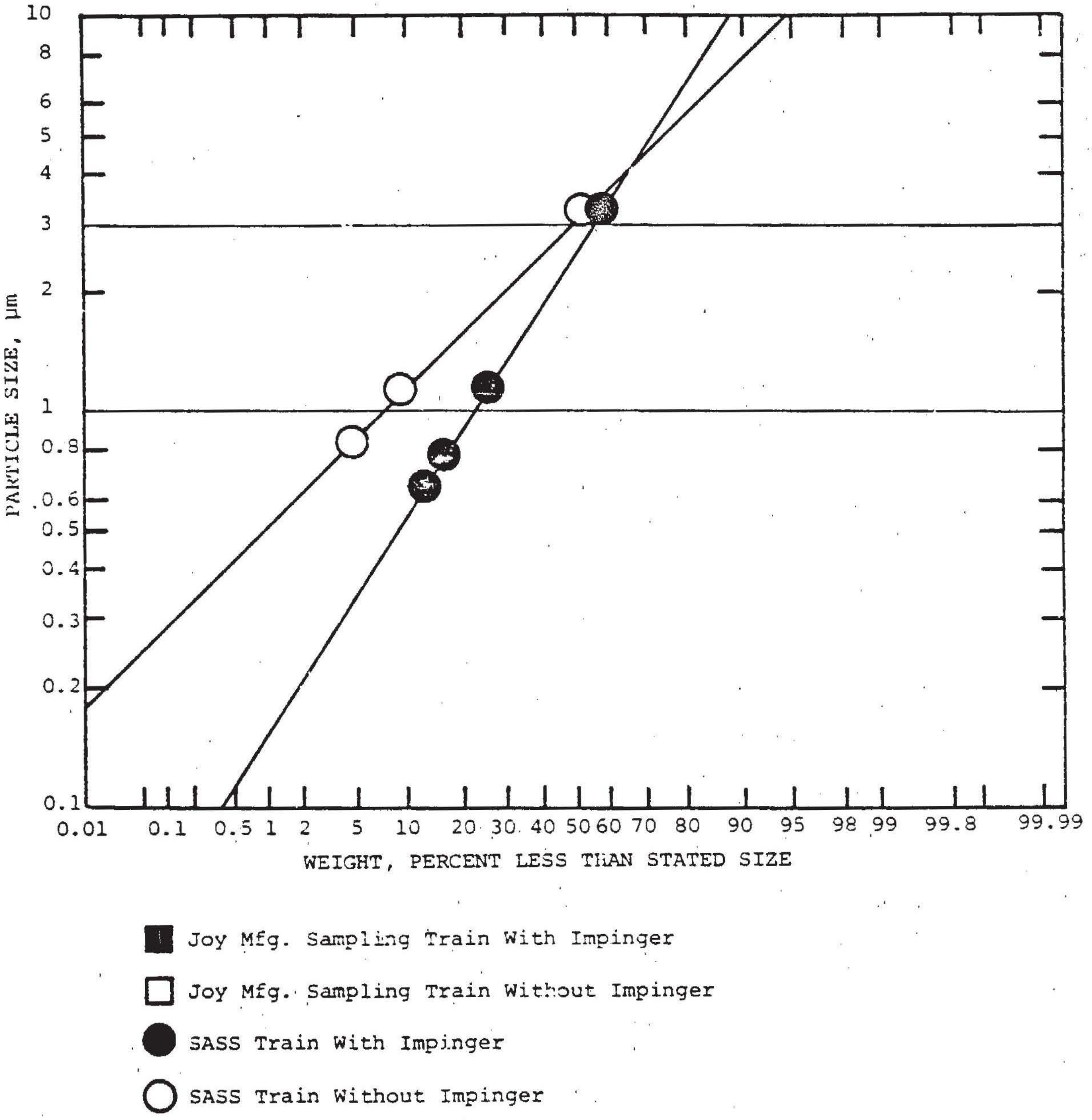


Figure 4-33. Particle size distribution for calcination of gypsum (Test 06)

3. Emissions and emissions factors--Emission factors can be listed with several different units. The following lists some of these emissions and factors based on this test alone:

0.056	gr/DSCF
9.4	T/yr
2.2	lb/hr
0.2	lb/ton produced

4.2.8 Brick Manufacturing--Clay Grinding Process

A. Process Description (Ref. 4-16)--

The manufacture of brick and related products such as clay pipe, pottery, and some types of refractory brick involves the mining, grinding, screening, and blending of the raw materials, and the forming, cutting or shaping, drying or curing, and firing of the final product.

Surface clays and shales are mined in open pits; most fine clays are found underground. After mining, the material is crushed to remove stones and stirred before it passes onto screens that are used to segregate the particles by size.

The basic flow diagram of a brick manufacturing process is shown in Figure 4-34.

B. Particulate Test Set-up--

The heaviest grain loading of particulate from brick manufacture comes from the clay grinding and screening process. For this reason KVB tested the grinding operation. The major fraction of particles is generated by the grinding and screening operations which are controlled by a baghouse (see Figure 4-35).

To evaluate the efficiency of the baghouse, the inlet and exit duct were sampled for particulate. The larger SASS sampling train was used to sample the exit duct and the smaller Joy sampling train was used to sample the inlet duct. However, due to the geometry of the inlet ducts of the

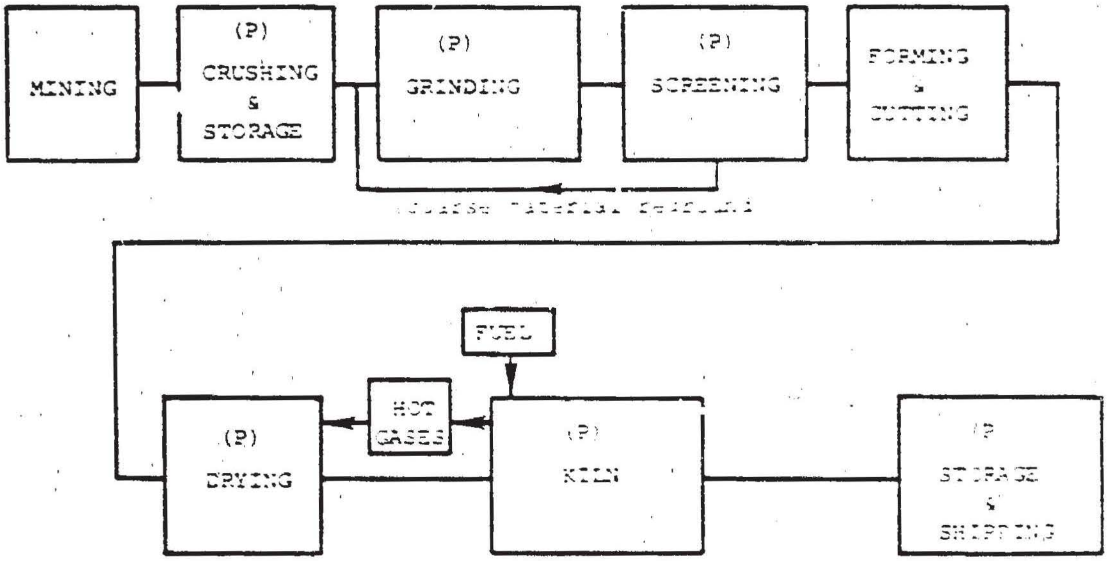


Figure 4-34. Basic flow diagram of brick manufacturing process. "P" denotes a major source of particulate emissions.

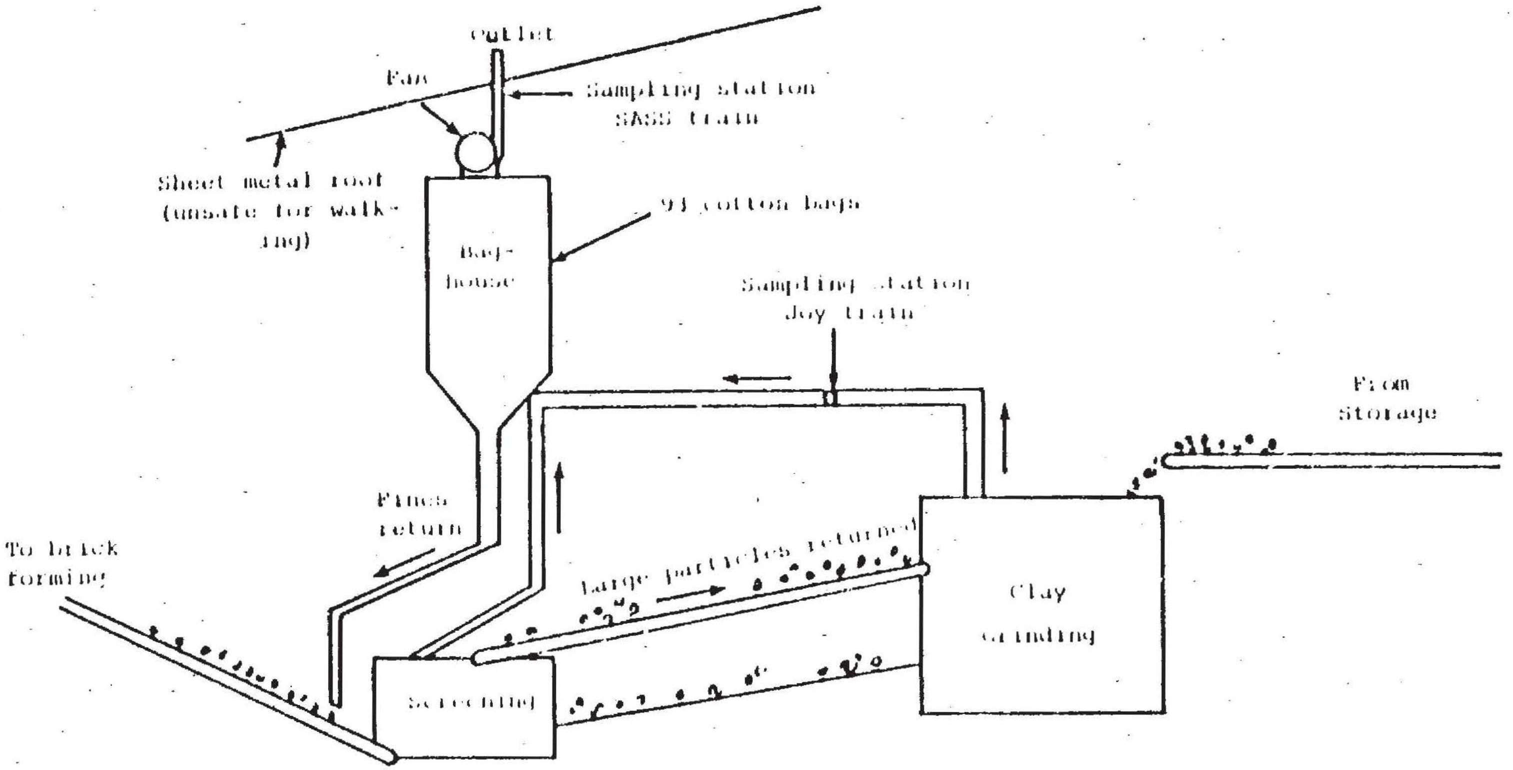


Figure 4-15. Brick manufacturing-clay grinding process

baghouse leading from the screens and grinder, only the section of duct attached to the grinding operation was accessible for sampling. A 2" sampling port was cut into this section on a long straight section, 20 ft from the nearest bend (see Figure 4-35). The velocity profile in the inlet duct, at this location, and in the baghouse exit is given in Table 4-44 A 3" sampling port was cut in the exit duct at the underside of the roof (Figure 4-35). . It was not possible to sample beyond this point because the roof was unsafe for walking. This section of the duct was only two ft above the fan. Therefore, the turbulence was high. Also only 1/3 of the flow through the baghouse came from the clay grinding operation. It was determined by difference that the other 2/3 came from the screening operation and leaks in the system. It was necessary to assume that the inlet stream from the grinder was representative of the inlet stream from the screen in order to determine baghouse efficiency.

The particulate samples were taken at Velocity Point 6 through a 3/8" nozzle with Joy sampling train for the baghouse inlet and through a 7/16" nozzle Velocity Point 5 with SASS sampling train for the baghouse exit.

C. Test Results--

The results of the tests discussed in this section, Tests 8S and 8J, 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 4-45 lists the results from these analyses for Test 8J and 8S.

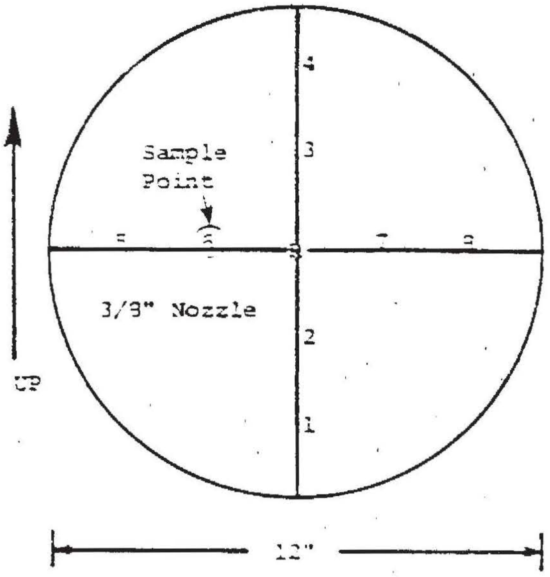
D. Discussion of Results--

1. Efficiency of the baghouse--The efficiency of a control device is calculated from the following equation:

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

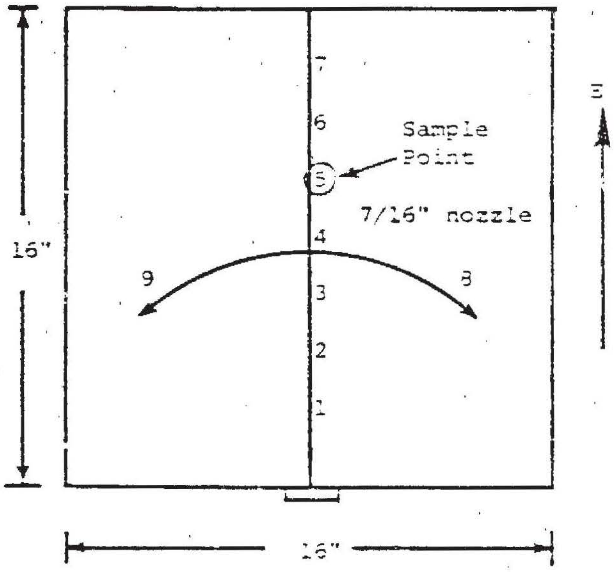
where the wt in and wt out does not include the impinger catch.

TABLE 4-44. VELOCITY PROFILE FOR BRICK GRINDING PROCESS (TEST 8)



INLET TO BAGHOUSE

Temperature: 75°F
Static Pressure: -2.1"H_2O



OUTLET FROM BAGHOUSE

Temperature: 84°F
Static Pressure: +1.2"H_2O

Distance from End of Port	Velocity Point #	Velocity ft/sec	Distance from End of Port	Velocity Point #	Velocity ft/sec
3/4"	1	44.1	1"	1	39.1
3"	2	44.5	3"	2	52.1
6"	R	46.2	6"	3	63.1
9"	3	50.1	8"	4	59.2
11-1/4"	4	53.9	10"	5	75.8
3/4"	5	50.1	13"	6	83.8
3"	6	45.2	15"	7	47.3
6"	R	46.9	8"	8	66.8
9"	7	46.9	8"	9	71.4
11-1/4"	8	--			
	Average 2175 SCFM	47.5			61.5 6020 SCFM

TABLE 4-45. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES FROM BRICK GRINDING OPERATION (TEST 8)

SAMPLE #	Joy 10µm Cyclone 8J-2S	SASS 10µm Cyclone 8S-2S
PERCENT OF CUT	98.5	45.0
XRF ANALYSIS		
Barium	t	t
Calcium	0.95/0.1	1.3/0.2
Iron	2.4/0.3	2.9/0.3
Manganese		
Potassium	1.2/0.1	1.2/0.1
Silicon	17	15
(Sulfur)		(2.1/0.6)
Titanium	t	t
TOTAL[1]	23	22
Sulfates, H_2O sol[2]	t	1.02
(Sulfur, from $SO_4^=$)[4]	(t)	(t)
Nitrate (H_2O sol)[2]	t	t
Total Carbon[3]		
(Volatile Carbon)[3]		
(Carbonates)[3]	t	t
TOTAL ANALYZED	21	23
BALANCE	79	77
	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

However, in this case the mass of matter going into the baghouse has two origins; the grinding operation and the screening operation. The grain loading from the grinder was measured, but the grain loading from the screening operation was not. It was assumed that the grain loading was similar to the loading for the grinder. Thus the efficiency of the baghouse was calculated.

$$[[3(1.169) - 0.0064]/3(1.169)] \times 100\%$$
$$= 99.8\%$$

The factor 3 comes from the flow split--1/3 of the total flow is from the grinder.

2. Particle size distribution--Figure 4-36 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 plots are presented for each train, one including the impinger catch, and the other ignoring it. In this case the loading of the large cyclone on the Joy train overwhelms the impinger catch so that there was negligible difference between the "with" and "without" curves. Considering that there were no gases present which would cause pseudo particulates, it would seem that only the very fine particles which would find their way through the filter would end up in the impinger. Therefore, the impinger catch was believed to be properly included in the measurements of the suspended particles. The breakdown of the particle size distribution including the impinger catch is as follows:

	Percent of Particles			
	>10μm	10-3μm	3-1μm	<1μm
Inlet (Test 8S)	98.6	0.85	0.3	0.15
Outlet (Test 8S)	44	4	4	48

explained as follows referring to the sketch below. The sketch shows a conceptual particle size distribution for the inlet and outlet of the baghouse (99.8% of the particulate matter is removed). The inlet

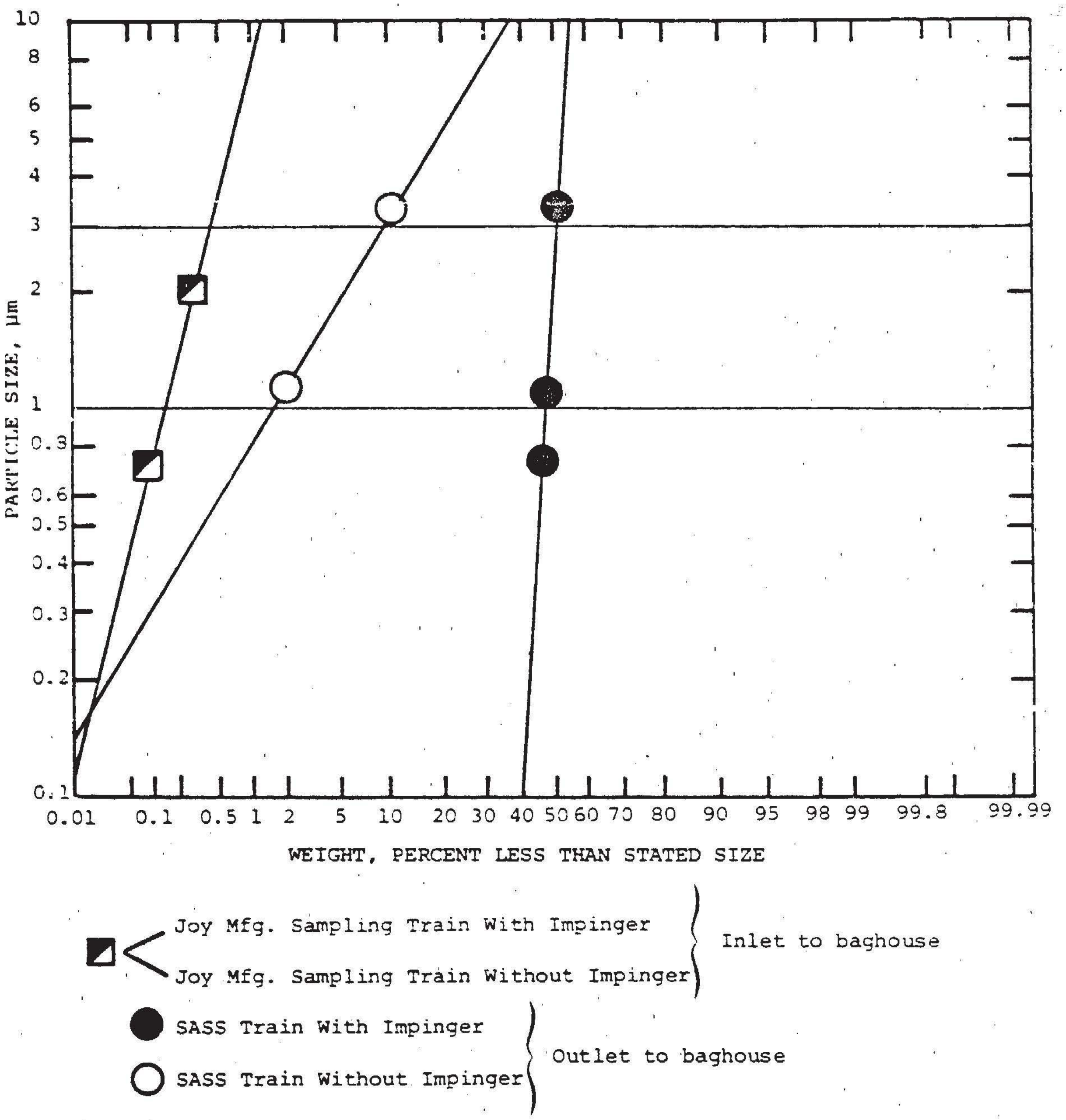
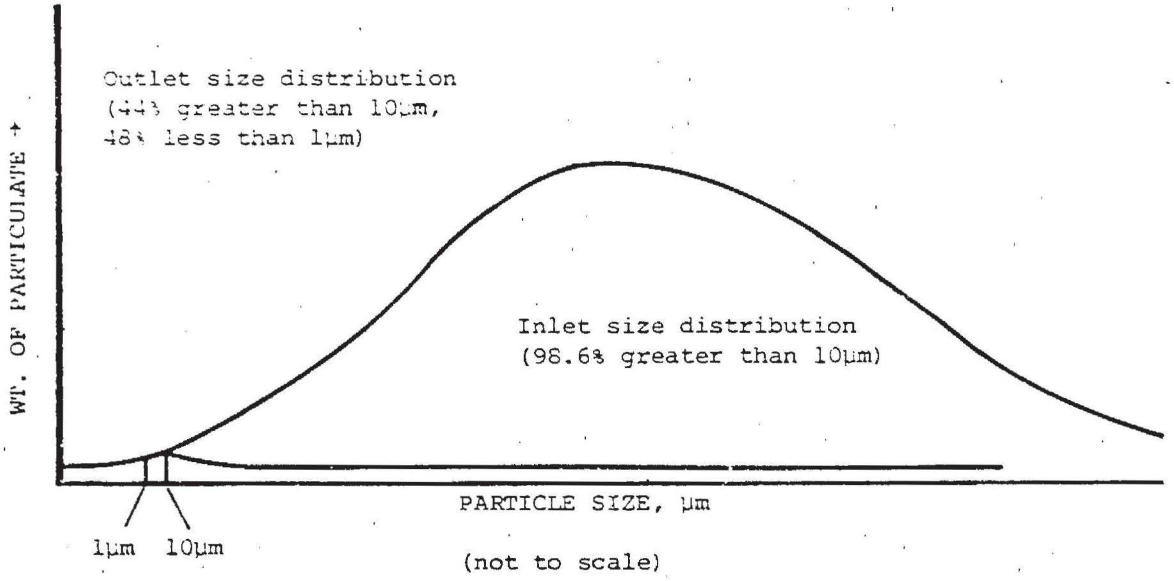


Figure 4-36. Particle size distribution for brick grinding process (Test 08)

distribution shows 98.6% of the particles with size >10µm. The baghouse removes nearly all the material that is >10µm and a much lesser amount of the very fine materials, <1µm. Some of the coarse material in the outlet can be attributed to "sneakage" which is material that leaks around the bag points or through small holes in the bags, etc. The net result is an apparent bimodal distribution.



The mean particle size of the particulate material entering the baghouse is greater than 10µm, and the mean particle size exiting the baghouse is about 2µm.

3. Chemical Composition--Table 4-45 lists the results from the chemical analysis of the particulate fraction for each of the tests discussed in this section (inlet-Test 8J and outlet-Test 8S). Silicon is the most predominant species. Iron, titanium, calcium, and carbonates are next in order. All other elements detected were in low concentrations

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

	Inlet (Test 8J)	Outlet (Test 8S)
gr/DSCF	1.169	0.0064
T/yr	26.6	0.4
lb/hr	21.5	0.354
lb/ton produced	0.7	0.01

4.2.9 Glass Melting Furnace

Soda-lime glass is produced in large, direct-fired, continuous melting furnaces, and other types of glass are melted in small batch furnaces having capacities ranging from only a few pounds to several tons per day. Air pollution from small batch furnaces is minor, but the production of soda-lime glass creates problems of air pollution control.

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

A complete process flow diagram for the continuous production of soda-lime glass is shown in Figure 4-37. Silica sand, carbonates, cullet (broken glass), and other raw materials are transferred from railroad hopper cars and trucks to storage bins and other raw materials are received pre-packaged. These materials are withdrawn from the storage bins, weighed, and blended in a mixer. The mixed batch is then conveyed to the batch charged to the side of the furnace.

Two basic configurations are used in designing continuous, regenerative furnaces--end port, Figure 4-38 and side port, Figures 4-39 and 4-40. In the side port furnace (type of furnace tested in Test 20) the flame passes in one direction across the melter for 15-20 minutes, then the flow is reversed during the next time cycle. The side port design is commonly used in large furnaces with melter areas in excess of 500 square feet.

In the end port configuration (type of furnace tested in Test 28 and 35) the flames travel in a horizontal U-shaped path across the surface of the glass within the melter. Fuel and air are mixed at the port and ignite in the furnace and discharge through a second port adjacent to the first on the same end wall of the furnace. While the end port design has been used extensively in smaller furnaces with melter areas from 50 to 300 square feet, it has also been used in furnaces with melter areas up to 800 square feet.

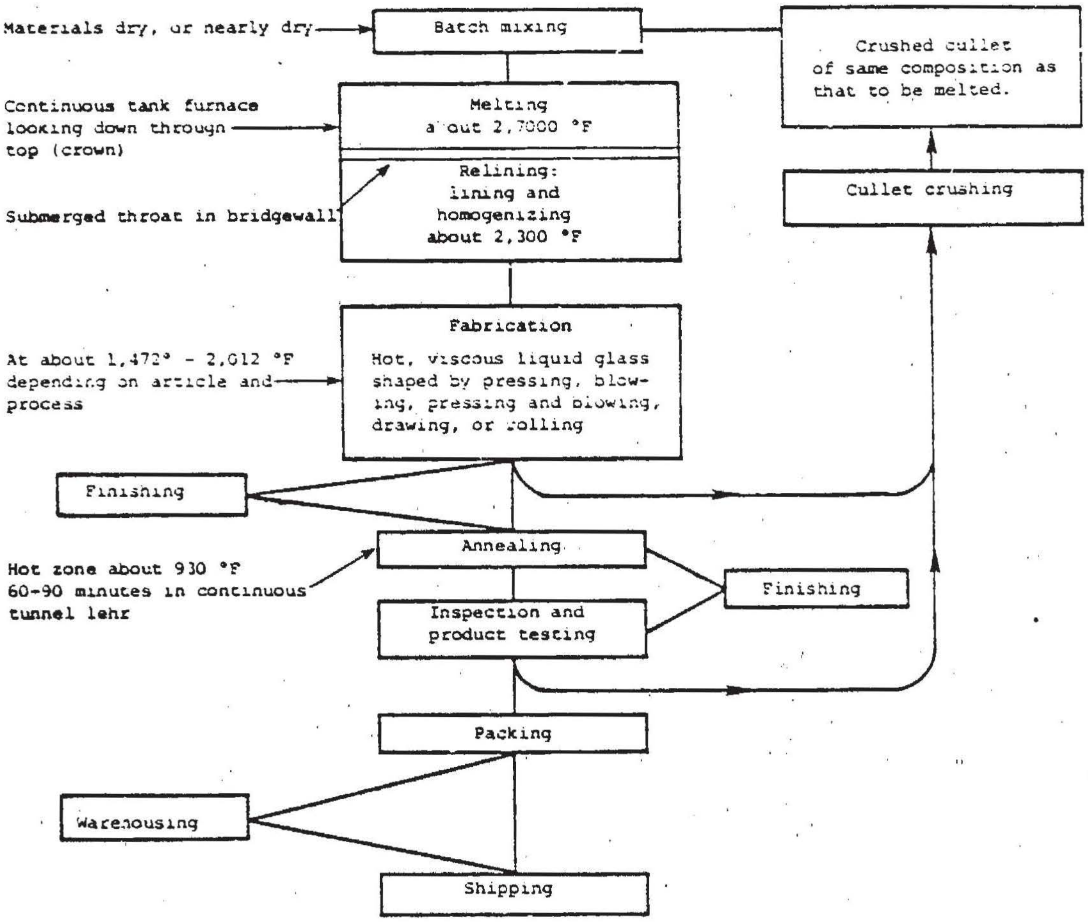


Figure 4-37. Flow diagram for soda-lime glass manufacture (Ref. 4-17).

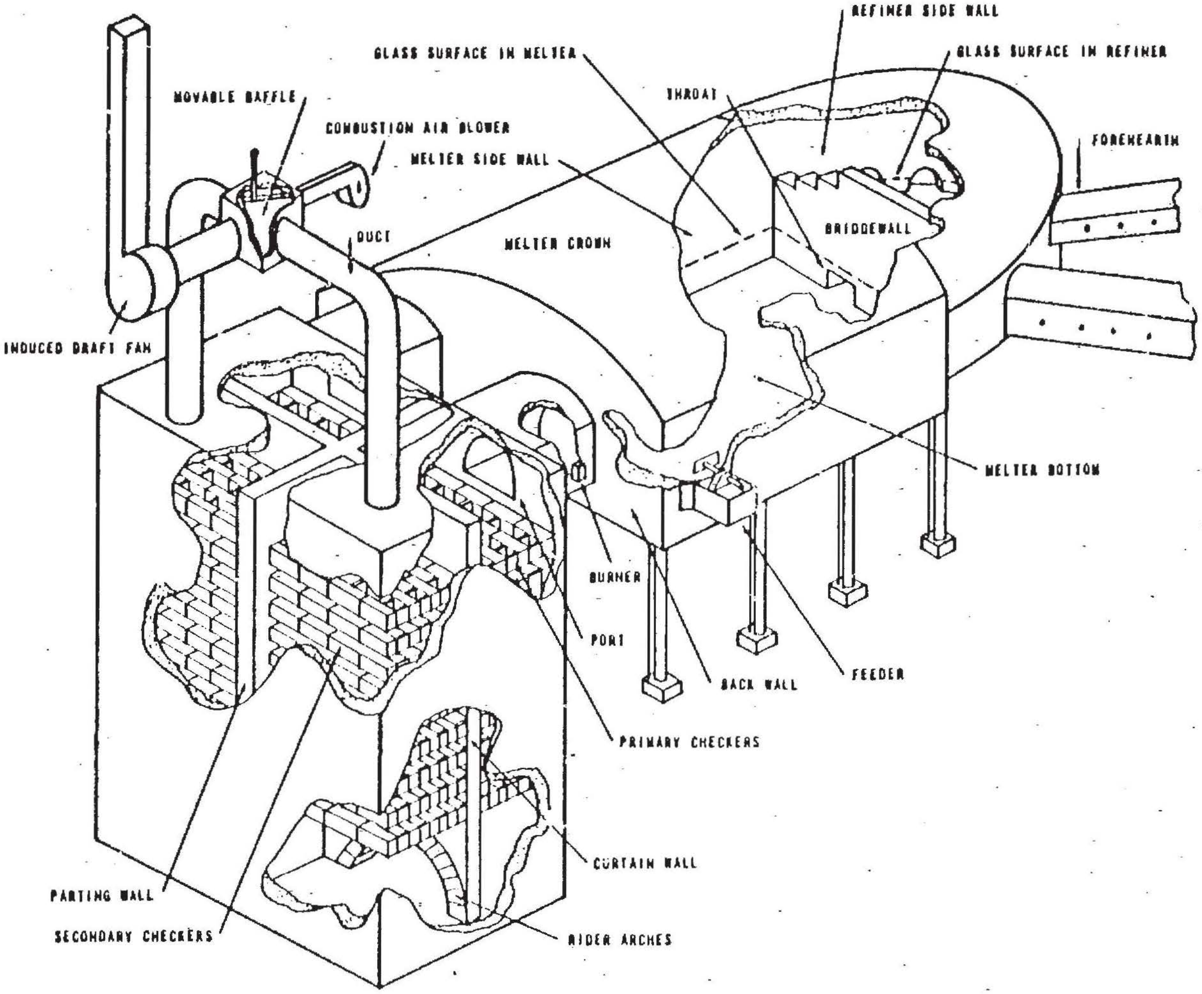


Figure 4-38. Glass melting furnace (end port). Similar to the furnace on Tests 28 and 35 (Ref. 4-17).

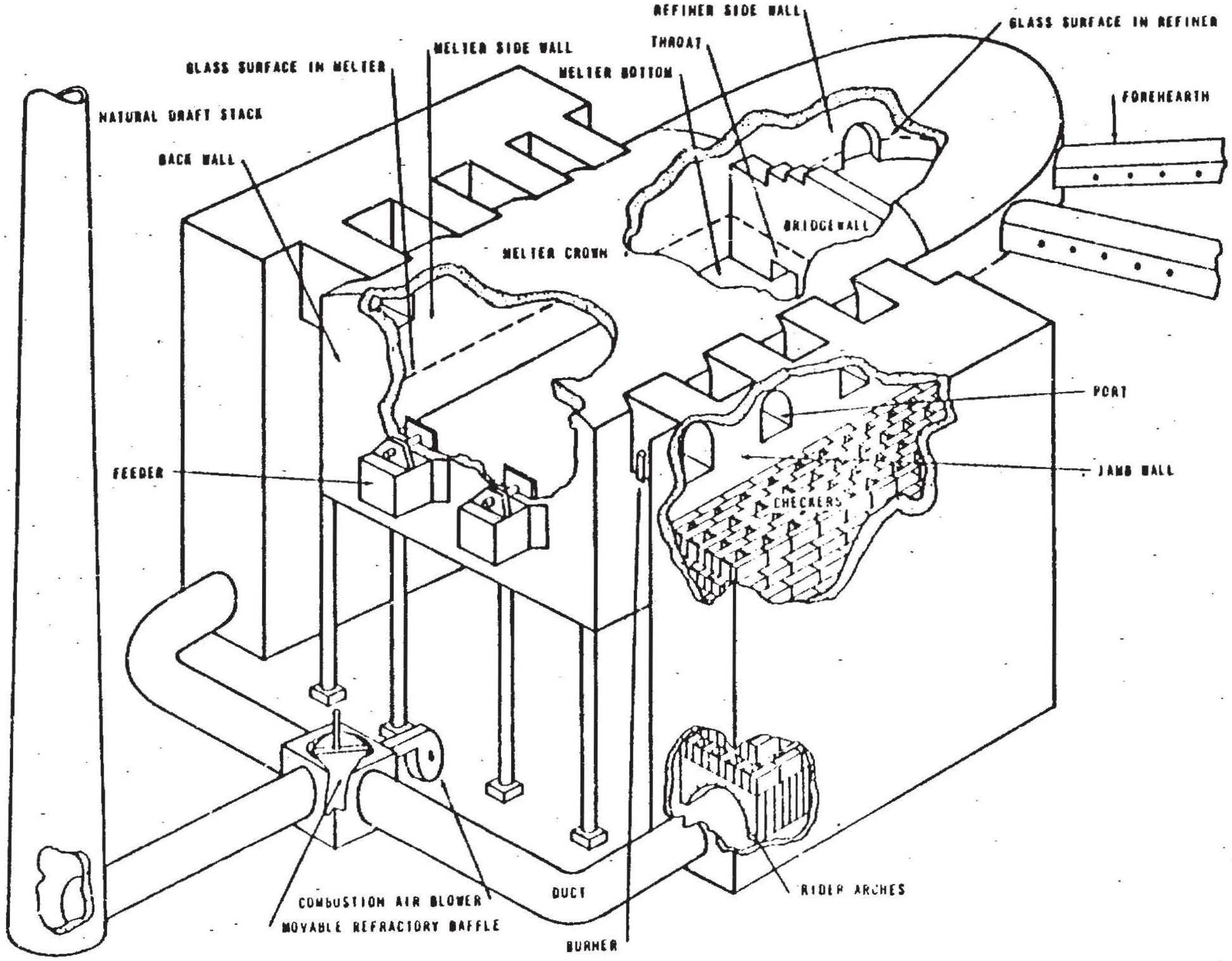


Figure 4-39. Glass melting furnace (side port). Similar to Test 20 furnace (Ref. 4-17).

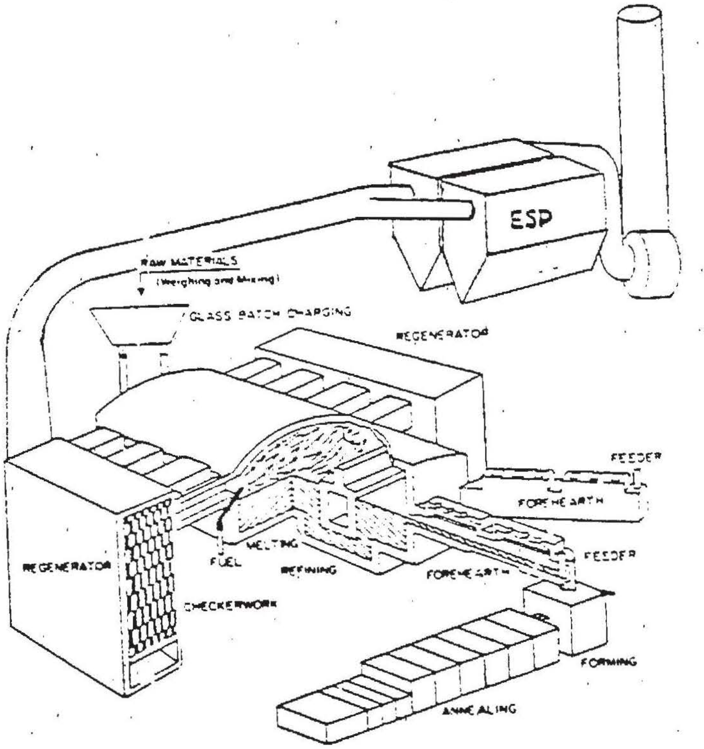


Figure 4-40. Glass melting furnace (side port) with ESP. Similar to Test 20 furnace.

B. Particulate Test Setup--

1. Test #20, flint glass melting furnace with an electrostatic precipitator--Two sampling trains were used simultaneously to sample the inlet and exit of the ESP. The inlet station was located on the horizontal duct (53-1/2 inch diameter) leading to the ESP (see Figure 4-41). Two 2-1/3 inch diameter test ports were provided at least six duct diameters from the nearest bend or obstruction. Table 4-48 lists the velocity profile in the inlet duct at a static pressure of -5.2"H_2O and 540°F. Due to the small diameter of the port openings, the velocity points for distances greater than 36-1/2 inches into the stack were not able to be measured. The particulate sample was taken through a 5/16" diameter nozzle at Velocity Point #17.

The sampling ports for the ESP exit were located on the vertical section of the stack leading to the atmosphere, approximately 80 ft above ground level. Table 4-47 lists the velocity profile in the exit stack. The particulate sample was taken through a 3/4" nozzle at Velocity Point #18.

2. Test #28 and Test #35, flint glass melting furnace having no particulate control equipment--These two tests were done on the same glass melting furnace operating at approximately the same conditions, and at the same position on the stack at about 60 ft above ground level on the straight section leading to the atmosphere. An accidentally melted vacuum line during Test #28 resulted in no data for the small Joy sampling train. Both Sass and Joy sampling trains were run simultaneously for Test #35. The velocity profile for both these tests are listed in Table 4-48. For both SASS tests (Test 28 and Test 35) a nozzle diameter of 7/8 inch was used at velocity point #12, and a nozzle diameter of 7/16 inch was used for the Joy train on Test #35 at velocity point #3.

C. Test Results--

The results of the three tests 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. Tables 4-49, 4-50, and 4-51 list the results from this analysis for Tests 20, 28, and 35 respectively.

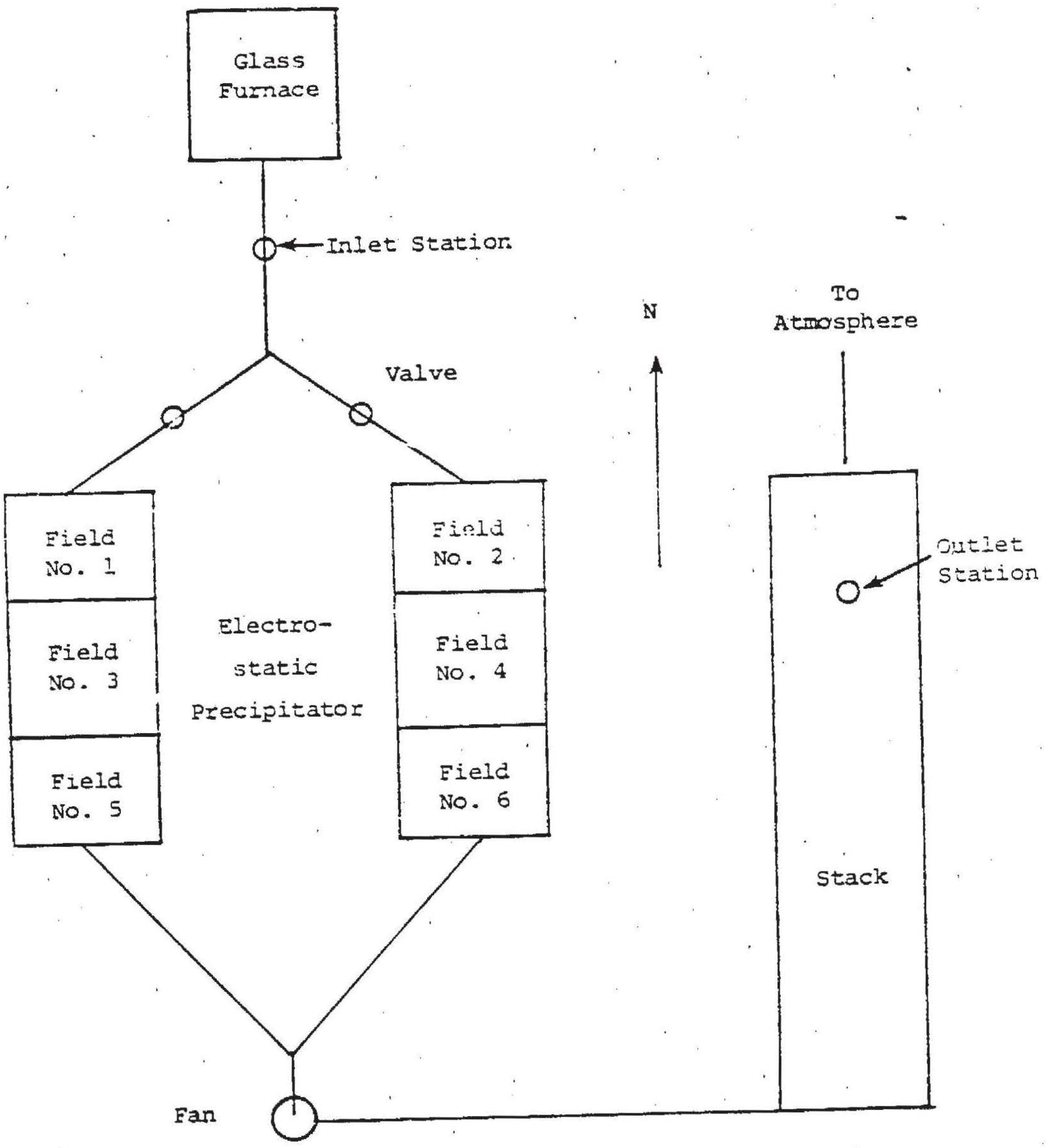


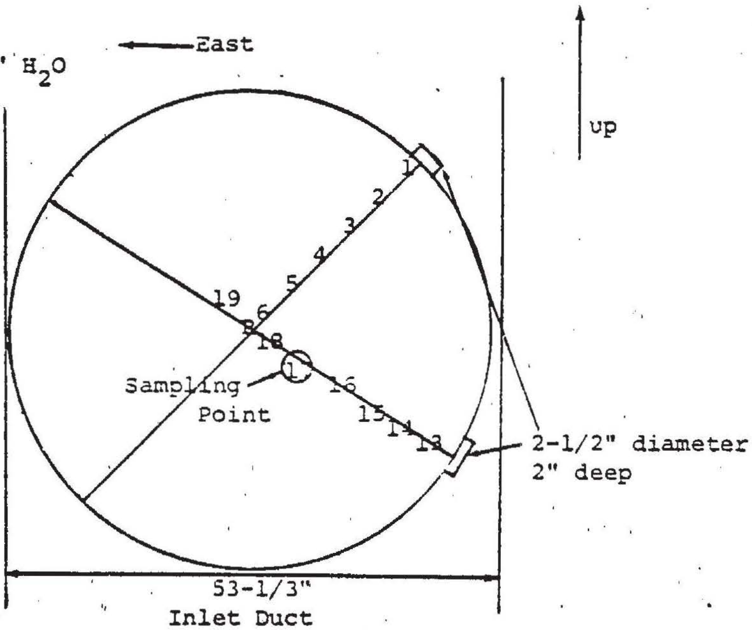
Figure 4-41. Flow diagram for glass furnace with ESP control.

TABLE 4-46. VELOCITY PROFILE (TEST 20S)

TABLE 1

Static Pressure = -5.2" H_2O

Temperature = 540°F



Inlet Duct

Distance from End of Port	Velocity			
	Point #	ft/sec	Point #	ft/sec
3-1/8"	1	68.0	13	69.8
5-5/8"	2	74.5	14	73.9
8-3/8"	3	75.6	15	74.5
11-1/2"	4	77.8	16	77.8
15-3/8"	5	77.8	17	77.8
21 -	6	76.7	18	78.9
28-3/8	R	76.2	12	79.4
36-1/2	7	75.6	19	86.0

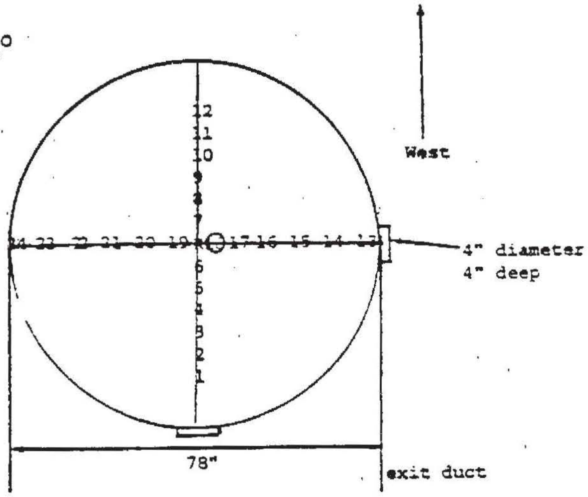
Average 76.3 ft/sec

71436 acfm

TABLE 4-47. VELOCITY PROFILE (TEST 20S)

Static Pressure = +.25"H_2O

Temperature = 440°F



Distance from End of Port	Velocity			
	Point #	ft/sec	Point #	ft/sec
5-5/8	1	34.8	13	33.7
9-1/4	2	36.9	14	38.9
13-1/8	3	37.9	15	39.9
17-7/8	4	36.9	16	39.9
23-1/2	5	37.9	17	39.9
31-5/8	6	37.9	18	38.9
43	R	40.8	R	38.9
54-3/8	7	40.8	19	38.9
62-1/2	8	39.9	20	38.9
68-1/8	9	37.9	21	37.9
72-7/8	10	38.9	22	38.9
76-3/4	11	37.9	23	37.9
80-3/8	12	34.8	24	35.9

Average 38.1 ft/sec

75856 acfm

TABLE 4-48. VELOCITY PROFILE FOR GLASS MELTING FURNACE
(TEST 28 & 35)

Test #28

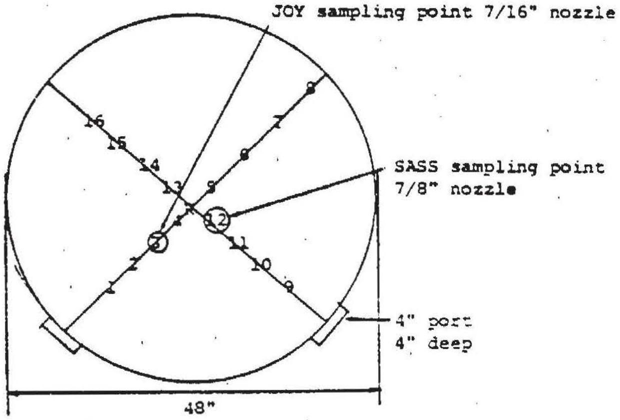
Static Pressure = -1.0"H_2O

Temperature = 800°F

Test #35

Static Pressure = -.82"H_2O

Temperature = 820°F



Distance from End of Port	Velocity Test #28				Velocity Test #35			
	Point #	ft/sec	Point #	ft/sec	Point #	ft/sec	Point #	ft/sec
5.1"	1	35.5	9	37.6	1	36.9	9	34.8
8.5	2	38.5	10	37.6	2	40.8	10	30.1
12.9	3	40.4	11	37.6	3	45.1	11	36.9
18.9	4	41.3	12	38.5	4	46.0	12	39.9
27.5	R	43.6	R	40.4	R	48.4	R	39.8
36.1	5	45.6	13	43.1	5	54.3	13	44.3
[illegible].1	6	50.3	14	44.8	6	50.7	14	46.0
46.5	7	47.2	15	45.6	7	49.1	15	46.0
49.9	8	44.8	16	44.8	8	47.6	16	44.3

TABLE 4-49. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR TEST 20

	Inlet		Impinger Catch	
	1µm Cyclone	Filter	Outlet	Inlet
SAMPLE #	20J-4S	20J-5S	20S-IC	20J-IC
PERCENT OF TOTAL CATCH	24.3	57.0	91.2	14.5
XRF ANALYSIS				
Arsenic	t	t		
Calcium	2.8/0.4			t
Chromium	t	t		
Cobalt				t
Iron			t	
Lead	t	t		
Potassium	2.1/0.5	2.3/1		
Selenium		t	4.6/0.5	3.6/0.4
(Sulfur)	(24/7)	(30/10)	(10/3)	(15/4)
Tin	t	4.6/0.6		
TOTAL[1]	5	7	5	4
Sulfates, H_2O sol[2]	60.91	53.83	21.36	43.25
(Sulfur, from $SO_4^=$)[4]	(20.3)	(18)	(7.1)	(14.4)
Nitrate (H_2O sol)[2]			t	
Total Carbon[3]	13	2.46	12	17
(Volatile Carbon)[3]	(9)	--	(12)	(12)
(Carbonates)[3]				
TOTAL ANALYZED	79	82	37	64
BALANCE	21	18	63	36
	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

TABLE 4-50. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT (TEST 28)

SAMPLE #	Filter 28S-5S	Impinger 28S-IC
PERCENT OF CUT	73.24	16.28
XRF ANALYSIS		
Arsenic	2.6/0.3	
Calcium	t	
Chromium	t	t
Iron		t
Lead	t	
Molybdenum		t
Nickel		t
Potassium	2.0/0.3	
Selenium		3.8/0.4
(Sulfur)	(26/10)	(20/7)
TOTAL[1]	3	4
Sulfates, H_2O sol[2]	60	29
(Sulfur, from $SO_4^=$)[4]	(20)	(9.55)
Nitrate (H_2O sol)[2]		
Total Carbon[3]		29
(Volatile Carbon)[3]		(29)
TOTAL ANALYZED	63	60
BALANCE	37	40
	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

TABLE 4-51. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT (TEST 35)

SAMPLE #	Joy 1μm Cyclone 35J-4S	Joy Filter 35J-5S	Joy Impinger 35J-IC	SASS Filter 35S-5S	SASS Impinger 35S-IC
PERCENT OF CUT	35.93	25.31	25.40	65.82	14.69
XRF ANALYSIS					
Arsenic	2.1/0.3	1.9/0.3	3.7/0.5	1.4/0.2	t
Calcium	1.1/0.2		t	t	t
Chromium	t	t		t	t
Iron			t		t
Lead	t	t		t	
Nickel					t
Potassium	2.9/1	3.7/0.6	t	3.1/0.6	t
Selenium			3.5/0.5		6.7/0.7
(Sulfur)	(21/8)	(27/10)	(14/4)	(24/8)	(13/4)
Zinc			t		t
TOTAL	5	6	8	6	8
Sulfates, H_2O sol[2]	62	67	22	59	34
(Sulfur, from $SO_4^=$)	(20.80)	(22.19)	(7.48)	(19.51)	(11.23)
Nitrate (H_2O sol)		t	ND		
Total Carbon			31		22
(Volatile Carbon)			(28)		(20)
TOTAL ANALYZED	67	73	61	65	64
BALANCE	33	27	39	35	36
	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

D. Discussion of Results--

1. Electrostatic precipitator--Using the solid weight data (does not include impinger catch) from both sampling trains for the inlet and exit to the ESP, the efficiency was calculated to be 98.2%. If the total catch is used the efficiency is 83%. The added weight in the impingers may be due to pseudo particulates (i.e. gases that react to form particles $SO_3 + H_2O \rightarrow H_2SO_4$). Baghouses and scrubbers are also available and are efficient as the control equipment reported here.

2. Particle size distribution--Figures 4-42 and 4-43 are 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 large amount of material collected on the filter, it would seem that pseudo particulates were present. Therefore, the impinger catch was believed to be properly not included in the measurements of the suspended particulates from glass furnaces for particle size distribution. The break-down of the particle size distribution, not including the impinger catch, is as follows:

	Percent of Particles -			
	>10 µm	10-3 µm	3-1 µm	<1 µm
Controlled (Test 20S)	14	13	25	58
Uncontrolled (Test 20J)	.7	.5	1.8	98
" (Test 28S)	.6	.8	1.6	97
" (Test 35S)	6	3	4	87
" (Test 35J)	2.5	2	2.5	93

Figure 4-43 is the size distribution plot for Test 28 and Test 35. Note that the uncontrolled emissions from these two glass furnaces have a mean particle size of less than 0.1 µm and that the controlled emissions with ESP have a mean particle diameter of about 1 µm.

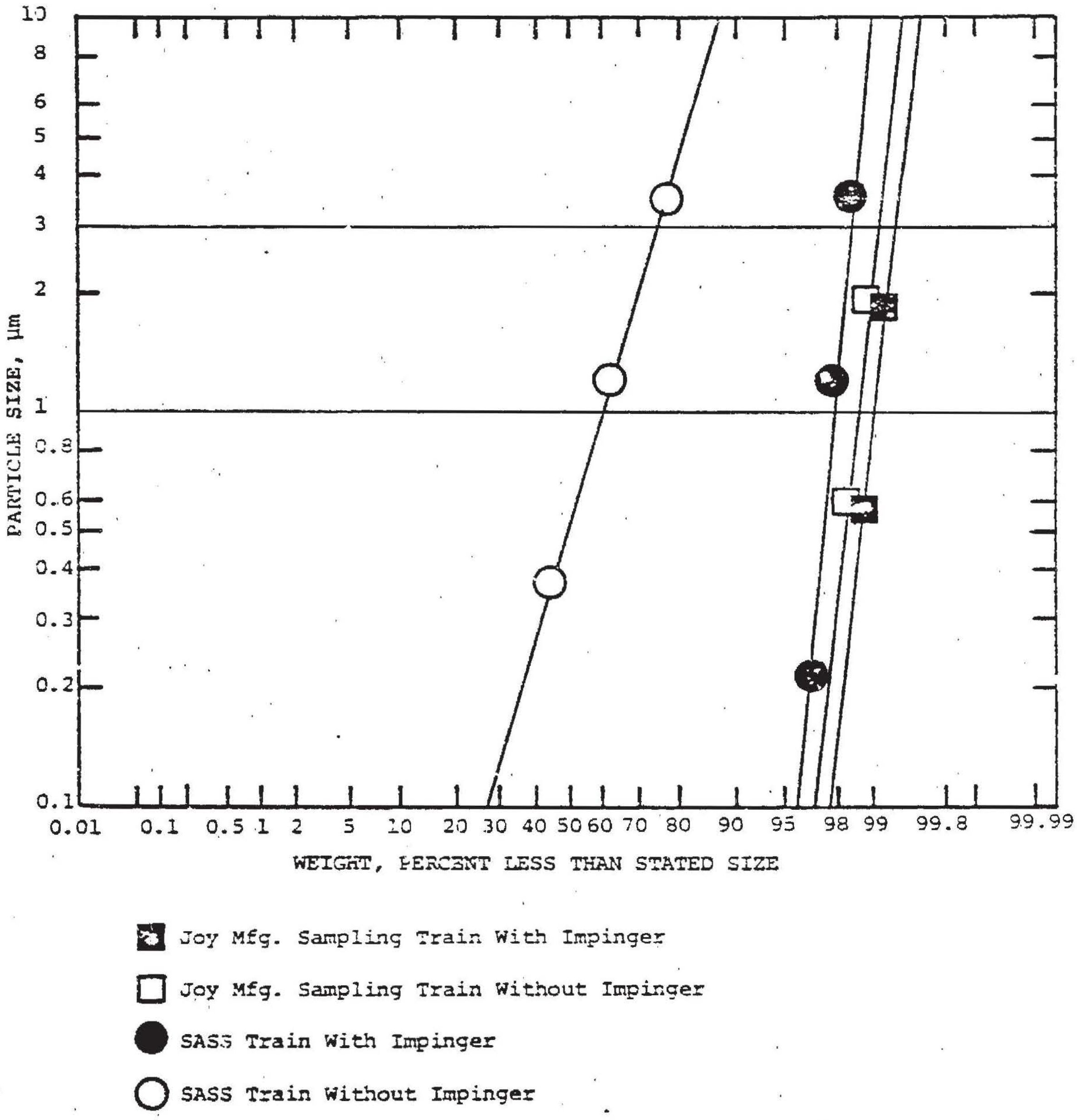


Figure 4-42. Particle size distribution for glass furnace (Test 20).

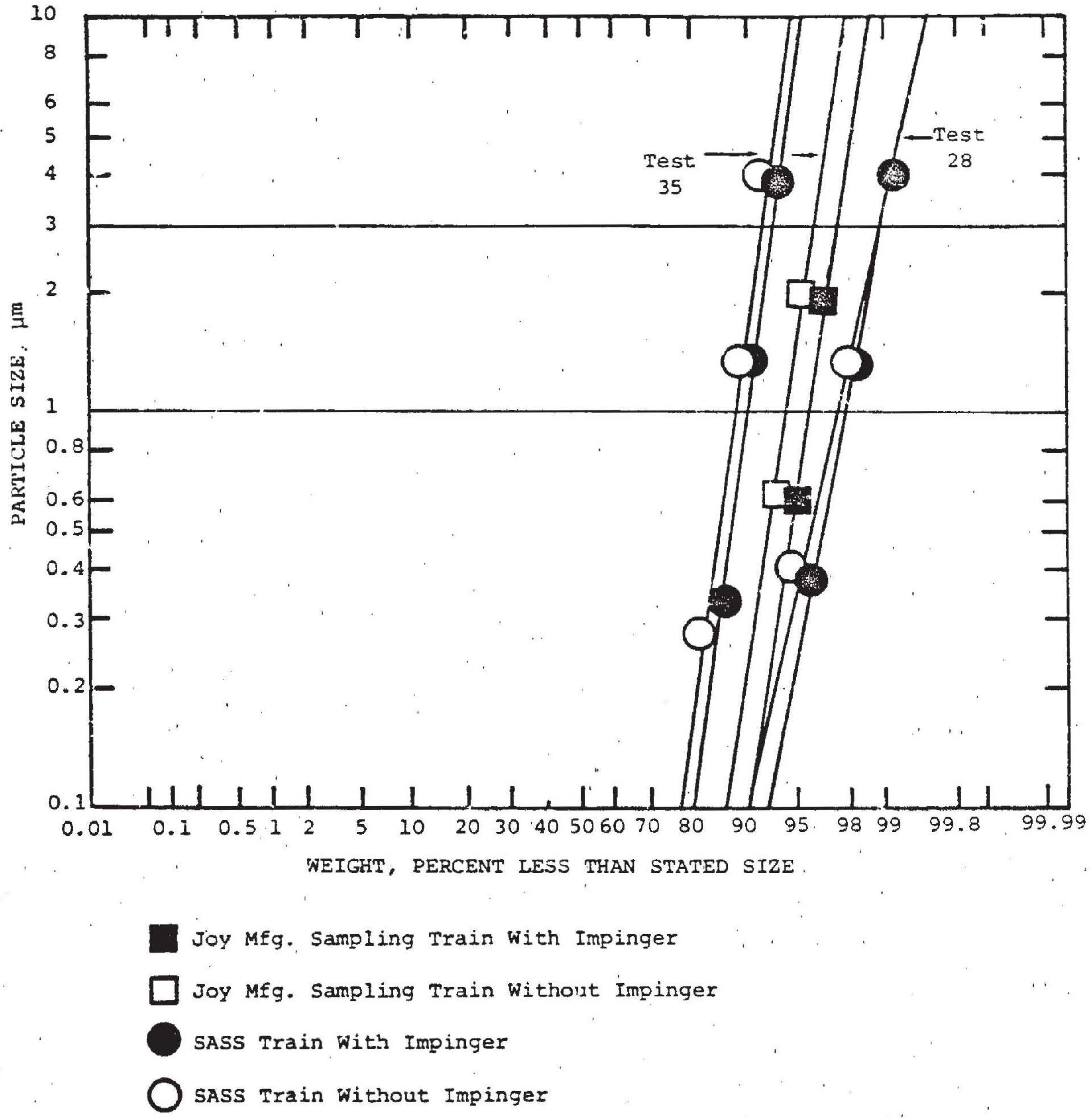


Figure 4-43. Particle size distribution for glass furnace. (Tests 28 & 35)

3. Chemical composition--Tables 4-49, 4-50, and 4-51 list the results from the chemical analysis of the particulate fraction for each of the tests discussed in this section. Sulfates are the most predominant species present and seem to be evenly distributed over the entire size range. Note that the sulfate concentration is about halved for the controlled particulates. Nitrates seem to appear more strongly in the impinger catches.

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

	Controlled	Uncontrolled			
Units	Test 20S	Test 20J	Test 28S	Test 35S	Test 35J
gr/DSCF	.0062	.0364	.0612	.0594	.0469
T/yr	8.0	37	30.2	25.5	27.8
lb/hr	1.83	8.59	7.19	6.06	6.62
lb/MMBtu	.02	.11	.19	.19	.20
lb/ton glass melted	.14	.67	1.56	1.31	1.43
lb/hr*	---	9.26	10.85	9.96	9.96

* calculated from the following equation

$$X_1 = a + 0.0226(S_2)^2 - 0.329\ X_2 - 4.412\ X_3 - 0.9379\ X_4 - 0.635\ (X_5)^2 + 6.170\ X_5$$

(Ref. 4-17)

where

X_1 = particulate emissions, lb/hr
X_2 = process wt, lb/hr-ft^2 melter
X_3 = wt fraction of cullet in charge
X_4 = checker volume, ft^3/ft^2 melter
X_5 = melter area, ft^2/100
a = constant involving two nonqualitative independent factors relating the type of furnace (side port or end port) and type of fuel (U.S. Grade 5 fuel or natural gas).

a = -0.493 end port--U.S. Grade 5 fuel oil
a = -0.623 side port--U.S. Grade 5 fuel oil
a = -1.286 end port--natural gas
a = -1.416 side port--natural gas.

4.2.10 Fiber Glass Wool Manufacturing

A. Process Description--

Glass fiber products are manufactured by melting various raw materials to form glass (predominantly borosilicate), drawing the molten glass into fibers, and coating the fibers with an organic material. The two basic types of fiber glass products, textile and wool, are manufactured by different processes. A typical flow diagram for wool products is shown in Figure 4-44.

In the manufacture of wool products, which are generally used in the construction industry as insulation, ceiling panels, etc., glass marble is fed directly into the forming line. The marbles are melted with natural gas at 1250°F. The liquid glass passes through fine holes, which produces 1/64" fibers. These fibers are converted to wool as they pass through high velocity gas jets. A secondary blower directs the wood through the collecting surface. The organic binder is sprayed onto the hot fibers as they fall from the forming device. The fibers are collected on a moving, flat collecting surface and transported through a curing oven at a temperature of 400°F to 600°F (200° to 315°C) where the binder sets. Depending upon the product, the wool may also be compressed as a part of this operation. The major particulate emissions from the fiber glass wool manufacturing processes are from the forming line and curing oven.

B. Particulate Test Set-up--

Two sampling trains were used simultaneously to sample one of two exhaust ducts from the forming line. The velocity profile in this duct is listed in Table 4-52. Note that the velocities across the stack were very uneven. Two velocity points were chosen for sampling which had values similar to the average velocity. Velocity point 9 was used for the smaller Joy train with a 5/16" nozzle and velocity point 14 was used for the larger SASS train with a 11/16" nozzle.

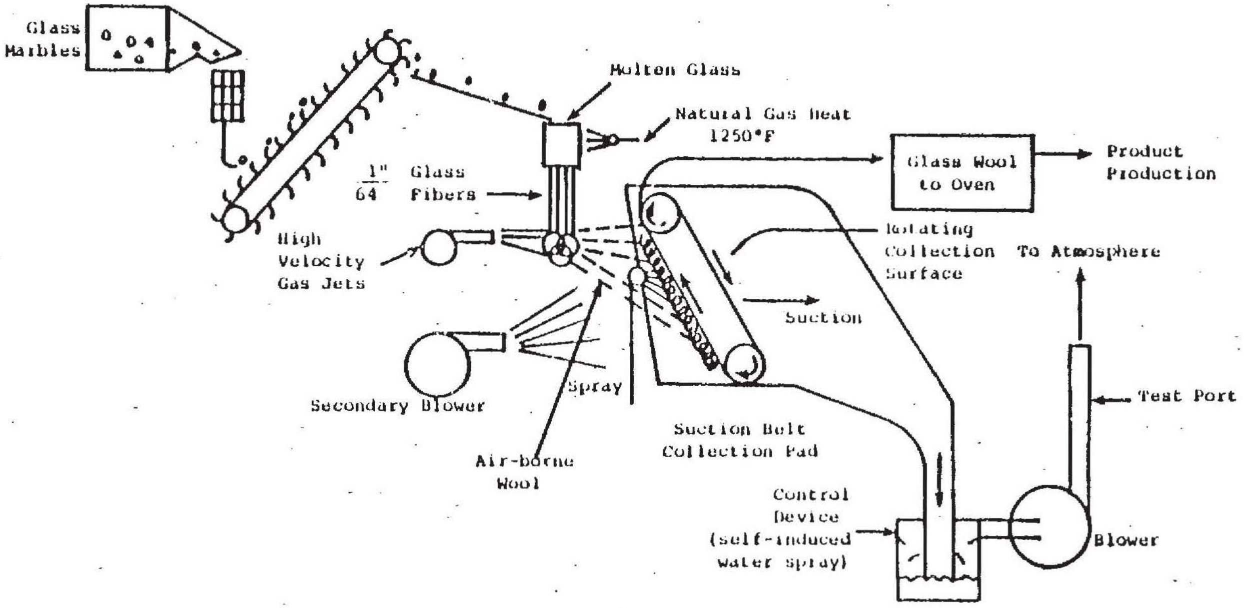
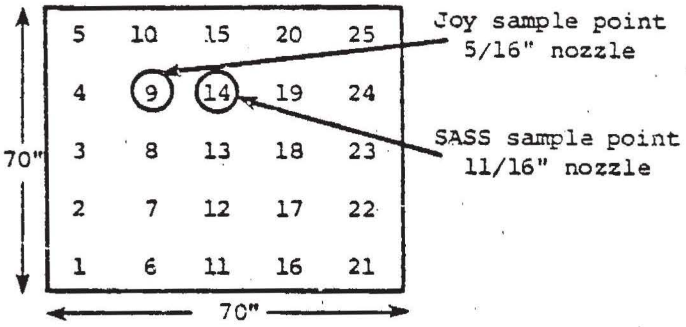


Figure 4-44. Typical flow diagram for fiber glass production (forming line).

TABLE 4-52. VELOCITY PROFILE FOR FIBER GLASS MANUFACTURING (TEST 38)

Temperature: 160°F

Static Pressure: +0.55" H_2O



Distance From End of port			Velocity			
	Point #	ft/sec	Point #	ft/sec	Point #	ft/sec
8	1	60.3	11	50.5	21	7,5
22	2	60.3	12	48.6	22	7.5
36	3	55.6	13	46.7	23	17.1
50	4	53.9	14	43.5	24	27.0
64	5	50.5	15	38.2	25	23.4
8	6	57.2	16	31.9		
22	7	53.9	17	27.0		
36	8	51.2	18	34.1		
50	9	43.5	19	41.8		
64	10	47.7	20	40.5		

Average: 40.9 ft/sec
70,019 SCFM

C. Test Results--

The results of the two tests (38S and 38J) 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 4-53 lists the results from this analysis.

D. Discussion of Results--

1. Particle size distribution--Figure 4-45 is a plot of particle size (µm) vs accumulated weight percent, the latter plotted on a probability scale as explained in Section 4.2.3 B. 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 catch, it would seem that the effects of pseudo particulates would not be significant. Therefore, the impinger catch was believed to be properly included in the measurements of the suspended particulates from fiber glass forming lines. The breakdown of the particle size distribution including the impinger catch is as follows:

	Percent of Particles			
Test #	Greater than 10µm	10-3µm	3-1µm	Less than 1µm
38S	0.6	0.2	0.2	98.9
38J	0.2	0.2	0.4	99.2

Both sampling trains gave very similar size distribution curves which had a mean size of less than 0.1µm. However, during the test at this glass fiber forming line, larger particles (1/2 - 1" diameter discs) were occasionally observed. It appeared that these particles had been formed by agglomeration on the wall of the duct and had then broken loose.

2. Chemical composition of the particulate matter--Table 4-53 presents the chemical analysis of the particulate fraction for each of the tests discussed in this section. Carbon in the form of volatile carbon is the most abundant species, followed by chlorine, nitrates, and sulfates. Most of the elements tended to be fairly evenly distributed over the size range except for chlorine and potassium. Chlorine tended to concentrate in the impingers;

TABLE 4-53. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR FIBER GLASS WOOL MANUFACTURING (TEST 38)

SAMPLE #	SASS Filter 38S-5S	SASS Impinger 38S-IC	Joy Impinger 38J-IC
PERCENT OF CUT	12	86	76
XRF ANALYSIS			
Chlorine	2.5/0.5	25/8	7.8/2
Iron		t	
Potassium	3.9/1		
(Sulfur)	(<3)	(<3)	(<4)
TOTAL[1]	7	25	8
Sulfates, H_2O sol[2]	t	t	t
(Sulfur, from $SO_4^=$)[4]	(t)	(t)	t
Nitrate (H_2O sol)[2]	t	t	t
Total Carbon[3]	15	21	46
(Volatile Carbon)[3]		(18)	(42)
(Carbonates)[3]			
TOTAL ANALYZED	22	46	54
BALANCE	78	54	46
	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

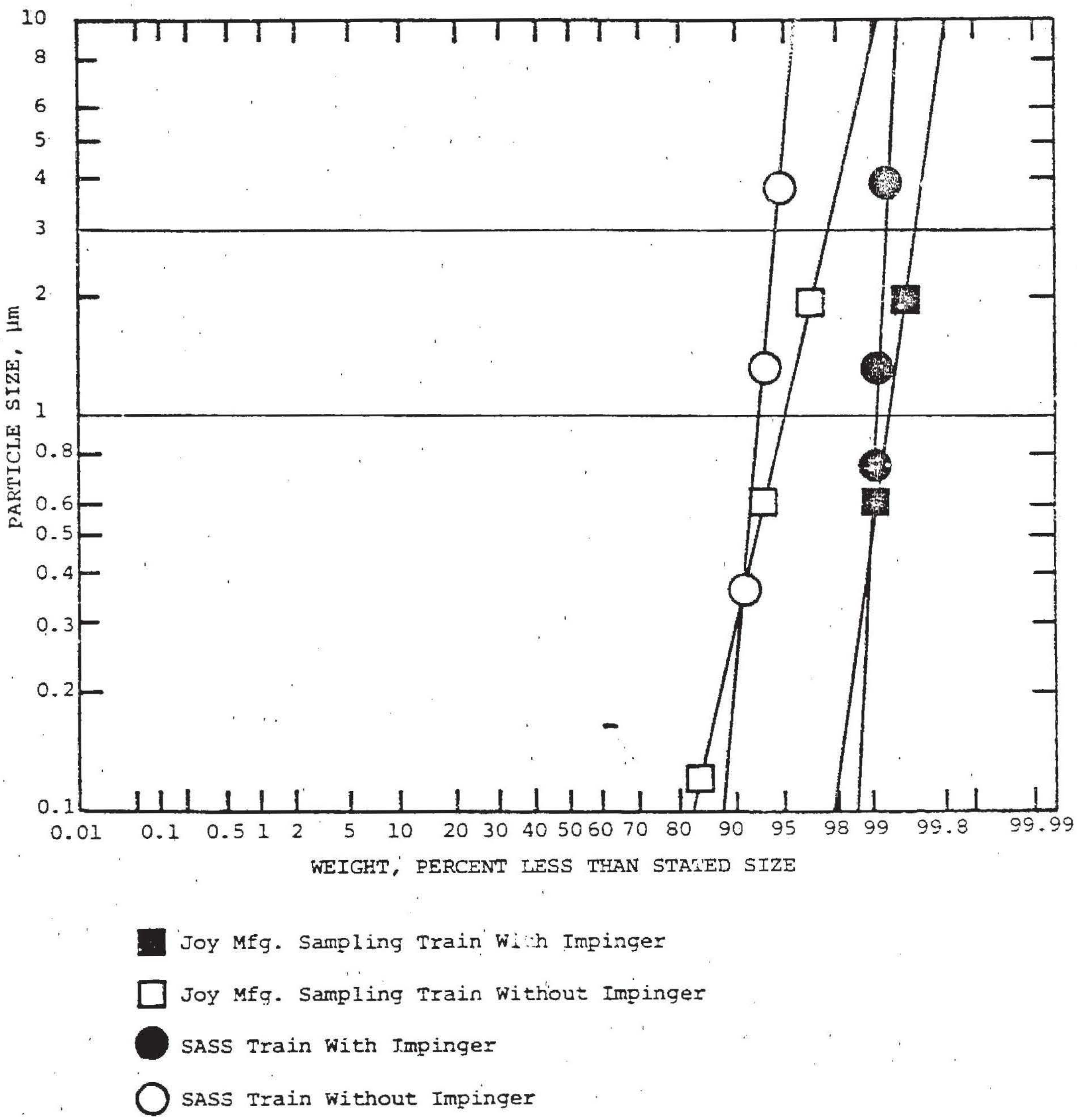


Figure 4-45. Particle size distribution for fiber glass manufacturing (Test 38)

potassium ended up mostly on the filter. The low carbon value on the SASS filter and the absence of volatile carbon can be attributed to the fact that the filter is held in a 400°F oven which bakes off the volatile portion of the carbon.

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

Units	Test #38S	Test #38J	Average
gr/DSCF	0.0170	0.0136	0.0153
T/yr	84.0	67.2	75.6
lb/hr	19.2	15.4	17.3
lb/ton produced	32.0	25.6	28.8
lb/uncontrolled ton produced			57.6

per AP-42 (Ref. 4-18)

4.2.11 Asphalt Roofing Manufacture

A. Process Description (Ref. 4-19)--

The manufacture of asphalt roofing felts and shingles involves saturating fiber media with asphalt by means of dipping and/or spraying. Although it is not always done at the same site, preparation of the asphalt saturant is an integral part of the operation. This preparation, called "blowing," consists of oxidizing the asphalt by bubbling air through the liquid asphalt for 8 to 16 hours. The saturant is then transported to the saturation tank or spray area. The saturation of the felts is accomplished by dipping, high-pressure sprays, or both. The final felts are made in various weights: 15, 30, and 55 pounds per 100 square feet (0.62, 1.5, and 2.7 kg/m^2). Regardless of the weight of the final product, the material distribution is approximately 40% dry felt and 60% asphalt saturant.

Figure 4-46 is a schematic drawing of the production line for manufacturing asphalt shingles similar to the asphalt roofing tested in this study. The major sources of particulate emissions from asphalt roofing

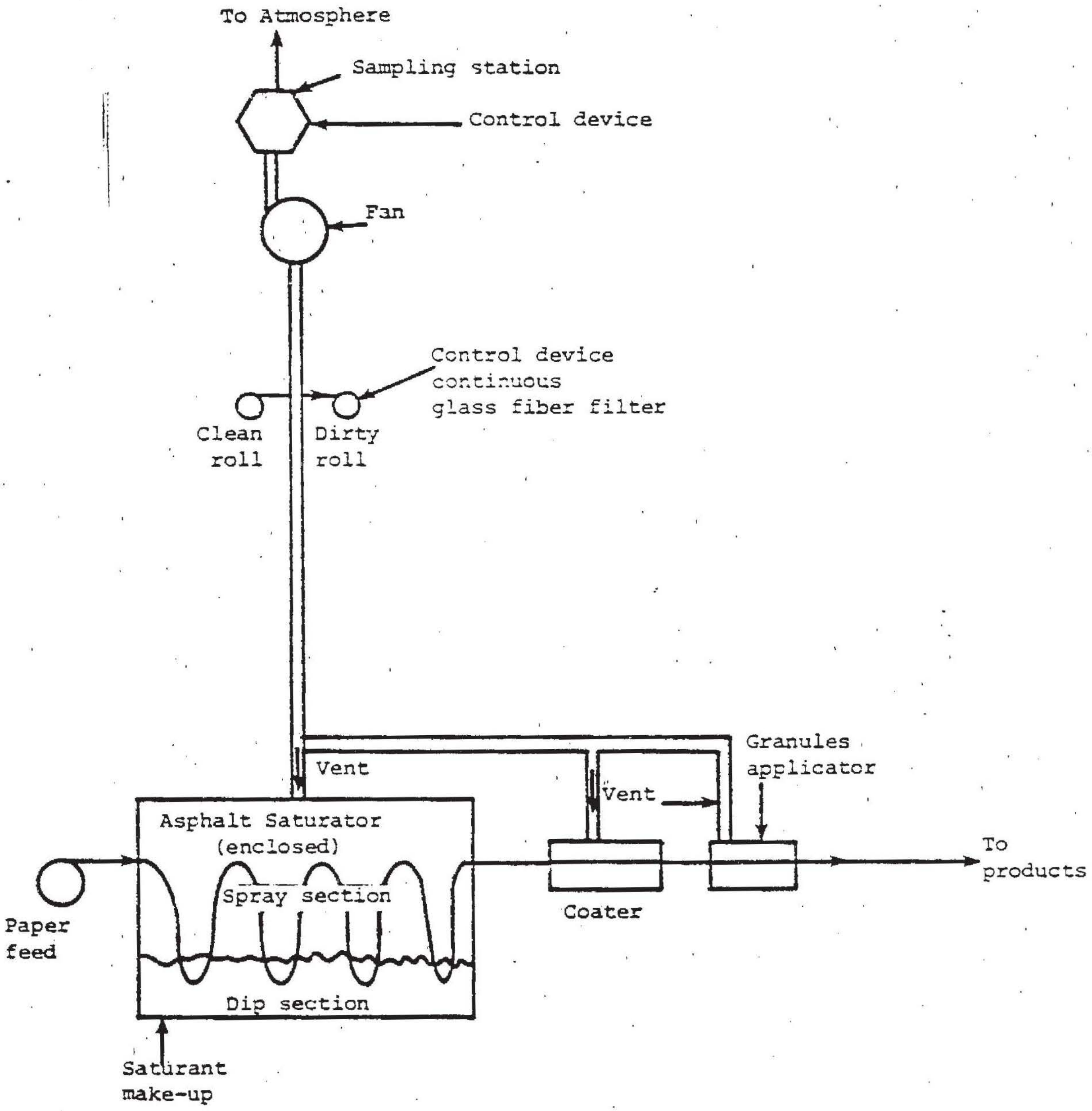


Figure 4-46. Schematic for manufacturing asphalt shingles, mineral-surfaced rolls and smooth rolls (Test 2S).

plants are the asphalt blowing operations and the felt saturation. The felt saturator was the part of the operation tested in this study. The form of particulate was mostly asphalt mist.

B. Particulate Test Set-up--

The location of the particulate sampling was at the end of the duct from the control device leading to the atmosphere (see Figure 4-46). The velocity profile in the duct at this section is listed in Table 4-54.

Both sampling trains were used near the same point to obtain more precise data (duplicate tests). The larger (4 SCFM) SASS train was run with a 5/8" nozzle at Velocity Point 4 and the small (1 SCFM) Joy train was run at 5/16" nozzle at velocity point 5. The test was done in the morning of 1/31/78.

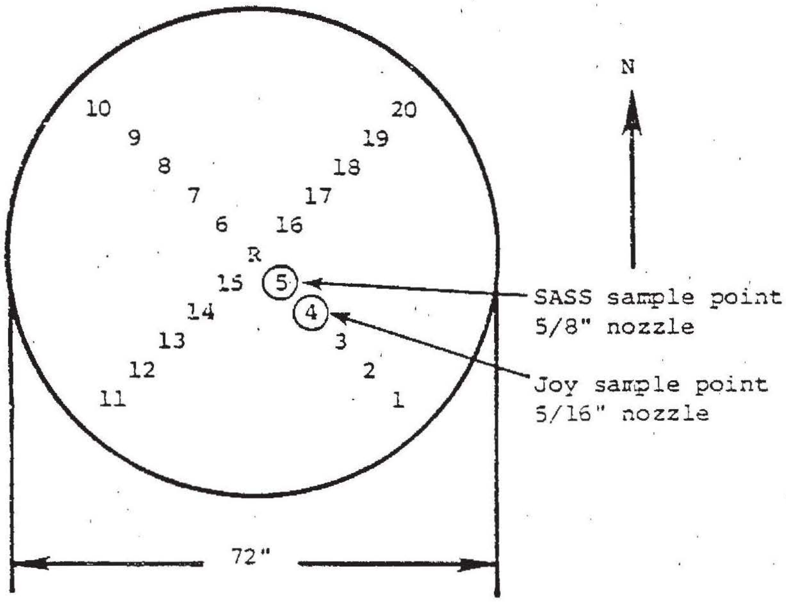
C. Test Results--

The results of the two tests (25S and 25J) discussed in this section are listed in Table 4-1. Elemental composition, sulfate, nitrate, and carbon analyses 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 4-55 lists the results from this analysis.

D. Discussion of Results--

1. Particle size distribution--Figure 4-47 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 the large amount of material collected in the impinger, it would seem that this fraction should be properly included in the measurements of the suspended particulates. The matter in the impinger is mostly organics. These are aerosols and solvents that were condensed in the impingers. Also because of the very small weight percent of matter captured in the cyclones of the small 1 CFM Joy train, it is believed that this size distribution data for the Joy train is not as accurate as the SASS train. The breakdown of the particle size distribution for the SASS test is as follows:

TABLE 4-54. VELOCITY PROFILE FOR ASPHALT ROOFING (TEST 25)



Distance from Edge of Stack	Velocity Point #	Velocity ft/sec	Velocity Point #	Velocity ft/sec
1.8"	1	31.5	11	26.3
5.9"	2	41.1	12	44.3
10.5"	3	38.6	13	41.6
16.3"	4	37.3	14	35.5
24.6"	5	35.2	15	33.0
36.0"	R	33.78	R	33.0
47.4"	6	35.2	16	34.5
55.7"	7	37.9	17	36.6
61.5"	8	39.2	18	40.5
66.1"	9	42.2	19	42.3
70.0"	10	44.0	20	39.8
		Average: 37.0		
		45521 SCFM		

TABLE 4-55. CHEMICAL COMPOSITION IN PERCENT FOR ASPHALT ROOFING MANUFACTURE (TEST 25)

SAMPLE #	Impinger 25S-IC
PERCENT OF CUT	13 (wate residue only)
XRF ANALYSIS	
Calcium	3.4/0.7
Chlorine	12/3
Chromium	t
Cobalt	1.8/0.3
Iron	2.1/0.3
Manganese	t
Nickel	t
Potassium	t
Selenium	t
(Sulfur)	(20/7)
Zinc	t
TOTAL[1]	22
Sulfates, H_2O sol[2]	23
(Sulfur, from $SO_4^=$)[4]	(7)
Nitrate (H_2O sol)[2]	
Total Carbon[3]	24
(Volatile Carbon)[3]	(23)
(Carbonates)[3]	
TOTAL ANALYZED	69
BALANCE	31
	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

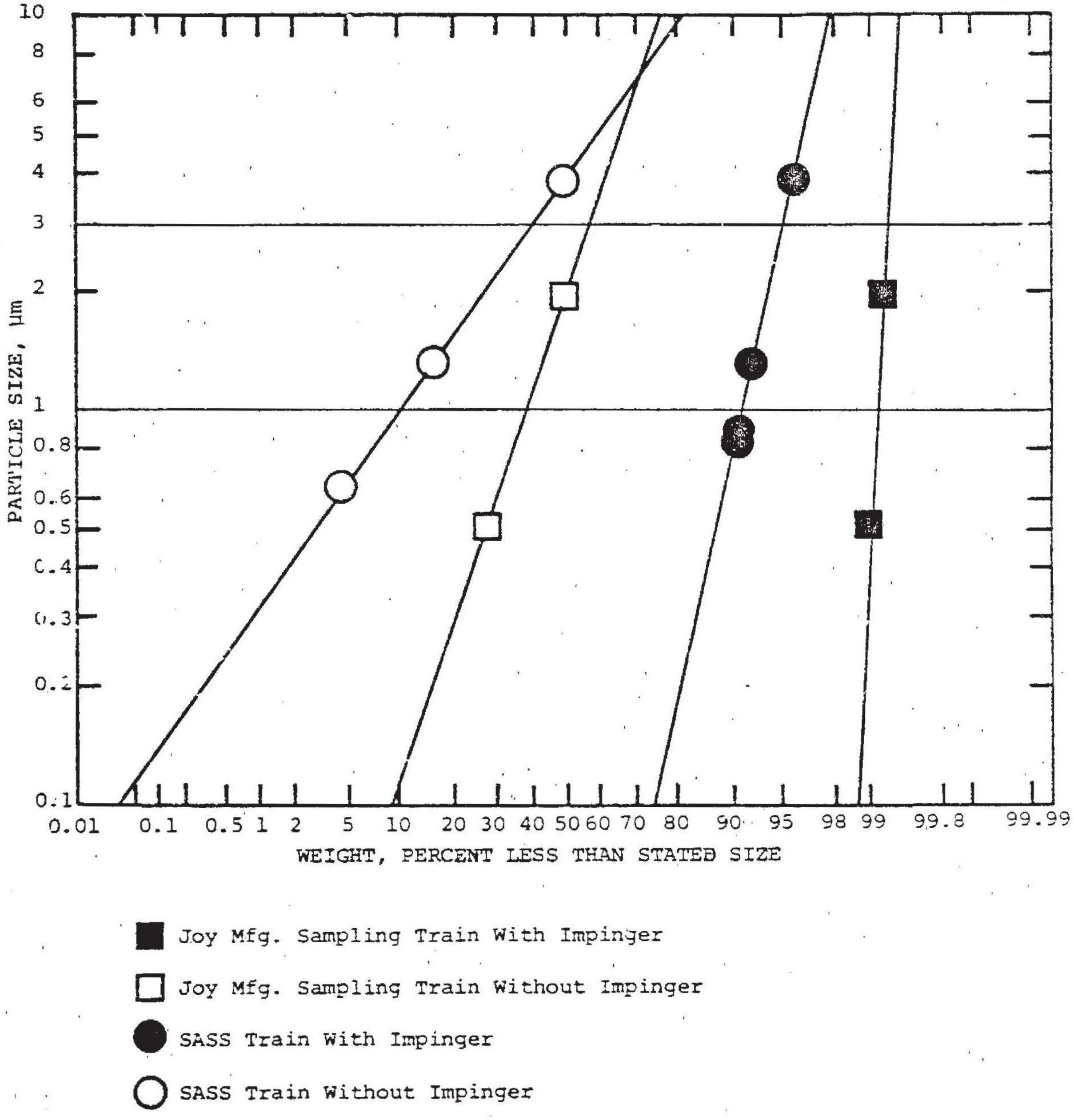


Figure 4-47. Particle size distribution for asphalt roofing manufacturing (Test 25).

	Percent of Particles			
	Greater than 10μm	10-3μm	3-1μm	Less than 1μm
With impinger	2.3	2.8	4	91
Less impinger	18	40	31	11

From Figure 4-47 the mean particle size is 0.01μm including the impinger, and 4μm without the impinger.

An appropriate reminder here is that the SCAQMD includes the condensible material. However, it is believed that condensible material of this type should not be used to determine the size distribution of solid particles.

2. Chemical composition of particulates--Table 4-55 lists the results from the chemical analysis of the impinger fraction for the SASS train. Unfortunately, this was the only fraction with a large enough sample for chemical analysis. The organic fraction (85%) of the impinger catch (which is 85.4% of the total catch) was not analyzed for major chemical composition because it was believed to be mostly volatile carbon. It was not possible to analyze this fraction, methyl chloroform extract, for chemical composition because of the tarry nature of the sample (see Section 3.2.26). Of the 15% of the impinger catch that was analyzed, volatile carbon was the most abundant species. Sulfates were next abundant followed by calcium and iron. All other elements detected were in small amounts (<1.0%).

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.

Units	Test 25S	Test 25J
gr/DSCF	0.0075	0.0078
T/yr	10.4	10.5
lb/hr	2.94	2.98
lb/ton of felt produced	0.28	0.28

4.2.12 Asphaltic Concrete Batch Plants

A. Process Description (Ref. 4-20 & 4-21)--

Plants produce finished asphaltic concrete through either batch or continuous aggregate mixing operations. Different applications of asphaltic concrete require different aggregate size distributions, so that the raw aggregates are crushed and screened at the quarries. The coarse aggregate usually consists of crushed stone and gravel, but waste materials, such as slag from steel mills or crushed glass, can be used as raw material.

As processing for either type of operation (batch or continuous) begins, the aggregate is hauled from the storage piles and placed in the appropriate hoppers of the cold-feed unit. The material is metered from the hoppers onto a conveyor belt and is transported into a gas or oil-fired rotary dryer.

As it leaves the dryer, the hot material drops into a bucket elevator and is transferred to a set of vibrating screens where it is classified by size into as many as four different grades. At this point it enters the mixing operation.

In a batch plant, which was the type tested in this program, the classified aggregate drops into one of the four large bins. After all the material is weighed out, the sized aggregates are dropped into a mixer and mixed dry for about 30 seconds. The asphalt, which is a solid at ambient temperatures, is pumped from heated storage tanks, weighed, and then injected into the mixer. The hot, mixed batch is then dropped into a truck and hauled to the job site. Figure 4-48 illustrates a batch plant similar to the one tested and indicates the location of particulate sources in the operation. There are many sources of fugitive particulate emissions as shown in the sketch. In this program the ducted emissions controlled by a baghouse were characterized, as were the partially controlled emissions entering the baghouse.

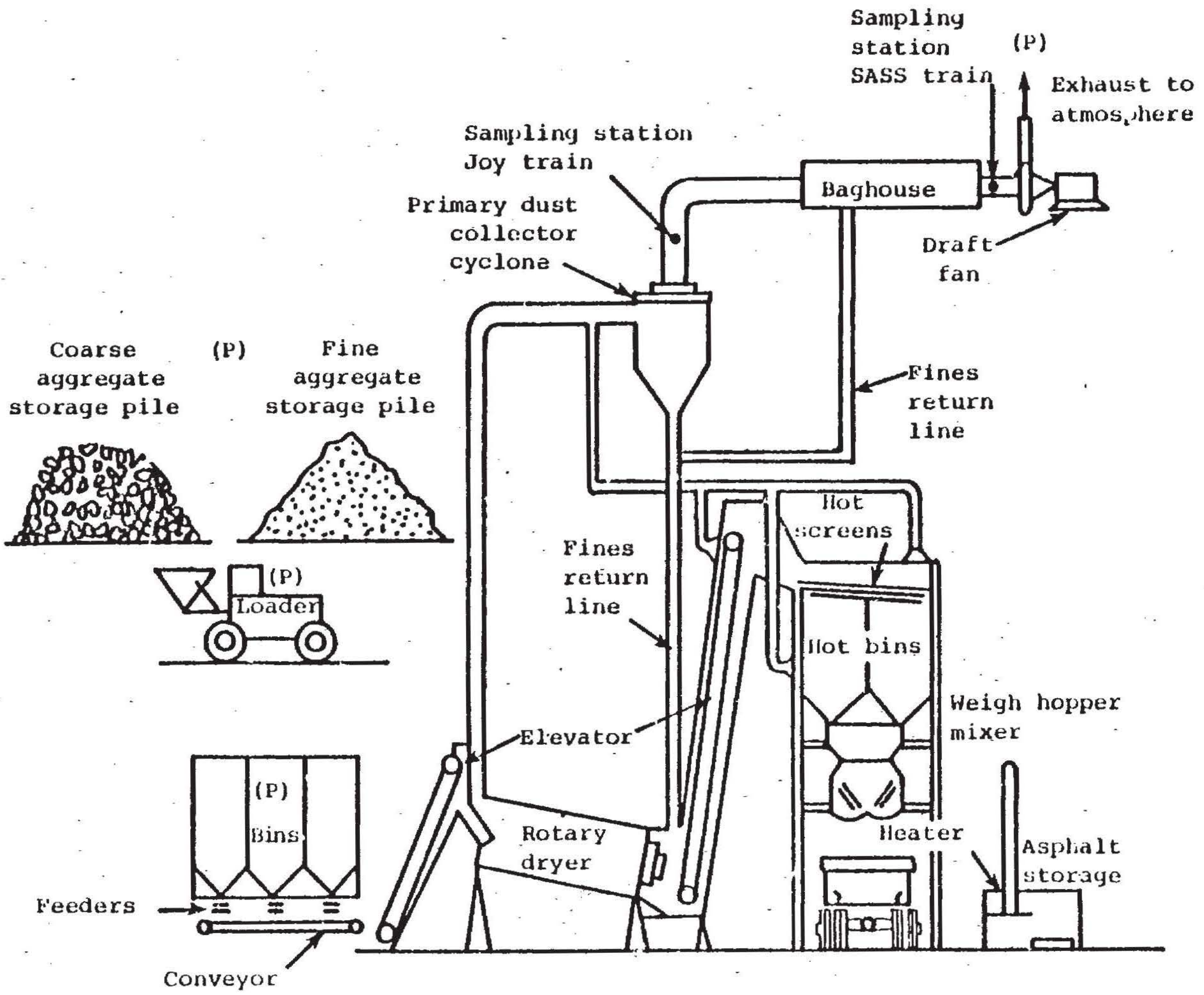


Figure 4-48. Batch hot-mix asphalt plant. "P" denotes particulate emission points.

B. Particulate Test Set-up--

Two trains were used simultaneously to sample the inlet and outlet of the baghouse. The inlet station was located on the vertical duct approximately 12 ft ahead of the bend entering the baghouse. The velocity profile of the inlet duct was taken through the three 3" diameter ports provided. The velocity profile in the inlet and exit ducts of the baghouse are listed in Table 4-56.

The outlet sample station was located on the horizontal section of the duct about eight ft upstream of the fan. In the interest of the safety of the crew, the velocities were not taken through the vertical port. Therefore Velocity Points 10 through 15 were obtained by swinging the pitot tube. A 7/16" nozzle was used at Velocity Point #3 on the outlet duct and a 5/16" nozzle was used at Point #3 of the inlet duct.

C. Particulate Test Results--

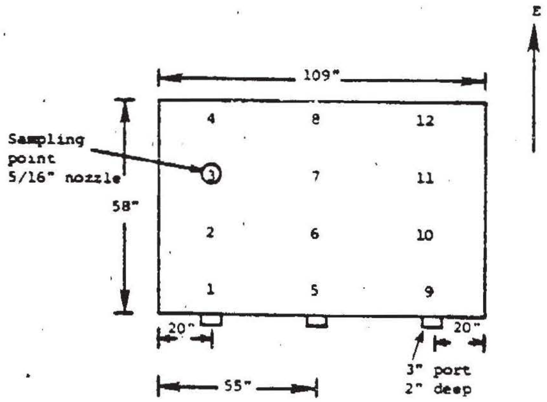
The results of the two tests (Test 29S and 29J) discussed in this section are listed in Table 4-1. Elemental composition, sulfate, nitrate, and carbon analysis were determined for all fractions of particulate catches which contained weights in excess of 100 mg. The details for these procedures are discussed in Section 3.2.2. Due to the very heavy loading on the inlet side of the baghouse, the cyclones and filter in the small sampling train had filled to total capacity and caused a pressure drop during sampling which resulted in stopping the sampling.

D. Discussion of Test Results--

1. Efficiency of the baghouse--Using the solid catch data (i.e. without the impinger catch) from both sampling trains for the inlet and exit, the baghouse efficiency was calculated to be 99.95%. Using the total catch, the efficiency would be 99.92%.

2. Particle size distribution--Figure 4-49 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, the other ignoring it. Considering the large amount of material collected upstream of the filter, it would seem that the

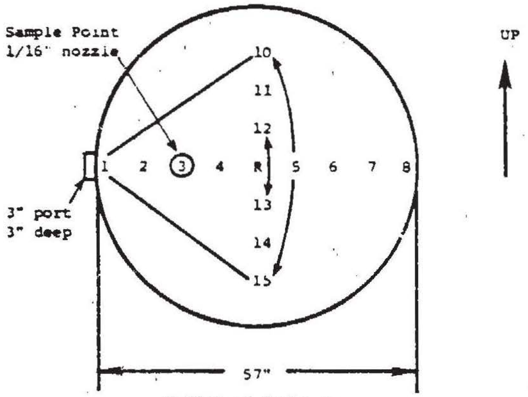
TABLE 4-56. VELOCITY PROFILE--ASPHALT BATCH PLANT (TEST 29)



Inlet to Baghouse

Temperature: 160°F

Static Pressure: -4.5" H_2O



Outlet of Baghouse

Temperature: 160°F

Static Pressure: -11" H_2O

Distance from End of Port	Velocity Point #	Velocity ft/sec
8"	1	30.2
20"	2	30.2
32"	3	34.1
44"	4	37.2
8"	5	31.9
20"	6	36.7
32"	7	38.2
44"	8	41.8
8"	9	37.2
20"	10	34.1
32"	11	28.9
44"	12	28.3

Average: 34.1 ft/sec

75337 scf

Distance from End of Port	Velocity Point #	Velocity ft/sec
5"	1	68.8
9-3/8"	2	76.3
14-5/8"	3	85.3
22-3/8"	4	85.3
33"	R	95.4
43-5/8"	5	95.4
51-3/8"	6	85.3
56-5/8"	7	85.3
61"	8	81.0
37"	10	95.4
35"	11	81.0
34"	12	89.5
34"	13	85.3
35"	14	73.9
37"	15	68.8

Average: 84.6 ft/sec

75354 scf

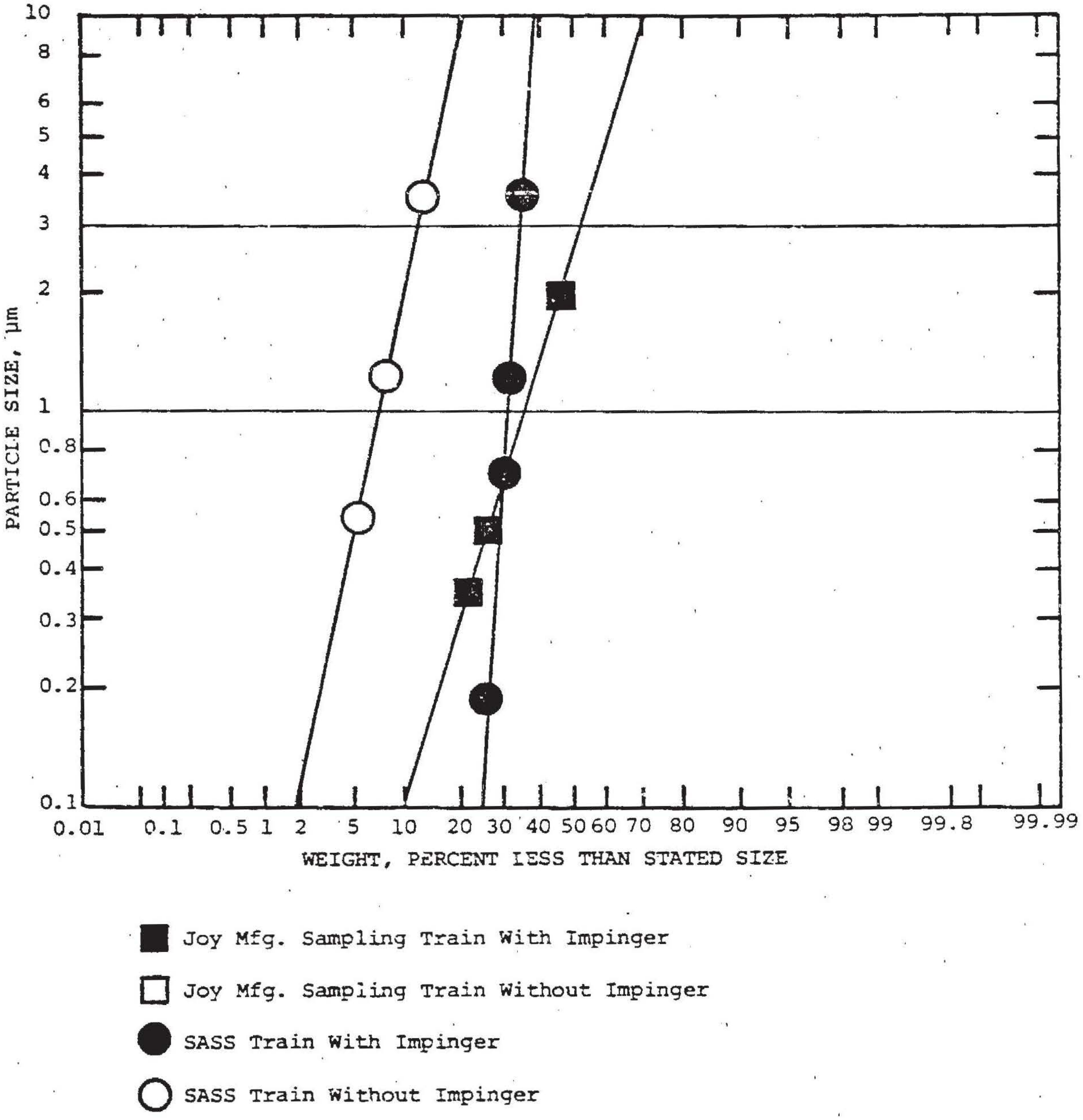


Figure 4-49. Particle size distribution for asphaltic concrete batch plant (Test 29)

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 asphaltic concrete plants. As a result of the filling of the cyclones in the Joy train, a particle size distribution curve could not be made. It is estimated from visual examinations that the mean particle size for the inlet is greater than 100μm. The breakdown of the particle size distribution for the baghouse outlet including the impinger is as follows:

	Percent of Particles			
	Greater than 10μm	10-3μm	3-1μm	Less than 1μm
Test 29S	60	6	4	30

The mean particle size for the baghouse outlet is approximately 60μm. Although the baghouse has a high efficiency some of the coarser particles still penetrate, no doubt due to small leaks in and around the bags.

3. Chemical composition of particulates--Table 4-57 lists the results from the chemical analysis of the particulate fraction for the tests discussed in this section. Although silicon is not detected with XRF (see Section 3.2.2 B), it is clear that silicon is the most abundant element in these samples. The unanalyzed portion of Table 4-57 is primarily SiO_2 and other compounds of silicon.

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 29S	Uncontrolled Test 29J
gr/DSCF	0.00776	11.485
T/yr	1.56	2079.9
lb/hr	4.34	5777.5
lb/ton produced	0.02	34
lb/ton produced (Ref. 4-22)	0.1	45

TABLE 4-57. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES IN PERCENT FOR ASPHALT BATCH PLANTS (TEST 29)

SAMPLE #	10µm Cyclone 29S-25	Filter 29S-5S	10µm Cyclone 29J-2S
WT. PERCENT OF CUT	62	3.6	54
XRF ANALYSIS			
Arsenic	t		
Barium	t		t
Calcium	2.4/0.3	10/3	1.9/0.3
Chromium	t		t
Iron	3.6/0.5	1/0.1	4.3/0.5
Potassium	1.5/0.5		1.5/0.2
Silver	t		
(Sulfur)	(<8)	(<4)	(<3)
Titanium	t	t	t
TOTAL[1]	8	11	8
Sulfates, H_2O sol[2]	2		
(Sulfur, from $SO_4^=$)[4]	(t)		
Nitrate (H_2O sol)[2]	t		
Total Carbon[3]			t
(Volatile Carbon)[3]			
(Carbonates)[3]			(t)
TOTAL ANALYZED	10	11	8
BALANCE	90	89	92
	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