

Note: This is a reference cited in *AP 42, Compilation of Air Pollutant Emission Factors, Volume I Stationary Point and Area Sources*. AP42 is located on the EPA web site at www.epa.gov/ttn/chief/ap42/

The file name refers to the reference number, the AP42 chapter and section. The file name "ref02_c01s02.pdf" would mean the reference is from AP42 chapter 1 section 2. The reference may be from a previous version of the section and no longer cited. The primary source should always be checked.

AP-42 Section Number: 9.9.1

Reference Number: 33

**Title: Fine Particle Emissions From
Stationary And Miscellaneous
Sources In The South Coast Air
Basin, Final Report**

**National Technical Information
Service**

February 1979

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-293 923

**Fine Particle Emissions from Stationary
and Miscellaneous Sources in the
South Coast Air Basin. Final Report**

KVB, Inc, Tustin, CA

Prepared for

California State Air Resources Board, Sacramento

Feb 79

FINE PARTICLE EMISSIONS FROM
STATIONARY AND MISCELLANEOUS SOURCES
IN THE SOUTH COAST AIR BASIN
FINAL REPORT

PB 293923



KVB 5806-783

PREPARED FOR:
CALIFORNIA AIR RESOURCES BOARD
SACRAMENTO, CALIFORNIA

PREPARED BY:

H. J. TABACK
A. R. BRIENZA
J. MACKO
N. BRUNETZ
KVB, INC.

FEBRUARY 1979

REPORT DOCUMENTATION PAGE		1. REPORT NO. ARB-R-A6-191-30-79-94	2.	3. Recipient's Accession No.
4. Title and Subtitle Fine Particle Emissions From Stationary and Miscellaneous Sources in the South Coast Air Basin - Final Report		5. Report Date February 1979		
7. Author(s) H.J. Taback, A.R. Brienza, J. Macko, N. Brunetz		8. Performing Organization Rept. No. KVB 5806-783		
9. Performing Organization Name and Address KVB, Inc. 17332 Irvine Blvd. Tustin, CA 92680		10. Project/Task/Work Unit No.		
12. Sponsoring Organization Name and Address Air Resources Board State of California P.O. Box 2815 Sacramento, CA 95812		11. Contract(C) or Grant(G) No. (C) ARB A6-191-30 (G)		
13. Type of Report & Period Covered Final		14.		
15. Supplementary Notes				
16. Abstract (Limit 200 words) The report presents results of a program to characterize fine particulate emissions from stationary and miscellaneous sources in the California South Coast Air Basin. Point source emissions were sampled using an EPA Source Assessment Sampling System, which divides the particulate matter into four size ranges: >10, 3-10, 1-3, and <1µm. These samples were analyzed to determine elemental composition (by x-ray fluorescence); sulfates and nitrates (by wet chemistry); and carbon content (by carbon analyzer) in the forms of volatile, carbonate and total carbon. Data for the area source particulate samples in the same size range were obtained from the literature. From these data, emission profiles were developed for 81 of the 135 Source Classification Codes which are found in the Basin. The profiles provide composition data for each size category. Approximately 66 percent of the particulate matter emitted from point sources was in the fine (<10µm) size range. These emissions amounted to 83 tons per day (tpd), with combustion of fuels being the predominate application category. The area source fine particulate emissions totalled 385 tpd. These data are presented in tabulated and gridded (by 10km) formats. A discussion of control technology emphasizes costs and efficiencies. The emission profiles are presented in the Appendix.				
17. Document Analysis				
a. Descriptors Air Pollution Aerosols Sulfates Nitrates		Dust Particle Size		
b. Identifiers/Open-Ended Terms Stationary Sources Suspended Particulate Matter Particle Size Distribution				
c. COSATI Field/Group				
18. Availability Statement Release Unlimited. Available from National Technical Information Service 5285 Port Royal Rd. Springfield, VA 22161		19. Security Class (This Report) unclassified 20. Security Class (This Page)		
21. No. of Pages 582 MF 1A01		OPTIONAL FORM 272 (4-77) (Formerly NTIS-35)		

"The statements and conclusions in this report are those of KVB, Inc. and not necessarily those of the State Air Resources Board. The mention of commercial products, their source or their use in connection with material reported herein is not to be construed as either an actual or implied endorsement of such products."

ABSTRACT

An investigation of fine particulate emissions from stationary and miscellaneous sources in the greater Los Angeles area was conducted. The objectives were to help provide information on the origin of the ambient aerosol (haze) and to develop a basis from which to plan control strategy. The program results included extensive field test data, an inventory of total suspended particulate (TSP) emissions, a comprehensive profile on these emissions (i.e., by size distribution and chemical composition) and recommendations of alternative methods of emission control. The particulate inventory was delivered to the ARB in the form of computer print-outs and magnetic tapes. The emission profiles developed on the program were presented as an appendix to this report. These profiles divide the TSP emissions by weight percent into four categories, $>10\mu\text{m}$, $3-10\mu\text{m}$, $1-3\mu\text{m}$, and $<1\mu\text{m}$. Within each category, the chemical composition is tabulated in weight percent. These data include: elemental composition (by X-ray fluorescence); sulfate and nitrate composition (by wet chemistry); and carbon content (by carbon analyzer) in the forms of volatile, carbonate, and total carbon.

ACKNOWLEDGEMENTS

KVB is pleased to acknowledge the participation of the following other organizations which contributed to the success of the program in the roles described:

Abacus Programming Corp., Santa Monica, CA--Inventory Software
Design and Programming

Rockwell International, Air Monitoring Center, Newbury Pk., CA--
Sulfate, Nitrate and Carbon Analyses

Armament Systems Corp. (formerly Analox), Anaheim, CA--X-ray Fluorescence
Analysis

Glass Packaging Institute, Irvine, CA--Voluntary guidance in the
selection and assistance in arrangements for testing glass furnaces

Western Oil and Gas Association, Los Angeles, CA--Voluntary assistance
and guidance in the refinery aspects of the program

South Coast Air Quality Management District, El Monte, CA, and
Ventura County APCD--EIS Data, Preliminary Inventory Data
and Valuable Consultation

Southern Research Institute, Birmingham, AL--Voluntary consultation
in cyclone design and data interpretation

Mar-Dee Manufacturing Co., Santa Ana, CA--Cyclone and Filter Holder
Fabrication

Aerotherm Division of Acurex Corp., Mountain View, CA--Cyclone
Calibration and SASS Train

Southern California Edison, Rosemead, CA, and Los Angeles Department
of Water and Power, Rosemead, CA--Utility Boiler Test Coordination

The following individuals played key roles:

J. Faskind	ARB	Research Contract Manager
H. J. Taback	KVB	Program Manager
A. R. Brienza	KVB	Project Engineer
N. Brunetz	KVB	Test Director
J. Macko	KVB	Test Engineer
G. L. Anderson	KVB	Technician
J. L. Stredler	Abacus	Data System Analyst
R. S. Tolchin	Abacus	Programmer
J. G. Kulleck	Armament Systems	Manager, XRF Analysis
G. Colovos	Rockwell AMC	Manager, Analytical Chemistry
L. S. Shepard	Rockwell AMC	Asst. Mgr., Analytical Chemistry
W. B. Smith	Southern Research	Consultant
R. R. Wilson, Jr.	Southern Research	Consultant
D. Blake	Aerotherm	Consultant
R. Knable	Aerotherm	Consultant
W. Martin	Mar-Dee	Machinist
R. Ferb	Research-Cottrell	Control System Analyst

CONTENTS

<u>Section</u>	<u>Page</u>
ABSTRACT	iii
ACKNOWLEDGEMENTS	iv
LIST OF FIGURES	viii
LIST OF TABLES	xv
1.0 OVERVIEW	1-1
1.1 Introduction	1-1
1.2 Summary and Conclusions	1-3
1.3 Recommendations for Further Research	1-8
References for Section 1.0	1-13
2.0 INVENTORY	2-1
2.1 Data Sources	2-1
2.2 Data Management	2-2
2.3 Engineering Analysis	2-6
2.3.1 Point Source Emission Factors	2-6
2.3.2 Emission Profiles	2-18
2.3.3 Area Sources	2-32
References for Section 2.0	2-101
3.0 FIELD TESTING	3-1
3.1 Approach	3-1
3.2 Methodology	3-2
3.2.1 Sampling	3-3
3.2.2 Analysis Methods	3-45
3.2.3 Data Reduction	3-52
3.3 Quality Control	3-65
3.3.1 Cyclone Calibration	3-65
3.3.2 Laboratory Quality Assurance Program	3-74
3.3.3 Redundant Field Sampling and Analysis	3-76
3.3.4 Equipment Maintenance and Calibration	3-84
3.4 Forms	3-85
References for Section 3.0	3-110

CONTENTS (CONTINUED)

<u>Section</u>	<u>Page</u>
4.0 TEST RESULTS	4-1
4.1 Test Program	4-1
4.2 Summary of Test Results	4-3
4.2.1 KVB Boiler Tests	4-17
4.2.2 Industrial Boilers	4-41
4.2.3 Wood Waste Boiler	4-50
4.2.4 Utility Boilers	4-58
4.2.5 IC Engines	4-95
4.2.6 Portland Cement Manufacture	4-100
4.2.7 Calcination of Gypsum	4-111
4.2.8 Brick Manufacturing--Clay Grinding Process	4-118
4.2.9 Glass Melting Furnace	4-128
4.2.10 Fiber Glass Wool Manufacturing	4-145
4.2.11 Asphalt Roofing Manufacture	4-151
4.2.12 Asphalt Concrete Batch Plants	4-158
4.2.13 Rice Drying Process	4-165
4.2.14 Carob Roasting	4-172
4.2.15 Steel Heat Treating	4-178
4.2.16 Abrasive Blasting	4-185
4.2.17 Aluminum Foundry	4-192
4.2.18 Steel Production--Sinter Plant	4-198
4.2.19 Steel Production--Open Hearth Furnace	4-206
4.2.20 Boric Acid Production	4-213
4.2.21 Chemical Fertilizer Plants	4-219
4.2.22 Paint Spray Booths-Automobile	4-225
4.2.23 Wood Processing	4-232
4.2.24 Refinery Process Heaters	4-243
4.2.25 Catalytic Cracking	4-248
4.2.26 Alfalfa Dehydration	4-255
4.2.27 Cotton Ginning Operations	4-258
4.3 Particulate Control Equipment Efficiencies	4-260
References for Section 4.0	4-265
5.0 PARTICULATE EMISSION CONTROL TECHNOLOGY	5-1
INTRODUCTION	5-1
5.1 Methods of Control	5-4
5.1.1 Settling Chambers & Momentum Separators	5-4
5.1.2 Cyclones	5-9
5.1.3 Wet Scrubbers	5-14
5.1.4 Fabric Filters	5-30
5.1.5 Electrostatic Precipitators	5-39
5.2 Cost of Particulate Controls	5-48
5.2.1 Cost Basis	5-49
5.2.2 Cost Data	5-50
References for Section 5.0	5-62

FIGURES

<u>Number</u>		<u>Page</u>
1-1	Spatial distribution of point and area source TSP emissions	1-10
2-1	Breakdown of particulate sources into ARB application category for each county in the SCAB.	2-3
2-2	a. Composite of emission into source classification for SCAB b. Fraction of emissions from each county c. Fraction of field tests done for each source classification	2-4
2-3	Emission factors as a function of fuel sulfur content for utility boilers.	2-13
2-4	1.2 tons per acre of construction per month of activity. Emission factor applies particles <30µ inch diameter.	2-37
2-5	Agricultural tillage dust particle size distribution.	2-42
2-6	Location of major agricultural areas in the South Coast Air Basin.	2-44
2-7	Location of major sanitary landfills in the South Coast Air Basin.	2-46
2-8	Livestock feedlot particle size distribution.	2-49
2-9	Areas encompassing major feedlots.	2-50
2-10	Unpaved road particle size distribution.	2-53
2-11	Paved road particle size distribution.	2-58
2-12	Forest fire particle size distribution.	2-64
2-13	Location of major forest acreage in the South Coast Air Basin.	2-65
2-14	Residential fireplace emissions particle size distribution; soft woods.	2-69
2-15	Wheat waste burning size distribution.	2-73
2-16	Alfalfa waste burning particle size distribution	2-74
2-17	Apricot waste burning particle size distribution	2-75
2-18	Peach waste burning particle size distribution.	2-76
2-19	Ditch bank weed burning particle size distribution	2-77
2-20	Factors affecting tread wear.	2-80
2-21	Salt spray emission calculation model.	2-90
2-22	Sea spray particle size distribution.	2-92
2-23	Spatial distribution of stationary TSP emissions (numbers on grid indicate emissions in tons/day).	2-98

FIGURES (CONTINUED)

<u>Number</u>		<u>Page</u>
3-1	Schematic of SASS.	3-4
3-2	Probe details.	3-6
3-3	Cyclone train and filter holder with oven.	3-7
3-4	SASS cyclone dimensions.	3-8
3-5	Filter housing assembly.	3-10
3-6	Impinger train out of case.	3-11
3-7	Vacuum pump.	3-12
3-8	Control unit.	3-14
3-9	Particulate sampling train.	3-17
3-10	Environmental Protection Agency-Southern Research Institute Five-Stage cyclone.	3-18
3-11	Cyclone 1.	3-20
3-12	Cyclone 2.	3-21
3-13	Cyclone 3.	3-22
3-14	Filter holder.	3-23
3-15	Joy train cyclone assembly.	3-24
3-16	Joy train cyclone assembly schematic.	3-26
3-17	Assembled top view.	3-27
3-18	Cyclone 1 design sketch.	3-28
3-19	Design sketch, reverse exit tube for Cyclone 1.	3-29
3-20	Cyclone 2 design sketch.	3-30
3-21	Cyclone 3 design sketch.	3-31
3-22	Stainless steel ball & socket connectors.	3-32
3-23	Joy Manufacturing Co. control unit.	3-33
3-24	KVB modified Joy Manufacturing Co. sampling case.	3-33
3-25	Joy Manufacturing Co. probe.	3-33
3-26	SASS operating nomogram.	3-37
3-27	SASS train sample recovery--probe, cyclones, filter.	3-41
3-28	Illustration of particle size distribution construction.	3-58
3-29	D ₅₀ particle size, μm vs temperature $^{\circ}\text{R}$ at flow rate of 1.0 acfm and 1.00 gm/cm ³ .	3-60

FIGURES (CONTINUED)

<u>Number</u>		<u>Page</u>
3-30	Temperature correction curves for the six cyclones used in the program.	3-62
3-31	Cyclone flow rate vs D_{50} cut point for small cyclones.	3-63
3-32	Cyclone flow rate vs D_{50} cut point for small and SASS cyclones.	3-64
3-33	Typical cyclone fractional efficiency curve.	3-67
3-34	SiO_2 test dust.	3-69
3-35	SiO_2 -- small dust cyclone cup catch.	3-69
3-36	SiO_2 test dust -- small cyclone filter catch.	3-70
3-37	Cyclone calibration. KVB (ARB) SASS cyclones.	3-71
3-38	Comparison - calibration results for two sets of SASS cyclones.	3-72
3-39	Calibration results, KVB 1 cfm cyclone.	3-73
4-1	Distribution of field tests (total 41 tests).	4-2
4-2	Schematic of 80 horsepower boiler.	4-20
4-3	Cross section through windbox.	4-21
4-4	Cross section through firebox.	4-21
4-5	KVB test boiler installation.	4-22
4-6	Particle size distribution (Test 01).	4-26
4-7	Particle size distribution (Test 02).	4-27
4-8	Particle size distribution (Test 03).	4-28
4-9	Ash + asphaltenes vs fuel sulfur.	4-38
4-10	Particulate emissions (Test 01, 02, & 03) vs fuel sulfur	4-38
4-11	Particle size distribution for high fuel sulfur-low fuel sulfur comparison.	4-39
4-12	An industrial water tube boiler.	4-42
4-13	Particle size distribution for industrial boiler (Test 16).	4-45
4-14	Wood chip and sawdust boiler.	4-52
4-15	Particle size distribution for wood waste boiler (Test 05).	4-57
4-16	Flue gas flow from utility boilers.	4-60
4-17	Particle size distribution for utility boilers (Test 11).	4-80

FIGURES (CONTINUED)

<u>Number</u>		<u>Page</u>
4-18	Particle size distribution for utility boilers (Test 12).	4-81
4-19	Particle size distribution for utility boilers (Test 13).	4-82
4-20	Particle size distribution for utility boilers (Test 21).	4-83
4-21	Particle size distribution for utility boilers (Test 22).	4-84
4-22	Particle size distribution for utility boilers (Test 23).	4-85
4-23	Particle size distribution for utility boilers (Test 24).	4-86
4-24	Particle size distribution for utility boilers (Test 32).	4-87
4-25	Particle size distribution for utility boilers (Test 33).	4-88
4-26	Particle size distribution summary for utility boilers (18 tests).	4-91
4-27	Emission factors as a function of fuel sulfur content for utility boilers.	4-94
4-28	Schematic of IC engine (Test 15).	4-96
4-29	Particle size distribution for IC engines (Test 07).	4-103
4-30	Cement production.	4-105
4-31	Particle size distribution for cement manufacturing (Test 09).	4-110
4-32	Gypsum calcining operation.	4-113
4-33	Particle size distribution for calcination of gypsum (Test 06).	4-117
4-34	Basic flow diagram of brick manufacturing process.	4-119
4-35	Brick manufacturing-clay grinding process.	4-120
4-36	Particle size distribution for brick grinding process (Test 08)	4-125
4-37	Flow diagram for soda-lime glass manufacture.	4-129
4-38	Glass melting furnace (end port).	4-130
4-39	Glass melting furnace (side port).	4-131
4-40	Glass melting furnace (side port) with ESP.	4-132
4-41	Flow diagram for glass furnace with ESP control.	4-134
4-42	Particle size distribution for glass furnace (Test 20).	4-142
4-43	Particle size distribution for glass furnace (Tests 28 & 35).	4-143
4-44	Typical flow diagram for fiber glass production (forming line).	4-146
4-45	Particle size distribution for fiber glass manufacturing (Test 38).	4-150

FIGURES (CONTINUED)

<u>Number</u>		<u>Page</u>
4-46	Schematic for manufacturing asphalt shingles, mineral-surfaced rolls and smooth rolls (Test 23).	4-152
4-47	Particle size distribution for asphalt roofing manufacturing (Test 25).	4-156
4-48	Batch hot-mix asphalt plant.	4-159
4-49	Particle size distribution for asphaltic concrete batch plant (Test 29).	4-162
4-50	Rice dryer flow diagram (Test 4).	4-166
4-51	Schematic of screen sections for rice dryer (Test 4).	4-167
4-52	Particle size distribution (Test 4).	4-169
4-53	Food processing--carob roasting (Test 37).	4-173
4-54	Particle size distribution for carob roasting operation (Test 37).	4-177
4-55	Steel heat treating process.	4-179
4-56	Particle size distribution for steel heat treating operation (Test 14).	4-182
4-57	Abrasive blast metal cleaning.	4-186
4-58	Particle size distribution for abrasive blasting (Test 34).	4-190
4-59	Thirty-five ton aluminum reverberatory melting furnace.	4-193
4-60	Particle size distribution for aluminum foundry (Test 10).	4-197
4-61	Basic flow diagram of iron and steel processes.	4-199
4-62	Continuous iron ore sintering process.	4-201
4-63	Particle size distribution for sinter plant (Test 26).	4-205
4-64	Open hearth furnace.	4-207
4-65	Particle size distribution for open hearth furnace (Test 36).	4-210
4-66	Boric acid production production flow diagram	4-214
4-67	Particle size distribution for boric acid plant (Test 17)	4-218
4-68	Chemical-Fertilizer pelletizing	4-220
4-69	Particle size distribution for chemical fertilizer plants (Test 19)	4-224
4-70	Automatic spray booth	4-226

FIGURES (CONTINUED)

<u>Number</u>		<u>Page</u>
4-71	Particle size distribution for spray booth (Test 27) (Water base).	4-230
4-72	Particle size distribution for spray booth (Test 31) (Oil base).	4-231
4-73	Wood sanding with particulate controls.	4-235
4-74	Wood resawing with particulate controls.	4-236
4-75	Particle size distribution for wood sanding operation (Test 30)	4-241
4-76	Particle size distribution for wood resawing operation (Test 39)	4-242
4-77	A vertical cylindrical refinery heater.	4-244
4-78	Particle size distribution for refinery process heater (Test 40)	4-247
4-79	Particle size distribution for CO boiler-FCC unit (Test 4).	4-253
4-80	Particle size distribution for alfalfa dehydration.	4-257
4-81	Baghouse size includes impinger.	4-263
4-82	Cyclone and electrostatic precipitator efficiency curve.	4-264
5-1	Areas of application for particulate control devices (Ref. 5-2).	5-2
5-2	Settling chamber (Ref. 5-1).	5-5
5-3	Typical settling chamber collection efficiency (Ref. 5-1).	5-7
5-4	Momentum separator (Ref. 5-1).	5-8
5-5	Typical momentum separator collection efficiency (Ref. 5-1).	5-10
5-6	Reverse flow cyclone (Research-Cottrell).	5-11
5-7	Typical multi-cyclone collection efficiency (Ref. 5-1).	5-13
5-8	Typical spray tower.	5-15
5-9	Chevron type mist eliminator (Munters Corp.).	5-17
5-10	Theoretical collection efficiency for various sized droplets in a spray tower (Ref. 5-1).	5-19
5-11	The effect of liquid-to-gas ratio on particulate collection in a spray tower (Ref. 5-1).	5-20
5-12	Floating-bed scrubber (Ref. 5-1).	5-22
5-13	Impingement plate scrubber (Impinjet) (Ref. 5-1).	5-22

FIGURES (CONTINUED)

<u>Number</u>		<u>Page</u>
5-14	Venturi scrubber and mist eliminator (Research-Cottrell).	5-25
5-15	Path of dust particles (Ref. 5-1).	5-26
5-16	Typical venturi scrubber particulate collection efficiency (Research-Cottrell).	5-29
5-17	Typical pulse jet fabric filter (Research-Cottrell).	5-31
5-18	Fabric filter particulate collection efficiency (Ref. 5-4).	5-36
5-19	Typical precipitation process (courtesy of Research-Cottrell).	5-40
5-20	Typical full-size electrostatic precipitator (Research-Cottrell).	5-41
5-21	ESP collection efficiency (Research-Cottrell).	5-45
5-22	Typical fly ash temperature vs. resistivity curve (Research-Cottrell).	5-47
5-23	Settling chamber and momentum separator cost data.	5-51
5-24	Cyclone and multicyclone cost data.	5-53
5-25	Wet scrubber spray, tray, and pack tower cost data.	5-55
5-26	Venturi scrubber cost data.	5-57
5-27	Fabric filter cost data	5-59
5-28	Electrostatic precipitator cost data.	5-61

TABLES

<u>Number</u>		<u>Page</u>
1-1	EIS/KVB TSP Particulate Emission Inventories (tons/year)	1-7
1-2	Estimated 1976 Area Source Fine Particle Emissions Summary	1-9
1-3	Grid-Zones Having Estimated Emission Rates in Excess of 5 tons/day	1-11
2-1	TSP Emission Factor Summary and Analysis	2-9
2-2	Profile Key Index	2-23
2-3	Profile Key Assignment to SCC Numbers	2-25
2-4	1976 Area Source Fine Particle Emissions Summary	2-33
2-5	Road & Building Construction Particulate Emissions Summary	2-37
2-6	Estimated Average Farm Implement Passes per Crop	2-39
2-7	1976 SCAB Agricultural Tillage Summary	2-43
2-8	Existing Major Class I and II Sanitary Landfill Sites in the South Coast Air Basin	2-47
2-9	Summary of Unpaved Road Emission Factors per Road Location	2-54
2-10	Summary of VMT per Unpaved Road Location in Basin	2-55
2-11	Paved Roadway Particulate Emissions in SCAB	2-60
2-12	Forest Acreage, Fuel Estimates, and Emissions	2-62
2-13	Structural Fires	2-67
2-14	Agricultural Waste Burning Emission Factors	2-79
2-15	Number of Tire Attrition Emissions Summary	2-84
2-16	Brake Lining Attrition Emissions Summary	2-86
2-17	Brake Lining Attrition Emissions Summary	2-88
2-18	Comparison of EIS/KVB and Other Particulate Emission Inventories	2-96
2-19	Major 10-KM Grid Emitters	2-97
2-20	Fine Particle Inventory Summary	2-100
3-1	Sample Storage/Shipping Containers	3-43
3-2	Laboratory Calibration of the Five-Stage Cyclones D ₅₀ Cut Points	3-59
3-3	Redundant sampling Results	3-78

TABLES (CONTINUED)

<u>Number</u>		<u>Page</u>
3-4	Redundant Carbon Analysis	3-80
3-5	Redundant Sulfate and Nitrate Analysis	3-81
3-6	Element Composition of Particulate Samples by XRF Analyses in Percent for Redundant Analysis	3-82
3-7	XRF vs AA for Element Composition of Particulate Samples in Percent	3-83
4-1	Summary of Field Test Results	4-5
4-2	Fuel Oil Characteristics	4-18
4-3	Velocity Profile in KVB Boiler Stack	4-24
4-4	Chemical Composition of Particulate Samples for Industrial Boilers (Test 01)	4-31
4-5	Chemical Composition of Particulate Samples for Industrial Boilers (Test 02)	4-32
4-6	Chemical Composition of Particulate Samples for Industrial Boilers (Test 03)	4-33
4-7	Mass Balance for Test 01	4-34
4-8	Mass Balance for Test 02	4-35
4-9	Mass Balance for Test 03	4-36
4-10	Velocity Profile for Industrial Boiler (Test 16)	4-43
4-11	Chemical Composition of Particulate Samples for Test 16	4-46
4-12	Fuel Analysis Results Test No. 16--Fuel Oil	4-47
4-13	Mass Balance Elements for Industrial Boiler (Test 16)	4-48
4-14	Wood Waste Boiler - Stack Velocity Profile (Test 5)	4-53
4-15	Chemical Composition of Particulate Samples for Wood Waste Boiler (Test 5)	4-55
4-16	Particulate Test Set-up Data For Utility Boilers	4-61
4-17	Chemical Composition of Particulate Samples for Utility Boilers (Test 11)	4-63
4-18	Chemical Composition of Particulate samples for Utility Boilers (Test 12)	4-64
4-19	Chemical Composition of Particulate Samples for for Utility Boilers (Test 13)	4-65
4-20	Chemical Composition of Particulate Samples for Utility Boilers (Test 21)	4-66
4-21	Chemical Composition of Particulate Samples for Test 22	4-67

TABLES (CONTINUED)

<u>Number</u>		<u>Page</u>
4-22	Chemical Composition of Particulate Samples for Test 24	4-68
4-23	Chemical Composition of Particulate Samples for Test 32	4-69
4-24	Chemical Composition of Particulate Samples for Test 33	4-70
4-25	Fuel Analysis Results of Utility Boiler #6 Fuel Oil	4-71
4-26	Mass Balance for Test 11	4-72
4-27	Mass Balance for Test 12	4-73
4-28	Mass Balance for Test 13	4-74
4-29	Mass Balance for Test 21	4-75
4-30	Mass Balance for Test 22	4-76
4-31	Mass Balance for Test 24	4-77
4-32	Mass Balance for Test 32	4-78
4-33	Mass Balance for Test 33	4-79
4-34	Velocity Profile for Internal Combustion Engine (Test 7)	4-97
4-35	Velocity Profile for IC Engine (Test 15)	4-98
4-36	Chemical Composition of Particulate Samples for IC Engines (Test 7)	4-101
4-37	Chemical Composition of Particulate Samples for IC Engines (Test 15)	4-102
4-38	Results of Fuel Analyses Fuel Type No. 2 Diesel (Test 15)	4-104
4-39	Velocity Profile for Cement Manufacturing	4-107
4-40	Chemical Composition of Particulate Samples for Gas Fired Cement Kiln (Test 9)	4-108
4-41	Chemical Composition of Particulate Samples for Coal Fired Kiln (Test 18)	4-109
4-42	Velocity Profile for Gypsum Calcination (Test 6)	4-114
4-43	Chemical Composition for Gypsum Calcinator (Test 6)	4-116
4-44	Velocity Profile for Brick Grinding Process (Test 8)	4-122
4-45	Chemical Composition of Particulate Samples from Brick Grinding Operation (Test 8)	4-123
4-46	Velocity Profile (Test 20S)	4-135
4-47	Velocity Profile (Test 20S)	4-136

TABLES (CONTINUED)

<u>Number</u>		<u>Page</u>
4-48	Velocity Profile for Glass Melting Furnace (Test 28 & 35)	4-137
4-49	Chemical Composition of Particulate Samples for Test 20	4-138
4-50	Chemical Composition of Particulate Samples (Test 28)	4-139
4-51	Chemical Composition of Particulate Samples (Test 35)	4-140
4-52	Velocity Profile for Fiber Glass Manufacturing (Test 38)	4-147
4-53	Chemical Composition of Particulate Samples for Fiber Glass Wool Manufacturing (Test 38)	4-149
4-54	Velocity Profile for Asphalt Roofing (Test 25)	4-154
4-55	Chemical Composition for Asphalt Roofing Mfg. (Test 25)	4-155
4-56	Velocity Profile--Asphalt Batch Plant (Test 29)	4-161
4-57	Chemical Composition of Particulate Samples for Asphalt Batch Plants (Test 29)	4-164
4-58	Chemical Composition of Particulate Samples for Rice Dryer (Test 4)	4-171
4-59	Velocity Profile--Carob Roasting (Test 37)	4-174
4-60	Chemical Composition of Particulate Samples for Carob Roasting Operation (Test 37)	4-176
4-61	Velocity Profile--Steel Heat Treating (Test 14)	4-180
4-62	Chemical Composition of Particulate Samples for Steel Heat Treating (Test 14)	4-183
4-63	Velocity Profile for Abrasive Blasting (Test 34)	4-187
4-64	Chemical Composition of Particulate Samples for Abrasive Blasting (Test 34)	4-188
4-65	Velocity Profile for Aluminum Reverberatory Furnace (Test 10)	4-195
4-66	Chemical Composition of Particulate Samples for Aluminum Foundry	4-196
4-67	Velocity Profile for Test 26	4-202
4-68	Chemical Composition of Particulate Samples for Test 26	4-204
4-69	Velocity Profile for Open Hearth Furnace (Test 37)	4-209
4-70	Chemical Composition of Particulate Samples for Test 36	4-212

TABLES (CONTINUED)

<u>Number</u>		<u>Page</u>
4-71	Velocity Profile for Boric Acid Plant (Test 17)	4-215
4-72	Chemical Composition of Particulate Samples for Boric Acid (Test 17)	4-216
4-73	Velocity Profile for Chemical Fertilizer (Test 19)	4-221
4-74	Chemical Composition of Particulate Samples for Chemical Fertilizer Plants	4-222
4-75	Velocity Profile for Spray Booth, Test 27 (Water Base)	4-227
4-76	Velocity Profile for Paint Spray Exhaust, Test 31 (Oil Base)	4-228
4-77	Chemical Composition of Particulate Samples for Paint Spray Booths	4-233
4-78	Velocity Profile for Wood Sanding Operation (Test 30)	4-237
4-79	Velocity Profile for Wood Resaw Operation (Test 39)	4-238
4-80	Chemical Composition of Particulate Samples for Wood Processing	4-240
4-81	Velocity Profile for Process Heater (Test 40S)	4-246
4-82	Chemical Composition of Particulate Samples for Refinery Process Heaters	4-249
4-83	Velocity Profile for CO Boiler Exhaust (Test 41s)	4-251
4-84	Chemical Composition of Particulate Samples for CO Boiler - FCC Unit	4-252
4-85	Alfalfa Dehydration Test Results	4-256
4-86	Cotton Gin Test Results	4-259
4-87	Control Equipment Efficiency	4-261
4-88	Size Efficiency Calculation Results	4-262
5-1	Application Table	5-3
5-2	Fabric Characteristics	5-34
5-3	Comparison of Fabric Filter Cleaning Methods	5-38

SECTION 1.0

OVERVIEW

1.1 INTRODUCTION

In order to characterize air quality in the California South Coast Air Basin (SCAB) and to provide information on which to base control strategy decisions, the ARB has sponsored a series of programs to inventory emissions from stationary sources and investigate the systems in place for their control. The NO_x, SO_x and VOC* programs have already been completed and the present program documents the work performed to provide the same information for fine particulates.

Air-suspended matter having particle diameters of less than 10 μ m is defined as fine particulates. Emitted from stationary sources, fine particulates contribute to the ambient aerosol, causing haze or reduced visibility, and constitute a human health hazard. Because of their visibility, some of the earliest efforts to control air pollution were directed at particulate emissions. As a result, the mass flow of particle emissions has been reduced by 95% or more from what prevailed under previously uncontrolled conditions. Because of the classifying nature of the control processes applied, however, the remaining particulate emissions are in the fine particle range. This material tends to remain suspended in the ambient air and, compared with coarser particle ranges, constitutes the greatest health hazard.

Fennelly (Ref. 1-1) indicates that for very fine (<1 μ m) particles that enter the pulmonary system, more than 30% will remain there. In considering a fine particulate standard recently, the U.S. EPA decided that particles <15 μ m are in the respirable range. In combustion sources, KVB (Ref. 1-2) and others (Ref. 1-3) have found that the smaller particles often have higher concentrations of toxic metals than do larger particles. This effect is due

* Volatile Organic Compounds

to selective condensation in the cooling gas. Friedlander (Ref. 1-4) identified fuel-oil fly ash as a significant constituent in the ambient aerosol of the Basin.

Particles having diameters of 0.3 to 1.0 μ m are considered to be most effective in light scattering and, therefore, haze production. This is because this size range corresponds to the wavelength range of visible light. Thus, while emissions of (coarser) particulates in the Basin have been greatly reduced as a result of applied controls, fine particle that are still emitted by stationary sources contribute significantly to reduced visibility and increased health hazards. In view of these considerations, a study of the persistent fine fraction of particulate emissions was considered justified. A contract was accordingly awarded by the ARB, resulting in the work described here.

The objectives of this program were to:

- a. Characterize the emissions of fine particulates from stationary sources in the South Coast Air Basin and Ventura County in terms of:
 - . identification and location of point and area sources
 - . individual source annual emission rates
 - . seasonal and temporal operational variations
 - . particle size distributions
 - . predominant chemical compositions
- b. Report the above data (excluding chemical compositions) in the EPA's Emission Sub-system format on IBM-compatible magnetic tape.
- c. Generate the following computer print-outs or typed reports:
 - . Application Category Report
 - . Geographic Location Listing (10 km grid)
 - . Emission profile listing by SCC Code
- d. Provide particle size distribution and chemical composition data in the form of emission profiles
- e. Assess the cost effectiveness of potential methods of reducing the emissions identified.

1.2 SUMMARY AND CONCLUSIONS

In order to accomplish the above objectives, the first steps undertaken were: to prepare a preliminary inventory of total suspended particulates (TSP) without consideration of particle size or composition; to identify the major emission sources; and to determine the distribution of emissions among the various source types.

On the basis of this preliminary inventory, a field test program was next conducted to characterize emissions from the sources selected, emphasizing those source types producing the greater amounts of emissions. Seventy-eight particulate sampling runs were then made, 40 using the EPA Source Assessment Sampling System (SASS) and 37 employing a modified EPA Method 5 train. In each run particles were collected in three cyclones with particle size cuts of 10, 3 and 1 μ m followed by a backup filter and water impinger. Whenever catches in excess of 100 milligrams were acquired, they were analyzed for chemical composition. A summary of the sources tested is as follows:

<u>Source Type</u>	<u>No. of Runs</u>
Utility Boiler	18
Industrial Boiler	10
IC Engine	3
Hog Fuel (Woodchip) Boiler	1
Gypsum Plant	1
Brick Plant	2
Cement Plant	2
Glass Furnace	6
Fiberglass Plant	2
Asphalt Roofing Plant	2
Asphalt Paving Plant	2
Rice Dryer	2
Carob Plant	2
Heat Treating Process	2
Sand Blasting Process	2

Open Hearth Plant	2
Spray Booth	4
Boric Acid Plant	2
Fertilizer Plant	2
Wood Processing	5
Process Heater	1
Fluidized Bed Catalytic Cracking (FCC Unit)	1

In preparing for the field test program a commercial SASS unit without the standard organic module was acquired along with a commercial Method 5 unit. With the assistance of the Southern Research Institute a set of three cyclones having the same cut sizes as the SASS train were designed and fabricated for the Method 5 train. Subsequently, both the SASS and the Method 5 cyclone sets were calibrated at 400 °F using sperical aluminum powder. At flow rates of 4 and 1 SCFM, respectively, the results were as follows:

Nominal Cut Size, μm	SASS $D_{50}^*, \mu\text{m}$	Method 5 $D_{50}^*, \mu\text{m}$
10	9.2	8.3 (9.1) [†]
3	3.8	1.9 (4.1) [‡]
1	1.3	0.6 (1.2) [§]

* D_{50} is the aerodynamic diameter at which 50% of the particles would be retained in the cyclone and 50% would pass through.

†The numbers in parenthesis are the D_{50} 's obtained by Southern Research on identical cyclones using a vibrating orifice aerosol generator calibration technique (See Section 3.2.1).

§The value of (1.2) shown was not measured directly by Southern Research but was derived from measurements at a lower temperature.

Particle size distributions were calculated for each particulate sampling run. Chemical analysis of the particulate catches consisted of X-ray fluorescence analysis for elemental composition, wet chemistry for nitrate and sulfate content, and carbon analysis for volatile, carbonate, and total carbon values.

From these data--plus data found in the literature--emission profiles were prepared for 81 of the 135 Source Classification Codes which are found in the Basin. The profiles divide the TSP emissions by weight percent into

four categories: $>10\mu\text{m}$, $3-10\mu\text{m}$, $1-3\mu\text{m}$ and $<1\mu\text{m}$. The XRF analysis, sulfates, nitrate and carbon composition are listed in weight percent for each size category.

The next step in the program was to generate a final inventory. The ARB provided Emission Information Subsystem (EIS) data files for the South Coast Air Quality Management District (SCAQMD), which includes Los Angeles, Orange, Riverside, and San Bernardino Counties, and the Ventura Air Pollution Control District (VAPCD), along with a breakdown of human population data for the Basin on a 1 Km grid map. The EIS data were the basis for the KVB final inventory. The emission factors in the EIS files were reviewed by KVB and adjusted where necessary by applying correction factors determined from data obtained in tests of specific sources or from data for a group of sources identified with a certain Source Classification Code (SCC) number. The emission profiles were keyed to the specific sources. Additionally, source types not contained in the EIS files, primarily area sources, were added to the data base.

The final inventory was delivered to the ARB under separate cover as computer print-outs and magnetic tape files. The primary elements delivered are as follows:

- . a total suspended particulates report with 10 km-grid mapping
- . a total suspended particulates report by ARB application category
- . a plant index
- . an emission profile listing (Appendix A of final report)
- . an SCC report
- . a point source emission file in EIS format (tape)
- . an area source file (tape)
- . an SCC report file (tape)

The inventory, which has the time frame of 1975-1976, shows total suspended particulate emissions of 510 tons/day. Of this, 385 tons/day derived from miscellaneous area sources, such as fugitive dust (290 tons/day) sea salt (55 tons/day), automotive tires and brakes (30 tons/day), and various forms of open burning (12 tons/day). Of the 125 tons/day emitted by point

sources, 28 percent came from mineral sources, notably one sand and gravel and one brick manufacturing plant (both in Ventura County). Utility boilers accounted for 27% of the point source emission, while the entire category of "Combustion of Fuel" accounted for 30% of the point source emissions.

Over 90% of the total emissions (point and area source) have a particle size of less than ten μm . This assessment was based on an analysis of available emission profiles for the various application categories. It should be pointed out, however, that the major category, "Miscellaneous Area Sources," here includes only particulate contributions of $10\mu\text{m}$ and smaller. A summary of the overall TSP and fine particulate emissions for the period covered is as follows:

<u>Application Category</u>	<u>TSP Tons/Day</u>	<u>Fine Particle ($<10\mu\text{m}$) Tons/Day</u>
Petroleum	2.1	1.2
Solvent use	3.2	2.1
Chemical	1.5	1.4
Metallurgical	11.5	10.4
Mineral	35	6.8
Combustion of fuel	38	35
Food and agriculture	30	24
Wood processing	0.4	0.2
Waste burning	1.6	1.1
Misc. industrial	1.2	0.5
Misc. area sources	<u>385</u>	<u>385</u>
Total	510	468

From these totals, it can be seen that 66% of the particulates emitted from point sources in the Basin were in the fine ($<10\mu\text{m}$) particle size range.

Table 1-1 summarizes the TSP particulate emissions of both point and area sources by application category. As given, area sources account for 80% of the TSP. In this connection, it should be pointed out that the Table 1-1 data and that tabulated just above do not reflect fugitive dust emissions attributable to "paved road travel." This major classification comprises materials released from roadbeds, including deposited dusts but not automotive exhaust particulates or matter released from tires or brakes. Paved road travel emissions and the rationale for their omission in these totals are explained in Section 2.3.3.

TABLE 1-1. EIS/KVB TSP PARTICULATE EMISSION INVENTORIES
Tons/Year

Application Category	No. Point Sources	1975-76 EIS/KVB File		
		Point Sources	Area Sources	Total
<u>Petroleum</u>		750		750
Production	34	50	0	50
Refining	25	600	0	600
Marketing	8	100	0	100
<u>Organic Solvent Use</u>		1160		1160
Surface coating	546	1150	5	1150
Degreasing	5	10	0	10
Other	4	5	0	5
<u>Chemical</u>	137	540	0	540
<u>Metallurgical</u>	547	4200	0	4200
<u>Mineral</u>	480	12600	0	12600
<u>Waste Burning</u>	48	75	500	600
<u>Combustion of Fuel</u>		13900		13900
Utility boilers	187	9100	0	9100
Industrial devices	1084	2700	0	2700
Commercial/institutional	199	600	0	600
Petroleum	316	1500	0	1500
<u>Wood Processing</u>	25	130	0	130
<u>Food and Agriculture</u>	163	460	11000	11000
<u>Miscell. Industrial</u>	72	440	10	450
<u>Unclassified (Misc. Area)</u>	0	0	140,500	140,500
Fugitive dust			105,000	105,000
Forest & structural fires			4,500	4,500
Tires and brakes			11,000	11,000
Sea salt			20,000	20,000
	1900 Sources			
Total, Tons/Year,		34000	152,000	185,830
(Total), Tons/Day		(93)	(416)	(510)

Table 1-2 is a detailed breakdown, with estimated accuracies, of the miscellaneous area sources by county in the SCAB. These estimates involve an overall uncertainty of +65,000 tons/year (180 tons/day) and -36,000 tons/year (-99 tons/day). Unlike the previous two tables, paved road travel emissions are included in Table 1-2.

Figure 1-1 furnishes a spatial distribution of point and area TSP sources based on a 10-km grid map of the SCAB. Each grid element shows the daily emission rate, while Table 1-3 itemizes those grid elements with TSP emission rates greater than 5 tons/day.

Finally, an investigation of control techniques was made. Control techniques reviewed in the report include:

- . Mechanical collectors (cyclones, settling chambers, etc.)
- . Wet scrubbers
- . Electrostatic precipitators
- . Fabric filters (baghouses)

Cost data for control systems were obtained from Research-Cottrell and are presented. These data present installed cost as a function of: mean particle size; volumetric flow rate; and particulate loading.

This report consists of five sections, the present discussion comprising Section 1.0. Section 2.0 deals with the emission inventory; it describes the data sources and presents the detailed data used in the inventory compilations. Various summary tables and plots are also presented. Section 3.0 presents the sampling and analysis methodology as well as an assessment of the data quality. Section 4.0 is a detailed discussion of results obtained from each of the tests conducted. Finally, Section 5.0 is a treatment of control techniques and their associated costs of application.

1.3 RECOMMENDATIONS FOR FURTHER RESEARCH

On this program, a maximum effort has been made to perform as many tests as possible within budgetary constraints. There are many additional sources that could not be tested due to lack of time or the availability of

TABLE 1-2. ESTIMATED 1976 AREA SOURCE FINE PARTICLE EMISSIONS SUMMARY (a)

	South Coast Air Basin Counties (b)						(c) of Emissions Tons/yr	Percent Grand 'Total	Estimated Percent Accuracy
	Orange	Los Angeles	River- side	San Bernardino	Ventura	Santa Barbara			
Road & Building Con- struction	21,000	24,000	7,100	11,000	6,400	1,000	71,000	20.9	+50,-20
Agricultural Tilling	1,300	1,200	3,100	800	3,100	40	9,500	2.8	+25
Refuse Disposal Sites	60	200	20	20	20	6	300	<0.1	+25,-20
Livestock Feedlots	150	3	150	950	5	5	1,300	0.4	+50
Unpaved Road Travel	2,000	14,000	2,000	1,800	2,600	230	23,000	6.8	+40
Paved Road Travel (d)	33,000	140,000	7,600	12,000	8,800	3,100	200,000(d)	58.8	+50
Fugitive Dust--Subtotal							305,000	89.7	
Forest Fires	120	700	600	430	530	50	2,400	0.7	+50,-20
Structural Fires (e)	40	160	10	15	10	5	200	<0.1	+100,-20
Fireplaces	70	280	30	60	20	10	500	0.1	+100,-10
Residential Natural Gas	20	90	5	10	10	5	100	<0.1	+25
Cigarettes	130	520	30	50	30	10	800	0.2	+20,-50
Agricultural Burning	20	50	30	--	400	10	500	0.1	+25
Combustion--Subtotal							4,500	1.3	
Tire Attrition	1,400	5,700	320	490	370	130	8,400	2.5	+20
Brake Lining Attrition	530	2,100	120	180	140	50	3,100	0.9	+20
Automotive--Subtotal							11,000	3.2	
Sea Salt--	4,000	6,700	---	---	3,500	5,800	20,000	5.9	+50,-20
Grand Total							340,000	100%	

a) Emission estimates are based on particles $\leq 10 \mu m$

b) Includes only that portion of County within SCAB

c) Rounded to three significant figures

d) A large (but unknown) percentage of the 200,000 tons/year is assignable to other area source categories only some of which were studied on this program. For this reason (see Section 2.3.3 A-6) it was not included in the final inventory count as indicated in Table 2-18.

e) Includes property, contents and vehicle loss.

KVB 5806-783

TABLE 1-3. GRID-ZONES HAVING ESTIMATED
EMISSION RATES IN EXCESS OF 5 TONS/DAY

UTM Coord.		Nearest City	Emissions (Ton/Day)	Principal Source Type
E/W	N/S			
280	3790	W. Ventura	10.8	Ceramic manufacturing
300	3770	Pt. Mugu	7.4	Elect. gen. & area.
320	3800	Fillmore	19.1	Sand and gravel
360	3750	LA Airport	5.3	Area
370	3740	Torrance	9.4	Elect. gen. & area
380	3740	Paramount	6.4	280 Pt. sources & area sources
380	3730	LA Harbor	5.9	250 Pt. sources & area sources
390	3730	Long Beach	11.5	Elect. gen. & area
450	3770	Fontana	11.1	Steel manufacturing

the test unit. As mentioned earlier, only 70% of the SCC's found in the Basin had emission profiles developed for them. In most cases a source type has had to be characterized by the emission from only a single plant tested.

To give a greater universality to the emission profiles developed in this program and to develop additional new profiles, it is recommended that further testing be considered. Particulate testing with the full characterizations achieved on this program is expensive, particularly if compared to any other type of pollution testing. The trains used in this program performed adequately, but it is questionable if this would have been true had more economical approaches been applied. Therefore, to insure that these presently developed data are to be meaningfully used with any future new data that are generated, it is recommended that the same general procedures used on this program be employed in any subsequent efforts.

REFERENCES

SECTION 1.0

- 1-1 Fennelly, P. E., "Primary and Secondary Particulates as Air Pollutants," JAPCA, July 1975.
- 1-2 Cato, G. A., "Field Testing: Trace Elements and Organic Emissions from Industrial Boilers," EPA 600/2-76-086b, KVB, Inc., October 1976.
- 1-3 Goldstein, H. L. and Siegmund, C. W., "Influence of Heavy Fuel Oil Composition and Boiler Combustion Conditions on Particulate Emissions," Env. Science & Tech., November 1976.
- 1-4 Friedlander, S. K., "Chemical Element Balances and Identification of Air Pollution Sources," Env. Science & Tech., 7:235, 1973.

SECTION 2.0

INVENTORY

2.1 DATA SOURCES

The data used in this particulate emission inventory were obtained from the following sources:

1. Various government agency files
2. Field testing
3. Literature
4. Engineering analyses
5. Personal contacts with government and industry personnel.

The final inventory was compiled using the South Coast AQMD and Ventura County APCD EIS* (Ref. 2-1) data bases for the major point sources, and a KVB-developed area source file. The EIS files were checked for completeness and emission data credibility. Adjustments in emission factors were made as required based on information acquired from the field test program and other studies performed during the program. The following key data were contained in the EIS data base:

1. Plant name, address, ID No., etc.
2. Standard Industrial Code (SIC)
3. Source Classification Codes (SCC)
4. UTM Coordinates
5. Stack height
6. Pollutant identification
7. Emission factor
8. Throughput rates
9. Estimated emissions
10. Seasonal variations
11. Operating period (hr/day, day/week, week/yr)

*Emission Inventory Subsystem/Permit and Registration

Field test data were used to formulate emission profiles and to develop emission factors for new sources or check those factors on sources already characterized by the Districts or the EPA in AP-42 (Ref. 2-3).

Other sources of information included personal contacts with various industry associations and government agencies (especially the ARB, EPA Office of Air Quality Planning and Standards in Durham, EPA Region 9, local air pollution districts, and the Southern California Association of Governments (SCAG)). The data received from these sources were used to derive additional emission profiles in a form compatible with the inventory format.

From summaries of the EIS files, a breakdown of total particulate emissions into industrial source categories (referred to hereafter as ARB Application Categories) for each county was tabulated as shown in Figure 2-1. A summary of emissions by application categories for the entire SCAB is given in Figure 2-2a. The fraction of the total particulate emissions from each county is given in Figure 2-2b. From these breakdowns of emissions into application categories, the Phase II field test program was developed. The distribution of the field tests among the various application categories is shown in Figure 2-2c.

2.2 DATA MANAGEMENT

The data to be processed as part of the final particulate emission inventory included:

1. EIS data for major and minor point sources of SCAQMD
2. EIS data for major and minor sources of Ventura County
3. Additional area data for sources such as forest fires, fugitive dust, tire attrition, and agricultural burning
4. Emission profile number vs SCC number
5. Population distribution by one kilometer grid
6. Emission factor adjustments to EIS data

The available EIS data processing software was incorporated for processing the EIS data. In this system, individual sources could be modified,

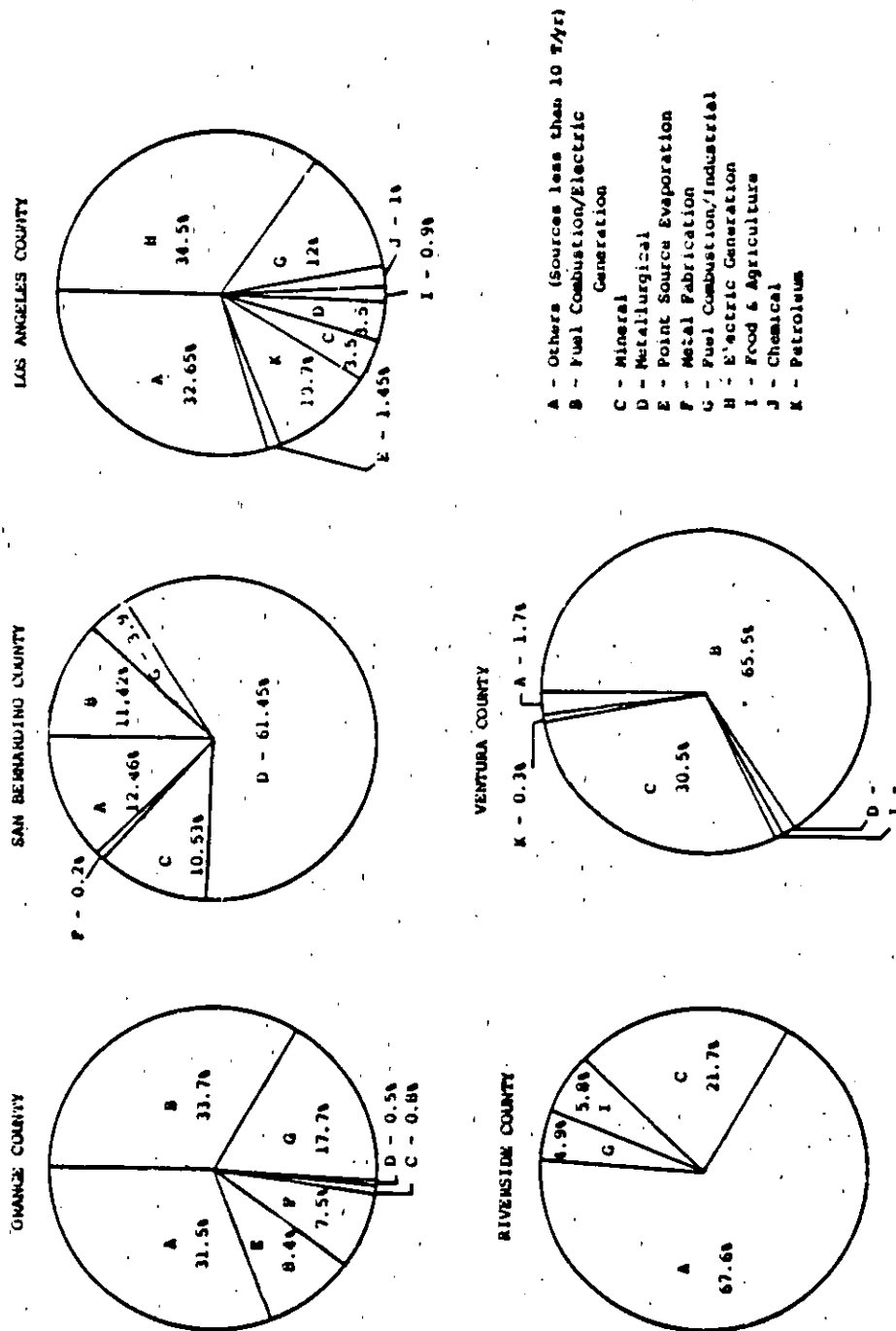


Figure 2-1. Breakdown of particulate point sources into ARB application category for each county in the SCAB.

KVB 5806-783

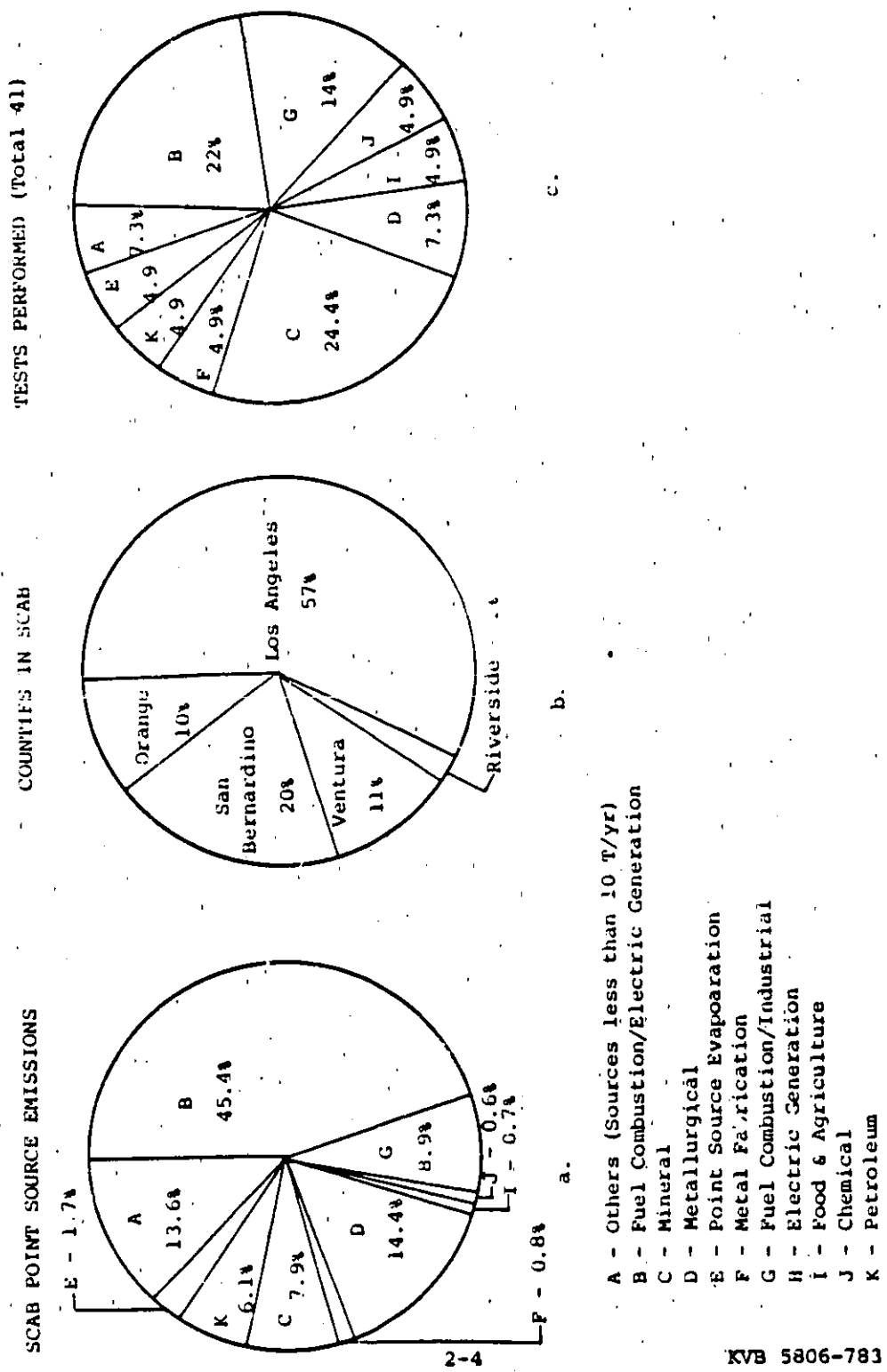


Figure 2-2. a. Composite of point source emissions into source classification for SCAB.
 b. Fraction of point source emissions from each county.
 c. Fraction of field tests done for each source classification.

added, or deleted. KVB added a feature which also permitted the data to be modified by SCC number. For example, the emissions in the EIS data base from certain utility boilers (identified by a specific SCC number) appeared to be too high based on recent test data. The emissions from those units were modified by one correction factor applied to all the emissions of that specific SCC number.

For each SCC number an emissions profile key was assigned, if available. Each emission profile provides a breakdown of the total suspended particulate (TSP) emissions into four size ranges (% by weight) and for each size range a chemical compositional breakdown is provided (% by weight). Storage and Retrieval of Aerometric Data (SAROAD) codes were assigned to each chemical species identified. Each profile also contains information concerning the method of determining the profile and rating number indicating the relative velocity of the profile. The 49 profiles developed during the program are presented in the Appendix, Volume II. SCC's for which no profiles are available were assigned a "not classified" key number.

Area source emission rates were added to the EIS data file using the emission factors and throughput data presented in Section 2.3.4. These sources, including natural emissions, fugitive dust, and tire attrition, constituted a large portion of the total emissions in the Basin. Since a standard format was not yet available for describing emissions not meeting the EIS point source criteria, KVB chose to develop an area source data base for this purpose based on general guidelines proposed by the ARB (Ref. 2-4). The format was designed to allow description of emissions by their one kilometer grid location and process (or activity).

Each source in the inventory was categorized by a Source Classification Code (SCC) number which was occasionally qualified by the SIC number. (SCC numbers for area sources were created together with ARB personnel.) A file was created with all information relative to these SCC numbers, the emission correction factors to be applied to all sources with the given SCC/SIC number, the profile key to identify the profile for this source type, the relevant ARB application category, and summer or winter differentials to be used to alter emissions seasonally if warranted by the source type. This SCC file was used as the major system link between sources and their profiles. From these data files a final inventory was produced in the form of various

computer reports and magnetic tapes which were delivered to the ARB under separate cover. A description of the final inventory reports and a discussion of the results are presented in Section 2.4. First, however, is a discussion of the various technical considerations (i.e., emission factors, emission profiles, etc.) that were used in preparing the inventory.

2.3 ENGINEERING ANALYSIS

2.3.1 Point Source Emission Factors

There has been considerable interest in the development of emission factors that can be employed to estimate emissions from specific sources based upon a knowledge of the pertinent operating characteristics of the source. Such procedures are in common use throughout the country by local control agencies to estimate air pollution emission rates for point and area sources. One of the primary objectives of the ARB fine particulate emission study was to critically evaluate the emission factors for fine particulate emissions used by the SCAQMD and local APCD's and to develop new emission factors for sources not contained in the EIS data system that were applicable to the South Coast Air Basin. The following discussion outlines the methodology employed during the analysis for point sources. Emission factors for area sources are discussed in Section 2.3.3 since they required a significantly different approach.

Point source emission factors for industrial point sources in the Basin were divided into nine application categories: (1) the combustion of fuels, (2) evaporative emissions, (3) mineral products, (4) metallurgical, (5) petroleum, (6) wood operations, (7) food and agriculture, (8) metal fabrication, and (9) chemical uses. In general, emission rates from these sources had been calculated by the local control agencies using emission factors and the appropriate information on fuel usage, product throughput, etc. The combustion of fuel categories represented a large part of the total particulate emissions in the Basin and therefore was given primary emphasis in the analysis of point source emission factors.

A. Approach--

A comprehensive listing of point source emission factors may be found in the EPA publication, "Compilation of Air Pollution Emission Factors" (Ref. 2-3), hereafter referred to as "AP-42." The SCAQMD has its own emission factors which have been employed in the process estimating emission rates for industrial point sources contained in the EIS data file. To a certain extent, these emission factors were the same, because frequently SCAQMD data were used as the basis for the development of AP-42 emission factors. In other instances the emission factors differed because the SCAQMD sometimes based its emission factors on its own test data in preference to using AP-42 values.

A specific objective of this study was to examine the point source emission factors used by the SCAQMD and AP-42. This was done for three reasons. First, much of the data used to generate emission factors for specific source types stem from studies conducted as far back as the 1950's. Second, certain emission factors listed in AP-42 intended for use nationally may not necessarily represent conditions in the Basin. Finally, it was necessary to generate entirely new emission factors where none had existed previously.

Field tests were conducted to provide data to assist in emission factor evaluation and development. In addition, data from several related projects, specifically oriented to improving AP-42 emission factors, have been incorporated into this analysis. In most cases, these studies had been directed at conditions within the Basin making them directly applicable to the current study.

Comparisons have been made between the emission factors used by the SCAQMD, those contained in AP-42, and those generated in this and related studies. Where KVB felt that available data disagreed with the SCAQMD emission factors, correction factors were applied to the emission rates listed in the EIS data system to update these emission estimates. The intent was to have the EIS data file, delivered to the ARB, reflect the best and most recent information available. This was a vital part of the improvements incorporated into the final KVB data base.

B. Results--

In this section the various adjustments made to the SCAQMD emission factors in their EIS file prior to running the final TSP inventory will be discussed. The results are tabulated in Table 2-1 and explained in the following discussion. In the table for each source type and applicable SCC number, the AP-42 (Ref. 2-3) emission factor is listed along with emission factors obtained from the SCAQMD EIS file and derived from KVB test data. Each emission factor column provides both control ("con") and uncontrolled ("unc") emissions data where available. For the SCAQMD the data are presented as "specific" or "overall" from the standpoint of whether the data applied to one particular source or whether it represented a composite of data from multiple sources. The SCAQMD value shown in the table is the emission factor that was in the AQMD's EIS data base used for the final ARB inventory run. At the right side of the table are two columns indicating whether or not a change was made to the AQMD value. If no change was made, the "EIS Correction Factor" column has a 1.0 and the next column "Final Inventory Emission Factor" contains a value identical to the AQMD column.

1. Combustion of fuel -- Residual oil combustion from power plants represents the largest point source type for TSP emissions in the Basin accounting for over 45%. This source type was given a great deal of investigation and analysis considering not only the AP-42 emission factor, the field test data (18 tests) from this program, but other oil-fired utility boiler test data from the KVB confidential file of client data. Figure 2-3 summarizes these data.

Note that the data points in Figure 2-3 are filled or open, with the filled points indicating the total particulate catch including impinger and the open points indicating the EPA Method 5 data which do not include the impinger catch. For the tests conducted on this program, points were plotted both with and without the impinger catch.

It was the decision of the ARB that for this inventory the TSP should include the impinger catch. But most of the comparison data were for the EPA Method 5. Therefore, the data were analyzed on the no-impinger basis first and then on the total catch basis.

TABLE 2-1. TSP EMISSION FACTOR SUMMARY AND ANALYSIS

Description	Applicable SCC Code	Units	AP-42		1. Specific		Overall		EVB		Other		EIS Proposed Correction Factor	Final Inventory Emission Factor	Comments		
			Avg. '77		Line		Line		Line		Line					Line	
			Unc	Con	Unc	Con	Unc	Con	Unc	Con	Unc	Con					
c. COMBUSTION OF FUELS																	
Residual Oil Combustion-- Power Plants	1-01-004-M	lb TSP/ 10 ³ gal	5.5 (front 1/2) 0.2365	-	-	-	7.14 (total)	1 (total)	1 (total)	0.42	(a)	-	0.42	3.0			
Distillate Oil Combustion-- Industrial	1-01-005-M	lb TSP/ 10 ³ gal	7.0 (front 1/2) 0.485	-	-	-	-	7.2 (total)	1.4-4.7 (b) (front 1/2)	1.0	-	-	1.0	7.14			
Petroleum Gas Process Heaters	1-06-001-04	lb TSP/ 10 ⁶ ft ³	20 (total)	22.1	27 (total)	27 (total)	27 (total)	9 (total)	---	1.0	-	-	1.0	27			
Oil Boiler FCC Unit	1-06-002-01	lb TSP/ 10 ³ bbl through- put	45 (range 7- 150)	4.3 (d)	14 (total)	14 (total)	14 (total)	32 (e) (total)	25 (c)	1.0	-	-	1.0	14	Corrected specific emissions		
Weg Fuel Boiler	1-03-009-02	lb TSP/ ton burned	36 (total)	3.6	3.6 (total)	3.6 (total)	3.6 (total)	3.6 (total)	2.5 (f)	1.0	-	-	1.0	3.6	From the Baseline		

(a) See Figure 2-3

(b) Cato, G. A., et al., "Application of Combustion Modifications to Control Pollutant Emissions from Industrial Boilers," EPA 600/2-76-086.

(c) EPA Source Test Data, September, 1977.

(d) Value in EIS for source tested by EVB.

(e) ESP working poorly during test

(f) BWH Assoc. TSP test June 27, 1977 - throughput not specified; assumed to be 1500 lb/dry wood/hr

(Front 1/2) refers to the EPA Method 5 which requires the Impinger catch in the TSP determination (Total) refers to the AP-42 method which includes the Impinger catch in the TSP determination.

Control Action Code

001 - Scrubber
007 - Mech. collector (cyclone)
012 - Elect. st. precip.
015 -
016 -
018 - Baghouse

KVB 5806-783

TABLE 2-1. Continued

Description	Applicable SAC Code	Units	AP42 unf. con.	Specific EIS Listing			Overall			KVB			Other unf. con.	Control Mod. & Eff.	EIS Proposed unf. con.	Final Inv. Emit. Fac.
				SAC/401			SAC/401			SAC/401						
				unf. con.	unf. con.	unf. con.	unf. con.	unf. con.	unf. con.	unf. con.	unf. con.	unf. con.				
D. MINERAL PRODUCTS																
Gypsum-Calciner	3-05-015-01	lbs TSP/ton prod	90	0.1	0.1	0.1	0.2	---	016	99	1.0	0.1				
Clay grinding & pulverizing	3-05-001-02	lbs TSP/ton prod	%		0.48		0.7	0.1 (b)	010	99.5	1.0	0.48				
Cement Kiln	3-05-006-01 3-90-002-01	lbs TSP/tbl	4%	0.05	0.1		0.05 (d)	49 % 0.05 (d) calc. 0.09 (g)	016	99.9	1.0	0.3				
Glass Furnace-- open top	3-05-014-01	lbs TSP/ton prod	3		~1.5 (e)		1.43	2.25 (j)		note	1.0	1.5				
Glass line	3-90-006-08	lbs TSP/mcf	378 (e)	250			265.3			wet scrubber	1.0	250				
Fiberglass forming	3-05-012-04	lbs TSP/ton	50		4.8		29	4.37 (h) 5.01	001	99	1.0	4.8				
Asphalt Roofing Felt saturators	3-05-001-04	lbs TSP/ton felt	2.0	0.1	0.6		0.3	see foot- note (h)	015	98		0.6				
Asphaltic Concrete Batch Plant	3-05-002-01	lbs TSP/ton prod	45	0.1	0.03		34	32 (i) (range) 1-46	018	99.9		0.03				
E. FOOD AND AGRICULTURE																
Carob Master Direct fired	3-02-002-01 3-90-004-99	lbs TSP/ton pulp lbs TSP/mcf	7.6		23		6.1 1333				1.0	23				
Rice Dryer	3-02-999-96	lb TSP/ton thru.		0.3			0.1		screens							

a) Aeros Code Designation

b) Selections include screening & grinding operations

c) EPA/EVB Test--downstream from cyclones and upstream from baghouse

d) One tenth of a percent change in efficiency accounts for 0.05 lbs/tbl emissions; 99.9% eff. accounts for 0.3 lbs/tbl; 99.9% eff. accounts for 0.05 lbs/tbl

e) Derived from KVB source test 5300cf Natural Gas/ton glass produced correlation factor

f) Derived from EIS file LA plant 5095, permit #P06882

g) Derived from EIS file Riv. plant 0074, Beds 14 and 15 Oil & Gas fired

h) Derived from EIS file Riv. plant 0020, Beds 31 and 32

i) AP40 May '73, range of thirteen Los Angeles Source Test

j) AP40 May '73, Statistical Analysis of 25 Los Angeles Source Tests, p. 775, Particulars Emission Calculated Value 1

k) AP40 May '73, Emissions from Two Installations Venting Asphalt Saturators, Table 110-12, p. 342-3,
0.416 gr/scf, 0.590 gr/scf, 0.535 gr/scf

LVB reported 0.0075 gr/scf and 0.0076 gr/scf downstream fiber filter plus mist eliminator control devices reported 98% overall eff.

(1 - 0.0075) x 100 = 99.25% (1 - 0.0076) x 100 = 99.74%

(1 - 0.416) x 100 = 58.4%

(1 - 0.590) x 100 = 41.0%

(1 - 0.535) x 100 = 46.5%

TABLE 2-1. Continued

Description	Applicable NESHAP	Unit	Air Emissions				Total lb/yr	Comments
			PM ₁₀	PM _{2.5}	SO ₂	NO _x		
D. MANUFACTURING PROCESSES								
Spray Booth Water base enamel	6-02-003-01	lbs TSP/ ton coat- ing	Not listed	Not listed	Not listed	Not listed	Not listed	
Spray Booth Acrylic solvent	6-02-003-99	lbs TSP/ ton sol- vent coat- ing	Not listed	70	Not listed	Not listed	90	
E. CHEMICAL USES								
Boiling Acid	3-01-999-99	lbs TSP/ ton prod.	Not listed	3.15	Not listed	Not listed	98	Only one in Basis
Fertilizer- Rotary Dryer	3-01-030-01	lbs TSP/ ton pro- cessed	Not listed	90	Not listed	Not listed	1.0	
F. WOOD OPERATION								
Plywood Sanding		(c) lbs TSP/ hr	Not listed	35	Not listed	Not listed	98 96	
Plywood Sanding	3-02-007-02	lbs TSP/ ton	Not listed	70	Not listed	Not listed	98 96	
Wood Resawing		(c) lbs TSP/ hr	Not listed	20	Not listed	Not listed	98 96	0.2 lbs/ hr lumber yard

(a) Unit used during test

(b) Rating during test

(c) AP-42 lists under dust emissions as a control device related to emissions and not device related

(d) Based on reported 90% wet scrubber efficiency

TABLE 2-1. Continued

Description	Applicable MCA Code	Limits	Appl. (1) MCA Code	MCA Code						Other MCA Code	Control No. 1777	EIS Proposed Location Factor	Final EIS Proposed Location Factor	Comments
				MCA Code										
				2000	2001	2002	2003	2004	2005					
9. METALLURGICAL OPERATIONS														
Steel heat treating--salt bath	3-09-001-99	lbs TSP/ton process	Not listed	2.0 (d)				3.0	3.11	--	016	94.9	1.0	Controlled emissions not listed
Steel sand blasting ^c	3-09-999-99	lbs TSP/ton	Not listed	1.43 (b) 2105 calc	4%			15.36	1.04	--	016	99.9	1.0	Controlled emissions not listed
Aluminum smelting--tower, furnace	3-04-001-03	lbs TSP/ton al	4.3	New furnace not yet tested				(c) 0.04	0.01	--	--	--	N/A	Revised specific emissions
Iron sintering	3-03-008-03	lbs TSP/ton prod	0.67 22 calc	41			NA	8.4	1.0	--	016	98.2	1.0	0.73
Steel open hearth as lance	3-03-009-01	lbs TSP/ton	0.35 17.4				(c) 0.17	0.67	(4) 0.11 150%		012	98	1.0	0.17
			.98%				9.3	4.2						

(a) Columbia Steel Co. 1951 test on new
ESP; tons of steel not reported.(b) MCAJED Memo to all engineers Aug. 3,
1977 from William Hammond; 4% of
the amount of sand used.(c) MCAJED Memo to all engineers, Aug. 3,
1977 from William Hammond.

(d) Control device not listed in EIS printout.

(e) Controlled emissions based on 99.9%
control efficiency measured by KVB test crew.

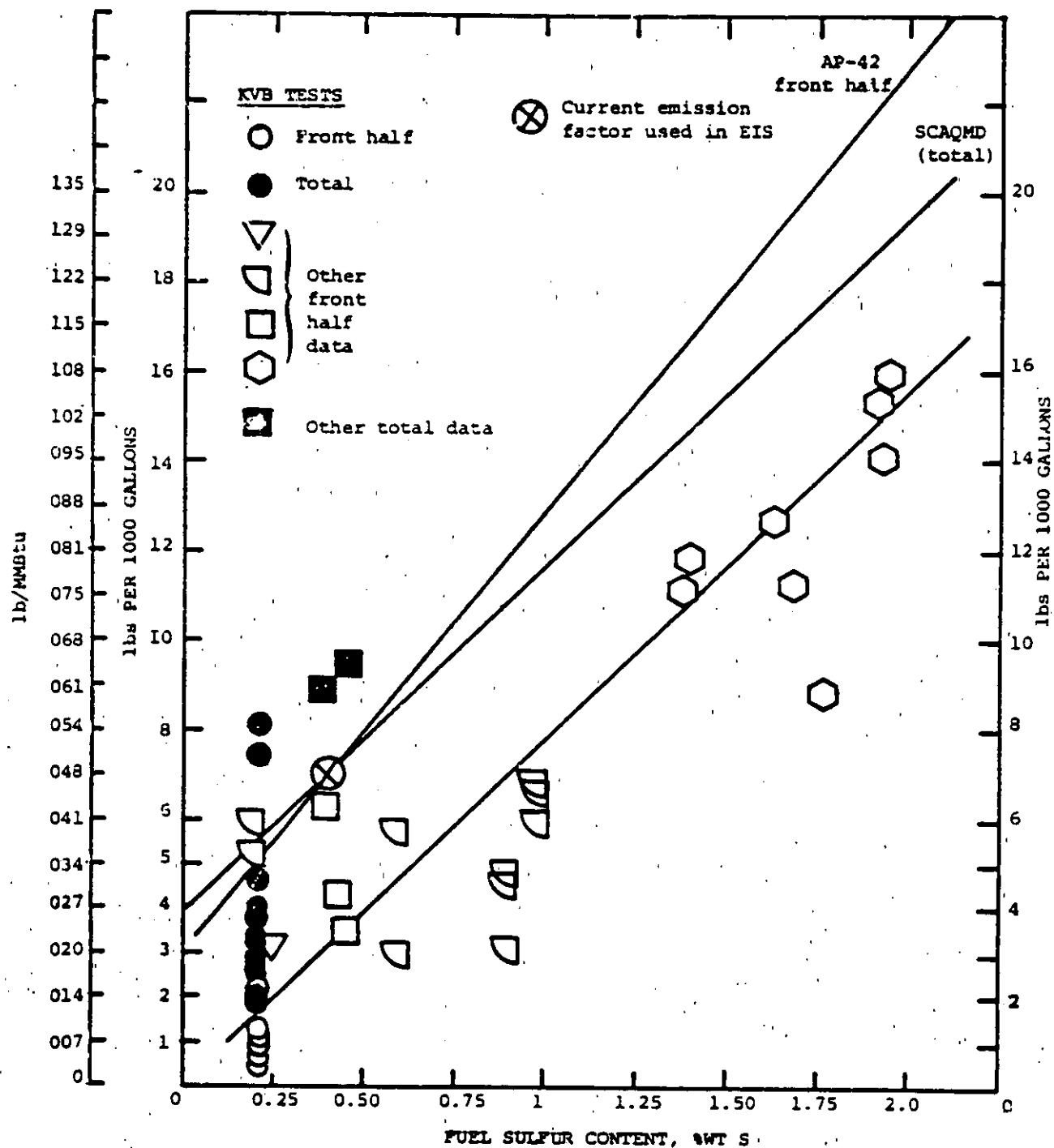


Figure 2-3. Emission factors as a function of fuel sulfur content for utility boilers.

The AP-42 emission factor curves plotted in Figure 2-3 are substantially higher than any of the KVB test data. The front half data (i.e., without impinger) for the 18 tests conducted for this program (9 SASS and 9 Joy), while there is a significant spread, do agree with the other front half data. The lower curve is the best fit through these data. Since the front data, taken on this program appear to be valid because they are consistent with other data by different crews at different locations, it seems reasonable to assume that the total catch data taken on this program should also be valid. The mean emission factor value for total catch measurements is 3 lb/1000 gal burned which is the value selected for use in the final inventory.

Distillate oil combustion by industrial sources also represents an important industrial source of particulates. Once again it was difficult to make a comparison between AP-42's value for a front half catch and the SCAQMD's value for total particulates. However, there was good agreement between KVB and the SCAQMD. Therefore, no correction factor to the EIS system was felt necessary.

For CO boilers the AQMD did not use a single emission factor but used the test data for each source. A review of the EIS data indicated that the average CO boiler TSP emission was 14.4 lb/1000 bbl throughput. This is on the low end of the AP-42 range but all units in the Basin utilize electrostatic precipitators (ESP). The unit tested by KVB had been listed in the EIS file at the equivalent of 4.3 lb/1000 bbl which was obviously low compared to KVB test data of 32 lb/1000 bbl. It was later learned that the EPA had recently tested the same CO boiler. The EPA used a Method 5 train and a SCAQMD train and measured total emissions (including the impinger) in both cases. The results were 32 and 25 lb/1000 bbl respectively. KVB corrected EIS file for the emissions of the specific CO boiler involved in the tests.

2. Mineral products--Table 2-1b presents a comparison of the emission factors used to estimate the particulate emissions emitted from mineral product operations. Since the SCAQMD used test results from these sources rather than emission factors, the comparison between SCAQMD values and those obtained in this program has been made for a particular unit tested.

The results of the gypsum calciner test conducted by KVB are a factor of 2 greater than that found by the AQMD and that listed in AP-42. The reason for this is believed to be an abnormal baghouse operation on the day of the test as commented on by the operators. No correction was made.

The emission factor for the claygrinding and pulverizing operation for brick manufacturers generated from KVB test data are lower than the values listed in AP-42 (the value in the EIS system). If the fugitive dust from this process could have been included (not tested in this study) the emission factor would be much higher and thus be closer to the AP-42 value. Also the clay was slightly more moist due to rainy weather. This would greatly aid in reducing the emission. Therefore the emission factor used in the current EIS system was left unchanged.

The results of the coal fired cement kiln test indicated that there was good agreement between KVB and AP-42. The SCAQMD's value listed in the EIS however was six times greater than that listed in AP-42 or measured by KVB. A close look at the effects of control device efficiency revealed that a 0.1% change in efficiency results in a 0.05 lb/bbl cement emission increase. Therefore a 99.9% efficiency results in a 0.05 lb/bbl emission factor while a 99.3% efficiency results in 0.3 lb/bbl emission factor. The latter efficiency seemed reasonable for an industrial process. This coupled with the limited number of tests taken was the basis for not initiating an emissions factor change to the EIS file.

The emission factors generated from the results of KVB field testing for the glass furnaces are in good agreement with the values listed in AP-42 and the current EIS system. The emission factors in the EIS system were left unchanged except in the case where there was no listing for a glass furnace. When there was not a listing the controlled emission factor was assigned to the plant. Often other plant data needed to be obtained to make an entry in the EIS system.

In comparing KVB's measured emissions from fiberglass forming operations against those listed in AP-42 and the EIS system it was found that KVB's value was approximately midway between them. A source test conducted by the SCAQMD at a similar plant supports their lower value. Based on the limited number of samples taken and variables in the operation, a point source emission factor change was not felt to be appropriate.

KVB's measured emission factor for an asphalt roofing felt saturator was approximately one-half the value found in the EIS system. It was difficult to use AP-42's value for comparison purposes because it is only given for uncontrolled sources. KVB and the SCAQMD's values are for controlled devices. No correction factor was applied.

In reviewing the EIS computer printout for the asphaltic concrete batch plant tested, a decimal error located in the emission factor was noted and corrected. KVB's measured value supported the now correct SCAQMD value and therefore, no further change was necessary. AP-42's value appeared to be high in this case.

3. Food and agriculture--The carob roaster in Table 2-1c shows agreement between the KVB test results and the AP-42 results but disagreement with the AQMD results. The AQMD emissions were on a million cubic feet basis instead of a ton of product basis as in AP-42. No changes in emissions were made but the AQMD was recommended to change the basis for computing emissions. The KVB results for the rice dryer were in agreement with AP-42. There are no rice dryers in the Basin.

4. Evaporative sources--Table 2-1d presents a comparison of the emission factors used in estimating the emissions from water-based and solvent-based spray paint booths. There is no existing emission factor listing for this category in AP-42. Also, since the SCAQMD used test results from these sources rather than overall emission factors, the comparison between the SCAQMD's values and those obtained in this program has been made for a particular unit tested.

5. Metallurgical operations--Table 2-1g presents a comparison of the emission factors used to estimate the particulate emissions from metallurgical operations. Here again, the SCAQMD used test results from these sources rather than overall emission factors for computing a source's annual emissions.

An absence of emission factors in AP-42 for steel heat treating and steel sand blasting was noted. KVB's measured emissions upstream and downstream of a control device for these operations were difficult to compare against the SCAQMD's uncontrolled values. No corrections were applied.

For the aluminum reverberatory furnaces tested the EIS listing was found to be outdated and in the process of being revised. There was also wide disagreement between the three emission factor sources. The SCAQMD overall emission factor for this operation was found to lie midway between AP42 and KVB. It was therefore felt that the SCAQMD emission factor was best suited.

KVB's measured emission factors for an open hearth steel furnace (oxygen lance) are slightly higher than the SCAQMD's source test emission factor and those listed in AP-42. The reason is that the electrostatic precipitator being used is not as efficient as it had been in the past. This reduced efficiency results in a slightly higher controlled emission factor.

The factor listed in the EIS system was deemed correct and therefore not altered. The SCAQMD's overall emission factor for this category appears to be low. There was not sufficient test information available, however, to critique it with a reasonable degree of accuracy.

2.3.2 Emission Profiles

A. Description--

A unique aspect of the current program was the development of emission profiles -- the identification of the elements in four particle size ranges represented by the TSP emission rates currently given in emission measurements.

A primary objective of this program was to identify the elemental emissions and size distribution for each stationary source type in the Basin. Thus an emission profile was formulated for each Source Classification Code (SCC) emitting particulate material in the Basin. Both point and area sources were included. All plant devices identified by the same SCC and SIC number were given the same emission profile. Conversely, it was important that profiles be truly representative of the device in general. Additional advantages of developing aggregate profiles by SCC number were: (1) estimations based on larger data samples were more statistically reliable than single data samples, (2) profiles were compatible with the EIS concept by describing devices by the SCC number system, and (3) volume of profile data was reduced to a more manageable level.

The initial intent was to provide a profile for each SCC listed in the data base. In many instances, however, an individual profile was found to cover several SCC and SCC/SIC combinations. The profile data base was therefore formulated and indexed by a profile number. Separate profile numbers (with identical specie distributions) were given to SCC/SIC combinations to facilitate data management, specifically the segregation of emissions from devices with similar SCC codes in two different industry classes into the appropriate ARB Application Categories.

In each profile the chemical elements of the particulates were identified by their appropriate SAROAD code for each size range (4 ranges.) A typical profile is shown on the following page. Associated with each emission profile was an estimate of its relative credibility. This estimate of credibility was strictly subjective and has been included to give a relative level of confidence to the specific profile. No statistical significance has been or should be given to these error estimates.

The emission profiles developed in the current study are presented in the Appendix. A profile lists the SAROAD code, elemental name, and percent contribution of each species. The elements are also summed by size distribution. A sample profile is presented on the next page. Two reports are used to relate the profiles to the devices in the inventory. The SCC report (sorted by SCC number and profile number) lists all devices in the inventory and gives the profile number of the profile that describes the emission breakdown for the particular device. The profile file (Appendix) lists the profiles by profile number.

B. Methodology--

Two general approaches were used to formulate the emission profiles: one where only one data point was available to characterize many sources and the other where multiple data points were available. In cases where a profile was available from only one source and that source was believed to be representative of all such source types in the Basin, then that particular source emission profile was used. An appropriate credibility estimate was given to reflect the relative confidence level of these data. It was anticipated early in the program that a significant number of source types would fall into this category due to the limited amount of field tests available. Therefore, test locations were carefully selected on the basis of the representative nature of their emissions to all other devices of that particular type. In this way, data from this source could be assumed to apply to other non-tested sources.

EXAMPLE OF EMISSION PROFILE. OTHER PROFILES LISTED IN APPENDIX.

Title: Utility Boilers (Residual
Fuel)

Profile Key: 0006

Source of Data:

X KVB Test
X Literature Data--Ref.*
X Estimate--Basis†

Applicable SCC's

1-01-004-01, 1-02-004-01
1-02-004-03, 1-02-005-01
1-02-005-02, 1-02-005-03

Confidence Level: II

Test # 11,12,13,21,22,23,24,32,33

Size Range		>10µm	3-10µm	1-3µm	<1µm	Composite
Wt% TSP in Size Range		3	4	8	85	100
Species	SAROAD Code	Wt% of Species in Indicated Size				
		0.1% < t < 1.0%				d < 0.1%
Arsenic	12103	d	d	d †	d	d
Barium	12107	t			t	t
Bromine	12109				d	d
Cadmium	12110		d	d	d	
Calcium	12111	t	t	t	10	10
Chromium	12112			t	t	t
Cobalt	12113		d	d	d	d
Copper	12114	d	d	d	d	d
Iron	12126	4	4	4	2	2
Lead	12128	d	d	d	d	d
Manganese	12132	d	d	d	d	d
Molybdenum	12134	d	d		d	d
Nickel	12136	2	2	2	5	5
Potassium	12180	t	t	t	t	t
Selenium	12134	d	d	d	d	d
Strontium	12168	d	d	d	d	d
Titanium	12161	d	d	d	d	d
Vanadium	12164	t	t	t	t	t
Zinc	12167	t	t	t	t	t
Sulfates	12403	20	20	20	30	28
Nitrate						
(H ₂ O sol)	12306	d	d	d	d	d
Total Carbon	12116	30	30		20	22
(Volatile Carbon)	15101	(20)	(20)	(20)	(14)	(15)
Subtotal		56	56	56	67	67
Other		44	44	44	33	33
Total		100	100	100	100	100

*Ref 2-9

†Estimated to be same as 10µm size fraction
() included in total car

10/78

KVB 5806-783

1. Single data point profiles--The weight percent of each size range was obtained from the particle size distribution plot (which included the impinger catch) given in Section 4 for each industrial type tested. The details of how these curves were generated are discussed in Section 3.2.3 B. Whenever data was taken on a control device, the downstream (outlet) data was used to generate the profile for both chemical composition and size distribution. The chemical composition for each size range was obtained from the analyses for the particulate catches as discussed in Section 3.2.2. The first, second, and third cyclone analysis results were used in conjunction with the $>10\mu\text{m}$, $10-3\mu\text{m}$, and $3-1\mu\text{m}$ size range respectively. The filter and impinger catch analysis results were used in conjunction with the $<1\mu\text{m}$ size range. For each impinger catch there was an organic fraction which was obtained from methyl chloroform extraction of the impinger condensate as explained in Section 3.3.3-C and an inorganic fraction which was the remaining impinger residue as also explained in Section 3.2.2-C. Because the organic fraction residue could not be removed from the evaporation dish as discussed in Section 3.2.2-D (page 3-52), for chemical analysis purposes only the inorganic fraction of the impinger catch was used with the filter analysis to fully characterize the $<1\mu\text{m}$ size range. The percent of carbon in the organic fraction was incorporated with the carbon concentration of the $<1\mu\text{m}$ size range for each profile.

Whenever there were no data for a size range of a particular profile and there were data for the other size ranges, then an estimate was made. This estimate generally assumed that the concentrations of the chemical constituents were the same for each size range. It is believed that this is a good assumption because most of the profiles where complete data were available indicated that the concentrations of the chemical constituents were similar for the size range, except for sulfate and condensible carbon. Sulfates tend to be about two to three times more concentrated in the smaller sizes (impinger) than in the larger sizes. Condensible carbon usually ends up in the impinger catch (small size) and showed up in the impinger organic fraction.

2. Multiple data point profiles--The second approach used was to develop emission profiles based on data from several sources within a particulate source type. This involved: (1) acquiring the data, (2) determining the relative magnitudes of each source compared to the total emission from the source type, and (3) forming a composite profile by factoring the data from each source by an appropriate weighting factor. In this manner, emission profiles were developed for individual source types that in actuality represented the average emissions from sources of that category (SCC number).

The approach used to assign profile numbers (keys) to each source type (SCC number) was as follows:

1. A current list of all source types (SCC number) that were emitting particulates into the SCAB was generated from the most recent (April 1978) EIS summary.
2. Each item on this list of source types was assigned a four-digit number. These are listed in Table 2-2. The number 0000 indicates that there was no data available to generate the emission profile. The number 0099 indicates that the source type is not classified. All other numbers were assigned to a specific source type.
3. Each of the profile numbers listed in Table 2-2 were matched with the appropriate SCC number from the list generated from the current EIS file (1 above). In many instances, an individual profile was found to cover several SCC and SCC/SIC combinations. The profile data base was therefore formulated and indexed by a profile number. This is listed in Table 2-3.

TABLE 2-2. PROFILE KEY INDEX

<u>Profile Key</u>	<u>Source Classification</u>	<u>Reference</u>
0000	Data not available for profile	
0001	Industrial boilers (crude and residue)	Sec. 4.2.1
0002	Industrial boilers (diesel fuel)	Sec. 4.2.2
0003	Internal combustion engines (diesel fuel)	Sec. 4.2.5
0004	Internal combustion engines (gas fuel)	Sec. 4.2.5
0005	Wood waste boiler	Ref. 2-8, Sec. 4.2.4
0006	Utility boilers (residual fuel)	Ref. 2-9, Sec. 4.2.4
0007	Rice dryer	Sec. 4.2.13
0008	Coffee/Carob roasting	Sec. 4.2.14
0009	Steel heat treating	Sec. 4.2.15
0010	Steel abrasive blasting	Sec. 4.2.16
0011	Aluminum foundry	Sec. 4.2.17
0012	Steel-sinter plant	Sec. 4.2.18
0013	Steel-open hearth furnace	Ref. 2-10, Sec. 4.2.19
0014	Calcination of gypsum	Sec. 4.2.7
0015	Brick grinding and screening	Sec. 4.2.8
0016	Cement production	Sec. 4.2.6
0017	Glass melting furnace	Sec. 4.2.9
0018	Fiberglass forming line	Sec. 4.2.10
0019	Asphalt roofing	Sec. 4.2.11
0020	Asphaltic concrete batch plant	Sec. 4.2.12
0021	Paint spray booth (water solvent)	Sec. 4.2.22
0022	Paint spray booth (oil solvents)	Sec. 4.2.22
0023	Boric acid manufacture	Sec. 4.2.20
0024	Chemical fertilizer (urea)	Sec. 4.2.21
0025	Wood operation (resawing)	Sec. 4.2.23

TABLE 2-2. (Continued)

0026	Wood operation (sanding)	Section 4.2.23
0027	Petroleum heaters (natural gas fuel)	Section 4.2.24
0028	Petroleum--FCC Units/CO Boilers	Ref. 2-11 Section 4.2.25
0029	Feed and grain operations	Ref. 2-12
0030	Limestone kilns	Ref. 2-13
0031	Basic oxygen furnace (steel)	Ref. 2-10
0032	Electric arc furnace (steel)	Ref. 2-14
0033	Rock crushers	Ref. 2-15
0034	Rock screening and conveying	Ref. 2-15
0035	Structural fire	
0036	Residential natural gas burning	
0037	Fireplaces	
0038	Tire attrition	
0039	Cigarette smoke	
0040	Sea salt spray	
0041	Brake lining wear	
0042	Livestock dust	
0043	unpaved roads	
0044	Construction dust	
0045	Agricultural burning	
0046	Forest fires	
0047	Landfill dust	
0048	Agricultural tilling	
0049	Industrial Boiler (natural gas fuel)	
0099	Not classified	

TABLE 2-3. PROFILE KEY ASSIGNMENT TO SCC NUMBERS

<u>SCC#</u>	<u>Profile Key</u>
1-01-004-01	0006
1-01-005-01	0002
1-01-006-01	0049
1-01-006-02	0049
1-02-004-01	0006
1-02-004-03	0006
1-02-005-01	0006
1-02-005-02	0006
1-02-005-03	0006
1-02-006-01	0049
1-02-006-02	0049
1-02-006-03	0049
1-02-007-01	0049
1-02-007-02	0049
1-02-007-07	0049
1-03-005-02	0002
1-03-006-02	0049
1-03-007-03	0049
1-05-002-06	0049
2-01-001-01	0002
2-01-002-01	0049
2-02-002-02	0049
2-06-013-01	0099
3-01-009-99	0099
3-01-017-01	0000
3-01-999-99	0099
3-02-001-99	0099
3-02-005-01	0029
3-02-006-01	0029
3-02-006-02	0029

TABLE 2-3. (Continued)

3-02-007-30	0029
3-02-008-99	0029
3-02-999-98	0099
3-02-003-02	0000
3-03-003-04	0000
3-03-003-06	0000
3-03-003-99	0099
3-03-008-02	0000
3-03-008-03	0012
3-03-008-99	0099
3-03-009-01	0013
3-03-009-03	0031
3-03-009-05	0032
3-04-001-01	0011
3-04-001-99	0099
3-04-003-01	0000
3-04-003-50	0000
3-04-004-03	0000
3-04-007-01	0032
3-04-007-09	0099
3-04-999-99	0099
3-05-001-04	0019
3-05-001-99	0019
3-05-002-01	0020
3-05-002-99	0020
3-05-003-02	0015
3-05-006-02	0016
3-05-006-99	0099
3-05-007-99	0016
3-05-008-01	0015
3-05-008-02	0015
3-05-008-99	0099
3-05-011-01	0016
3-05-012-04	0018

TABLE 2-3. (Continued)

3-05-011-99	0099
3-05-014-01	0017
3-05-014-11	0017
3-05-015-02	0014
3-05-015-99	0014
3-05-016-99	0030
3-05-017-01	0000
3-05-017-99	0099
3-05-020-01	0033
3-05-020-02	0033
3-05-020-05	0033
3-05-020-06	0034
3-05-020-80	0099
3-05-020-99	0099
3-05-025-01	0033
3-05-025-99	0099
3-05-999-88	0099
3-05-999-99	0099
3-06-001-02	0027
3-06-001-03	0000
3-06-001-04	0027
3-06-001-09	0099
3-06-002-01	0028
3-06-009-99	0099
3-06-011-99	0099
3-06-012-03	0000
3-06-999-97	0099
3-06-999-98	0099
3-07-004-99	0099
3-07-020-99	0099

TABLE 2-3. (Continued)

3-09-001-88	0099
3-09-001-99	0099
3-09-030-04	0000
3-09-030-99	0099
3-09-999-99	0099
3-63-009-01	0099
3-90-005-05	0000
3-90-006-05	0011
3-90-006-08	0000
3-90-006-31	0000
3-90-006-99	0099
3-90-008-99	0099
3-99-999-99	0099
4-C -001-01	0021
4-02-003-01	0022
4-02-004-01	0022
4-02-004-05	0022
4-02-005-99	0099
4-02-007-01	0000
4-02-008-01	0000
4-02-008-03	0000
4-04-001-99	0099
4-90-999-99	0099
5-03-002-01	0045
9-12-071-00	0043
9-13-081-00	0046
9-14-001-07	0036
9-14-034-00	0037
9-24-089-95	0035
9-27-619-50	0039
9-41-009-52	0041

TABLE 2-3 (Continued)

9-47-239-00	0048
9-47-307-42	0044
9-47-549-01	0040
9-49-000-00	0047
9-49-999-01	0038
9-49-999-98	0042
9-49-999-99	0047

C. Critical Profiles--

Due to the magnitude of the sources which they represent, several emission profiles were recognized to have a significant impact on the results of the final inventory. These include: (1) combustion of fuels for utility and industrial boilers, (2) cement production, (3) fugitive dust from unpaved roads and construction, and (4) tire dust from wear. Detailed discussion of the development of these profiles are included in the following section.

1. Combustion of fuels--The combustion of fuels constitutes about 50% of the particulate emissions from point sources in the SCAB. This large source of emission was broken down into two groups: (1) emissions from utility boilers and (2) emissions from industrial boilers.

Nine field tests*, with two sampling trains for a total of 18 tests, were done on utility boilers burning low sulfur residual fuel. These were used to develop the emission profile for utility boilers burning residual fuel. The results from these tests indicated that 85% by weight of the particles were less than 1µm. Thirty-six percent of the total particulates were sulfates, 22% were carbon, 10% were calcium, 5% were nickel and 2% were iron. All other elements that were detected by the analysis were in concentrations less than 1%. This profile (profile key 0001) is listed in the Appendix (Vol. II).

The results of two field tests* on industrial boilers burning diesel fuel were used to develop the emission profile for industrial boilers. The results indicated that 96% by weight of the particulates were less than 1µm of which 65% were sulfates, 15% were carbon, and all other elements detected were in concentrations less than 1%. This profile (profile key 0002) is listed in the Appendix.

2. Cement production--The results of two field tests* and data from Reference 2-16 were used to develop the emission profile for the production of Portland Cement. These results indicated that 34% by weight of the particles

* These field tests are discussed in detail in Section 4.0

were less than 1 μ m, 34% between 3-1 μ m, 24% between 10-3 μ m, and 8% greater than 10 μ m. Twenty five percent of the composite of the sizes were sulfates, 10% silicon, 20% calcium, 8% carbon, and all other elements detected were in concentrations less than 1%. This profile (profile key 0016) is listed in the Appendix.

3. Fugitive dust--The fugitive dust emission constitutes about 80% of the particulate emission from the accountable area sources. Fugitive dust emissions are broken into five groups: (1) road and building construction, 55%, 2) unpaved roads 18%, 3) agricultural tilling, 7%, 4) livestock feed lots, 1%, and 5) refuse disposal sites, <1%. Only road and building construction and unpaved roads will be discussed here. From the literature, (Ref. 2-17,18), it was determined that 45% by weight of the particles were greater than 10 μ m, 15% between 10-3 μ m, 12% between 3-1 μ m, and 28% less than 1 μ m, for construction dust. Twenty percent were silicon, 8% aluminum, 2% calcium, 3% iron, and 2% potassium. All other elements listed were in concentrations less than 1%. The profile for construction dust (profile key 0044) is given in Appendix A. The profile for fugitive dust from unpaved roads is similar to that of construction dust. From the literature (Ref. 2-17,18) it was determined that 55% by weight of the particles were greater than 10 μ m, 15% between 10-3 μ m, 12% between 3-1 μ m, and 18% less than 1 μ m. Twenty percent were silicon, 8% aluminum, 2% calcium, 3% iron, and 2% potassium. All other elements listed were in concentrations less than 1%. The profile for fugitive dust from unpaved roads (profile key 0043) is listed in the Appendix.

4. Tire Dust--Emissions from tire attrition constitutes about 7% of the particulate emissions from the accountable area sources. From the literature (Ref. 2-17,18) it was determined that breakdown of the particle size distribution is as follows:

	>10 μ m	10-3 μ m	3-1 μ m	<1 μ m
Tire Dust	60%	5%	15%	20%

The dust is composed of about 90% carbon, and 1% zinc. The remaining element is hydrogen. Further information on tire dust is presented in the next section (Section 2.3.3 C.1)

2.3.3 Area Sources

An important aspect of the KVB fine particulates emission inventory was the identification of sources of fine particulate emissions not under permit and generally not included or adequately characterized in previous inventories. These sources were categorized into four main groups: 1) fugitive dust sources, 2) combustion sources, 3) automobile sources, and 4) sea salt spray. Because these are diffuse and not concentrated sources like industrial point sources, they are referred to as area sources. Emission factors for these sources were therefore based on land area, population, land use, or other criteria characteristic of the area source.

Table 2-4 presents a summary of the area source suspended particulate emission estimates for each of the sources considered. Precise emission rates were difficult to estimate due to the complex nature and non-availability of applicable data for each source type.

A second objective of the area source inventory was to identify the particle size and chemical composition of the reported particulate emissions from each source type. Again, precise particle sizing and chemical composition were difficult to obtain for many area source types due to the wide variation in materials associated with each area source. Specific source chemical composition analysis can be found under that section titled "Area Profiles."

A third objective of the study was to locate these area sources geographically in the South Coast Air Basin. To this end, information was secured from various governmental agencies on population distribution, land use, agricultural plantings, construction and road building, etc. Maps corresponding to the approximate location of each source were developed. Area sources based on population were distributed on a per capita basis based on information from the ARB.

TABLE 2-4. ESTIMATED 1976 AREA SOURCE FINE PARTICLE EMISSIONS SUMMARY (a)

	South Coast Air Basin Counties (b)						(c) of	Percent	
	Emissions Tons/yr								
	Orange	Los Angeles	River- side	Bernardino	Ventura	Santa Barbara			Grand Total
Road & Building Construction	21,000	24,000	7,100	11,000	6,400	1,000	71,000	20.9	+50,-20
Agricultural Tilling	1,300	1,200	3,100	800	3,100	40	9,500	2.8	125
Refuse Disposal Sites	60	200	20	20	20	6	300	<0.1	125,-20
Livestock Feedlots	150	3	150	950	5	5	1,300	0.4	150
Unpaved Road Travel	2,000	14,000	2,000	1,800	2,600	230	23,000	6.8	140
Paved Road Travel (d)	33,000	140,000	7,600	12,000	8,800	3,100	200,000(d)	58.8	150
Fugitive Dust--Subtotal							305,000	89.7	
Forest Fires	120	700	600	430	530	50	2,400	0.7	+50,-20
Structural Fires (e)	40	160	10	15	10	5	200	<0.1	+100,-20
Fireplaces	70	280	30	60	20	10	500	0.1	+100,-10
Residential Natural Gas	20	90	5	10	10	5	100	<0.1	125
Cigarettes	130	520	30	50	30	10	800	0.2	+20,-50
Agricultural Burning	20	50	30	--	400	10	500	0.1	125
Combustion--Subtotal							4,500	1.3	
Tire Attrition	1,400	5,700	320	490	370	130	8,400	2.5	120
Brake Lining Attrition	530	2,100	120	180	140	50	3,100	0.9	120
Automotive--Subtotal							11,000	3.2	
Sea Salt--	4,000	6,700	---	---	3,500	5,800	20,000	5.9	+50,-20
Grand Total							340,000	100%	

a) Emission estimates are based on particles $\leq 10 \mu m$

b) Includes only that portion of County within SCAB

c) Rounded to three significant figures

d) A large (but unknown) percentage of the 200,000 tons/year is assignable to other area source categories studied and not studied in this inventory. For this reason (see Section 2.3.3-A-6) it was not included in the final inventory count as indicated in Table 2-18.

e) Includes property, contents and vehicle loss.

KVB 5806-783

The following sections present a discussion of the methodologies and references used in making these estimates. In general, the procedure involved the establishment of two criteria: 1) an emission factor coupled with 2) an appropriate inventory. Using this format, improvements of either criteria can be readily employed to improve future estimates.

It must be pointed out that many of the emission factors applied to the inventories presented were developed specifically for this study of South Coast Air Basin and are not necessarily appropriate or applicable to other study areas.

Those emission factors based on studies conducted outside the air basin were carefully reviewed and reevaluated when it was deemed necessary in order to make the raw emission factor more applicable to the study area.

A. Fugitive Dust--

Significant sources of atmospheric dust arise from the mechanical disturbance of granular material exposed to the air. Dust generated from these open sources is termed "fugitive" because it is not discharged to the atmosphere in a confined flow stream.

In the 1976 inventory (Table 2-4), fugitive dust accounted for approximately 75% of the 140,000 tons of suspended particulate matter (<10 μ m particles) estimated to be emanating from the area sources considered excluding paved road travel. The six fugitive dust areas considered are: (1) road and building construction, (2) agricultural tilling, (3) refuse disposal sites, (4) livestock feedlots, (5) unpaved road travel, and (6) paved road travel. As can be seen in Table 2-4, road and building construction coupled with unpaved road travel account for 66% of the total 1976 area source estimate (excluding paved road travel). The basis for excluding paved road travel is explained in Section 3.2.3-6.

For the above categories of fugitive dust sources, the dust generation process is caused by two basic physical phenomena:

1. Pulverization and abrasion of surface materials by application of mechanical force through implements (wheels, blades, etc.)
2. Entrainment of dust particles by the action of turbulent air currents generated by winds, moving vehicles, etc.

The air pollution impact of a fugitive dust source depends on the quantity and drift of the dust particles emitted into the atmosphere. In addition to large dust particles that settle out near the source (often creating a localized nuisance problem), considerable amounts of fine particles are also emitted and dispersed over much greater distances from the source (Ref. 2-19).

The quantities of dust reported as emissions in this report are defined as being comprised of particles smaller than 10 μ m and having a particle density of 2.0 - 2.5 g/cm³. Further particle size breakdown into <10 μ m, <3 μ m, and <1 μ m intervals is included in each sub-category discussion. The correlation between Ambient Hi-Volume Samples and the Pasquile-Gifford Diffusion equation for ground level sources was employed by the referenced studies (Refs. 2-17,13) as the basis for computing the original emission factors.

1. Road and building construction--Recent studies (Refs. 2-20,21) have concluded that road and building construction activities are significant sources of fugitive dust. Such emissions are associated with land clearing, blasting, ground excavations, cut and fill operations, and the construction of the particular facility itself. As can be seen in Table 2-4, construction activities accounted for the single largest source of particulate matter (excluding paved road travel).

Pedco-Environmental Specialists (Ref. 2-17) and Midwest Research Institute (Ref. 2-18) have conducted investigations into the emissions from construction operations. An uncontrolled emission factor of 1.2 tons per acre of construction per month of activity for particles <30 μ m was determined. However, Pedco also concluded that a 50% reduction in emissions is possible if adequate dust control such as watering twice daily is practiced. Review of SCAQMD's Rules 402 and 403 on Fugitive Dust, communication about Rules 402 and 403 with the SCAQMD (Ref. 2-22) and on-site observations of construction sites revealed that a 50% reduction is indeed possible and was therefore used in this study.

Also, approximately 20% by weight of the particles lie in the 30 μ m to 10 μ m particle size interval. Therefore an emission factor of 0.5 tons per acre-month for building construction was chosen to be applicable to the study area with this factor including the 50% reduction achieved by watering. For highway construction an emission factor of 0.25 tons per acre-month was estimated based on communications with the ARB (Ref. 2-21).

An inventory of the acre-months of building and road construction for 1976 was obtained from the APB (Ref. 2-21). Table 2-5 lists the acre-months of construction activity and emissions per county. An emission factor of 6.3 tons per 1000 people per year was entered into the final inventory. A population based emission factor was chosen to best reflect the location of their emissions since residential construction, at least, would be in proportion to the neighboring population density.

On the average, dust emissions from construction operations have the following particle size characteristics:

<u>Particle Diameter</u>	<u>Weight Percent</u>
<1 μ m	24
1-3 μ m	16
3-10 μ m	24
>10 μ m	36

A particle size distribution plot is presented in Figure 2-4.

TABLE 2-3. ROAD & BUILDING CONSTRUCTION
PARTICULATE EMISSIONS SUMMARY

County	Acre-months Construction			Emissions tons/yr
	Residential	Non- Residential	Roads	
Orange	29,894	6,004	11,832	21,000
Los Angeles	25,627	13,304	20,184	24,000
Riverside	8,078	1,236	9,860	7,100
San Bernardino	12,501	1,738	14,384	11,000
Ventura	9,737	1,085	3,828	6,400
Santa Barbara	1,172	258	1,144	1,000
Total				71,000 tons/yr

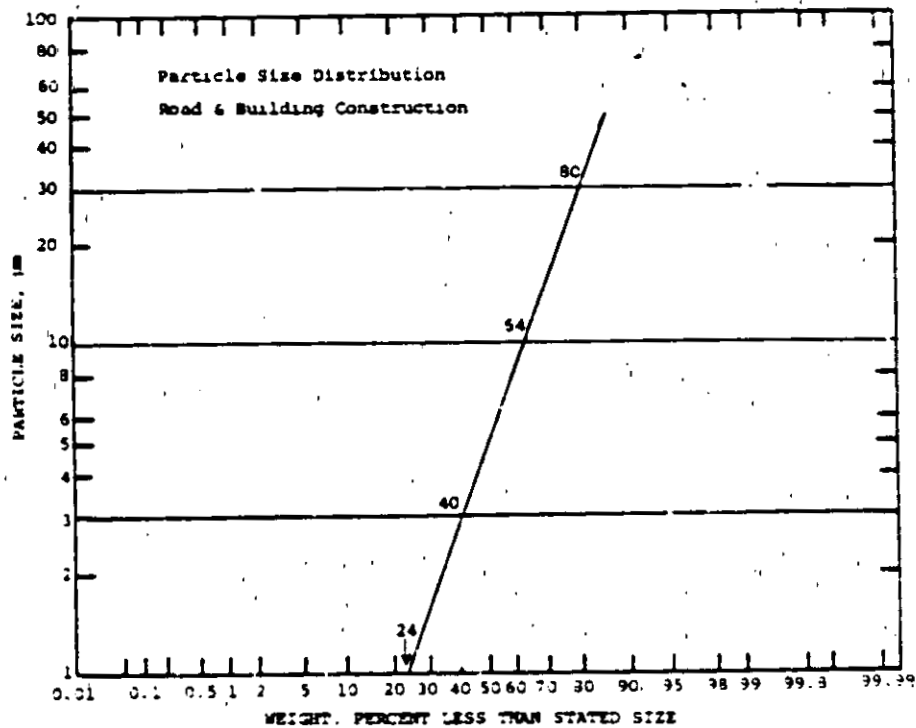


Figure 2-4. Road and building construction dust
particle size distribution.

2. Agricultural tillage--Approximately 9500 tons per year of fugitive dust (particles <10µm) were estimated to be coming from agricultural tilling operations within the basin as shown in Table 2-4.

The two universal objectives of agricultural tilling are the creation of the desired soil structure to be used as the crop seedbed and the eradication of weeds. Plowing, the most common method of tillage, consists of some form of cutting loose, granulating, and inverting the soil and turning under the organic litter. Implements that loosen the soil and cut off the weeds but leave the surface trash in place, have recently become more popular for tilling in dryland farming areas.

During a tilling operation, dust particles from the loosening and pulverization of the soil are emitted into the atmosphere as the soil is dropped to the surface. Dust emissions are greatest when the soil is dry and during final seedbed preparation (Ref. 2-23).

In developing an emissions estimate, a threefold approach was taken:

1. Establishment of a 1976 inventory of the harvested acreage of field, truck, orchards, outdoor nursery, and improved pasture.
2. Determination of the passes per crop made by a farming implement that disturbs the soil significantly.
3. Development of the proper emission factor to apply to farming operations within the Basin.

An inventory of harvested acreage was compiled with the aid of the 1976 County Agricultural Commission's Crop Reports (Refs. 2-24 through 29). The passes per crop were determined through lengthy communication with numerous University of California Cooperative Extension Service Farm Advisors (Refs. 2-30 through 33). The estimated average number of passes per crop type are presented in Table 2-6.

TABLE 2-6. ESTIMATED AVERAGE FARM IMPLEMENT PASSES PER CROP

<u>Field Crops</u>	<u>Estimated Average passes per crop</u>
Barley	3
Lima beans	3
Hay, alfalfa	0.5
Hay, grain	3
Improved pasture	1
Sugar beets	4
Wheat	3
Corn	3
Grass	3
Safflower	3
Misc. Seed	3
<u>Truck Crops</u>	
Asparagus	3
Beans	3
Beets	4
Berries--Strawberries	6
Berries	3
Broccoli	3
Cabbage	3
Carrots	5
Cauliflower	3
Corn	3
Cucumbers	3
Egg Plant	3
Endive	3
Garlic	3
Lettuce	3
Cantaloupe	3
Crenshaw	3
Honeydew	3
Misc. Melons	3
Watermelons	3
Misc. Vegetables	3
Okra	3
Onions	5
Peas	3
Peppers	3
Potatoes	3
Pumpkins	5
Radishes	3
Romaine	3
Rutabaga	3
Squash	3
Tomatoes	3
Turnips	5
Parsley	3
Parsnips	3
<u>Orchard Crops</u>	
Citrus	3
Deciduous	3
<u>Nursery</u>	
Outdoor Field Grown	3
Cut flowers	3

Source: References 2-30 through 2-33.

KVB 5806-783

Current farming practices in orchards disclosed that only 10-20% of the acreage presently allotted to orchards is actually tilled. An increased use of herbicides is the reason for this practice.

A field study conducted by Midwest Research Institute (Ref. 2-18) concluded that the quantity of dust emitted from agricultural tilling is proportional to the area of land being tilled. In addition, emissions depend on the following variables: soil texture, soil moisture, and tractor speed. Available test data indicate no substantial dependence of emissions on the type of tillage implement being used when operating at a typical speed of 6 mph (Ref. 2-18).

The equation for estimating the total amount of tillage dust emissions is as follows:

$$e \text{ (tilling)} = \frac{1.4s (S/5.5)}{(PE/50)^2} (C) \pm 15\%$$

where: e = emission factor (pounds per acre)

s = silt content (particles between 2 μ m-50 μ m as defined by the U.S. Dept. of Agriculture) of the surface soil (0-4 inches depth) percent

S = implement speed (miles per hour)

PE = Thornthwaite's precipitation-evaporation index corrected for irrigation

C = particle sizing factor (e.g. 65% wt. <10 μ m diameter particles, see Figure 2-5)

The silt content of SCAB agricultural lands generally range from 10-30%. A mid-range value of 20% was chosen. Also, reports on the moisture content of the top four inches of soil during tilling varied from a PE Index of 17 to 56 (Refs. 2-39,32,34,35). A value of 41 was chosen to be representative. Implement speed varied considerably so a value of 5.5 mph was chosen.

By inserting this information into the forementioned tillage dust equation, an emission factor of 27 lb per acre pass was derived. A particle size distribution plot is shown in Figure 2-5. On the average, dust emissions calculated for agricultural tilling have the following particle size characteristics (Ref. 2-18):

<u>Particle Diameter</u>	<u>Weight Percent</u>
<1 μ m	25%
1-3 μ m	17%
3-10 μ m	22%
>10 μ m	36%

A summarization of the inventory and emission estimates by crop group and county are presented in Table 2-7. Figure 2-6 depicts the major agricultural areas to which these emission estimates were assigned. The aid of County Agricultural Commissioners' Farm Advisors (Refs. 2-31,36-38) and an ARB memo (Ref. 2-39) were solicited in estimating the percentage of crops contained within the Air Basin when a county such as Riverside extends outside the study area.

3. Refuse Disposal Sites--Over 15 million tons of liquid and solid waste were disposed of annually in the 45 major landfill sites located in the basin. This accounted for approximately 300 tons of fugitive dust. Disposal involves the collection, transportation, unloading, and soil covering of daily refuse. For our purposes, the dust associated with unloading and soil covering will be considered to constitute the major portion of the dust generated from the total disposal cycle.

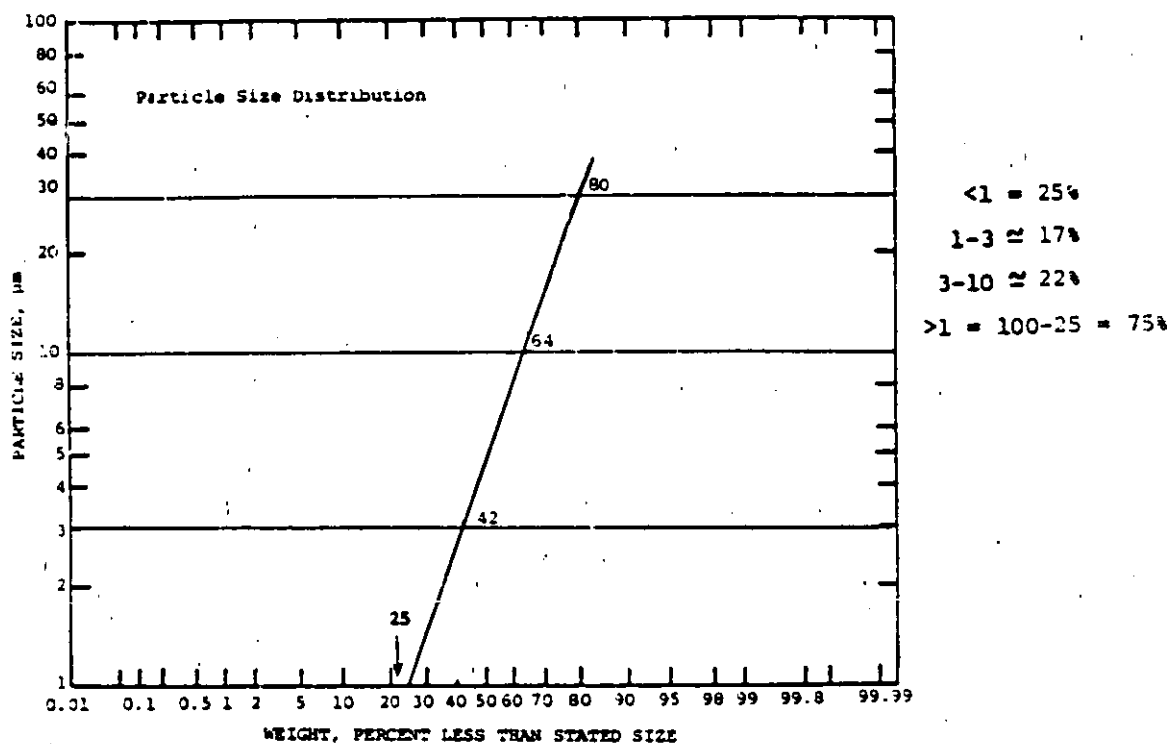


Figure 2-5. Agricultural tillage dust particle size distribution.

TABLE 2-7. 1976 SCAB AGRICULTURAL TILLAGE SUMMARY

County-SCAB	TOTAL ACREAGE TILLED (1)						% in Basin	Emissions tons/yr
	Field Crops	Vegetable Crops	Orchards	Outdoor Nursery	Imp. Pasture	Total		
Orange	52,000	36,000	3,000	NA	NA	97,800	100	1300
Los Angeles	83,000	30,000	1,100	7500	1100	122,700	(3)	1200
Riverside	327,000	125,000	23,000	--	34,000	509,000	45	3100
San Bernardino	82,000	5,600	8,000	1200	--	96,800	60	800
Ventura	51,000	112,000	63,300	NA	NA	226,300	100	3100
Santa Barbara	---	1200	---	< 800	--	3,000	(4)	40
TOTAL								9500

NA - Not Applicable

(1) Values obtained by multiplying the annual acres harvested reported in the 1976 County Crop Reports by the passes per crop-factor (Table 2-6).

(2) Emission estimated based on coupling the 27 lbs dust per acre pass with the calculated total annual acres passes.

(3) Source: Ref. 2-37

80% Field Crops

45% Vegetable Crops

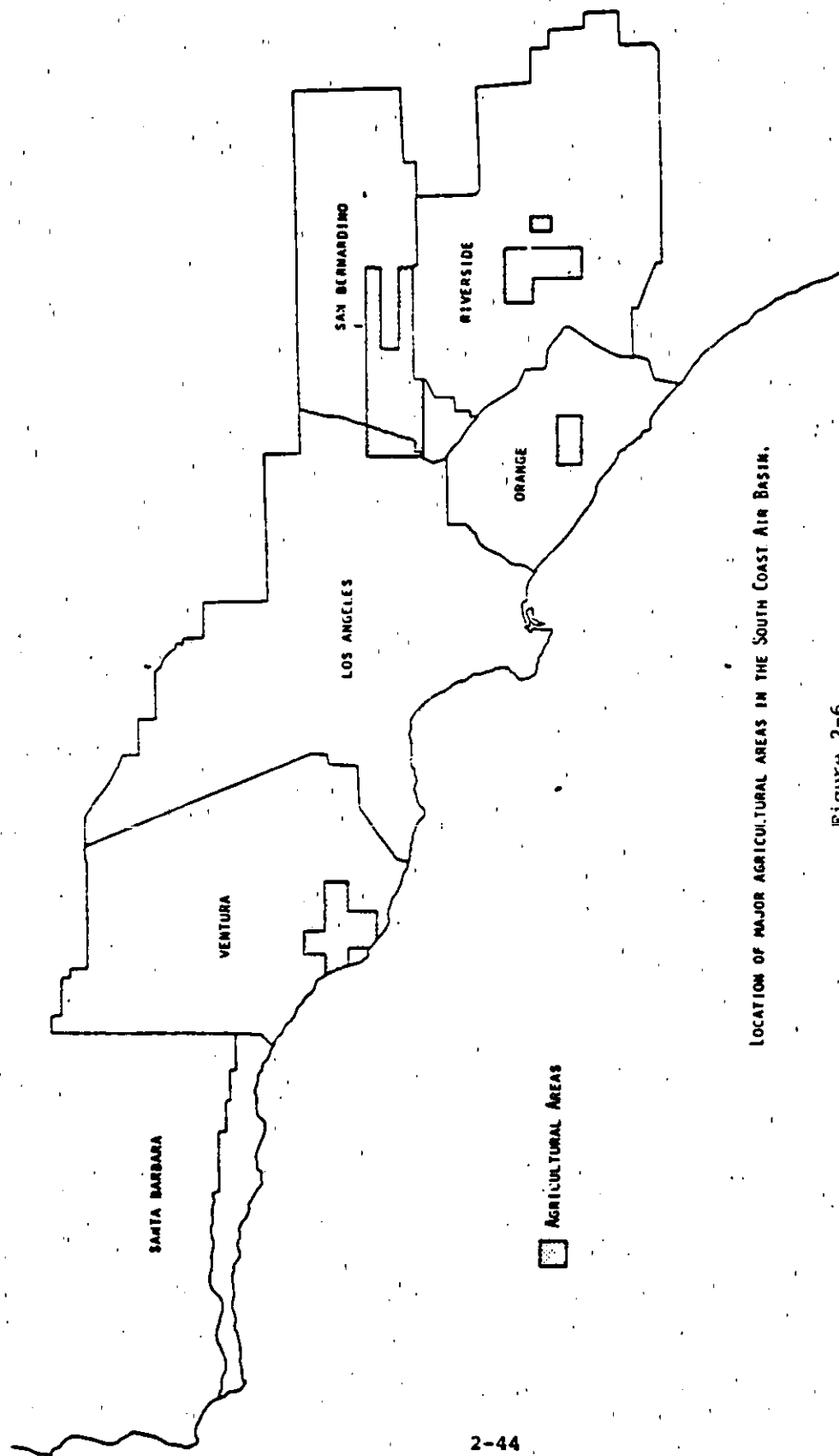
100% Citrus

90% Outdoor Nursery

100% Imp. Pasture

(4) Only that portion of county in SCAB was initially considered

KVB 5806-783



LOCATION OF MAJOR AGRICULTURAL AREAS IN THE SOUTH COAST AIR BASIN.

Figure 2-6.

KVB 5806-783

A threefold approach was taken in the establishment of the 300 tons per year estimate:

1. Review of County Solid Waste Management Plans to establish site location and annual refuse disposal
2. Determination of the surface area worked based on the annual quantities of refuse disposed
3. Establishment of an applicable emission factor

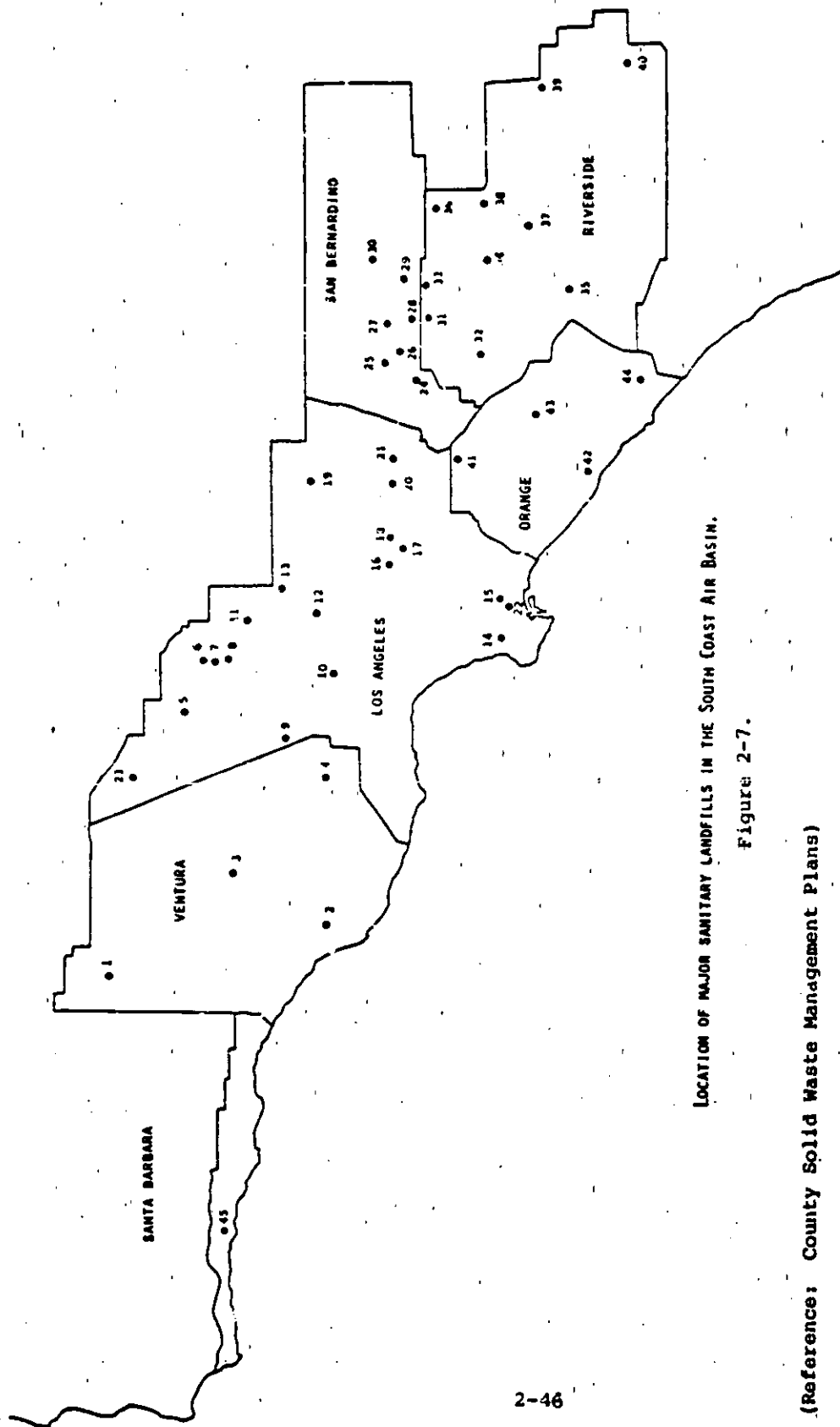
Coyote Canyon landfill site was chosen as a model refuse site. The surface area worked was estimated to be equal to $2/3$ power of the volume of the disposed refuse (Ref. 2-40). One cubic yard of compacted refuse was estimated to weigh 21200 pounds (density of 0.71 g/cm^3) (Ref. 2-41). Review of numerous articles on fugitive dust emissions failed to reveal an emission factor specifically designed for landfill sites.

Since the activities at a landfill site approximate those found at a construction site, the 0.5 ton per acre-month of activity for construction was chosen. Investigation of dust control practices at Orange County landfill sites (Ref. 2-42) disclosed that continuous watering of the dirt roadway and active dump area is common practice. Also, continuous watering is practiced at a majority, if not all, municipal sites in the basin. Therefore, it was felt that the 0.5 ton per acre-month was indeed appropriate.

The specific site locations and annual refuse disposed can be found in Figure 2-7 and Table 2-8. Emissions were entered into the final inventory on the basis of site location.

Particle sizing information on fugitive dust from construction sites was also judged to be applicable to landfill sites.

4. Livestock dust--An EPA sponsored study (Ref. 2-17) has been conducted to quantify the fugitive dust emissions from livestock feedlots. A total of 48 samples were taken at 24 different feedlot locations. Emission factors of 8 tons/1000 hd/year for uncontrolled lots with less than 25,000 head, and 5 tons/1000 hd/year for feedlots with more than 25,000 head (particle $<30\mu\text{m}$) were derived. Additional particle sizing information was not taken, however.



LOCATION OF MAJOR SANITARY LANDFILLS IN THE SOUTH COAST AIR BASIN.

Figure 2-7.

(Reference: County Solid Waste Management Plans)

KVB 5806-783

TABLE 2-8. EXISTING MAJOR CLASS I AND II SANITARY LANDFILL SITES
IN THE SOUTH COAST AIR BASIN

(Reference - County Solid Waste Management Plans)

Quantity of Waste Received	Class	Reported Acreage	Liquid	Tons/Year Solid	Total
<u>Ventura County, 1973</u>					
1. Orsha	II		-	1,086 -	1,086
2. Santa Clara	II	47	-	434,400 -	434,400
3. Toland Road	II	120	-	36,200 -	36,200
4. Lima	I	230	-	144,800 -	144,800
All Other Class II Sites		440	-	167,400 -	167,400
Total		437			791,886
<u>Los Angeles County, 1974</u>					
5. W. Valley Refuse Center	II	230	-	550,000	550,000
6. Bradley Avenue Dump	II	63	-	332,000	332,000
7. Penrose Pit	II	73	-	398,000	398,000
8. Hewitt Pit	II	117	-	436,000	436,000
9. Celestus Land Fill	I	416	36,000	320,000	356,000
10. Mission Canyon Land Fill	II	1,491	-	1,394,000	1,394,000
11. Burbank City Land Fill	II	133	-	75,000	75,000
12. Toyon Canyon Land Fill	II	40	-	795,000	795,000
13. Scholl Canyon Land Fill	II	484	-	450,000	450,000
14. Palos Verdes Land Fill	I	295	280,000	1,300,000	1,580,000
15. Ascon	II	65	85,000	422,000	507,000
16. Operating Industries	II	190	177,000	589,000	766,000
17. City of Whittier Land Fill	II	117	-	107,000	107,000
18. Puente Hills Land Fill	II	1,214	17,000	1,165,000	1,182,000
19. Azusa Western	II	307	-	271,000	271,000
20. B.N.R. Land Fill	I	583	294,000	352,000	606,000
21. Spadra Land Fill	II	199	13,000	192,000	205,000
22. Harbor Dump	II	25	-	160,000	160,000
23. Chiquita Canyon Land Fill	II	40	-	33,000	33,000
All Other Minor Class II Sites		N.R.		56,050	56,050
Total		4,082	862,000	9,341,000	10,203,000
<u>San Bernardino County, 1974</u>					
24. Milliken	II	106	-	215,500	215,500
25. Cajon	II-2	106	1	- 117,500 -	117,500
26. Fontana	II	82	-	64,000	64,000
27. Mespe Peak	II	63	-	16,600	16,600
28. Colton	II	94	-	93,700	93,700
29. Yucaipa	II	560	-	34,600	34,600
30. Big Bear	II	70	-	11,600	11,600
Total		1,081			581,500
<u>Riverside County, June 1975</u>					
31. West Riverside	II-2	63	-	- 52,700 -	52,700
32. Corona	II-2	101	-	- 88,350 -	88,350
33. Highgrove	II-2	280	-	8,100	8,100
34. Mead Valley	II-2	240	-	8,100	8,100
35. Elsinore	II-2	44	-	12,400	12,400
36. Redlands	II-1	904	-	15,500	15,500
37. Double Butte	II-2	580	-	61,380	61,380
38. Lamb Canyon	II-2	788	-	- 48,050 -	48,050
39. Idyllwild	II-2	30	-	- 3,010 -	3,010
40. Anna	II-2	10	-	1,550	1,550
Total		1,940			222,140
<u>Orange County, December 1975</u>					
41. Gilada	II	335	-	758,000	758,000
42. Corvato Canyon	II	593	-	2,130,000	2,130,000
43. Santiago Canyon	II	160	-	374,000	374,000
44. Prima DeSchocha	II	945	-	478,000	478,000
Total		1,933		1,740,000	1,740,000
<u>Santa Barbara, 1975</u>					
45. Tajiquas	II	130	-	202,900	202,900
GRAND TOTAL		11,380			13,782,426

A particle size distribution plot shown in Figure 2-8 was generated based on the assumptions that the silt content of the soil contained within a feedlot pen is higher than that of construction and unpaved roads, and that the moisture content of the soil may be somewhat higher due to livestock excretions.

On the average therefore, it is estimated that dust particles from feedlots would have the following particle size characteristics:

<u>Particle Diameter</u>	<u>Percent by Weight</u>
<1 μ m	46
1-3 μ m	16
3-10 μ m	13
>10 μ m	25

A recent inventory of particulate emissions from feedlots located within the basin was conducted by the Air Resources Board (Ref. 2-43). Emissions of 1400 tons (particles <30 μ m) were estimated. Basis for this estimate was the abovementioned study and the California Livestock Statistics Report for 1976. A recent study (Ref. 2-44) on this same subject conducted by the SCAQMD was used as a tool in evaluating the ARB's estimate.

The specific emission factors applied in the ARB estimate are (Ref. 2-39):

Cattle	8 T/1000 hd/yr
Sheep & Hogs	1.25 "
Goats	1.25 "
Turkeys	0.2 "

Emissions totaling 1300 tons (particles <10 μ m) were entered into the final inventory. Feedlot locations, Figure 2-9, were extracted from the California Livestock Statistics Report.

5. Unpaved road travel--Studies (Refs. 2-17,18,45-48) have shown that significant quantities of fugitive dust are emitted during vehicular travel on unpaved roadways. Dust plumes trailing behind vehicles traveling on unpaved roads are a familiar sight in rural areas. When a vehicle travels over an unpaved road, the force of the wheels on the road surface causes pulverization

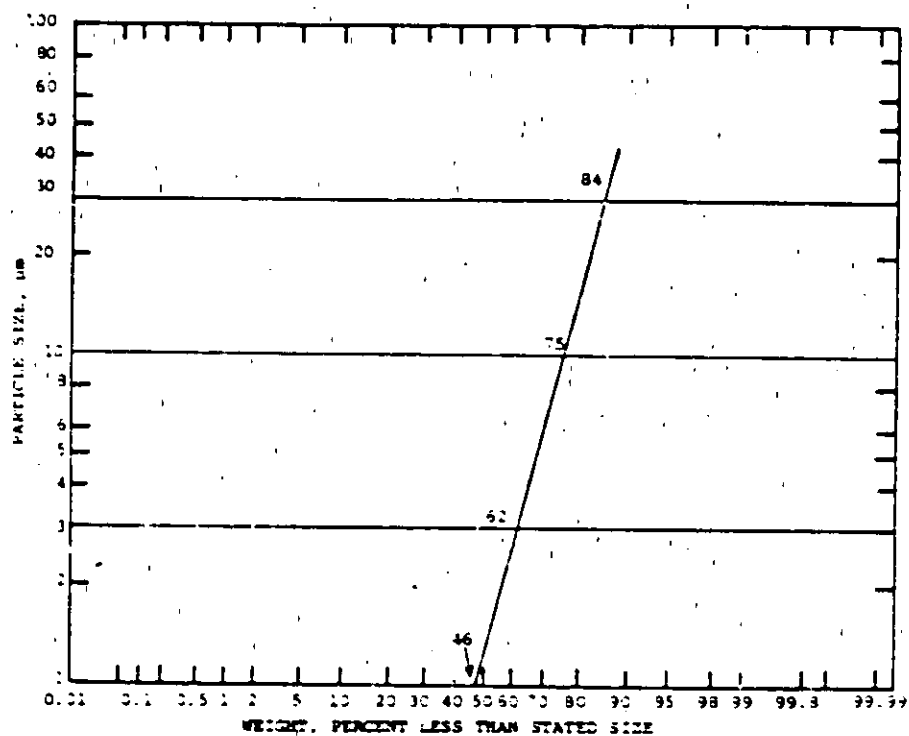


Figure 2-3. Livestock feedlot particle size distribution.

Source: KVB Engineering Analysis of comparable fugitive dust sources.

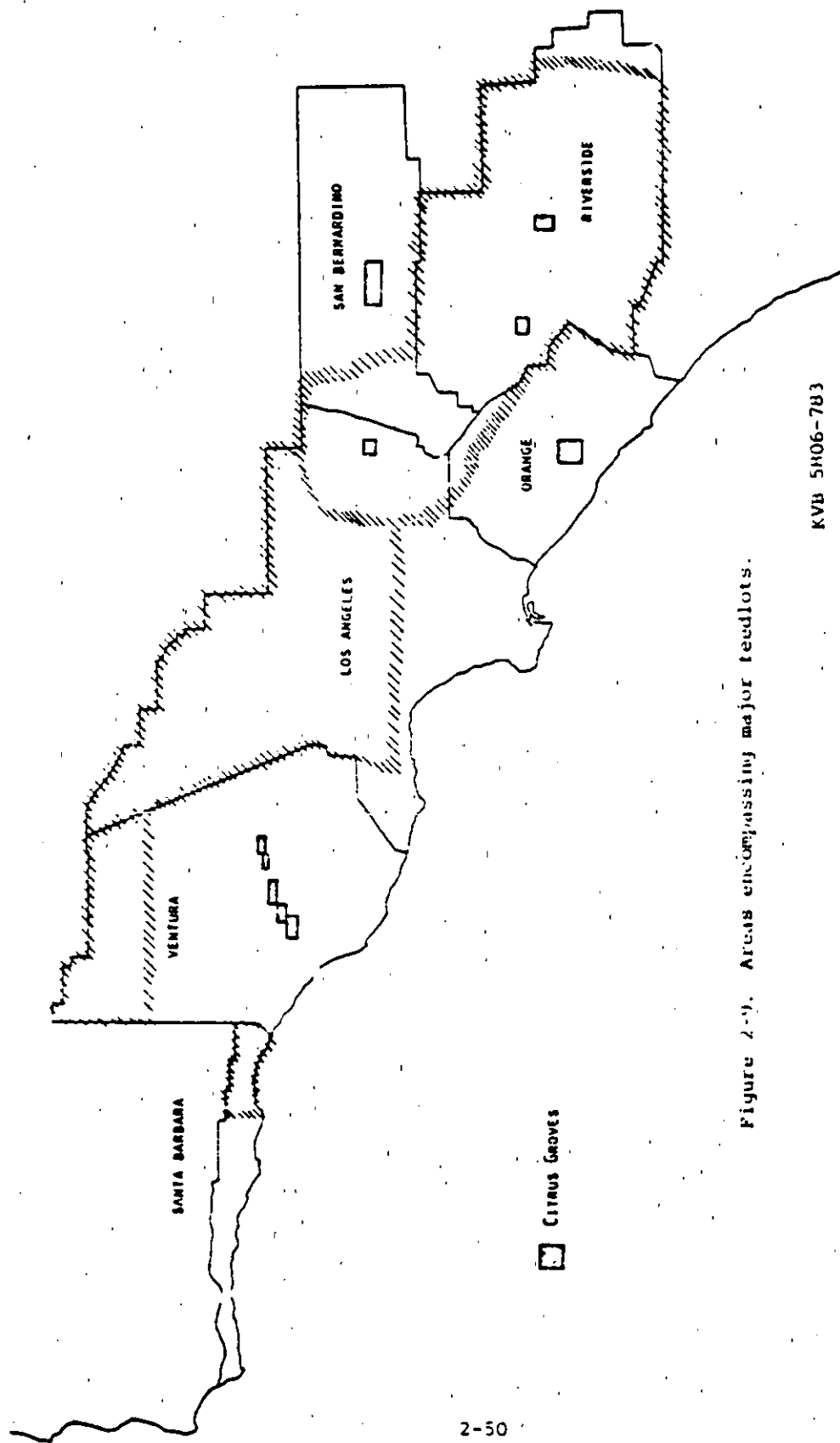


Figure 2-9. Areas encompassing major feedlots.

KVB 5H06-7R3

of the surface material. Particles are lifted and dragged from the rolling wheels while the road surface is exposed to strong air currents in turbulent shear with the surface. The turbulent wake behind the vehicle continues to act on the road surface after the vehicle has passed. The amount of surface fines on an unpaved road is normally close to an equilibrium value. The fines which are injected into the atmosphere by vehicular traffic are replaced in the same process by new fines which are generated by abrasion of surface material. This equilibrium can be upset, however, by a windstorm or other severe phenomenon, and for a time emissions are reduced (Ref. 2-18).

A literature search of existing emission factors for unpaved road travel revealed that no one factor is applicable to all conditions, but that a mathematical expression (Ref. 2-18) encompassing the variables affecting dust generation would give a good approximation within $\pm 20\%$. The equation for estimating the total amount of road dust emissions with drift potential greater than 25 feet is as follows:

$$e \text{ (unpaved roads)} = 0.13s \left(\frac{365 - W}{365} \right) (3s) (C_p)^*$$

where e = emission factor (pounds per vehicle mile)

s = silt content of road surface material (percent);[†]

W = average vehicle speed (miles per hour)

(continued next page)

* A recent study of unpaved road emissions, EPA-600/2-78-050, March 1978, recommends an emission factor of:

$$\text{lb/vehicle-mile} = (5.9) \left(\frac{5}{12} \right) \left(\frac{5}{30} \right) \left(\frac{W}{3} \right)^{0.8} \left(\frac{d}{365} \right), d_p < 30 \mu\text{m}$$

where d = number of dry days/year, and W = vehicle weight (tons). For particle diameters $< 30 \mu\text{m}$, C_p above would be 0.61 (Figure 2-13) and the two expressions would be identical, except for the vehicle weight and speed corrections.

† EPA no longer recommends using the silt content of the native top soil unless $s \leq 15\%$; if $s > 15\%$, use 15%.

Se = vehicle speed correction factor⁵ (Ref. 2-20)

30 mph	25% approx. control eff.
20 mph	65% " " "
15 mph	80% " " "

W = mean annual number of days with 0.01 in. or more of rainfall*

C_p = particle size range factor, see Figure 2-10 [e.g. to determine the emission factor for particles less than 10µm, C_p is 0.46 (or 46% from Figure 2-10)].

On the average, dust emissions from unpaved road travel have the following particle size characteristics:

<u>Particle Size</u>	<u>Weight Percent</u>
<1µm	13
1-3µm	12
3-10µm	16
>10µm	54

A summary of the individual road types, miles per hour speed restrictions, and emission rates per county are presented in Table 2-9. Per county inventories of the vehicle miles traveled per year (VMT) per road type were obtained from the Air Resources Board (Ref. 2-49). Table 2-10 presents a summary of the estimated VMT for each county within the study area.

Applying the emission factors presented in Table 2-9 to the inventory in Table 2-10 resulted in a total emissions rate from these sources of approximately 23,000 tons per year. This is equal to approximately 16% of all area sources accounted for in Table 2-4.

⁵ Based on the assumption that "uncontrolled" speed is typically 40 mph. Between 30-50 mph emissions are linearly proportioned to vehicle speed. Below 30 mph, however, emissions appear to be proportioned to the square of the vehicle speed.

* The temporary reduction in emissions because of rainfall is accounted for by neglecting emissions on "wet" days, i.e., days with more than 0.01 inches of rainfall.

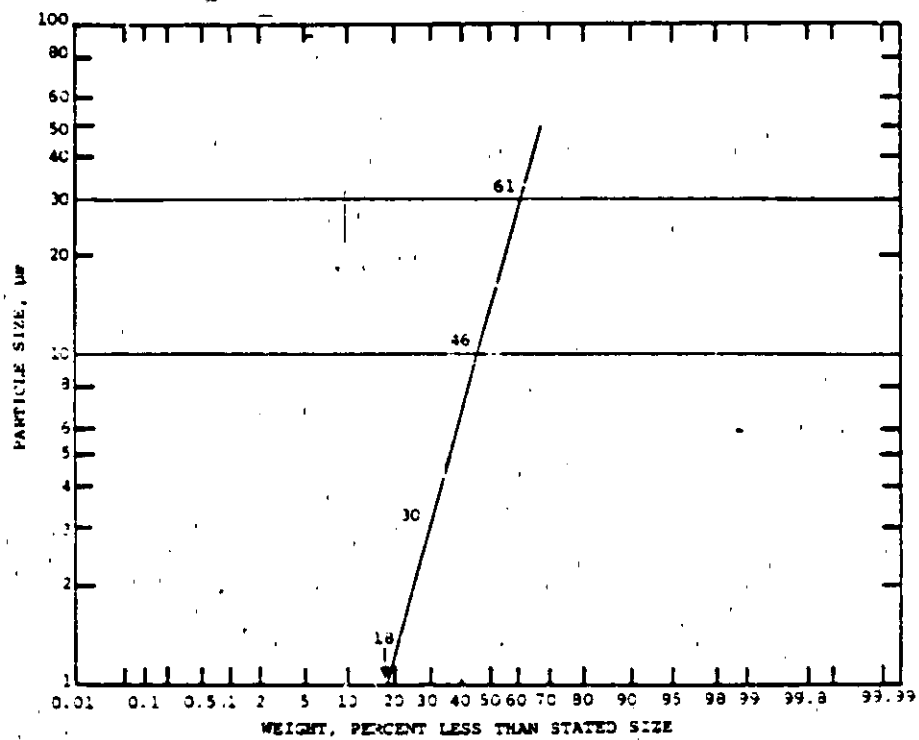


Figure 2-10. Unpaved road dust particle size distribution. Source: Ref. 2-18.

TABLE 2-9. SUMMARY OF UNPAVED ROAD EMISSION FACTORS
PER ROAD LOCATION

County-SCAB	ROAD LOCATION TYPES					
	City & County	U.S. Forest & Parks	Timber Prod.	BLM	Agriculture	W (1)
Orange	3.65 lbs/VMT 30 MPH	1.14 lbs/VMT 20 MPH	--	--	2.23 lbs/VMT 25 MPH	40
Los Angeles	3.65 lbs/VMT 30 MPH	1.14 lbs/VMT 20 MPH	--	--	2.23 lbs/VMT 25 MPH	40
Riverside	3.93 lbs/VMT 30 MPH	1.22 lbs/VMT 20 MPH	--	--	2.40 lbs/VMT 25 MPH	15
San Bernardino	3.93 lbs/VMT 30 MPH	1.22 lbs/VMT 20 MPH	--	--	2.40 lbs/VMT 25 MPH	15
Ventura	3.65 lbs/VMT 30 MPH	1.14 lbs/VMT 20 MPH	0.57 lbs/VMT 20 MPH	6.49 lbs/VMT 40 MPH	2.23 lbs/VMT 25 MPH	40
Santa Barbara	3.65 lbs/VMT 30 MPH	1.14 lbs/VMT 20 MPH	--	--	2.23 lbs/VMT 25 MPH	40

(1) Mean annual number of days with 0.01 in. or more of rainfall.

KVB 5806-783

TABLE 2-10. SUMMARY OF VMT PER UNPAVED ROAD LOCATION IN BASIN¹

County-SCAB	City & County	U.S. Forest & Parks	VMT x 10 ³			Totals	
			Timber Production	BIM	Agriculture	VMT x 10 ³	Emissions T/Yr
Orange	807	651	---	---	159	1600	2,000
Los Angeles	5647	6135	---	---	240	--	14,000
Riverside	555	813	---	---	309	--	2,000
San Bernardino	504	1236	---	---	66	--	1,800
Ventura	142	1983	467	174	497	--	2,600
Santa Barbara ²	60	160	---	---	20	240	230
Total ³							23,000

¹ Source (Ref. 2-49)

² Original VMT estimates for entire county
Assume 5% in SCAB area

³ Carried to two significant figures

KVB 5806-783

6. Particulate emissions from paved roadways--The action of vehicular traffic on a dust laden paved roadway causes some of the material to be emitted into the atmosphere. The larger particles (>100µm) emitted will normally settle out within 20 to 30 feet from the edge of the roadway and, therefore, are not included in the area source emission profile. Particles of less than 100µm diameter will be dispersed depending upon their diameter and extent of atmospheric turbulence.

An equilibrium roadway dust loading will result when a balance is achieved between the material deposition and removal rates. The former rate includes: tire and brake lining wear; pavement wear; atmospheric dust fallout; mud and dust carryout from unpaved areas; vehicle engine particulate emissions; etc. Material is removed from the roadway under the action of: entrainment by tire motion and vehicle-generated turbulence; wind erosion (for wind speeds exceeding 13 mi/hr); rainfall washing; street sweeping; etc.

Measurements of airborne particulates emanating from paved roadways were reported in References 2-113 and 2-114. Both studies addressed dust entrainment from dry streets in the Kansas City area. These data were the basis of the AP-42 recommended emission factor of 0.012 lb/vehicle-mile. However, this single value must be modified to account for dust removal by rain, tire and brake lining emissions, and high-speed, high-volume traffic patterns.

Dust removal by rain was accounted for by assuming that rainfall in excess of 0.01 in./day would completely inhibit particulate emissions of any kind from the roadway. This is the same criterion utilized in the analysis of unpaved roads. Thus, the basic emission factor was modified by a term:

$$\left(\frac{365 - W}{365} \right)$$

where W is the number of days/year with rainfalls exceeding 0.01 in./day.

Reference 2-114 performed microscopic analyses of collected particulate samples and found traces of rubber tire particles. Other sections in this report estimated particulate emissions from tire and brake wear, therefore, these totals were subtracted from the paved road emissions in order to prevent double counting.

The equilibrium dust content on high-speed, high-volume roadways was expected to be less than on residential, commercial or industrial surfaces. This is due to the high traffic volume producing a high removal rate, i.e:

$$\text{Mass rate of removal} = \frac{\text{lb}}{\text{vehicle/mile}} \times \frac{\text{vehicle}}{\text{hour}} = \frac{\text{lb}}{\text{hour-mile}}$$

This removal rate would be partially offset by engine-generated particulates, pavement wear and dirt carryout (directly proportional to traffic volume). However, other deposition sources (background dust fallout, etc.) would be, to a first approximation, independent of traffic volume.

No quantified data was found describing particulate emissions from high-speed, high-volume paved roadways and it was assumed that these conditions would produce one-half the emission factor recommended in AP-42, i.e. 0.006 lb/vehicle-mile, based on the considerations previously discussed.

The particle size distribution from paved roads was taken as the mean of the appropriate tests reported in Ref. 2-113 and is shown in Figure 2-11. This distribution has the following characteristics:

<u>Particle Size</u>	<u>Weight Percent</u>
<1 μ m	13
1-3 μ m	25
3-10 μ m	34
>10 μ m	28

Freeway and highway travel represents 50% of the total vehicle-miles traveled (VMT) in the South Coast Air Basin, according to Ref. 2-115. Total vehicular travel on paved roads in the SCAB, excluding towed trailers, amounts to an estimated 7.2×10^{10} VMT/year (cf. Table 2-15) and, with the emission factors developed, represents a gross particulate emission rate of 330,000 tons/year.

This amount was reduced by those corresponding to tire wear (3400 tons/year) and brake wear (3100 tons/year) in order not to double count these sources. The resultants were further reduced by the average number of rainy days (>0.010 in./day) in the SCAB (32 days/year) to achieve an estimated total particulate emission rate of 290,000 tons/year.

Reference 2-113 produced the particle size distribution shown above which allowed the specification of the total emission rate associated with particles <10 μ m in diameter, i.e. 72% by weight. Thus, the total emissions in

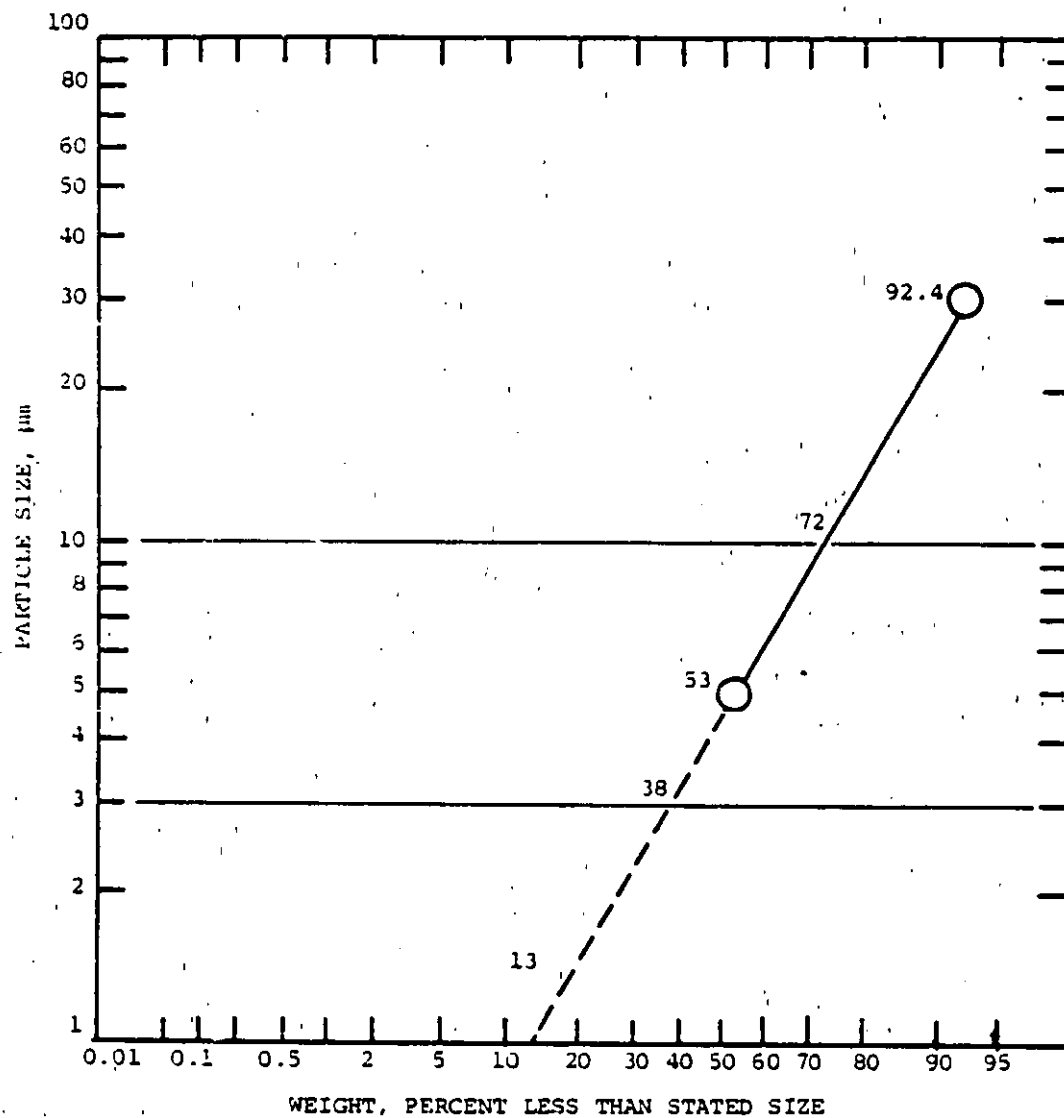


Figure 2-11. Paved road particle size distribution.
(Source: Ref. 2-113).

this size range was 210,000 ton/year (70,000 ton/year from freeways/highways and 140,000 tons/year from surface streets).

Table 2-11 presents the emissions from paved roadways in the SCAB (for data by roadway category and particulate type. These figures must be viewed with caution since, according to AP-42, 40% by weight of samples collected were analyzed to be engine combustion generated particulates. These particles would have been included in a mobile source inventory and it would be incorrect to include them again in a new category--paved road travel.

Vehicular travel on paved roads produces particulate emissions categorized as (AP-42): engine exhaust particles (40% by weight); mineral matter (59% by weight); and biological and tire dust (1% by weight). However, the engine exhaust particles have already been included as a mobile source contribution and, therefore, should not be counted again by this study. Mineral matter emissions result from re-entrainment of background dust depositing on the roadway and from dirt and mud carried out from unpaved areas. Thus, a large percentage of the roadway dust emissions actually originated from an area source not considered in the present work, e.g., wind erosion of open fields, and it would not be correct to attribute them to paved road travel. Tire (and brake) attrition has been separately considered and was not counted again as a paved road dust area source.

Strictly speaking, the only particulate emissions directly attributable to roadway traffic would be pavement degradation, tire and brake lining attrition, and engine combustion particles. The first item was not quantified by this study, while the second has been separately estimated. The last item has already been discussed. Thus, a large, but unknown, fraction of the particulate emission rates shown in Table 2-11 have been considered elsewhere.

B. Combustion--

Fugitive combustion related sources accounted for 13% of the total estimated area source emissions computed in the final 1976 inventory. The area sources and their respective emissions covered under combustion in the final inventory are:

1) Forest Fires	2400 T/yr
2) Structural	200 "
3) Fireplaces	500 "

TABLE 2-11. PAVED ROADWAY PARTICULATE EMISSIONS IN SCAB*
 $d < 10 \mu\text{m}$, 32 rainy days/year

Roadway Category	Particulate Type, Tons/Year		Total, Tons/Year
	Exhaust	Mineral	
Freeway/Highway	28,000	42,000	70,000
Surface Street	56,000	84,000	140,000
	84,000	126,000	210,000

Note: Particulate emissions from tire and brake wear were separately estimated.

- See text.

4) Residential natural gas consumption	100 "
5) Cigarettes	300 "
6) Agricultural burning	<u>500 "</u>
TOTAL	4500 T/yr

1. Forest fires--Forest fires consumed over 23,000 acres of forest and privately owned lands within the SCAB in 1976. An estimated 370,000 tons of combustible material (fuel) was consumed in the process shown in Table 2-12.

The most apparent atmospheric contaminant from forest burning is particulate emissions. The size and intensity (or even the occurrence) of a wildfire is directly dependent on such variables as the local meteorological conditions, the species of trees and their moisture content, and the weight of consumable fuel per acre (fuel loading). Once a fire begins, the dry combustible material (usually small undergrowth and forest floor litter) is consumed first, and if the energy release is large and of sufficient duration, the drying of green, live material occurs with subsequent burning of this material, as well as the larger dry material. Under proper environmental and fuel conditions, this process may initiate a chain reaction that results in a widespread conflagration.

The complete combustion of a forest fuel requires a heat flux (temperature gradient), an adequate oxygen supply, and sufficient burning time. The size and quantity of forest fuels, the meteorological conditions, and the topographic features interact to modify and change the burning behavior as the fire spreads; thus, a wildfire will attain different degrees of combustion during its lifetime (Ref. 2-50).

Knowledge of the chemical nature of forest fuels, combined with what is known about pyrolysis and combustion, suggests that particulates formed by forest fires will consist primarily of a complex mixture of soot, tars, and volatile organic substances. The majority of particles found in fire smoke are formed from the gaseous organic compounds produced by pyrolysis and combustion. The processes of nucleation, condensation, and coagulation combine in a continuous chain of rapid events to form both liquid and solid particulates ranging upwards in size from about 0.002 microns. Particles are also formed by the mechanical tearing action of turbulent forces present in the fires zone (Ref. 2-51).

Research on forest fire emissions conducted by the USDA Forest Service Southeastern Forest Experimental Station (Ref. 2-51) concluded that:

TABLE 2-12. FOREST ACREAGE, FUEL ESTIMATES, AND EMISSIONS

<u>County-SCAB</u>	<u>Acres</u>	<u>Tons Consumed</u>	<u>Emissions, Tons/Yr</u>
Orange	2800	16,000	120
Los Angeles	3400	85,000	700
Riverside	5100	78,000	600
San Bernardino	1800	52,000	430
Ventura	9800	68,000	530
Santa Barbara	<u>430</u>	<u>6,900</u>	<u>50</u>
TOTAL	23,330	368,000	2,400

- 1) The median diameter of particles in forest fire smoke is approximately 0.2 micron, i.e. 50% of the particulate weight occurs at this size.
- 2) Approximately 80% of the mass of all particulates is below 1 micron (see Figure 2-12)
- 3) Regardless of fuel type, average particle size remains essentially constant.*

A high level of confidence in these indications was reached by the Southeastern Forest Service when coupled with the results of other investigations. However, these conclusions apply mainly to forest acreage located in the Southeastern portion of the United States. Although differences in fuel type do exist between Southern California forests and forests of the southeastern part of the United States, the effects of these differences on particulate size and mass loading are not known at this time. Impactor studies performed by the Pacific Northwest Forest and Range Experiment Station (Ref. 2-52) on the burning of Douglas fir[†] under laboratory conditions revealed that 92% of the particulate mass was <1µm aerodynamic diameter and that 69% was <0.3µm. As can be seen in Figure 2-12 these values do not differ significantly from those measured by the Southeastern Forest Service. Therefore, until further studies concerning SCAB forest fire characteristics are conducted, it is assumed that the characteristics of SCAB forest fires do not differ significantly from those characteristics observed by the Southeastern Forest Service.

The emission rate of particulates depends heavily upon the fire type and fuel moisture content, and, to a lesser extent, upon fuel type and arrangement. Heading fires generally produce about three times more particulates than backing fires, everything else being equal. Also, for a given fire, emission rates during the smoldering phase can be eight times higher than in the flaring phase (Ref. 2-51).

Studies (Refs. 2-50,54) have estimated that from 16-17 pounds of particulate matter are released per ton of fuel burned. The acreage of forest and privately owned lands burned in 1976 and their associated fuel loading values were obtained from National Forest Services (Ref. 2-55,56) and the Air Resources Board (Ref. 2-57). The acres burned, material consumed, and estimated emissions are presented in Table 2-12. Figure 2-13 presents the location of the major forest acreage in the South Coast Air Basin.

*Location of four fuel types tested are: Deridder, LA; New Born, NC; Ft. Lauderdale, FL; Round Oak, GA.

[†]Douglas fir comprises approx. 10% of the total SCAB forest acreage and ~26% of the forest acreage occupied by trees (Ref. 2-53).

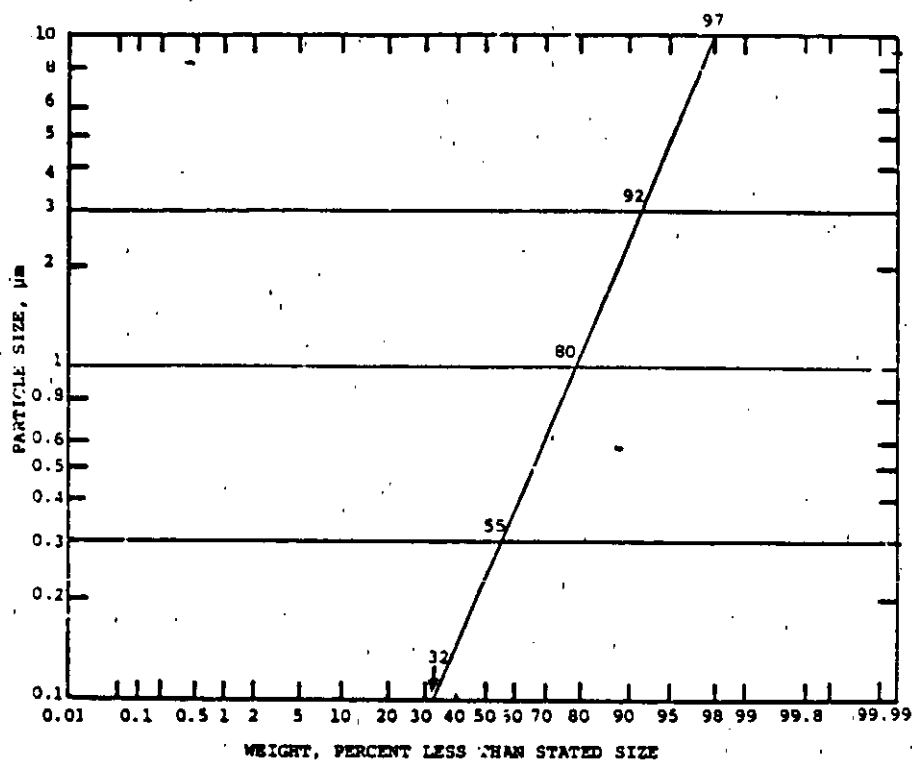


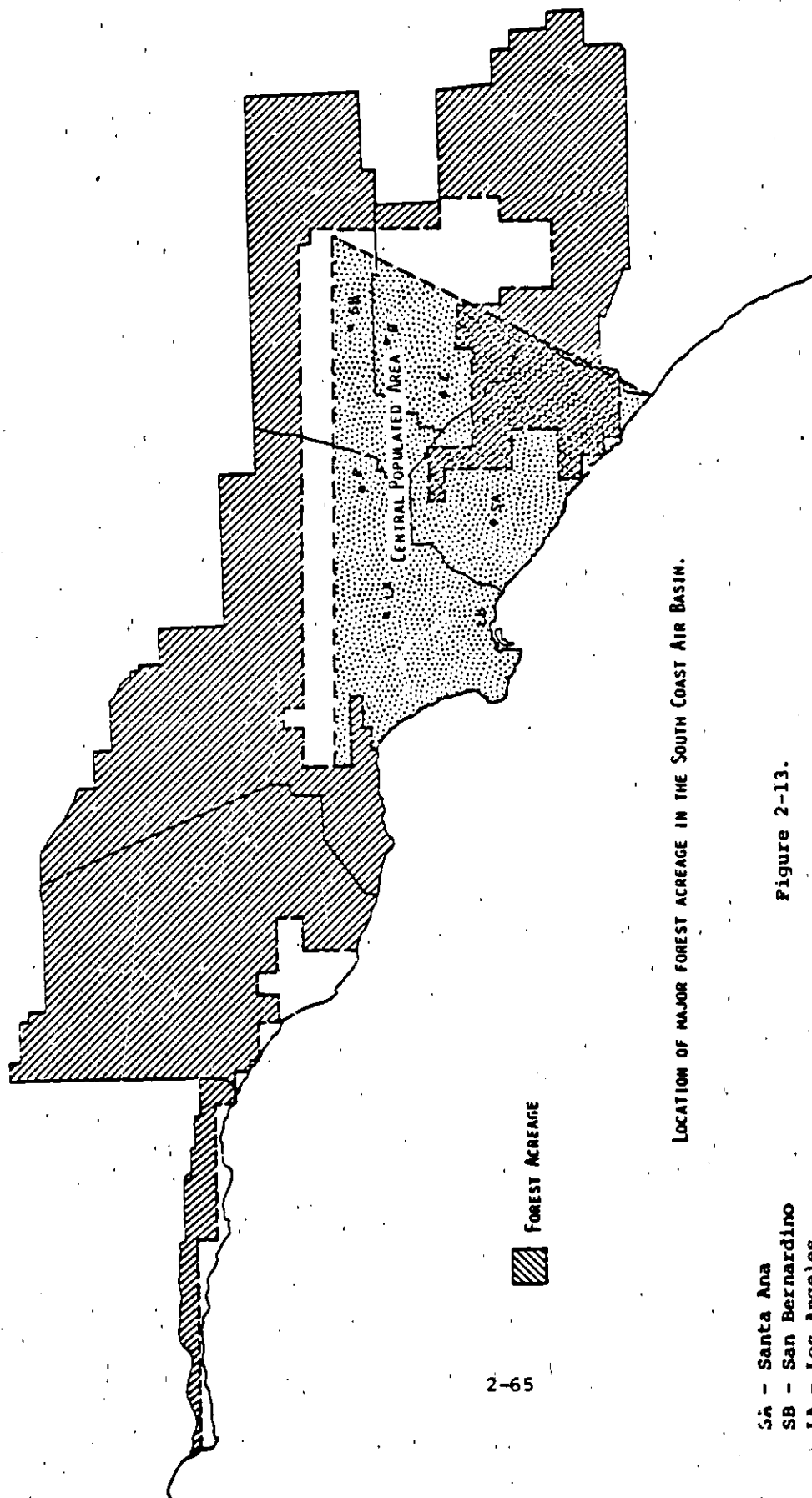
Figure 2-12. Forest fire particle size distribution.

Source: Ref. 2-51

Average of four fuel types
from locations at:

- a) Derrider, LA
- b) New Born, NC
- c) Ft. Lauderdale, FL
- d) Round Oak, GA

Note: Particle sizing data on fuel types native to
Southern California not available; assume
differences at this time to be negligible.



- SA - Santa Ana
- SB - San Bernardino
- LA - Los Angeles
- LB - Long Beach
- P - Pomona
- R - Riverside
- C - Corona

Figure 2-13.

KVB 5806-783

2. Structural fire--A recent study (Refs. 2-53, 59) conducted by the ARB and SCAQMD was employed in estimating the quantity of particulate matter emitted to the atmosphere during a structural or vehicular fire. Emissions of 500 tons/yr or 0.24 tons/yr per 10,000 people were reported for the entire state of California. The SCAB estimate of 500 tons per year was derived by multiplying the 0.24 tons per 10,000 people per year by the 1976 SCAB population (Ref. 2-60).

The approach taken in the above mentioned study was:

- 1) Using CFIR Reports (Ref. 2-61), establish a monetary value of property, contents, and vehicle loss due to fire in 1976.
- 2) Establish the monetary value equivalent to the combustion of one house, car, and contents.
- 3) Establish fuel loading factors per category.
- 4) Compute emission factors using AP-42 as a guide.
- 5) Convert the derived emission rate into a population based emission factor to better distribute the calculated emissions.

Table 2-13 presents the above discussed approach, values assigned and emission estimates. Due to the diversity of material consumed within a structural fire, a particle size distribution plot was not available. It was assumed to be similar to the particle size distribution for forest fires.

3. Fireplaces--As shown in Table 2-4, approximately 500 tons of particulate matter (particle <10µm) were estimated to be emanating from the combustion of firewood in residential fireplaces.

A study (Ref. 2-62) conducted on fireplace emissions for the EPA estimated the total average particulate mass emission rate to be 21 pounds per ton wood burned.* Differences in emissions existing between the wood burned in the SCAB (mainly pine, orange and eucalyptus) and of that burned in the above mentioned study (alder, fir, locust, and pine) are assumed to be negligible for this study. A literature search failed to disclose any other applicable data.

* Average soft wood moisture content 12.5% by wt.
Average soft wood density 0.43 g/cc
One cord of wood contains 90 cf wood (Ref. 2-63)

TABLE 2-13. STRUCTURAL FIRES (a)

Category	Dollar Value lost - 1976 (b)	Unit Equivalency Factor	Fuel Loading Factor	Emission Factor	Static Emissions Tons
Property	133,018,066	\$50,000 per house	20 tons wood (c)	340 lbs/house (d)	452
Contents	80,644,958	\$10 per lb.		16 lbs/ton (d)	32
Vehicles	15,906,917	\$5000 per vehicle		8.4 lbs/vehicle (e)	13
Sub-Total					500

2-67

Population based emission factor - $994,000 \text{ lbs particulates} \times \frac{1}{21,224,000 \text{ people}} = 0.047 \text{ lbs/person}$
('76 state pop)

SCAB Emissions: $0.047 \text{ lbs/person} \times 10,334,520 \text{ people} \times \frac{\text{Ton}}{2000 \text{ lbs}} = 240 \text{ tons}$

- (a) Source (Refs. 2-37, 38)
- (b) Ref. 2-61
- (c) Ref. 2-64
- (d) Ref. 2-65
- (e) Ref. 2-66

KVB 5806-783

Particle sizing data from the above mentioned study is presented in Figure 2-14. Since soft woods are mainly burned in the SCAB, only soft wood particle sizing data was considered. On the average, particulate emissions from residential fireplaces have the following particle size characteristics.

<u>Particle Size</u>	<u>Weight Percent</u>
<1 μ m	36
1-3 μ m	12
3-10 μ m	14
>10 μ m	38

The median particle size was found to be about 3 microns; 66.3% of the particulate was condensibles caught in the back half of the sampling train.

In establishing an inventory of active wood burning residential fireplaces in the SCAB, local government agencies were contacted as to the number of existing fireplaces. It was soon discovered that such information per se was not available. A second approach of obtaining information on the number of single family and/or dwelling units in a county was taken. County assessor's offices (Refs. 2-67 to 2-70) were contacted.

To this inventory, two assumptions were made due to the lack of available data to characterize the fireplace units located within the inventory:

1. Ten percent of all reported existing dwelling units possess and use their wood burning fireplaces annually
2. Each dwelling unit included in the 10% estimate burns 1/4 cord of wood per burning season.

A census of KVB personnel and their fireplace burning habits was solicited in arriving at the 10% estimate.

An emission factor of 0.45 tons per 10,000 people was entered into the final inventory. A population based emission factor was chosen to best reflect the location of the emissions.

4. Residential natural gas combustion--The Southern California Gas Company (SCGC) (Ref. 2-71) reported that 286 billion cubic feet of natural gas was sold to its residential customers in 1976. The population served was

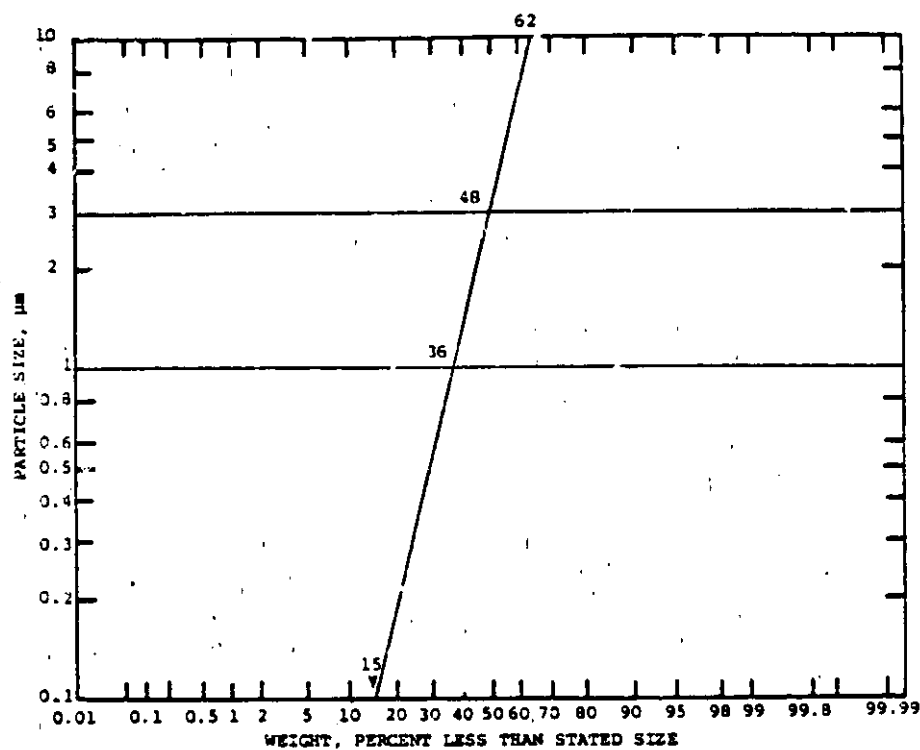


Figure 2-14. Residential fireplace emissions particle size distribution; soft woods.

Source: Ref. 2-62.

approximately 11,300,000 people excluding the city of Long Beach. The SCAB population in 1976 was approximately 10,300,000 people (Ref. 2-60). Realizing that the bulk of its customers do reside in the Basin, the entire 286 billion cubic feet was applied to the SCAB. Also, according to a SCGC fact sheet (Ref. 2-72), space heating accounted for 65% and water heating 21% of the average household appliance operating costs per year on a comparative cost basis.

Studies (Refs. 2-73-74) conducted on natural gas-fired warm air heating systems concluded emission factors of $0.00084 \text{ lb}/10^6 \text{ Btu}$ and $0.00071 \text{ lb}/10^6 \text{ Btu}$ for front half catches only. Back half results were not available. Particle size was considered to be 100% less than 1 micron (Ref. 2-74). The $0.00084 \text{ lb}/10^6 \text{ Btu}$ value was selected to represent emissions from warm air heating units typical of the study area since this study was based on tests run in the Los Angeles area and the other study was not. Gas-fired hot water or steam systems were also found to be similar to warm air heating systems and use the same type of burner. Based on this finding, emissions from water heaters and residential steam heating systems are assumed to be similar to those from warm air heating systems.

Based on the above inventory and emission factors, 100 tons per year of particulate matter was estimated to be emanating from residential natural gas combustion in the Basin. An emission factor of 0.13 tons per 10,000 people/year was entered into the final inventory. A population based emission factor was judged to reflect the location of the dwelling units using natural gas. The Southern California Gas Company estimates that greater than 95% of the single family dwelling units it serves use natural gas for space heating.

Although some correction factor greater than one should have been applied to this emission factor to account for the impinger catch, it was ignored because the basic emission of 100 T/yr is so small that it would not be cost-effective to develop a correction factor.

5. Cigarette smoke--It was estimated that approximately 800 tons per year of particulate matter was generated by the combustion of approximately 30 billion cigarettes in the Basin. Nationwide, 610 billion cigarettes (Ref. 2-75) were consumed by an estimated 150 million adult (over 18) Americans (Ref. 2-76) in 1976. Based on these 1976 statistics, it was estimated that 4100 ciga-

rettes were consumed per adult. Applying this factor to the reported 7.4 million adults (Ref. 2-76) residing in the SCAB in 1976, it was estimated that 30 billion cigarettes were consumed in 1976.

A past study (Refs. 2-77, 73) experimentally determined that 1000 cigarettes without filters produced 1.0 pound of smoke--gaseous and particulate matter. Measurements were not made on the quantity of smoke that was contributed by sidestream smoke, however. Sidestream smoke is defined as that smoke which emanates from the burning tip of a cigarette and goes directly into the atmosphere. Researchers (Ref. 2-79) have calculated that even when a smoker inhales, two-thirds of the smoke from a burning cigarette still goes into the environment.

Various studies (Refs. 2-80, 81) done on smoking have classified sidestream smoke as consisting of 90% gaseous and 10% particulate matter. Sidestream smoke has 3.3 times the particulate matter contained in exhaled smoke. A smoker's lungs act as a very effective filtering agent and remove nearly all of the particulate matter in mainstream smoke (Ref. 2-82). Mainstream particulates being exhaled were therefore considered negligible.

The conclusion from the above information and from personal observation is that approximately 50% of the one pound of smoke/1000 cigarettes is sidestream smoke. Ten percent of this sidestream smoke was assumed to be particulate matter. Particle sizing data were not available, but it is assumed that all particles being emitted are <10 microns in diameter.

A particulate emission factor of 0.05 lb per 1000 cigarettes smoked was calculated. This accounts for approximately 2.5% of the total weight of 1000 cigarettes without filters. A number of filterless cigarettes were weighed in KVB's lab to arrive at an average cigarette, without filter weight of 0.9 grams.

Based on the above information, an emission factor for the final inventory was developed as follows:

$$\begin{aligned} & \frac{1.0 \text{ lb smoke}}{1000 \text{ cigarettes}} \times \frac{0.5 \text{ lb sidestream smoke}}{1.0 \text{ lb smoke}} \times \frac{0.1 \text{ lb particulates}}{\text{lb of sidestream smoke}} \\ & \times \frac{4100 \text{ cigarettes}}{\text{adult}} \times \frac{3 \text{ adults}}{4 \text{ persons}} \times \frac{\text{ton}}{2000 \text{ lb}} = \frac{0.00008 \text{ ton}}{\text{person}} \text{ or } \frac{0.08 \text{ ton}}{10,000 \text{ persons}} \\ & \times 10,000 \text{ persons in the SCAB} = 800 \text{ tons/yr} \end{aligned}$$

6. Agricultural burning--The particulate emissions from the burning of agricultural wastes in California have been recognized for several years (Ref. 2-83). The ARB and the EPA have sponsored several studies (Refs. 2-84, 85, 86) with the intent of developing emission factors for such operations.

The ARB and local districts have also implemented regulations that severely restrict the open burning of waste materials. Existing regulations (Ref. 2-87) require burn permits to be issued by local government control agencies prior to the burning of farm wastes, burns conducted for range improvement, forest management, and pest control or the improvement of wild life or game habitats. Such burns could only be conducted during "permissive burn" days as determined by local meteorological conditions. Burn permits recorded the location and quantity of material to be burned. Extensive studies (Ref. 2-84) on emissions from burning agricultural wastes in California were conducted by Dr. Ellis Darley. Some of the pertinent conclusions reached were:

- 1) As a class, field crops and weeds produce considerably more pollutants (Part., CO, HC) than did orchard and vine crops.
- 2) Back firing field crops resulted in lower emissions of particulates but not CO and HC when compared with head firing. The use of back fires significantly reduces particle size, the averages being 0.11 and 0.22 microns, respectively.
- 3) For all fuels (crops) except avocado, it appears that drying down to at least 35% moisture would minimize particulate emissions.
- 4) The vast majority of particles from burning agricultural waste are submicron in size. The mass median diameter (MMD) of most particles is below 0.3 microns. Orchard fuels tend to yield smaller particles than do field crop fuels. The particle size distribution can be altered by manipulating the firing practice. Examples of Darley's size distribution plots for various crops are shown in Figures 2-15 to 2-19.
- 5) The average emissions of all plant material tested at the indicated average fuel moisture (dry weight basis) is shown on page 2-78 as follows:

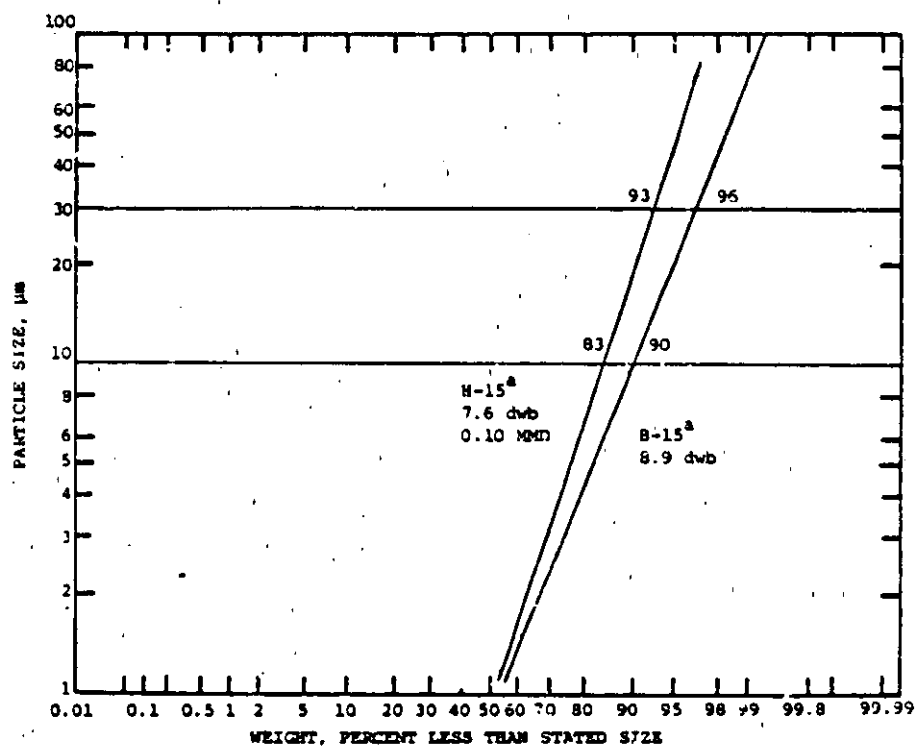


Figure 2-15. Wheat waste burning size distribution.

^a H and B: head and back fires, respectively; 15 or 25 refers to percent of slope used.

dwb: dry weight basis

MMD: Mass Median Diameters, microns.

Source: Ref. 2-84

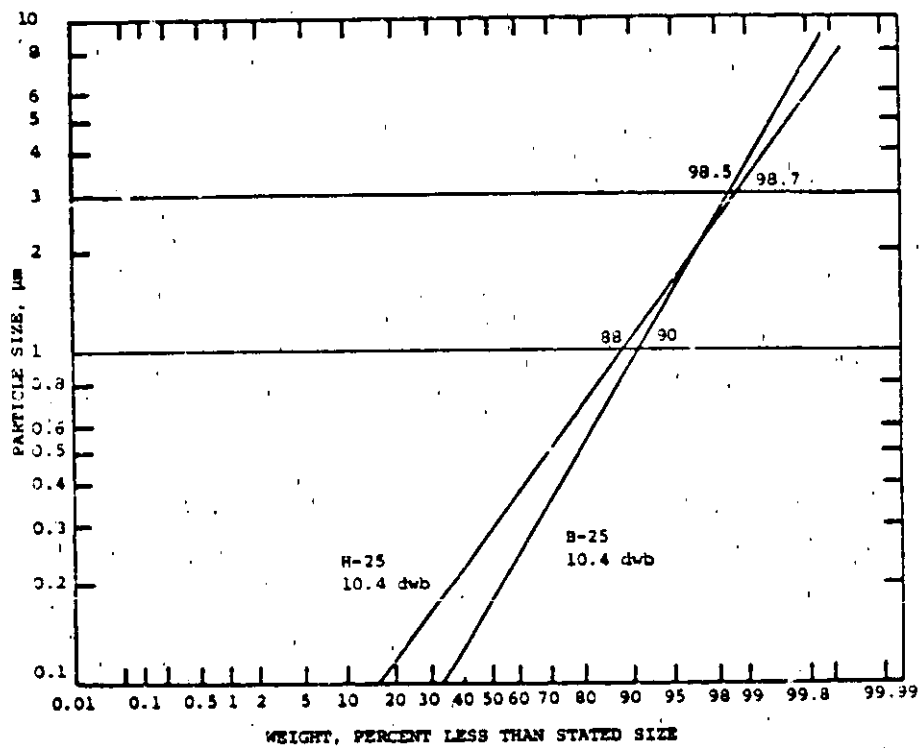


Figure 2-16. Alfalfa waste burning particle size distribution.

Source: Ref. 2-84

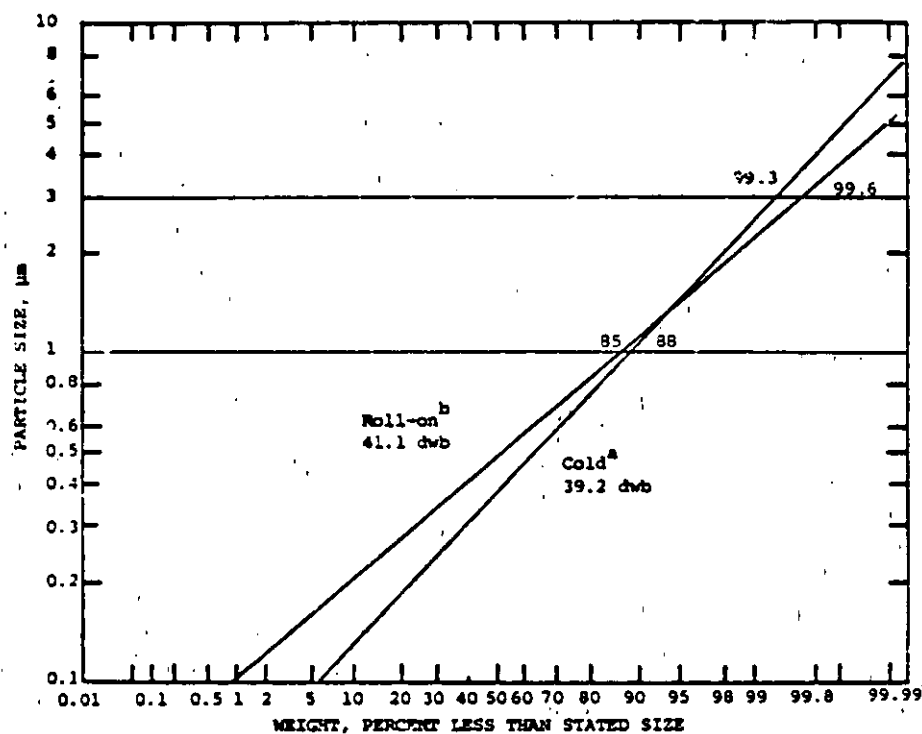


Figure 2-17. Apricot waste burning particle size distribution.

- ^a Fuel was ignited at the bottom of the pile with a large propane torch without the aid of hot coals or pre-existing fire.
- ^b Fuel was ignited by rolling the pile onto the glowing embers of a pre-existing fire.

Source: Ref. 2-84

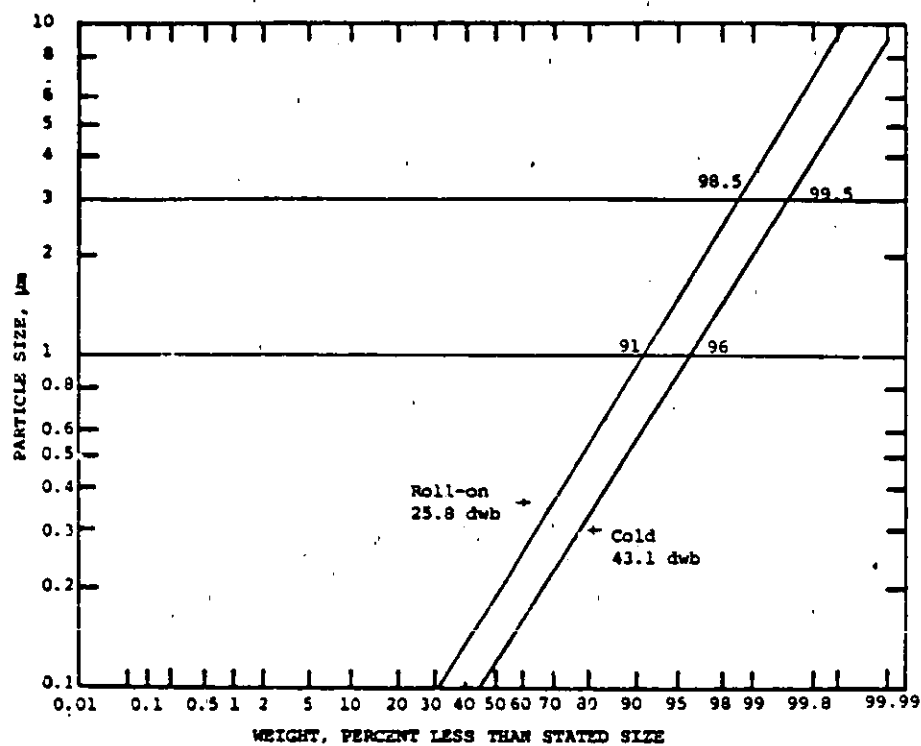


Figure 2-18. Peach waste burning particle size distribution.

Source: Ref. 2-84

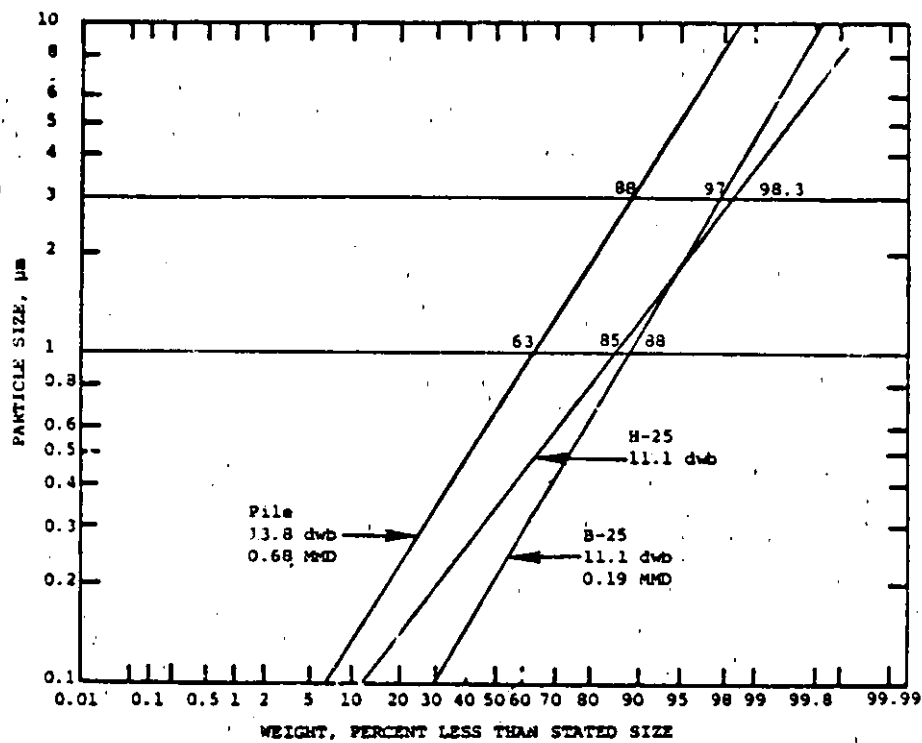


Figure 2-19. Ditch bank weed burning particle size distribution.

Source: Ref. 2-84

	<u>Avg. Fuel Moisture (dry wt basis)</u>	<u>Avg. Part. Emissions lbs/ton Fuel Burned</u>
Field Crops (incl. weeds)	12.3	18.3
Orchard Crops (incl. vines)	40.3 (Test Cond. 1)	8.7
	23.7 (Test Cond. 2)	5.4

A detailed summary of emission factor ranges per crop type is presented in Table 2-14. The factor range selected is based on the assumption that burning would be conducted under those conditions where lower emissions could be expected.

Annual reports by the ARB were issued with estimates of the air pollution impact of these burns utilizing this inventory and the emissions factors referred to above. It was estimated by the ARB that 500 tons of particulate matter were emitted in the SCAB due to agricultural burning in 1976 (Ref. 2-88). These emissions were distributed into the agricultural regions as shown in Figure 2-6.

C. Automotive--

Only two areas of automotive type particulate emissions were considered in the final 1976 inventory. The areas considered and their respective emissions are: tire tread attrition--8400 tons, and brake lining attrition--3100 tons. Combined, they accounted for approximately 8% of the total 140,000 tons of particulate matter attributed to area sources.

1. Tire tread attrition--Every year, U.S. motorists wear off nearly 1.1 million tons of tire tread through the driving of a reported 63 trillion miles (Refs. 2-89,90). Tires provide the sole contact between the vehicle and the roadway surface and must transmit the interactive forces required for propulsion and control. In doing this, tire tread material is worn away by a variety of processes. Many of the factors affecting tread wear are presented in Figure 2-20.

Two schools of thought among scientists exist on the fundamental mechanisms of wear. The first mechanism, called "thermal activated molecular stick slip," results from the extreme heat developed due to the relative motion of the tire at the road surface which breaks down the chemical composition of the rubber causing a loss at the surface of a certain number of molecules. The second mechanism is based on abrasion between the tire and the

TABLE 2-14. AGRICULTURAL WASTE BURNING EMISSION FACTORS

<u>Particulates, lb/ton of Fuel Burned</u>				
<u><5</u>	<u>5-10</u>	<u>10-15</u>	<u>10-20</u>	<u>>20</u>
<u>Field and Weeds</u>				
tule	barley cotton rice mixed weeds	bean corn peas sorghum wheat ditch bank weeds	hay safflower	alfalfa asparagus oats
<u>Orchard and vines</u>				
apple apricot boysen- berry grape nectarine prune	almond cherry date fig peach pear walnut	olive	avocado	

Source: Ref. 2-84

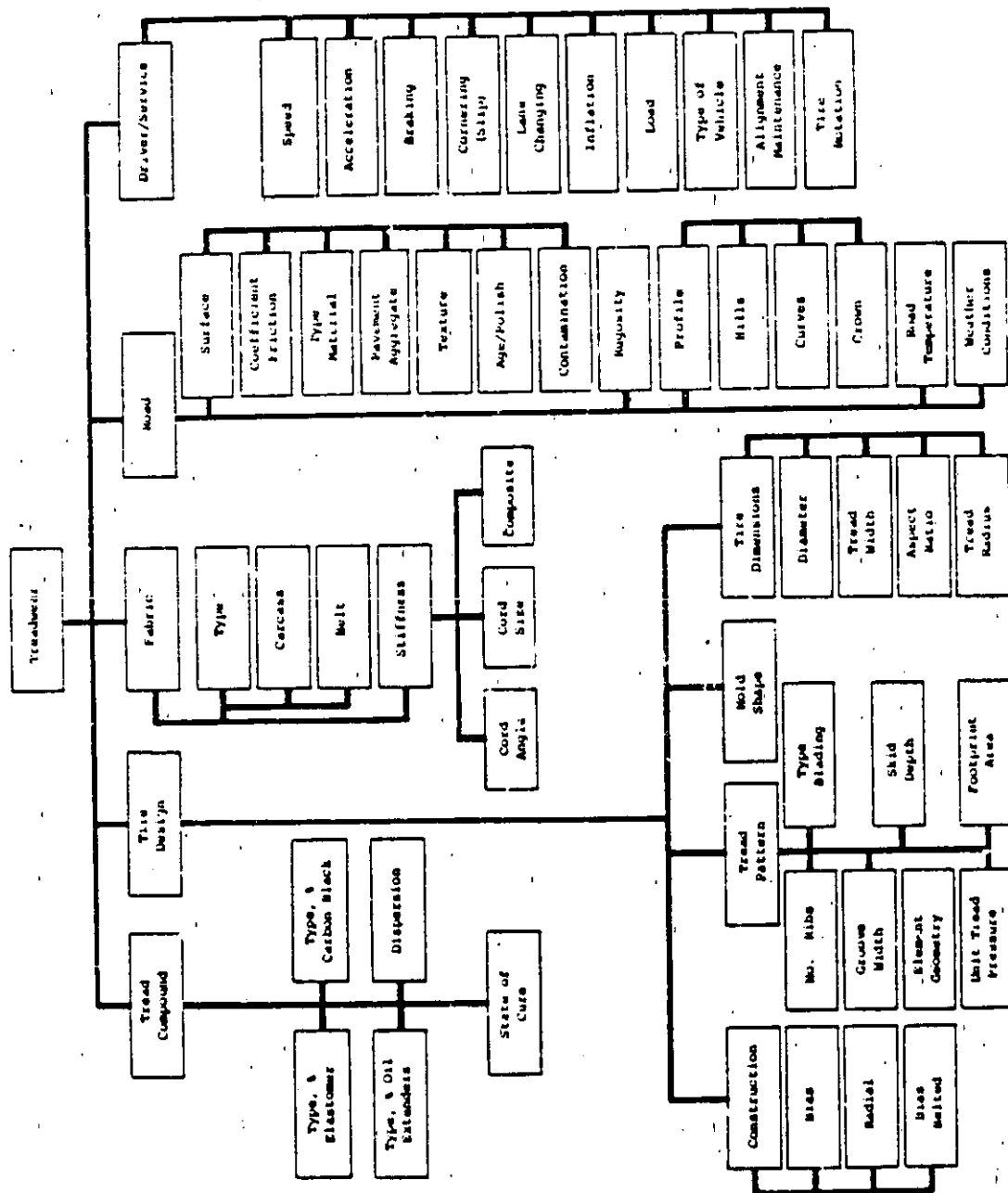


Figure 2-20. Factors affecting tread wear. Source: Ref. 2-91.

road surface causing mechanical removal of small rubber pieces. A combination of these factors is likely to occur under normal driving conditions.

Numerous studies (Refs. 2-89,92-96) have been conducted to characterize tire tread emissions as to mass loss, particle size, and gaseous emissions. The two most significant studies involving dynamometer and actual road driving tests cited are ones conducted by General Motors (Refs. 2-95,96) and by J. P. Subramani, Ph.D. thesis, University of Cincinnati (Ref. 2-94).

General Motors estimates a tire wear rate of 0.048 g/tire-mile for travel on the San Gabriel Freeway. Eighty percent or 0.038 g/tire-mile was estimated to settle out within a few meters of the road's edge. Tests conducted for rubber content on roadside soil and dust samples proved this to be true. The remaining 20% is believed to consist of gaseous and airborne (<7 micron) particles. This line of reasoning falls into line with General Motors (Ref. 2-96) overall tire tread wear conclusion that the emission rate of gases and airborne particulate matter is nearly independent of wear rate and accounts for only 1-20% of the total emissions.

Particle sizing data taken on GM dynamometer tests concluded that 24% of the airborne mass under dynamic sampling conditions was composed of particles <0.43 microns and that tires emit particles into basically two size fractions, large particles >7 microns and small particles <0.4 microns.

In the J.P. Subramani thesis project, actual road wear rates as well as dynamometer wear rates were measured. To establish an actual road wear rate, 43 cars were driven under winter and summer conditions in the City of Cincinnati. Wear rates of 0.146 g/tire mile and 0.0873 g/tire-mile respectively were measured.

Dynamometer tests involving two automobiles reported wear rates of 0.05 g/tire-mile and 0.0431 g/tire-mile. Further testing to correlate dynamometer and road tests was advised.

Particle sizing data was obtained during the dynamometer tests. Particle measurements were made in three sizes of fractions: >10 micron, <2 microns, and those caught in a millipore filter. Conclusions drawn were

that 50% by weight of the particles were in the >10 micron size fraction, with the remainder consisting of particles $\leq$ 2 micron in size. This conclusion is similar in size classification to that of General Motors.

Based on the foregoing discussion, an automobile tire wear rate of 0.070 g/tire mile was derived. Of this, 30%, or 0.021 g/tire mile was estimated to consist of particles <10 microns in size, 5-10% wt. to be gaseous, and the remaining 60% to consist of primarily sedimentary type particles-- particles which settle out within a few meters of the road's edge.

The basis for the 0.070 g/tire-mile was the fact that Southern Californians do a lot of freeway as well as city type driving. An average value composed of General Motor's freeway estimate of 0.048 g/tire-mile and J. P. Subramani's city summer estimate of 0.087 g/tire-mile was therefore concluded to be applicable to Southern California. The particle size distribution was derived through the averaging of the dynamometer test results conducted by J. P. Subramani and General Motors.

Taking into account the semi-quantitative particle size distribution expressed by General Motors and Subramani, the following particle size distribution for the non-gaseous factor of worn tire tread was prepared for use on this inventory.

Particle size:	>10 μ m	10-3 μ m	3-1 μ m	<1 μ m
Percent:	60	5	15	20

Tire attrition rates of 0.203 g/tire-mile and 0.161 g/tire-mile for medium (5,000-10,000 lb curb wt.) and heavy duty (>10,000 lb curb wt.) vehicles, respectively, were also calculated. Differences existing in wear rates and total tread loss (Ref. 2-97) are the criteria for the above wear rates. The particle size distribution is assumed to be similar to that of automobile tires.

Once vehicular tire wear rates were established a vehicle inventory for 1976 needed to be developed. Information from a recent 1976 vehicle inventory for the SCAR, developed by the SCAQMD (Ref. 2-97), and an ARB document entitled "Data Base & Documentation for Estimating Emissions from Motor Vehicles in California" (Ref. 2-98) was solicited for this purpose. Vehicles were grouped into basically three weight groups:

- 1) Automobile and commercial two axle; <5000 lb curb wt.
- 2) Medium duty; 5,000-10,000 lb curb wt.
- 3) Heavy duty; >10,000 lb curb wt.

In addition, annual mileage estimates were assigned to each class based on the above mentioned sources. Table 2-15 presents the results of the foregoing discussion. Emissions totaling 28,000 tons were estimated. Of this, 8100 tons are estimated to consist of particles <10 microns in size with a majority in the respirable size range. Also, infrared and pyrolysis analysis of airborne particulates indicated that the airborne particulate is not simply composed of small pieces of rubber, but that some of the particulate is degraded polymer and/or extender oil (Ref. 2-95).

That portion of the total particulate loss labeled as sedimentary is believed to settle out within a few meters of the roadway's edge. Tests (Ref. 2-95) conducted along a stretch of the San Gabriel Freeway proved this to be partially true.

Roadway tread rubber removal mechanisms such as chemical degradation, and to a lesser extent in Southern California, rain runoff, were also cited. Information on particle re-entrainment which is probably significant was not available, however.

2. Brake lining attrition--Brake lining attrition from vehicles operating within the SCAB in 1976 accounted for an estimated 3100 tons of asbestos material. A literature search for information on emissions from brake lining attrition failed to disclose any information on the subject. The Environmental Protection Agency is planning to conduct research into this area in the future, however.

The approach taken in establishing an emissions estimate was one of coupling a vehicle brake lining attrition factor to a vehicle annual mileage estimate. Information from a recent SCAQMD inventory (Ref. 2-97) on brake lining emissions was solicited for the purpose of developing an attrition factor. Discussions with brake lining manufacturers and actual physical measurements by SCAQMD were made to determine the quantity of lining material available per brake shoe, per weight class and average lining life. Basic assumptions made were:

TABLE 2-15. SUMMARY OF TIRE ATTRITION EMISSIONS

	Estimated Annual Mileage	No. of Tires	Vehicles in SCAB	Total Attrition	Airborne μm of	Emissions tons/yr	
						Total	Airborne
Light Duty Vehicles							
Automobiles	12,000	4	4,950,064	0.040 ^a	0.034	18,317	5,495
Com 1 2 axle <5000# curb wt.	12,000	4	813,041			3,009	903
Trailer 1 axle	1,000	2	195,178			30	9
2 axle	1,000	4	36,294			11	3
3 axle	1,000	6	723			5	<1
						21,400	6,400
Medium Duty Vehicles							
Com 1 2 axle >5000-10,000# curb wt.	88,000	6	86,362	0.401 ^b	0.071	680	
3 "	49,100	10	449			50	
Trailer 1 axle	1,500	2	29,199			47	
2 "	44,000	8	28,240			2,456	
3 "	44,000	6	314			19	
4 "	3,500	8	36			<1	
						3,100	940
Heavy Duty Vehicles							
Com 1 2 axle >10,000# curb wt.	88,000	6	22,630	0.161 ^c	0.056	212	
3 "	49,100	10	24,330			2,118	
4 "	8,800	14	343			8	
Trailer 1 axle	7,900	4	1,800			10	
2 "	44,000	8	19,639			1,246	
3 "	7,900	12				3	
4 "	7,900	16				<1	
						3,600	1,100
							9,400

a) Source: KVB Attrition Study
b) Proportional SCAQMD's medium to light emission factors--2.9 correction factor
c) Proportional SCAQMD's heavy to light emission factors -2.3 correction factor

KVB 5806-783

- 1) Density of brake lining material is 150 lbs/ft³
- 2) Brake lining on the average contains 80%wt asbestos material
- 3) 25% of the lining material remains on the shoe or pad

Due to the proprietary nature of brake lining material, accurate information on lining composition was not available. Table 2-16 presents the emission factors calculated per weight class.

In the development of a vehicle inventory, information from an ARB Document on motor vehicle emissions (Ref. 2-98) and a SCAQMD vehicle inventory (Ref. 2-97) were solicited. Results are presented in Table 2-17.

Particle sizing data was not available, but it is assumed that all particles would be less than 10µm

D. Sea Salt Spray--

Presently there is no precise estimate as to the mass of sea salt spray particles emitted into the atmosphere at the surf zone due to wave action. Concentrations of sea salt in ambient air, however, have been measured at several locations in the basin (Refs. 2-99,100). Results from the California Aerosol Characterization Experiment (ACHEX) were used to estimate the sea salt emissions occurring along the SCAB coastline. Two approaches were taken using this information.

The first approach was to use the results from a study (Ref. 2-101) concerned with strategies for approaching and achieving the National Ambient Air Quality Standards for particulates in the Los Angeles Region. Conclusions contained in this report were based on the data contained within the ACHEX study. Sea salt concentrations of 6-10 µg/m³ were measured in the coastal areas, e.g., Lennox, Dominguez Hills. In addition, to arrive at an emissions estimate, the air flow through this region or window needed to be estimated.

The basic assumptions made were:

- 1) Average height of the inversion layer is 2000 ft (0.61 Km)--window height.
- 2) Window length is 190 miles (300 Km), the projected length of coastline in the Basin.

TABLE 2-16. BRAKE LINING ATTRITION EMISSION FACTOR CALCULATIONS

Assumptions: Density of all brake lining material is 150 lbs/c.f.
 brake lining contains 80% wt. asbestos material.
 Attrition consumes 75% of lining material during lining lifetime

Light Duty Vehicles

Automobile & commercial 2 axle; <5,000 lbs. curb wt.

- Without Disc: 1) Average New Lining 6.25 in³/shoe
 2) Average Lining Life 30,000 miles
 3) Brake Shoe per axle 4

Lining expended per axle: $6.25 \text{ in}^3/\text{shoe} \times \frac{4 \text{ shoes}}{\text{axle}} \times \frac{1 \text{ c.f.}}{1728 \text{ in}^3} \times \frac{150 \text{ lbs}}{\text{c.f.}} \times 0.8 \text{ asbestos content}$

$$\times 0.75 \text{ attrition} \times \frac{\text{shoe life}}{30,000 \text{ mi.}} \times \frac{10^6 \text{ mi.}}{10^6} = 43.4 \text{ lbs}/10^6 \text{ VMT}$$

- With Disc: 1) Average New Lining 2.81 in³/pad
 2) Average Lining Life 40,000 miles
 3) Brake pads per axle 4

Lining expended per axle: $2.81 \text{ in}^3/\text{pad} \times \frac{4 \text{ pads}}{\text{axle}} \times \frac{1 \text{ c.f.}}{1728 \text{ in}^3} \times \frac{150 \text{ lbs}}{\text{c.f.}} \times 0.8 \times 0.75$

$$\times \frac{\text{pad life}}{40,000 \text{ mi.}} \times \frac{10^6 \text{ mi.}}{10^6} = 14.6 \text{ lbs}/10^6 \text{ VMT}$$

Source: Ref. 2-97

KVB 5806-783

TABLE 2-16. Continued

Medium Duty Vehicles

Commercial vehicles, 5,000-10,000 lbs. curb wt.

1) Average New Lining	30 in ³ /shoe
2) Average Lining Life	50,000 miles
3) Brake shoes per axle	4

Lining expended per axle: 125 lbs/10⁶ VMT

Heavy Duty Vehicles

Commercial Vehicles >10,000 lbs. curb wt.

- 1) Average New Lining

2) Average Lining Life	50,000 miles
3) Brake shoes per axle	4

Lining expended per axle: 23 axle front--83 lbs/10⁶ VMT
Rear or trailer--233 lbs/10⁶ VMT
1 & 2 axle--233 lbs/10⁶ VMT

TABLE 2-17. BRAKE LINING ATTRITION EMISSIONS SUMMARY

	Estimated Annual Mileage	Number of Vehicles in SCAB	% VMT Using Front Disc Brakes	Emission Factors, lbs/10 ³ VMT		Emissions		
				With Disc	Without Disc	With Fr. Disc T/Yr	Without Disc T/Yr	Total T/Yr
Light Duty Vehicles								
Automobiles	12,000	4,950,066	90% ^{a,b}	14.6x10 ⁻³	43.4x2	1378	516	1894
Comm'l 2 axle <5000# curb wt.	12,000	813,041				326	65	391
Trailer 1 axle	1,000	195,179			43.4			4
2 Axle	2,000	36,294			43.4x2			2
3 Axle	1,000	723			43.4x3			<1
								<u>2212</u>
Medium Duty Vehicles								
Comm'l 2 axle >5000-10,000# curb wt.	49,100	86,307			125x2			95
Comm'l 3 "	49,100	449			125x3			4
Trailer 1 axle	3,500	79,399			125x1			6
2 "	44,000	28,248			125x2			155
3 "	44,000	314			125x3			3
4 "	3,500	38			125x4			<1
								<u>264</u>
Heavy Duty Vehicles								
Comm'l 2 axle >10,000# curb wt.	49,100	22,640			242x3	46		46
3 "	49,100	24,330			549	328		328
4 "	8,800	343			762	1		1
Trailer 1 axle	7,900	1,800			142x3	2		2
2 "	44,000	79,639			242x3	201		201
3 "	7,900				342x3	<1		<1
4 "	7,900				442x3	<1		<1
						<u>580</u>		<u>3100 Total</u>

a All post-1970 GM passenger cars equipped with front disc brakes

b Source: (Ref. 2-97)

KVB 5806-783

- 3) Sea salt concentration of $8 \mu\text{g}/\text{m}^3$ is uniform throughout the window
- 4) Annual average on-shore wind velocity is 6 mph (or 10 kmh) (Ref. 2-102)
- 5) On-shore sea breeze blows 36% of the time (Ref. 2-103)
- 6) 75% by wt of the sea salt particles are $<10 \mu\text{m}$ in size (Ref. 2-100)

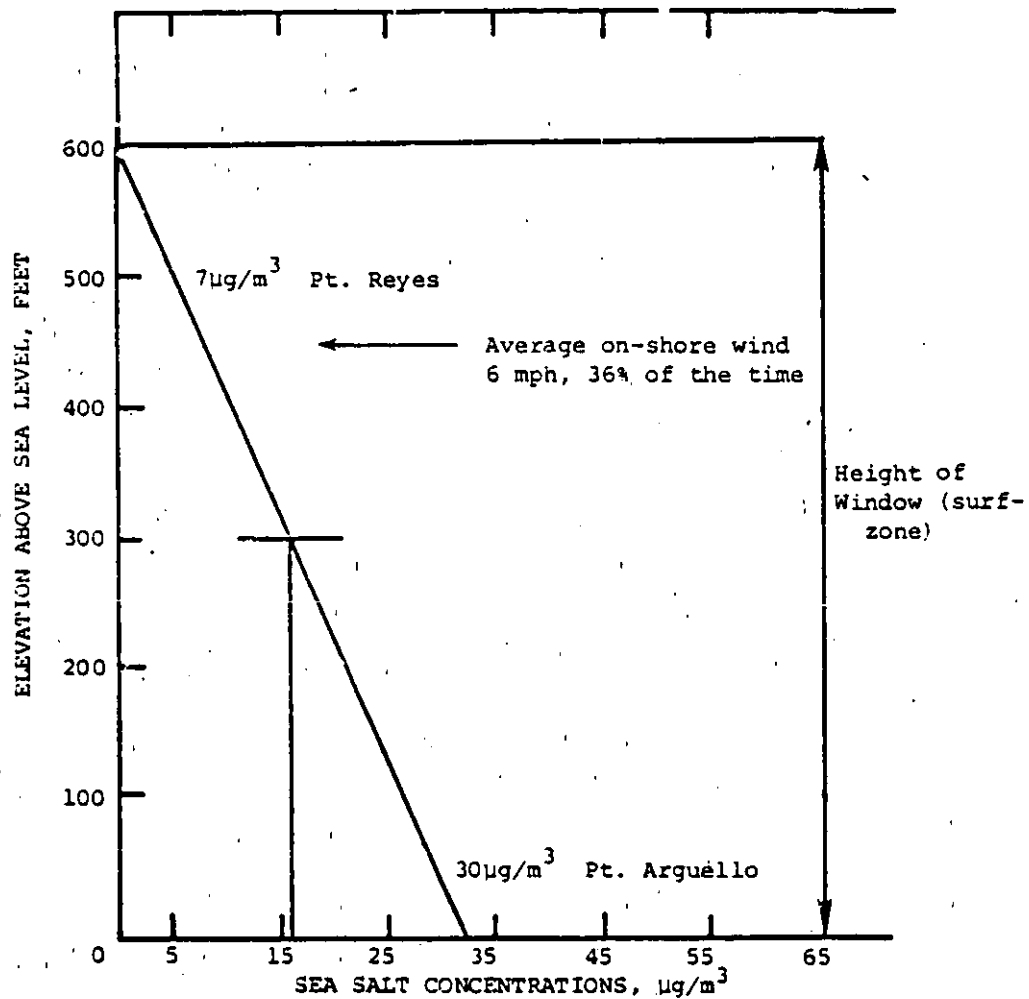
Using this approach, 39,000 tons (particles $<10 \mu\text{m}$) of sea salt was estimated to originate from the SCAB surf zone each year.

The second approach involved using measured concentrations of sea salt at 50 ft above the surf and 500 ft above the surf and establishing a linear concentration gradient as shown in Figure 2-21. As discussed below the measured concentrations were taken at periods of wind velocity higher than the average wind of 6 mph. Therefore, an adjustment was made to the average concentration of $17 \mu\text{g}/\text{m}^3$ to account for conditions under average winds. A value of $12 \mu\text{g}/\text{m}^3$ was selected. To calculate the emissions, it was assumed that all the salt spray was generated over the height of the gradient which extrapolates to zero concentration at a height of 600 ft. Using this approach and the other assumptions shown in Figure 2-21, a value of 20,000 tons/year of sea salt emissions less than $10 \mu\text{m}$ in size were calculated.

The following is an explanation of the data used to develop this estimate.

The ambient sea salt aerosol concentrations were measured at two on-shore sites--Pt. Reyes and Pt. Arguello. Source of this information was the ACHEX study.

The sampling station at Pt. Reyes Lighthouse was on a cliff 500' (0.18 Km) above sea level and well exposed to the winds. The data collected here is presumed to be representative of background marine coastal conditions along the Central Pacific Coast of the United States, however, this data may not be applicable along the Southern California coastline.



Other assumptions: a. Length of coastline including curvature - 220 miles
(350 Km)
b. 76% by weight of sea salt particles are less than $10\mu\text{m}$ in size (Ref. 2-100)

Figure 2-21. Salt spray emission calculation model.

Source: Ref. 2-100)

Data were collected over a ten day period. During the first week of testing, concentrations of $3.5 \mu\text{g}/\text{m}^3$ with 4-11 mph (6-18 kmh) onshore winds were measured. During the second week of testing, concentrations of $4.4 \mu\text{g}/\text{m}^3$ with a 22-34 mph (35-55 kmh) on-shore winds were measured. Winds were higher during this period, but surface trajectories were generally off-shore.

At Pt. Arguello the air was dominated by the ocean breeze. The sampling site was located within 100 yds of the sea and about 50' above the surf zone. The atmosphere was disturbed during the period of sampling by a weak storm front passing through Central Southern California. This period was also characterized by a wide range of conditions from weak winds 4 mph (6 kmh) to rather high winds of 12 mph (19 kmh). Winds in this area generally blow from the north at 6-10 mph (10-16 kmh).

Sea salt concentrations during this period ranged from $1-100 \mu\text{g}/\text{m}^3$. Based on the available information extracted from the ACHEX study, a value of $30 \mu\text{g}/\text{m}^3$ was chosen to represent the average sea salt concentration at Pt. Arguello. Particle sizing data were also taken. Figure 2-22 presents the results of the particle sizing test.

Based on these data, the 20,000 ton/yr of sea salt emissions were estimated to have the following particle size distribution:

<u>Particle Size</u>	<u>Weight Percent</u>
<1 μm	2
1-3 μm	20
3-10 μm	54
>10 μm	24

For the final inventory, the second approach was selected because it appeared to follow the more reasonable approach considering the available data. It was also evident that regardless of the approach taken, the quantity of salt particles being emitted from the surf zone into the atmosphere is appreciable, that is, 39,000 ton/yr or 20,000 ton/yr.

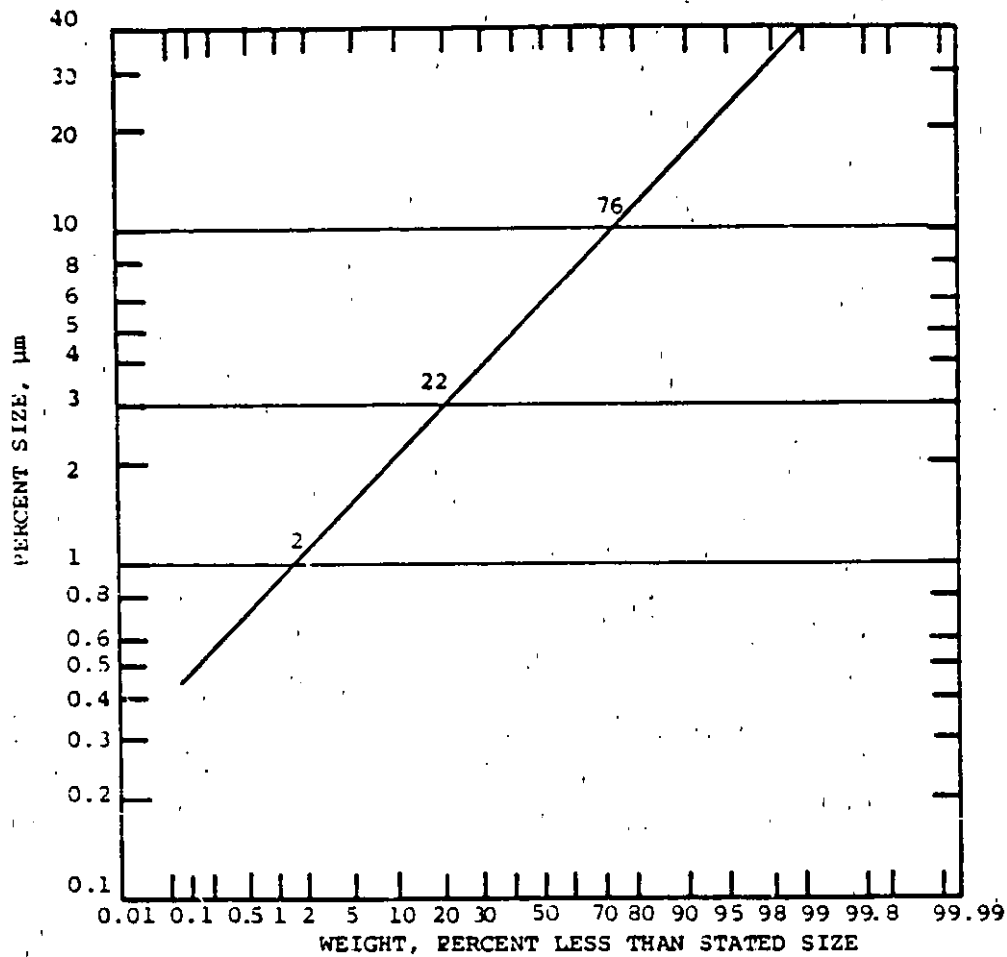


Figure 2-22. Sea spray particle size distribution.

Source: Ref. 2-100

2.4 INVENTORY RESULTS

The final TSP emission inventory was produced in August 1978 using EIS data tapes received from the ARB. The tape from SCAQMD was produced in February 1978 and the tape from Ventura APCD was produced in December 1977. Placing a baseline date on the inventory is difficult. The EIS efforts at SCAQMD and VAPCD were initiated in 1975 but data processing, correcting and updating continued from that time until the tapes used on this inventory were finally produced. Considering the span of time involved in incorporating new source data into the EIS system, the most appropriate time base to assign to the inventory is 1975-76.

The emission factors, area source data and emission profiles used in the inventory are discussed in the previous sections. In this section, the results of the inventory will be discussed.

2.4.1 Physical Description and Use Instructions

The inventory was delivered to the ARB in the form of one bound volume of computer printouts, one printed volume of emission profiles, plus three reels of computer tape. The following is a description of these reports to help facilitate their use.

A. Computer Printouts--

The computer report includes a plant index, an inventory by 10 kilometer grid squares, an inventory by ARB application categories and a SCC report.

The plant index is arranged by county and plant ID number. Because of a continuing problem with the EIS software, it was not possible to sort the plant file to arrange it in alphabetical order. Fortunately, this is not a large inconvenience since for a large part of the listing the plant ID numbers were assigned alphabetically. The index contains (in addition to county and ID) the plant name and address and its Universal Transverse Mercator (UTM) coordinates. Once a plant has been found in the index, the complete emission record can be found in the 10 kilometer grid file by looking up the UTM coordinates and the plant ID number.

The 10 kilometer grid report contains the following information:

- a. The UTM coordinates of the grid
- b. The major city that the grid includes
- c. The population of that grid
- d. A listing of each plant in the grid contained in the EIS files and emitting particulates. For each plant, it contains:
 - (1) The county in which the plant is located
 - (2) The plant ID Number
 - (3) The plant SCC and SIC codes
 - (4) Summer and winter, week-day and week-end emissions plus the total annual emissions
 - (5) A profile key which relates those TSP emissions to a compositional (size and chemical) breakdown contained in the Emission Profile Report,
- e. A summary of area source emissions by applications category

The application category report contains the identical information; however, the sources are arranged in application categories and the emissions for each category are summarized by point area and total emissions. The terminology "Minor Sources" seen in the summary is obsolete and was not used in this inventory. All entries are zero. All point source emissions are listed under "Major Sources" and area sources are correctly reported as indicated.

The SCC report lists the profile keys, application categories and emission factor corrections for all SCC numbers encountered in the source file. This report is sorted in two orders--by SCC number and by profile key. The latter provides all SCC's covered by a single profile.

B. Emission Profile Report--

The emission profiles are bound in a separate volume. It contains 49 different profiles. Each profile indicates the distribution of TSP emissions into size ranges: $>10\mu\text{m}$, 3 to $10\mu\text{m}$, 1 to $3\mu\text{m}$, and $<1\mu\text{m}$. For each of these size ranges, a chemical composition of the emissions is provided. Instructions for using the data are included in the volume.

C. Magnetic Tape Files--

The files submitted on magnetic tape include the EIS point source file, the area source file and the SCC file.

The EIS tape file contains, for each point source emitting TSP, all of the information in the EIS files of the SCAQMD, SBAPCD, and VCAPCD. The data are in the EIS format. The file layouts are identical to those for the hydrocarbon file delivered last May. (Refer to Vol. II of the H/C final report - Reference 2-53).

The area source tape file contains the area source data. File layouts were also contained in the H/C final report (Ref. 2-53).

The SCC file contains for each SCC number the applicable profile key, application category and emission factor correction.

2.4.2 Total Suspended Particulate (TSP) Emissions

The TSP emissions in the Basin plus Ventura County are 174,000 tons/year which accounts for 3900 point sources and the area sources presented in Section 2.3.3. A breakdown of these emissions according to application categories is presented in Table 2-18. Also presented in these tables are the data from 1975 inventories obtained from the local control districts (Refs. 2-105 - 110), the ARB (Ref. 2-111) and the Air Quality Management Plan produced jointly by the South California Association of Governments (SCAG), SCAQMD and ARB (Ref. 2-112). The total point source emissions are in close agreement. The EIS/KVB inventory has lower point source combustion emissions because of a reduction in utility boiler emission factor from 7.1 lb TSP/1000 gal to 3.0 lb TSP/1000 gal made by KVB as a result of field tests as discussed earlier in Section 2.3.1. The AQMP has a similar number for utility boilers. The EIS/KVB inventory has larger "Mineral" emissions primarily from two large sources in Ventura County, a sand and gravel plant and a brick plant which account for over 80% of the reported emissions. Again, the AQMP is in agreement showing an even higher emission.

TABLE 2-18. COMPARISON OF EIS/KVB AND OTHER PARTICULATE EMISSION INVENTORIES
TSP Emissions, Tons/Year

Application Category	No. Point Sources	1975-76 EIS/KVB Emission			Comparison AP40 AP40 1975 Inv. Mile. 2-105-110	1975 AP40		1976 AP40	
		Point Sources	Area Sources	Total		Point Sources	Area Sources	Point Sources	Area Sources
<u>Petroleum</u>		750		750	1500	1100		1300	
Production	34	50	0	50				1550	
Refining	25	600	0	600			1300	1700	
Marketing	8	100	0	100				25	
<u>Organic solvent use</u>		1160		1160	1000	1150		200	
Surface coating	546	1150	5	1155			1000		
Degreasing	5	10	0	10					
Other	4	5	0	5			350		
<u>Chemical</u>	137	540	0	540	1000			200	
<u>Metallic</u>	547	4200	0	4200	5500			520	
<u>Mineral</u>	480	12600	0	12600	6200			15700	
<u>Waste Burning</u>	48	75	500	575	500			20	
<u>Combustion of Fuel</u>		13900		13900	17500			15000	
Utility boilers	107	9100	0	9100			15000	8500	
Industrial devices	1004	2700	0	2700			5500	1800	
Commercial/Institutional	199	600	0	600			3500	600	
Petroleum	316	1500	0	1500				4100	
<u>Food Processing</u>	25	110	0	110					
<u>Food and Agriculture</u>	163	460	11000	11460	200		1100	200	
<u>Miscellaneous Industrial</u>	72	440	10	450				1500	
<u>Unidentified (Misc. Area)</u>	0	0	140,500	140,500			36000		93000
Fugitive dust			105,000	105,000					
Potential structural fires			4,500	4,500					
Tires and leaches			11,000	11,000					
Sea salt			20,000	20,000					
<u>Total, Tons/Year, (Overall, Tons/Day)</u>		34000 (93)	152,000 (414)	186,000 (510)	31000 (90)	37000 (100)	36000 (100)	37000 (100)	93000 (255)

The KVB area sources were discussed in Section 2.2.3. The area sources accounted for in the ARB and AQMP inventories compared to the KVB inventory are as follows:

<u>Area Source</u>	<u>ARB, Ton/Y</u>	<u>AQMP, Ton/Y</u>	<u>KVB, Ton/Y</u>
Wild fire	22,000	Not indicated	2,400
Structural fire	5,000	Not indicated	200
Farming	3,000	6,800	10,000
Construction & demolition	4,000	84,000	71,000
Unpaved roads	2,000	Not indicated	23,000
Equipment (movers, etc.)	200	260	Neglected

Since the detailed basis for the various estimates (other than for the KVB estimates discussed previously) is not available, there is little to be said regarding the differences in values. Before preparing the final inventory, KVB coordinated their area source estimate with the ARB staff.

2.4.3 Spatial Distribution

A map showing the spatial distribution of the TSP emission in the Basin and Ventura County is shown in Figure 2-23. Table 2-19 identifies the grids with TSP emissions greater than 5 ton/day.

TABLE 2-19. MAJOR 10-KM GRID EMITTERS

<u>UTM Coord.</u>		<u>Nearest City</u>	<u>Emissions (Ton/Day)</u>	<u>Principal Source Type</u>
<u>E/W</u>	<u>N/S</u>			
280	3790	W. Ventura	10.8	Ceramic manufacturing
300	3770	Pt. Mugu	7.4	Elect. gen. & area.
320	3800	Fillmore	19.1	Sand and gravel
360	3750	LA Airport	5.3	area
370	3740	Torrance	9.4	Elect. gen. & area
380	3740	Paramount	6.4	280 Pt. sources & area
380	3730	LA Harbor	5.9	250 Pt. sources & area
390	3730	Long Beach	11.5	Elect. gen. & area
450	3770	Fontana	11.1	Steel manufacturing

2.4.4 Fine Particle Summary

The objective of the program was to assess not only the total suspended particulate emissions but also the fine particle emission, i.e., the fraction with particle size less than 10 microns.

Since it was outside of the scope of this contract to program the emission profiles, it was not possible to perform a rigorous computation of the mass of fine particle emissions. Instead, a close approximation was made by estimating the particle size distribution for each application category. This estimate was made by inspection of the emission profile in the Appendix and establishing a percentage of the emissions with particle sizes less than 10 μ m.

Table 2-20 presents these results. Note that an estimate of the percent of TSP <10 μ m was made for the point sources in each application category. The area source emissions reported in this inventory (i.e., Table 2-18) were already adjusted so that they only included the <10 μ m portion.

In summary of the 174,000 ton/year TSP inventoried in this study, 161,000 ton/year or over 90% are less than 10 μ m. Of the 34,000 ton/year TSP from point sources shown in Table 2-18, 31,000 ton/year or 90% are fine particles.

TABLE 2-20. FINE PARTICLE INVENTORY SUMMARY

Application Category	% of TSP <10µm	TSP Ton/yr (Table 2-17)	Fine Particle Emissions	
			Ton/yr	Ton/day
Petroleum	60	750	450	1.2
Organic Solvent Use	70	1160	800	2.1
Chemical	90	540	500	1.4
Metalurgical	90	4200	3800	10.4
Mineral	20	12600	2500	6.8
Waste Burning	70	600	400	1.1
Combustion of Fuel				
Utility Boiler	97	9100	8800	24
Other	90	4800	4300	11.8
Wood Processing	60	130	70	0.2
Food & Agriculture	80	11000	8800	24
Misc. Industrial	50	450	200	0.5
Area Sources				
Agricultural Tilling	100*	9900	9900	27
Road & Building Construction	100*	71000	71000	195
Livestock Feedlots	100*	1300	1300	3.6
Unpaved Roads	100*	23000	23000	63
Forest Fires	100*	2400	2400	6.6
Structural Fires	100*	200	200	0.5
Other Combustion	100*	1900	1900	5.2
Tire & Brake Attrition	100*	11000	11000	30
Sea Salt	100*	20000	20000	55
		TOTAL	171000	467

* The emissions calculated for area sources only included that portion of TSP <10µm.

REFERENCES

SECTION 2.0

- 2-1 "Comprehensive Data Handling Systems, Emissions Inventory/Permits and Registration Subsystem (EIS/PSR) Program Documentation and Users Guide," EPA.
- 2-2 Grisinger, J. E., "Development of Coordinate System Transformation Equations Required for Air Quality Modeling in the SCAB," CARB Staff Report, July 1977.
- 2-3 "Compilation of Air Pollution Emission Factors," Supplements 1-7, Publication AP-42, EPA, April 1977.
- 2-4 Area Source Guidelines
- 2-5 "Combustion Emission Factors for EIS/EDP," (See Units), Southern California Air Pollution Control District, November 17, 1977.
- 2-6 Goldstein, H. L. and Siegmund, C. W., "Influence of Heavy Fuel Oil Composition and Boiler Combustion Conditions on Particulate Emissions," Exxon Research & Engineering Co., Article published in Environmental Science and Technology, Vol. 10, No. 12, November 1976.
- 2-7 Personal Communications with Mr. Arnold Perm, Chief of Air and Hazardous Materials Section, Environmental Protection Agency.
- 2-8 Sittig, M., Particulates and Fine Dust Removal, Noyes Data Corp., 1977, Page 201.
- 2-9 Friedlander, S. K., Smoke, Dust and Haze, 1977, J. Wiley and Sons, Inc., Page 20.
- 2-10 Sittig, M., Particulates and Fine Dust Removal, Noyes Data Corp., 1977, Page 292.
- 2-11 Ibid., Page 440.
- 2-12 Ibid., Page 175.
- 2-13 Ibid., Page 250.

- 2-14 Sittig, M., Particulates and Fine Dust Removal, Noyes Data Corp., 1977, Page 293.
- 2-15 Ibid., Page 454.
- 2-16 Friedlander, S. K., Smoke, Dust, and Haze, 1977, Page 301.
- 2-17 Jutze, G. A., et al., "Investigation of Fugitive Dust Sources Emissions and Control," PEDCo Environmental Specialists, Inc., Cincinnati, Ohio, prepared for Environmental Protection Agency, Research Triangle Park, NC, EPA-450/3-74-036a, June 1974.
- 2-18 Cowherd, C., Jr., et al., "Development of Emission Factors for Fugitive Dust Sources," Midwest Research Institute, Kansas City, MO, prepared for Environmental Protection Agency, Research Triangle Park, NC, EPA-450/3-74-037, June 1974.
- 2-19 "Compilation of Air Pollutant Emission Factors," Section 11.2, Third Edition, Environmental Protection Agency, August 1977.
- 2-20 "1976 Emissions from Construction & Demolition," a document for the 1976 Emission Inventory, SCAQMD, 1977.
- 2-21 "1976 Construction Activity Particulate Emissions in the State of California," Air Resources Board memorandum, June 14, 1978.
- 2-22 Personal communication, Mr. Herb Whitehead, SCAQMD Southern Zone Office, June 13, 1978.
- 2-23 "Compilation of Air Pollutant Emission Factors," Section 11.2.2, Third Edition, Environmental Protection Agency, August 1977.
- 2-24 "Los Angeles County 1976 Crop and Livestock Report," Los Angeles County Agriculture Commission, 1976.
- 2-25 "Orange County 1976 Agriculture Crop Report," Orange County Department of Agriculture.
- 2-26 "Riverside County Agriculture Crop Report 1976," Riverside County Agriculture Commission.
- 2-27 "Annual Crop and Livestock Report 1976," San Bernardino County Department of Agriculture.
- 2-28 "Ventura County Agriculture Crop Report 1976-77," Ventura County Agriculture Commissioner.

- 2-29 "Santa Barbara County 1976 Crop Report," Santa Barbara County Agricultural Commissioner.
- 2-30 Personal communication, Mr. Jack Davidson, U.C. System Farm Advisor, San Bernardino County Cooperative Extension Service, June 15, 1978.
- 2-31 Personal communication, Mr. Harvey, U.C. System Farm Advisor, Riverside County Cooperative Extension Service, June 15, 1978.
- 2-32 Personal communication, Mr. Bob Burns, U.C. System Farm Advisor, Ventura County Cooperative Extension Service, June 15, 1978.
- 2-33 Personal communication, Mr. Jim Harnett, Orange County Agricultural Commissioner Office, Orange County, June 15, 1978.
- 2-34 Personal communication, Mr. Vick Smothers, Orange County Soil Conservation Service, Orange County, June 16, 1978.
- 2-35 Personal communication, Mrs. Arlene Togel, Soils Specialist, Soil Conservation Service, Riverside County, June 15, 1978.
- 2-36 Personal communications with Mr. Leon Spaugy, Riverside County Agricultural Commissioner's Office, Riverside County, June 19, 1978.
- 2-37 Personal communications with Mr. Wotanode, Los Angeles County Agricultural Commissioner's Office, Los Angeles County, June 19, 1978.
- 2-38 Personal communications with Mr. Greg Hayes, Santa Barbara Agricultural Commissioner's Office, Santa Barbara County, June 15, 1978.
- 2-39 Anonymous, ARB Memorandum, "Farming Operations," Preliminary Documentation, June 14, 1978.
- 2-40 Anonymous, Emission Factors for Fugitive Dust from Solid Waste Disposal, a document for the 1976 Emission Inventory, SCAQMD, 1977.
- 2-41 Anonymous, "In-Situ Investigation of Movements of Gases Produced from Decomposing Refuse," Engineering-Sciences, Inc., California State Water Quality Control Board Publication No. 31, 1965.
- 2-42 Private communications with Mr. Bill Johnson, Orange County Solid Waste Management District, May 25, 1978.
- 2-43 Anonymous, "Area Source Particulate Emissions," Memorandum, Air Resources Board, June 14, 1978.
- 2-44 Anonymous, "Support Documentation for Area Sources - Farming Operations Section Feedlots," SCAQMD, 1977.

- 2-45 Anderson, C., "Air Pollution from Dusty Roads," as presented at the 17th Annual Highway Engineering Conference, April 1971.
- 2-46 "Air Pollution from Unpaved Roads," a research paper by the School of Engineering, University of New Mexico, January 12, 1971.
- 2-47 Jutze, G. A., et al., "Investigation of Fugitive Dust Sources Emissions and Control," PEDCO Environmental Specialists, Inc., Cincinnati, Ohio, prepared for Environmental Protection Agency, Research Triangle Park, NC, EPA-450/3-74-036a, June 1974.
- 2-48 Hoover, J. M., Surface Improvement and Dust Palliation of Unpaved Secondary Roads and Streets, Final Report, by Engineering Research Institute, Iowa State University, ERI Project 856-S, submitted to the Iowa State Highway Commission, July 1973.
- 2-49 Anonymous, "Vehicle Miles Traveled (VMT) by Road Type Location and County," Memorandum, Air Resources Board, June 14, 1978.
- 2-50 Compilation of Air Pollutant Emission Factors, Section 11.1-1, Third Edition, Environmental Protection Agency, August 1977.
- 2-51 McMahon, Charles K. and Ryan, Paul W., Some Chemical and Physical Characteristics of Emissions from Forest Fires, USDA Forest Service, Macon, Georgia, Paper presented at the 69th Annual Meeting of the Air Pollution Control Association, June 27 to July 1, 1976.
- 2-52 Martin, Robert E. and Sandberg, David V., Particulate Sizes in Slash Fire Smoke, Pacific Northwest Forest and Range Experiment Station, U.S. Department of Agriculture, Research Paper, PNW-199.
- 2-53 Taback, H. J., et al, Control of Hydrocarbon Emissions from Stationary Sources in the California South Coast Air Basin, Air Resources Board, Contract No. 5-1323.
- 2-54 Biswell, H. H., Darley E. F. Goss, J., Miller, G. I., "Air Pollution from Forest and Agriculture Burning," Journal of Fire and Flammability, Vol. 4, April 1973.
- 2-55 Personal Communication with Mr. H. B. Cahill, National Forest Service, Ventura County, California, May 25, 1978.
- 2-56 Personal Communications with Mr. Harning, Ventura County Fire Chief, Ventura County, California, May 25, 1978.
- 2-57 Personal Communications with Mr. T. McLaughlin, State of California, Air Resources Board, June 15, 1978.
- 2-58 Anonymous, "Emission Factors for House and House Contents Burning," a support document by the SCAQMD, August 1977.

- 2-59 "1976 Emissions from Structural Fires," a support document by the SCAQMD, October 1977.
- 2-60 Personal Communications with Nels Rasmussen, Department of Population, State of California, May 1978.
- 2-61 California Fire Incident Reporting System, California State Fire Marshall, Sacramento, California.
- 2-62 Alguard, D. A., Snowden, W. D., Stolberg, W. E., Swanson, G. A., Source Sampling Residential Fireplaces for Emission Factor Development, Valentine Fisher, T. Tomlinson, Seattle, Washington, prepared for the Environmental Protection Agency, Research Triangle Park, NC, EPA 450/3-76-010, November 1975.
- 2-63 Baumeister, Theodore, Mark's Mechanical Engineers Handbook, Sixth Edition, Section 7-18, 1958.
- 2-64 Busch, A. F., Leonard, J. J., Yandy, W. H., "Gas Analyses in Large Fire Experiments," Report 68-25, UCLA, Department of Engineering, May 1968.
- 2-65 Compilation of Air Pollution Emission Factors, AP-42, Section on "Open Burning," Environmental Protection Agency, Office and Air Waste Management, February 1976.
- 2-66 Compilation of Air Pollution Emission Factors, Section on "Auto Incineration," U.S. Environmental Protection Agency, Office and Air and Waste Management, February 1976.
- 2-67 Personal Communications with Mr. Bruce Dear, Orange County Tax Assessor's Office, May 19, 1978.
- 2-68 Personal Communications with Mr. Mark F. Balys, Riverside County Planning Department. May 19, 1978.
- 2-69 Personal Communications with Mrs. Dudley Iverson, San Bernardino Tax Assessor's Office, May 19, 1978.
- 2-70 Personal Communications with Los Angeles County Tax Assessor's Office, May 19, 1978.
- 2-71 Personal Communications with Mr. Elliot Harris, Southern California Gas Company, Los Angeles, California, June 21, 1978.
- 2-72 1978 Facts, Southern California Gas Company, as of January 1, 1978.

- 2-73 Matthews, B. J. and Surprenant, N. F., "Emissions Assessment of Conventional Combustion Systems," Vol. I, TRW, Inc., Redondo Beach, California, prepared for the Environmental Protection Agency, Research Triangle Park, NC, under Contract No. 68-02-2197.
- 2-74 Brookman, G. T. and Kalina, P. W., "TRC Measuring the Environmental Impact of Domestic Gas-Fired Heating Systems," Paper presented at 67th Annual Meeting, Air Pollution Control Associations, June 1974.
- 2-75 Hoffman, Dietrich, Wynder, Earnest, "The Less Harmful Affects of Smoking," World Smoking and Health, Vol. 2, Number 2, American Chemical Society Journal, June 16, 1977.
- 2-76 Personal Communications with Bud Steinfeld, Department of Commerce, Bureau of Census, Los Angeles, California, May 10, 1978.
- 2-77 Marchesane, Vincent J., Towers, Thomas and Wohlers, Henry C., "Minor Sources of Air Pollutant Emissions," Journal of the Air Pollution Control Association, Vol. 20, No. 1, January 1970.
- 2-78 Personal Communications with Mr. V. Marchesoni, Co-publisher of reference 47, May 25, 1978.
- 2-79 "Second Hand Smoke - Take A Look at the Facts," Brochure, distributed by the American Lung Association, August 1977.
- 2-80 Personal Communications with Mr. Dennis Mizoguchi, Smoker Hotline, Long Beach, Information Source: Smoking Digest, October 1977.
- 2-81 The Health Consequences of Smoking, Page 94, Table 1, 1975.
- 2-82 Minutes of a speech presented by David M. Burns, M.D., Medical Staff Director, Clearinghouse for smoking and health, Bureau of Health Education, Center for Disease Control, Atlanta, GA 30333, at the workshop on rights of non-smokers, conducted by National Interagency Council on Smoking and Health, New York, NY, held at the University of Maryland, College Park, MD, January 11, 1975.
- 2-83 Darley, E. F., et al, "Contribution of Burning of Agricultural Waste to Photochemical Air Pollution," Journal of APCA, Vol. 18, No. 12, December 1966.
- 2-84 Darley, E. F., et al, "Emission Factors from Burning Agricultural Wastes Collected in California," report for CARB Contract 4-011.
- 2-85 Wayne, L. G. and McQueary, M. L., "Calculation of Emission Factors for Agricultural Burning Activities," report for EPA Contract 68-02-1005.
- 2-86 Darley, E. F., "Emission Factor Development for Leaf Burning," report for EPA Contract 5-02-6876.

- 2-87 State of California Health and Safety Code, Subchapter 2, Title 7.
- 2-88 California Air Resources Board, Agriculture Burning Report for 1976, June 2, 1978.
- 2-89 Dannis, M., Rubber Chemical Technology 47, 1011, 1974.
- 2-90 Byarly, T. R., Jr. and Raybold, R. L., "Investigation of Products of Tire Wear," NBS Report, 10834, 1972.
- 2-91 Kovac, Frederick J., "Technology Forecasting-Tire," Chemical Technology, January 1971, Page 22.
- 2-92 Brachacaek, W. and Pierson, W. R., Rubber Chemical Technology, 30, (a) 45, 1971.
- 2-93 Cardina, J. A., Rubber Chemical Technology 47, 1005, 1974.
- 2-94 Subramani, J. P., "Particulate Air Pollution from Automobile Tire Tread Wear," Ph.D. Thesis Project, University of Cincinnati, 1971.
- 2-95 Cadle, J. H. and Williams, R. L., "Gas and Particle Emissions from Automobile Tires in Laboratory and Field Studies," General Motors Research Publication, GMR-2542, Env. No. 37, October 1977.
- 2-96 Cadle, J. H. and Williams, R. L., "Characterization of Tire Emissions Using an Indoor Test Facility," Rubber Chemistry and Technology, Vol. 51, No. 1, March-April 1978.
- 2-97 Anonymous, Preliminary Draft of Tire and Brake Emissions in the SCAB, Vehicle Distribution Summary for SCQMD Areas, South Coast Air Quality Management District, October 1977.
- 2-98 Anonymous, Data Base and Documentation for Estimating Emissions from Motor Vehicles in California, State of California Air Resources Board, May 1977.
- 2-99 Friedlander, S. K., Smoke, Dust and Haze, Fundamentals of Aerosol Behavior, John Wiley and Sons, New York, 1977.
- 2-100 Anonymous, "Characterization of Aerosols in California," (ACMEX) Final Report, Volume I and IV, Air Resources Board, State of California, September 30, 1974.
- 2-101 Crawford, K. W. and Trijonis, J. C., "An Implementation Plan for Suspended Particulate Matter in the Los Angeles Region," prepared for the EPA Region IX by TRW, Contract No. 68-02-1384.
- 2-102 Personal Communications with the National Weather Service, Los Angeles, California, June 8, 1978.

- 2-103 Trijonis, John C., An Economic Air Pollution Control Model Application: Photochemical Smog in Los Angeles County in 1975, Vol. I, Source Sited: Neiburger and Edinger, 1954.
- 2-104 Sittig, M., Particulates and Fine Dust Removal, Noyes Data Corp., 1977, Page 55.
- 2-105 Southern California Air Pollution Control District, "Emission Inventory Report to the Board," November 1975.
- 2-106 Ventura County Air Pollution Control District, "Preliminary Source Emissions Inventory," August 1976.
- 2-107 Laird, John, Santa Barbara County Air Pollution Control District, Private Communication, March 18, 1977.
- 2-108 Riverside County Air Pollution Control District, "Average Emissions of Pollutants," 1975.
- 2-109 San Bernardino County Air Pollution Control District, "1975 Annual Report," 1975.
- 2-110 Orange County Air Pollution Control District, "1974 Emissions Inventory," 1975.
- 2-111 Bradley, Rich, "ARB 1975 Inventory of TSP for the South Coast Air Basin," Private Communication, September 14, 1978.
- 2-112 Draft Air Quality Management Plan, SCAG and SCAQMD, Los Angeles, California, August 1978, (Preliminary).
- 2-113 Cowherd, C., Jr., C. M. Maxwell, and D. W. Nelson, "Quantification of Dust Entrainment from Paved Roadways," Midwest Research Institute, Kansas City, MO. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, EPA-450/3-77-027, July 1977.
- 2-114 Axetell, K. and J. Zell, "Control of Reentrained Dust from Paved Streets," PEDCo Environmental Specialists, Inc., Cincinnati, OH. Prepared for U.S. Environmental Protection Agency, Region VII, Kansas City, MO, under Contract No. 68-02-1375, July 1977.
- 2-115 Xavier, T., "Data Base and Documentation for Estimating Emissions from Motor Vehicles in California," State of California Air Resources Board, Technical Services Division, May 1977.

SECTION 3.0

FIELD TESTING

The field tests conducted on this program provided a realistic assessment of the particulate emissions from stationary sources in the Basin. From the outset the experimental plans and procedures were coordinated with numerous government, industry, and research consultants to benefit from the advice of other experts in the field, avoid duplication, identify representative sources and insure high data quality.

The following sections present the experimental methods employed.

3.1 APPROACH

The number of stationary sources of particulate emissions in the Basin is huge. The objective of the test program was to provide as much information as possible to characterize the particulate emissions from these sources. An initial goal of 45-50 sources was established.

The EPA has categorized pollution sources using a system of Source Classification Codes (SCC). The sources in the Basin account for approximately 150 SCC numbers. For each of these an emission factor and an emission profile was desired. In many cases emission factor data were available. Very little data were available on which to base emission profiles. Therefore, the major emphasis was given to obtaining emission profile data.

From the preliminary inventory it was determined that fuel combustion accounted for 54% of the emissions in the Basin and metallurgical and minerals accounted for 24%. Major plants were identified in each source type such as power plant, cement plant, glass furnaces, and asphalt batch plants. Special sources like a steel mill, chemical plant, etc. were also listed.

Industry was found to be cautious and concerned about this testing. They often requested a full technical briefing. The glass industry used the Glass Packaging Institute GPI and the petroleum industry used the Western Oil and Gas Association (WOGA) as agents to monitor and control their participation. As a result of this concern a great deal of engineering time was required to gain entry to plants for testing. Even after tests were completed, there were return visits to review data. In the case of GPI and SCE, formal presentations of plans and results were made for each site tested.

To minimize the amount of coordination work, KVB took the approach of trying to conduct as many of the planned tests at one plant site as possible.

The test crew consisted of two engineers and two technicians. On all tests, all four worked together. Each test required one working day at the plant site plus two days for equipment turnaround and sample processing.

3.2 METHODOLOGY

Sampling and analysis methodology described in this section was evaluated during the Phase I period of the program. This is discussed in Section 4.2.1. The objectives were to (1) determine the particulate emission rate from ducted sources, (2) collect and preserve representative samples of these emissions and (3) analyze the samples for their chemical composition. The general approach to emission rate determination was to either measure the emission rate or to determine it by calculations from process data.

Presented in the following sections are a detailed description of the field test and laboratory equipment, some explanation for their selection, and a detailed description of test procedures and data reduction techniques followed during the program.

3.2.1 Sampling

Two sampling trains were used in the program, an EPA Source Assessment Sampling System (SASS) and a modified Method 5 train. Both trains consisted of heated probe; three calibrated cyclones with nominal cut sizes of 10, 3 and 1 μ m contained in an oven capable of being heated to 400°; a millipore filter also in the oven; two impingers containing distilled water; one dry impinger; one impinger containing desiccant; vacuum pump(s); and a drygas meter. The primary difference in the two trains is size. The SASS is larger with a sampling rate of 4.0 SCFM or 6.5 ACFM at 400°F where the Method 5 train has a sampling rate of 1.0 SCFM (1.65 ACFM at 400°F). The SASS requires two vacuum pumps. Both systems are essentially standard, commercially-available equipment except that the standard SASS has an organic sampling module between the filter and the impingers which was not used on these tests and a special cyclone set was designed and fabricated especially for use with the Method 5 train.

The purposes for using two trains were to:

- a. Simultaneously sample upstream and downstream of control devices to measure efficiency.
- b. Simultaneously sample at the same location to determine measurement accuracy.
- c. Provide flexibility in equipment size using the physically smaller Method 5 train in locations where the SASS was too large.

The smaller train was used upstream of all controlled devices and the faster sampling SASS was used downstream where the grain loading was substantially lighter.

Both the small and large cyclone sets were calibrated at the program outset. Pitot tubes, gauges, meter, thermo-couples and pyrometers were calibrated periodically throughout the program.

A. Equipment Description--

1. Source assessment sampling system (SASS) Ref. 3-1--The flow diagram for the SASS is shown in Figure 3-1. The SASS is available as a standard product of the Acurex Corporation, Mountain View, California. A description of the components follows.

HEATED PROBE

The SASS probe extracts gas/particulate samples from the source being tested, monitors the temperature and gas velocity of the source, and maintains sample temperatures above the condensation point of water/SO₂ mixtures. Figure 3-2 shows the internal arrangement of the assembled probe. The important features of the probe are the Type 316 stainless steel sampling tube; the fiberglass-insulated strip heater (incorporating a thermocouple for feed-back temperature control) wrapped around the sampling tube; a round probe body to allow sealing of the sampling port and rotation of the probe as necessary; strain relief for all electrical, thermocouple, and pitot line connections; a calibrated S-type pitot; and easily interchangeable probe tips with diameters from 1/4 to 3/4 inch in 1/16-inch increments as standard equipment. The probe is designed to withstand duct temperatures of up to 600°F.

PARTICULATE COLLECTION SYSTEM

The purpose of the particulate collection system is to maintain the sample gas stream at 400°F while collecting the particulate in three cyclones and a backup absolute filter. Figure 3-3 shows the system installed in the oven. Figure 3-4 schematically illustrates the three SASS cyclones and shows key dimensions of each. The cyclones were developed by the Southern Research Institute and Acurex's Aerotherm Division. The cyclone assembly is fabricated of 316 stainless steel. In order to be lightweight and compact for easy field use, and to be easily assembled, disassembled, and cleaned in the field, the cyclones were fabricated by spinning with inlet sections attached by welding. Support for the individual pieces in the oven is provided by tubing connections. As a result the cyclones are fragile and easily damaged. The middle cyclone failed midway in the program and was replaced by a machined unit which was less expensive and more rugged, but slightly heavier.

The seal between the top and body sections of the cyclones were originally made of Teflon. These Teflon seals proved to be troublesome because of their lack of flexibility and tendency to cold-flow, leading to difficulty in getting satisfactory leak tests. After a few tests, the Teflon was replaced with Viton which has been adopted by the EPA as an acceptable material for the system.

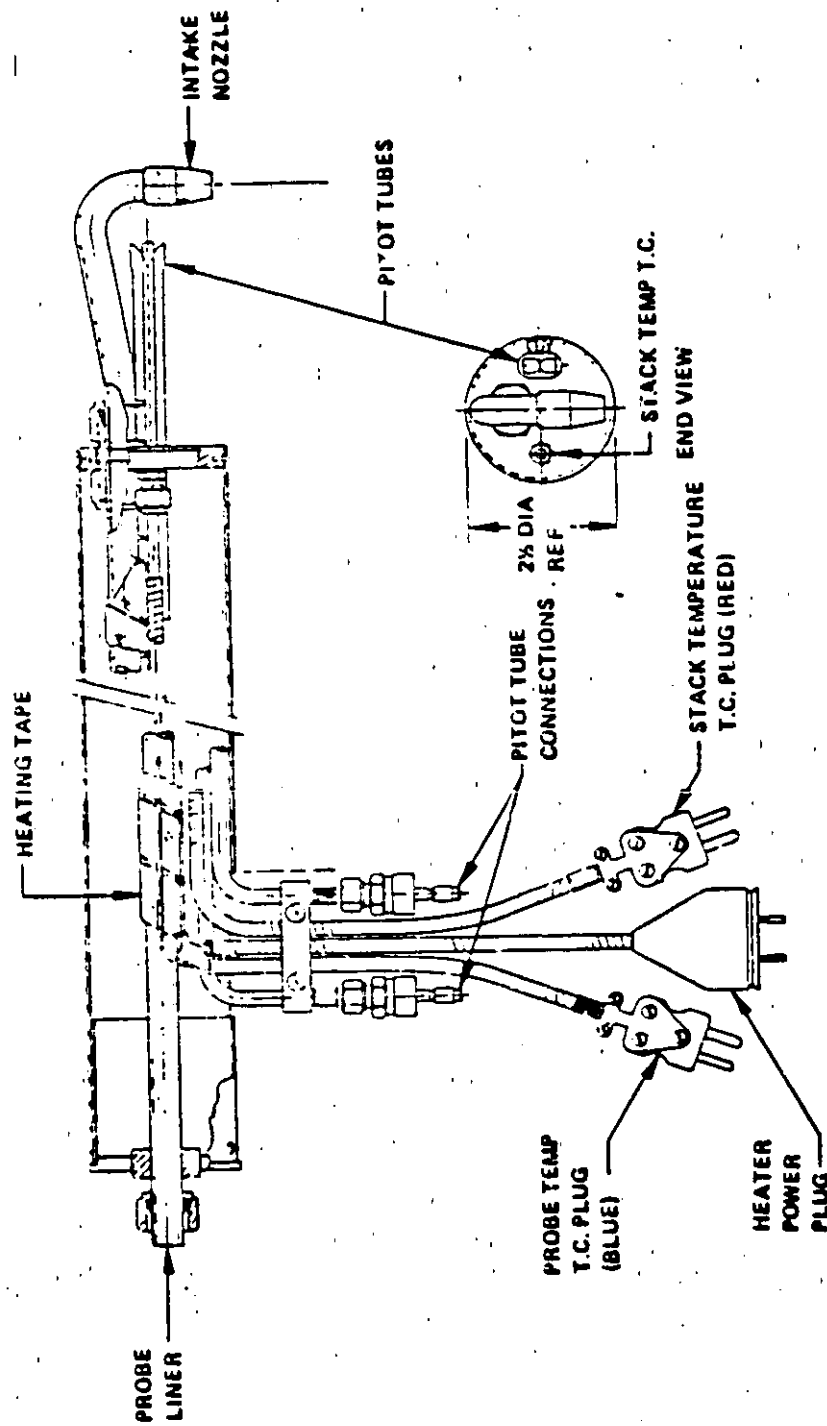


Figure 3-2. Probe Details (Ref. 3-1).

KVB 5806-783

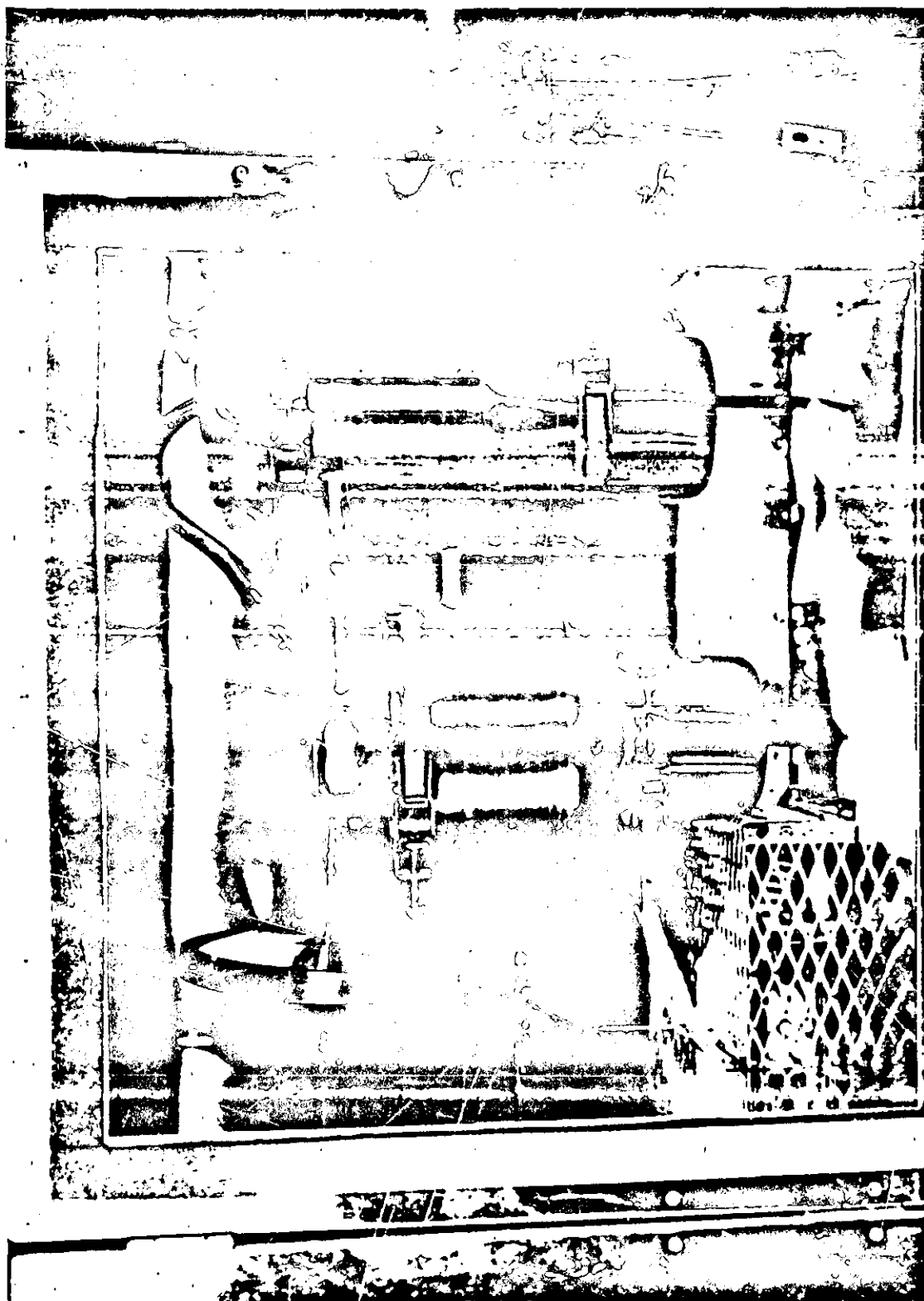
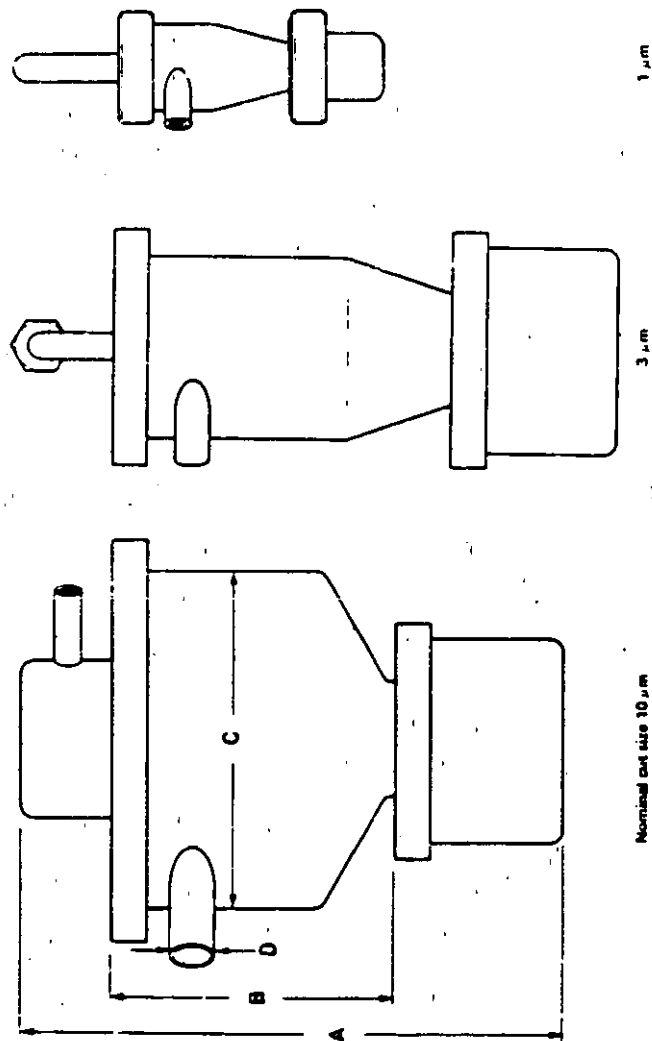


Figure 3-3. Cyclone train and filter holder with oven.
(Ref. 3-1)

KVB 5806-783



Cyclone	Dimensions			
	Total Height A, cm	Body Height B, cm	Body Diameter C, cm	Inlet ID D, cm
10 μm	26.0	13.2	15.2	5.1
3 μm	27.1	15.2	8.1	1.8
1 μm	16.6	7.6	3.7	0.9

Figure 3-4. SASE cyclone dimensions (Ref. 3-1).

The filter holder (Figure 3-3) houses and supports an absolute backup filter for the series cyclones. Because of pseudo particulate problems experienced with other filters (Ref. 3-19), only Reeve Angel 934AH filters were employed in the filter holders of both trains. These filters are made of borosilicate glass fibers and have an estimated porosity of 0.3 - 0.5 μ m. The filters were obtained in 150 mm diameters and were individually cut to 141 mm diameters to fit the holder.

The oven provides a constant temperature environment for the cyclones and filter, as well as mechanical protection. It also supports the probe by means of a collar attached to the side of the oven, which securely clamps the probe. The probe and oven collar are so designed that the probe can be rotated to any angular position.

IMPINGER ASSEMBLY

The impinger assembly collects any remaining condensables in the gas stream and dries the sample gas stream to avoid damaging the gas pumps and flow monitoring instrumentation. The impinger assembly, pictured in Figure 3-6 consists of four heavy wall glass bottles. 316 stainless steel and Teflon tubing directs gas flow. The first two impinger bottles contained 400 ml of distilled water. In each of these bottles, a straight section of tubing ducts the sample gas below the liquid level. The sample gas section of tubing ducts the sample gas below the liquid level. The sample gas bubbles through the liquid, allowing the various pollutant species to be scrubbed out. The third bottle was empty. The fourth impinger bottle contained granular silica gel to dry the gas. In this bottle also, the gas is ducted to the bottom of the bottle by a stainless steel tube and flows upward through the silica gel granules.

The remaining components of the impinger assembly (shown in Figure 3-6) include a thermocouple to monitor temperature of the gas exiting the silica gel, a small pump to agitate the ice/water slurry surrounding the bottles and carrying tray so the entire impinger assembly can be lifted out of its ice bath when required.

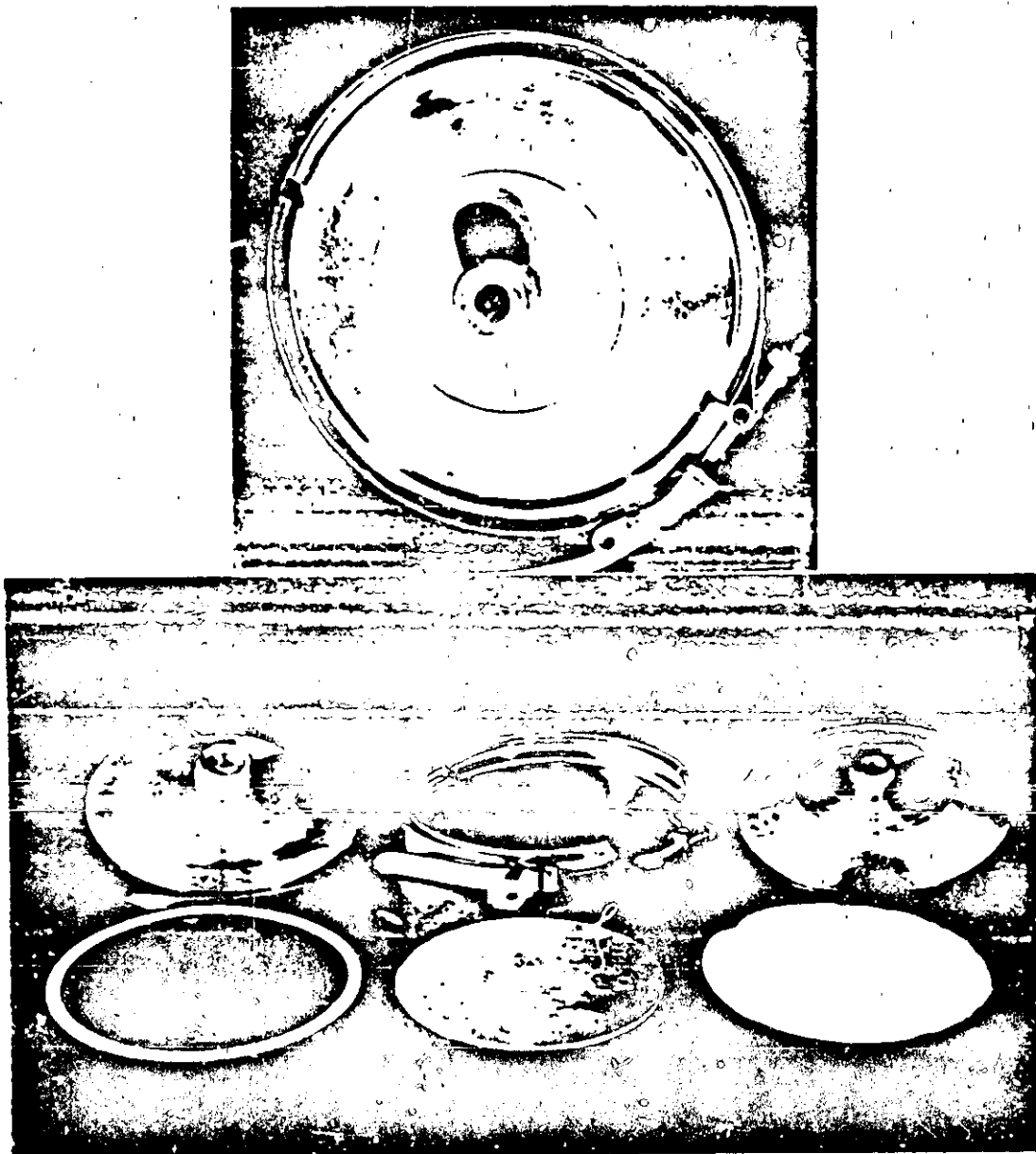


Figure 3-5. Filter housing assembly (Ref. 3-1).

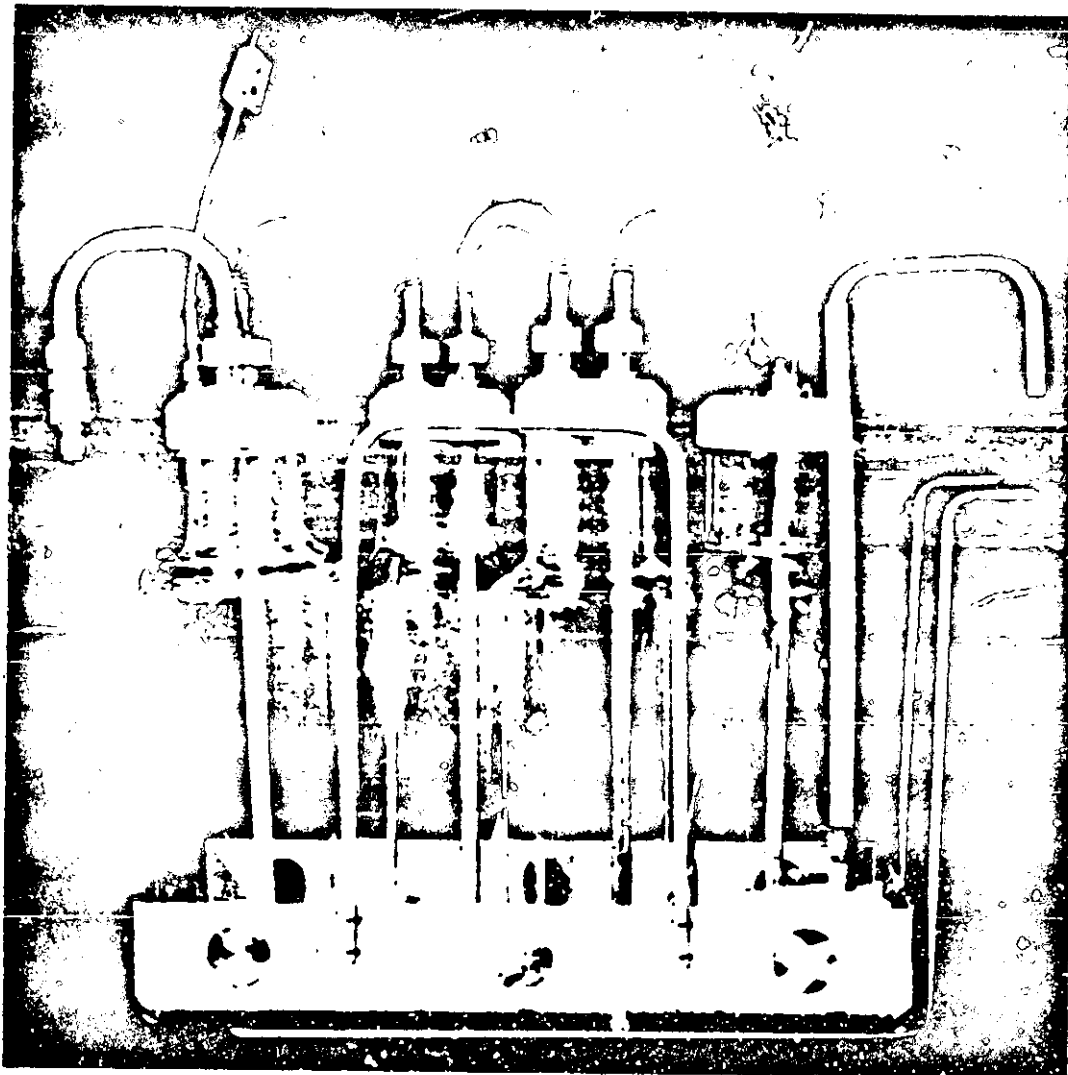


Figure 3-6. Impinger train out of case.
(Ref. 3-1)

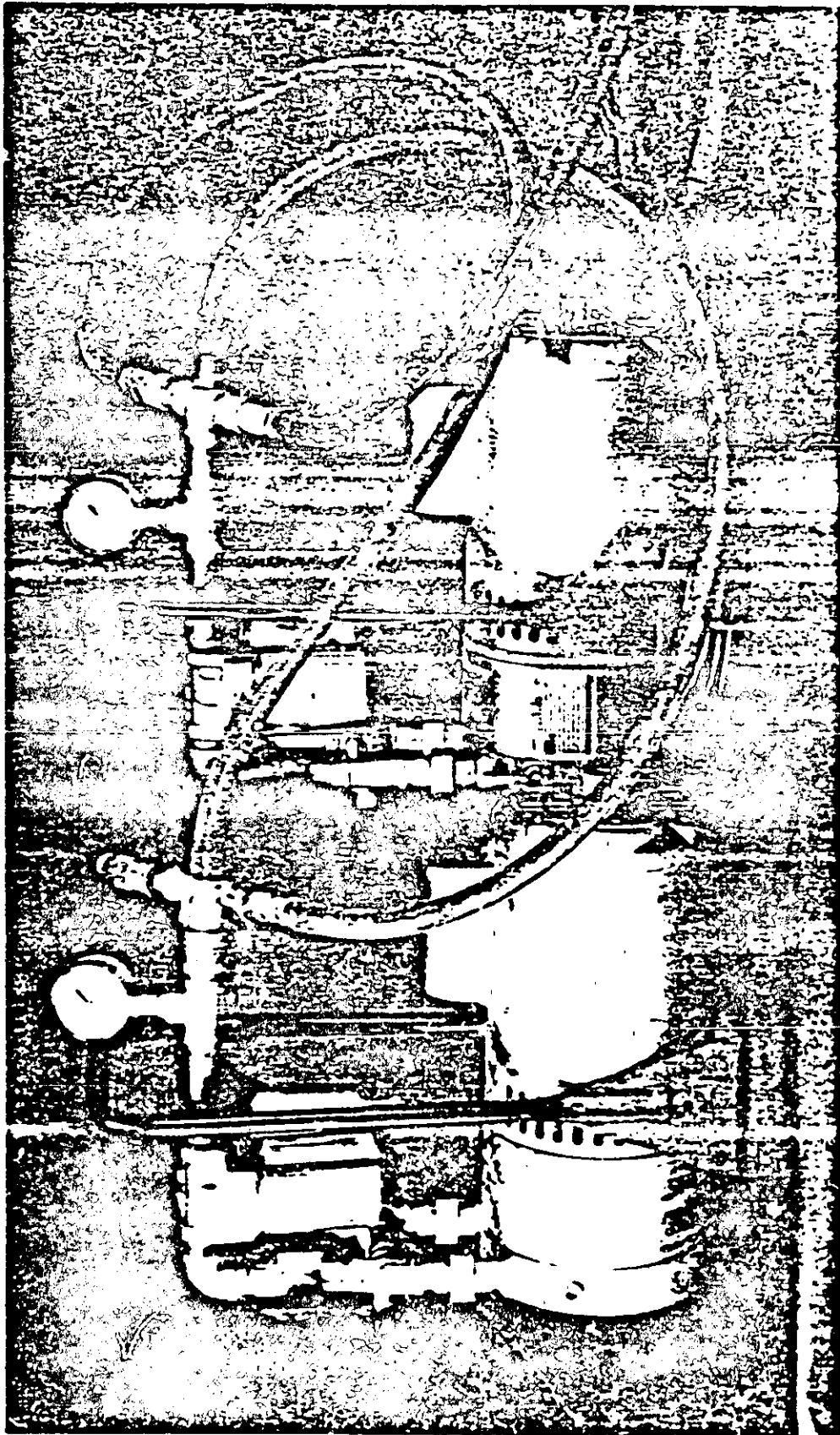


Figure 3-7. Vacuum pump (Ref. 3-1).

VACUUM PUMPS

Two vacuum pumps connected in series are used with the SASS. These carbon vane-type pumps (Gast, Model 1022) are modified by Acurex with a special shaft seal to reduce the leak rate to better than Method 5 standards. Each pump has a 3/4-hp motor, a flowrate of 10 ACFM at zero pressure drop, and weighs 59 lbs including all fittings. Each pump requires 10 amps/115 VAC.

CONTROL UNIT

The control unit contains all of the instruments for measuring stack velocity, sampling flowrate and cumulative flow, and temperatures at various points in the sampling system (Figure 3-8). All of the controls for the sampling system are located in the control unit except the valves for controlling sample flowrate. The valves are mounted on the vacuum pump, which is placed adjacent to the control unit when using the sampling system. Thus all of the controls and measurement displays are centered about the control unit.

The various switches, gauges, and connections seen on face of the control unit are described below:

Switches

There are five electrical switches with the following functions:

- . Main power (with pilot light and 3-ampere, 115-VAC circuit breaker)
- . Probe heater (with pilot light and 15-ampere, 115-VAC circuit breaker)
- . Oven heater (with pilot light and 3-ampere, 115-VAC circuit breaker)
- . Fan power
- . Elapsed time indicator start-stop switch

The oven circulation fan is connected so that during heating, the fan is in operation regardless of the position of the fan control switch. When the oven heater is "off," the fan may be turned "on" with the oven door open to hasten cooling of the oven, cyclones, and filter.

Elapsed Time Indicator

An elapsed time indicator is used to determine when to move from one traverse point to the next, when performing Method 5 sampling. It is also

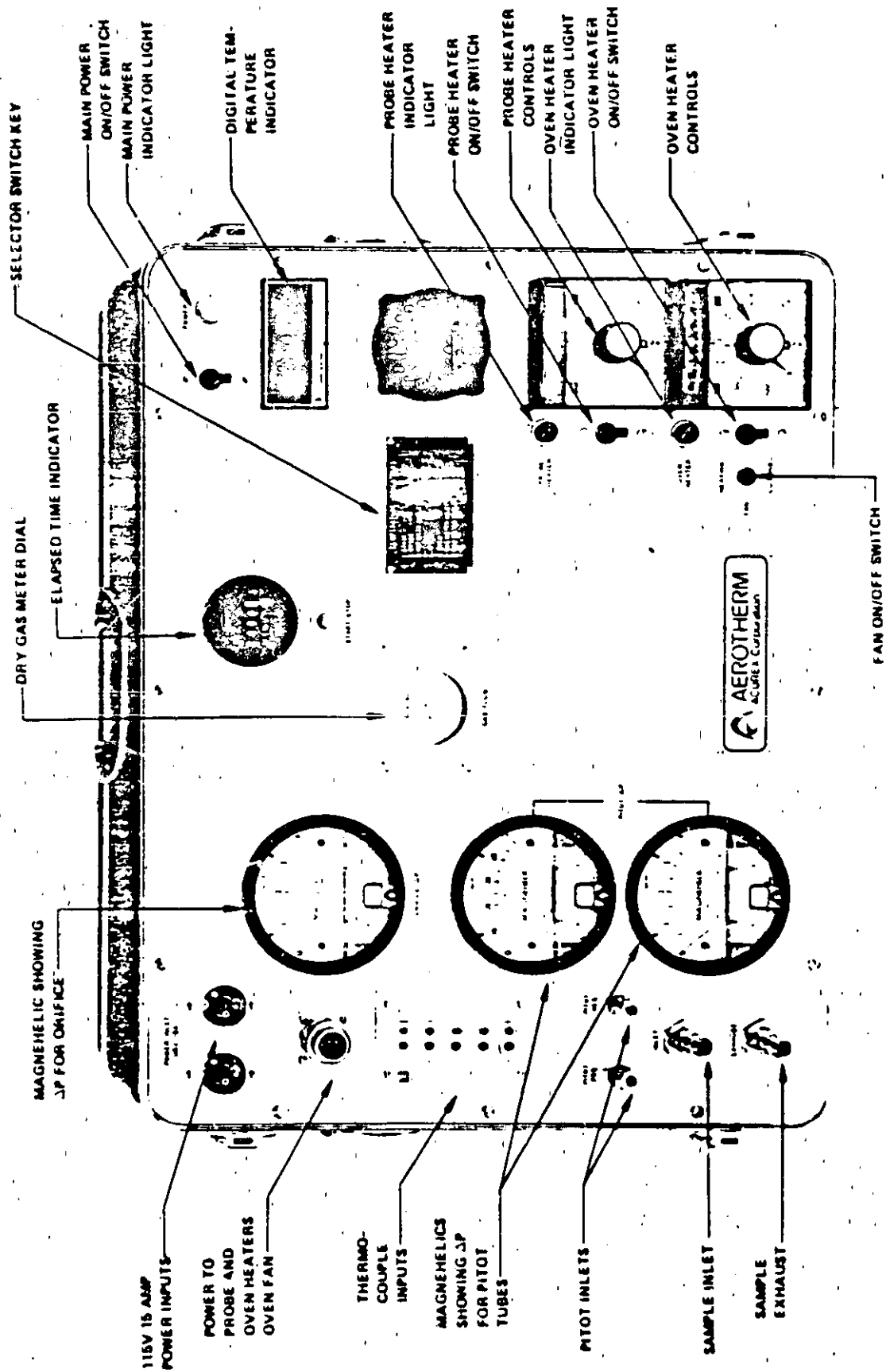


Figure 3-8. Control unit (Ref. 3-1).

useful for SASS sampling to monitor impinger solution change intervals, data logging intervals, and total sampling time. The indicator has a resolution of 1/10 of a minute. The indicator can be reset to zero, and started or stopped with a pushbutton located near the indicator.

Oven and Probe Heater Temperature Controls

Power to the oven and probe heating elements is modulated with adjustable temperature controllers. These controllers use chromel-alumel thermocouples for temperature sensing. Each controller has the following features:

- . Actual temperature continuously displayed
- . Maximum set-point is limited to 500°F by a mechanical stop
- . Power cycling is indicated by red and green lights

The controllers provided with the unit used on this program were of low quality and required continual adjustment to keep them in calibration. After several replacements, the test crew learned to use manual procedures to bring the temperatures to the desired level (i.e., 400°F for the probe and oven) after which the controller would generally hold the temperature, although the indicator might be as much as 100°F off the proper setting. Also, if the controller was turned to the upper limit of temperature (not beyond the scale), the control would lock, requiring disassembly.

Temperature Display

A digital temperature indicator is used together with an eight-point selector switch. The selector switch permits monitoring the temperature at each of the following locations:

- . Stack
- . Probe
- . Oven
- . Impinger train outlet
- . Gas meter inlet
- . Gas meter outlet
- . Two "spare" locations

The temperature range is 0°F to 1500°F with an accuracy of $\pm 4^\circ\text{F}$.

Gas Flow

The cumulative sample gas flow is measured by a Rockwell Model 415 gas meter, a high accuracy meter used for testing. The measurement is displayed by a digital counter and pointer with a resolution of 0.005 cu. ft.

Pressure Gauges

Three Magnehelic pressure gauges can be seen on the face of the control unit. One is used for monitoring the pressure drop across the orifice meter (see following discussion on orifice meter). The other two gages are connected in parallel and indicate the pressure differential of the pitot tube used for measuring stack velocity. One of the gages has a range from 0 to 0.5 inches of water; the other, usually 0 to 4 inches of water. Thus the pitot tube pressure differential can be determined with high precision over the full range.

Umbilical Line Connections

The umbilical line between the control unit, oven, and probe makes the connections with the control unit as follows:

- . Multipoint connector with AC power leads to oven, fan, and probe
- . Dual-pin thermocouple connectors for the stack, probe, and impinger thermocouples.

The separate 25-foot sample hose connects to the vacuum pumps. The exhaust hose of the pump is connected to the "inlet" fitting located on the control unit. The sample gas then passes through the gas and orifice meters in the manner of the typical Method 5 sampling train.

A quick-disconnect fitting is provided at the sample "exhaust" outlet on the control unit.

2. Method 5 sampling system (Joy Train)--The Method 5 sampling system is a standard Joy Manufacturing Company unit shown schematically in Figure 3-9. A special particulate sampling system was designed and fabricated to fit inside the standard oven. A description of the system components is presented below.

CYCLONE SET

In designing the cyclone set for the Joy train, KVB visited Southern Research Institute (SRI), where under EPA sponsorship they were developing a

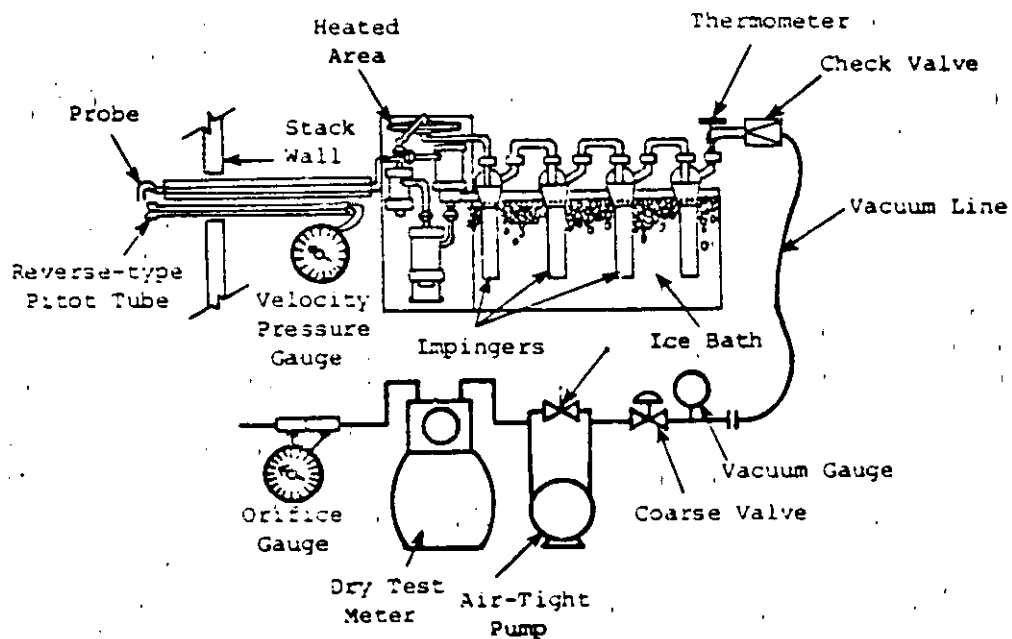


Figure 3-9. Particulate sampling train (modified Joy train).

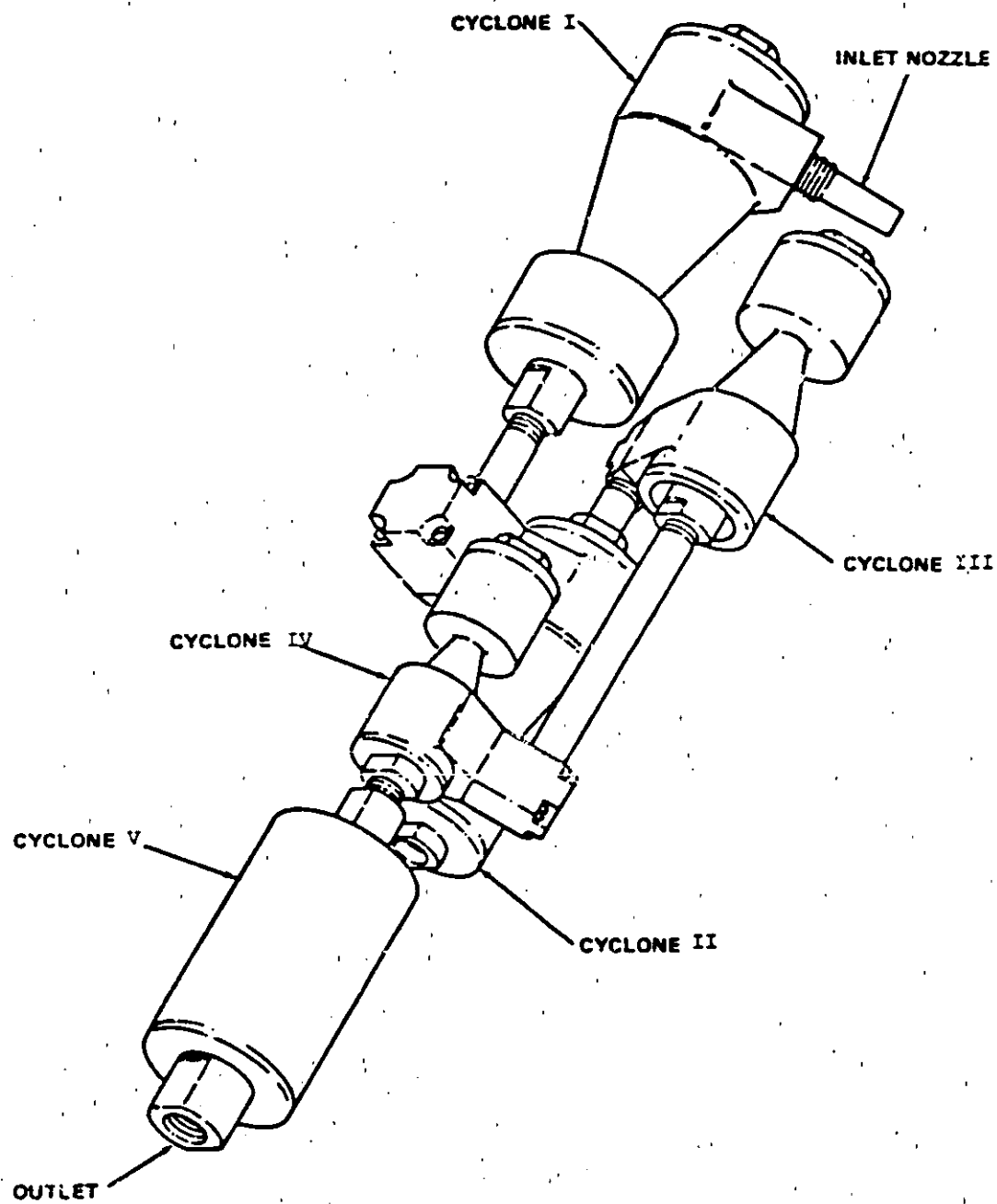


Figure 3-10. Environmental Protection Agency-Southern Research Institute Five-Stage Cyclone (Ref. 3-2).

five-stage cyclone system for in-stack sampling. The system, which is now developed, is shown in Figure 3-10 and the development program is documented in Reference 3-2. The objective was to design three cyclones that would have the same respective cut sizes as the three SASS cyclones except at a sampling rate of one SCFM. SoRI had calibration data on their five cyclones at ambient temperatures but not at 400°F. They were only in the process of developing a high temperature calibration procedure. Dr. Wallace Smith of SoRI calculated that their cyclones I, II, and IV should come as close to matching the SASS cyclones as any designs he could imagine. At the time, even the SASS cyclones had not been calibrated at 400°F. Drawings of the SoRI cyclones were obtained.

Review of the SoRI designs indicated the following problems:

- Eliminating two of the cyclones and fitting the units into the Joy oven caused problems in connecting the units.
- The internal threads between the cap and the body of the cyclones, while necessary for the SoRI objective of a small envelope, appeared to be potentially troublesome for field assembly and disassembly.
- The internal threads in the body could interfere with particulate removal.
- A means for more reliably connecting the cyclones together was required.

A modified design was prepared.

The internal dimensions of the three selected cyclones were used. The external features were designed so that the three cyclones and filter would fit and could be adapted to the 16" x 18" x 7" space of the Joy oven. This design would also eliminate some of the problems noted above. The cyclones are shown in the following figures:

- Figure 3-11 A photograph of Cyclone 1 assembled and disassembled. Also a drawing of Cyclone 1 is shown in Figure 3-18. The reverse exit tube-drawing is shown in Figure 3-19.
- Figure 3-12 A photograph of Cyclone 2 assembled and disassembled. Also a drawing of Cyclone 2 is shown in Figure 3-20.
- Figure 3-13 A photograph of Cyclone 3 assembled and disassembled. Also a drawing of Cyclone 3 is shown in Figure 3-21.
- Figure 3-14 A photograph of the filter holder assembled and disassembled.
- Figure 3-15 A photograph of the overall assembly of the cyclones and filter holder.

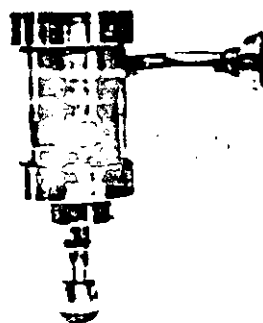


Figure 3-11. Cyclone 1.

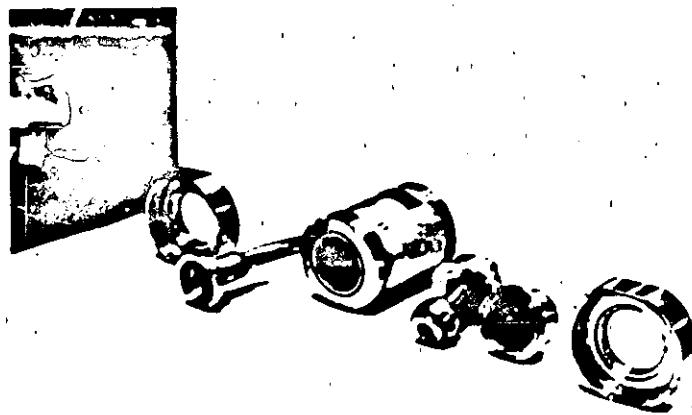
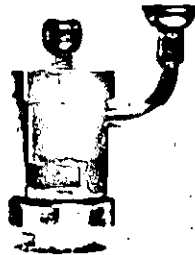


Figure 3-12. Cyclone 2.

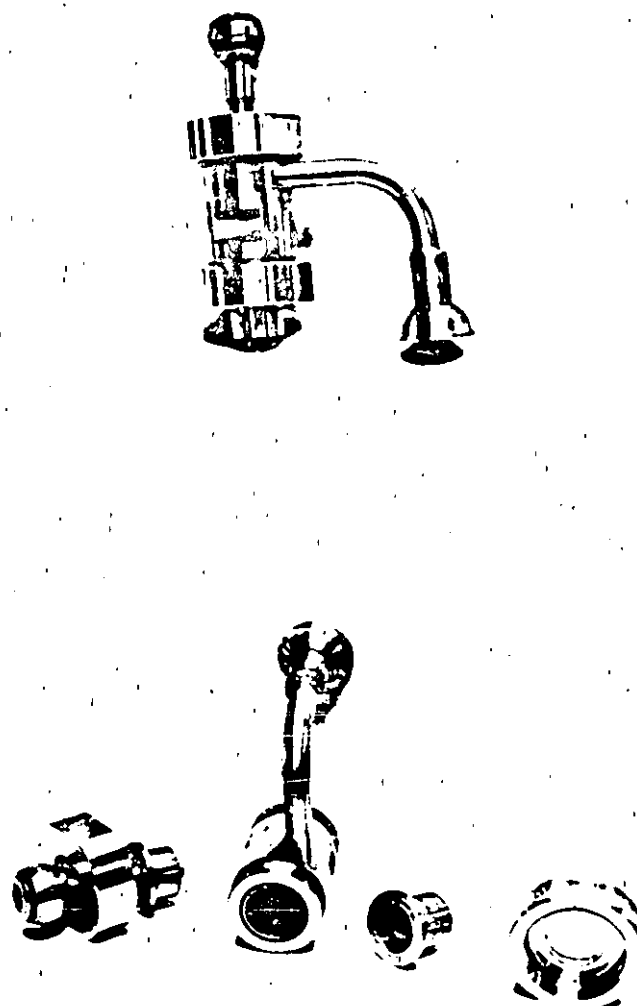


Figure 3-13. Cyclone 3.

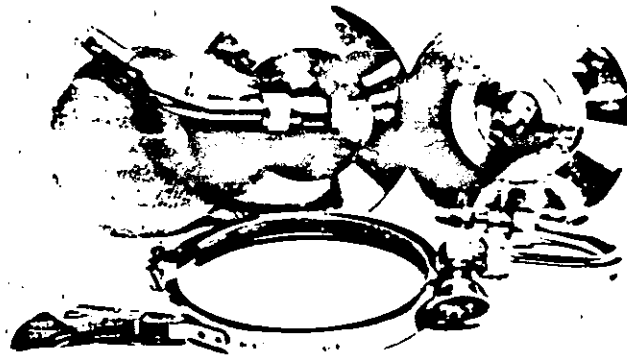
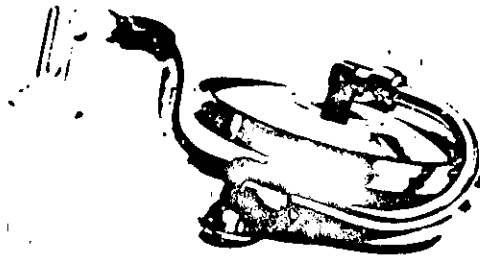


Figure 3-14. Filter holder.

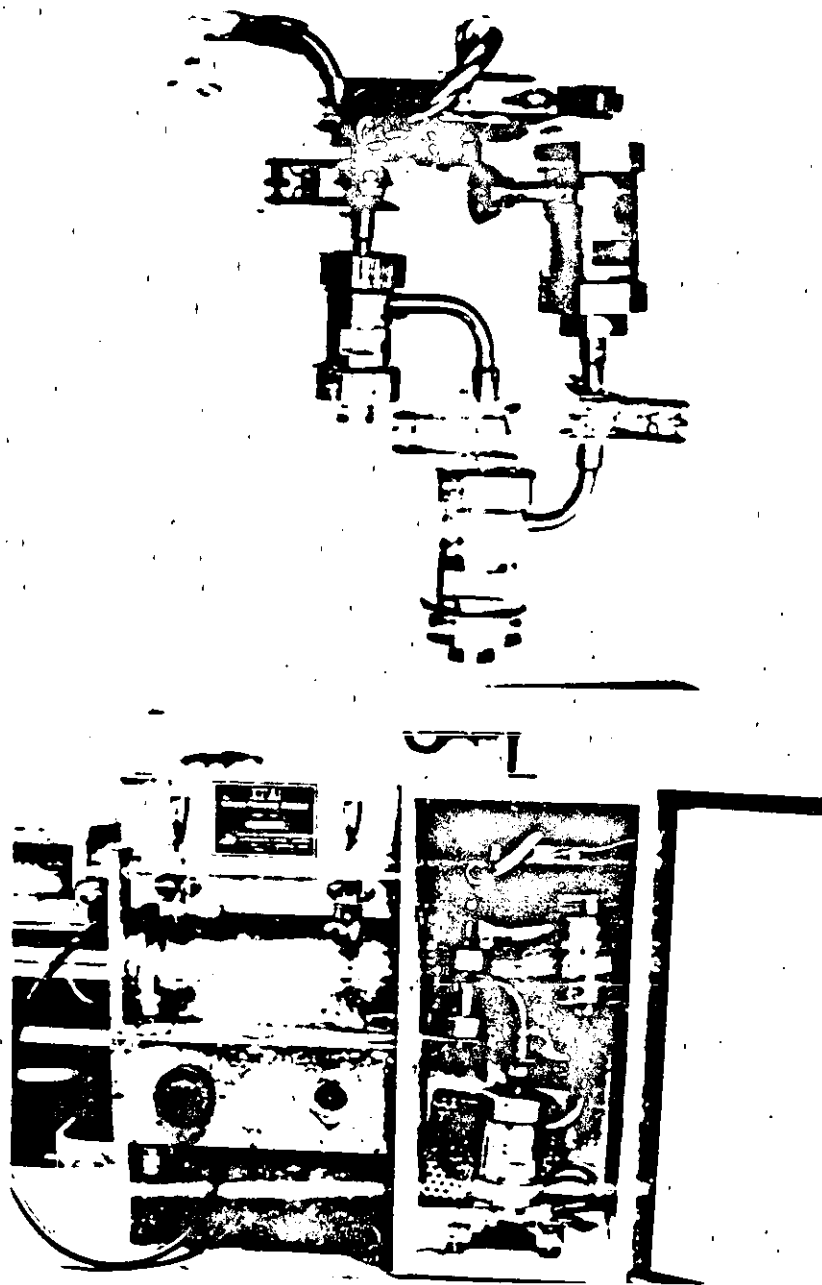


Figure 3-15. Joy train cyclone assembly.

- Figure 3-16 A drawing of the front view of the cyclones and filter holder assembled in the Joy oven.
- Figure 3-17 A drawing of the top view.
- Figure 3-18 Drawing of Cyclone 1.
- Figure 3-19 Drawing of reverse exit tube for Cyclone 1.
- Figure 3-20 Drawing of Cyclone 2.
- Figure 3-21 Drawing of Cyclone 3.
- Figure 3-22 Drawing of stainless steel ball and socket joints used to connect the cyclones to each other and to the probe. Note that grooves for "O" rings have been cut in ball joints to assure a positive seal when "O" ring is in place.

The units were fabricated from 316 stainless steel with high quality and precision. Subsequently, the SORI tests were completed, indicating that the cut points would be as follows:

	<u>400°F D₅₀ Cut Point (Ref 3-10)</u>
Cyclone I	9.1 μ m
Cyclone II	4.1 μ m
Cyclone III	1.3 μ m

Throughout the test program the small cyclones performed perfectly. The ball joints provided no sealing problems and are recommended highly for future designs.

After the initial trial runs with the small train it was found that the original filters on the Joy train were becoming clogged within a short duration. To alleviate this condition, a larger filter holder was fabricated and successfully installed in the unit. Where the original filters were only 47mm in diameter, the new filters were 141mm, the same size as the ones in the SASS train. This improved the sampling routine substantially, reducing the number of filter changes. Figures 3-15 and 3-16 show the larger filter in place.

SAMPLING UNIT

The sampling unit, Figure 3-24, consists of a stainless steel cabinet divided into two sections. The first section is a heated compartment containing provisions for a filter assembly and cyclones; the second section is a compartment containing the impinger train. Openings in the cabinet and clamping devices are provided for attachment of the probe in horizontal positions. Sampling train components in the oven are made of stainless steel, joined by ball and socket joints and provided with clamping devices.

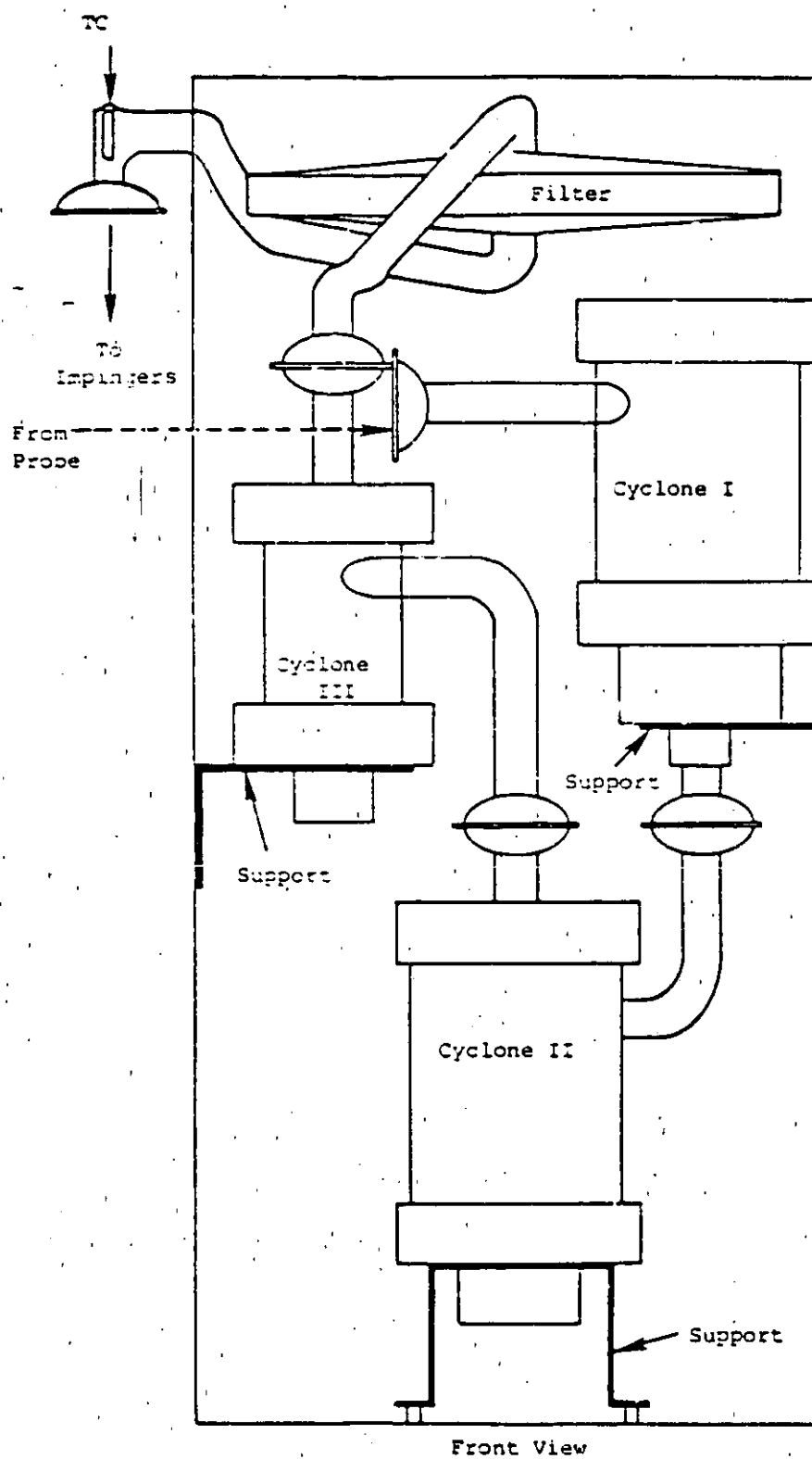
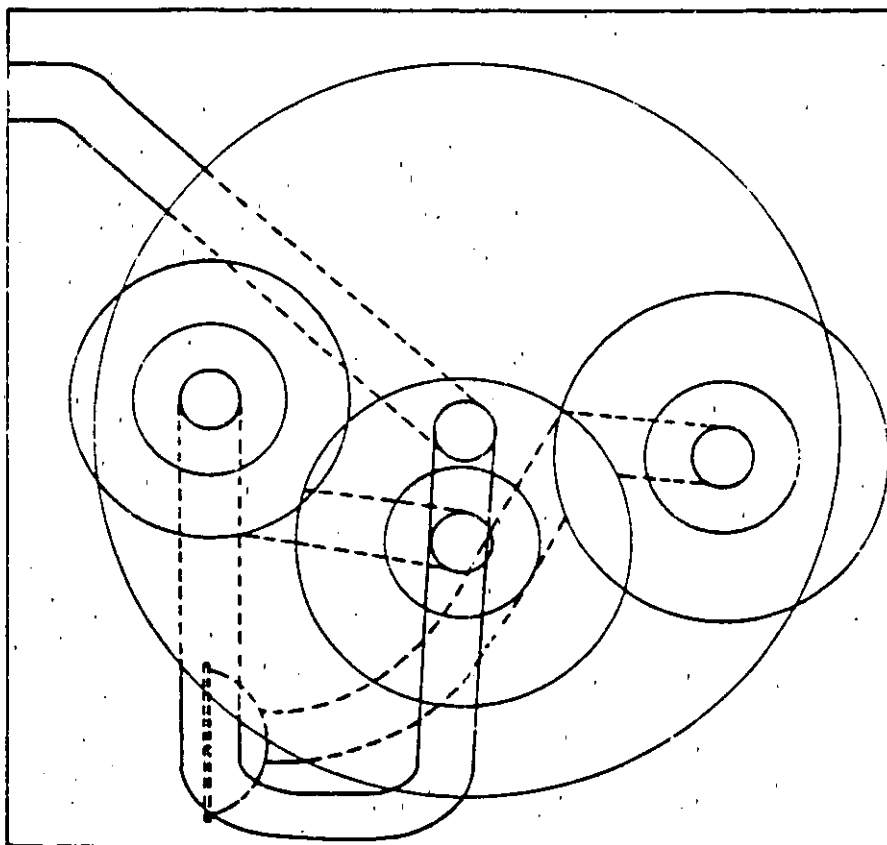


Figure 3-16. Joy train cyclone assembly schematic.

To
Impingers



Assembled Top View

Figure 3-17.

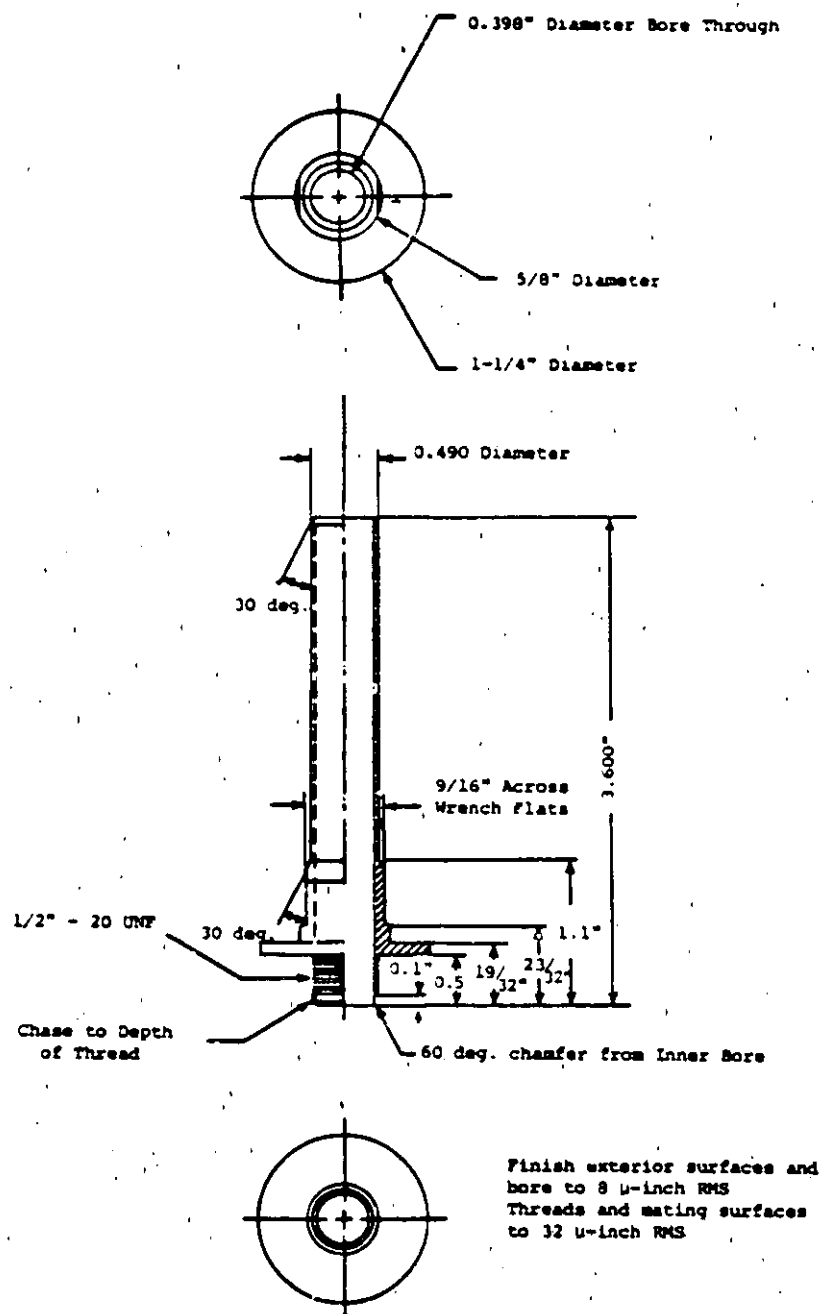
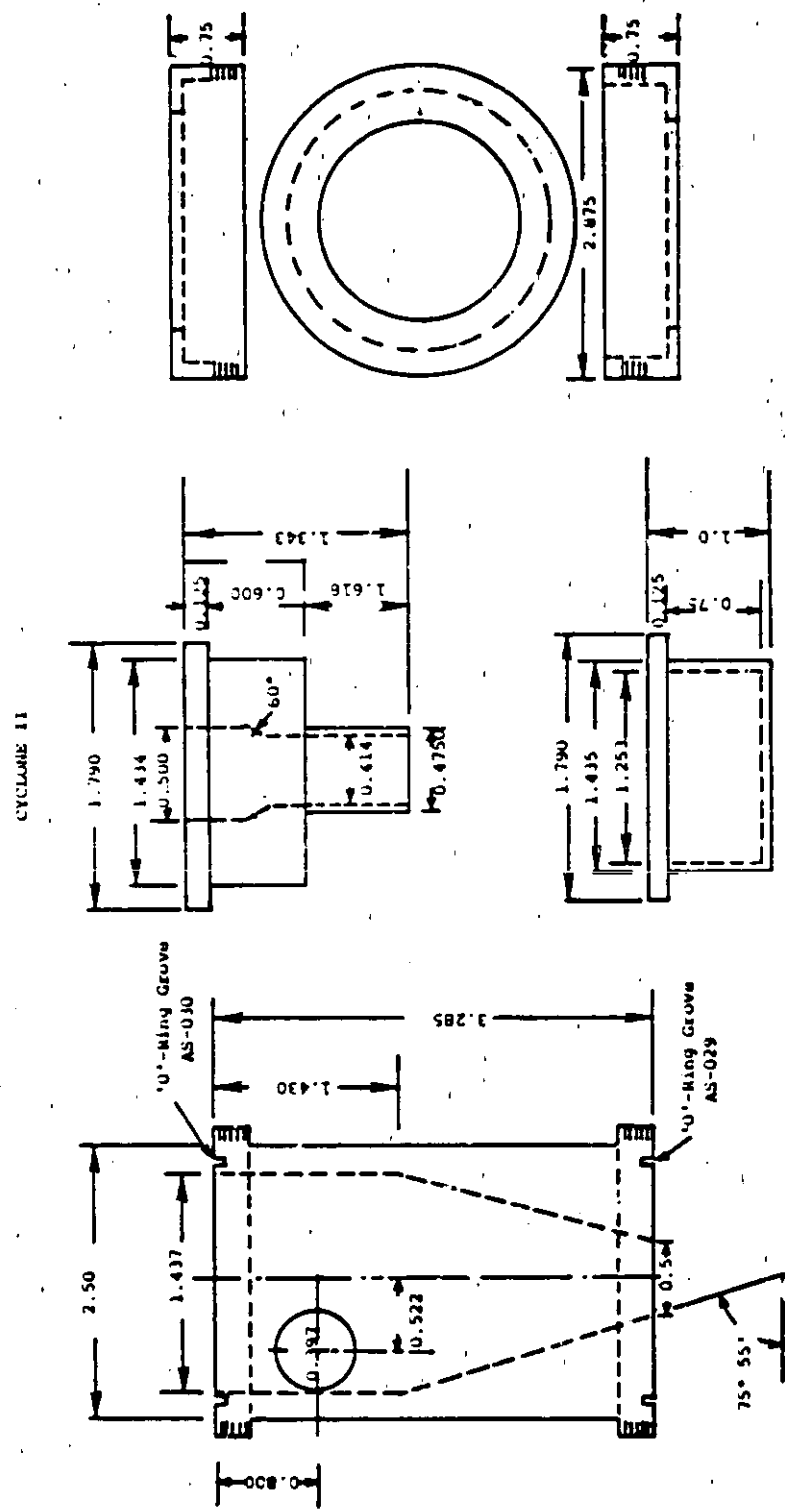


Figure 3-19. Design sketch, reverse exit tube for Cyclone 1.



CYCLONE 11

Figure 3-20. Cyclone 2 design sketch.

KVB 5806-783

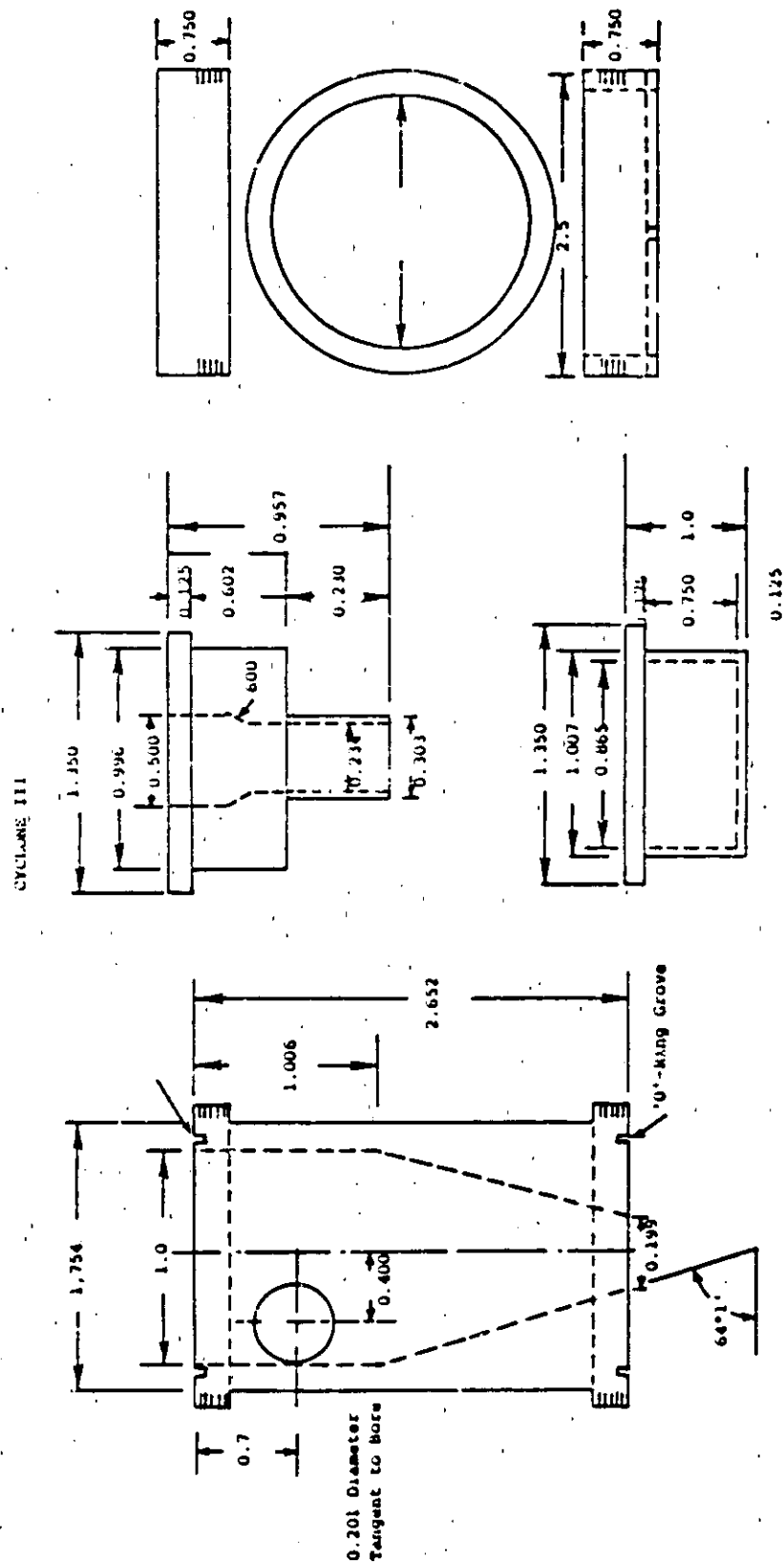


Figure 3-21. Cyclone 3 design sketch.

KVB 5806-783

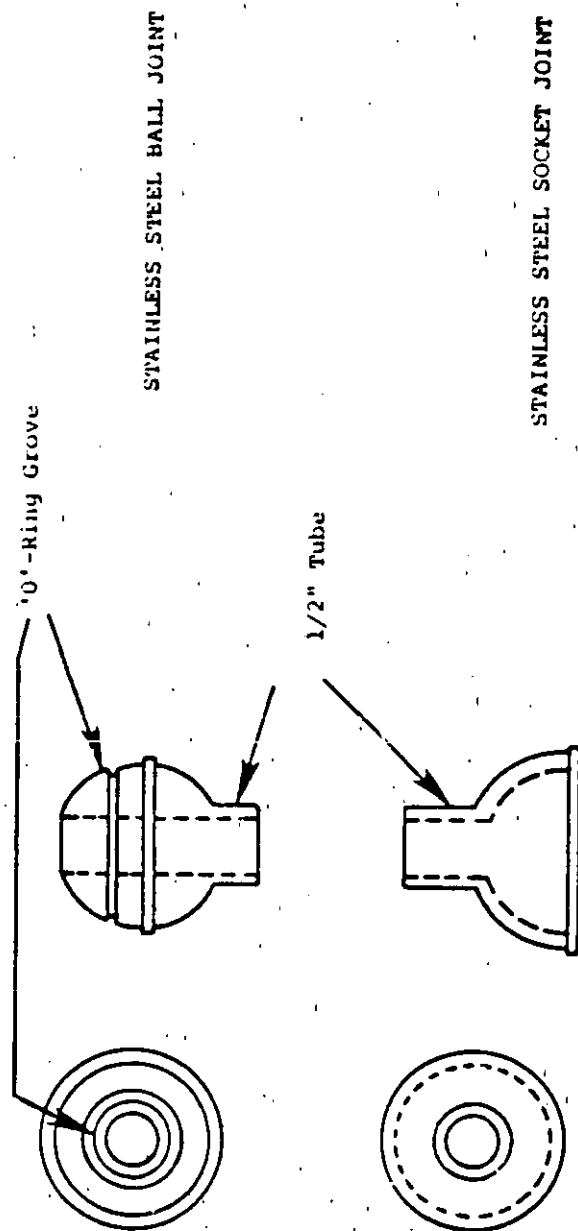


Figure 3-22. Stainless steel ball & socket connectors.

KVB 5806-783

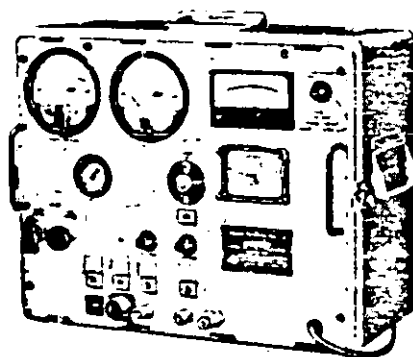


Figure 3-23. Joy Manufacturing Co. control unit.

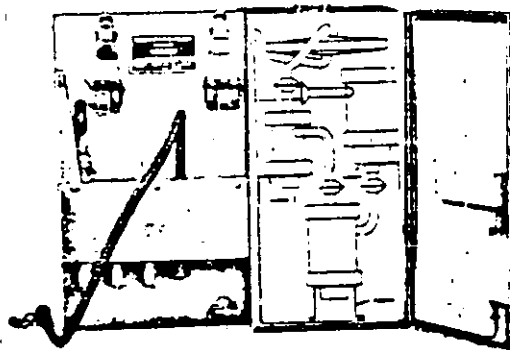


Figure 3-24. KVB modified Joy Manufacturing Co. sampling case.

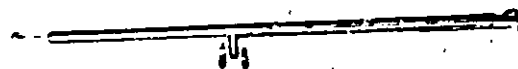


Figure 3-25. Joy Manufacturing Co. probe.

PROBE

The standard probe, Figure 3-25, has an effective length of five feet and consists of a sampling tube, a temperature probe, and a pitot tube. The sampling tube is a length of stainless steel tubing running through the center of an exterior stainless steel tube and terminating in a stainless steel joint a short distance beyond the end of the stainless tube. The stainless steel tubing is heated by a resistance element. Provision is made for use of a variety of sampling nozzles. The pitot tube consists of a pair of stainless steel tubes attached to the assembly.

IMPINGERS

Four impingers are connected in series with glass ball joint fittings. The first, third, and fourth impingers are of the Greenburg-Smith Design, modified by replacing the tip with a 1/2" ID glass tube extending to 1/2" from the bottom of the flask. The second impinger is of the Greenburg-Smith design with the standard tip.

METERING SYSTEM

A vacuum gauge, leak-free pump, thermometers capable of measuring temperature to within 5°F, dry gas meter with 2% accuracy, and related equipment are provided to maintain the appropriate sampling rate and to determine sample volume.

B. Sampling Procedures--

This section will present the procedures that were employed at the test site, including preparation, sampling, disassembly and sample recovery. Analytical procedures that were employed to determine the quantity and composition of the particulate samples are discussed in Section 3.2.2. These procedures apply to both the SASS and Joy sampling trains. The sampling and laboratory procedures outlined below illustrate the detailed preparations and precautions that were taken to insure quality control.

1. Preliminary evaluation of the test site--An important aspect of the sampling procedures was the preliminary assessment of the sampling test site. For a given industrial operation, a sampling location was selected based on accessibility and exhaust flow characteristics. A minimum of a 3-inch sampling port was required to accommodate the pitot and sampling nozzle and probe.

Ideally, the exhaust flow at this location should be fully mixed from the process or combustion zone and will be steady and uniform, not disturbed by elbows or dampers. This generally was not the case. A pitot tube traverse and temperature measurement was made in accordance with the procedures outlined in the Federal Register (Ref. 3-3). Data was recorded on the sheet illustrated in Form 5804-4 (Sect. 3.4). Based on the results of this traverse, sampling locations within the flow stream were selected to provide a spatially integrated sample.

2. Sample flow and isokinetic conditions--To preserve the cyclone "cut-off" points, the sampling flow rate was adjusted to maintain 4.0 SCFM at the required 400°F cyclone oven temperature conditions. Isokinetic sampling was also desired and was achieved to the degree possible by selecting the proper probe nozzle diameter. Isokinetic sampling is a condition where the velocity, V_n , of the sample through the nozzle is the same as the velocity, V_s , of the stack gas. The nozzle velocity V_n is related to the nozzle diameter, d , and to the meter flow rate Q_m by the following equations:

$$V_n = \frac{Q_n}{\frac{\pi}{4} \left(\frac{d}{12}\right)^2} \times \frac{1}{60}$$

$$Q_n = \frac{Q_m}{\left(1 - \frac{\%H_2O}{100}\right)} \cdot \frac{T_s}{T_m} \cdot \frac{P}{P_s}$$

for the isokinetic sampling the stack velocity equals the nozzle velocity:

$$V_s = V_n$$

substitute the $V_s =$

value from the

above equations

$$V_s = \frac{\frac{Q_m}{\left(1 - \frac{\%H_2O}{100}\right)} \cdot \left(\frac{T_s}{T_m}\right) \cdot \frac{1}{60} \cdot \frac{P_m}{P_s}}{\frac{\pi}{4} \left(\frac{d}{12}\right)^2}$$

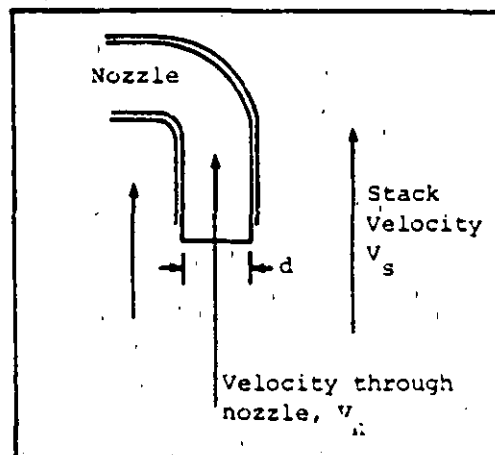
and solve for the nozzle diameter, d .

$$d = 24 \cdot \frac{Q_m}{\left(1 - \frac{\%H_2O}{100}\right)} \cdot \left(\frac{T_s}{T_m}\right) \cdot \left(\frac{P_m}{P_s}\right) \cdot \frac{1}{60}$$

Equation definitions
appear on following
page.

* All prepared data sheets used in these tests are presented in Section 3.4

T_s = stack temperature, °R
 T_m = dry gas meter temperature, °R
 V_s = stack velocity, ft/sec.
 V_n = velocity at nozzle, ft/sec
 Q_m = gas flow rate at meter, ft³/min
 Q_n = gas flow rate at nozzle, ft³/min
 d = diameter of nozzle, in.
 P_m = meter pressure, psia
 P_s = stack pressure, psia
 $\% H_2O$ = stack gas water content



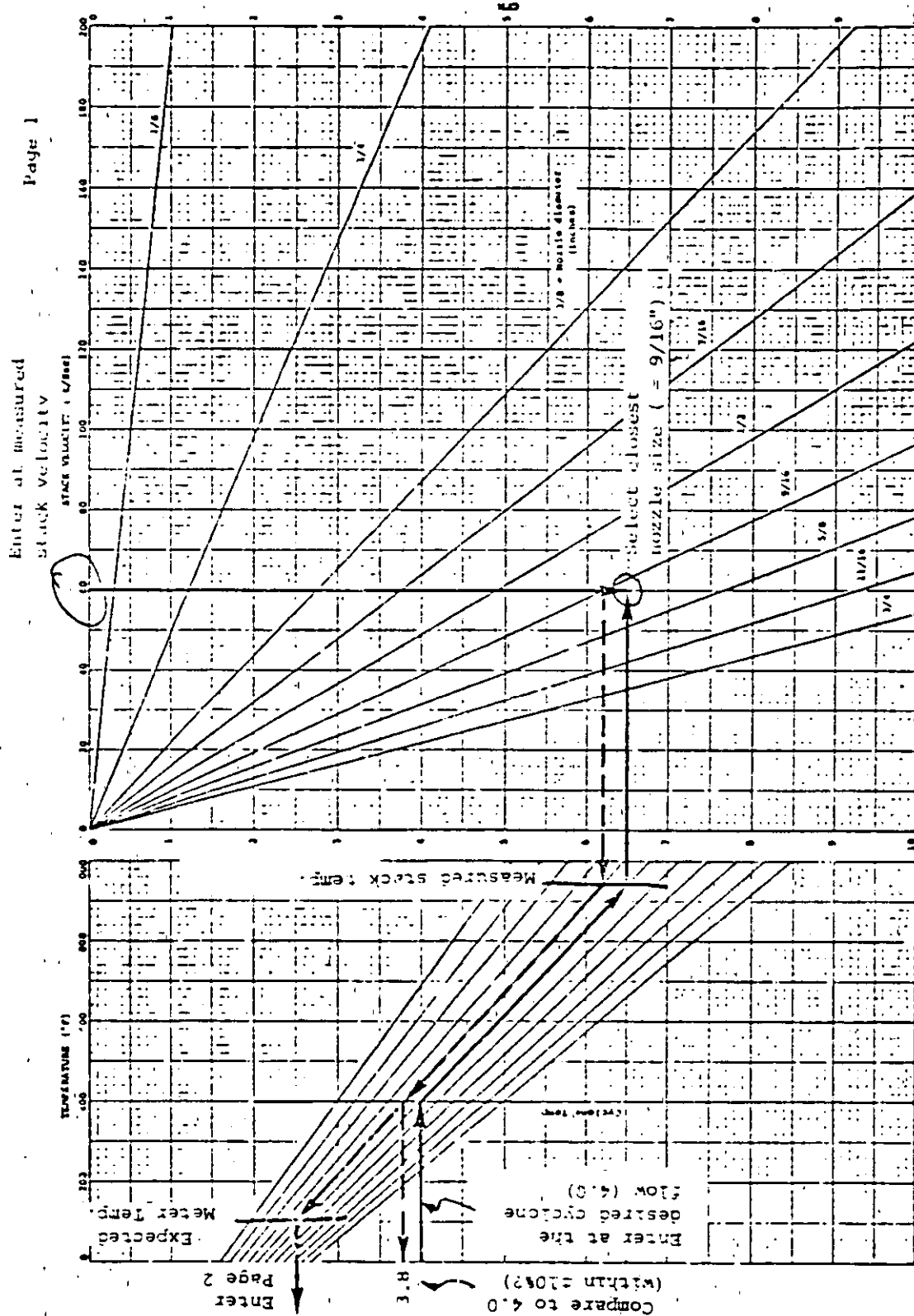
The sampling flow rate Q_m was maintained at 4.0 SCFM for the SASS and 1.0 SCFM for the Joy to preserve the cyclone cut-off points. The nozzle was chosen to have the closest diameter to the calculated diameter. For the Method 5 procedure, Q_m could be adjusted to account for the nozzle difference.

After the stack velocities and temperature levels have been established by the preliminary stack traverse, the nomogram illustrated in Figure 3-36 was used to select the proper nozzle diameter and for the required sampling rate. If stack conditions were encountered that were not covered by the nomogram, the above equations were used.

3. Preparation of the sampling trains--

a. Cleaning--Prior to sampling, all sampling train components and sample containers were cleaned first with distilled water, and then with acetone. The distilled water was dispensed in plastic wash bottles; the acetone was dispensed using Teflon or glass wash bottles. After each part was washed with acetone, it was dried in a filtered stream of dry air or nitrogen.

Any solid residues adhering to the internal surfaces were removed with tap water and a plastic scouring pad before proceeding with the solvent cleaning procedure.



Alt 2.0

Page 2

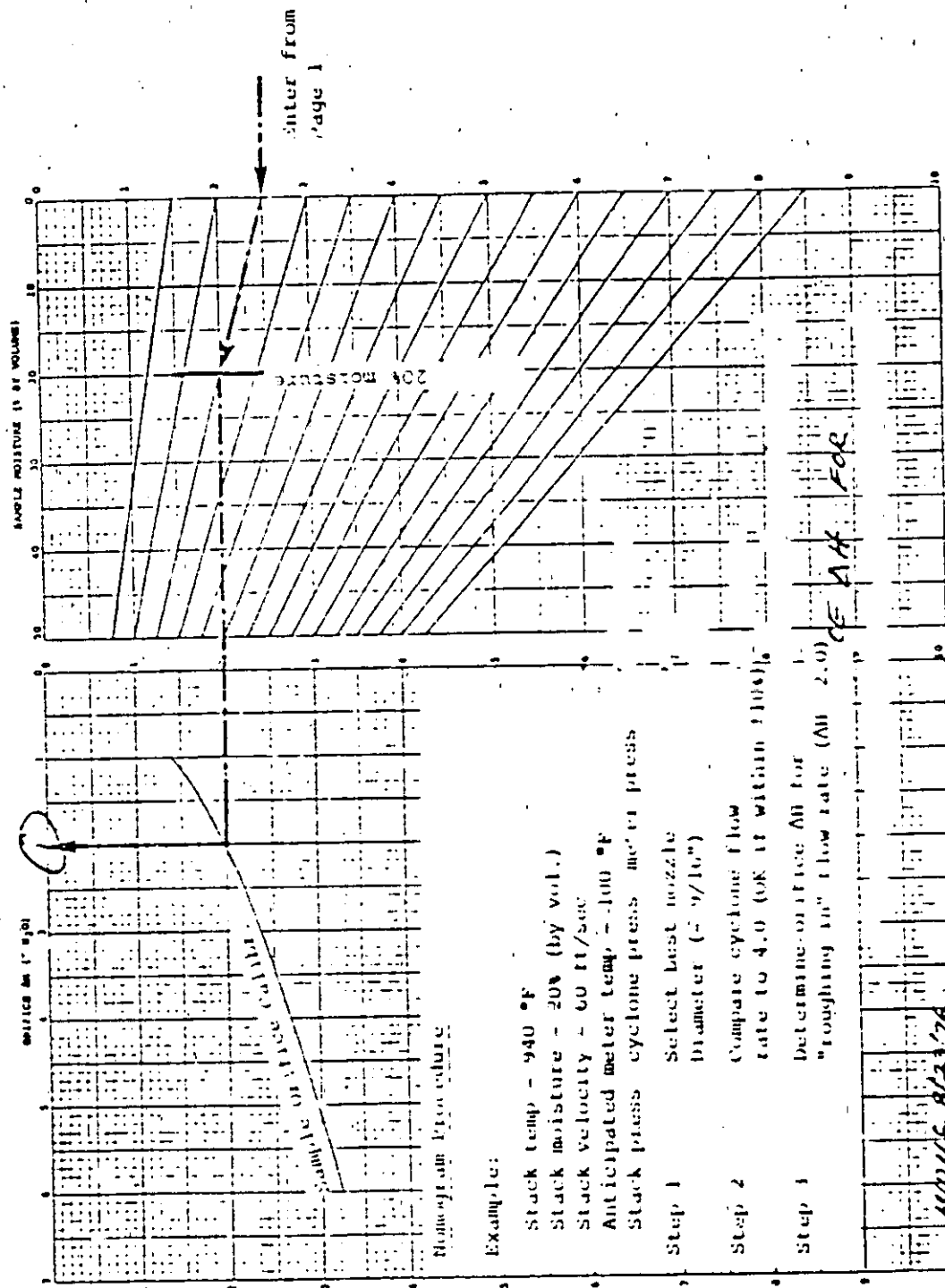


Figure J-26, (Continued) SASS operating nomogram.

KVb 5000-783

After cleaning, the cyclone assemblies were assembled and capped off. The other sections of the train, including the probe, filter housing, impinger trains, and interconnecting hoses, were capped off.

b. Filter preparation--Using stainless steel tweezers, each filter was placed in a clean, numbered 150 glass petri dish. They were baked at 220°F for at least three hours in a drying oven, then immediately transferred to a desiccator to cool.

The filters were weighed once and then a second time several hours later, to confirm the initial weighing. This was the weight used to determine the mass particulate catch on the filter. Several filters were prepared to be used in the event that particulate grain loading was high.

c. Impinger solutions--The following solutions and procedures were used for impinger sample bottles:

<u>Impinger</u>	<u>Reagent</u>	<u>SASS Quantity</u>	<u>Joy Quantity</u>
#1	H ₂ O	400 ml	100
#2	H ₂ O	400 ml	100
#3	empty	---	---
#4	(CaSO ₄)*	750 g	200 g

*3-mesh, color-indicating Drierite

It was sometimes necessary to replace the Drierite several times during a test run. A marked decrease in Impinger #4 outlet temperature (moisture absorption by Drierite produces heat) was found to indicate Drierite depletion when the Drierite color change was difficult to detect.

The spent Drierite was not kept for analysis. However, the weight gain due to added water was recorded and used to determine moisture of the stack gas.

4. Sampling trains assembly and preheating--Each component of the trains was transferred as a separate unit to the test site with all sealing caps in place. Care was taken when removing caps for correction of component so as to make certain that no foreign matter entered the components. A leak check was conducted with the probe capped before installing the probe nozzle. The leak rate was less than 0.05 CFM at 20"Hg pump suction. The proper nozzle selected

on the basis of the isokinetic requirements above was assembled and the sampling train was then ready for use.

The cyclone oven and probe were preheated to 400°F before sampling was started. This was required to prevent the condensation of moisture in the cyclone that may interfere with sample collection.

5. Sampling procedure--Actual sampling was conducted in an identical fashion as employed for EPA Method 5. The nozzle/probe assembly was inserted into the stack in the proper orientation to the initial sampling location in the flow stream.

The sampling run was initiated by turning on the vacuum pump and adjusting the intake valve to achieve the proper flow rate. Periodic checks and adjustment of flow rates and temperatures were made during the course of the sampling run. Data was recorded at periodic intervals on the data sheet shown in Form 5806-2, Section 3.4.

It was often necessary to change filters when sampling effluents with high fine particulate loadings in order to obtain sufficient sample volume. This was generally evidenced by a gradual increase in sample pump vacuum required to maintain sample flow. In this event, the train was shut down and a new filter assembly containing a clean filter was installed.

A total sample volume of between 500 and 1500 cubic feet was collected. When sufficient volume had been collected, the pump was turned off, the probe assembly removed from the stack, and the cyclone oven opened to expedite cooling. The nozzle probe and filter holder were disconnected and capped off. These items, along with the impingers with liquids, were transported to the laboratory for sample recovery.

6. Sample recovery--The procedure for transferring samples from the various portions of the SASS train into storage containers is outlined in the flow diagram given in Figure 3-27.

Table 3-1 lists the samples to be recovered from the SASS train and the recommended containers used for sample storage and shipping. In some cases, more than one container was required. All containers were cleaned prior to use according to the procedure used for cleaning the train as described above.

Figure 3-27.

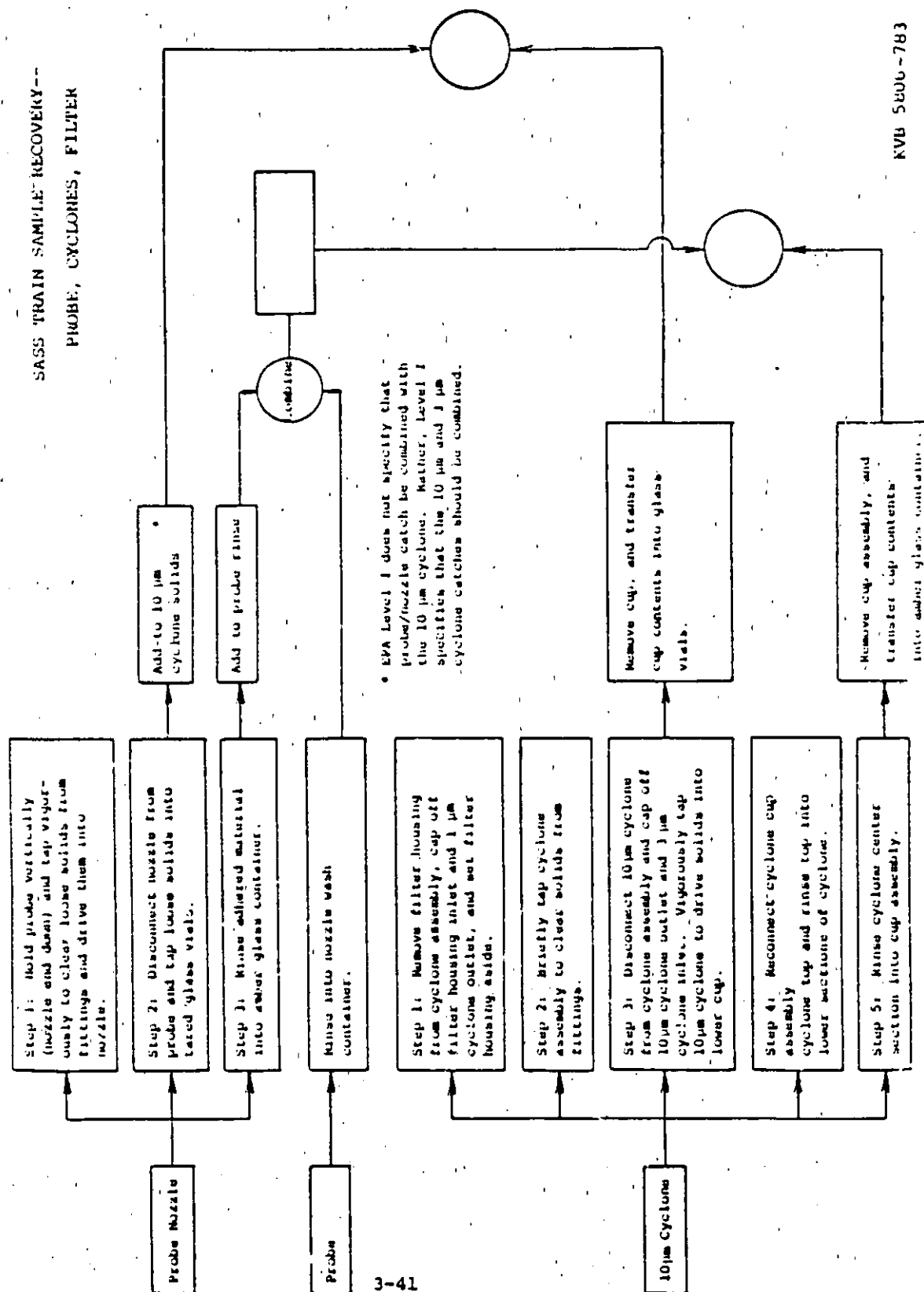
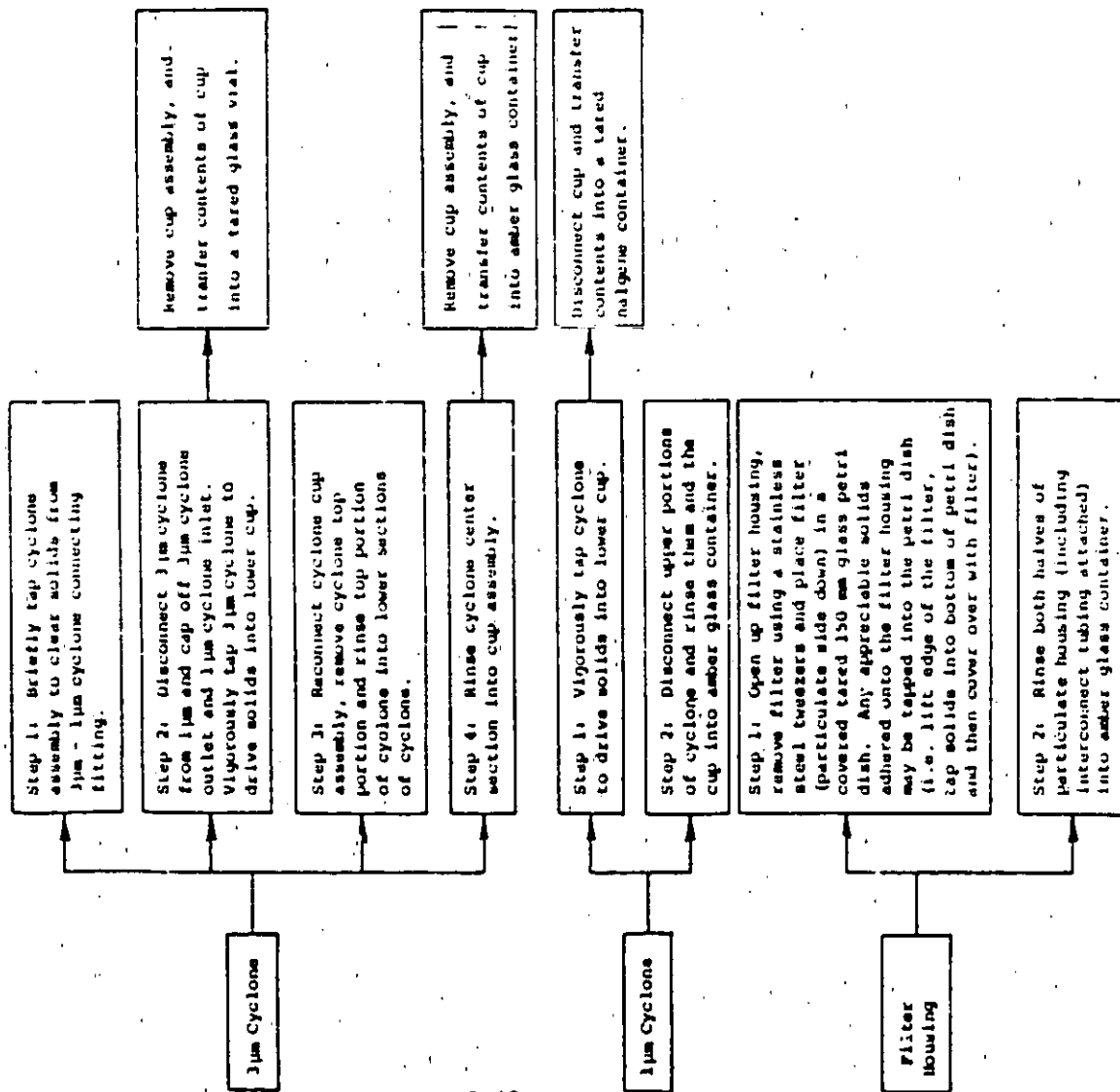


Figure 3-27 (Cont.)

SASS AND JOY TRAIN SAMPLE RECOVERY--
PROBE, CYCLONES, FILTER



1. Use distilled water for all rinses.
2. Handle all tared containers with gloves.
3. Transfer of solids may be assisted by the use of stainless steel spatulas and powder funnels. Nylon bristle brushes may also be used if necessary.

KVH 5H06-783

TABLE 3-1. SAMPLE STORAGE/SHIPPING CONTAINERS

Train Component	Sample Type	Container Required*
Probe and nozzle	solid tappings	Tared 4 dram vial
	solvent wash	250 ml amber glass
10 ₂ cyclone	cup solids	Tared 4 dram vial
	solvent wash	250 ml amber glass
13 ₂ cyclone	cup solids	Tared 4 dram vial
	solvent wash	250 ml amber glass
14 cyclone	cup solids	Tared 4 dram vial
		250 ml amber glass
Filter holder and filter	solid tappings and filter	Tared 150 mm glass petri dish
	solvent wash	Add to impinger
Impinger #1	contents & rinses	1 liter LPE
Impinger #2	contents & rinses	1 liter LPE
Impinger #3	contents & rinses	1 liter LPE

*All glass containers must have Teflon cap liners.

7. Sample processing and analysis--

a. Cyclones--Each cyclone solid catch was transferred to a transporting container, desiccated for one hour, and weighed. These samples were sent to Armament Systems Corporation for predominant elemental composition analysis by X-ray fluorescence, then to Rockwell Air Monitoring Center for sulfate, nitrate, and carbon analysis. The procedures for these analyses are discussed in Section 3.2.2.

Each cyclone was rinsed with distilled water and the rinsed material collected separately. The water was evaporated and the remaining sample baked for one hour at 250°F, desiccated, and weighed on an Ainsworth torsional balance. This weight was included in each of the cyclone's solid weight catches.

b. Filter--The filter was transferred to a petri dish, desiccated, for one hour, and weighed. The filter and particulate were sent to Armament Systems for predominant elemental composition analysis, then to Rockwell for sulfate, nitrate, and carbon analysis. The filter housing was rinsed with distilled water and collected with the impinger rinses.

c. Impingers--The volume of water in each impinger was measured. The water from the first three impingers was combined along with the water rinse from these impingers. The combined solution was extracted five times with 25 ml portions of reagent grade methyl chloroform for each 500 ml of solution to determine the organic content of the impinger catch. The methyl chloroform was transferred to a tared vial and evaporated at room temperature in a dry air stream. This sample was desiccated for one hour and weighed. This weight was the organics content of the impinger catch and was included in the weight of the impinger catch.

The water remaining from the above extraction was transferred to a tared beaker, evaporated to dryness, desiccated for one hour, and weighed. This sample was sent to Armament Systems for predominant elemental composition analysis by x-ray fluorescence, then to Rockwell AMC for sulfate, carbon and nitrate analysis.

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 Armanent 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 spectrometers) 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 STP435, 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 Glaque

* Formerly Analox 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 hydrofluoric 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^{2-}) 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^{2-} 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 this pH the barium complex is blue and the free MTB is brownish-red. (absorbs light at 460nm). 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 SO₄²⁻ 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^{2-} analysis, section 3.2.2, A.1.a. above) was filtered for the analysis of nitrate. Colorimetric analysis was performed using the Cd reduction-diazo dye method. The detection limit was 0.5 $\mu\text{g/ml}$ (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 instrument, 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 $^\circ\text{C}$ and then at 800 $^\circ\text{C}$. This filament is in a sealed system with O_2 flowing first over the filament, then through a furnace kept at 800 $^\circ\text{C}$, 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 $^\circ\text{C}$ for at least eight hours. The ampules were then cooled 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 l) 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 non-luminous blue-violet. 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:

$$\text{velocity (ft/sec)} = 2.9 [(\text{vel. head in H}_2\text{O})(\text{Temp } ^\circ\text{K})]^{1/2}$$
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 ($9.2 \mu\text{m}$ for SASS and $8.3 \mu\text{m}$ for Joy)
3. Second or Middle Cyclone Catch--contained only particles of the D_{50} calibrated cut size for this cyclone ($3.8 \mu\text{m}$ for SASS and $1.9 \mu\text{m}$ for Joy).
4. Third or Small Cyclone Catch--contained only particles of the D_{50} calibrated cut size for this cyclone ($1.3 \mu\text{m}$ for SASS and $0.6 \mu\text{m}$ 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 $0.01 \mu\text{m}$).
6. Impinger Catch--contained aerosols which were vapor through the 400°F filter and had condensed in the impinger, and submicron particles less than $0.01 \mu\text{m}$. However, pseudo particulates [particles formed after the filter, e.g., $\text{SO}_3 + 3\text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_4 \cdot 2\text{H}_2\text{O}$ and $2\text{NH}_3 + \text{SO}_3 + \text{H}_2\text{O} \rightarrow (\text{NH}_4)_2\text{SO}_4$] 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 articles 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/cm³. It is noted that when the data are extra-

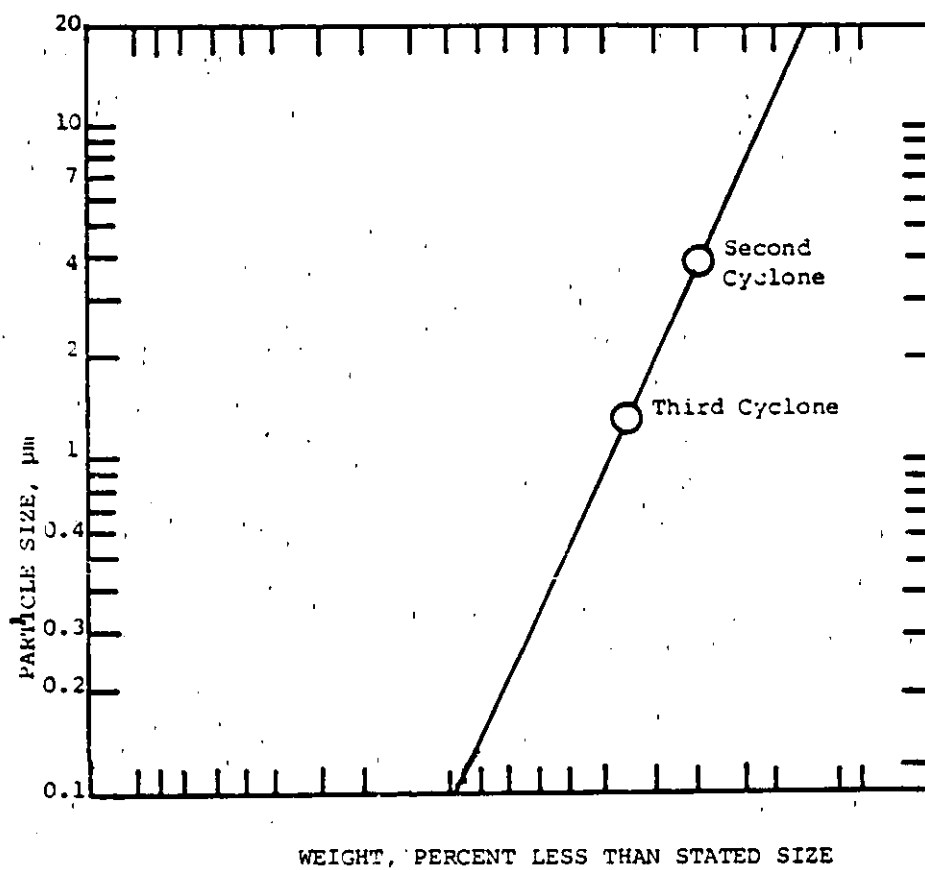


Figure 3-28. Illustration of particle size distribution construction.

TABLE 3-2. LABORATORY CALIBRATION OF THE FIVE-STAGE CYCLONES
D₅₀ 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
		Cyclone D ₅₀ Cut Points										
		Micrometers										
Flow	Temp											
l/min	°C											
7.1	25											
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)				

D₅₀ cut points enclosed in parentheses are derived from the experimental data using
Stoke's Law.

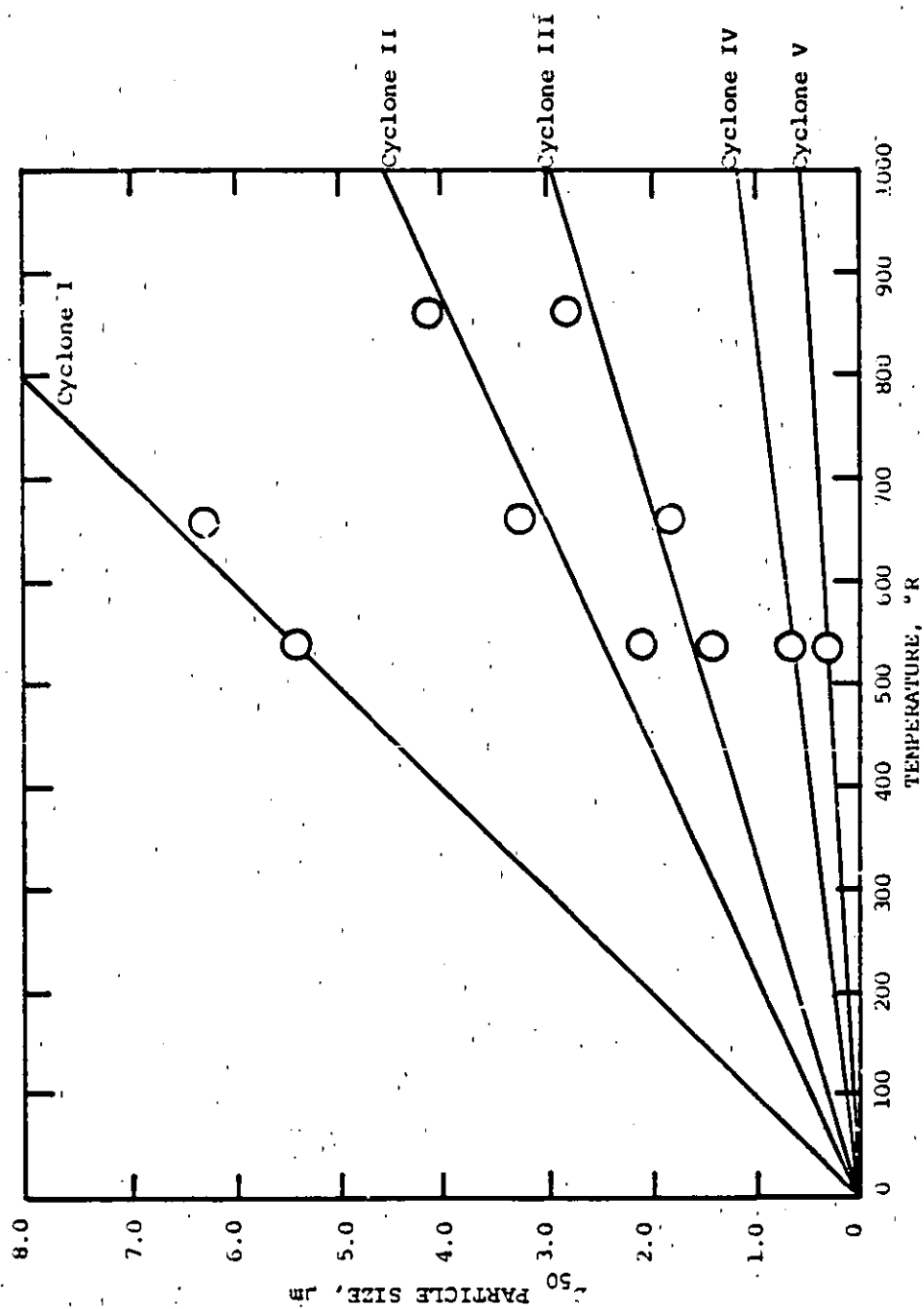


Figure 3-29. D₅₀ particle size, μm vs temperature °R
at flow rate of 1.0 acfm and 1.00 gm/cm³. KVB 5806-783

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:

$$\begin{aligned}
 \text{flow rate at cyclones} &= \frac{(V_s + V_w)}{t} \times \frac{T_o}{520} \\
 &= \frac{(912 + 96)}{240} \times \frac{660}{520} \\
 &= 5.33 \text{ wacfm}
 \end{aligned}$$

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	} these values are corrected for flow rate only
3 μ cyclone - 4.6	
1 μ cyclone - 1.6	

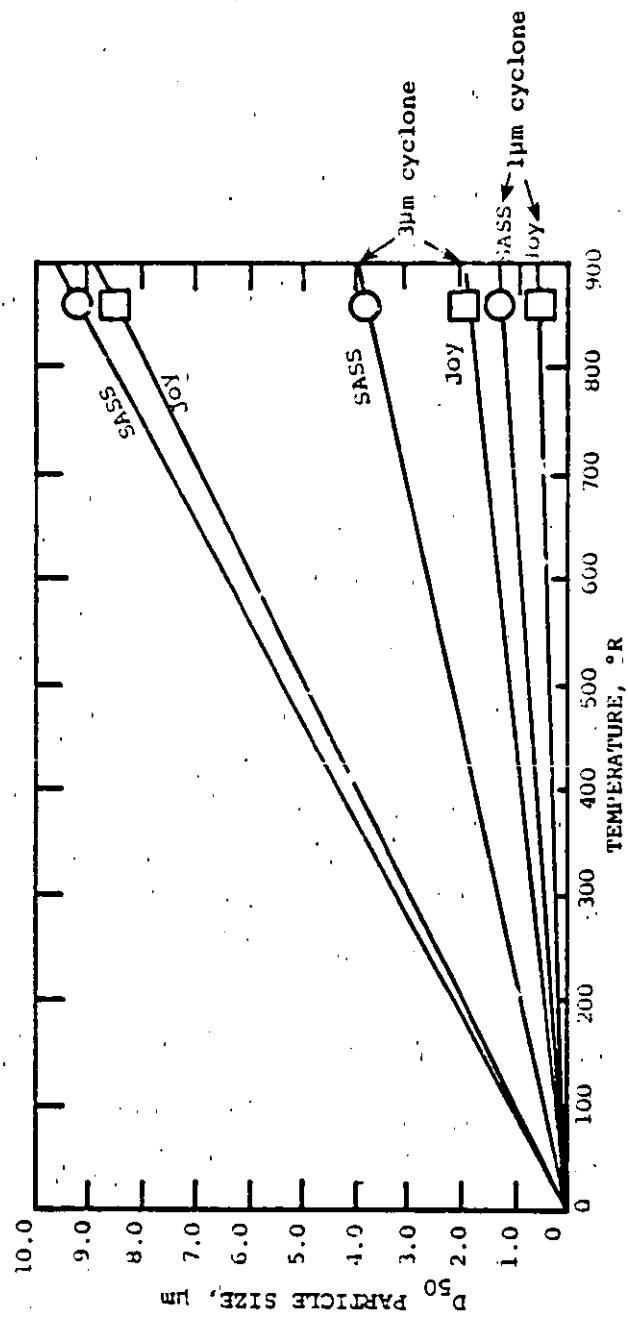


Figure 3-30. Temperature correction curves for the six cyclones used in the program.

KVB 5806-763

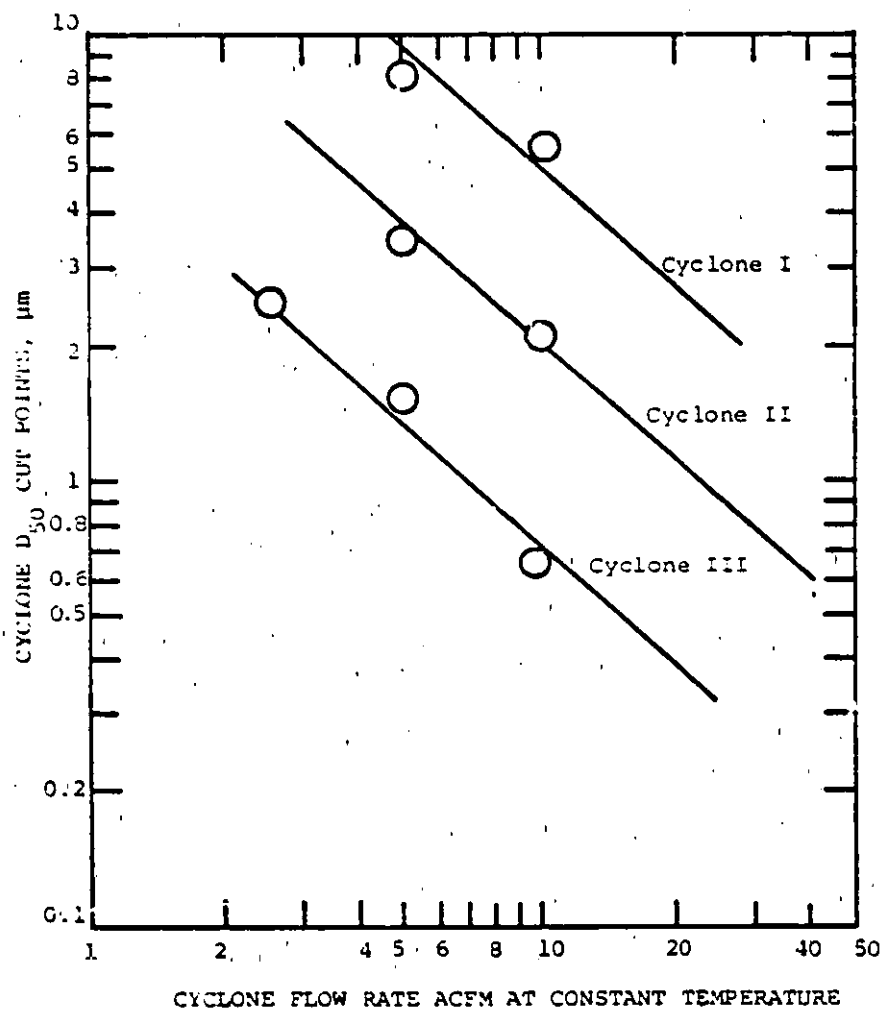


Figure 3-31. Cyclone flow rate vs D_{50} cut point for small cyclones.

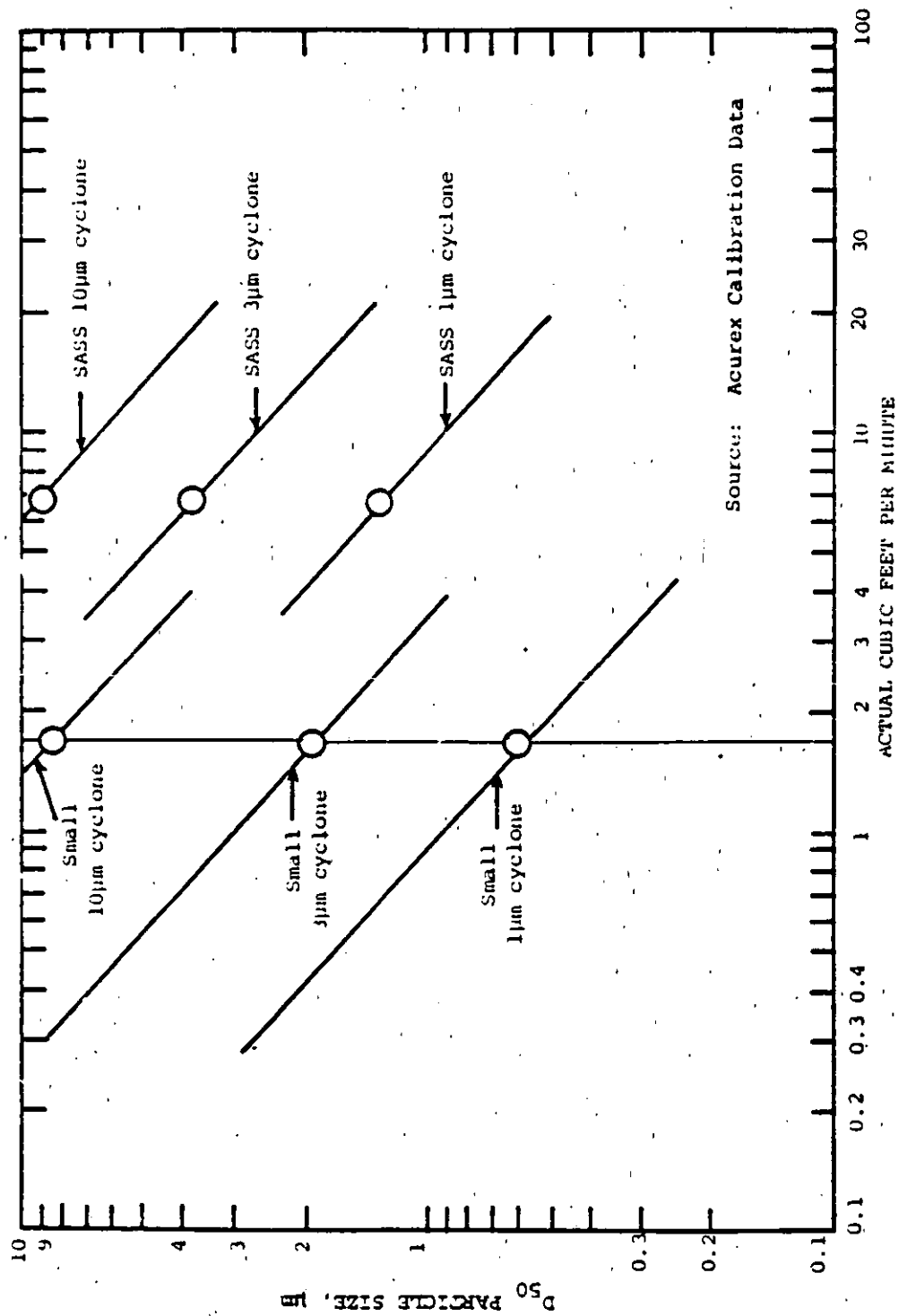


Figure 3-32. Cyclone flow rate vs D_{50} cut point for small and SASS cyclones.

KVB 5806-783

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
10 μ cyclone	→	11.5	→	8.9 μ m
3 μ cyclone	→	4.6	→	3.5 μ m
1 μ cyclone	→	1.6	→	1.3 μ m

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 $2.5 \mu\text{m}$ 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 μm . 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

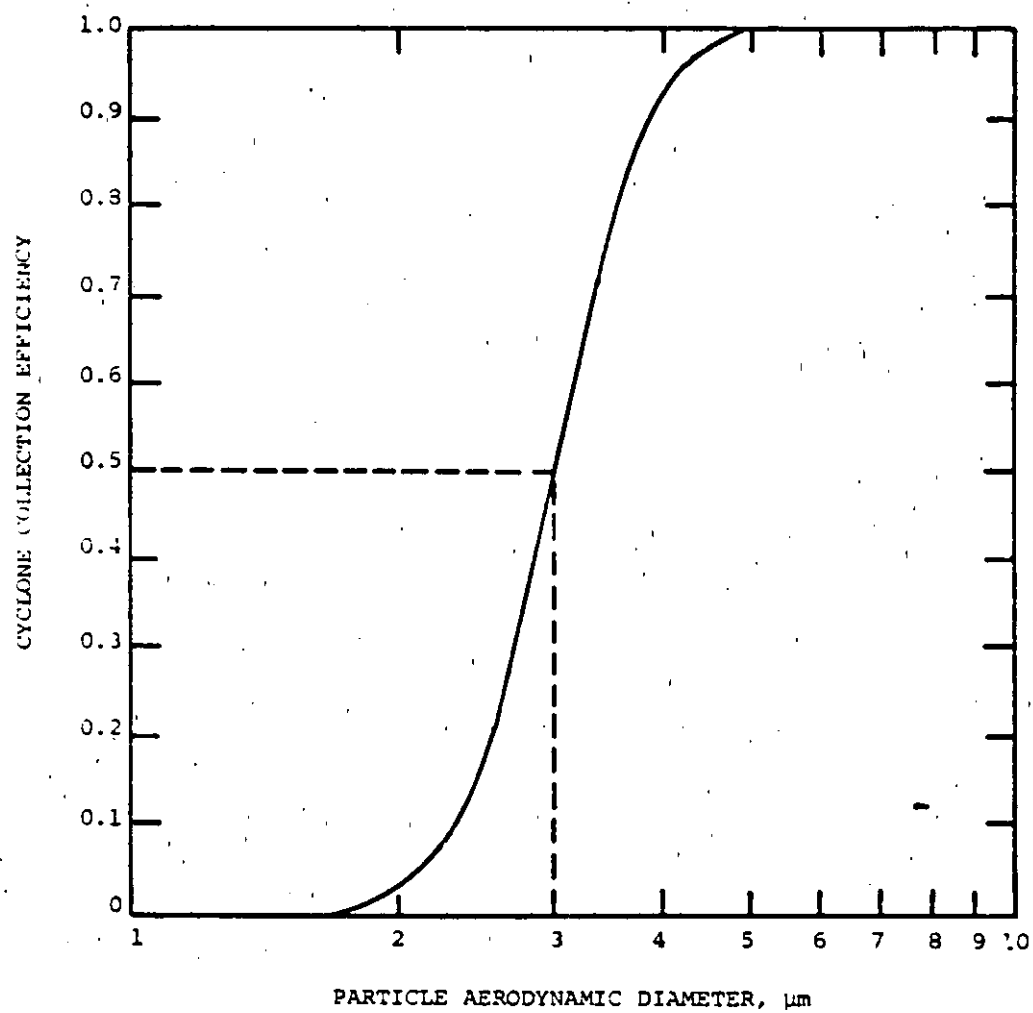


Figure 3-33. Typical cyclone fractional efficiency curve.

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 fragility 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 3-27. 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.

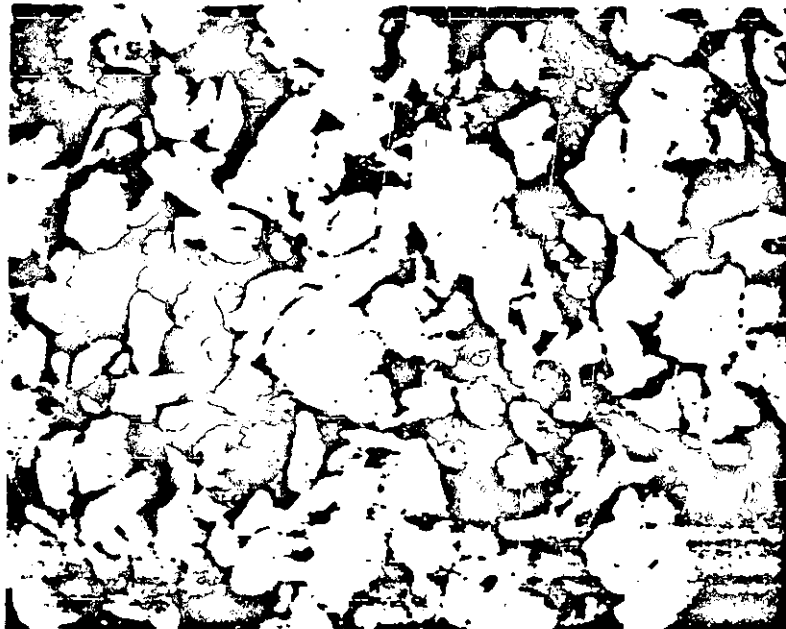


Figure 3-34. SiO_2 test dust.

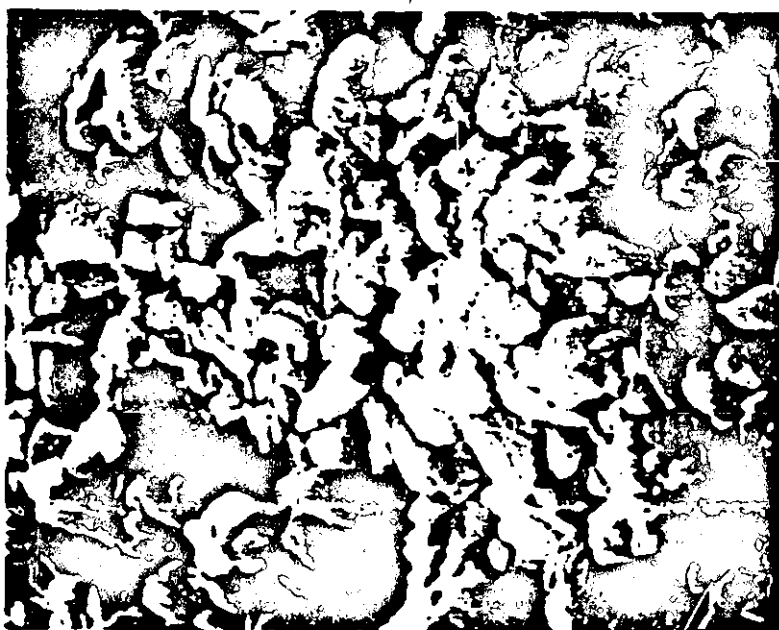


Figure 3-35. SiO_2 -- small dust cyclone cup catch.

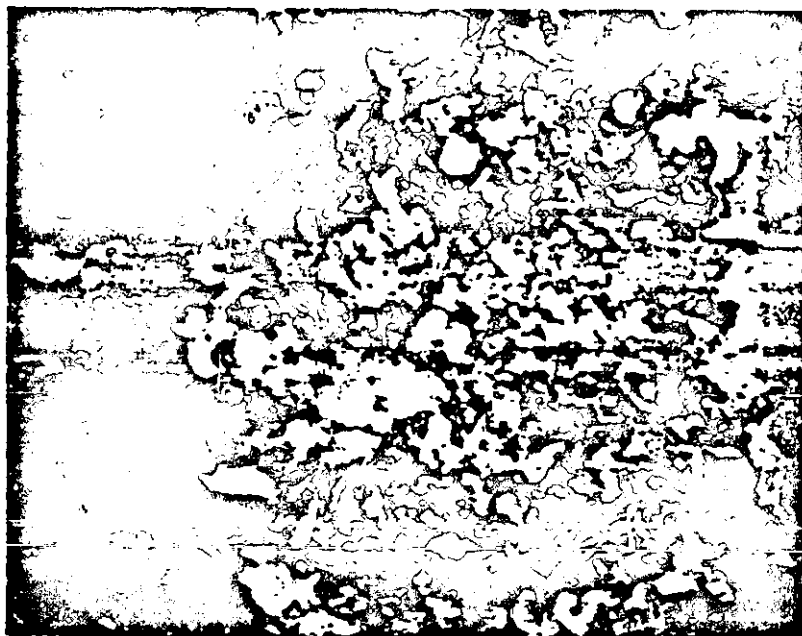


Figure 3-36. SiO_2 test dust -- small cyclone filter catch.

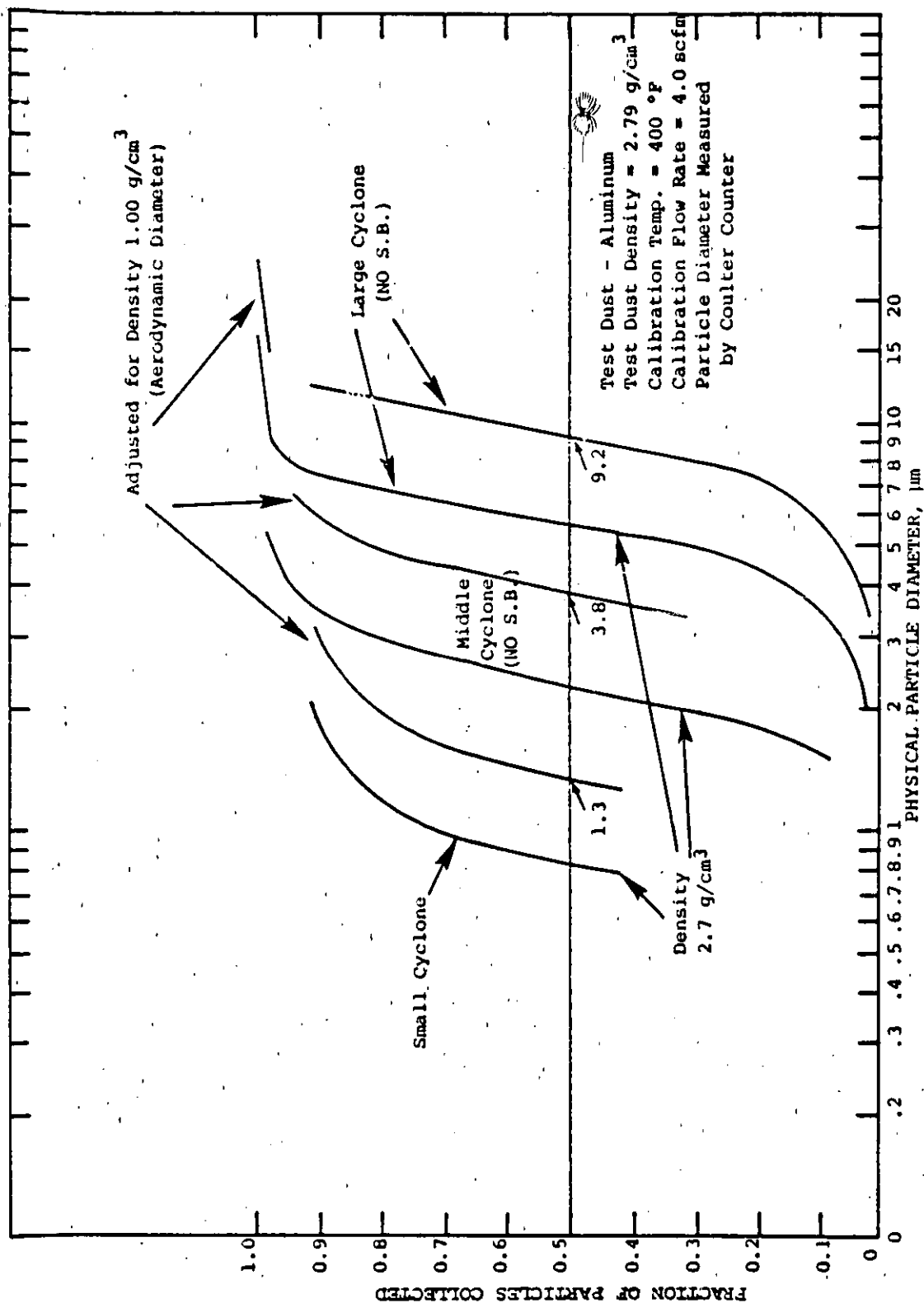


Figure 3-37. Cyclone calibration, KVB (ARB) SASS cyclones.

KVB 5806-783

Cyclone	D50 Cut Diameters, μm			
	KVB		EPA	
	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

^aSwirl busters removed

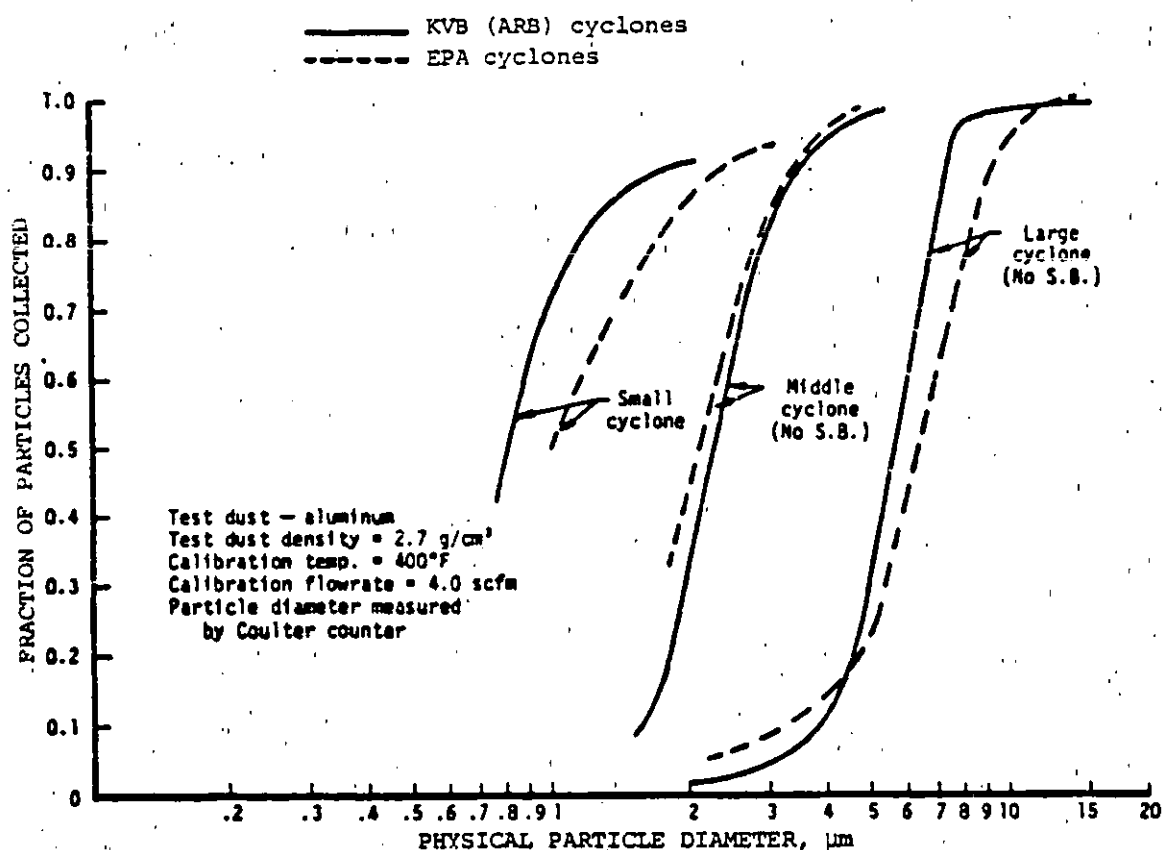


Figure 3-38. Comparison - calibration results for two sets of SASS cyclones.

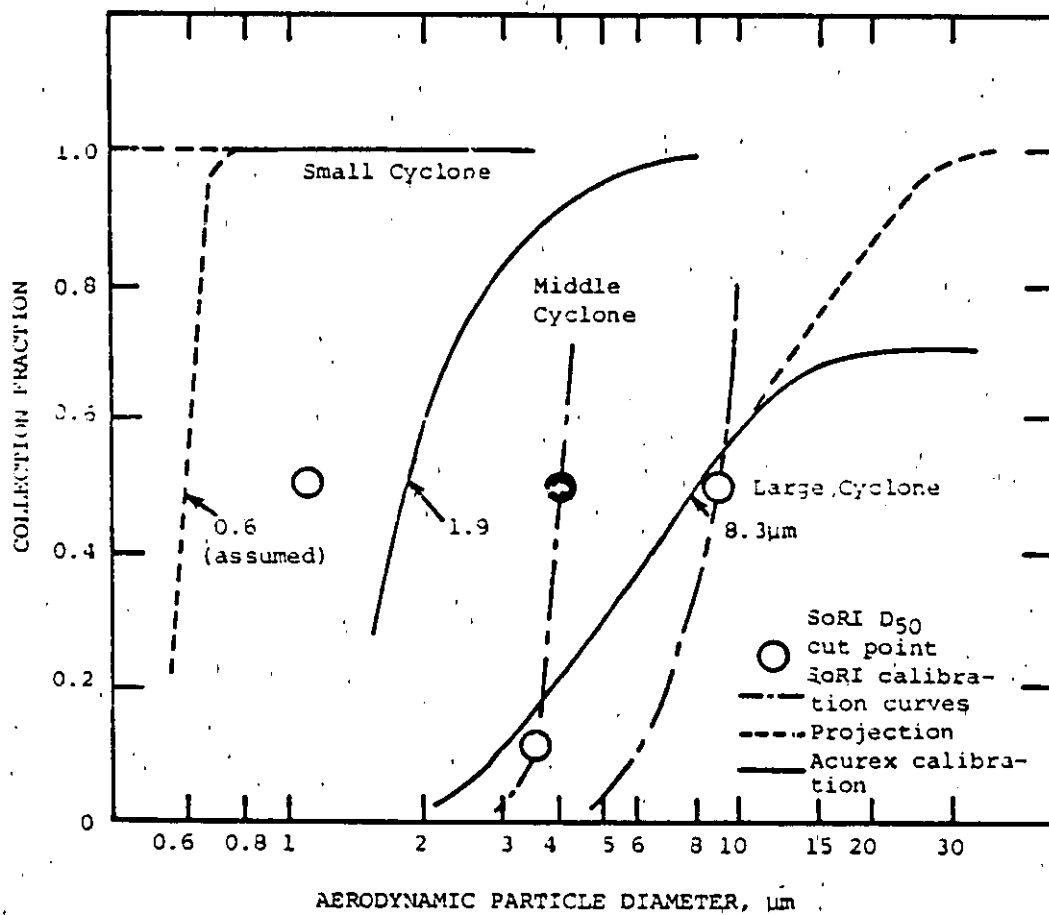


Figure 3-39. Calibration results, KVB 1 cfm cyclone.

KVB 5806-783

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 - 0.7 μ m. 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 0.6 μ m.

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 (15-30 μ m) 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:

<u>Parameter</u>	<u>Method</u>	<u>QA Measure</u>
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^{2-} , 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

B. Armament Systems, Inc.--

To ensure the quality of the energy dispersive X-ray fluorescence data the following procedures are routinely incorporated into the analysis of each sample:

1. Calibration is accomplished with the use of NBS standard reference materials and EPA standard reference samples. These calibration materials are processed twice daily--once before and once after each series of analyses. Calibration material responses have remained constant to within 10% for all processed samples.
2. Since the X-ray fluorescence process is nondestructive, the calibration materials which are used have been repeatedly checked for self-consistency. A long history of cross-calibration studies has also contributed to the credibility of the observed responses.
3. All processed samples are analyzed twice using two different photon fluorescing energies in order to optimize elemental responses over the entire range of interest. As a result, many of the major components are measured twice so that any inconsistencies in the data are easily observed.
4. Occasionally samples are prepared using two different procedures to determine the quality of preparation methods.
5. All reagent materials used in the preparation of samples are routinely checked by lot to validate their purity.

3.3.3 Redundant Field Sampling and Analysis

To maintain the accuracy and precision throughout the field test phase of the program, the following three items were conducted and will be discussed in this section:

- A. Simultaneous sampling with the two sampling trains--4 scfm SASS and 1 scfm Joy train.
- B. Unannounced duplicate samples for analysis for elemental composition by XRF, and sulfate, carbon and nitrate analysis.
- C. Blanks were run on the sampling trains.

A. Simultaneous Sampling--Joy vs SASS--

Whenever the two sampling trains were not being used to evaluate a control device and whenever possible the two Joy and SASS sampling trains were run simultaneously at approximately the same location in the stack. The two trains were handled as separate tests. Twenty-one such accuracy assessments were made. Table 3-3 lists these by test number and compares the results in gr/DSCF for each train. The right hand column is the percent of the standard deviation, %SD. This is calculated from the following equation:

$$\%SD = [(standard\ deviation)/mean] \times 100\%$$

The mean is taken from the values of the SASS train and the Joy train for each test. Three tests out of the 42 individual results justified being thrown out as bad data. These were: 1) Test 22--Joy, lost part of the sample; 2) Test 13--SASS, nozzle scraped port causing added weight; 3) Test 23--SASS, nozzle scraped port causing added weight. The average value for %SD of the 18 remaining tests is 16.4%.

Also Test 1 and Test 3 were duplicates of each other and on Test 3 a method 5 and an Anderson impactor were used. The results of these are discussed in Section 4.2.1. Slight variation in load and excess O_2 were the only variables for these two tests. Tests 11, 12, 13, 23, 24, 32, 33 were also repetitions of each other. The only variables were load and excess O_2 . These results are discussed in Section 4.2.4.

B. Unannounced Duplicate Samples for Analysis--

Some samples were sent to the analytical laboratories for duplicate analysis. The samples had different identification numbers. Requests for redundant analysis on other samples with the same identification were made. The following lists the number of replicate samples and analyses done:

TABLE 3-3. REDUNDANT SAMPLING RESULTS

TSP, Including Impinger Catch, gr/DSCF				
Test #	SASS Train	Joy Train	% Std Deviation	
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	20.2
	3	0.051	0.0365 Method 5 0.066)	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 (%) on the mean was calculated. The average of these values is 18%. Therefore, the precision of the carbon analysis is $\pm 20\%$, to be conservative. Table 3-5 lists the results for redundant sulfate and nitrate analysis. The average of % for sulfate analysis is 3.0. Again being conservative, the precision of the sulfate analysis is $\pm 5\%$. A conservative average for the nitrate analysis is $\pm 30\%$. 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	
25G-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
Calcium	t	t	2.2/0.4	1.7/0.5	t	t		
Chlorine	1.9/0.3	1.9/0.3	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

KVB 5806-783

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

Sample Number	23S-2S (10 μ in Cyclone)		26J-4S (1 μ in Cyclone)		11S-5S (Filter)	
	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 Typicality (Representative of Normal Operation): _____

Annual Process Time Rate: hr/day _____ day/week _____

wk./year _____

Process Diagram, Drawings Availability _____

Plant Entry and Exit _____

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-

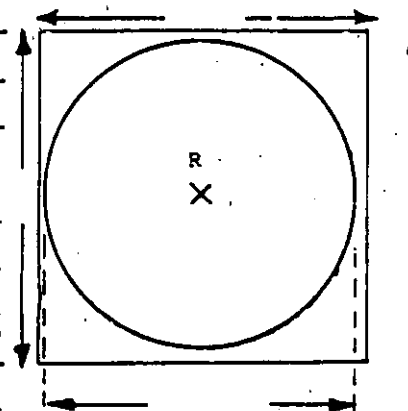
Sampling Station

Date _____

GAS VELOCITY DATA $Vel \text{ (ft/sec)} = 2.9 \sqrt{\Delta P (^{\circ}K)}$

[illegible]

- 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., $A_x D_x E$, Ft/Sec _____
or $B_x C_x D_x E$, Ft/Sec _____
- G. Area of Flue, Sq. Ft. _____
- H. Average Flue Temp., °F _____
- I. Flow Rate, $F_x G_x 60$, CFM _____
- J. Flow Rate, $520 \times I / (H + 460)$, SCFM _____
- 



KVB

Sample Code _____

Firm Name and Unit _____

Test No. _____ Page D-2

Sampling Station _____ Date _____

SPOT MONITORING DATA BY DRAEGER OR TLV SNIFFER

[illegible]

9/76

KVB 5804-5

3-90

KVB 5806-783

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, $100 \times F/G$ _____
 * See D on sampling train data sheet

Gas Density Correction Factor

Component	Volume Percent X Moisture Collection	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 = $\sqrt{\frac{1.00}{J}}$ = _____
 J 3-92

K V B. INC.
MOBILE LABORATORY DATA

Test No. _____ to _____
Test Engr. _____

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/93% O ₂ (ppm)									
10. NO(hot line) reading/93% O ₂ (ppm)									
11. NO ₂ (hot line) reading/93% 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)									

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.

3-95

KVB 5806-733

4/76
60-33

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 _____

PARTICULATE EMISSION CALCULATIONS

Test No. _____ Date _____ Location _____ Engr. _____

Unit No. _____ Fuel _____ Load _____

Pitot Factor, F_s _____ Barometric Pressure, P_{bar} _____ in. Hg

Tot. Liquid Collected, V_{lc} _____ ml Total Particulate, M_n _____ mg

Velocity Head, ΔP _____ iwg Stack Temp., T_s _____ °R Stack Area, A_s _____ ft²

Sample Volume, V_m _____ ft³ Stack Press., P_{sg} _____ iwg Excess O₂, XO_2 _____ %

Orifice Press. Diff., E _____ iwg Stack Gas Sp. Gravity, G_s _____ n.d.

Sample Time, θ _____ min Nozzle Dia., D_n _____ in. Meter Temp., T_m _____ °R

- *1. Sample Gas Volume $V_{m_{std}} = 0.0334 V_m (P_{bar} + H/13.6) \frac{520}{T_m}$ _____ SCF
2. Water Vapor $V_{w_{std}} = 0.0474 V_{lc}$ _____ SCF
3. Moisture Content $B_{w0} = \text{Eq. 2} / (\text{Eq. 1} + \text{Eq. 2})$ _____ N.D.
4. Concentration
 - a. $C = 0.0154 M_n / V_{m_{std}}$ _____ grains/DSCF
 - b. $C = 2.205 \times 10^{-6} M_n / V_{m_{std}}$ _____ lb/DSCF
 - c. $C = \text{Eq. 4b} \times 16.018 \times 10^3$ _____ grams/DSCM
5. Abs. Stack Press. $P_s = (P_{bar} \times 13.6) + P_{sg}$ _____ in. w abs.
6. Stack Gas Speed $V_s = 174 F_s \sqrt{\Delta P / P_s} \times \frac{1.00}{G_s}$ _____ ft/min
7. Stack Gas Flow
 - a. $Q_{sw} = \text{Eq. 6} \times A_s \times \frac{520}{T_s} \times \frac{P_s}{407}$ _____ WSCF/min
 - b. $Q_{sd} = \text{Eq. 7a} \times (1. - \text{Eq. 3})$ _____ DSCF/min
8. Material Flow $M_s = \text{Eq. 7b} \times \text{Eq. 4b} \times 60$ _____ lb/hr
9. XO₂ factor $XO_{2f} = 2090 / (20.9 - XO_2\%)$ _____ N.D.
10. Emission
 - a. $E = \text{Eq. 4b} \times F_e \times \text{Eq. 9}$ _____ lb/MMBtu
 - b. $E = \text{Eq. 4c} \times F_m \times \text{Eq. 9} \times 1000$ _____ ng/joule
11. Isokinetic $I = \frac{14077 \times T_s (V_{m_{std}} + V_{w_{std}})}{\theta \times V_s \times P_s \times D_n^2}$ _____

	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

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

	10u	3u	1u	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

PARTICULATE EMISSIONS

BOIL DOWN SHEET

TEST NO. _____ DATE _____
H₂O RESIDUE _____ ENGINEER _____

SAMPLE	PROBE	SASS TRAIN CYCLONES			IMPINGERS		TARE BEAKER	TARE BEAKER
		10μ	3μ	1μ				
Bottle No.	_____	_____	_____	_____	_____	_____	_____	_____
Boildown Beaker No.	_____	_____	_____	_____	_____	_____	_____	_____
Volume (ml)	_____	_____	_____	_____	_____	_____	_____	_____
Weighed Beaker No.	_____	_____	_____	_____	_____	_____	_____	_____
Final Wt. (g)	_____	_____	_____	_____	_____	_____	_____	_____
Initial Wt. (g)	_____	_____	_____	_____	_____	_____	_____	_____
Increase (g)	_____	_____	_____	_____	_____	_____	_____	_____
± Tare	_____	_____	_____	_____	_____	_____	_____	_____
Wt. (g)	_____	_____	_____	_____	_____	_____	_____	_____
-H ₂ O Residue	_____	_____	_____	_____	_____	_____	_____	_____
Part Wt.	_____	_____	_____	_____	_____	_____	_____	_____

SAMPLE	PROBE	JOY TRAIN CYCONES			IMPINGERS		TARE BEAKER	TARE BEAKER
		10μ	3μ	1μ				
Bottle No.	_____	_____	_____	_____	_____	_____	_____	_____
Boildown Beaker No.	_____	_____	_____	_____	_____	_____	_____	_____
Volume (ml)	_____	_____	_____	_____	_____	_____	_____	_____
Weighed Beaker No.	_____	_____	_____	_____	_____	_____	_____	_____
Final Wt. (g)	_____	_____	_____	_____	_____	_____	_____	_____
Initial Wt. (g)	_____	_____	_____	_____	_____	_____	_____	_____
Increase (g)	_____	_____	_____	_____	_____	_____	_____	_____
± Tare	_____	_____	_____	_____	_____	_____	_____	_____
Wt. (g)	_____	_____	_____	_____	_____	_____	_____	_____
-H ₂ O Residue	_____	_____	_____	_____	_____	_____	_____	_____
Part Wt.	_____	_____	_____	_____	_____	_____	_____	_____

REMARKS:

3-100

KVB 5806-783

KVB 5806-7
10/19/77

KVB

DATE _____ TEST NO. _____

FIRM AND UNIT _____

PARTICULATE SUMMARY SHEET

		TOTALS	% TOTAL
Probe (g)	_____	_____	_____
Cyclone 10	Wet (g) _____	_____	_____
	Dry (g) _____	_____	_____
	Total (g) _____	_____	_____
Cyclone 3	Wet (g) _____	_____	_____
	Dry (g) _____	_____	_____
	Total (g) _____	_____	_____
Cyclone 1	Wet (g) _____	_____	_____
	Dry (g) _____	_____	_____
	Total (g) _____	_____	_____
Filter (g)	_____	_____	_____
Impinger	Water (g) _____	_____	_____
	Org (g) _____	_____	_____
	Total (g) _____	_____	_____
Total Part. Wt. (g)	_____	_____	_____

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 _____

9/76 3-102 KVB 5806-783
 White - originator Pink - receipt 5804-8
 Yellow - lab Blue - attached to results

KVB

SIZE DISTRIBUTION WORK SHEET #1

Test No. _____ Company _____

	mg	%	Weight % Less Than Stated Size	Uncorrected Size, μ m	Corrected Size, μ m
<u>SASS</u>					
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 (wac/min)	_____				
<u>JOY</u>					
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 (wac/min)	_____				

KVB

SIZE DISTRIBUTION WORK SHEET #2

Test No. _____

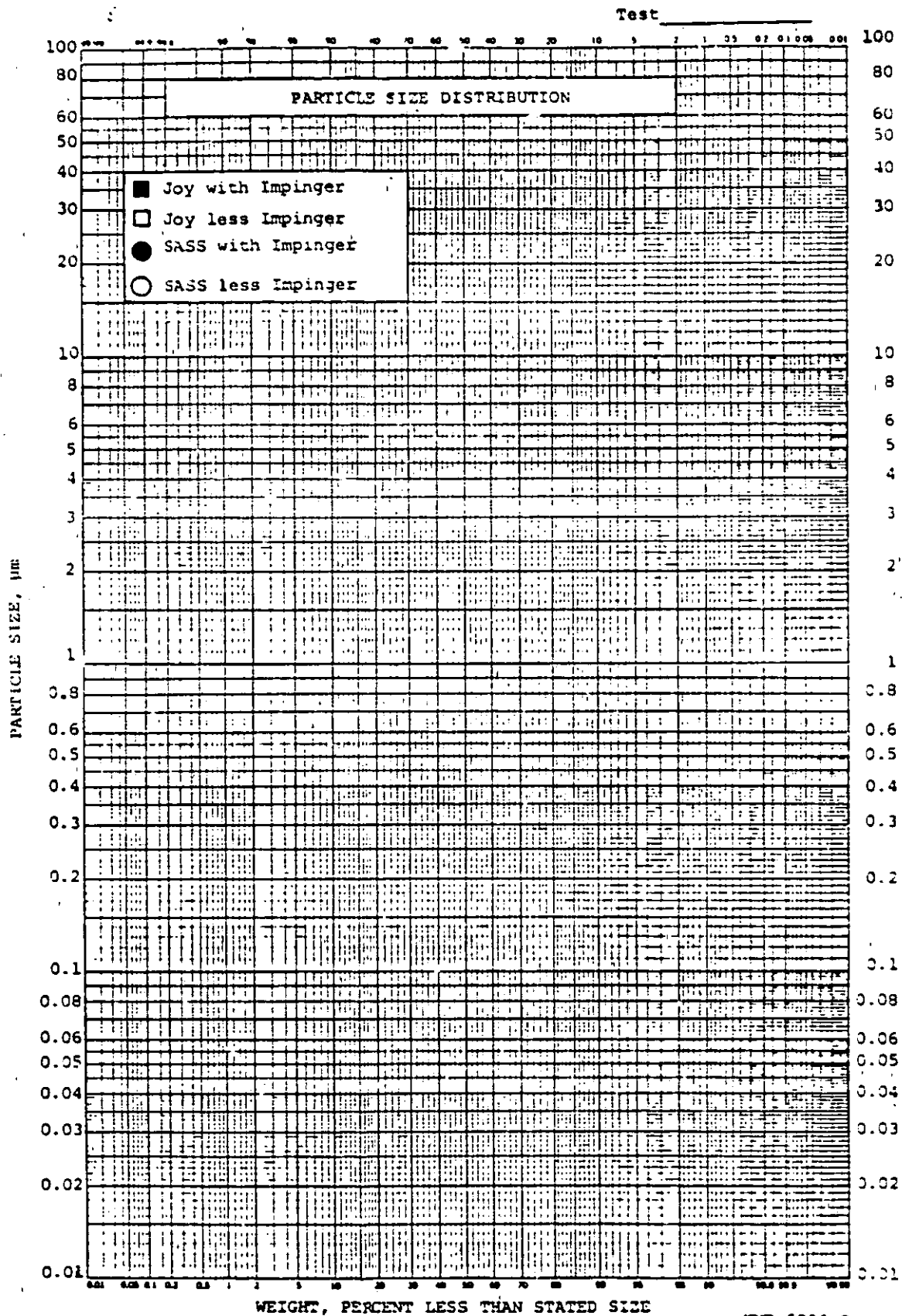
Company _____

	mg	%	Weight % Less Than Stated Size	Uncorrected Size, μ m	Corrected Size, μ m
<u>SASS</u>					
10 μ cyclone			100%	9.2	
3 μ cyclone				3.8	
1 μ cyclone				1.3	
Filter					
Total		100%	0%		

<u>JOY</u>					
10 μ cyclone			100%	8.4	
3 μ cyclone				1.9	
1 μ cyclone				0.6	
Filter					
Total		100%	0%		

KVB 5806-B

Rev. 3/7/78



ANALYSIS OF PARTICULATE SAMPLES
IN TABLE

* Sum of Sludge with ... equal 100 percent

Sample Number					
Percent of Dry					
Aluminum					
Antimony					
Arsenic					
Barium					
Bismuth					
Bromine					
Cadmium					
Calcium					
Chlorine					
Chromium					
Cobalt					
Copper					
Caesium					
Indium					
Iodine					
Iridium					
Iron					
Lead					
Manganese					
Mercury					
Molybdenum					
Nickel					
Niobium					
Sealium					
Palladium					
Phosphorus					
Platinum					
Potassium					
Rhenium					
Rubidium					
Ruthenium					
Scandium					
Selenium					
Silicon					
Silver					
Strontium					
Sulfur					
Tantalum					
Tin					
Titanium					
Tungsten					
Vanadium					
Zirconium					
Zinc					
Zirconium					
Sub Total Elements					
Sulfates % of solid					
Sulfur from SO ₄					
Nitrates % of solid					
Total Carbon					
Volatile Carbon					
Carbonates					
Sub Total					
Other					
Total					

ANALEX, INC.

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

Prepared for: _____

Date: _____

P.O.# _____

Sample Label: _____

Lab Run # _____

Concentrations are in _____

Aluminum	_____	Indium	_____	Rubidium	_____
Antimony	_____	Iodine	_____	Ruthenium	_____
Arsenic	_____	Iridium	_____	Scandium	_____
Barium	_____	Iron	_____	Selenium	_____
Bismuth	_____	Lead	_____	Silicon	_____
Bromine	_____	Manganese	_____	Silver	_____
Cadmium	_____	Mercury	_____	Strontium	_____
Calcium	_____	Molybdenum	_____	Sulfur	_____
Cesium	_____	Nickel	_____	Tantalum	_____
Chlorine	_____	Niobium	_____	Tellurium	_____
Chromium	_____	Osmium	_____	Thallium	_____
Cobalt	_____	Palladium	_____	Tin	_____
Copper	_____	Phosphorus	_____	Titanium	_____
Gallium	_____	Platinum	_____	Tungsten	_____
Germanium	_____	Potassium	_____	Vanadium	_____
Gold	_____	Rhenium	_____	Yttrium	_____
Hafnium	_____	Rhodium	_____	Zinc	_____
				Zirconium	_____

() qualitative estimate

* detected (<0.1% concentration)

\ not detected

3-107

KVB 5806-783

5806-E

KVB1 DATA

FIELD DATA

ANALYTICAL DATA

KVB NUMBER
mg TAKEN

S04

N03

YG/ML
%

YG/ML
%

CODE

KVB2 DATA

FIELD DATA

ANALYTICAL DATA

KVB NUMBER
mg TAKEN

CO3

VC

TC

YG/ML

YG/ML

YG/ML

CODE

REFERENCES

SECTION 3.0

- 3-1. Blake, D. E., "Source Assessment Sampling System: Design and Development," EPA-600/7-78-013, 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. Jiaque and Jaklewic, "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 Pochtman, 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.
- 3-10. 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, 11 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.

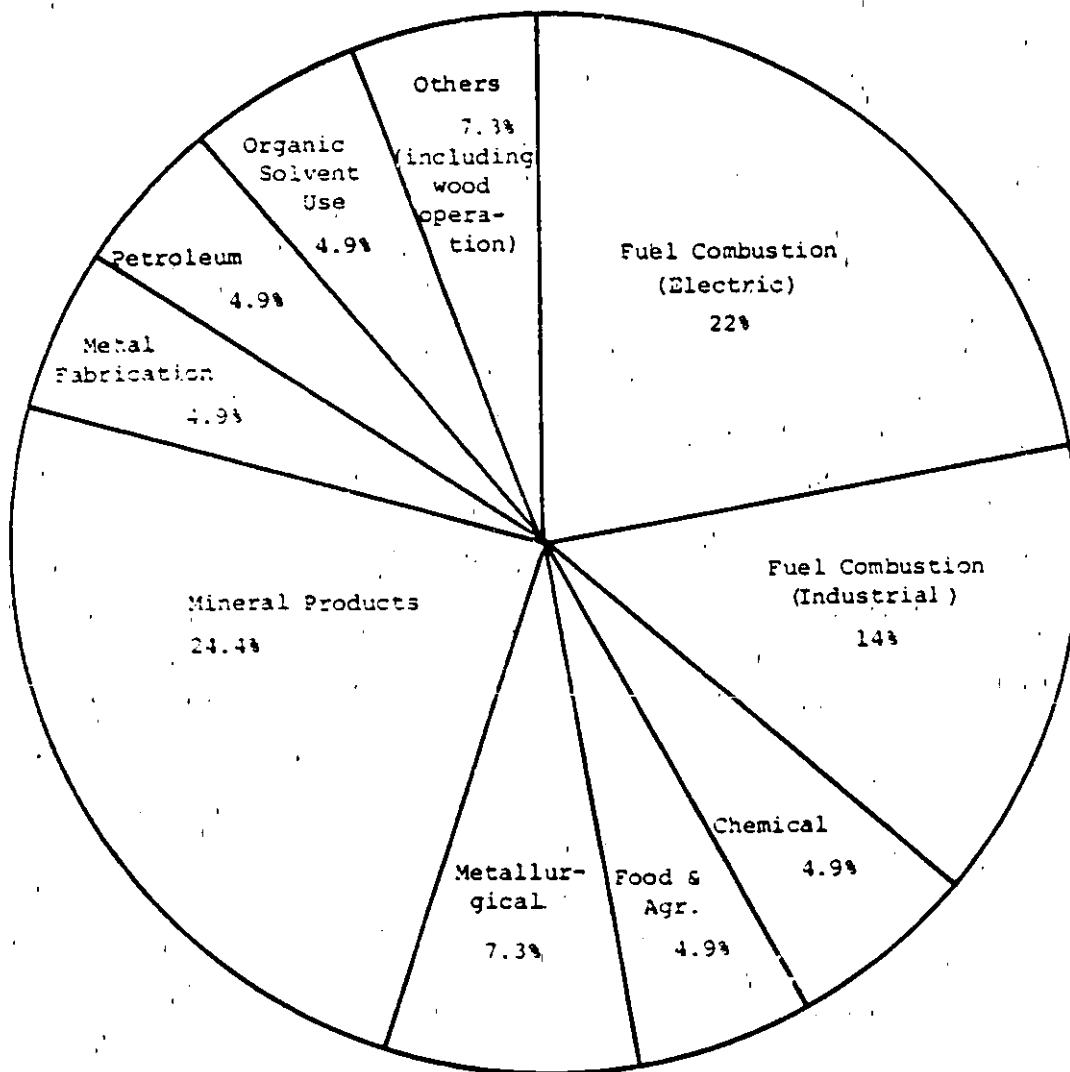


Figure 4-1. Distribution of field tests (total 41 tests)

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 from 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 O₂--This is the oxygen concentration in the exhaust gas measured at the sampling location. Combustion Sources.
- 12) CO₂--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 ($\frac{\text{Input} - \text{Output}}{\text{Input}} \times 100$ percent) is indicated.

TABLE 4-1. SUMMARY OF FIELD TEST RESULTS

Company/Industry Type	Test No.	Date	Sample Vol. dry wet		Flow Rate m³/hr	Temperature Stack Water		Temp. Stack Water	% O₂	Inlet Temp.	Filter Catch	Particulate Weight, µg		Filter Catch µg/20% Total			
			10µm System	1µm System		10µm System	1µm System										
FUEL COMBUSTION																	
Industrial Boiler	01S	9/13 1977	589	645	3.2	514	99	400	114			630.8	244.0	143.6	565.1	636	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	184.2
	02S	9/15 1977	917	101	3.72	515	106	401	130	54.2		256.1	234.9	349.1	275.6	390.9	1700.1
	02J	9/15 1977	81	90	.97	500	85	400	91	22.1		36.8	15.1	4.0	15.4	39.2	146.5
	03S	9/20 1977	570	629	3.47	516	101	400	122	63.7		268.8	116.7	126.9	277.1	1014.3	1898.0
	03J	9/20 1977	49	56	.93	500	88	369	79	26.4		36.7	3.1	3.5	18.7	4.3	116.8
	03HS	9/20 1977	62	70	1.17	500	100	305	99	16		-	-	-	124.4	63	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	301	118	20.2		34.6	9.6	6.3	100.1	883.8	1065.1
	16J	12/12 1977	229	263	1.10	450	100	300	119	2.8		2.7	3.1	8.2	24.2	87.0	129.0
IC Engine																	
	07S	10/20 1977	634	762	3.2	412	91	300	88	13.2		8.4	2.8	1.3	29.8	3618.4	1756.8
	07J	10/20 1977	207	243	1.156	412	90	396	103	5.5		3.6	1.4	1.2	1.2	192.7	268.3
	15J	12/17 1977	227	240	1.00	720	78	400	93	14.0		26.5	9.2	35.3	89.9	142.5	404.3
Wood Boiler	05S	10/13 1977	418	451	5.66	305	106	388	124	30.0		126.2	514.8	100.0	346.7	2168.2	4327.2
															346.7	1041.4	

KVB 5806-783

(Continued)

TABLE 4-1 (Continued).

Test No.	Stack Flow Rate lb/min	Excess O ₂	CO	Sampling Time min.	Plant Operation Time hr/ft	Exhaust Gas Analysis				Exhaust Gas Distribution, Percent of Total Gas				Control		Remarks
						Wt %	Vol %	Wt %	Wt %	Wt %	Wt %	Wt %	Wt %	Type	Efficient	
FUEL COMPOSITION																
01S	552	2.2		202.5		0.0672		0.120	0.0998	17	10	11	63	None		
01J	431	2.2		35		0.0896		0.131	0.1122	35	5	4	56	-		
02S	520	2.5		272		0.0285		0.128	0.043	0	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	13	6	7	76	-		
03J	476	2.5		60		0.0365		0.149	0.539	36	4	2	58	-		
03S	476	2.4		60		0.066		0.270	0.099	-	20	20	-	-		
04A	473	2.5		15		0.0179		0.073	0.0270	-	-	-	-	-		
16S	8181	8.37	9.0	240	8736	0.0203	6.2	1.43	0.0311	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	-		
01S	247	2.1	14.6	240	8736	0.0427	0.4	0.0901	0.0600	0.6	15	0.35	99.1	None		
01J	247	2.1	14.6	211.2	8736	0.0200	0.2	0.0324	0.0281	0.0	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	4.3	130	8736	0.159	35.7	8.17	0.214	0.3	4.45	4.45	74	None		

KVB 5806-783
(Continued)

TABLE 4-1 (Continued).

Test No.	Stack Flow Rate, lb/hr	Excess O ₂ , %	Sampling Time, min.	Plant Operation Time hr/yr	Emissions			Percent of Particles					Control		Remarks
					lb/hr	lb/yr	lb/1000 lb of feed	10µm	5µm	2µm	Type	Efficient			
11S	83373	4.8	240	8736	0.0091	284	65.0	0.0154	1.0	2.5	2	91.5	NONE		472 MM
11J	83373	4.8	240	8736	0.0078	241	55.6	0.0132	9	3	10	78	"		
12S	89817	5.9	240	8736	0.0072	242	55.5	0.0130	4	5	7	84.0	"		476 MM
12J	89817	5.9	240	8736	0.0058	196	44.8	0.0105	9	3	8	80.0	"		
13S	91323	6.2	360	8736	0.0271	928	212.4	0.050	0.1	0.9	3	95.5	"		472 MM
13J	91323	6.2	316	8736	0.0008	299	68.5	0.0162	2	0	0	98	"		
21S	84943	6.4	230.5	8736	0.0289	921	210.8	0.0554	1.5	1.3	2.2	95	NONE		450
21J	84943	6.4	229.6	8736	0.0084	268	61.3	0.0161	10	1.0	1.5	87.5	"		
24S	481018	6.5	240	8736	0.0112	202	46.2	0.0214	5	1	1	93.0	"		438
24J	481018	6.5	240	8736	0.0144	259	49.3	0.0275	5.5	0.5	0.6	96.5	"		
32S	79598	4.75	206.9	8736	0.0124	369	84.5	0.0211	1.5	1.5	1	94	"		
32J	79598	4.75	828.5	8736	0.0086	256	58.7	0.0147	0.1	0.7	4	95	"		
33S	85504	6.0	240	8736	0.0132	423	96.9	0.0244	4	4	5	87	"		455
33J	85504	6.0	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).

Well No.	Date 10-12-90	Access No.	Sampling Time, min	Plant Operation Time 8/10	Inorganic			Organic			Amount of Particles			Control System	Remarks
					mg/L	ppm	mg/L	mg/L	ppm	mg/L	mg/L	mg/L	mg/L		
215	1/10/94	7.0	1.0	8/10	0.009	10.7	29.0	0.022	0.02	0.02	0.75	1.6	9.75	None	1
215	1/10/94	7.0	1.0	8/10	0.0071	10.7	29.0	0.017	0.01	0.01	0.6	0.7	9.75	-	1
225	2/15/94	8.0	2.0	8/10	0.0109	10.7	29.0	0.023	0.02	0.02	1.1	5.8	9.7	-	1
225	2/15/94	8.0	2.0	8/10	0.0046	11.7	31.0	0.0070	0.01	0.01	1.1	1.5	9.6	-	1

*and data; not included in subsequent analyses

KVB 5816-783
(Continued)

TABLE 4-1 (Continued)

Company/Industry Type	Plant No.	Date	Sample Vol. Lbs.		Sample Rate Wt./Min.	Temperature, °F.	°C.	Pressure Atmos.	Flow GPM		Concentration % Solids		Total Solids Lb./Day			
			10/10 1977	10/5 1977					4.83	414	104	404	131	12.3	165.5	106.4
Cyanide	65	11/1 1977	699	701	4.91	85	95	202	94	15.5	130.9	12.8	1.7	1.6	39.5	291.0
	66	11/1 1977	115	117	0.98	75	89	205	51	105.4	681.5	14.9	5.2	2.5	3.5	3713.0
Cement	95	11/7 1977	982	985	1.99	165	94	395	132	31.5	98.5	124.9	34.3	19.5	142.1	142.7
	185	12/16 1977	940	992	4.11	181	92.1	390	89.5	35.4	145.9	105.1	53.8	27.6	151.7	606.4
Glass	205	1/12 1978	990	1002	5.14	420	89.7	309	145	5.6	7.1	4.1	-5.4	12.7	359.4	196.5
	203	1/12 1978	194	217	0.97	1001	76	174	90	7.5	5.6	2.4	111.1	264.7	56.8	457.5
Glass	205	2/16 1978	325	161	1.6	139	93	397	81	75.4	11.1	12.1	34.7	947.6	191.7	1293.7
	155	3/16 1978	370	410	3.7	835	100	380	94	48.4	90.2	49.0	82.3	938.4	192.7	1425.7
Glass	153	3/16 1978	170	186	0.94	835	116	697	110	54.4	24.0	16.9	256.9	181.0	134.1	715.6
	185	1/28 1978	915	961	1.8	154	104	399	105	11.2	7.6	2.2	3.1	120.8	820.4	1013.4
Fiberglass	103	3/28 1978	230	241	0.96	154	101	179	101	11.1	1.4	1.4	3.5	10.8	141.9	203.7
	255	1/31 1978	991	996	4.15	110.8	94	388	102	25.6	19.3	18.7	5.1	2.2	144.4	485.6
Asphalt Roofing	253	1/31 1978	234	239	0.99	139	85	249	109.5	8.8	1.1	1.4	1.7	0	11.5	110.1
	295	2/21 1978	834	911	1.9	175	92	400	113	18.1	261.2	15.2	8.7	15.0	55.2	420.4
Batch	293	2/21 1978	76	92	0.85	186	86	244	104	804.7	10911.8	10728.3	2182.9	12112	11.5	696.7

KVB 5806-783
(Continued)

TABLE 4-1 (Continued).

Test No.	Stack Flow Rate lb/min	Sampling Time, min	Plant Operation Time hr/day	Emissions			Percent of Pollution Control			Remarks						
				lb/min	lb/hr	lb/minute	lb/min	lb/hr	lb/minute							
MILLKAL																
6S	4508	19.0	0.5	105	8736	0.0558	9.4	2.16	NA	12	11.5	14	22			
8S	6435	Alt	--	145.2	2475	0.0084	0.4	0.96	NA	44	4	4	48	bag- house exit	99.8	baghouse exit
8J	7139	Alt	--	120	2475	1.169	26.6	21.5	NA	90.0	0.05	0.10	0.15	*	99.8	inlet
9S	12152	14.2	7.2	240	7728	0.0050	22.6	5.05	NA	0.0	32	10	20	Not Tested	Tested	fuel - gas
16S	14612	14.3	10.4	240	7728	0.0099	48	12.47	NA	0.0	24	11	34.0	Not Tested	Tested	fuel - coal
20S	14959	12.7	5.8	240	8736	0.00617	0.0	1.83	NA	1.4	0.6	1	97	ESP solid only	98.24	ESP Outlet
20J	27484	12.3	5.9	223	8736	0.0364	17	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	0.0812	10.2	7.19	NA	0.6	0.7	1.1	97.4	None		
35S	11888	11.0	8.0	100	8400	0.0594	25.5	6.06	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 in duct	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	0.0075	10.4	2.94	NA	2.3	2.8	4	91	Not Tested		
25J	44697	6.4	0.4	240	7072	0.0079	10.5	2.98	NA	0.5	0.2	0.3	99	*	*	
29S	65089	18.2	3.5	210	720	0.0077	1.56	4.18	NA	60	6	4	10	bag- house exit	9.9	
25J	58557	17.4	2.0	90	720	11.405	109.3	777.5	NA	--	--	--	--			

KVB 5806-783
(Continued)

TABLE 4-1 (Continued).

Company/Industry Type	Test No.	Date	Sample Vol. cu ft	Sample Rate min	Temperature, °F		°	°	Particulate Matter, µm						Total
					Stack	Water			10 µm	10 µm	10 µm	10 µm	10 µm	10 µm	
FOOD AND AGRICULTURE															
Rice	45	10/11 1977	973	996	5.00	87	100	202	117	37.5	127.8	64.9	7.6	1.0	57.6 94.3
Rice	4J	10/11 1977	190	197	0.99	86	91	205	116	36.6	141.1	2.2	1.0	0.7	6.8 190.3
CANALCO	376				Lost	Sample	Due	To	High	Temperature					1.9
CANALCO	37J	3/23 1978	232	241	0.99	115	101	400	122	180.3	304.9	1.0	8.1	7.1	112.3 174.1
METAL FABRICATION															
Heat Treat Steel	14S	11/24 1977	762	772	4.00	139	114	397	84	16.5	12.5	14.8	9.7	10.2	59.6 16.8
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
Sand Blast Steel	34S	3/14 1978	936	941	4.0	75	101	399	100	0.2	14.2	3.1	1.0	1.2	11.2 20.4
Sand Blast Steel	34J	3/14 1978	164	164	1.00	60	85	351	117	61.1	9852.6	202.4	186.6	17.1	2.8 100.3
METALLURGICAL															
Aluminum Foundry	10S	11/10 1977	220	1141	4.30	1141	105	404	81	57.0	12.1	8.4	5.1	47.0	51.1 27.7
Aluminum Foundry	10J	11/10 1977	334	383	1.22	1141	97	182	69	12.0	4.1	1.0	4.0	6.6	2.2 15.7
Sinter Plant	20S	2/2 1978	954	1023	4.2	229	87	376	108	35.1	87.1	36.7	14.1	100.1	234.2 2841.0
Sinter Plant	20J	2/2 1978	206	223	0.99	245	102	339	122	722.6	142.1	26.9	339.3	1180.4	180.4 135.9
Open Hearth Steel	30S	3/21 1978	690	161	3.8	422	107	402	91	373.1	70.3	66.1	161.0	251.1	722.8 16.0
Open Hearth Steel	30J	3/21 1978	170	189	0.90	406	101	403	90	227.9	206.9	99.1	585.2	1801.1	105.0 54.0

KVB 5806-783
(Continued)

TABLE 4-1 (Continued).

Test No.	Stack Flow Rate gpm	Excess O ₂	CO ₂	Sampling Time, min.	Plant Operation Time hr/yr	Emissions			Percent of Particles			Control		Remarks	
						SP/DA/27 W/g	lb/hr	lb/stack	lb/hr	lb/hr	lb/hr	Type	Efficient		
FACD AND AGRICULTURE															
45	124901	16	--	199.2	700	0.00935	1.5	10.03	NA	46	12	30	acres not tested	--	
4J	124901	16	--	198.9	700	0.0154	5.6	16.5	NA	89	2	8	--	--	
375													after burner lost test		
37J	1620	Air	--	233	2000	0.0711	2.0	2.0	NA	41	1	1	57	--	
METAL FABRICATION															
145	45190	Air	--	190	4080	0.00283	2.2	1.10	--	4	0	14	74	bag-house	Exit
14J	20767	Air	--	190	4080	0.0593	21.6	10.58	--	5	7	10	76	bag-house	Inlet
345	1662	Air	--	233	1040	0.00088	0.07	0.125	--	23	6	6	74	bag-house	Baghouse Exit
34J	11577	Air	--	159	1040	1.922	99.4	191.2	--	93	3.5	1.7	1.8		Baghouse Inlet
METALLURGICAL															
105	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		
265	118768	16.3	4.4	240	8320	0.0159	195	46.82	NA	2	1.2	1.4	95	ESP	Baghouse solids only Exit
26J	96855	15.8	5.0	225	8320	0.205	709	170.4	NA	6	1	1	92	ESP	Baghouse solids only Inlet
365	17551	9.5	10.5	181	8064	0.0366	22.3	5.55	--	2.2	3.8	7	87.5	ESP	ESP Exit
36J	19790	8.5	11.5	177	8064	0.206	141.4	35.08	--	8	3	4	82	90.3 ESP	ESP Inlet

KVB 5806-783
(Continued)

TABLE 4-1 (Continued).

Test No.	Block Flow Rate (lb/min)	Excess O ₂	Sampling Time, min.	Plant Operation Time, hr/yr	Leakage			Percent of Particles			Control		Remarks	
					g/DSCF	W/F	lb/hr	lb/min	lb/hr	lb/min	Type	Efficient		
ORGANIC SOLVENT USE														
27S	91400	Air	--	199	4000	0.00171	5.6	2.91	NA	32	5	5	59	--
27J	91400	Air	--	199	4000	0.00325	5.1	2.56	NA		4.4	15		--
31S	215,400	Air	--	240	2750	0.00240	6.9	5.0	NA	5	2.5	3	90	
31J	215,400	Air	--	240	2750	0.00282	7.8	5.7	NA	5	6	8	83	
CHEMICAL														
17S	10940	20.9	--	240	8736	0.0237	9.74	2.23	--	10	0.5	0.5	89	Baghouse Exit
17J	16903	20.9	--	55	8736	0.6105	389	88.7	--	15	1	0	84	Baghouse Inlet
19S	4688	Air	--	193	2000	0.00280	0.1	0.11	--	4	1	1	94	Baghouse Exit
19J	1979	Air	--	195	2000	0.7154	12.2	12.16	--	98.6	0.2	0	1.2	Baghouse Inlet
WOOD PROCESSING														
30S	4179	Air	--	192.3	2080	0.0022	0.1	0.078	NA	3	3	3	86	Baghouse Exit
30J	4206	Air	--	120	2080	0.0168	0.6	0.601	NA	37	4	12	36	Baghouse Inlet
30 S	4384	Air	--	70	2080	0.931	36.5	35.05	NA	--	--	--	--	Baghouse Exit
39S	6546	Air	--	240	2080	0.00317	0.2	0.2	--	60	11	9	20	Cyclone Inlet
39J	6701	Air	--	120	2080	0.366	21	20.0	--	99	0.3	0.3	0.7	Cyclone Outlet
PETROLEUM														
40S	16216	3.9		240	8736	0.00420	2.6	0.59	0.0062	4.5	2	1.5	91	None
41S	31399	0.9	10.7	240	8400	0.055	32.33	14.84	--	62	5	5	52	ESP Not Tested

KVB 5806-783

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 sub-contractor 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 performed by Truesdale 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.

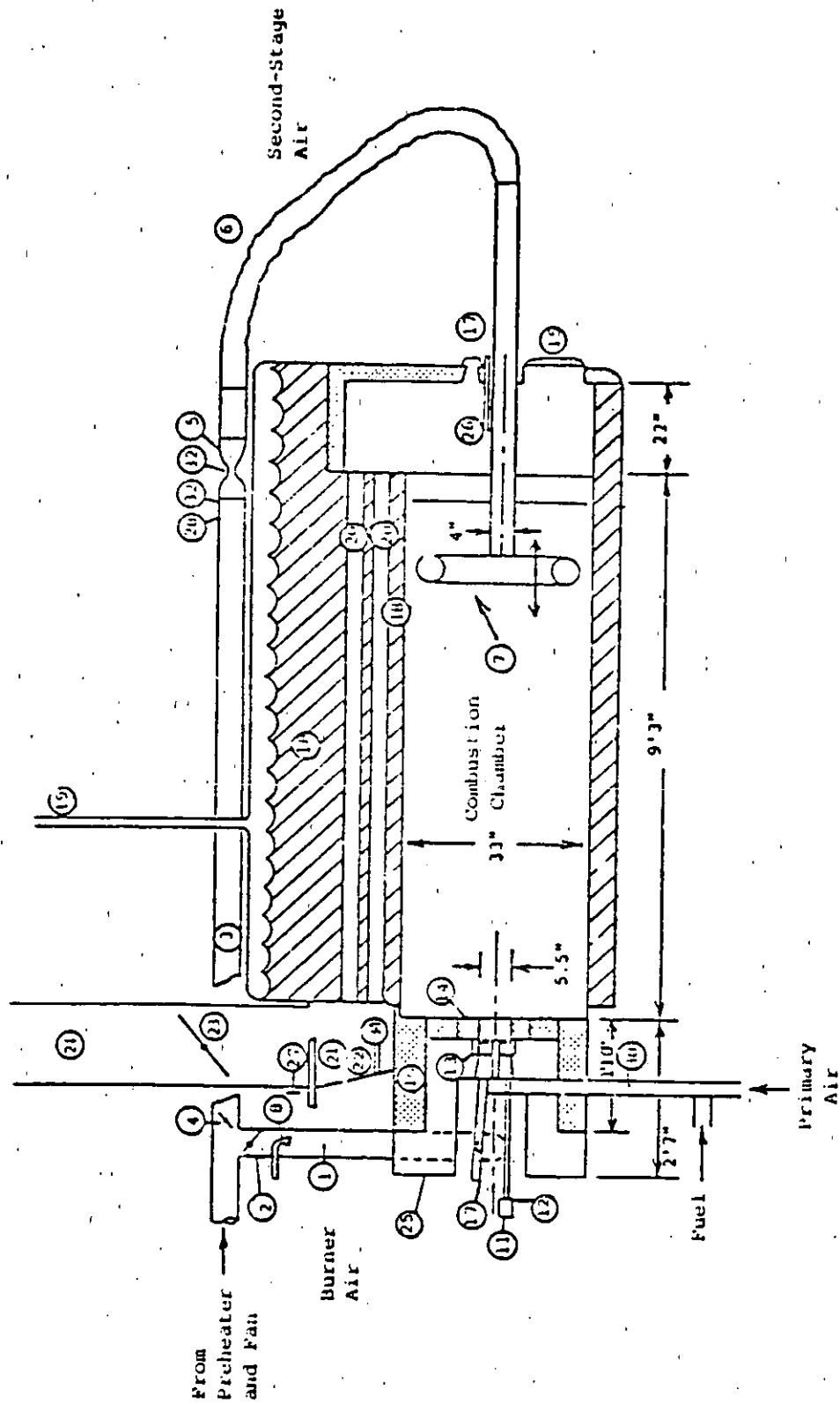


Figure 4-2. Schematic of 80-horsepower boiler.

KVB 5806-783

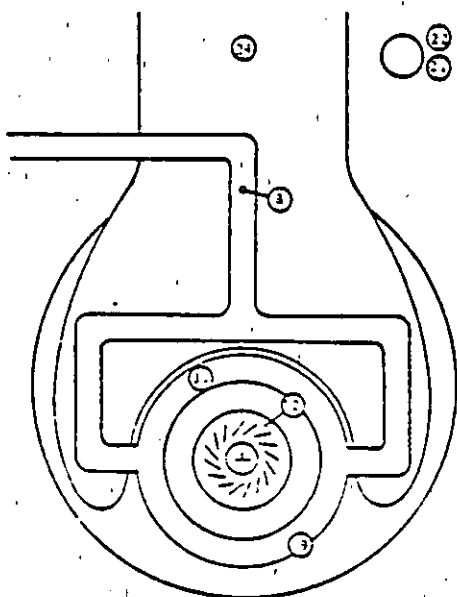


Figure 4-3. Cross section through windbox

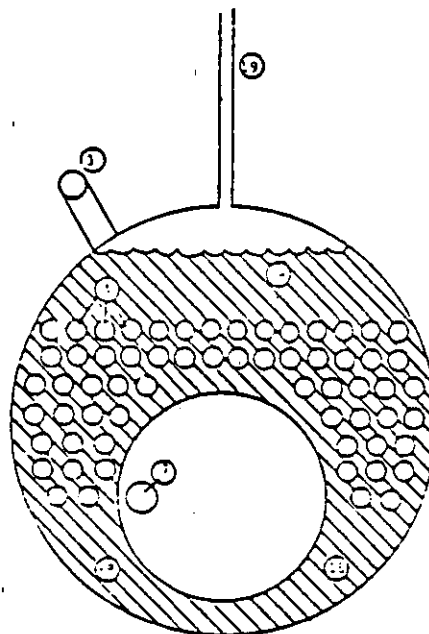


Figure 4-4. Cross section through fire-box

LEGEND FOR FIGURES 4-3 and 4-4

1. Primary Air Duct	18. Water Wall of Scotch Boiler
2. Primary Air Valve	19. Steam Vent
3. Staged Air Duct	20. Fire Tubes (62 With Diameter 2-7/8")
4. Staged Air Valve	21. Recirculation Gas Duct
5. Staged Air Venturi	22. Recirculation Gas Venturi(not shown)
6. Staged Air Flexible Hose	23. Damper
7. Staged Air Injection Torus and Inlet Pipe, Variable Position	24. Stack
8. Water Injection Nozzle	<u>Temperatures:</u>
9. Burner Support Cylinder	25. Windbox
10. Air Register	26. Hot End
11. Flame Detector	27. Stack
12. Ignitor	28. Second Venturi
13. Burner	29. Recirc. Venturi (not shown)
14. Ceramic Quarl - 5-1/2" Throat Diameter	30. Primary Air (not shown)
15. Observation Door	<u>Pressures:</u>
16. Fire Brick 25" Inside Diameter	31. Windbox
17. View Ports	32. Secondary Venturi
	33. Recirc. Venturi (not shown)
	<u>Gas Sample:</u>
	34. Stack

KVB 5806-783

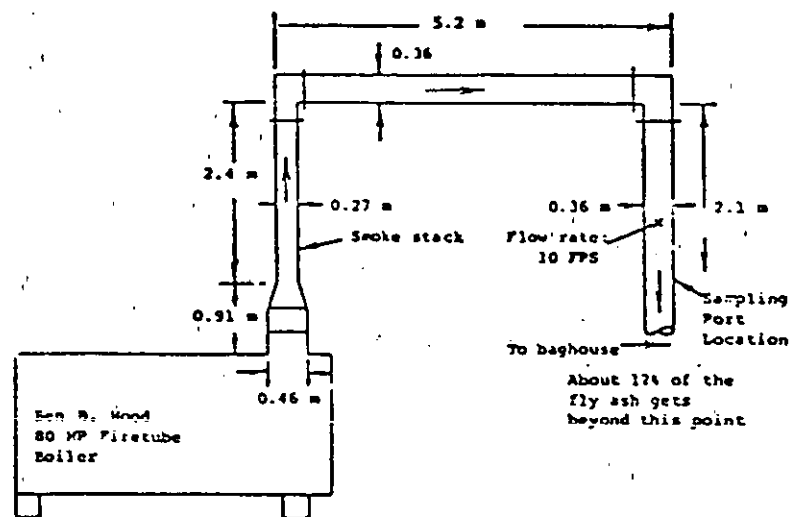


Figure 4-5. KVB test boiler installation

Instrumentation is available in the Combustion Laboratory for measuring fuel and air flows, temperatures (by thermocouple), and the concentrations of NO, CO, O₂, 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 1/8 inch nozzle for the Joy train was positioned 4 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

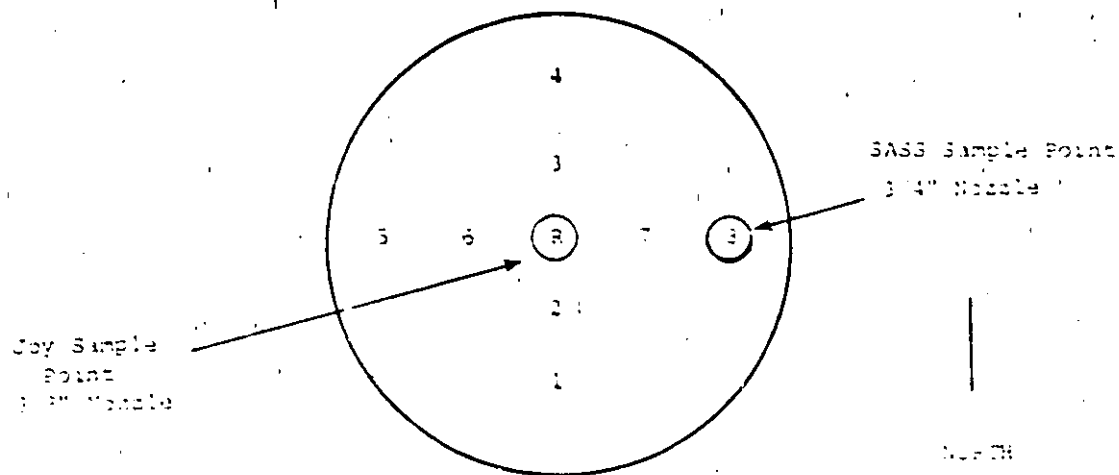
C. Particulate Test Results--

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 3.1.2. 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



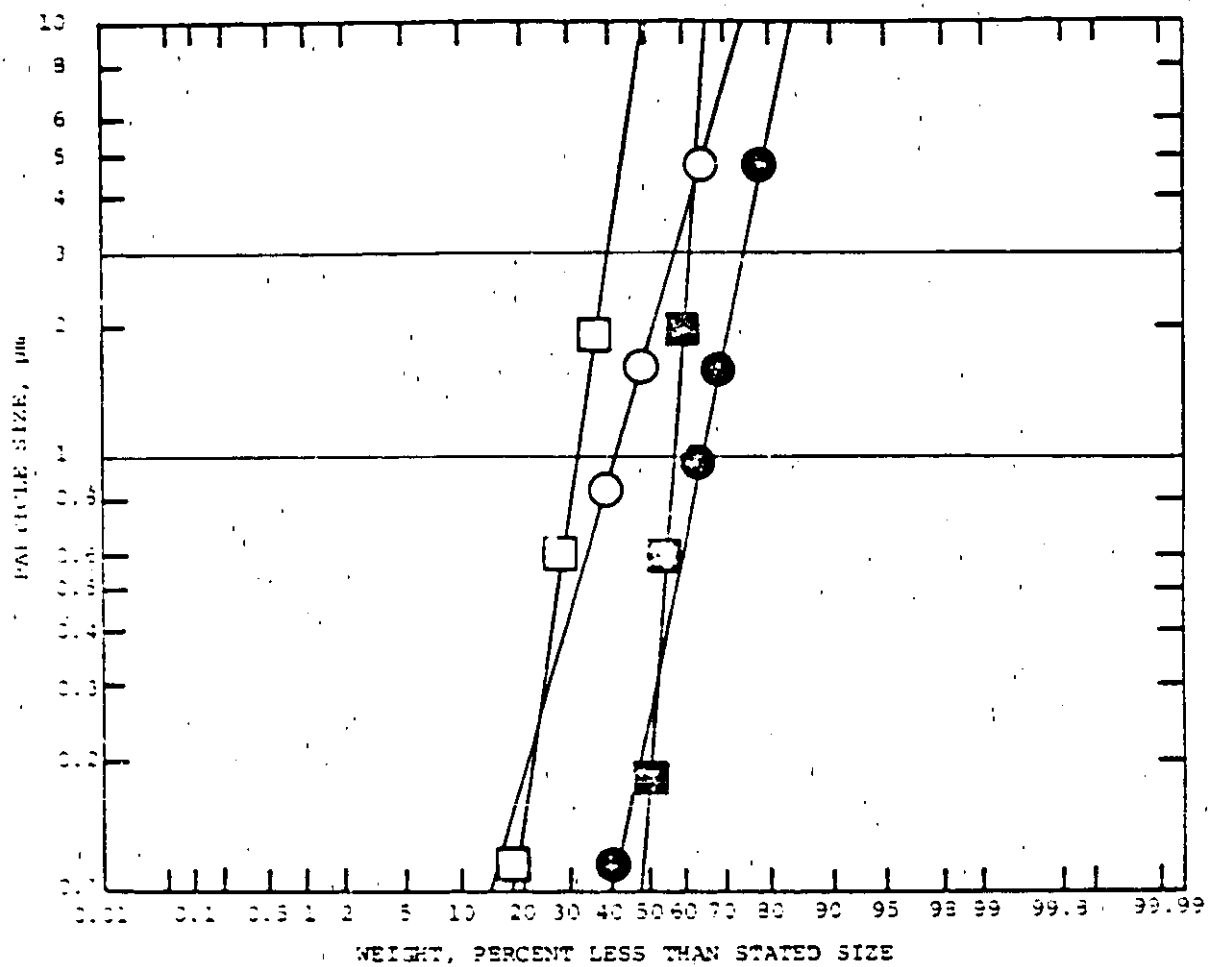
Distance from Edge of Duct	Point #	Velocity ft/sec	Point #	Velocity ft/sec
0.0	1	25.3	5	21.1
2.3	2	24.7	6	22.4
5.5	R	24.7	R	24.7
8.2	3	24.7	7	25.3
10.1	4	24.7	3	25.3

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	3 " "	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	

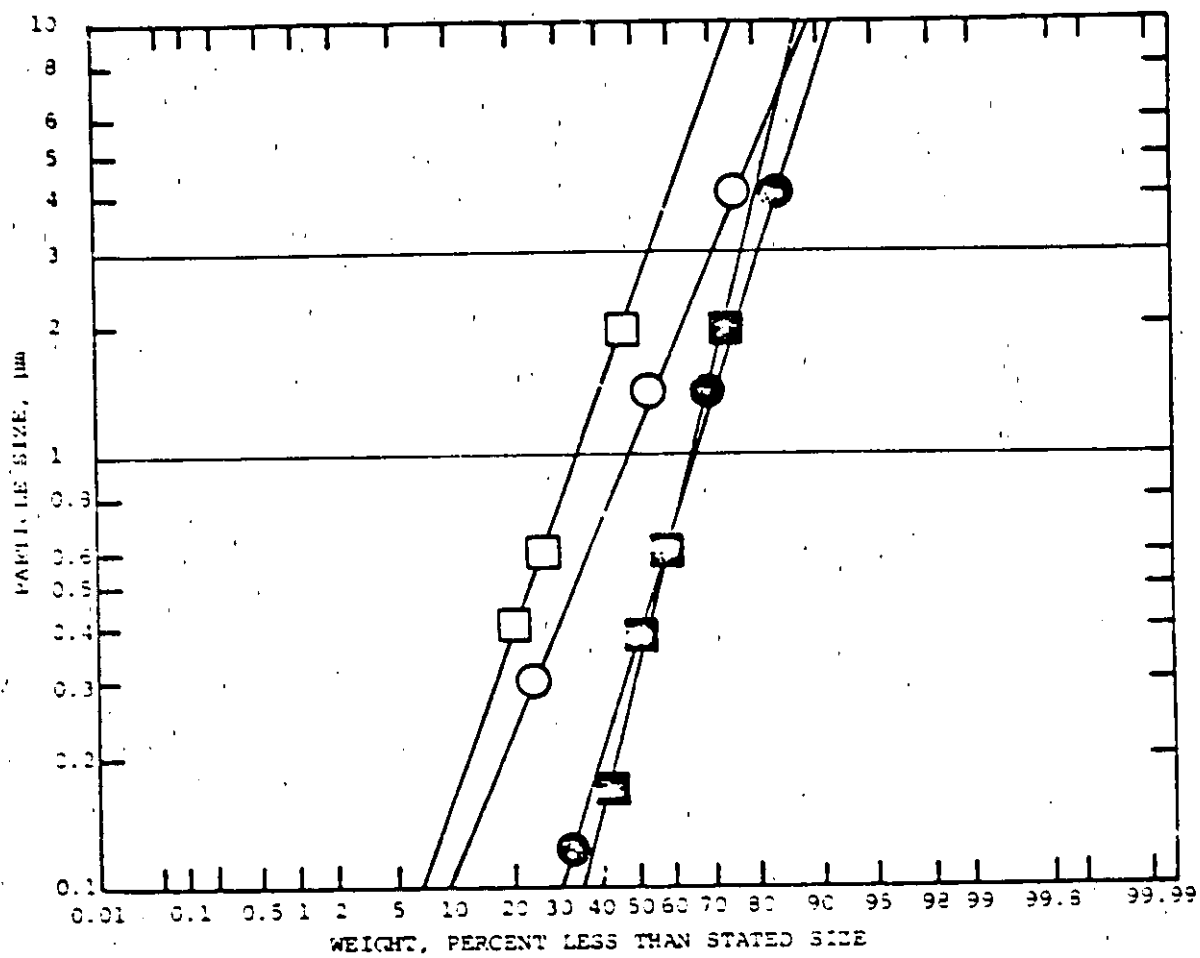
1. Accuracy and precision of the total particulate collection and size distribution--Simultaneous tests were done to compare the total particulate collection and size distribution using the SASS train, the small cyclone train, the current method 5 procedure and an Andersen cascade impactor. The data from these tests (Test 013, 010, 023, 020, 035, 030, 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:



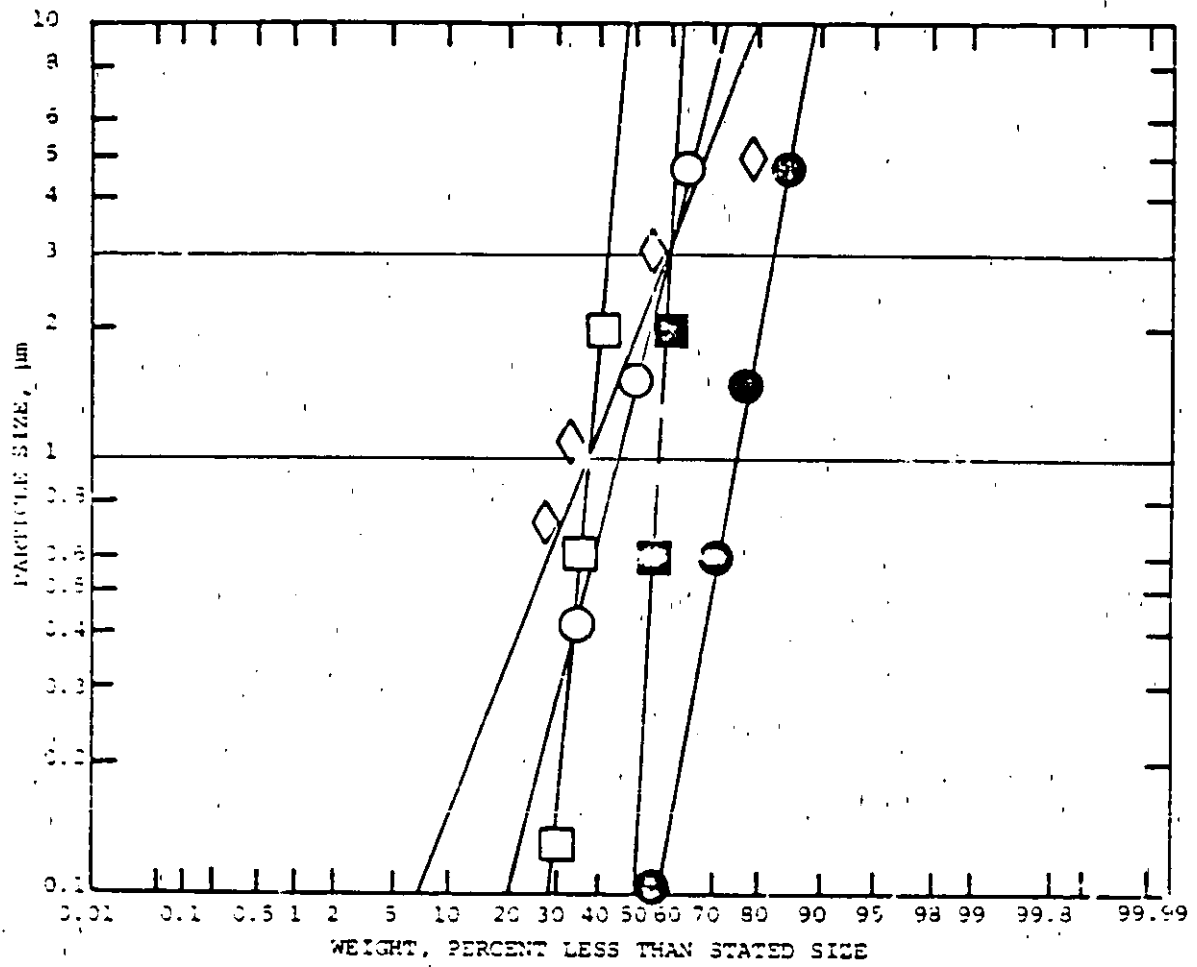
- Joy Mfg. Sampling Train With Impinger
- Joy Mfg. Sampling Train Without Impinger
- SASS Train With Impinger
- SASS Train Without Impinger

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



- Joy Mfg. Sampling Train With Impinger
- Joy Mfg. Sampling Train Without Impinger
- SASS Train With Impinger
- SASS Train Without Impinger

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



- Joy Mfg. Sampling Train With Impinger
- Joy Mfg. Sampling Train Without Impinger
- SASS Train With Impinger
- SASS Train Without Impinger
- ◇ Anderson Impactor

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

Test #	Method of Collection	gr/DSCF Particulate Emission		% of particles *			
		With Imp.	w/o Imp.	Less than 10µm		Less than 1µm	
				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
0105	Method 5	.0660	.0396	--	--	--	--
01A	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 pseudo 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 $\pm 30\%$, and the accuracy of the size distribution curves is also $\pm 30\%$. The $\pm 30\%$ 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*			
	With Imp.	w/o Imp.	10µm		1µm	
			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. J	.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/DSCP from the above list shows that the SASS data falls close to the mean and is within the $\pm 40\%$. 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 $\pm 40\%$ which is consistent with the result obtained here.

The precision of the size distribution curves is around $\pm 20\%$ from these data and about $\pm 10\%$ 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 (10 μ m cyclone, 3 μ m cyclone, 1 μ m cyclone, impinger, and filter catch) for Test 01, 02, and 03 were analyzed for major elements by x-ray fluorescence and for SO_4^{2-} , 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 #	10 μ m Cyclone 01S-2S	3 μ m Cyclone 01S-3S	1 μ m Cyclone 01S-4S	Filter 01S-1C	Impinger 01S-5S
PERCENT OF DUT	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 ₂ O 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 ₂ O 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. (% $\pm$ 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 #	10 μ m Cyclone 02S-2S	3 μ m Cyclone 02S-3S	1 μ m Cyclone 02S-4S	Impinger 02S-IC	Filter 02S-5S
PERCENT OF CUT	15.0	13.8	20.5	20.0	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	t	t	4.6	t	8.0
Sulfates, (H ₂ O) 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 ₂ O 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% $\pm$ 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 ₂ O sol ²	2.0	1.8	3.5	47	25
(Sulfur, from SO ₄ ²⁻) ⁴	(1.5)	(1.1)	(2.1)	(4.0)	(4.7)
Nitrate (H ₂ O 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								181.5 lb/hr fuel flow; 0.0112 lb/hr ash generated; 0.110 lb/hr TSP collected							
Fraction & Fraction Units	10 μ m Cyclone 24s 10 ⁻⁴ lb/hr	3 μ m Cyclone 5.5s 10 ⁻⁴ lb/hr	1 μ m Cyclone 5.6s 10 ⁻⁴ lb/hr	Filter 22s 10 ⁻⁴ lb/hr	Impinges 39s 10 ⁻⁴ lb/hr	Sum/Total ¹ 100s 10 ⁻⁴ lb/hr	Fuel Analysis Ash=0.017s 10 ⁻⁴ lb/hr								
Vanadium	2.3	1.2	2.0	11		36	110								
Iron	7.8	2.4	2.7	23	3.4	39	29								
Nickel	4.3	2.1	3.5	47	1.2	48	48								
Calcium			0.19	1.3	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	0.10	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	0.70	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	(280)	25000								
Sulfate	28	10	8.9	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						1018 $\times 10^{-4}$ lb/hr									
TSP						3180 $\times 10^{-4}$ lb/hr									

(1) Compare total column with fuel analysis column

KVB 5806-783

TABLE 4-8, MASS BALANCE FOR TEST 02

100 lb/hr of fuel; 0.029 lb/hr ash generated; 0.128 lb/hr ESP collected									
Fraction Fraction Units	10 μ m Cyclone 158 10^{-4} lb/hr	3 μ m Cyclone 145 10^{-4} lb/hr	1 μ m Cyclone 715 10^{-4} lb/hr	Filter 105 10^{-4} lb/hr	Impinger 115 10^{-4} lb/hr	Sum ^a 915 10^{-4} lb/hr	Total 1005 10^{-4} lb/hr	Fuel Analysis Ash=0.0165 10^{-4} lb/hr	
Vanadium	0.19	0.28	2.1	1.5		6.1	0.6	27	
Iron	0.48	0.85	3.4	5.1	3.2	14	14	22	
Nickel	0.38	0.56	2.5	8.0	0.52	12	12	8.4	
Calcium	0.30	1.2	6.7	0.40	1.0	14	15	22	
Magnesium								14	
Sodium								22	
Silicon								27	
Manganese	0.19	0.18	0.26		0.4	1.0	1.1	0.33	
Aluminum	0.19	0.18	0.53			0.90	0.93	1.8	
Barium			0.76		0.4	0.71	0.73	2.2	
Lead								0.2	
Zinc								0.05	
Molybdenum	0.19	0.18	0.26	0.21	0.4	1.2	1.3	0.11	
Copper	0.19	0.18	0.26	0.21	0.4	1.2	1.3	0.01	
Silver	0							0.99	
Zinc	0.19	0.18	0.26	0.42	0.4	1.3	1.5	0.16	
Titanium					0.4	0.4	0.41	1.2	
Cobalt	0.19	0.18	0.26	0.43	0.56	3.1	3.4	0.08	
Chromium	0.27	0.18	0.26	0.21	0.52	1.4	1.5	0.15	
Strontium		0.18	0.26		0.4	0.84	0.87	--	
Potassium			0.26	1.0		1.3	1.3	5100	
Sulfur	5.0	5.5	14	65	77	170	170		
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	480 $\pm$ 10^{-4} lb/hr	
							TSP	1280 $\pm$ 10^{-4} lb/hr	

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

KVB 5806-783

TABLE 4-9. MASS BALANCE FOR TEST 03

TEST 03									
100 lb/hr of fuel burned; 0.011 lb/hr generated; 0.410 lb/hr gas collected									
Fraction & Fraction	10 μ m Cyclone 140	3 μ m Cyclone 6.28	1 μ m Cyclone 4.78	Filter 15	Impinger 558	Sum 978	Total 1000	Fuel Analysis Ash-0.0178	
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	0.48	1.0	21		23	24		
Iron	1.3	0.71	2.4	15	10	30	31		
Nickel	0.98	0.77	3.1	20	1.9	34	36		
Calcium		0.13	0.48	4.5	92	97	100		
Magnesium									
Sodium									
Silicone									
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	1.1	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			0.14			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	139	80	110	18	54	190	410		
Vol. Carbon					47	47	(49)		
Carbonate	0.40	0.30	0.15			1.1	(1.1)		
Total							1141 $\times 10^{-4}$ lb/hr		
TSP							2100 $\times 10^{-4}$ lb/hr		

1) Complete total column with fuel analysis column
 * Pridow catch not analyzed

KVB 5806-783

The value of sulfur from XRF analysis can be compared to the value of sulfate ($\text{SO}_4/\text{S} = 96/32 = 3$). Divide the sulfate $\text{lb/hr} \times 10^{-4}$ by the sulfur $\text{lb/hr} \times 10^{-4}$; 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.

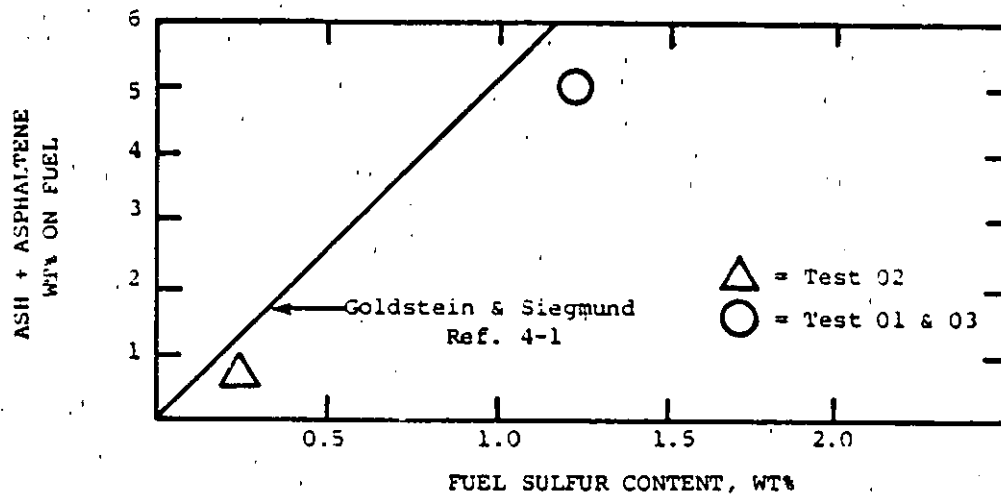


Figure 4-9. Ash + asphaltenes vs fuel sulfur.

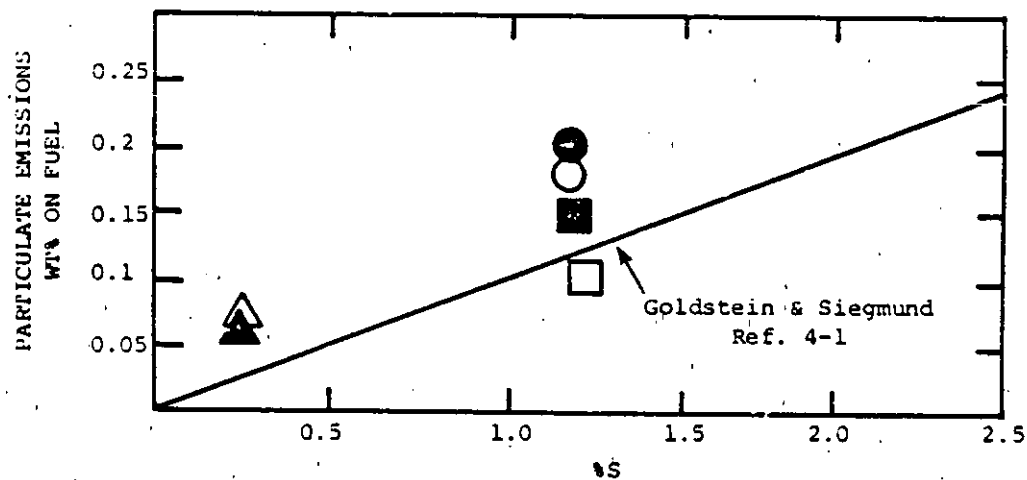


Figure 4-10. Particulate emissions (Test 01, 02, & 03) vs fuel sulfur.

- Test 01--SASS
- Test 01--Joy
- △ Test 02--SASS
- ▲ Test 02--Joy
- Test 03--SASS
- Test 03--Joy

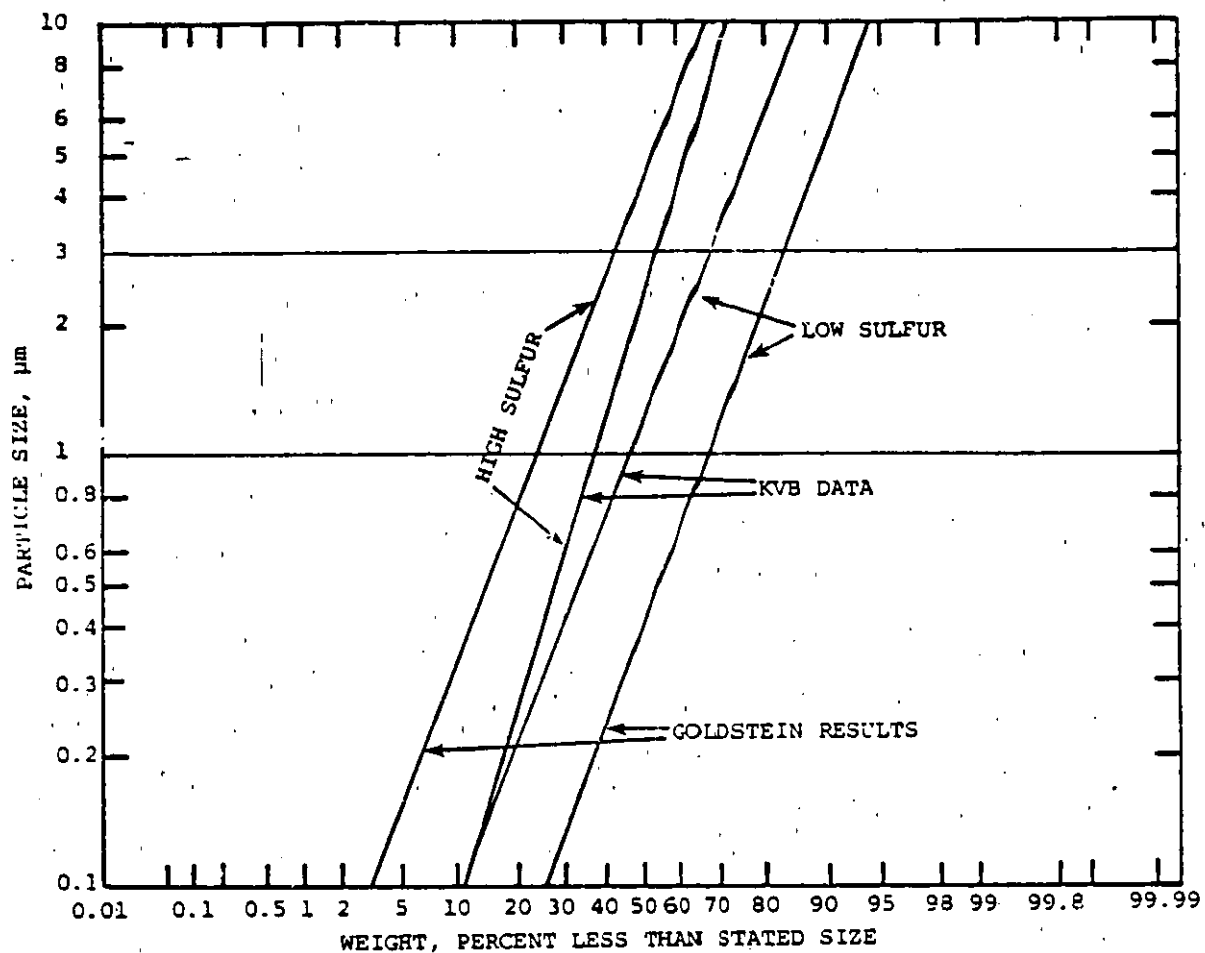


Figure 4-11. Particle size distribution for high fuel sulfur-low fuel sulfur comparison.

Also a test was designed as described below to determine any weight change. A gas stream of 831 ppm SO₂ 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 ft², 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.

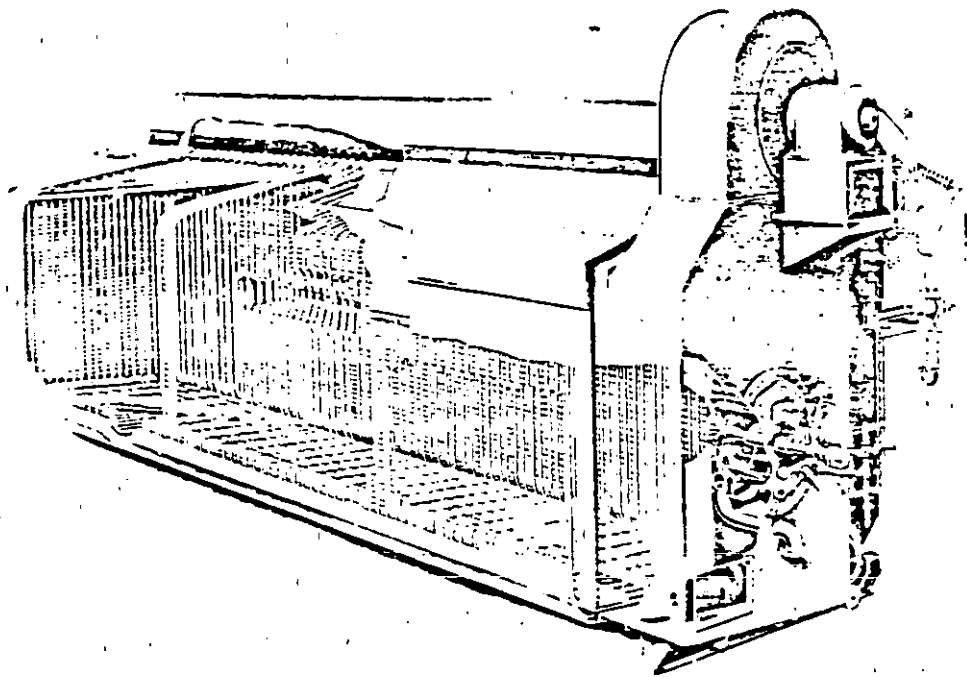
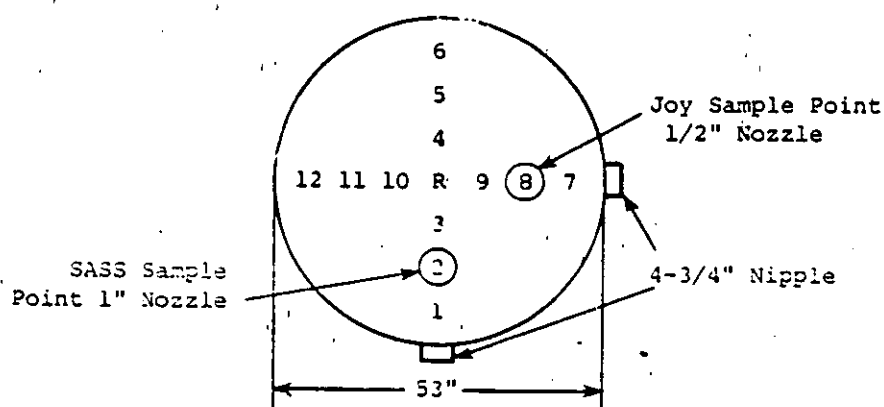


Figure 4-12. An industrial water tube boiler (The Babcock & Wilcox Co., New York).

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



Temperature 515 °F
 Static Pressure 0.6 in. H₂O
 Steam Load 18-22,000 lb/hr

Distance From		Velocity		
End of Port,* inches	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.

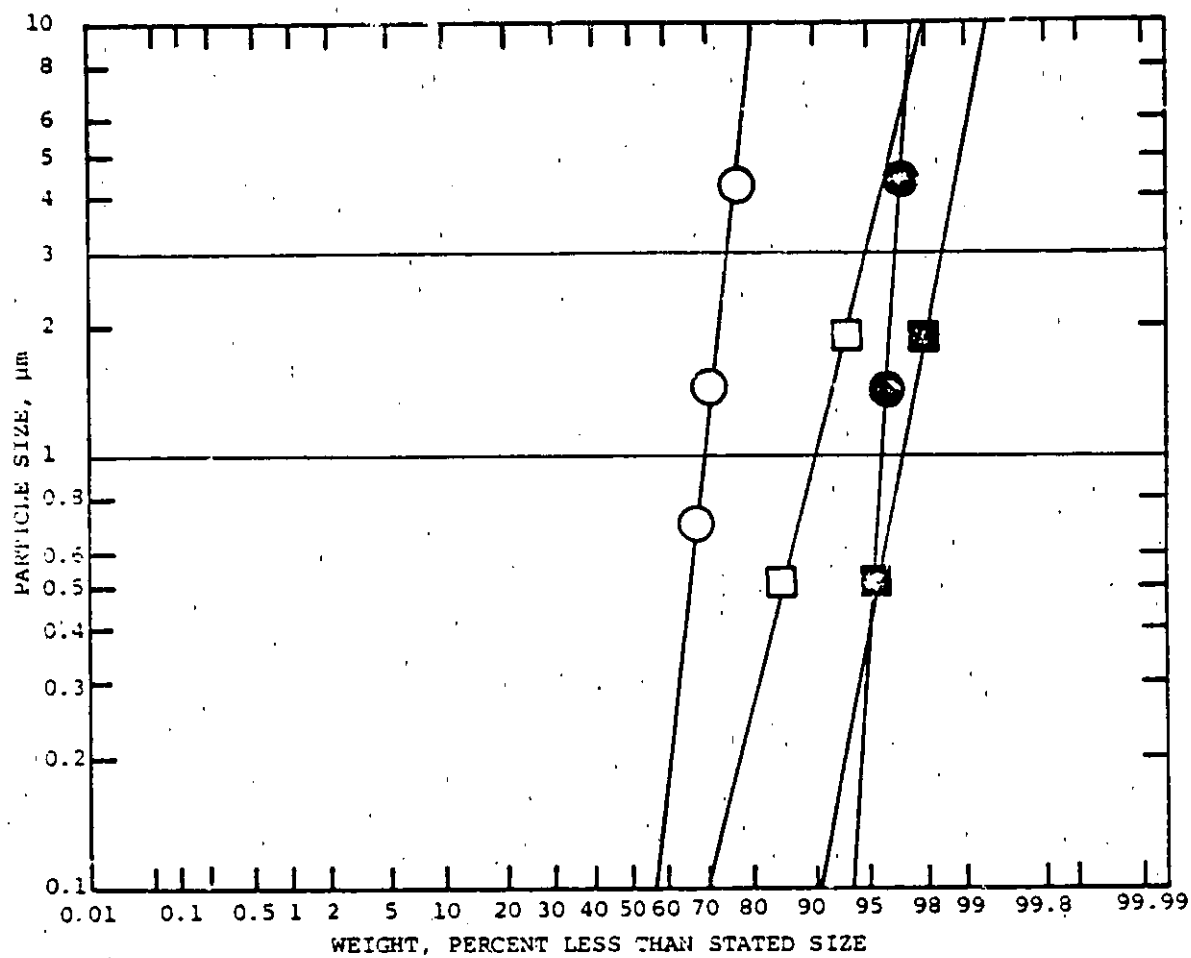
D. Discussion of Results--

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:

	<u>>10 μm</u>	<u>Percent of Particles</u>			<u><1 μm</u>
		<u>10 - 3 μm</u>	<u>3 - 1 μm</u>		
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



- Joy Mfg. Sampling Train With Impinger
- Joy Mfg. Sampling Train Without Impinger
- SASS Train With Impinger
- SASS Train Without Impinger

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 ₂ O sol ²	32	30	14.3	17.5
(Sulfur, from SO ₄) ⁴	(10.7)	(9.9)	(4.8)	(5.8)
Nitrate (H ₂ O 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 Oecvography 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:

	<u>Percent in Ash</u>
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)

SASS									
1000 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									
JUL									
Collector	Impinger 10 ⁻⁴ lb/hr	Filter 10 ⁻⁴ lb/hr	Sum 10 ⁻⁴ lb/hr	Total 100's 10 ⁻⁴ lb/hr	Fuel Analysis 10 ⁻⁴ lb/hr	Impinger 10 ⁻⁴ lb/hr	Filter 10 ⁻⁴ lb/hr	Sum 10 ⁻⁴ lb/hr	Total 100's 10 ⁻⁴ lb/hr
Bromine	t	t	t	t	t	t	14.7	t	t
Iron	240	16.2	276	295	53	t	t	49	56
Nickel	53	t	53	56	t	t	t	t	t
Calcium	5	29.5	42	45	t	5	t	5	t
Magnesium	t	t	t	t	t	t	t	t	t
Silicon	t	t	5	t	0.6	t	t	t	t
Manganese	t	t	t	t	t	t	t	t	t
Aluminum	t	t	t	t	2	t	t	t	t
Lead	t	t	t	t	t	t	t	t	t
Molybdenum	t	t	t	t	t	t	t	t	t
Copper	t	t	t	t	t	t	t	t	t
Silver	t	t	t	t	t	5	5	5	t
Zinc	5	5	5	5	t	t	t	t	t
Cobalt	t	t	t	t	t	t	t	t	t
Chromium	55	t	55	59	t	t	t	t	t
Potassium	t	t	t	t	t	t	t	t	t
Sulfur ¹	2162	141	2303	(1465)	4200	749	275	1024	(1177)
Calcium	t	t	t	t	t	t	t	t	t
Sulfate	3875	235	4110	4400	t	595	339	934	1073
Nitrate	492	t	492	527	t	10.8	1.4	12.2	14
Total Carbon	2362	164	2526	2704	t	54	400	454	1061
Volatile Carbon	2148	t	2148	(1400)	t	374	t	374	(430)
Selenium	t	t	t	t	t	t	t	t	t
Total Accounted for by Analysis				9,091	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 RFP analysis. "Sulfate" value 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.

KVB 5806-783

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	No. 26
gr/DSCF	0.02	0.0087	0.0071	0.010
T/yr	3.2	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 0.32% 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 ft³ 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 ft³ 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 $\pm$ 5% at 400 °F $\pm$ 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:

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

Fuel is conveyed (1) to the storage bin (2). Post-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 auger (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 separates the sawdust from the chips. The sawdust is heated air 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. Pre-heated 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 (10). Ash and entrained matter fall into the dropout chamber (10) through a multicone collector (11). Particulate passes through a rotary seal (12) to a dump box (13). Stack gases pass through a combustion air pre-heater (14). The forced draft air from fan (15) circulates through the air preheater and is metered to the furnace through linear flow dampers (16) for proper fuel combustion. Stack gases leave the air preheater, pass through an induced draft damper (17) which maintains a preset controlled pressure in the boiler combustion chamber (18). Final journey of the stack gases is through the induced draft fan (18) and out the exhaust stack (19) to atmosphere. Steam energy discharges through outlet (20) to process.

LEGEND:

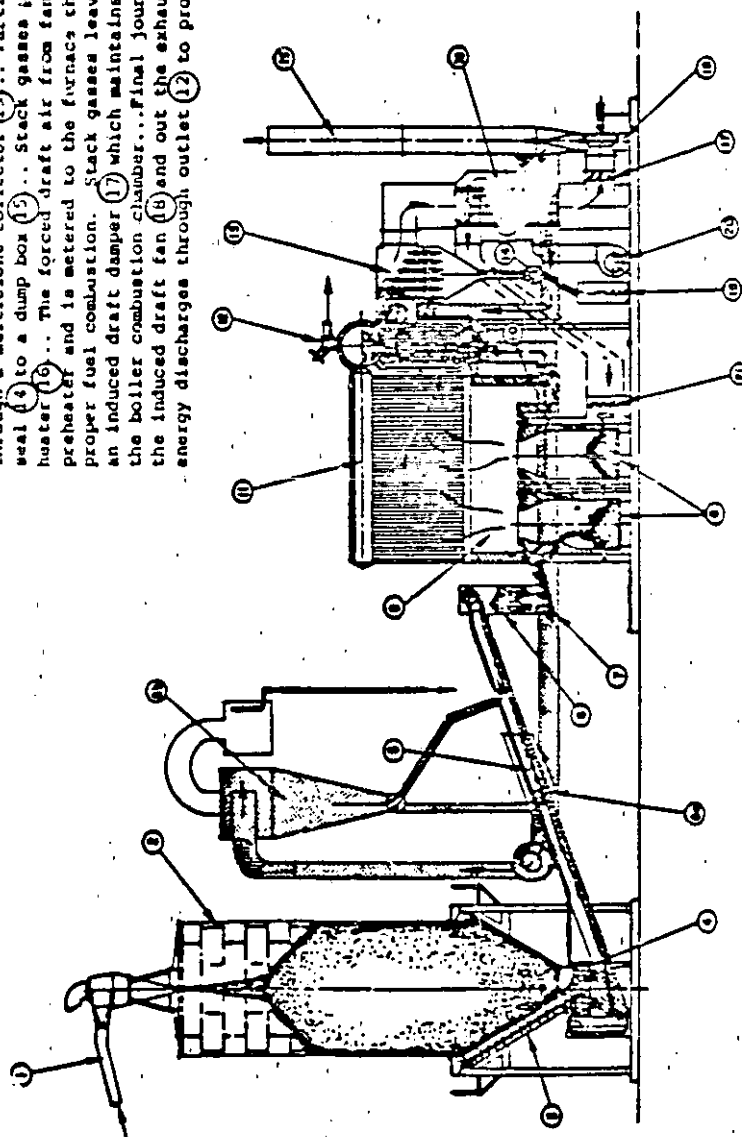
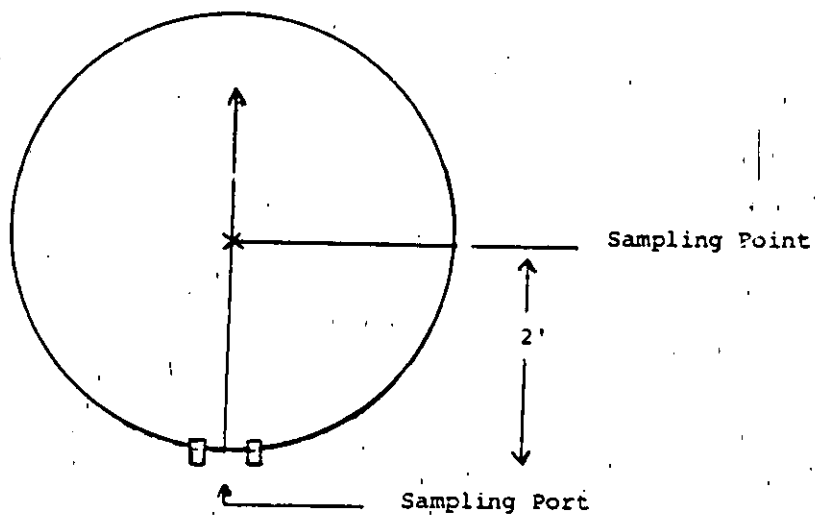


Figure 4-14. Wood chip and sawdust boiler.

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



Distance from Port Entrance, in.	Velocity Head, in. H ₂ O		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 Velocity

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 $1.2\% \pm 0.01\%$.

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:

	<u>1</u>
> 10 μ m	1
3 - 10 μ m	3
1 - 3 μ m	16
< 1 μ m	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)	(3.2/1.5)	(2.1/0.7)
Tantalum	t	t			
Zinc			t	t	
Total Elements ¹	23	34	16	15	2.0
Sulfates, H ₂ O sol ²	t	1.2	2.3	7.0	2.4
(Sulfur, from SO ₄ ²⁻) ⁴	(t)	(t)	(t)	(2.3)	(t)
Nitrate (H ₂ O 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

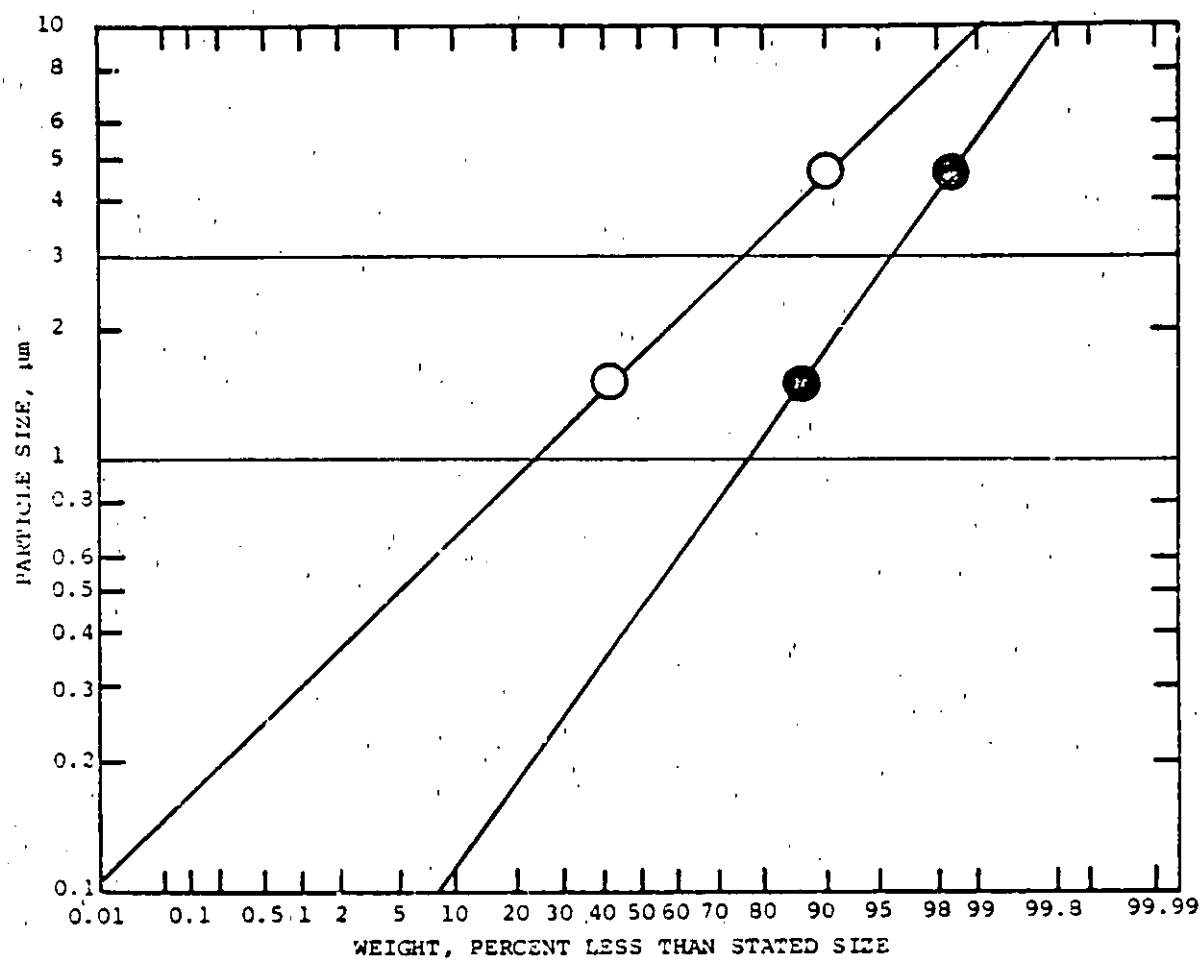
5 for values shown as X/Y, X is % of the element present and Y is the error (i.e. X% ± Y)

(t) 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% CO₂ and 16.6% O₂.

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.



- SASS Train With Impinger
- SASS Train Without Impinger

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.

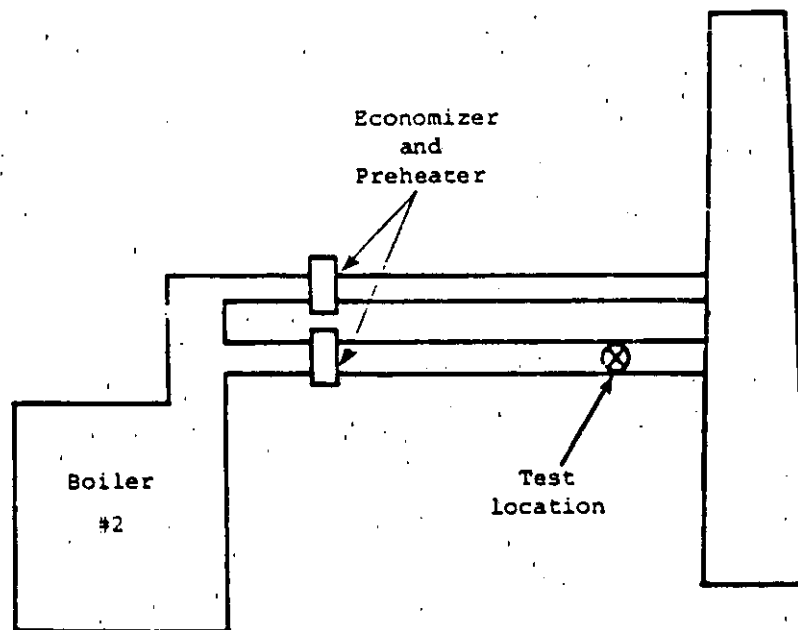
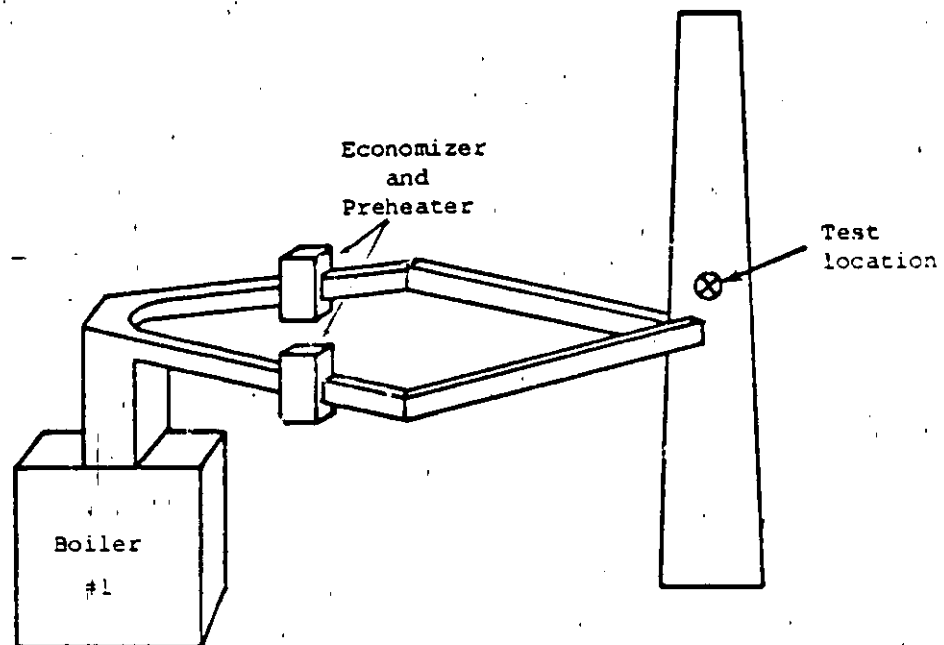


Figure 4-16. Flue gas flow from utility boilers.

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

Test #	Train	Sample Location		Velocity ft/sec At Test Point	Nozzle Diameter inches	Stack Temperature °F	Static Pressure Inches of Water	Stack Flow Calculated USCFM	Load MM	Boiler
		Distance From internal wall, inches	From Direction							
115	SASS	34	North	70.0	1/8	275	+1.0	823,736	472	1
117	Joy	34	East	42.1	1/4	275	+1.0	833,730	472	1
128	SASS	34	North	80.1	1/8	284	+1.0	898,170	276	1
129	Joy	34	East	54.6	1/4	275	+1.0	898,170	276	1
135*	SASS	34	North	88.6	1/8	281	+1.0	913,230	472	1
137	Joy	34	East	30.8	1/4	273	+1.0	913,230	472	1
215*	SASS	34	North	76.1	9/16	297	+1.0	849,434	450	1
217	Joy	34	East	47.0	5/16	290	+1.0	849,434	450	1
245	SASS	34	North	40.1	11/16	222	+1.3	481,018	238	1
247	Joy	34	East	23.0	7/16	220	+1.3	481,018	238	1
315	SASS	34	East	51.7	5/8	295	+1.0	795,981	453	1
327	Joy	34	East	51.7	1/4	292	+1.0	795,981	453	1
335	SASS	34	East	45.0	5/8	286	+1.0	855,043	455	1
337	Joy	34	East	45.0	5/16	286	+1.0	855,043	455	1
218	SASS	53	West	32.9	5/8	274	-0.8	378,394	174	2
219	Joy	65	West	32.9	5/16	275	-0.8	378,394	174	2
225	SASS	53	West	15.6	1.0	222	-0.75	215,124	90	2
227*	Joy	65	West	15.6	1/2	225	-0.75	215,124	90	2

*Bad data; not included in subsequent analyses

KVR 5806-783

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 1)

SAMPLE #	SASS Impinger (inorganic) 11S-1C	SASS Filter 11S-5S
PERCENT OF CUT	58	19
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 ₂ O sol) ²	15	35
(Sulfur, from SO ₄ ²⁻) ⁴	(4.9)	(11.8)
Nitrate (H ₂ O 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 Oceanographv 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-1C	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 ₂ O sol ²	16	41	40
(Sulfur, from SO ₄ ²⁻) ³	(5.3)	(14)	(13)
Nitrate (H ₂ O 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 ₂ O sol ²				21
(Sulfur, from SO ₄) ⁴				(6.9)
Nitrate (H ₂ O 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-1C
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 ₂ O sol ²	55	31
(Sulfur, from SO ₄) ⁴	(18.3)	(10.4)
Nitrate (H ₂ O 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 ₂ O sol ²	67
(Sulfur, from SO ₄ ²⁻) ⁴	(22)
Nitrate (H ₂ O sol) ²	5
Total Carbon ³	7.5
(Volatile Carbon) ³	
(Carbonates) ³	
TOTAL ANALYZED	84
BALANCE	16
	100%

1 detected in concentration of <1%

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

3 analyzed by wet chemistry--Section 3.2.2 A

4 analyzed by Oceanography carbon analyzer--Section 3.2.2 A

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

6 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 ₂ O sol ⁴	48	24	25
(Sulfur, from SO ₄ ⁼) ⁴	(16)	(8.1)	(8.5)
Nitrate (H ₂ O 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	7.9/0.3
Selenium	t	
(Sulfur)	(15/5)	(25/10)
Vanadium		t
Zinc	t	t
TOTAL ¹	t	18.4
Sulfates, H ₂ O sol ²	24	59
(Sulfur, from SO ₄) ⁴	(7.9)	(20)
Nitrate (H ₂ O sol) ²		
Total Carbon ³	18	t
(Volatile Carbon) ³	(9)	
(Carbonates) ³		
TOTAL ANALYZED	42	77
BALANCE	58	23
	100%	100%

2 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 ₂ O sol ²	59	23
(Sulfur, from SO ₄ ²⁻) ⁴	(20)	(7.8)
Nitrate (H ₂ O 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	19,230	19,250	19,260	19,250	19,278	19,287	19,255
Net Btu/lb	18,170	18,130	18,120	18,100	18,100	--	--	--
Alphaltenes, %	0.44	0.63	0.58	0.66	0.56	--	--	--
Metals in % of Ash								
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	5.66
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	e	e	e
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

* Truesdall Laboratories Inc.

† E. W. Saybolt & Co., Inc.

TABLE 4-26. MASS BALANCE FOR TEST 11

218,765 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	1.98
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	0.33	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; 19.34 lb/hr particulate from ash; 55.5 lb/hr particulate from SASS; 44.8 lb/hr particulate from Joy. $t < 0.1$ lb/hr.

Fraction & Fraction Units	SASS				Fuel Analysis Ash=0.009% lb/hr	Joy	
	Filter 21% lb/hr	Impinger 55% lb/hr	Sum 76% lb/hr	Total 100% lb/hr		Filter 29% lb/hr	Total 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	1.8	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					0.32		
Aluminum					0.34	t	t
Barium		t	t	t	0.22	0.5	0.17
Lead	t	t	t	t	0.13	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	2.35	7.7	(9.9) ²	485	3.94	(13.5) ²
Bromine		t	t	t			
Sulfate	5.02	4.9	9.9	12.7		5.18	18.16
Nitrate							
Total Carbon	1.19	4.3	5.5	7.1		2.68	9.1
Vol. Carbon		4.3	4.3	(5.1) ²			
Carbonate							
Cadmium		t	t	t			
Selenium		t	t	t			
Bismuth	0.04		0.04	0.05			
Cesium	t		t	t			
			Total	26.3		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		Fuel Analysis Ash=0.007% lb/hr
	Lepringer 78% lb/hr	Total 100% lb/hr	
Arsenic			0.32
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			0.28
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	19.1	
Vol. Carbon	12.23	(14.1)	
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 column² 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
Arsenic	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; 13.83 lb/hr particulate from ash; 46.2 lb/hr particulate from SASS; 59.3 lb/hr particulate from Joy							
Fraction & Fraction Units	SASS				Fuel Analysis Ash=0.0126 lb/hr	Joy	
	Filter 14% lb/hr	Impinger 75% lb/hr	Sum 89% lb/hr	Total ¹ 100% lb/hr		Impinger 74% lb/hr	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	0.03
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	1.11	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 particulate 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	0.99	2.79
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

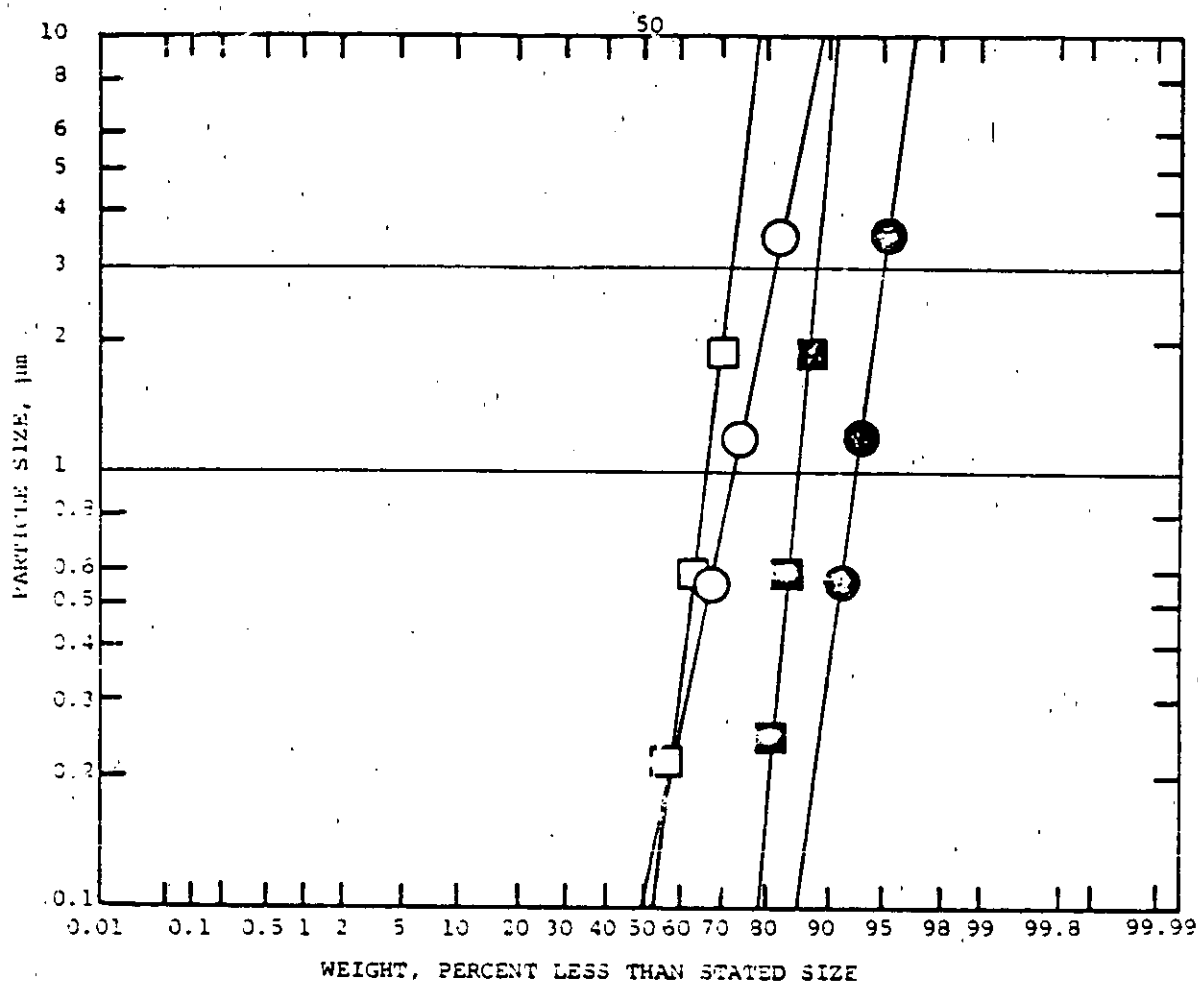
TABLE 4-33. MASS BALANCE FOR TEST 33

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
Silicon					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	(12.06) 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	

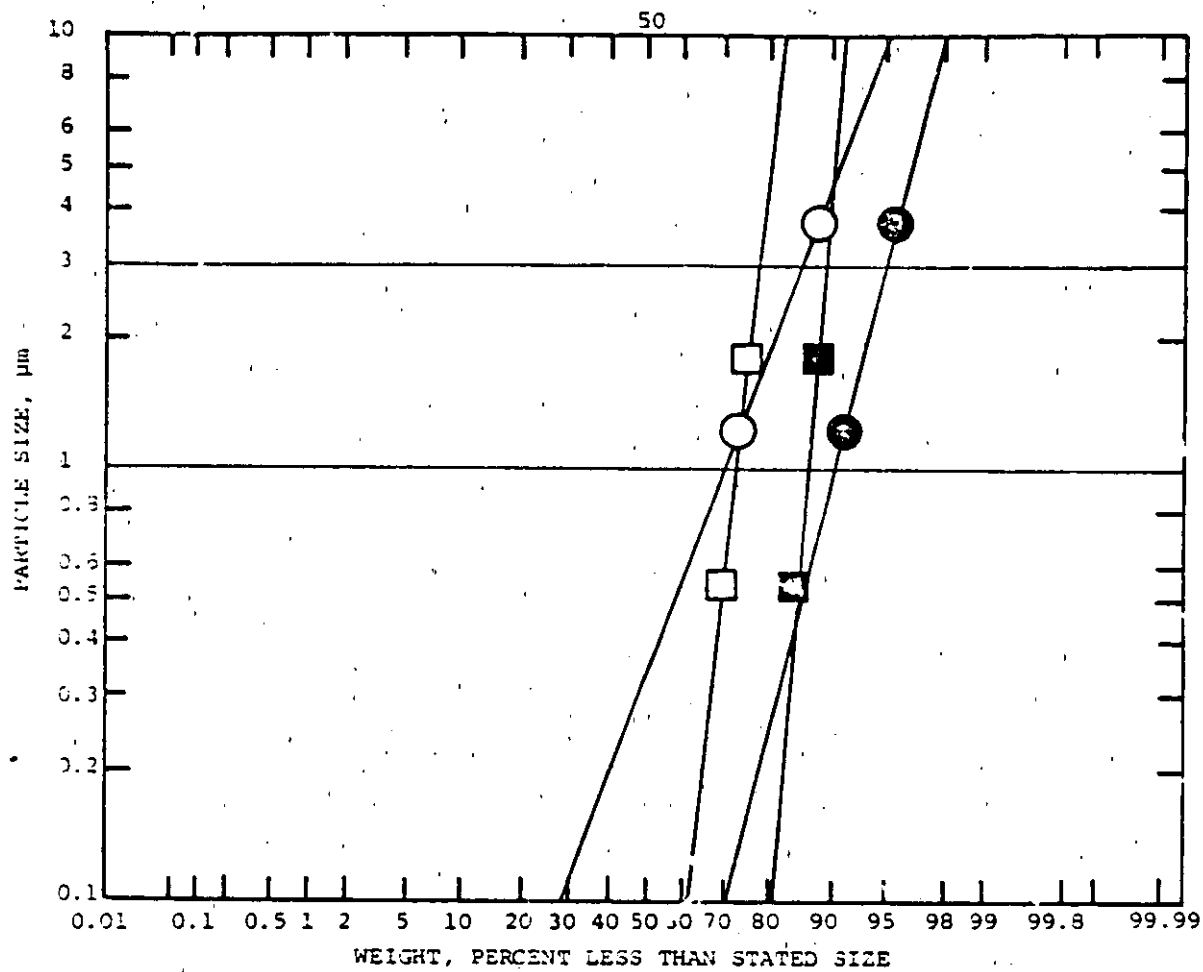
1 Compare total column with fuel analysis column

2 Not included in summation



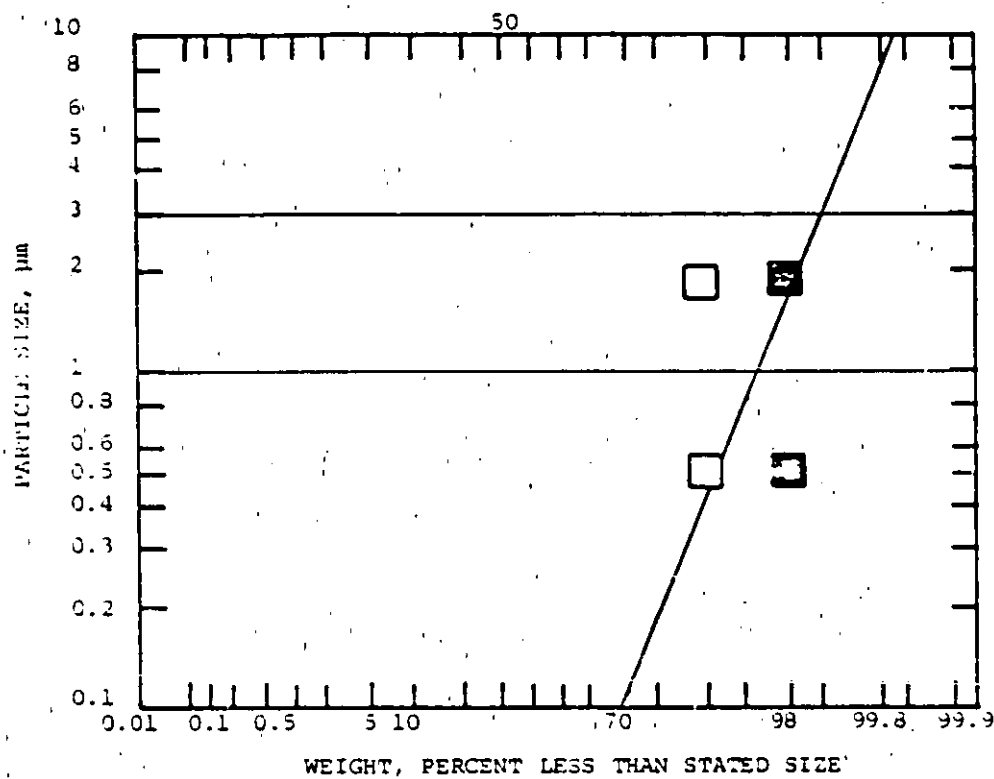
- Joy Mfg. Sampling Train With Impinger
- Joy Mfg. Sampling Train Without Impinger
- SASS Train With Impinger
- SASS Train Without Impinger

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



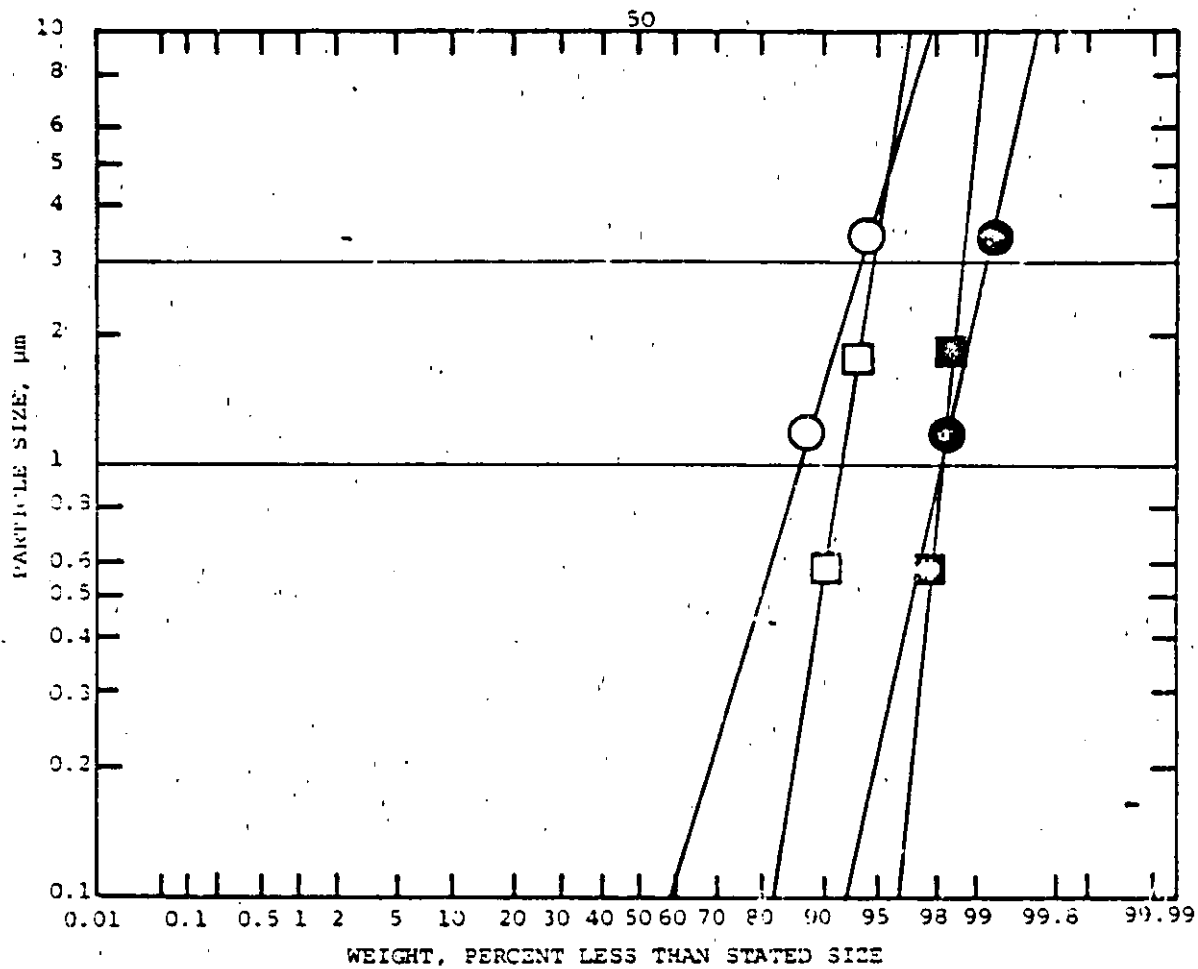
- Joy Mfg. Sampling Train With Impinger
- Joy Mfg. Sampling Train Without Impinger
- SASS Train With Impinger
- SASS Train Without Impinger

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



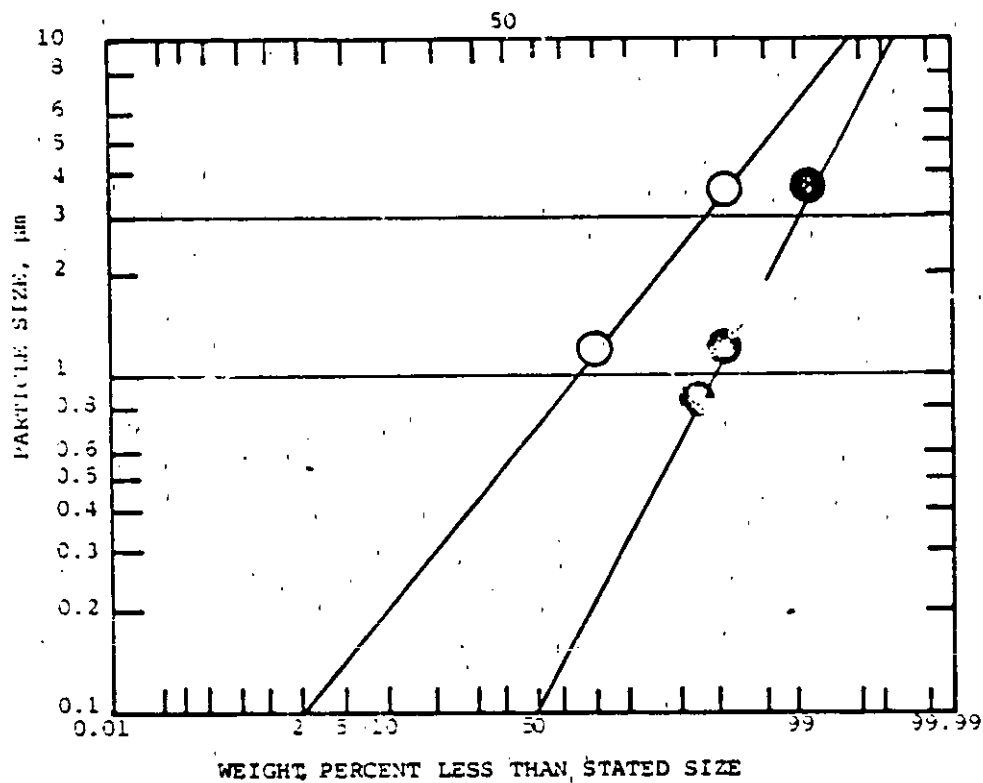
- Joy Mfg. Sampling Train With Impinger
 - Joy Mfg. Sampling Train Without Impinger
- (NOTE: Nothing collected in 3 μm cyclone)

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



- Joy Mfg. Sampling Train With Impinger
- Joy Mfg. Sampling Train Without Impinger
- SASS Train With Impinger
- SASS Train Without Impinger

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



- SASS Train With Impinger
- SASS Train Without Impinger

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

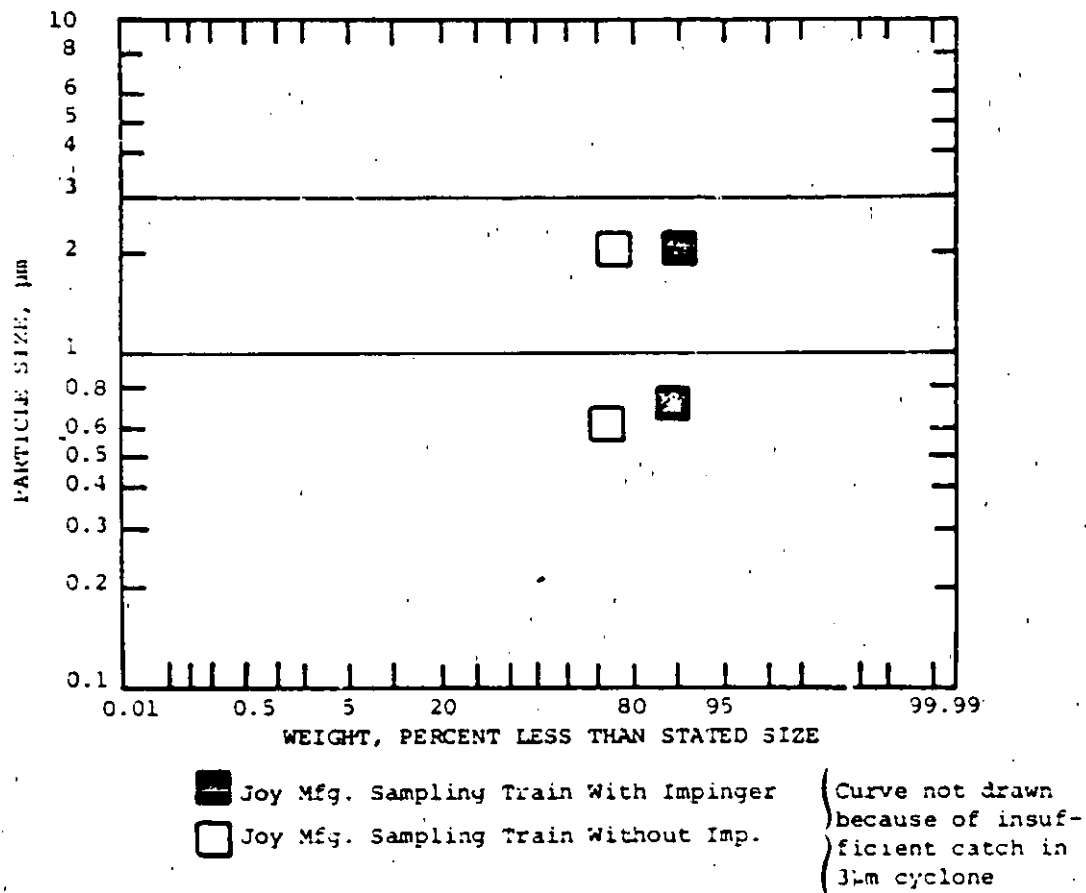
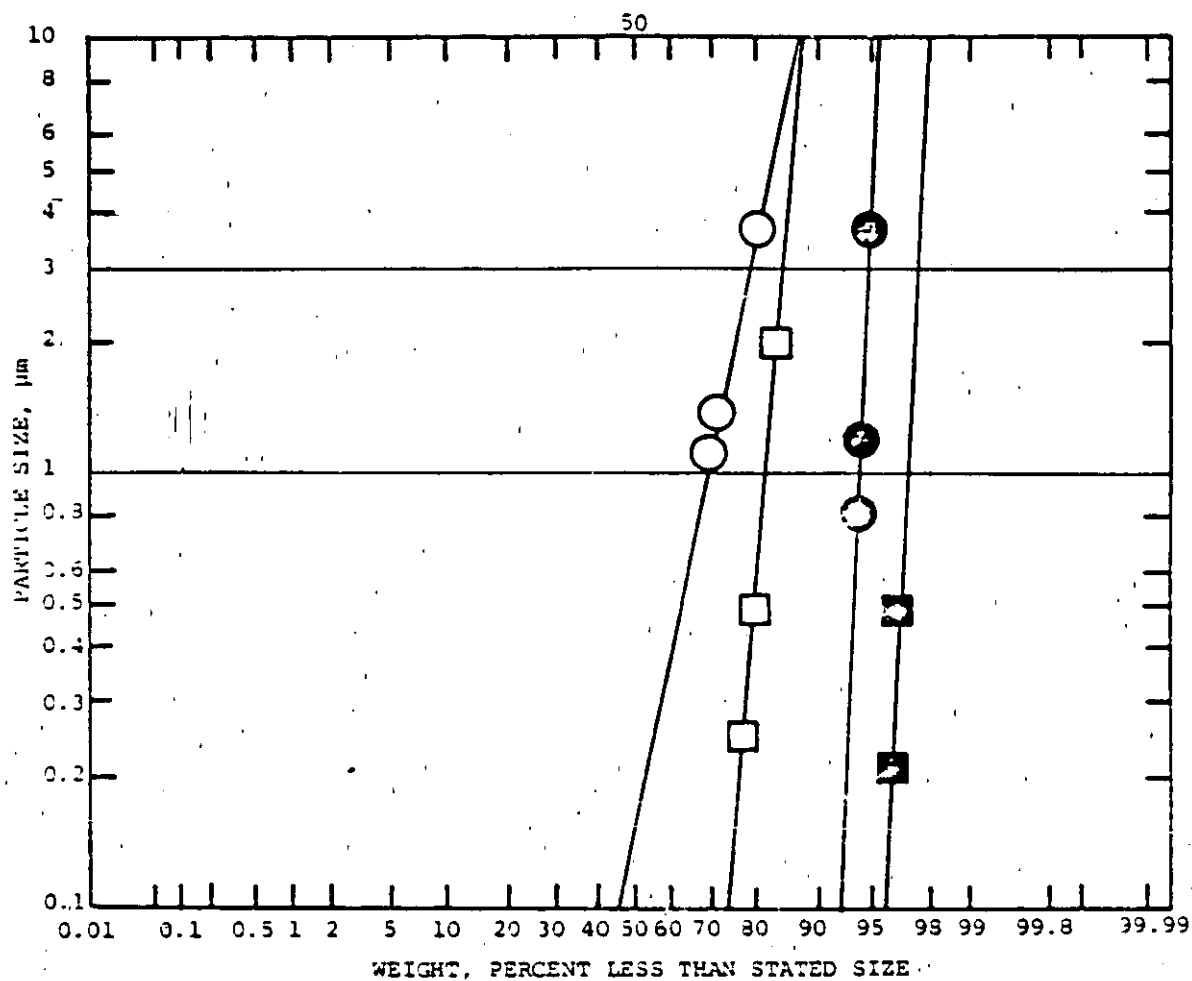


Figure 4-22. Particle size distribution for utility boilers (Test 23).



- Joy Mfg. Sampling Train With Impinger
- Joy Mfg. Sampling Train Without Impinger
- SASS Train With Impinger
- SASS Train Without Impinger

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

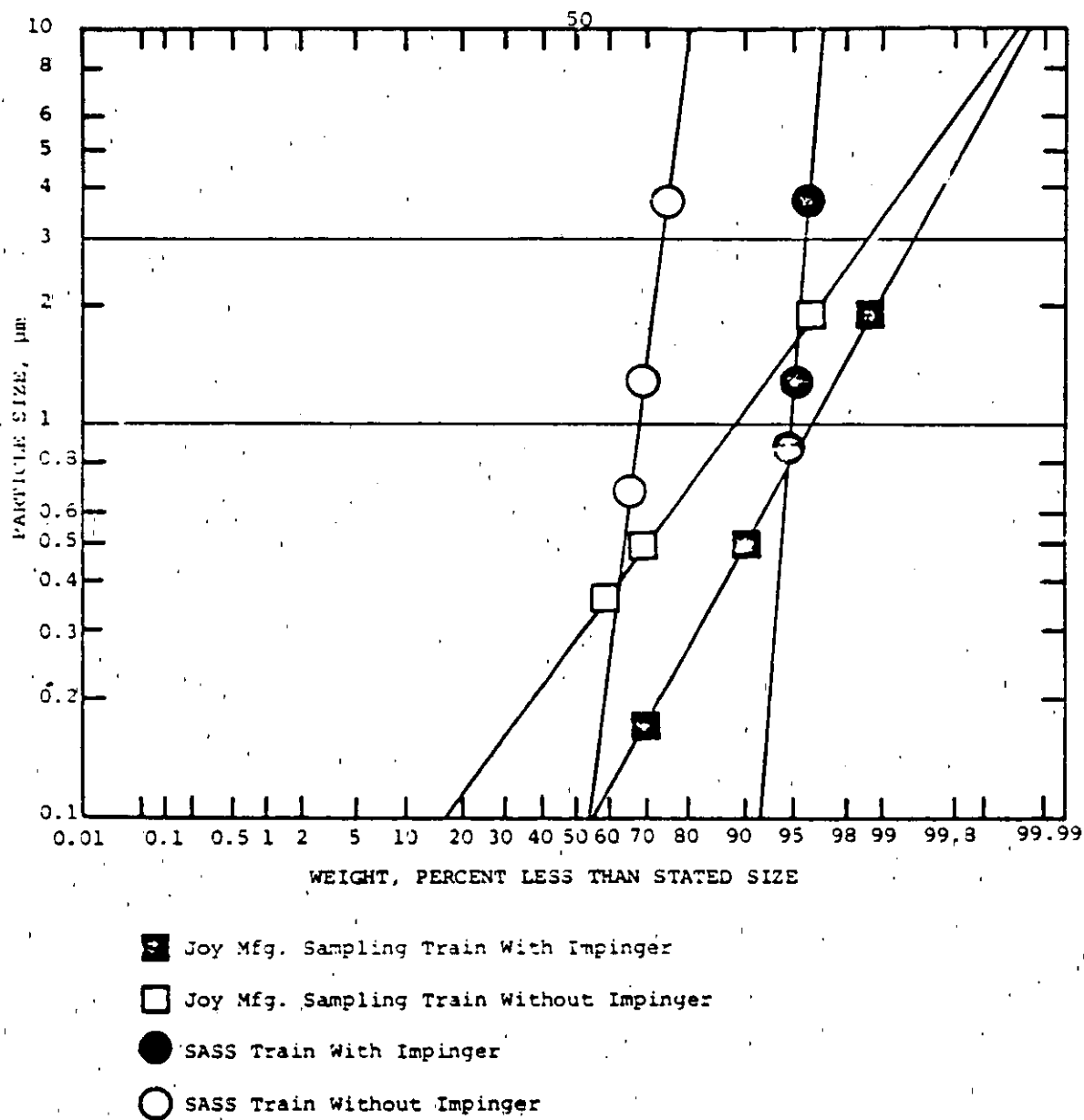
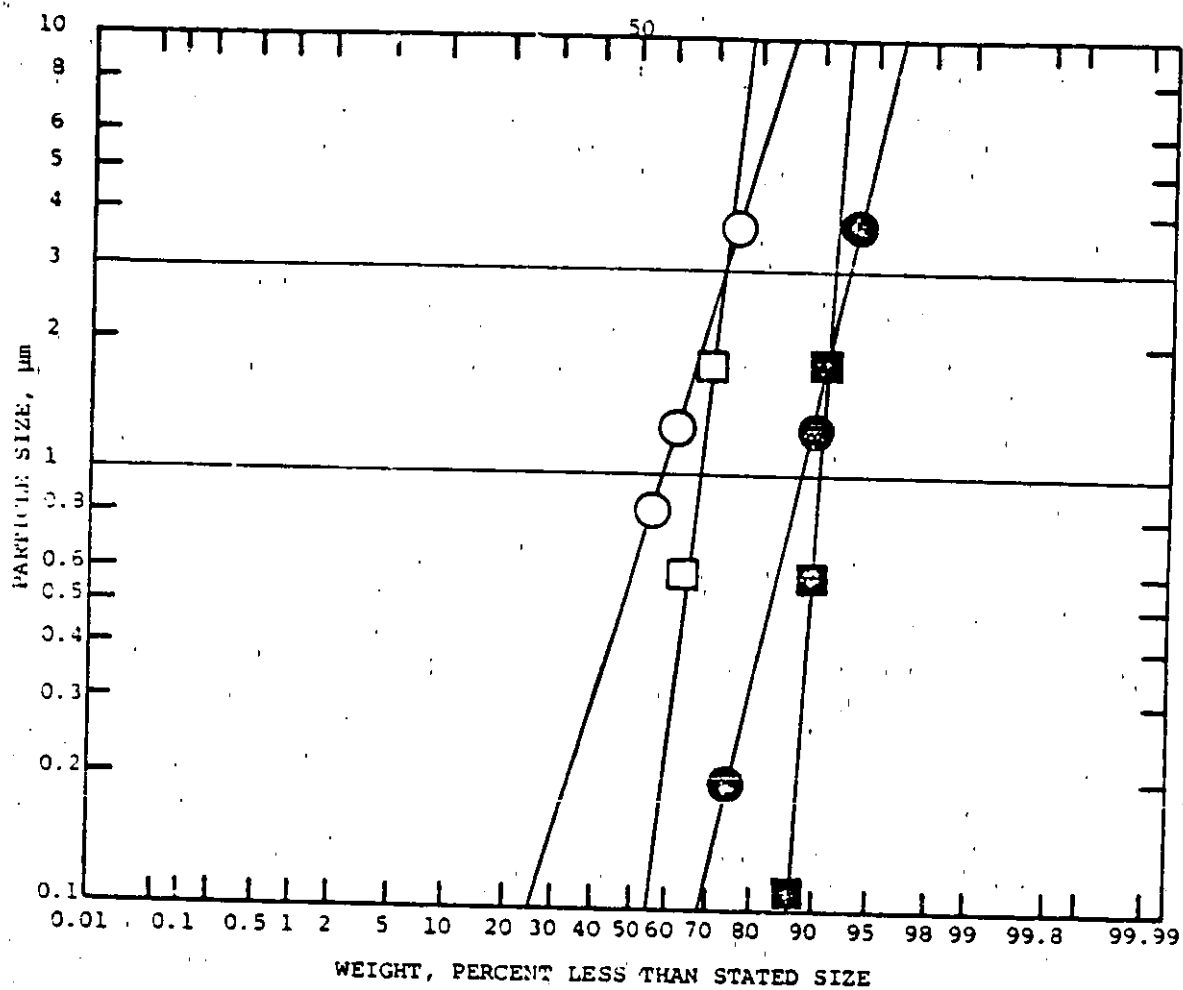


Figure 4-24. Particle size distribution for utility boilers (Test 32).



- Joy Mfg. Sampling Train With Impinger
- Joy Mfg. Sampling Train Without Impinger
- SASS Train With Impinger
- SASS Train Without Impinger

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

Test No.	Weight Percent of Particles*			
	>10 μ m	10-3 μ m	3-1 μ m	<1 μ m
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.

*Taken from Figure 4-26

Figure 4-26 is the particle size distribution range determined for the 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 μ m.

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.

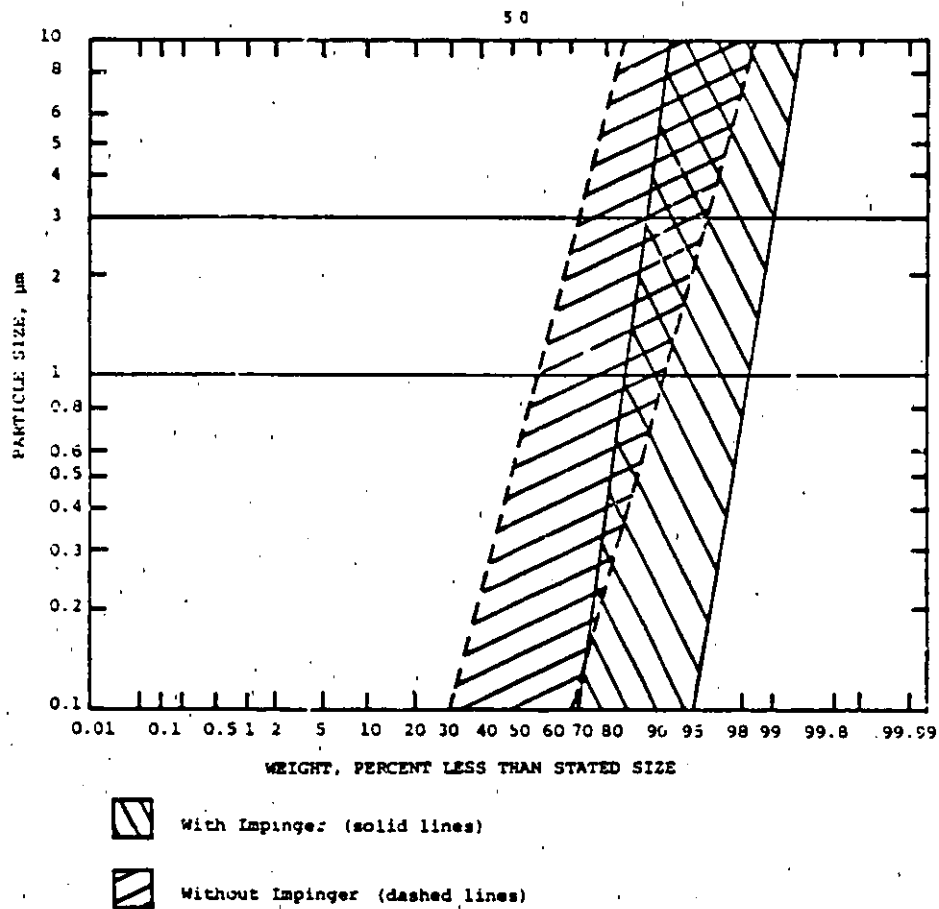


Figure 4-26. Summary of particle size distribution for utility boilers (15 tests)

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:

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

= 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. Emissions and emission factors--Emissions and emission factors can be listed for several different units. The list below shows some of these emissions and factors.

Test #	Emissions				lb/1000 gal burned
	gr/SCF	T/hr	lb/hr	lb/1000 Btu	
115	0.0091	284	65.03	0.0134	2.29
117	0.0078	243	55.6	0.0132	1.96
123	0.0072	242	55.5	0.0130	1.96
127	0.0058	194	44.3	0.0105	1.56
135*	0.0271	328	212.4	0.050	7.47
137	0.0088	299	68.5	0.0162	2.41
235*	0.0289	921	210.8	0.0534	8.06
237	0.0084	268	61.3	0.0161	2.34
243	0.0112	202	46.2	0.0214	3.35
247	0.0144	259	49.3	0.0275	4.37
323	0.0124	349	84.5	0.0211	3.09
327	0.0086	254	58.7	0.0147	2.14
335	0.0132	423	76.7	0.0244	3.56
337	0.0133	427	97.7	0.0246	3.59
215	0.0092	110	29.8	0.022	2.77
217	0.0071	101	23.0	0.017	2.13
225	0.0109	87	20.2	0.023	3.70
227*	0.0046	18	8.6	0.0099	1.57
Average	0.0098	252	57.1	0.0183	2.77

* Not included in the average (bad data)

KVB 5206-783

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 Symond (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 K73/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.

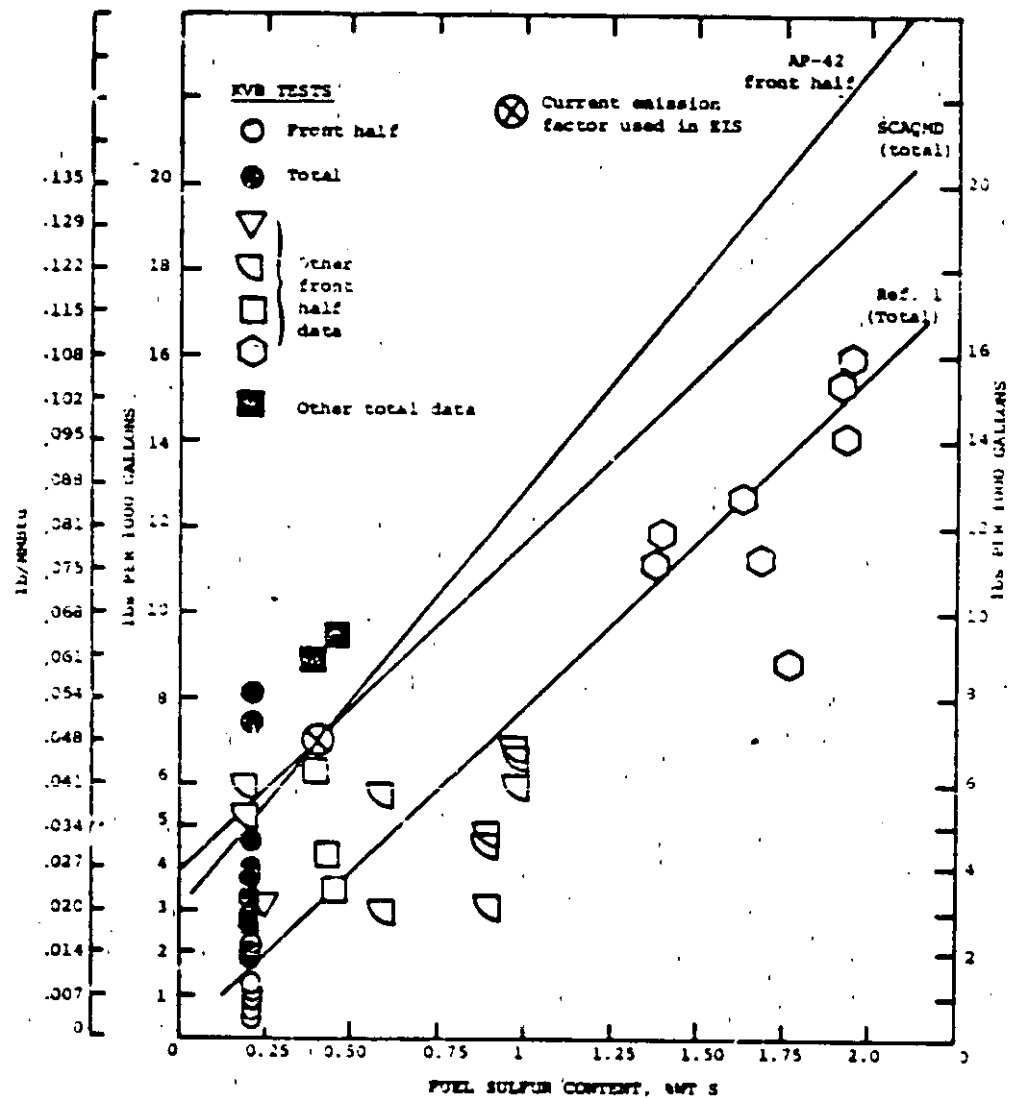


Figure 4-27. Emission factors as a function of fuel sulfur content for utility boilers.

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 3400 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 (1 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 3 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

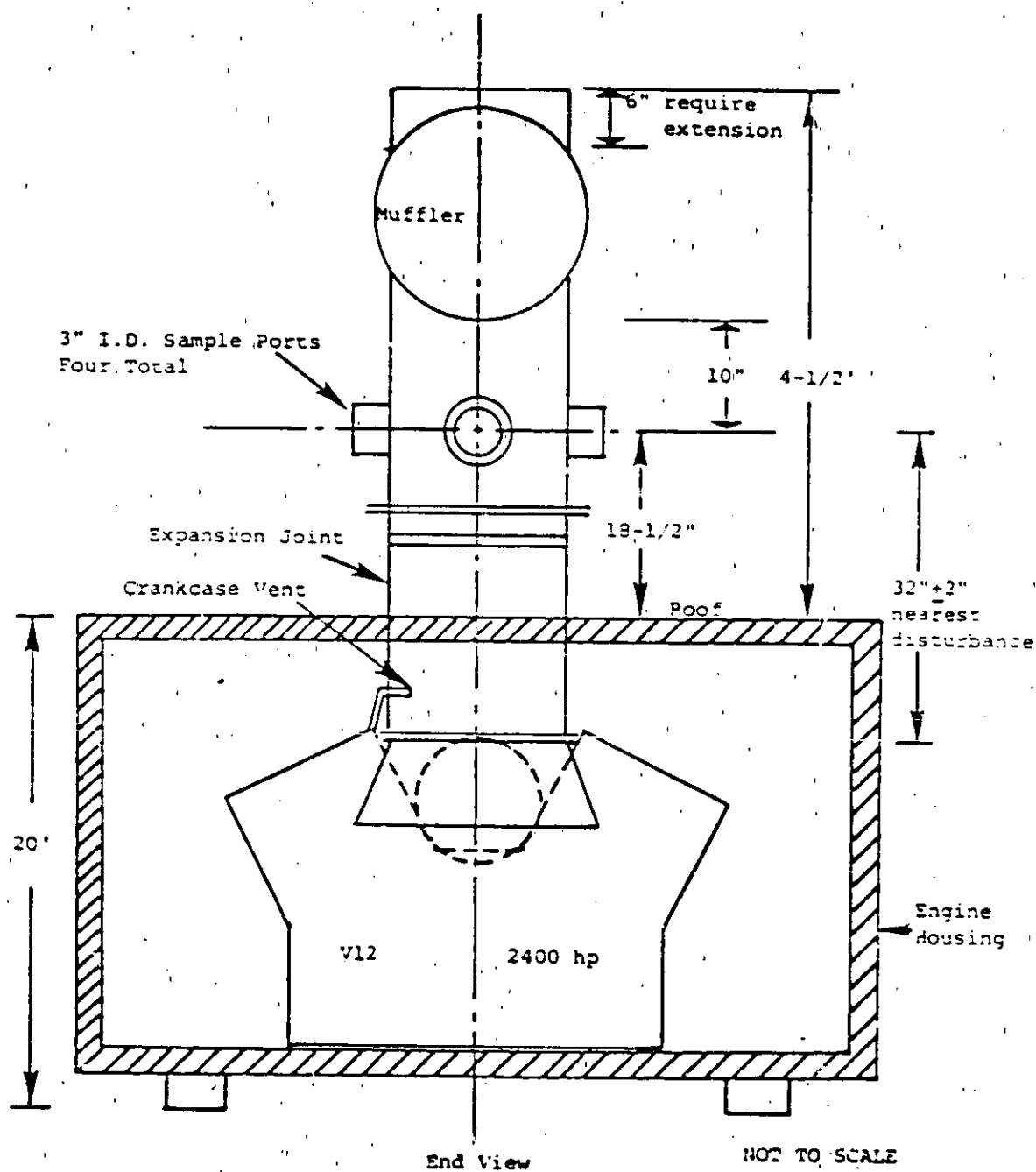
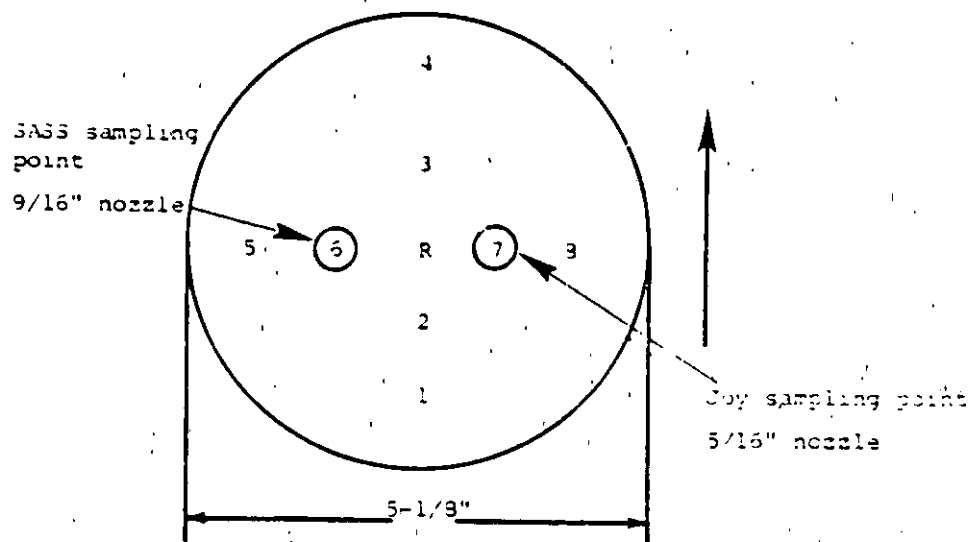


Figure 4-29. Schematic of IC engine (Test 15).

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



Temperature: 412°F

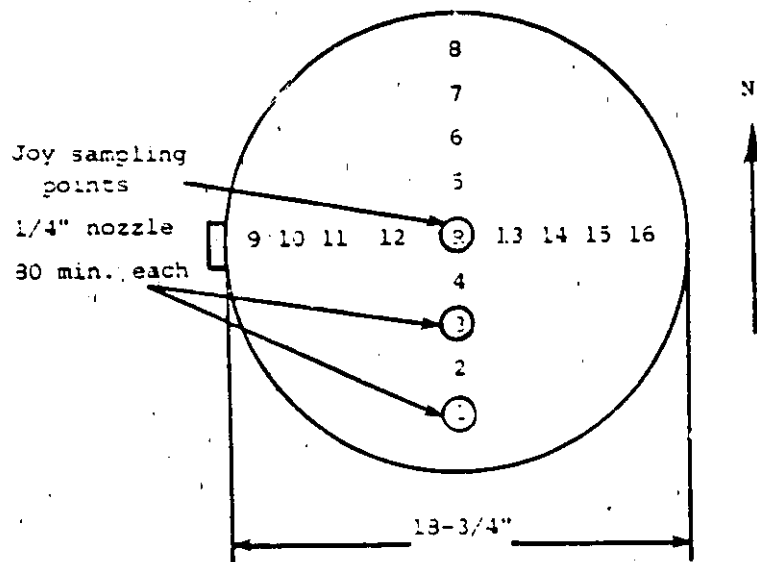
Static Pressure: 0.1" H₂O

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" H₂O

Distance from internal wall	Velocity			
	Point #	ft/sec	Point #	ft/sec
0.6"	1	137	8	97
2.0	2	134	9	61
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			
	>10 μm	10-3 μm	3-1 μm	<1 μm
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		Fuel--#2 Diesel Oil
	Test 7S	Test 7J	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 9% 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)

KVB 5806-783

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 ₂ O sol ²	6.3	43	48
(Sulfur, from SO ₄ ²⁻) ⁴	(2.1)	(14.5)	(16)
Nitrate (H ₂ O 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

KVB 5806-783

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

SAMPLE #	Joy Filter 15J-3S	Joy Impinger Organics 15J-10	Joy Impinger Condensate 15J-1C
PERCENT OF CUT	13.5	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 ₂ O sol ²	8.2	†	20.4
(Sulfur, from SO ₄) ⁴	(2.7)	†	(7)
Nitrate (H ₂ O 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

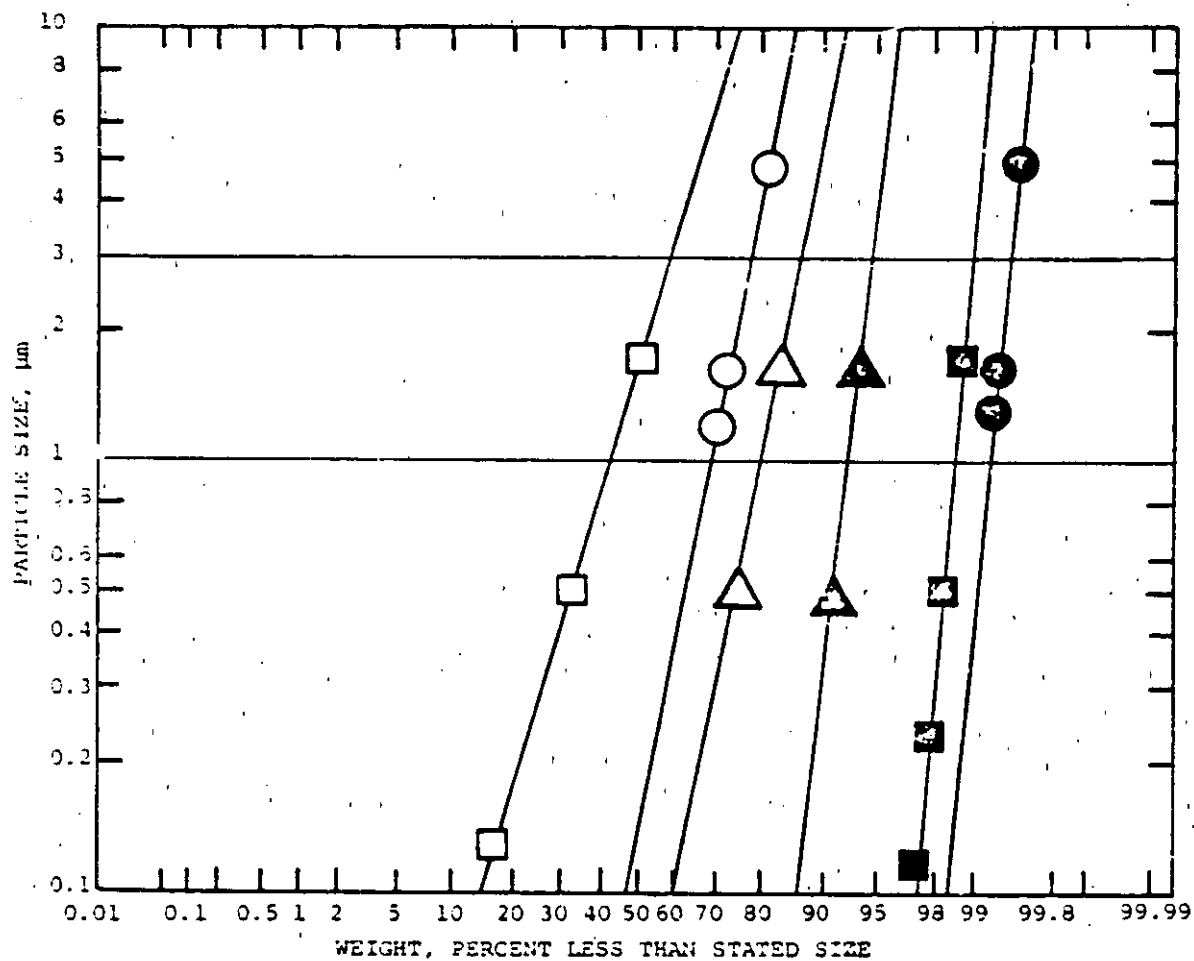
2 analyzed by wet chemistry--Section 3.2.2 A

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



- Joy Mfg. Sampling Train With Impinger (Test 7J)
- Joy Mfg. Sampling Train Without Impinger (Test 7J)
- SASS Train With Impinger (Test 7S)
- SASS Train Without Impinger (Test 7S)
- ▲ Joy Mfg. Sampling Train with Impinger (Test 15J)
- △ Joy Mfg. Sampling Train without Impinger (Test 15J)

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

KVB 5806-783

TABLE 4-38. RESULTS OF FUEL ANALYSES
FUEL TYPE NO. 2 DIESEL
(FOR TEST 15)

Sample	
Carbon, %	86.23
Hydrogen, %	13.28
Nitrogen, %	0.017
Sulfur, %	0.41
Ash, %	<0.001
Oxygen, %	0.06
Heat of Combustion:	
Gross Btu/lb	19,670
Net Btu/lb	18,460

Spark Source Mass Spectrographic Analysis of the Ash

	WT%
Tin	17.5
Boron	0.23
Silicon	9.7
Manganese	0.68
Iron	17.0
Magnesium	7.9
Lead	3.4
Aluminum	2.4
Copper	0.79
Zinc	7.1
Calcium	0.94
Nickel	0.41
Titanium	0.64
Cobalt	0.32
Chromium	0.086

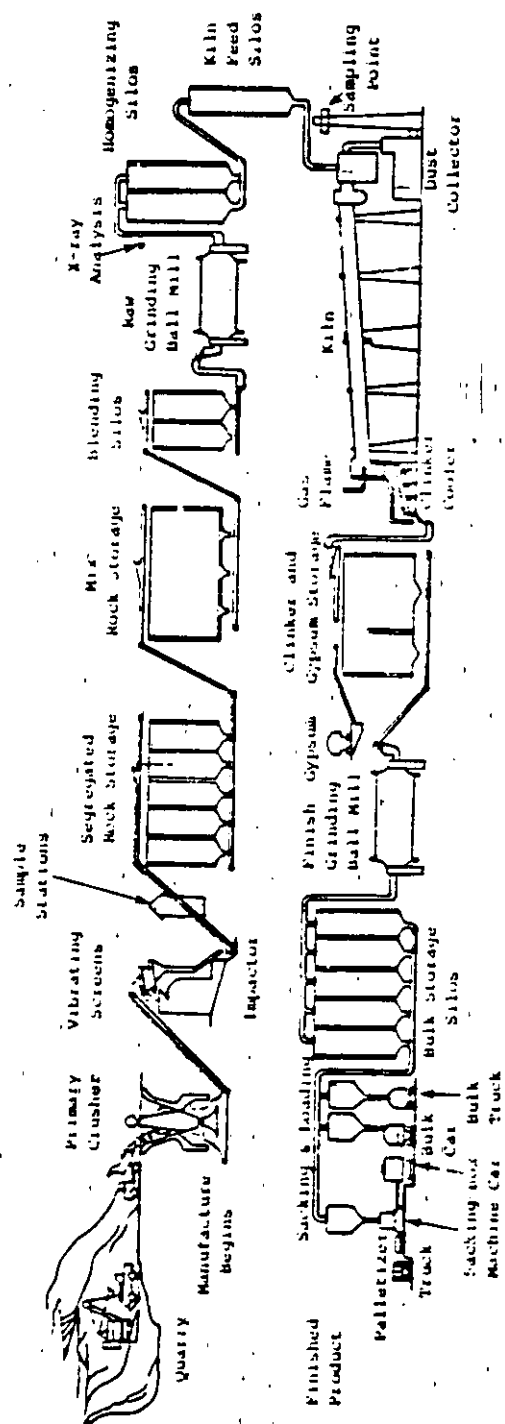


Figure 4-30. Cement production.

KVB 5806-783

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 13. 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 13. Note that for Test 13, 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--

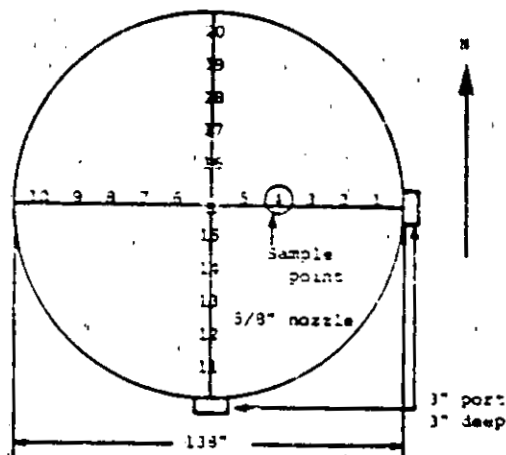
The results of the two tests discussed in this section are listed in Table 4-41. Major elemental composition, sulfate, nitrate and carbon analysis were determined for all fractions of particulate catches which contained weights in excess of 100 mg. The details for these procedures are discussed in Section 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 (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. 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			
	>10 μm	10-3 μm	3-1 μm	<1 μm
Test 9, gas fired	8	32	40	20
Test 13, coal fired	9	24	34	34

TABLE 4-39. VELOCITY PROFILE FOR CEMENT MANUFACTURING



	Test 9	Test 13
Temperature	365°F	375
Static Pressure	-0.1"H ₂ O	+0.2
Fuel	Gas	Coal

Distance from End of port	Velocity Point #	Test 9 Velocity ft/sec	Test 13 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	44.15
50-1/2	5	30.3	39.7
72	8	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	8	31.1	38.4
93-1/2	16	--	39.0
109-5/8	17	--	39.7
121	9	--	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	(0.2/0.3)		(0.4/0.4)
Titanium			t
TOTAL ¹	30	24	19
Sulfates, H ₂ O sol ²	1.26	1.63	4.27
(Sulfur, from SO ₄ ²⁻) ³	(0.42)	(0.56)	(1.42)
Nitrate (H ₂ O sol) ²	t	t	t
Total Carbon ¹	16	19	
(Volatile Carbon) ¹	(3.22)	(2.66)	
(Carbonates) ¹	(3.79)	(3.10)	
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)

6 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-1C	Filter 18S-5S
PERCENT OF DUT	9.9	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		1.5/0.3
(Sulfur)	(<3)	(2.7/0.7)	(5.2/0.2)	(40.10)	(4.9/2)
TOTAL ¹	25	20	22	2	25
Sulfates, H ₂ O 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 ₂ O 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

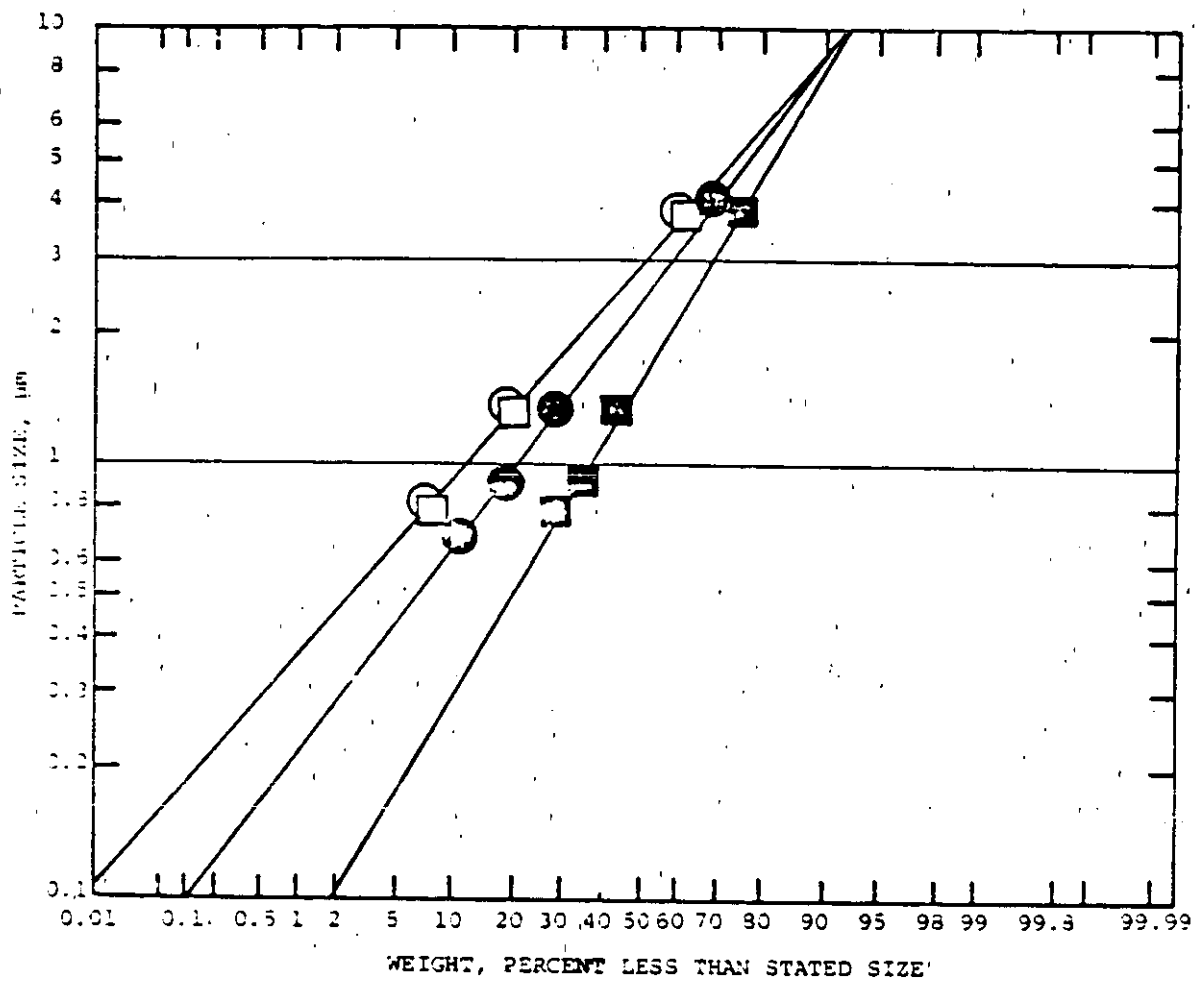
3 analyzed by Oceanography carbon analyzer--Section 3.2.2 A

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

KVB 5806-793



- SASS Train with Impinger) Test 18
- SASS Train without Impinger) coal
- SASS Train With Impinger) Test 9
- SASS Train Without Impinger) gas
- SASS Train Without Impinger) fired

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

KVB 5806-783

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

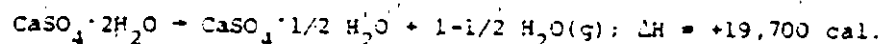
2. Chemical Composition - Tables 4-40 and 4-41 list the results from the chemical analysis of the particulate fraction for each of the tests discussed in this section. Calcium is the most predominant species, as one would expect. Carbon is second most abundant. Its origin is most likely from the uncombusted 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 $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$. When heated slightly, the following reaction occurs:



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, $\text{CaSO}_4 \cdot 1/2 \text{H}_2\text{O}$, 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

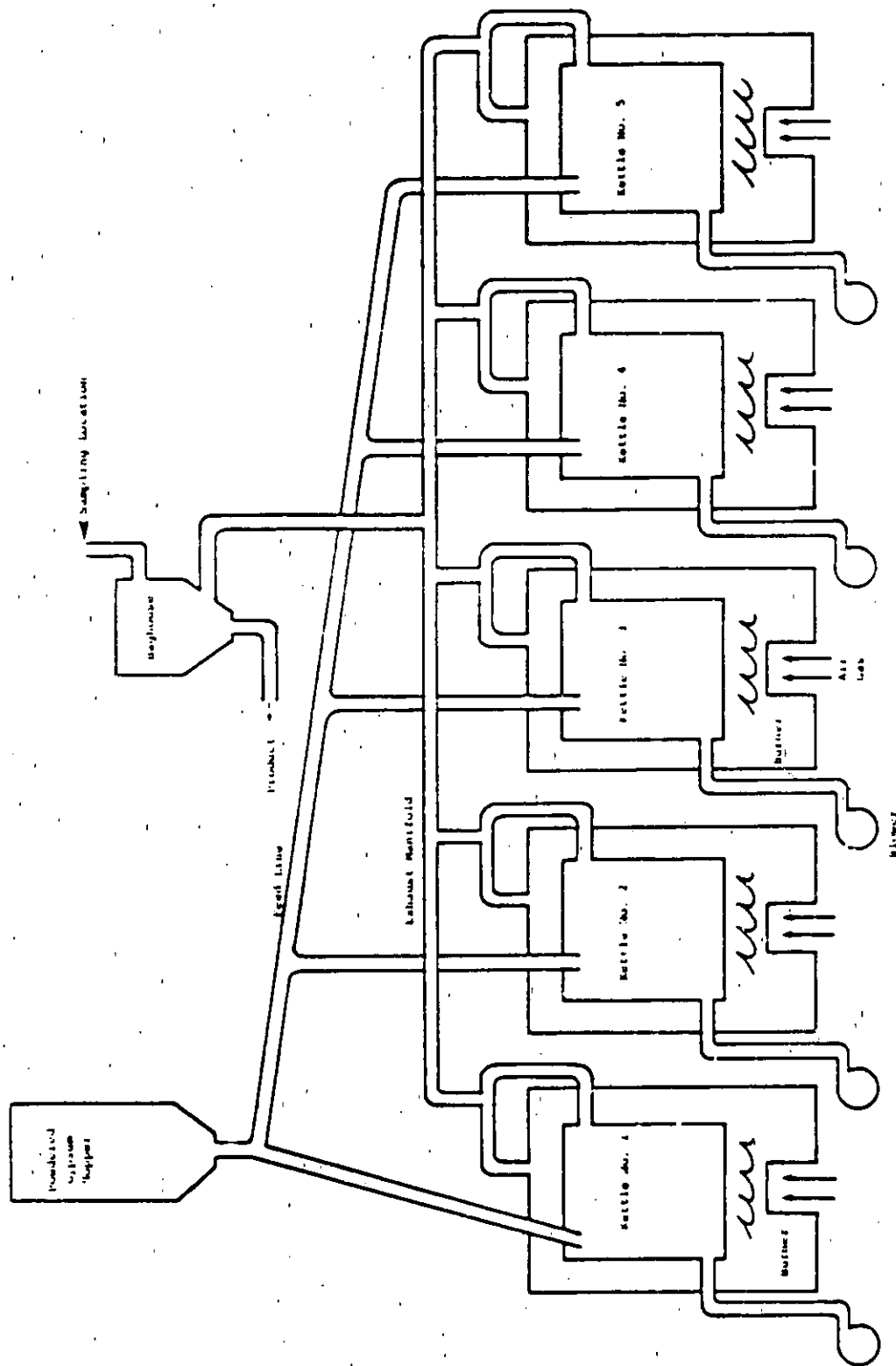
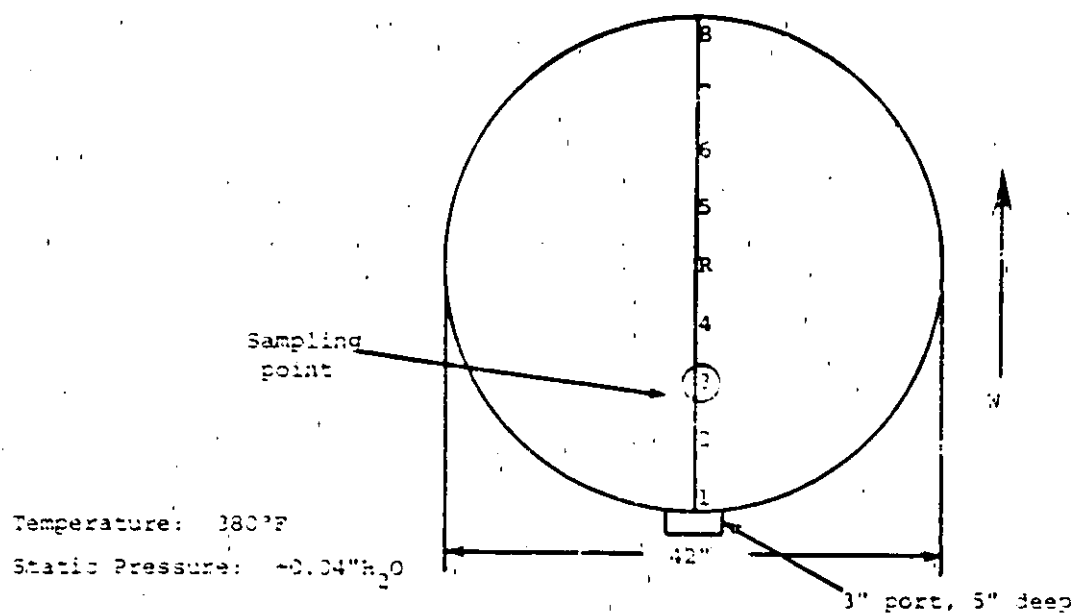


Figure 4-32. Gypsum calcining operation.

KVB 5806-783

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



<u>Distance From End of Port</u>	<u>Velocity Point #</u>	<u>Velocity ft/sec.</u>
6-3/8	1	14.1
9-3/8	2	18.6
13-1/4	3	17.2
18-1/5	4	13.6
26	R	18.6
33-1/2	5	17.2
38-7/8	6	15.7
42-5/8	7	14.1
45-5/3	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 (13% 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	>10 μm	10-3 μm	3-1 μm	<1 μm
impinger not included	6	44	43	7

The particle size distribution curve, Figure 4-33, indicates that the mean particle size is 3.0 μm . 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	10	9.7	15	7	15
Sulfates, H ₂ O sol ²	62	57	12	41	61
(Sulfur, from SO ₄ ²⁻) ⁴	(20)	(19)	(4.12)	(13)	(20)
Nitrate (H ₂ O 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

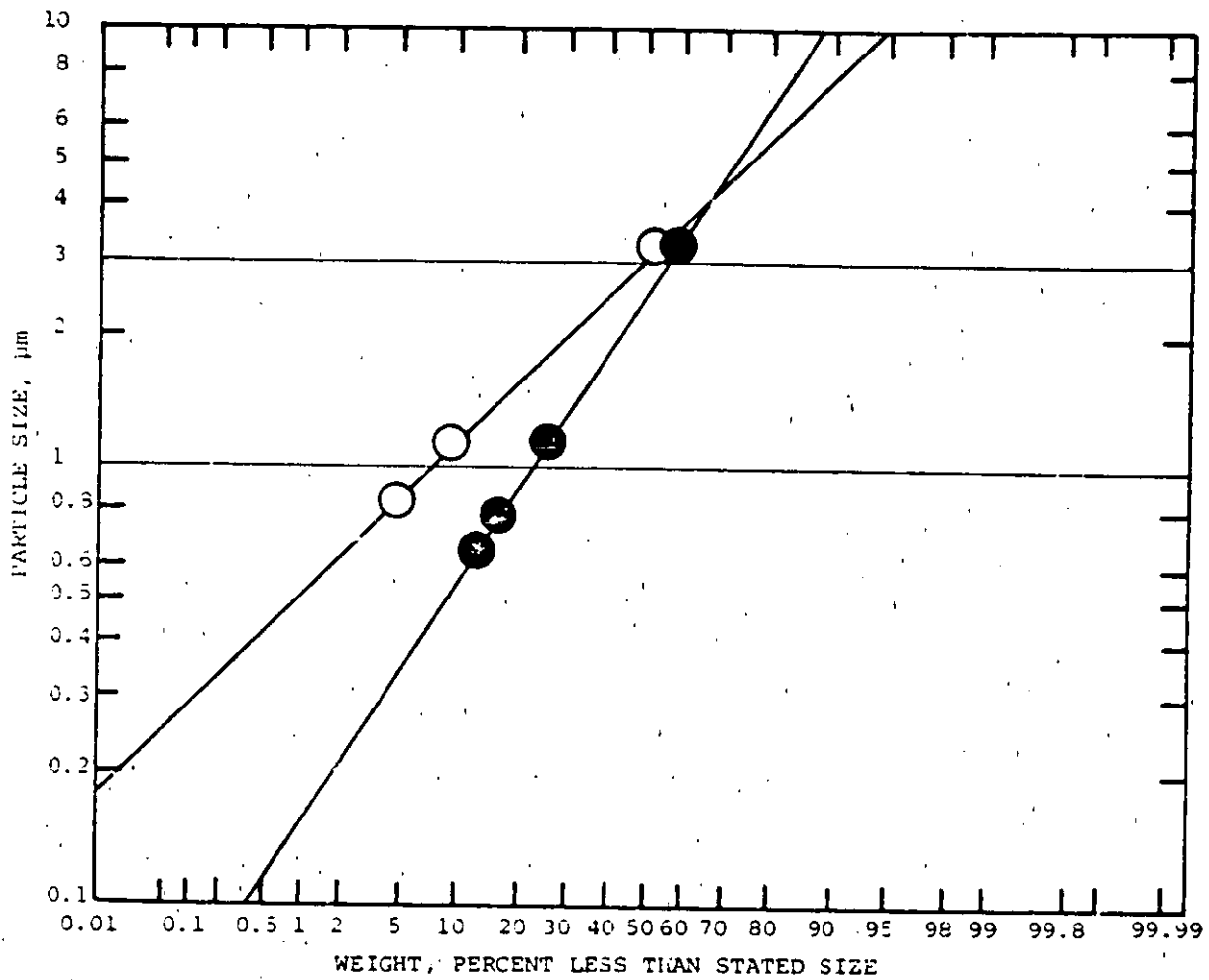
2 analyzed by wet chemistry--Section 3.2.2 A

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



- Joy Mfg. Sampling Train With Impinger
- Joy Mfg. Sampling Train Without Impinger
- SASS Train With Impinger
- SASS Train Without Impinger

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

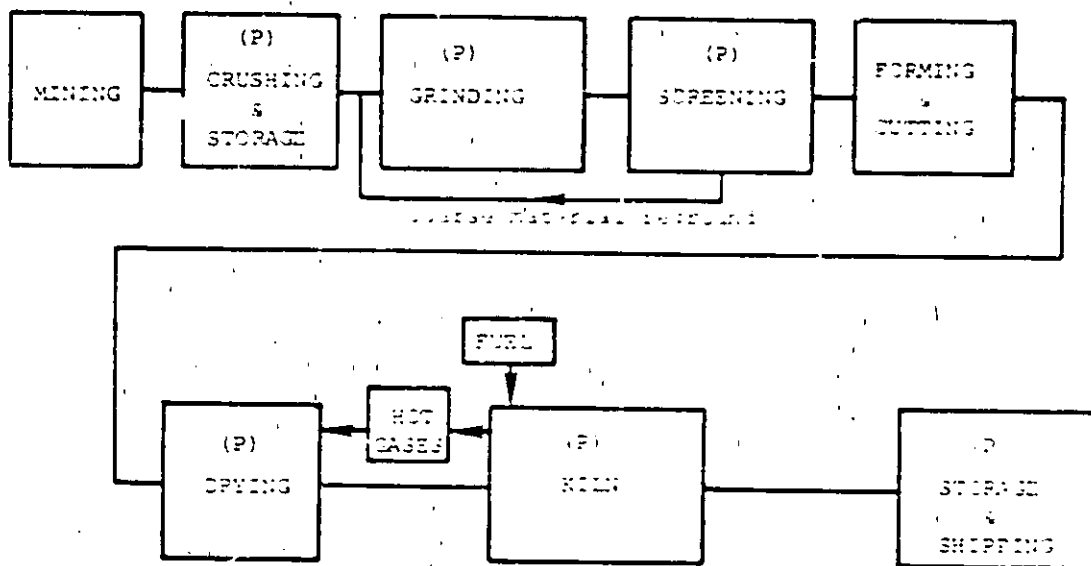


Figure 4-14. Basic flow diagram of brick manufacturing process.
 "P" denotes a major source of particulate emissions.

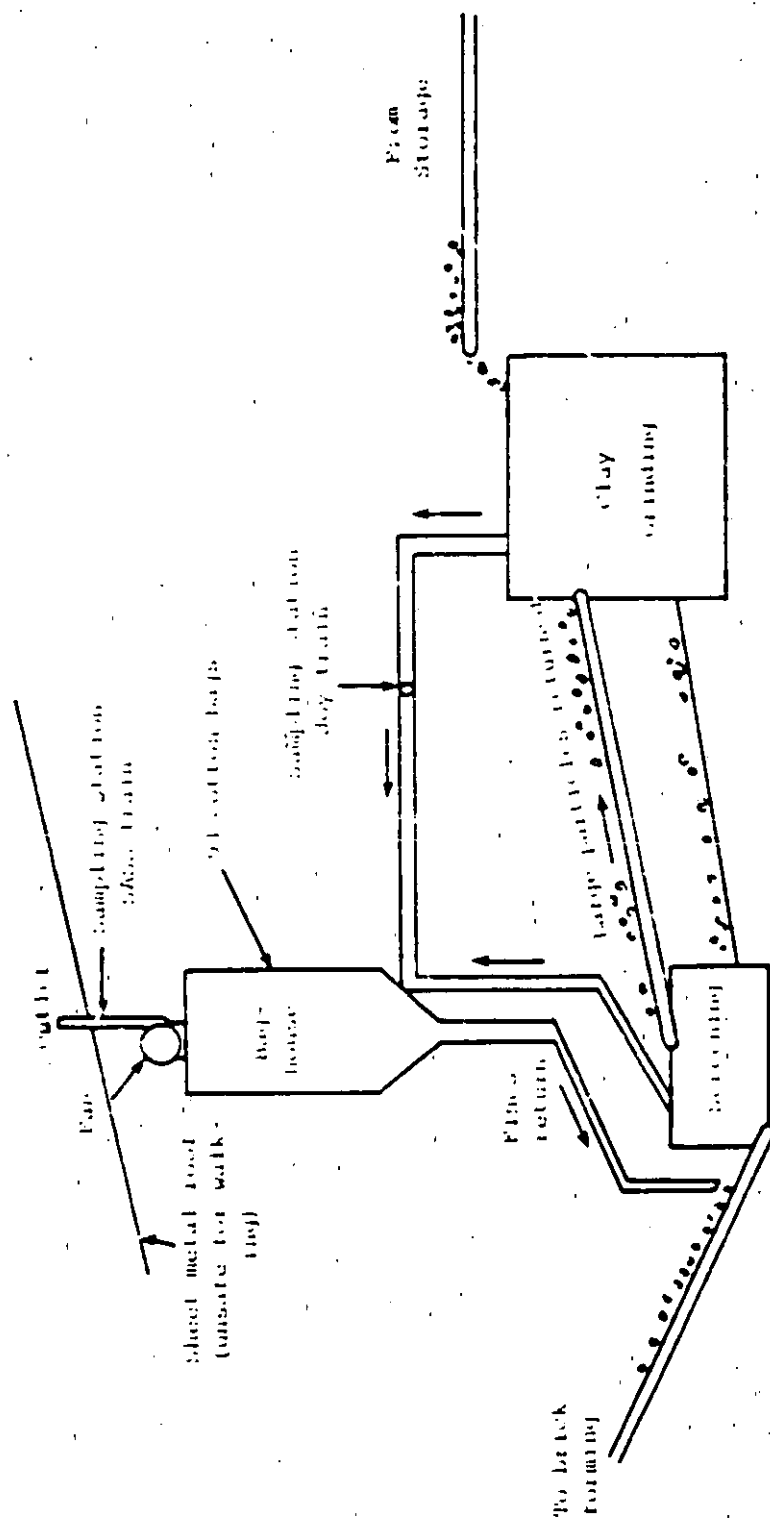


Figure 4-15. Brick manufacturing-clay grinding process

KVB 5806-783

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 assure that the inlet stream from the tripper 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 BASS sampling train for the baghouse exit.

C. Test Results--

The results of the tests discussed in this section, Tests 8S and 8U, 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 8U and 8S.

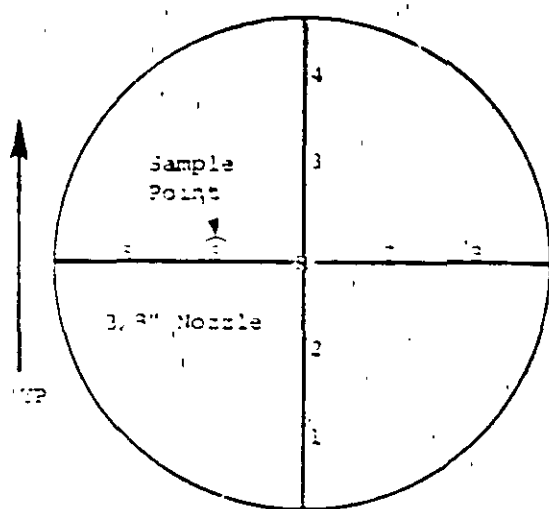
D. Discussion of Results--

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

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

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

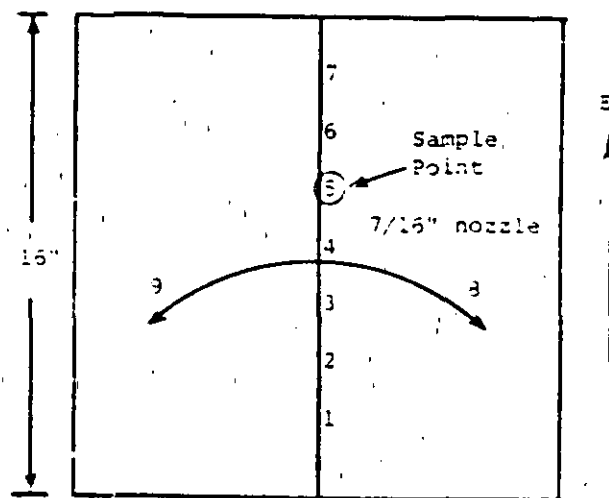
TABLE 4-44. VELOCITY PROFILE FOR BRICK GRINDING PROCESS (TEST 8)



INLET TO BAGHOUSE

Temperature: 73°F

Static Pressure: -0.1" H₂O



OUTLET FROM BAGHOUSE

Temperature: 84°F

Static Pressure: -1.2" H₂O

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"	3	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	83.9
3"	6	45.2	15"	7	47.3
5"	R	46.9	9"	8	66.8
9"	7	46.9	8"	9	71.4
11-1/4"	8	--			
	Average	47.5			61.5
	2175 SCFM				6020 SCFM

KVB 5806-783

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

SAMPLE #	Joy 10Lm Cyclone 8S-2S	SASS 10Lm 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 ²	23	22
Sulfates, H ₂ O sol ²	t	1.02
(Sulfur, from SO ₄ ²⁻) ⁴	(t)	(t)
Nitrate (H ₂ O 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

3¹ analyzed by Oceanography carbon analyzer--Section 3.2.2 A

4¹ 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. % ± 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.

$$\begin{aligned} & \{ [3(1.169) - 0.0064] / 3(1.169) \} \times 100\% \\ & = 99.8\% \end{aligned}$$

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			
	>10 μm	10-3 μm	3-1 μm	<1 μm
Inlet (Test 9S)	98.6	0.85	0.3	0.15
Outlet (Test 9S)	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

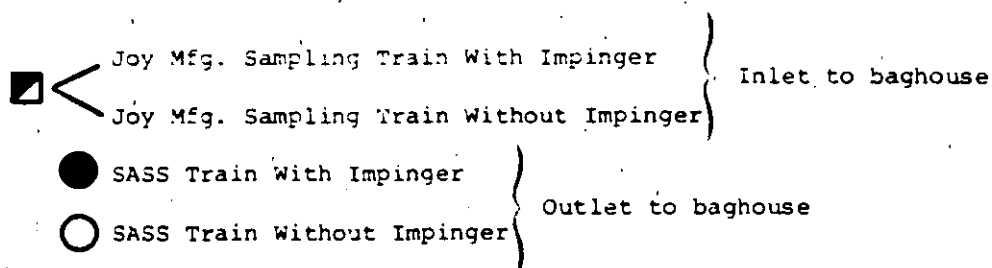
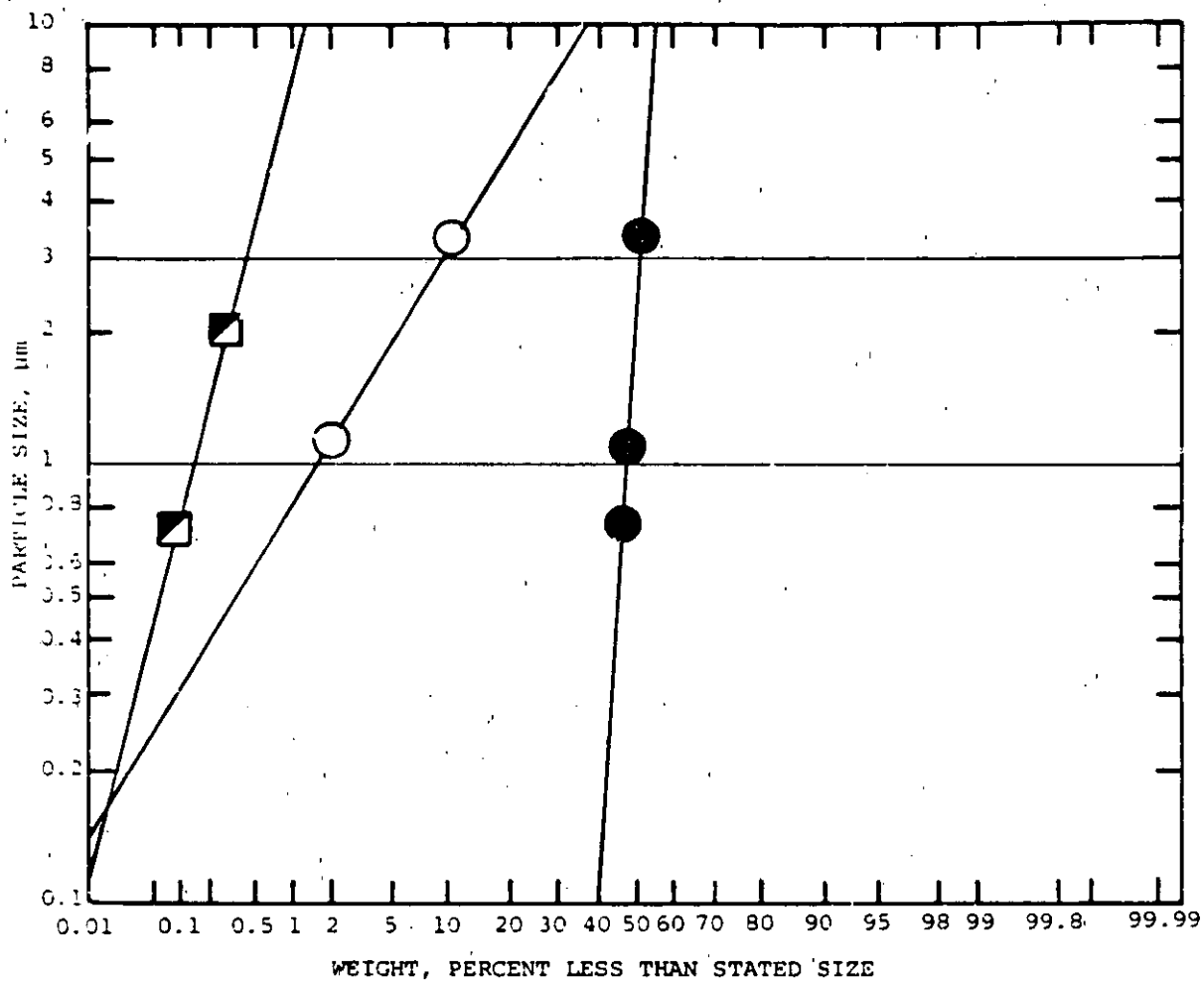
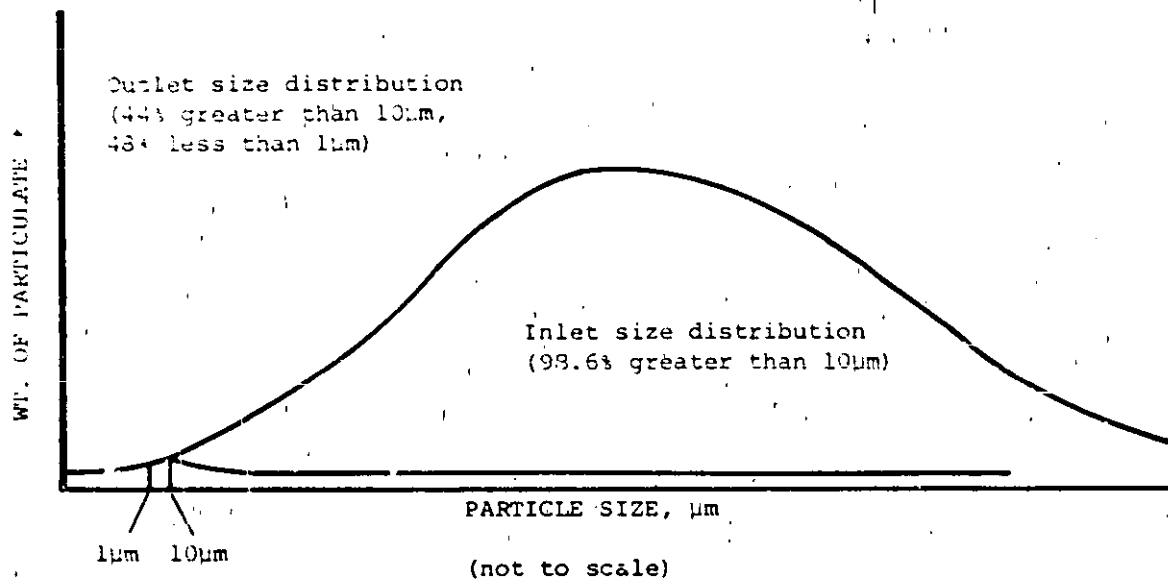


Figure 4-36. Particle size distribution for brick grinding process (Test 08)

distribution shows 98.6% of the particles with size $>10\mu\text{m}$. The baghouse removes nearly all the material that is $>10\mu\text{m}$ and a much lesser amount of the very fine materials, $<1\mu\text{m}$. 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 $10\mu\text{m}$, and the mean particle size exiting the baghouse is about $2\mu\text{m}$.

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.

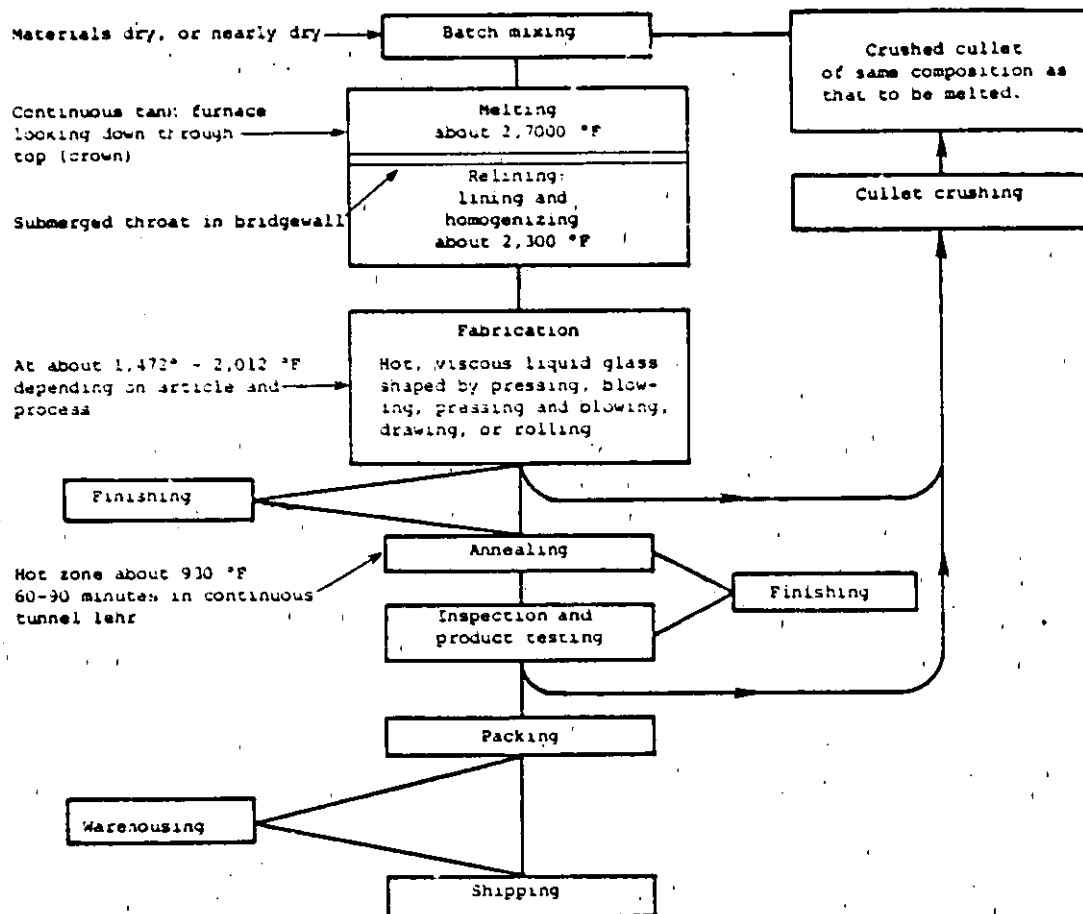


Figure 4-37. Flow diagram for soda-lime glass manufacture (Ref. 4-17).

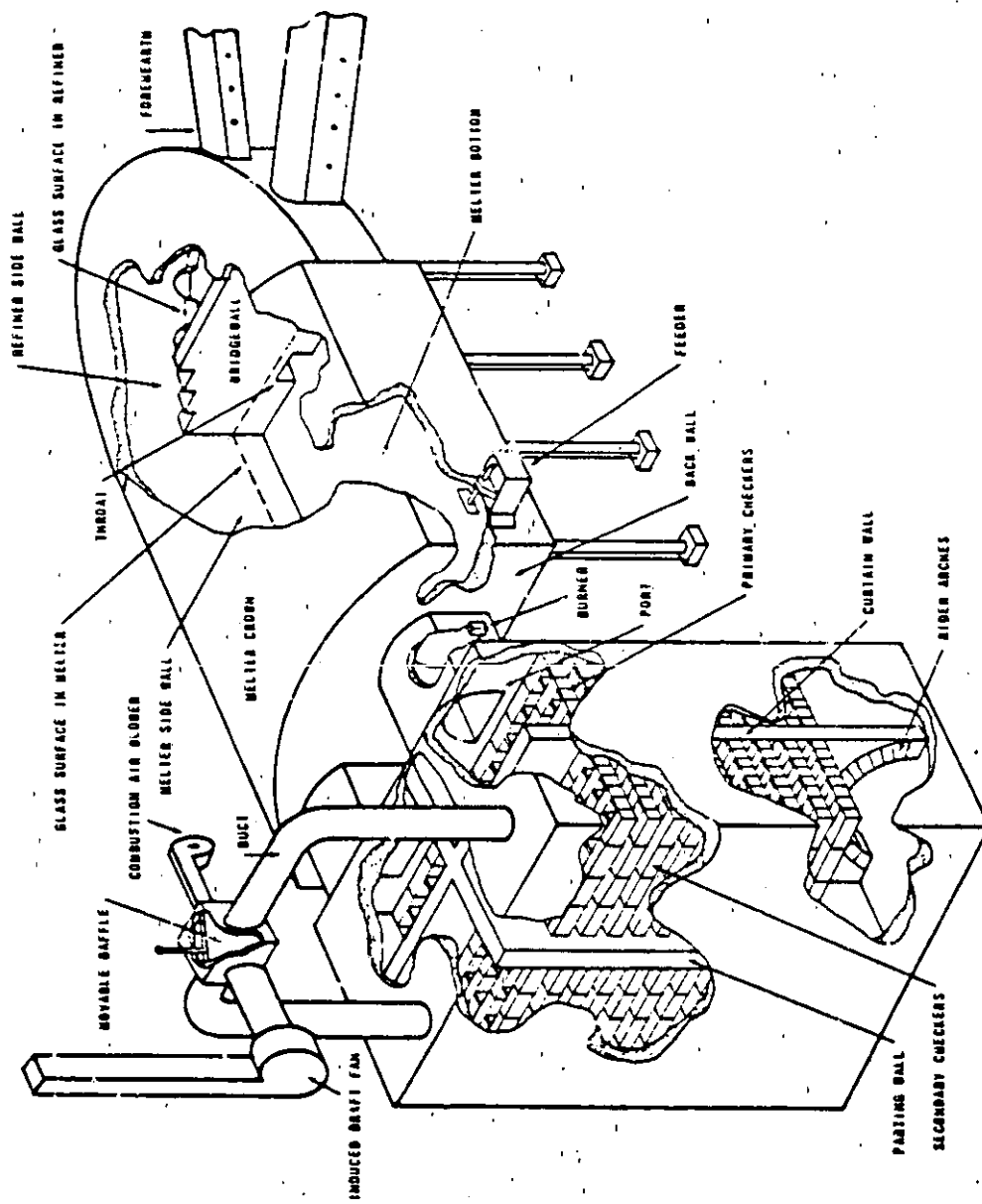


Figure 4-38. Glass melting furnace (end port). Similar to the furnace on Tests 28 and 35 (Ref. 4-17).

KVB 5806-783

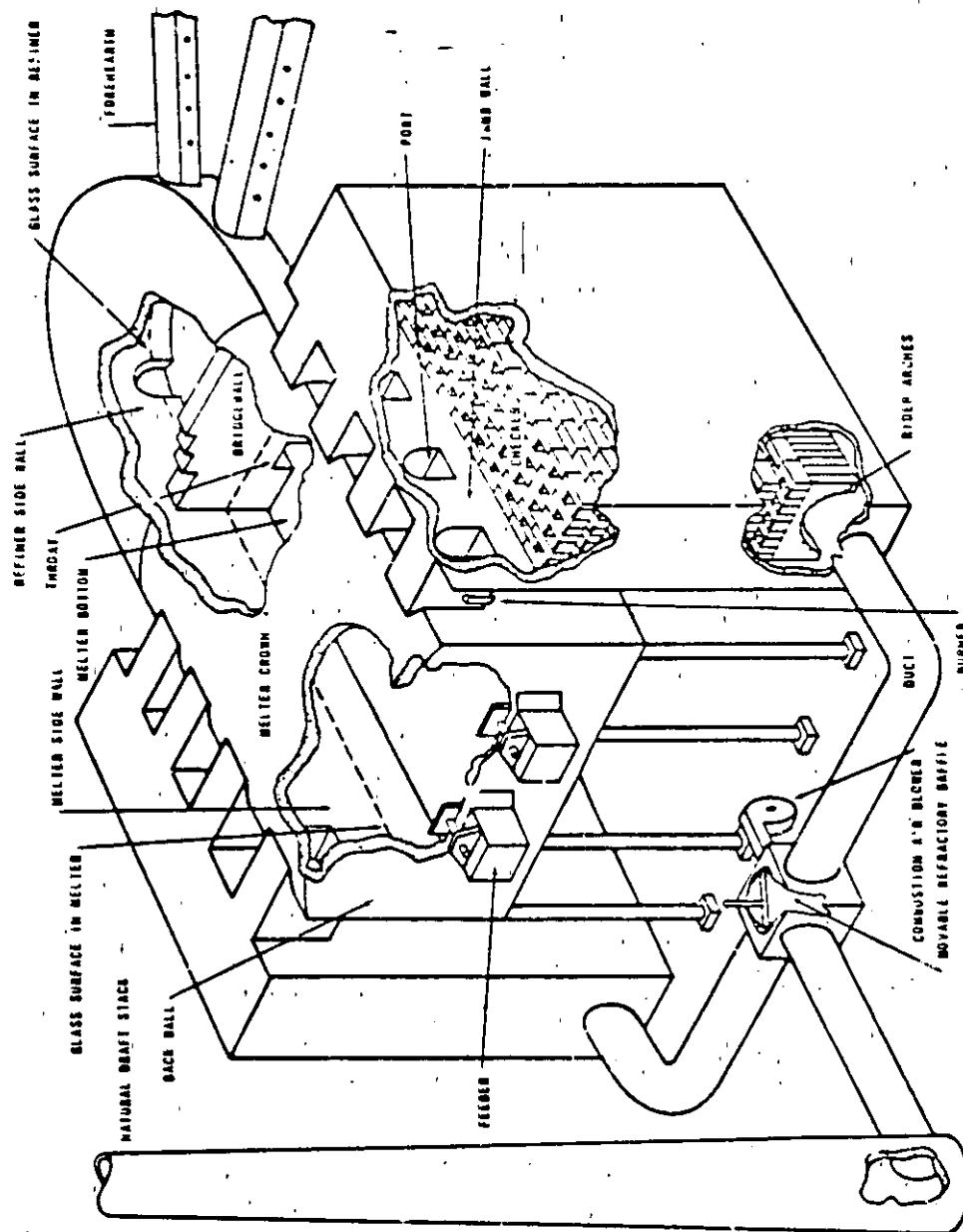


Figure 4-39. Glass melting furnace (side port). Similar to Test 20 furnace (Ref. 4-17).

KVB 5806-783

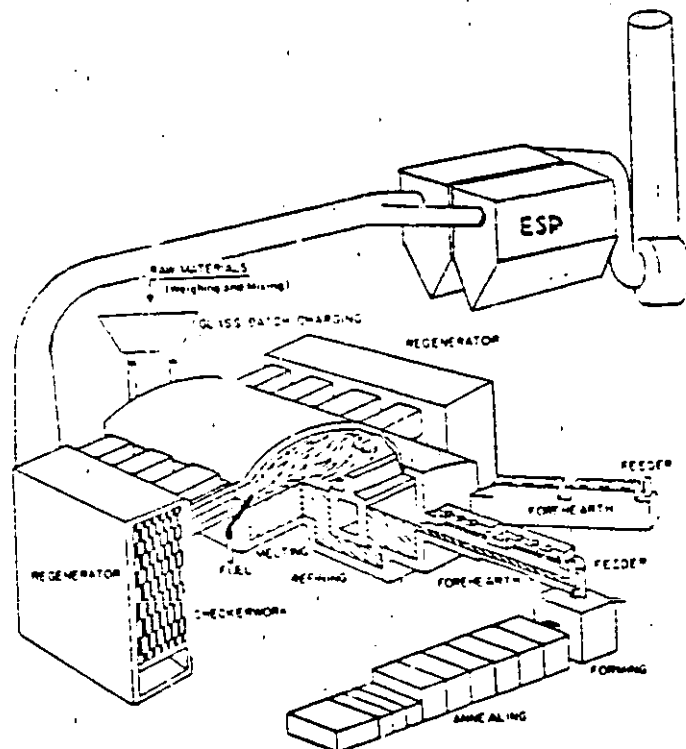


Figure 4-40. Glass melting furnace (side port) with ESP. Similar to Test 20 furnace.

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"H₂O 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.

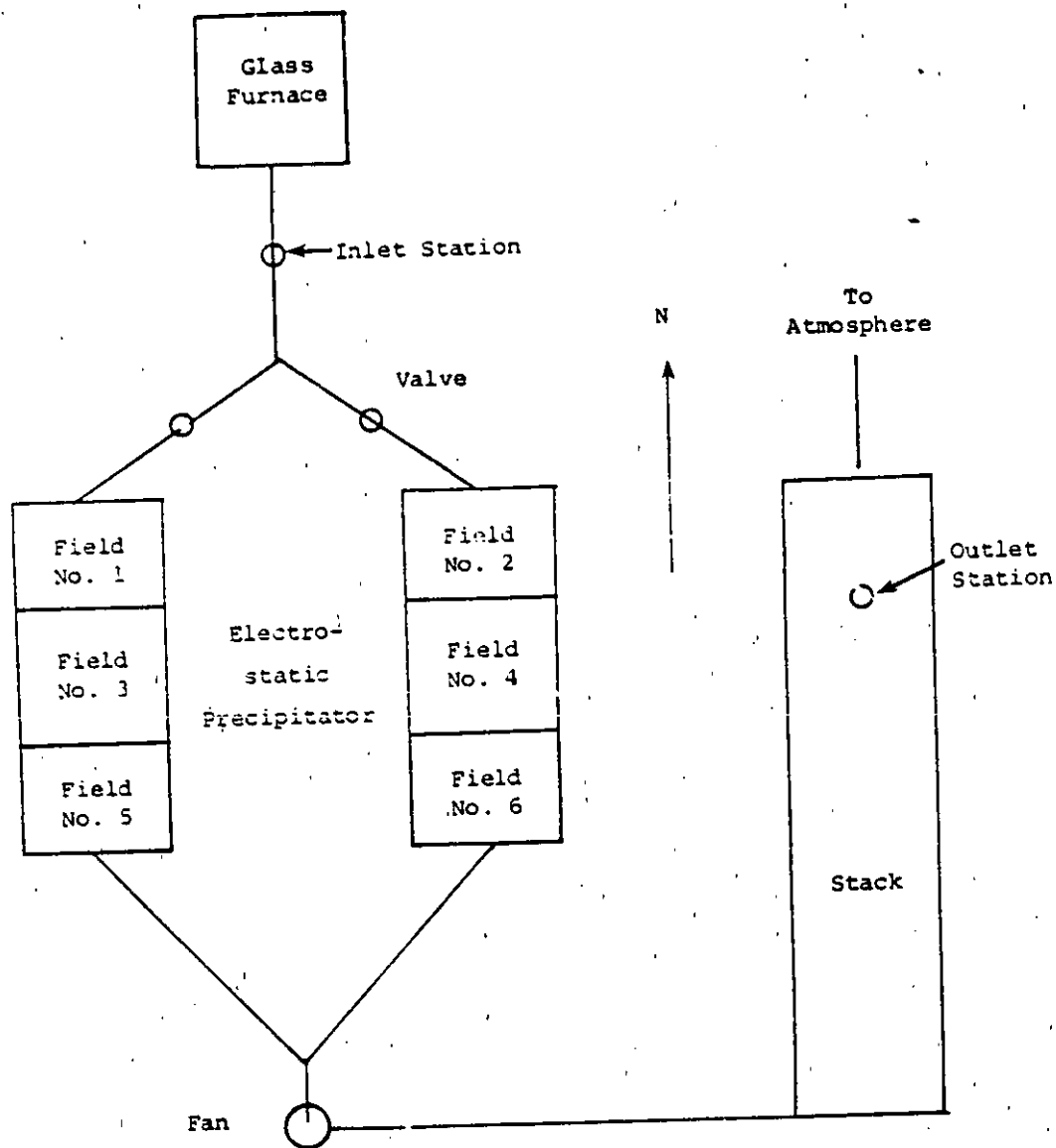
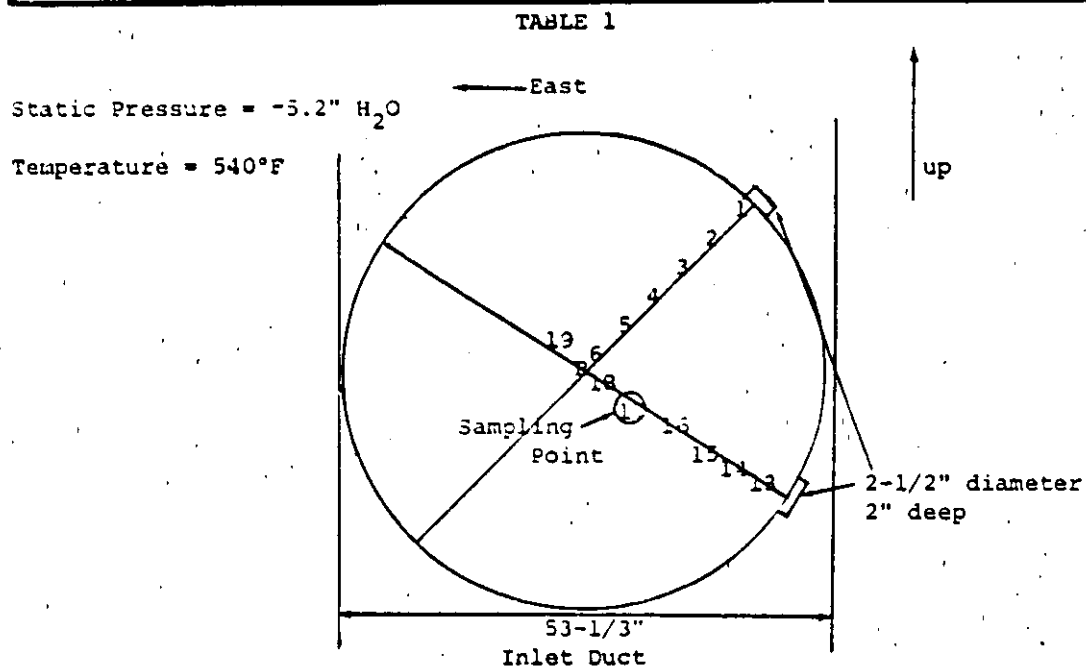


Figure 4-41. Flow diagram for glass furnace with ESP control.

TABLE 4-46. VELOCITY PROFILE (TEST 205)



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	7	76.2	12	79.4
36-1/2	7	75.6	19	86.0

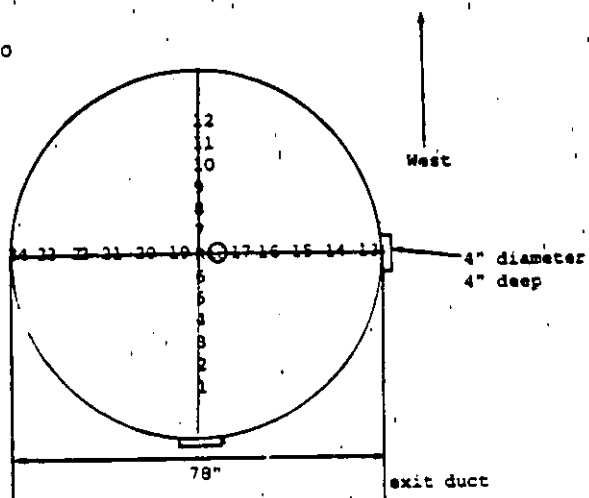
Average 76.3 ft/sec
71436 acfm

KVB 5806-783

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

Static Pressure = $\pm .25''\text{H}_2\text{O}$

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
21-1/2	5	37.9	17	39.9
31-5/8	6	37.9	18	38.9
43	R	40.8	R	33.9
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

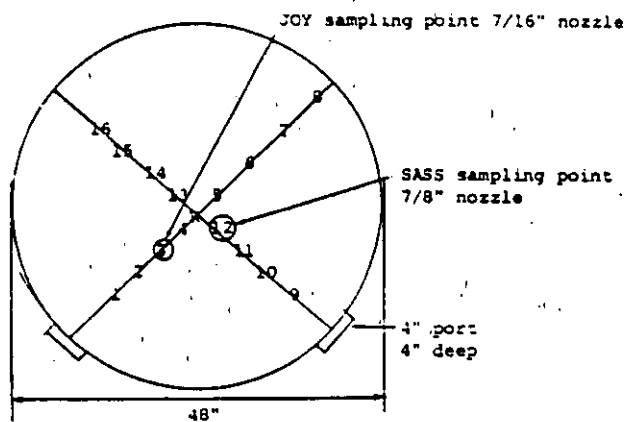
Static Pressure = $-1.0^{\circ}\text{H}_2\text{O}$

Temperature = 800°F

Test #35

Static Pressure = $-.82^{\circ}\text{H}_2\text{O}$

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	34.0
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
42.1	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

SAMPLE #	Inlet		Impinger Catch	
	1µm Cyclone	Filter	Outlet	Inlet
	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 ₂ O sol ²	60.91	53.83	21.36	43.25
(Sulfur, from SO ₄ ²⁻) ⁴	(20.3)	(18)	(7.1)	(14.4)
Nitrate (H ₂ O 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 ₂ O sol ²	60	29
(Sulfur, from SO ₄ ³) ⁴	(20)	(9.55)
Nitrate (H ₂ O 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 lum 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)	(24/3)	(13/4)
Zinc			t		t
TOTAL	5	6	8	6	8
Sulfates, H ₂ O sol ²	62	67	22	59	34
(Sulfur, from SO ₄ ²⁻)	(20.80)	(22.19)	(7.48)	(19.51)	(11.23)
Nitrate (H ₂ O 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 $\text{SO}_3 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_4$). 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 .

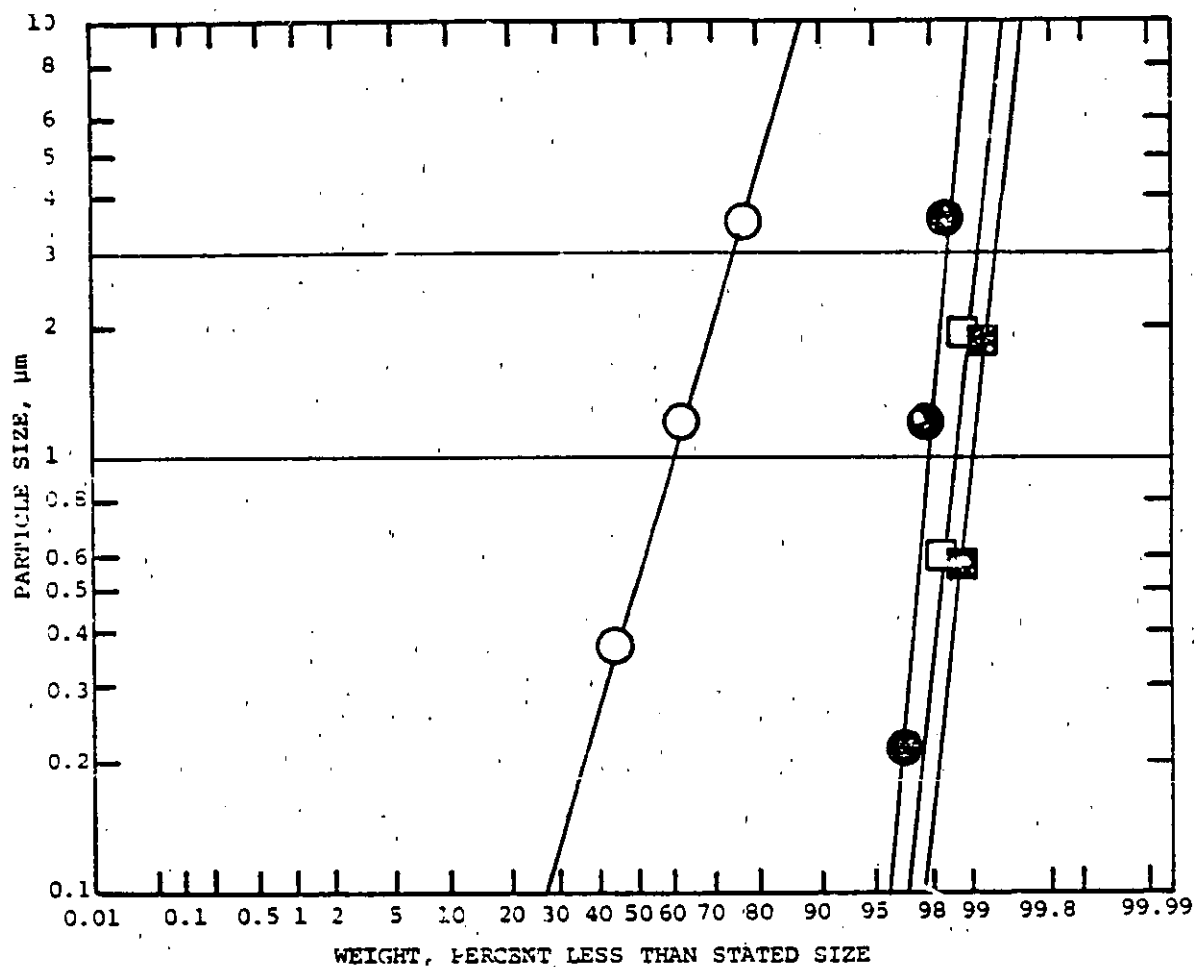
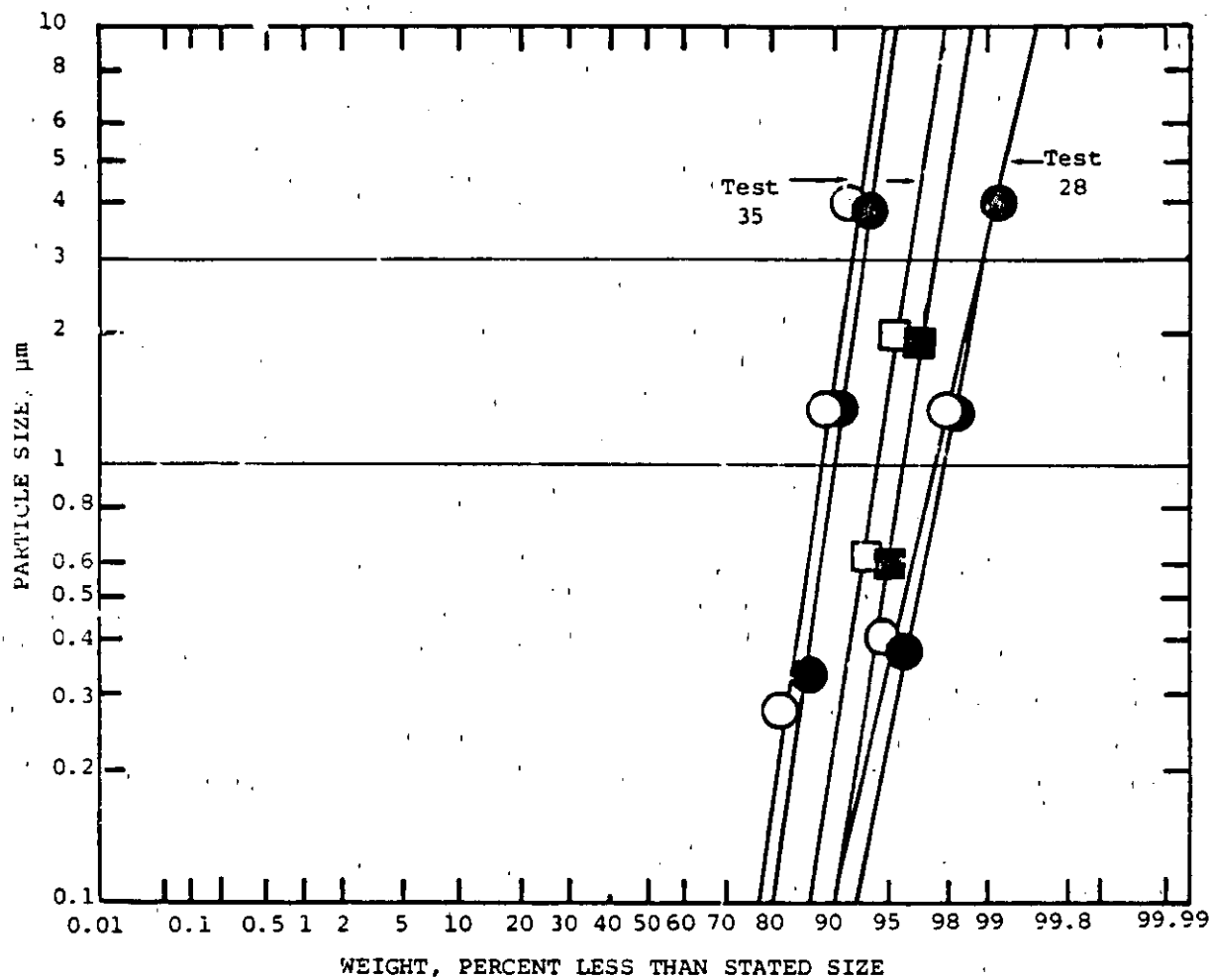


Figure 4-42. Particle size distribution for glass furnace (Test 20).

KVB 5806-783



- Joy Mfg. Sampling Train With Impinger
- Joy Mfg. Sampling Train Without Impinger
- SASS Train With Impinger
- SASS Train Without Impinger

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

KVB 5806-783

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.

Units	Controlled	Uncontrolled			
	Test 20S	Test 20J	Test 28S	Test 35S	Test 35J
gr/DSCF	.0062	.0264	.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	10.35	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-ft² melter

X_3 = wt fraction of cullet in charge

X_4 = checker volume, ft³/ft² melter

X_5 = melter area, ft²/100

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 wool 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 SAS5 train with a 11/16" nozzle.

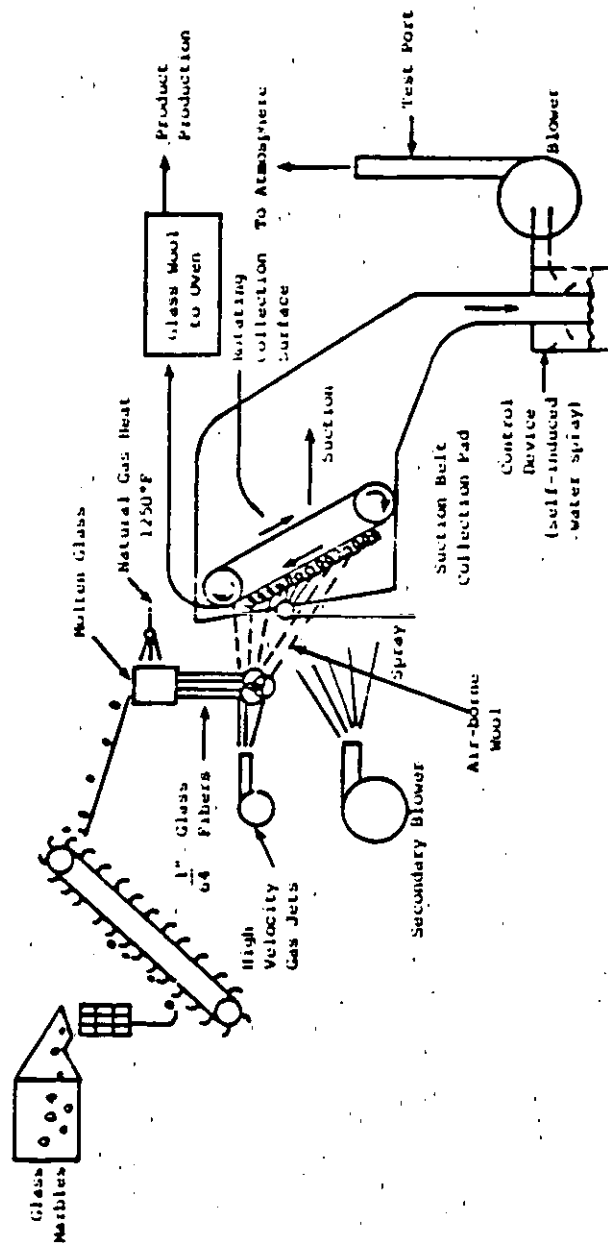
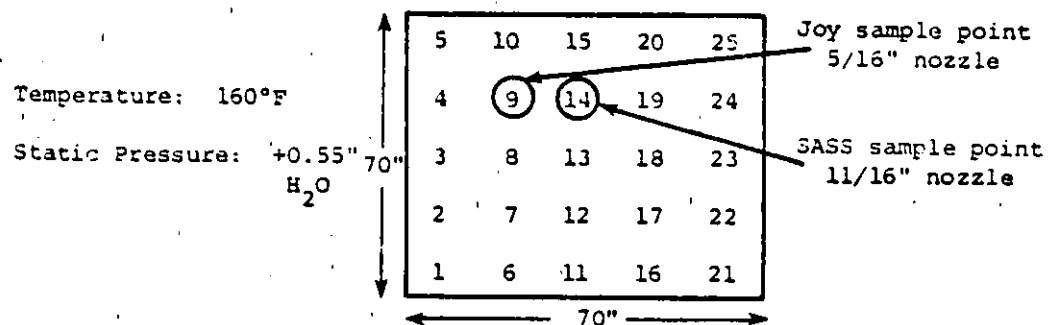


Figure 4-44. Typical flow diagram for fiber glass production (forming line).

KVB 5806-783

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



Distance From End of port	Velocity		Velocity		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

KVB 5806-783

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:

Test #	Percent of Particles			
	Greater than 10 μm	10-3 μm	3-1 μm	Less than 1 μm
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 0.1 μm . 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-1C	Jcy Impinger 38J-1C
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 ₂ O sol ²	t	t	t
(Sulfur, from SO ₄ ²⁻) ⁴	(t)	(t)	t
Nitrate (H ₂ O 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

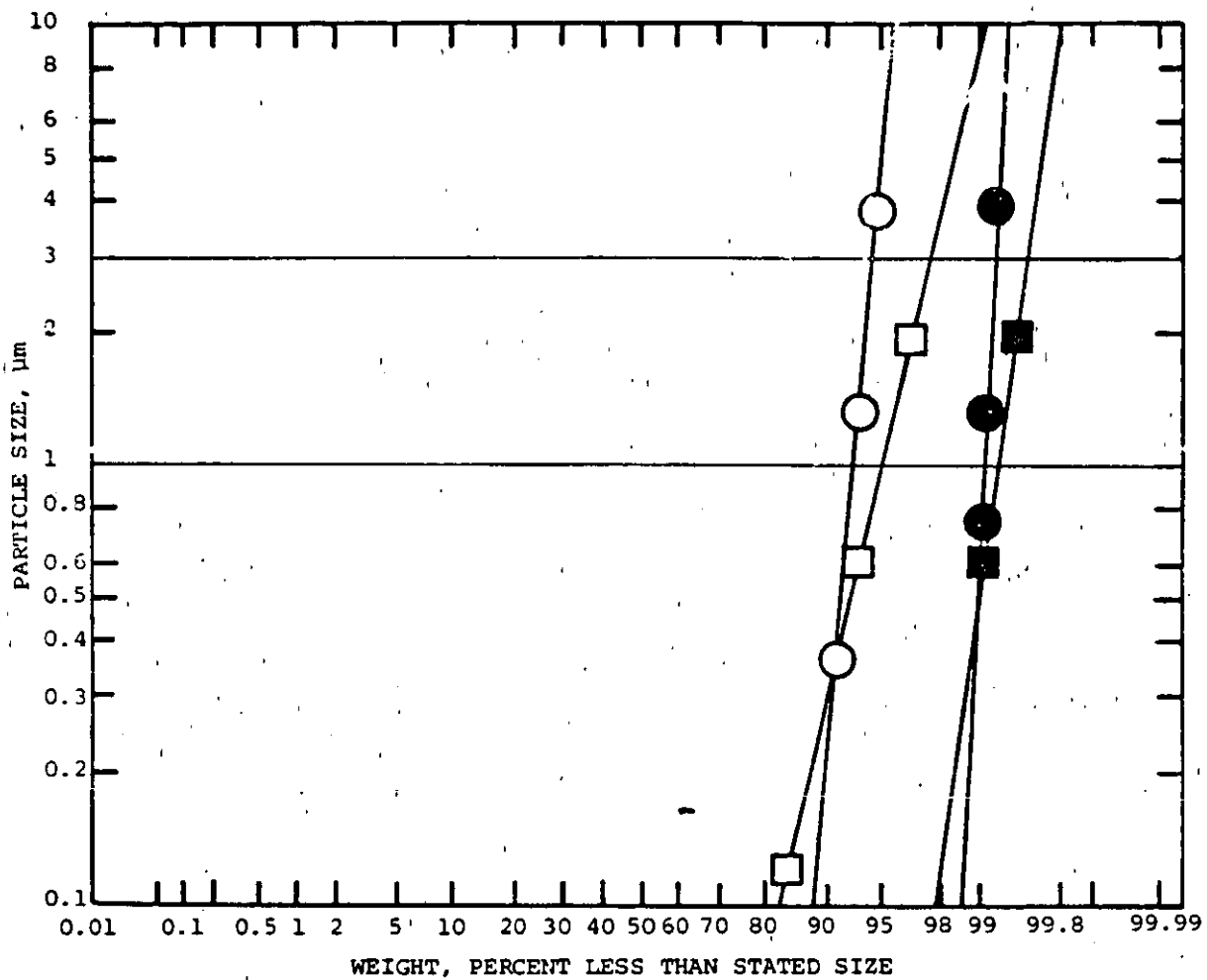
2 analyzed by wet chemistry--Section 3.2.2 A

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



- Joy Mfg. Sampling Train With Impinger
- Joy Mfg. Sampling Train Without Impinger
- SASS Train With Impinger
- SASS Train Without Impinger

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

KVB 5806-783

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, 1.3, and 2.7 kg/m²). 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

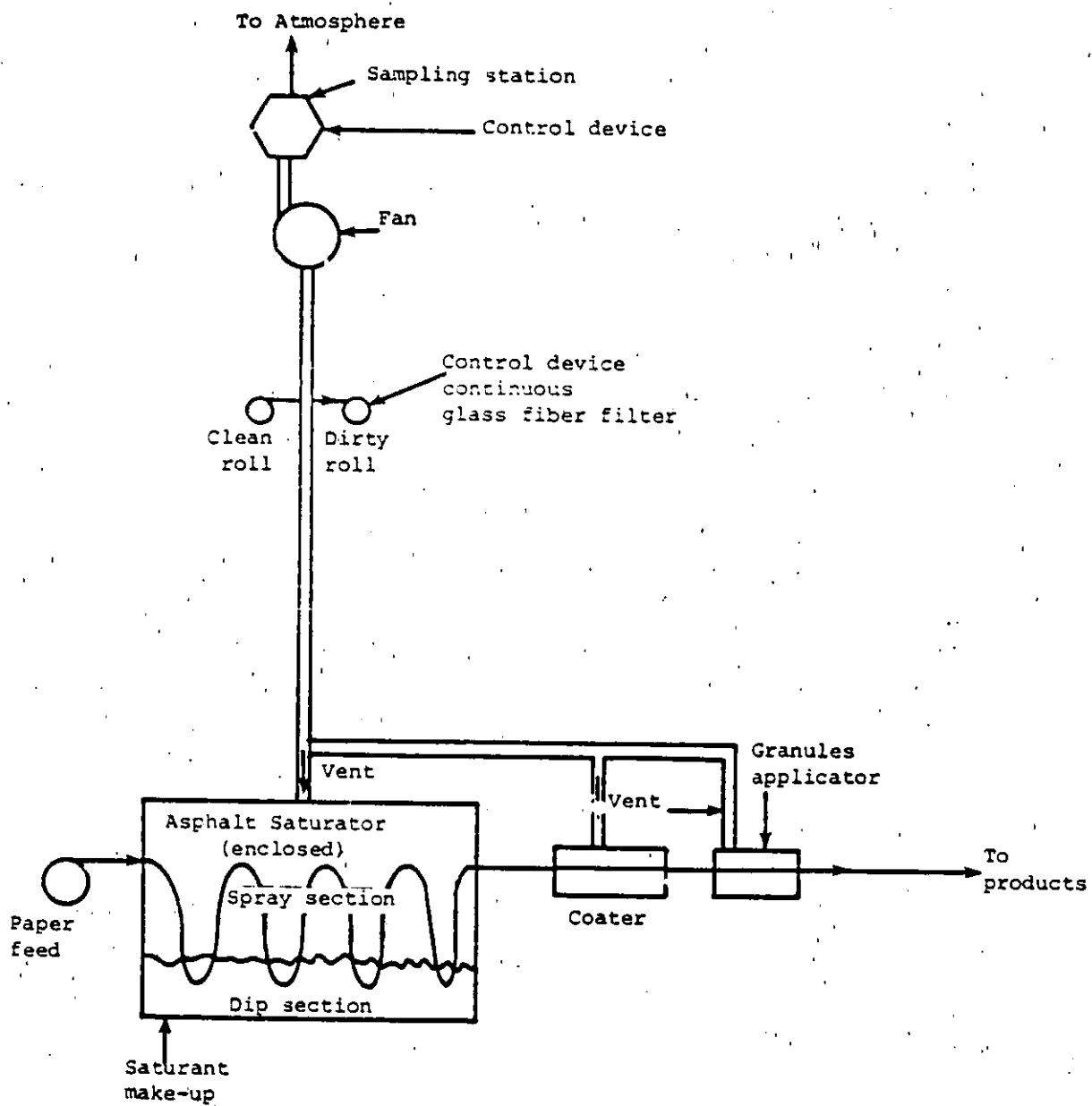


Figure 4-46. Schematic for manufacturing asphalt shingles, mineral-surfaced rolls and smooth rolls (Test 2S).

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.

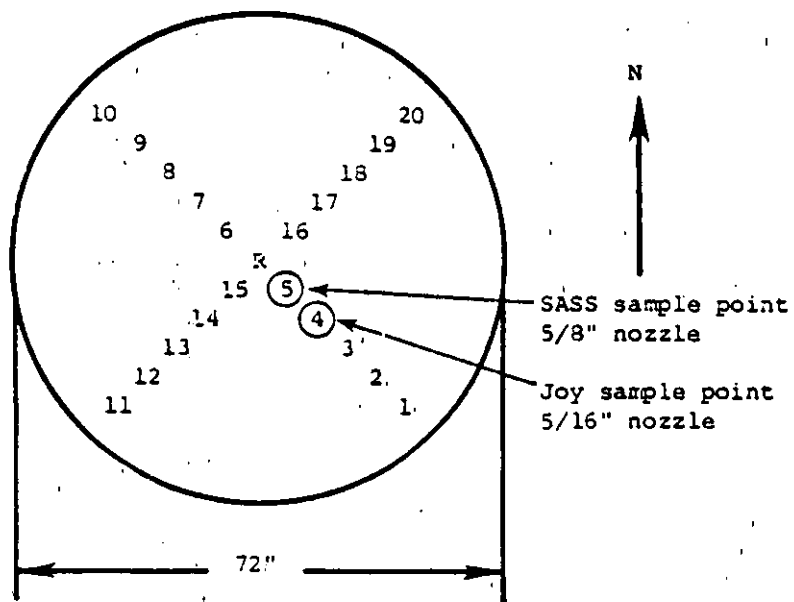
C. Test Results--

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)

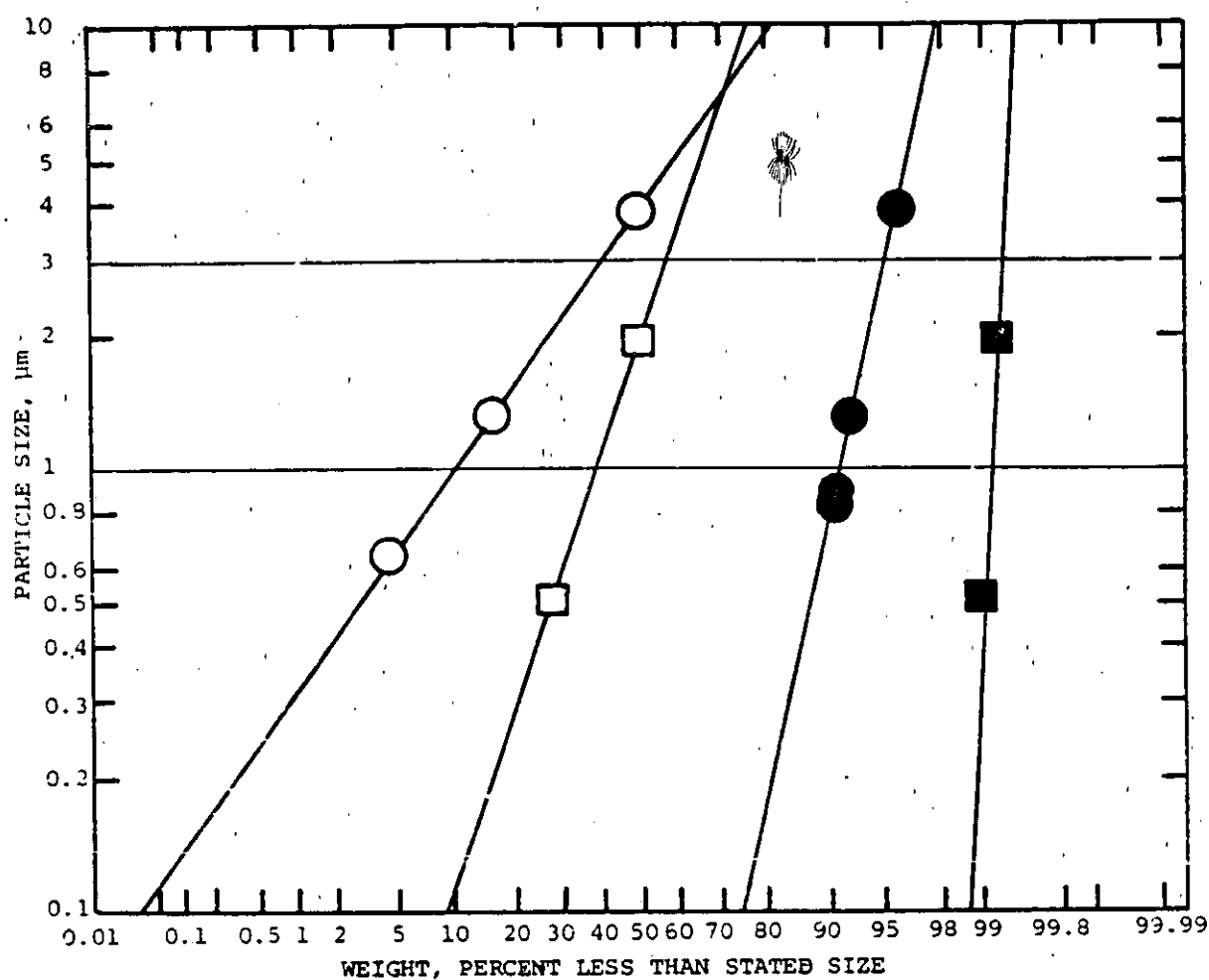


Distance from Edge of Stack	Velocity Point #	Velocity ft./sec	Velocity Point #	Velocity ft./sec
1.3"	1	31.5	11	26.3
5.9"	2	41.1	12	44.3
10.5"	3	38.6	13	41.6
16.3"	4	37.3	14	35.5
24.6"	5	35.2	15	33.0
36.0"	R	33.78	R	33.0
47.4"	6	35.2	16	34.5
55.7"	7	37.9	17	36.6
61.5"	8	39.2	18	40.5
66.1"	9	42.2	19	42.3
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 (water 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 ₂ O sol ²	23
(Sulfur, from SO ₄ ⁼) ⁴	(7)
Nitrate (H ₂ O 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



- Joy Mfg. Sampling Train With Impinger
- Joy Mfg. Sampling Train Without Impinger
- SASS Train With Impinger
- SASS Train Without Impinger

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

KVB 5806-783

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

From Figure 4-47 the mean particle size is 0.01 μ m including the impinger and 4 μ m 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.

<u>Units</u>	<u>Test 25S</u>	<u>Test 25J</u>
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.

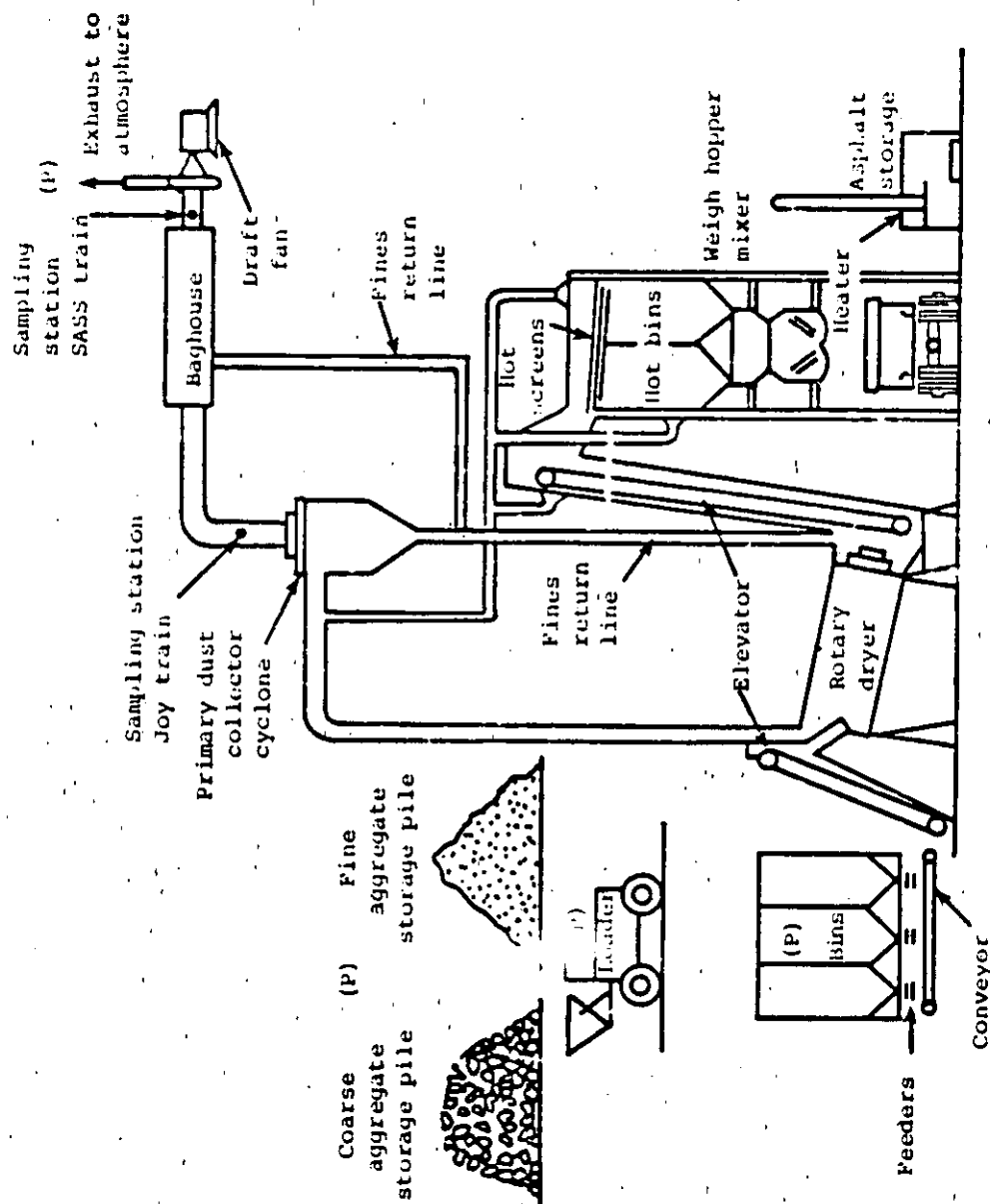


Figure 4-48. Batch hot-mix asphalt plant. "P" denotes particulate emission points.

KVP 5806-783

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--

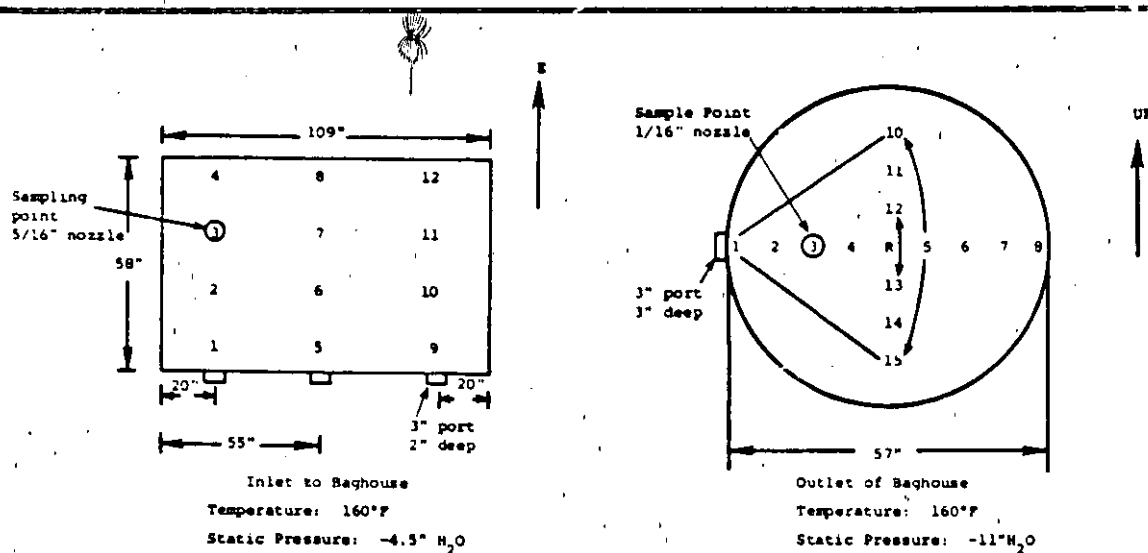
The results of the two tests (Test 29S and 29J) discussed in this section are listed in Table 4-1. Elemental composition, sulfate, nitrate, and carbon analysis were determined for all fractions of particulate catches which contained weights in excess of 100 mg. The details for these procedures are discussed 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--

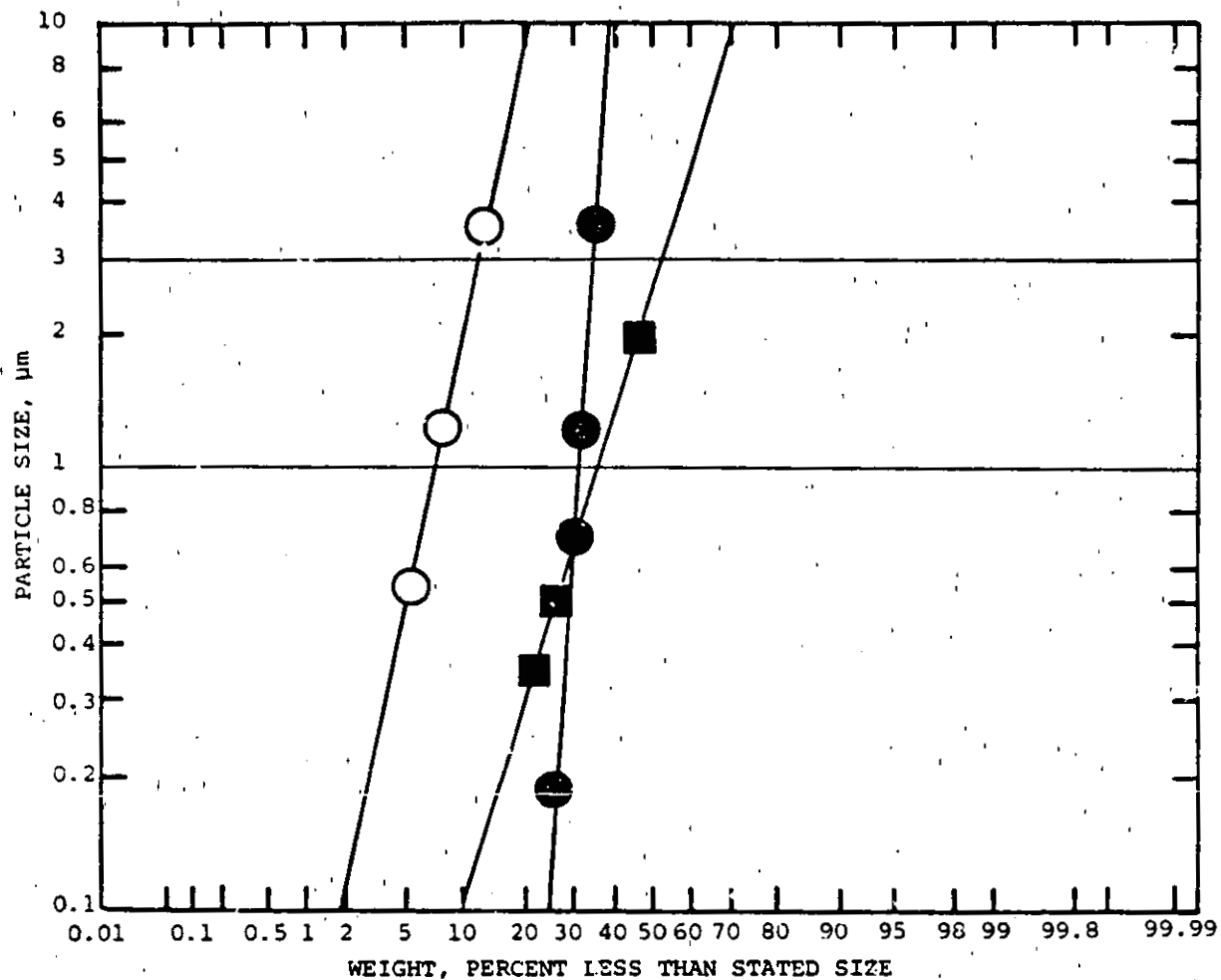
1. Efficiency of the baghouse--Using the solid catch data (i.e. without the impinger catch) from both sampling trains for the inlet and exit, the baghouse efficiency was calculated to be 99.95%. Using the total catch, the efficiency would be 99.92%.

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)



Distance from End of Port	Velocity Point #	Velocity ft/sec	Distance from End of Port	Velocity Point #	Velocity ft/sec
8"	1	30.2	5"	1	68.8
20"	2	30.2	9-3/8"	2	76.3
32"	3	34.1	14-5/8"	3	85.3
44"	4	37.2	22-3/8"	4	85.3
8"	5	31.9	33"	R	95.4
20"	6	36.7	43-5/8"	5	95.4
32"	7	38.2	51-3/8"	6	85.3
44"	8	41.8	56-5/8"	7	85.3
8"	9	37.2	61"	8	81.0
20"	10	34.1	37"	10	95.4
32"	11	28.9	35"	11	81.0
44"	12	28.3	34"	12	89.5
Average: 34.1 ft/sec			34"	13	85.3
75337 scf			35"	14	73.9
			37"	15	68.8
			Average: 84.6 ft/sec		
			75354 scf		



- Joy Mfg. Sampling Train With Impinger
- Joy Mfg. Sampling Train Without Impinger
- SASS Train With Impinger
- SASS Train Without Impinger

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 SiO₂ 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:

<u>Units</u>	<u>Controlled</u>	<u>Uncontrolled</u>
	<u>Test 29S</u>	<u>Test 29J</u>
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-55	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 ₂ O sol ²	2		
(Sulfur, from SO ₄ ⁼) ⁴	(t)		
Nitrate (H ₂ O 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 J.

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

5 for values shown as X/Y, X is t 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

FOOD AND AGRICULTURAL

4.2.13 Rice Drying Process

A. Process Description--

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

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

B. Particulate Test Set-up--

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

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

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

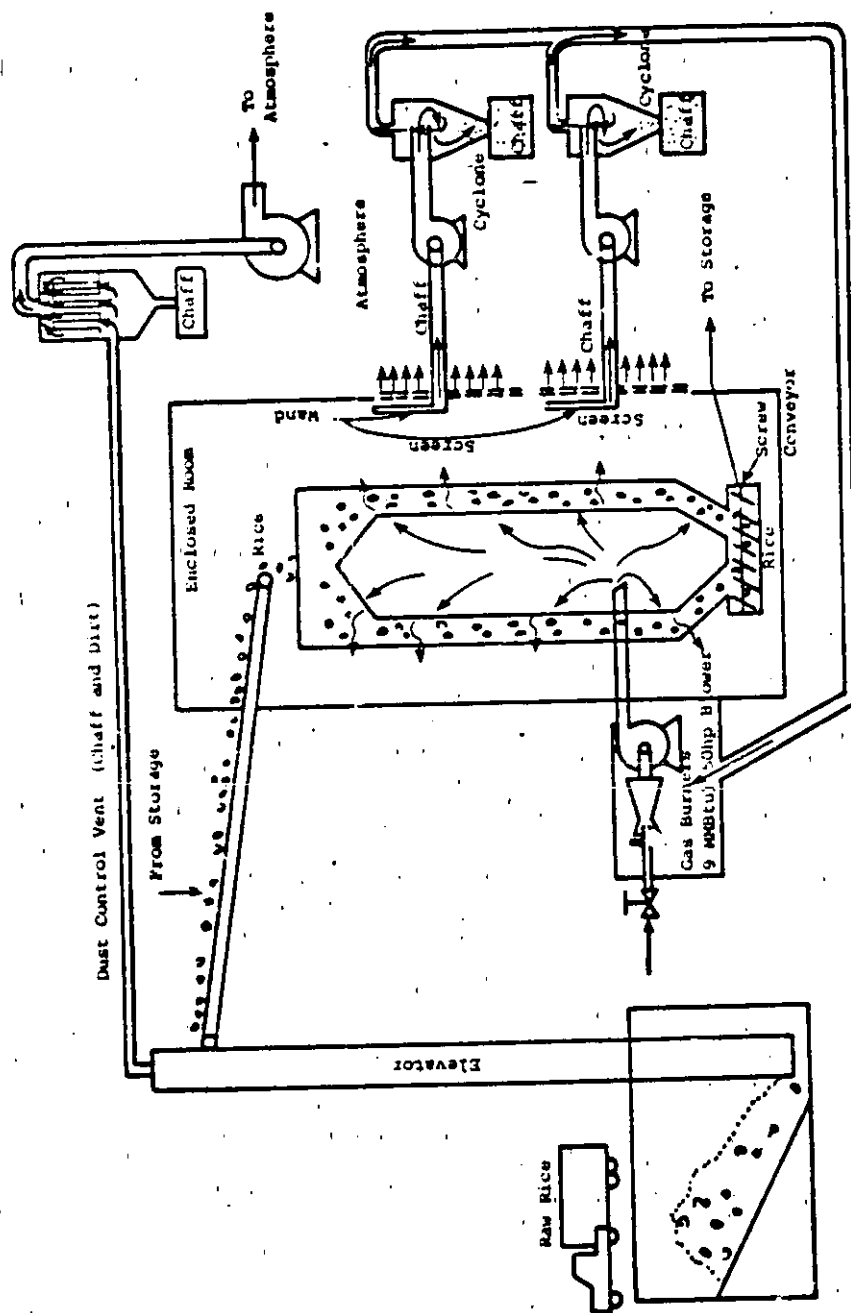
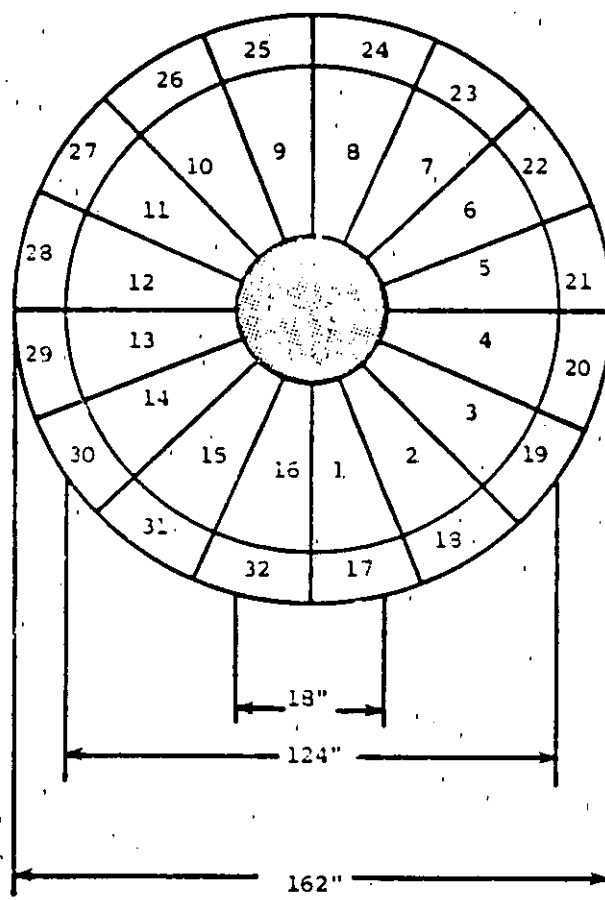


Figure 4-50. Rice dryer flow diagram (Test 4).

KVB 5806-783



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

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

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

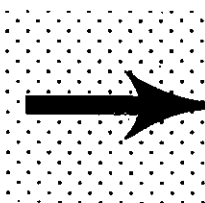
The total flow from the screens was calculated to be 128,000 SCFM. The sample point was chosen where the flow was 11 ft/sec. A 1" nozzle was used with the larger SASS train and a 1/2" nozzle was used with the smaller Joy train.

C. Test Results--

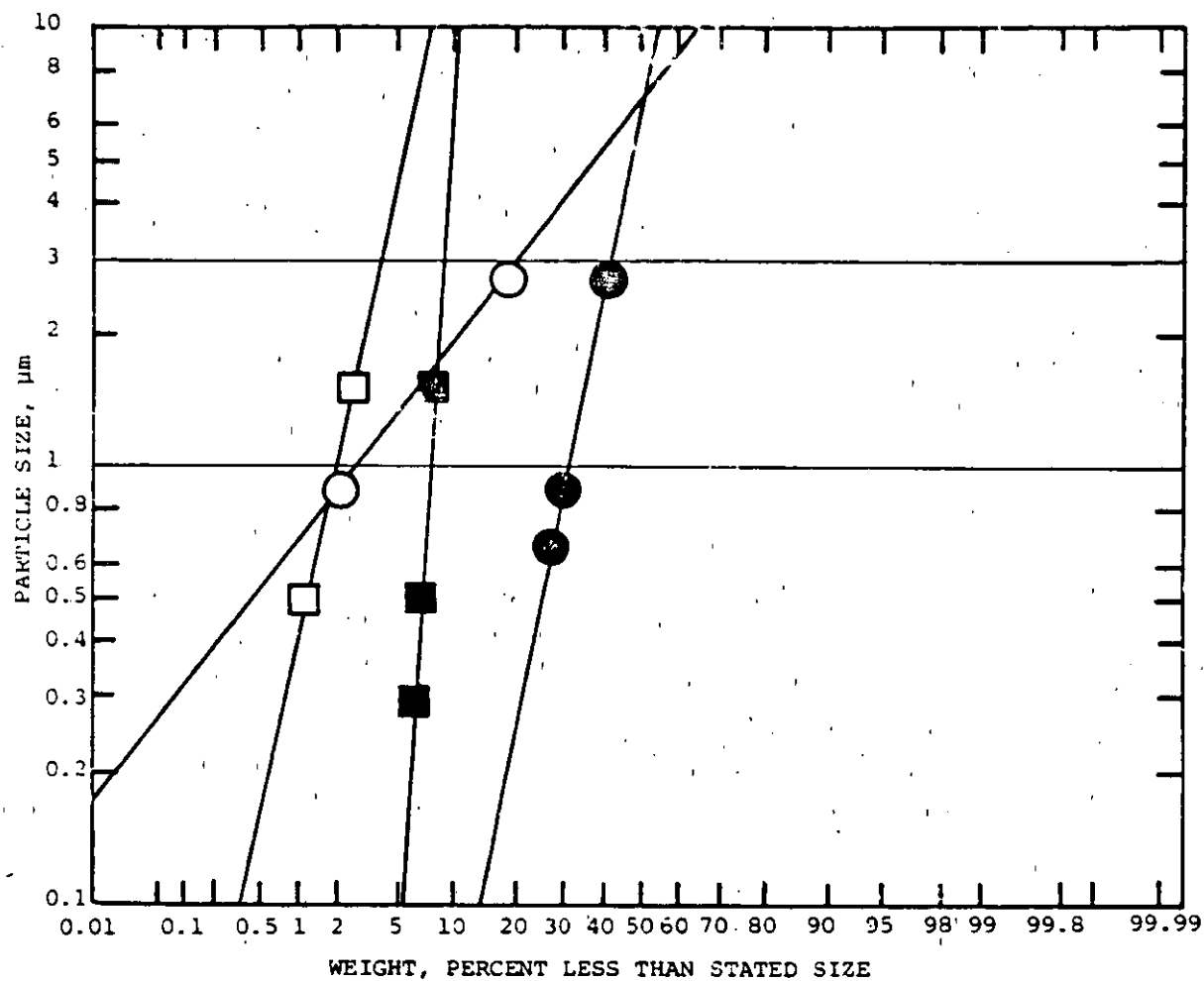
The results of the tests (Test 4S and 4J) discussed in this section are listed in Table 4-1. Major elemental composition, sulfate, nitrate and carbon analysis were determined for all fractions of particulate catches which contained weight in excess of 100 mg. The details for these procedures are discussed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

D. Discussion of Results--

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

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

SIGN
HERE



- Joy Mfg. Sampling Train With Impinger
- Joy Mfg. Sampling Train Without Impinger
- SASS Train With Impinger
- SASS Train Without Impinger

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

KVB 5806-783

Since neither train could be ~~sum~~ ^{lly}, it is difficult to say which of the results are more correct. For developing emission profiles, the two distributions including the impinger were averaged.

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

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

	<u>Test 4S</u>	<u>Test 4J</u>
gr/DSCF	0.0935	0.0154
T/yr	5	5.8
lb/hr	10.03	16.5
lb/ton produced	0.1	0.16
lb/ton produced (Ref. 4-22)	0.3	0.3

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

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

t detected in concentration of <1%

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

2 analyzed by wet chemistry--Section 3.2.2 A

3 analyzed by Oceanography carbon analyzer--Section 3.2.2 A

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

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

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

4.2.14 Carob Roasting

A. Process Description--

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

B. Particulate Test Set-up--

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

C. Test Results--

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

D. Discussion of Results--

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

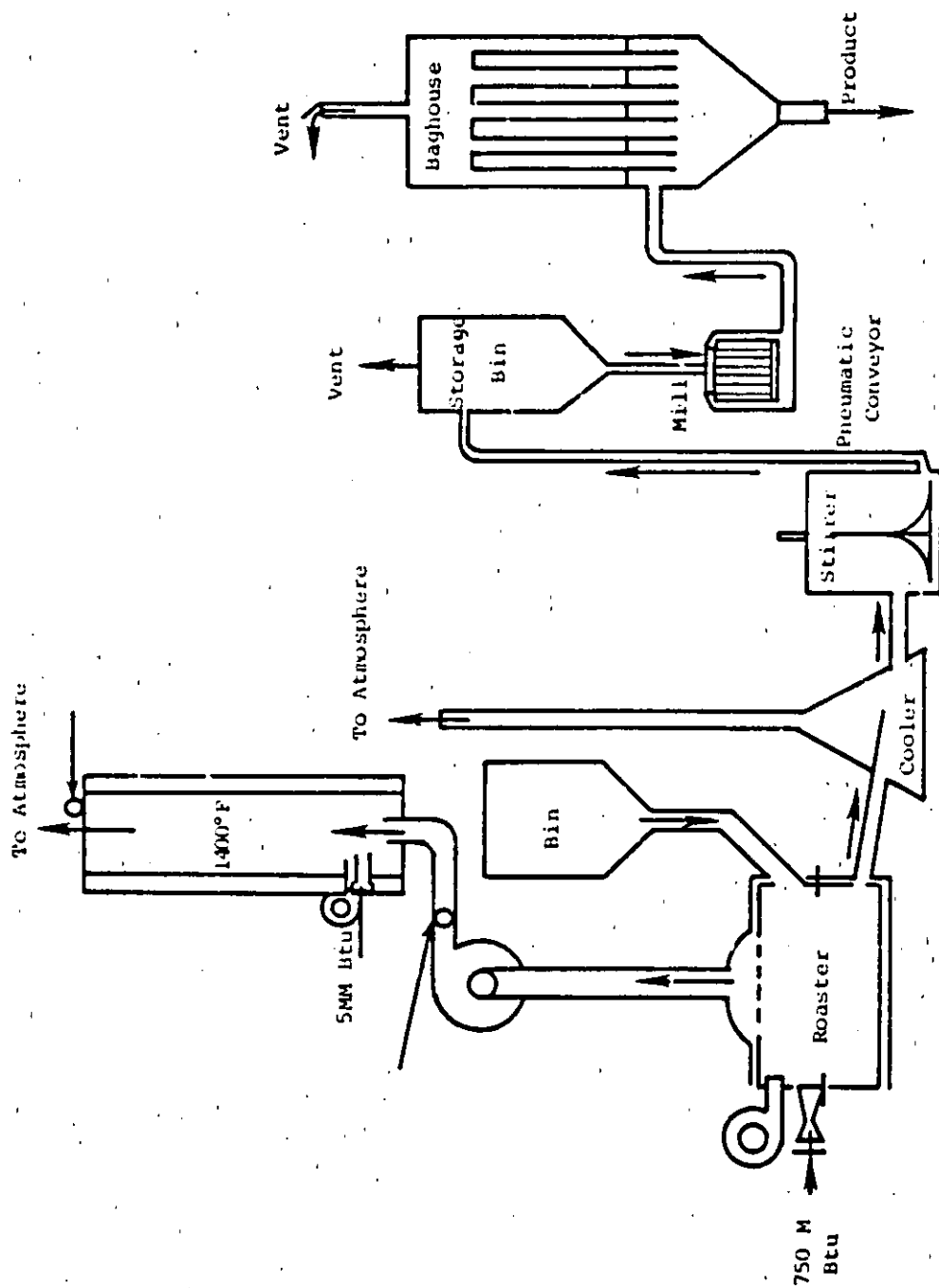
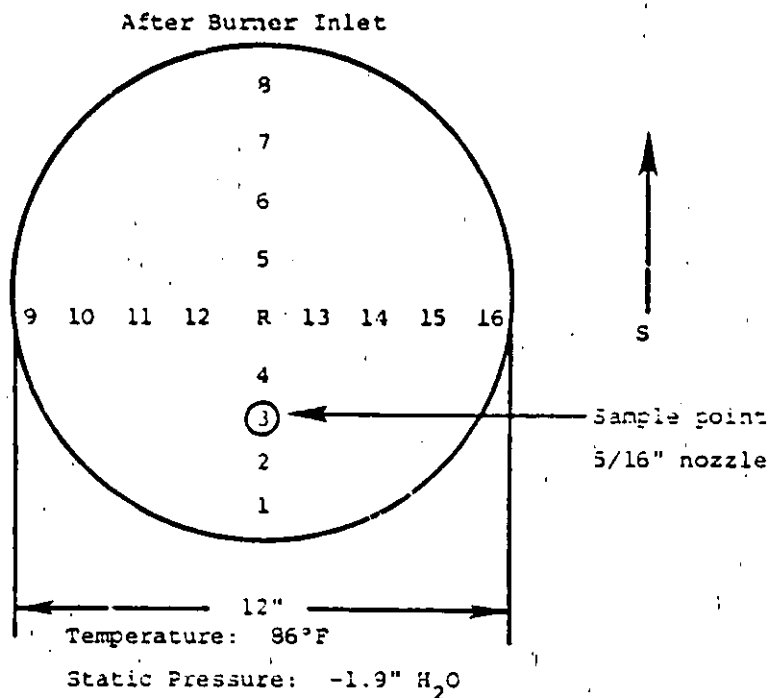


Figure 4-53. Food processing-carob roasting (Test 37)

KVB 5806-783

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



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

Average 39.5 ft/sec
1773 SCFM

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

	Percent of Particles			
	>10 μ m	10-3 μ m	3-1 μ m	<1 μ m
Without	97	0.5	0.5	2
With	35	1.0	1.0	60

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

2. Chemical composition--Table 4-50 lists the results from the chemical analysis of the particulate fraction for the test discussed in this section. Carbon was found to be the most abundant elemental. All other elementals detected were in concentrations of less than one percent.

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

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

SIGN
HERE

SIGN
HERE

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

SAMPLE #	Joy 10µm Cyclone 37J-2S	Joy Impinger 37J-1C
WT. PERCENT OF CUT	36	46
XRF ANALYSIS		
Calcium	t	
Iron	t	
Potassium	t	
(Sulfur)	(<4)	(<2)
TOTAL ¹	2	
Sulfates, H ₂ O sol ²		(t)
(Sulfur, from SO ₄ ²⁻) ⁴		t
Nitrate (H ₂ O sol) ²	t	t
Total Carbon ³	34	24
(Volatile Carbon) ³	(33)	(22)
(Carbonates) ³		
TOTAL ANALYZED	36	24
BALANCE	64	76
	100%	100%

t detected in concentration of <1%

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

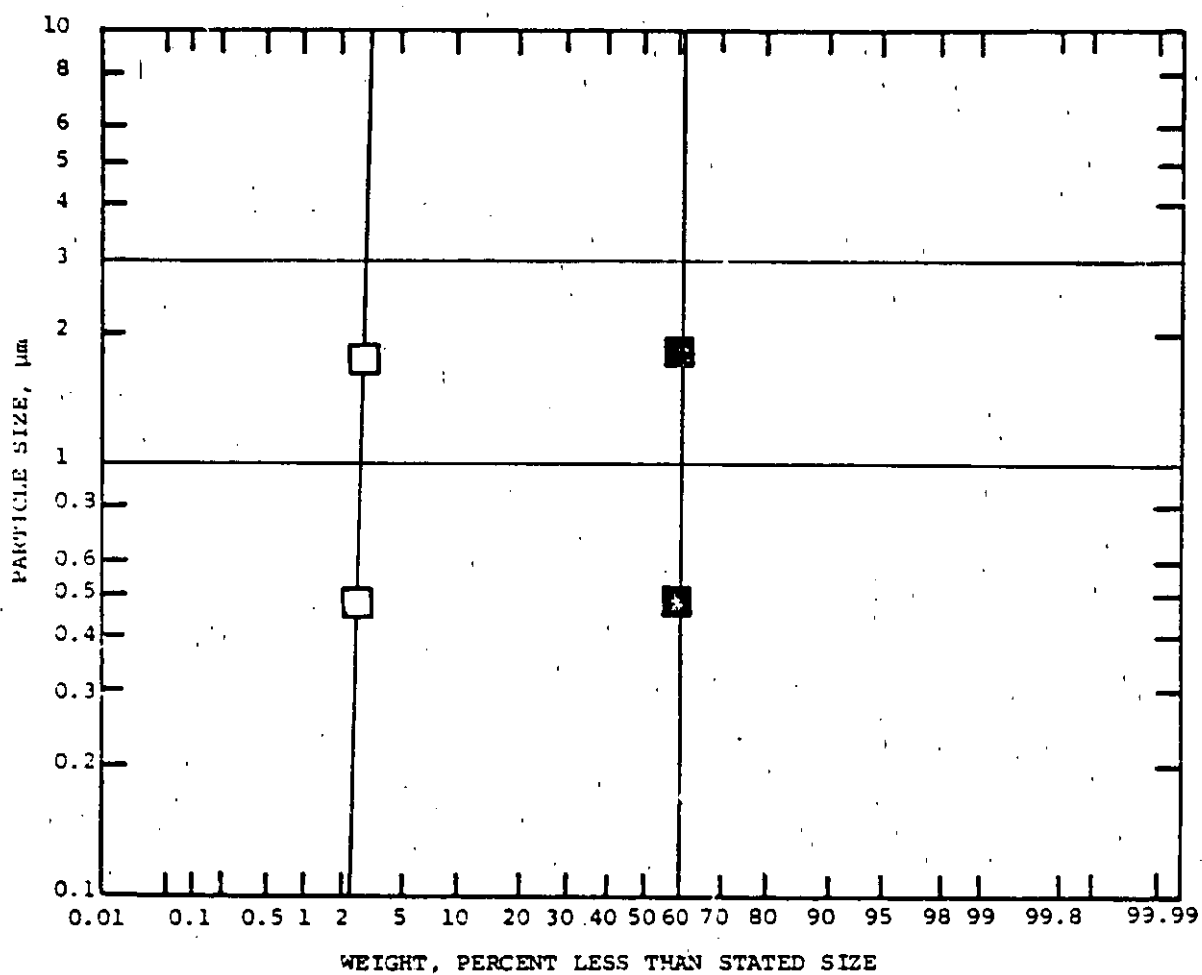
2 analyzed by wet chemistry--Section 3.2.2 A

3 analyzed by Oceanography carbon analyzer--Section 3.2.2 A

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

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

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



- Joy Mfg. Sampling Train With Impinger
- Joy Mfg. Sampling Train Without Impinger

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

KVB 5806-783

METAL FABRICATION

4.2.15 Steel Heat Treating

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

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

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

B. Particulate Test Set-up--

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

C. Test Results--

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

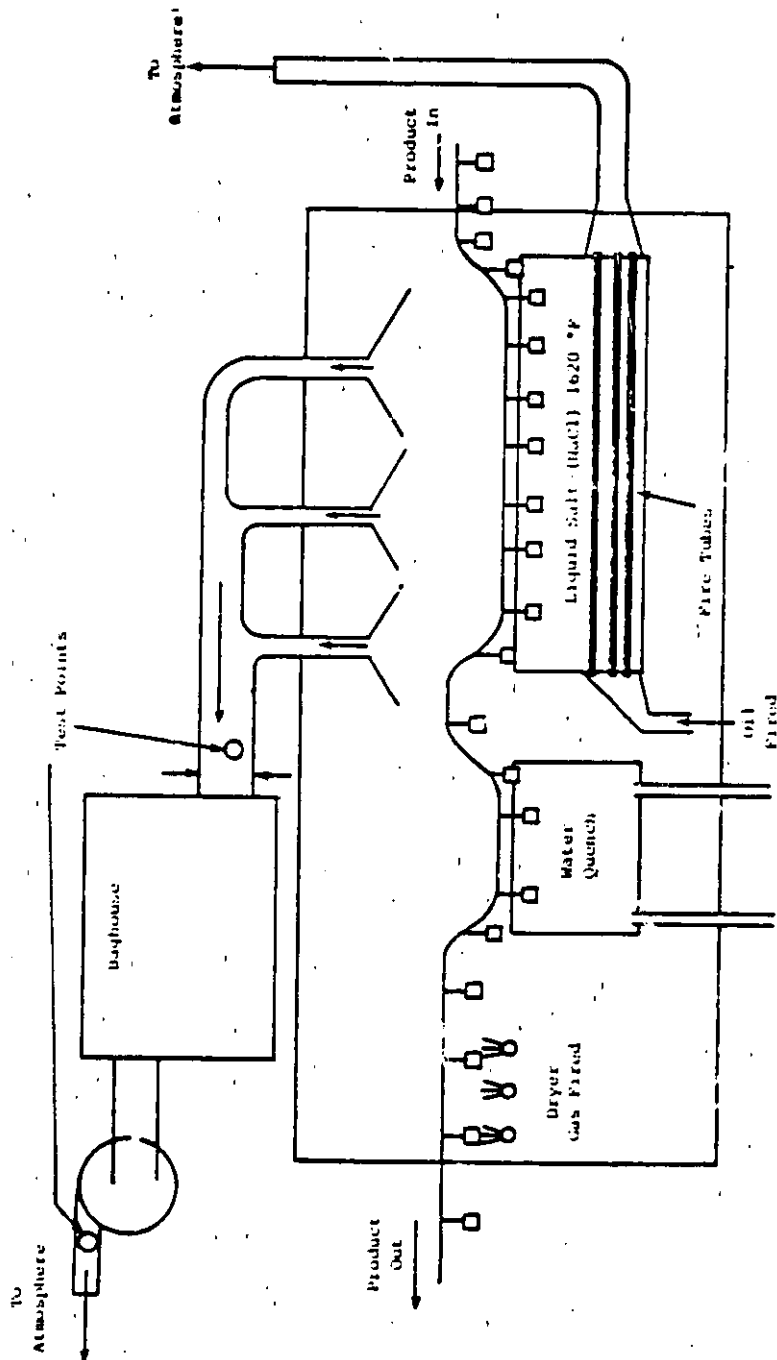
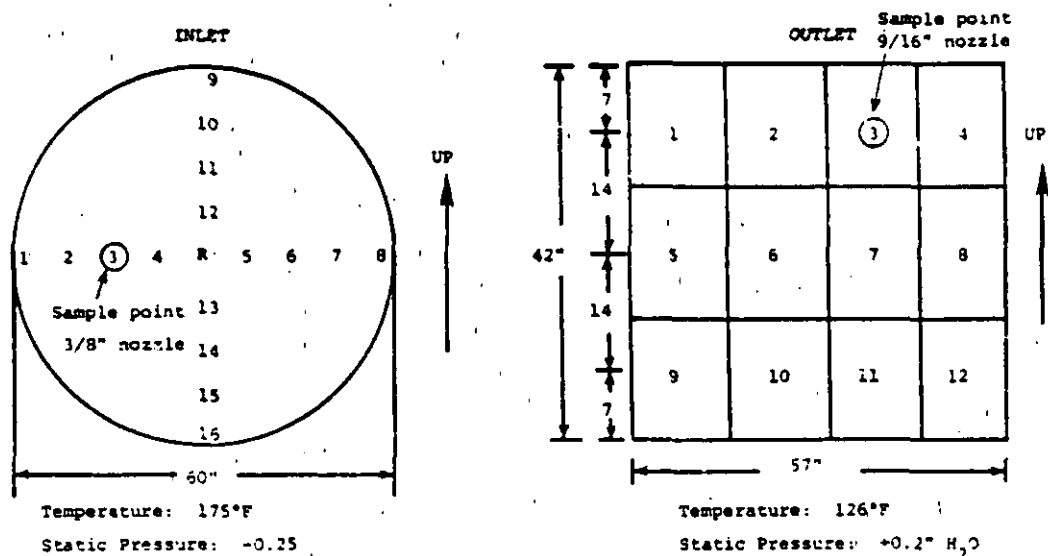


Figure 4-55. Steel heat treating process.

KVB 5806-783

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



Distance from end of port	Velocity				Distance from end of port	Velocity	
	Point #	ft/sec	Point #	ft/sec		Point #	ft/sec
4"	1	22.0	9	21.2	9	1	65.5
4-3/8	2	22.7	10	21.2	23-1/4	2	59.2
13-5/8	3	22.0	11	22.0	37-1/2	3	63.2
21-1/4	4	21.2	12	21.2	51-3/4	4	80.0
32	R	23.7	R	22.9	9	5	64.7
42-3/4	5	21.2	13	21.2	23-1/4	6	52.5
50-3/8	6	22.9	14	22.9	37-1/2	7	56.5
55-5/8	7	21.2	15	21.2	51-3/4	8	70.2
60	8	21.2	16	19.3	9	9	61.6
					23-1/4	10	55.3
					37-1/2	11	56.2
					51-3/4	12	58.3

Average: 21.8 ft/sec
20994 SCFM

Average: 51.8 ft/sec
45791 SCFM

D. Discussion of Results--

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

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

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

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

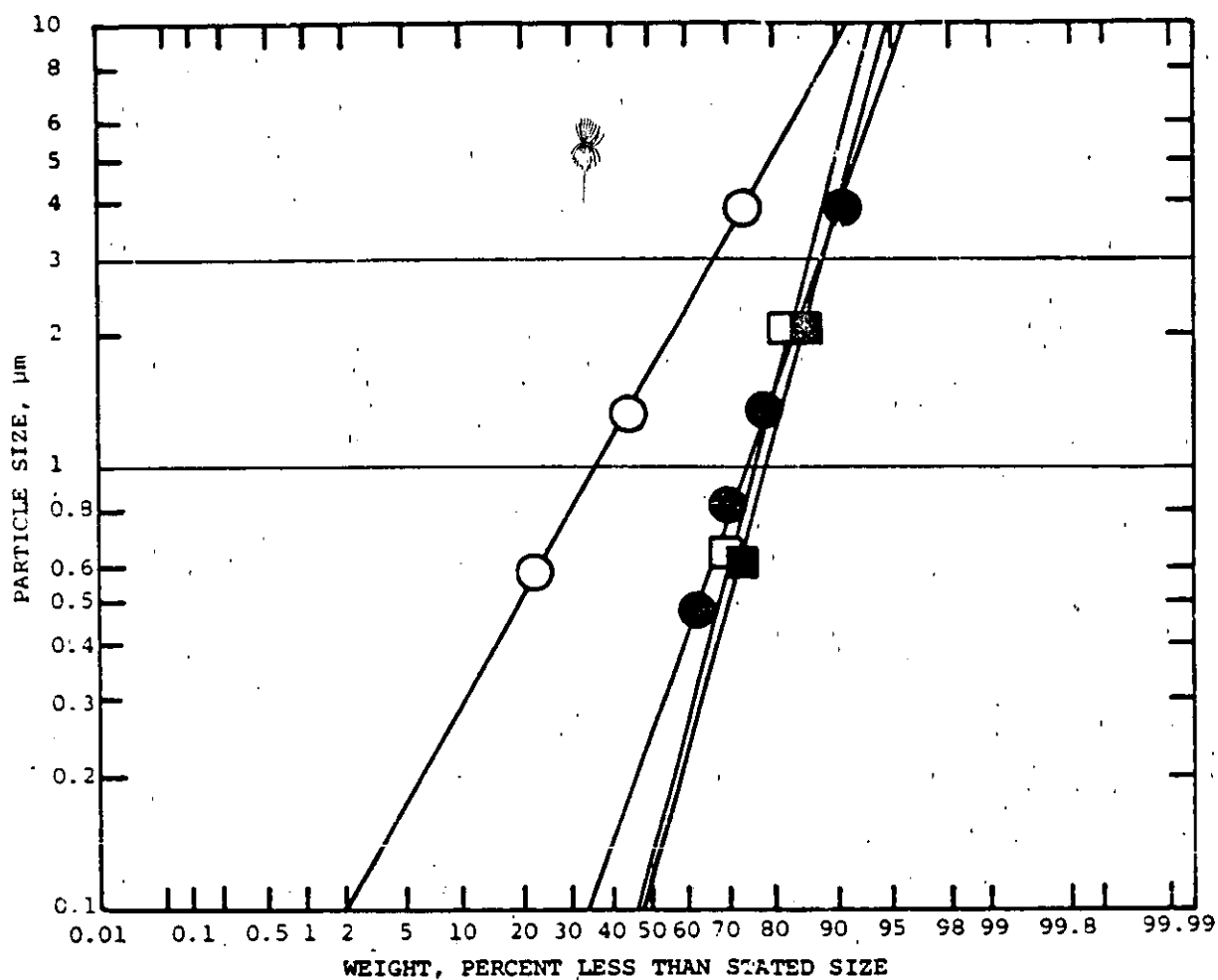
2. Particle size distribution--Figure 4-56 is a plot of particle size (μm) vs accumulated weight percent, the latter plotted on a probability scale as explained in Section 3.2.3 B. Two sets of curves are presented, one including the impinger catch and the other ignoring it. Considering that almost all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

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

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

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

KVB 5606-783



- Joy Mfg. Sampling Train With Impinger
 - Joy Mfg. Sampling Train Without Impinger
 - SASS Train With Impinger
 - SASS Train Without Impinger
- } Inlet
 } Outlet

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

KVB 5806-783

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

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

t detected in concentration of <1%

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

2 analyzed by wet chemistry--Section 3.2.2 A

3 analyzed by Oceanography carbon analyzer--Section 3.2.2 A

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

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

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

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

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

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

4.2.16 Abrasive Blasting

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

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

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

B. Particulate Test Set-up--

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

C. Test Results--

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

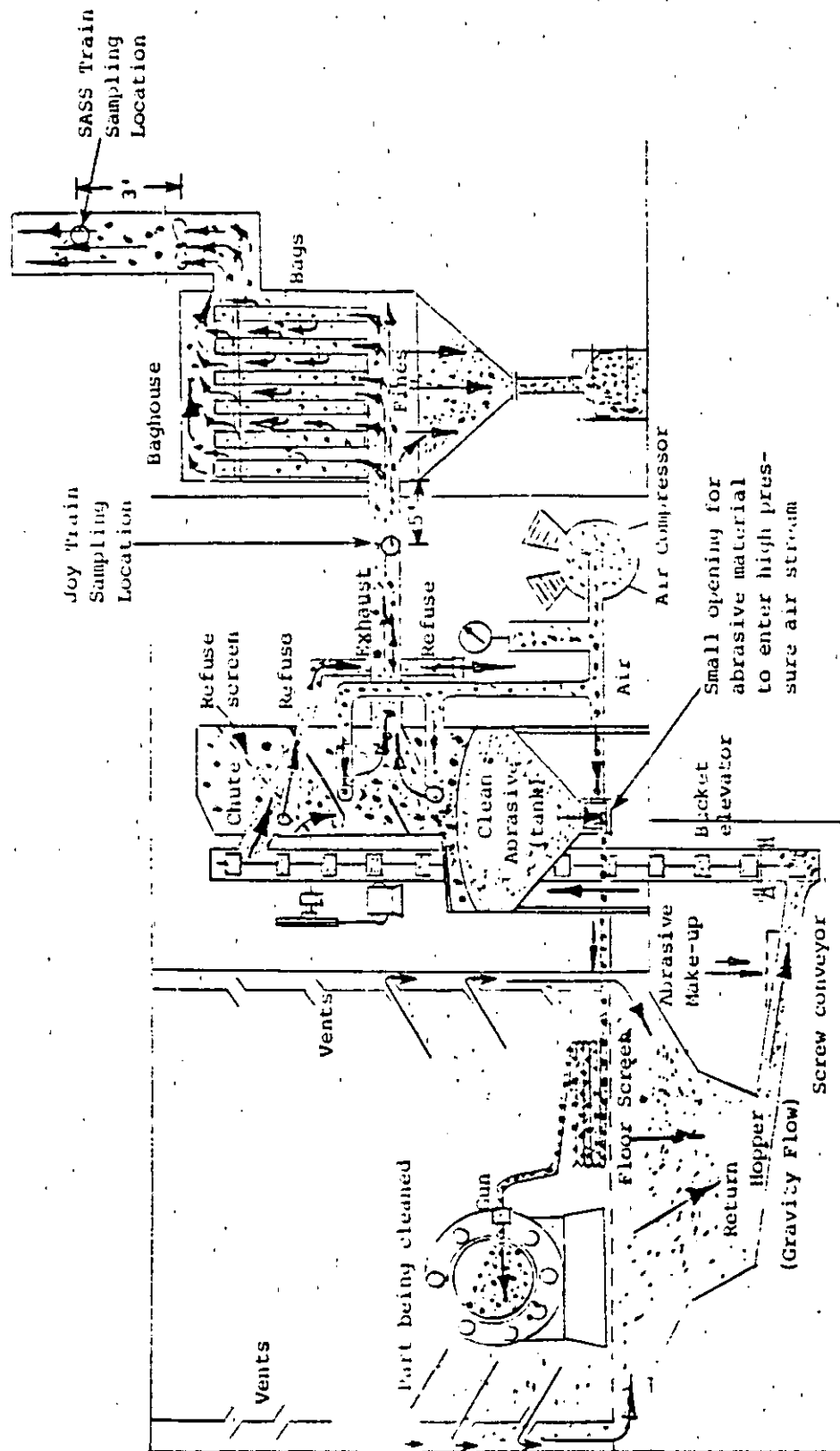
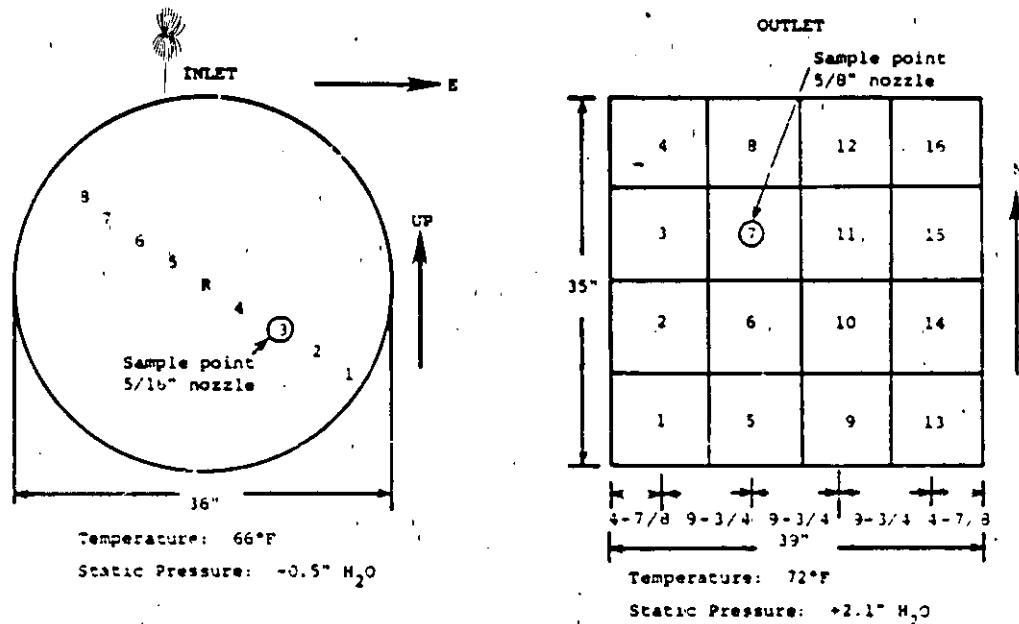


Figure 4-57. Abrasive blast metal cleaning.

KVB 5806-783

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



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

Average: 27.1 ft/sec
11635 SCFM

Average: 29.6 ft/sec
16509 SCFM

KVB 5806-793

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

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

t detected in concentration of <1%

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

2 analyzed by wet chemistry--Section 3.2.2 A

3 analyzed by Oceanography carbon analyzer--Section 3.2.2 A

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

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

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

D. Discussion of Results--

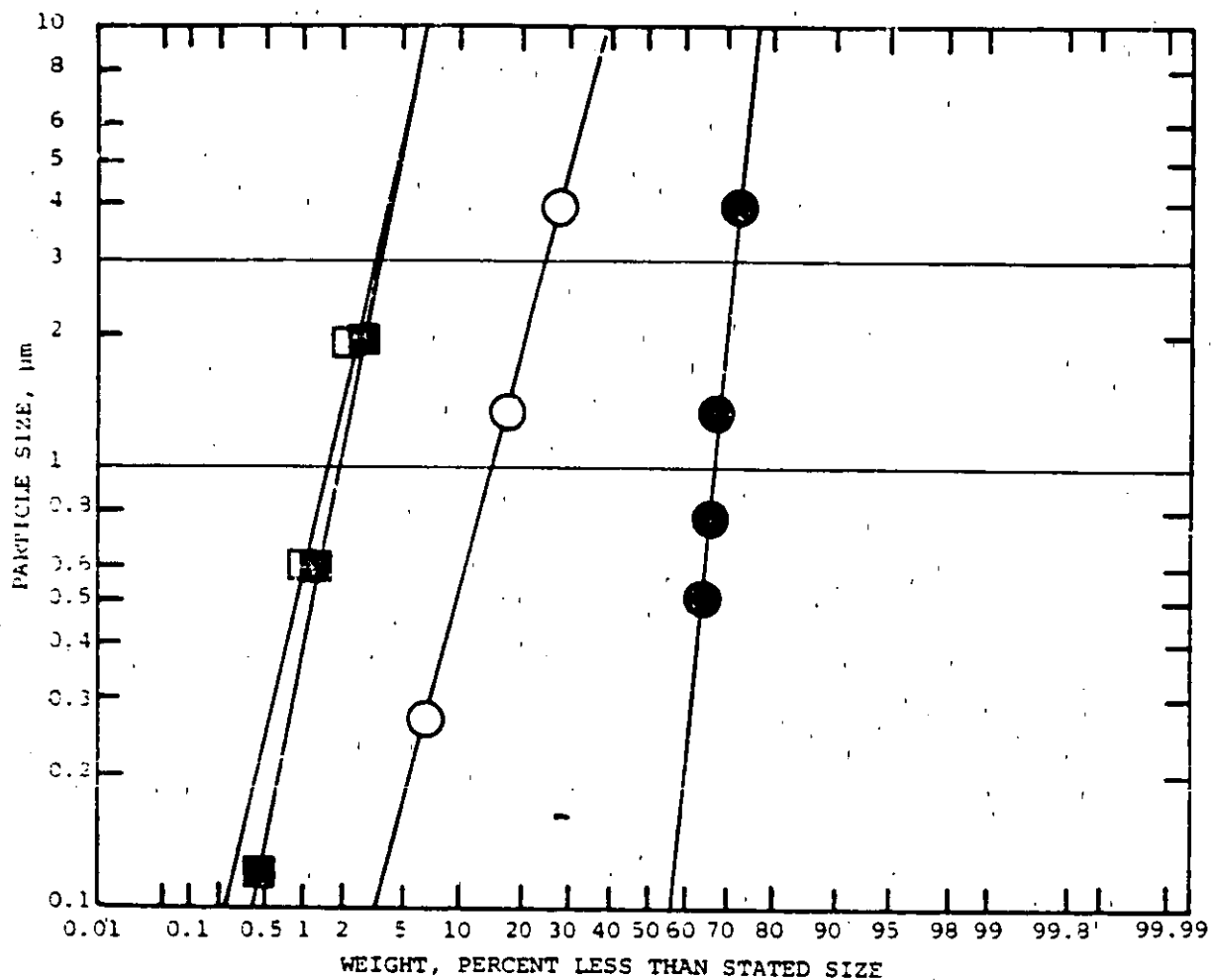
1. Baghouse efficiency--Using the mass loading (lb/hr) for both inlet and outlet to the baghouse, the efficiency was calculated to be 99.9% from the equation: $\text{efficiency} = [(\text{mass out} - \text{mass in}) / \text{mass in}] \times 100\%$.

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

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

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

3. Chemical composition--Table 4-64 lists the results from the chemical analysis of the particulate fraction for the tests discussed in this section. Unfortunately, the most abundant species, aluminum oxide Al_2O_3 , was not able to be detected by XRF analysis. Iron (iron oxide) found in the cyclones was significant in quantity (15-18%). Approximately 2% titanium and 0.3% sulfur was detected. The titanium is attributed to residual materials from parts being grit blasted in that facility previously.



- Joy Mfg. Sampling Train With Impinger
 - Joy Mfg. Sampling Train Without Impinger
 - SASS Train With Impinger
 - SASS Train Without Impinger
- } Inlet
 } Outlet

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

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.

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



NOTE

4.2.17 Aluminum Foundry (Reverberatory Furnace)

A. Process Description--

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

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

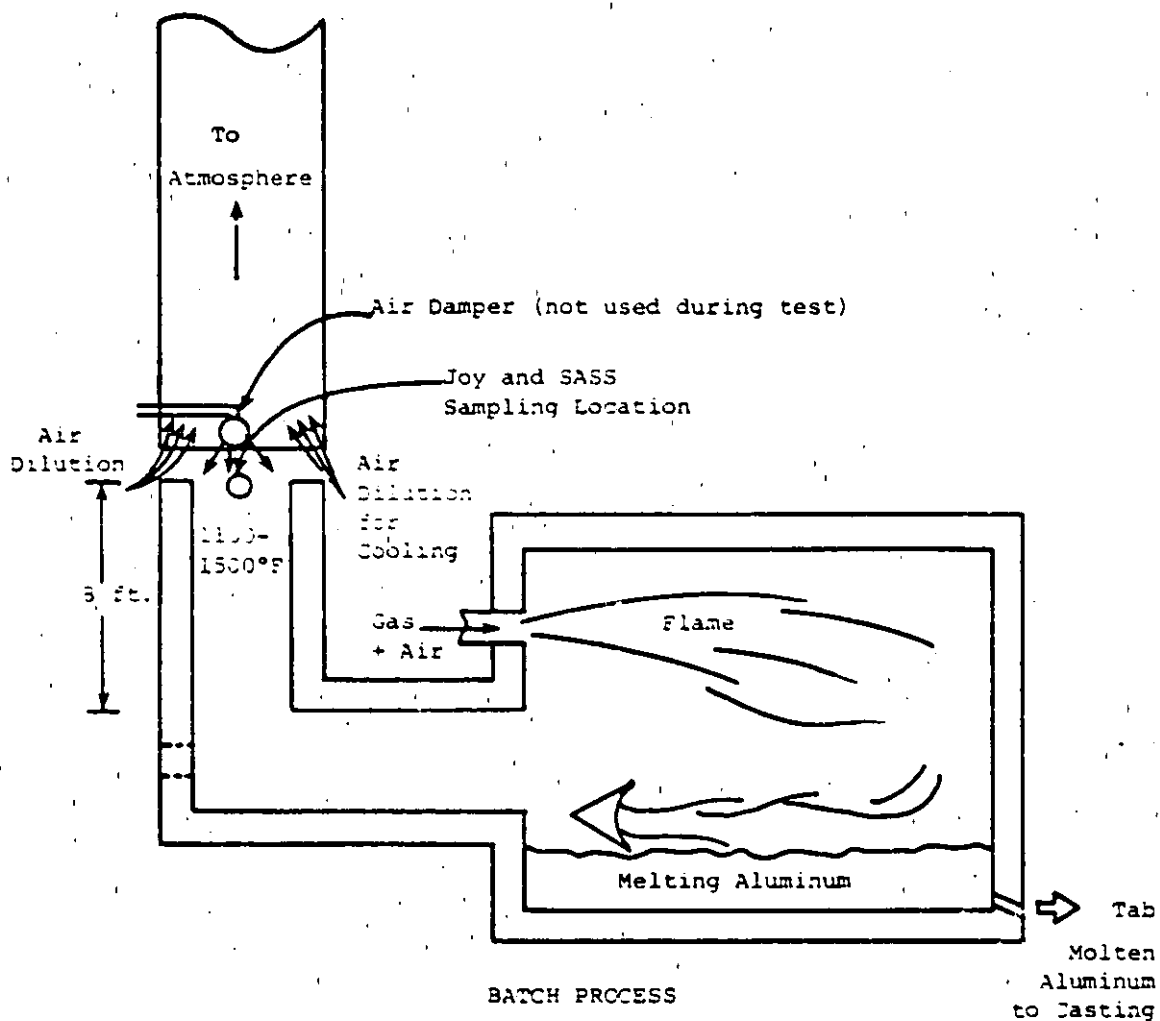


Figure 4-59. Thirty-five ton aluminum reverberatory melting furnace.

B. Particulate Test Setup--

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

C. Test Results--

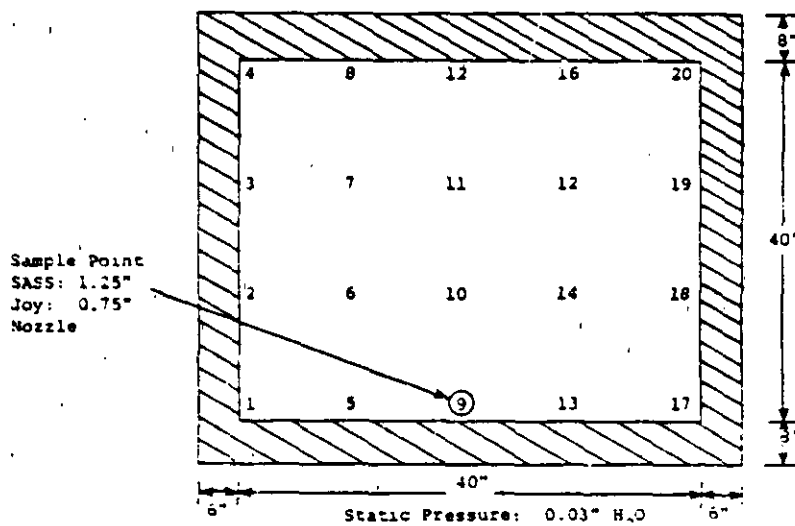
The results of the tests (Test 10S and 10J) discussed in this section, are listed in Table 4-1. Major elemental composition, sulfate, nitrate, and carbon analysis were determined for all fractions of particulate catches which contained weights in excess of 100 mg. The details for these procedures are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

D. Discussion of Results--

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

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

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



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

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

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

t detected in concentration of <1%

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

2 analyzed by wet chemistry--Section 3.2.2 A

3 analyzed by Oceanography carbon analyzer--Section 3.2.2 A

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

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

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

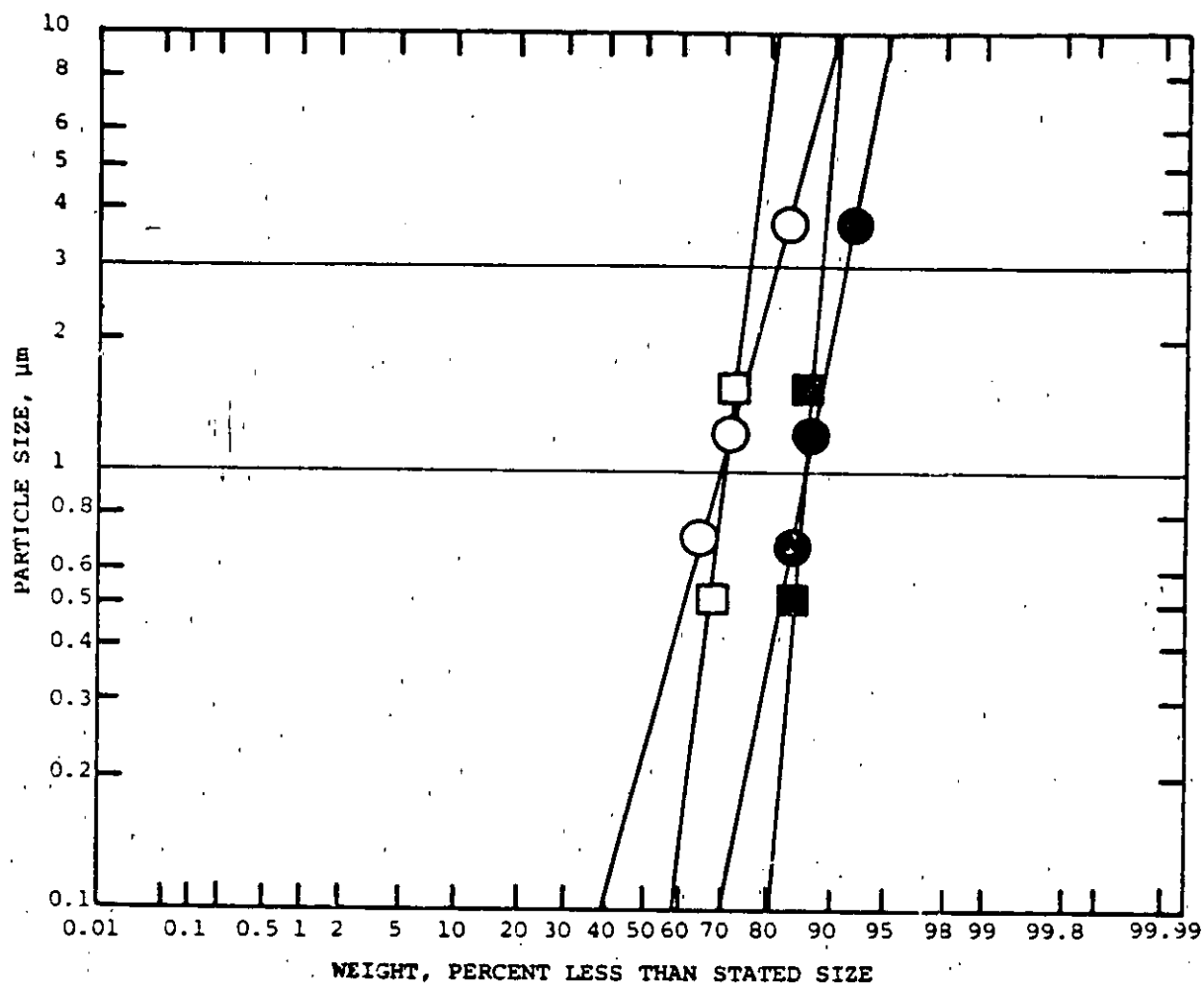


Figure 4-60. Particle size distribution for aluminum foundry (Test 10)

The mean particle size is $< .1 \mu\text{m}$ for aluminum melting furnaces. In spite of the highly irregular flow conditions measured in the duct the particle size distribution measurement with the two different trains were surprisingly similar.

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

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

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

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

4.2.18 Steel Production--Sinter Plant

A. Process Description--

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

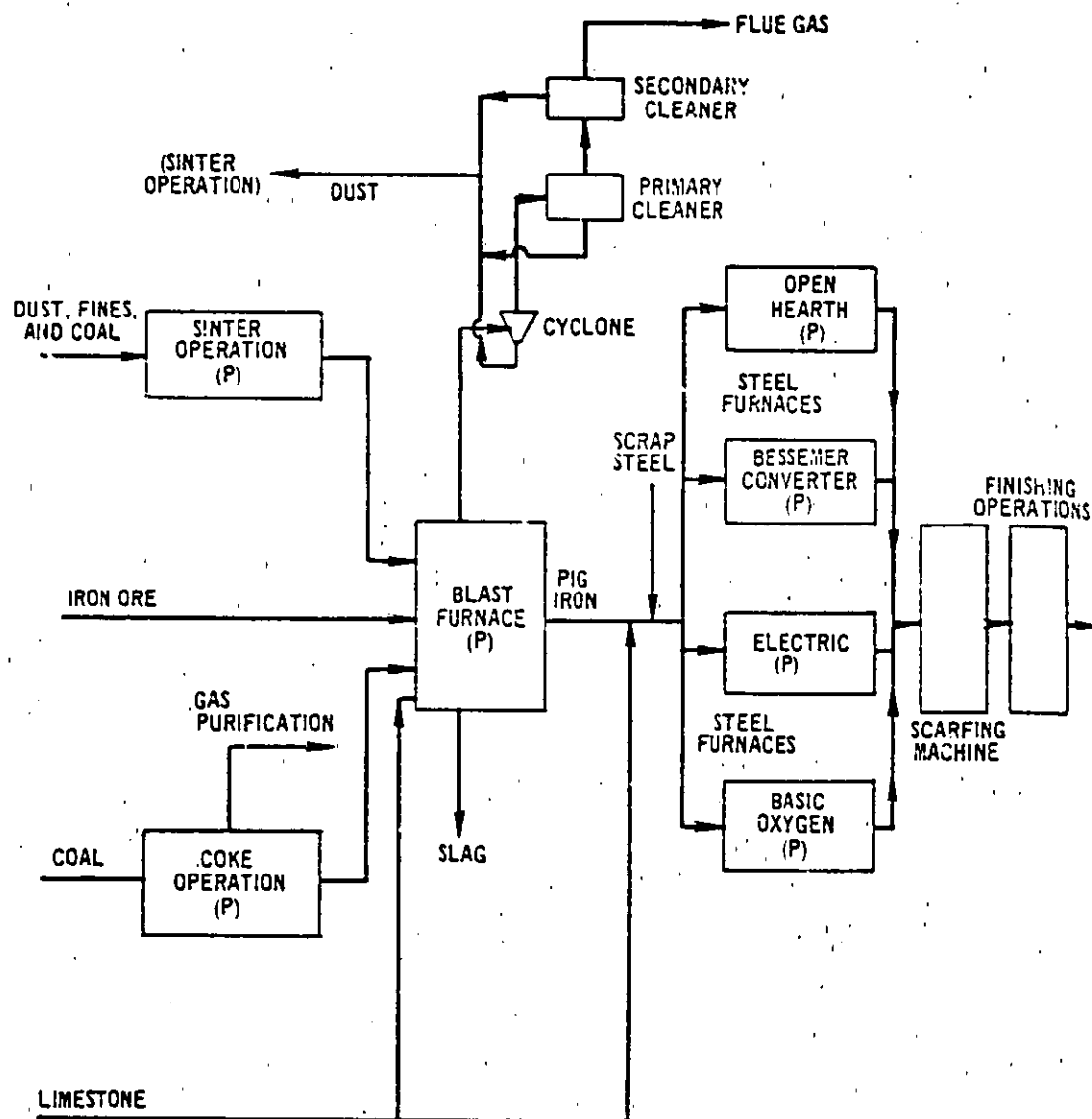
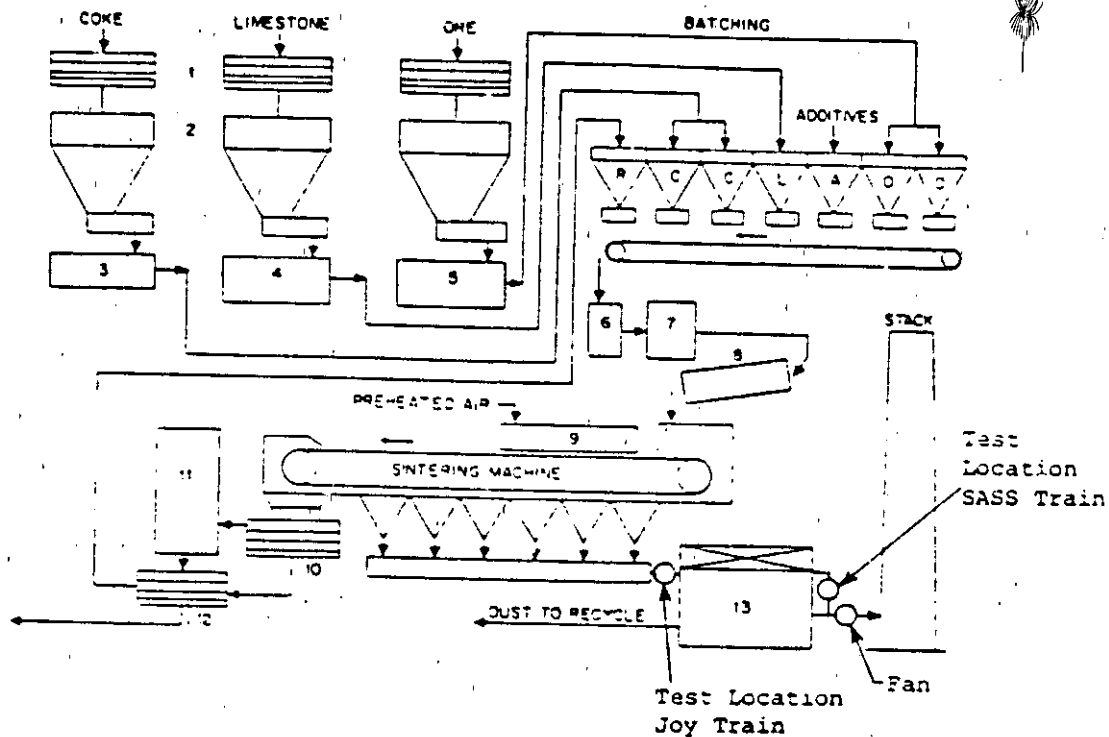


Figure 4-61. Basic flow diagram of iron and steel processes.
(P) denotes a major source of particulate emissions.

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

B. Particulate Test Set-up--

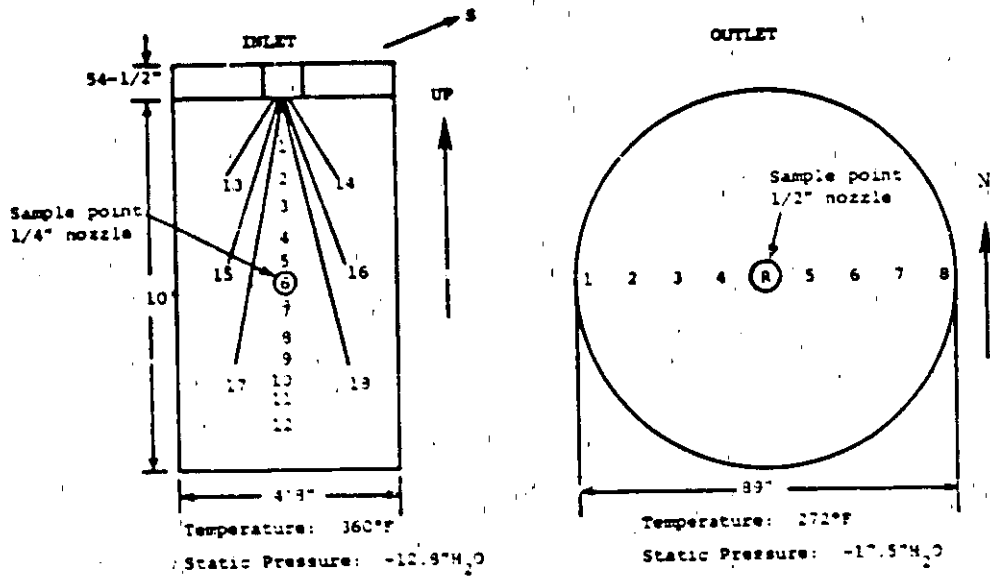
Two sampling trains were used simultaneously to sample the inlet and exit of the baghouse as shown in Figure 4-62. The inlet station was located on the horizontal underground section of the duct leading to the baghouse. A section 6" wide and 4' long was provided to sample the flue gases. Table 4-67 lists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



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

Figure 4-62. Continuous iron ore sintering process.

TABLE 4-67. VELOCITY PROFILE FOR TEST 26



Distance from end of port (inches)	Velocity		Distance from end of port (inches)	Velocity	
	Point #	ft/sec		Point #	ft/sec
55	1	58.0	7	1	62.1
69	2	62.0	13	2	62.1
79	3	60.4	21	3	60.4
89	4	59.6	33	4	63.5
99	5	59.6	44	5	74.7
109	6	58.8	64	6	77.5
119	7	58.3	75	7	80.2
129	8	59.2	83	8	85.4
139	9	60.4	90		80.2
149	10	59.6	Average: 71.0 ft/sec		
159	11	59.2	134,334 SCFM		
169	12	59.6			
71	13	62.0			
71	14	47.0			
104	15	62.2			
104	16	48.0			
130	17	64.3			
130	18	47.5			
Average: 56.7 ft/sec					
108,760 SCFM					

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

C. Test Results--

The results of the tests (Test 26J and Test 26S) discussed in this section are listed in Table 4-1. Elemental composition, sulfate, nitrate, and 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 4-68 lists the results from these analyses.

D. Discussion of Results--

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

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

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

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

TABLE 4-63. CHEMICAL COMPOSITION OF PARTICULATE SAMPLES
IN PERCENT FOR TEST 26

SAMPLE #	SASS 104 Cyclone 265-2S	Joy 104 Cyclone 26J-2S	Joy Inlet 10 Cyclone 26J-4S	Joy Inlet Filter 26J-3S	SASS Exit Filter 265-5S	SASS Exit Impinger 26S-1C	Joy Inlet Impinger 26J-1C
WT. PERCENT OF DUT	3.0	5.2	12	43	3.5	91	12
XRF ANALYSIS							
Arsenic				t	t		
Bromine			t	t	t		
Cadmium			t	t	t		
Calcium	9.3/2	12/3	1.1/0.4			t	
Chlorine	4.9/2	8/3	14/5	23/1C	30/10	17/4	16/5
Chromium	t	t				3.4/0.4	
Copper	t	t	1.6/0.4	1.2/0.2	1.6/0.2		
Cesium			t	t	t		
Iron	20/1	16/1	2.0/0.2	t	t	13	
Lead	t	2.0/1	13/2	12/2	12/2		
Manganese	t	t				t	
Molybdenum						t	
Nickel						1.9/0.3	
Potassium	31.1/1	5/2	9/4	16/5	20/7	t	t
Phosphorus		t	t	t	t		
Sulfur	(17/5)	(19/3)				(15/5)	(16/5)
Titanium		t					
Zinc			t	t	t		
TOTAL ¹	40	45	43	55	65	24	17
Sulfates, H ₂ O sol ²	8.23	6.01	2.12	1.40	7.46	22.81	25.49
Sulfur, from SO ₄ ²	(2.74)	(2.0)	t	t	(2.49)	(7.60)	(8.50)
Nitrates, H ₂ O sol ²	t	t					
Total Carbon ³	15		7	t	t	11	6
Volatiles Carbon ³	(12)		7			(10)	(6)
Carbonates ⁴	t	1.67					
TOTAL ANALYZED	63	53	52	56	72	58	48
BALANCE	37	47	48	44	28	42	52
	100%	100%	100%	100%	100%	100%	100%

1 detected in concentration of <1%

2 analyzed by x-ray fluorescence--Section 1.2.2 B

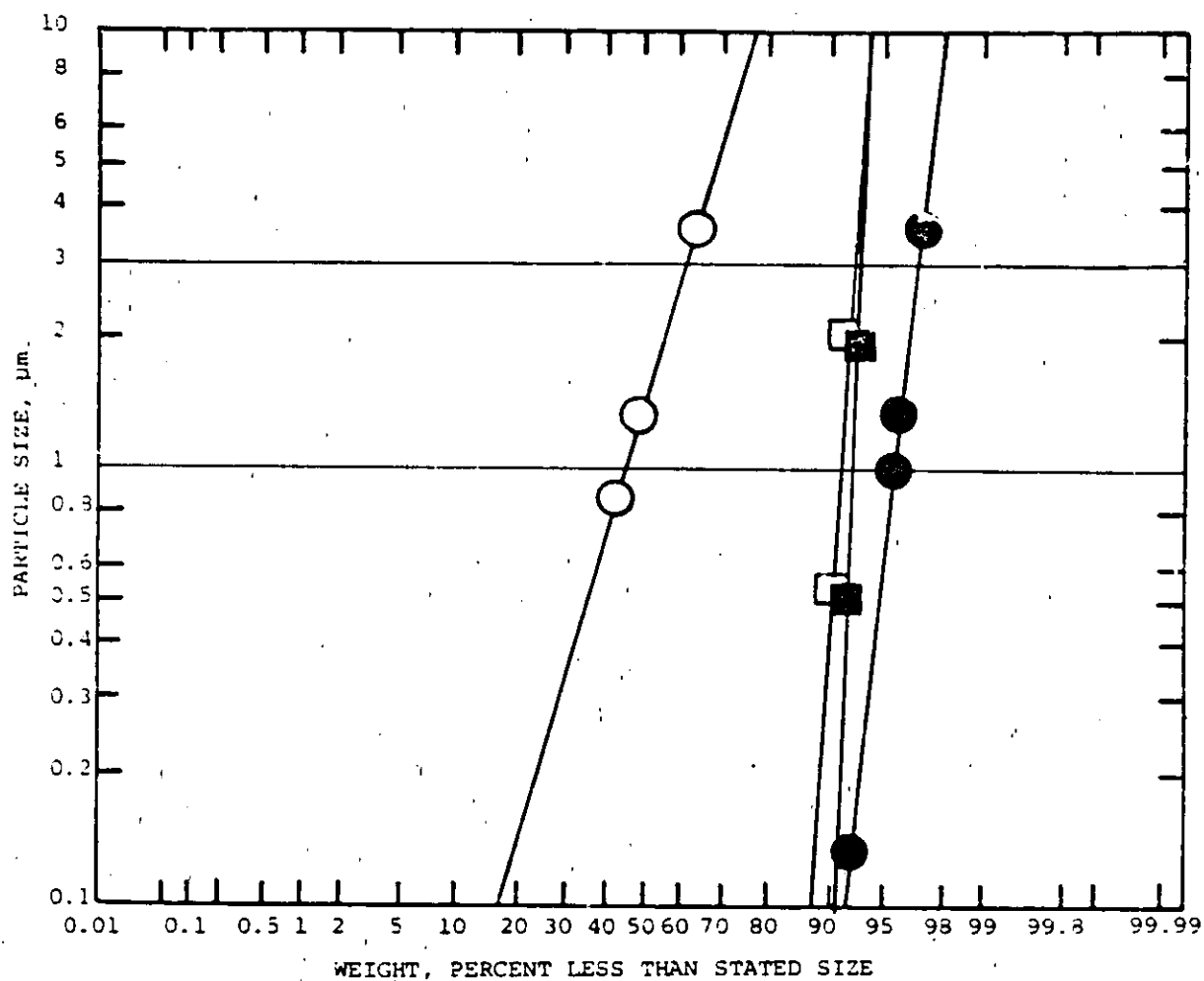
3 analyzed by wet chemistry--Section 1.2.2 A

4 analyzed by Oceanography carbon analyzer--Section 1.2.2 A

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

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

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



- Joy Mfg. Sampling Train With Impinger
 - Joy Mfg. Sampling Train Without Impinger
 - SASS Train With Impinger
 - SASS Train Without Impinger
- } Inlet
 } Outlet

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

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

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

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

4.2.19 Steel Production--Open Hearth Furnace

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

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

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

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

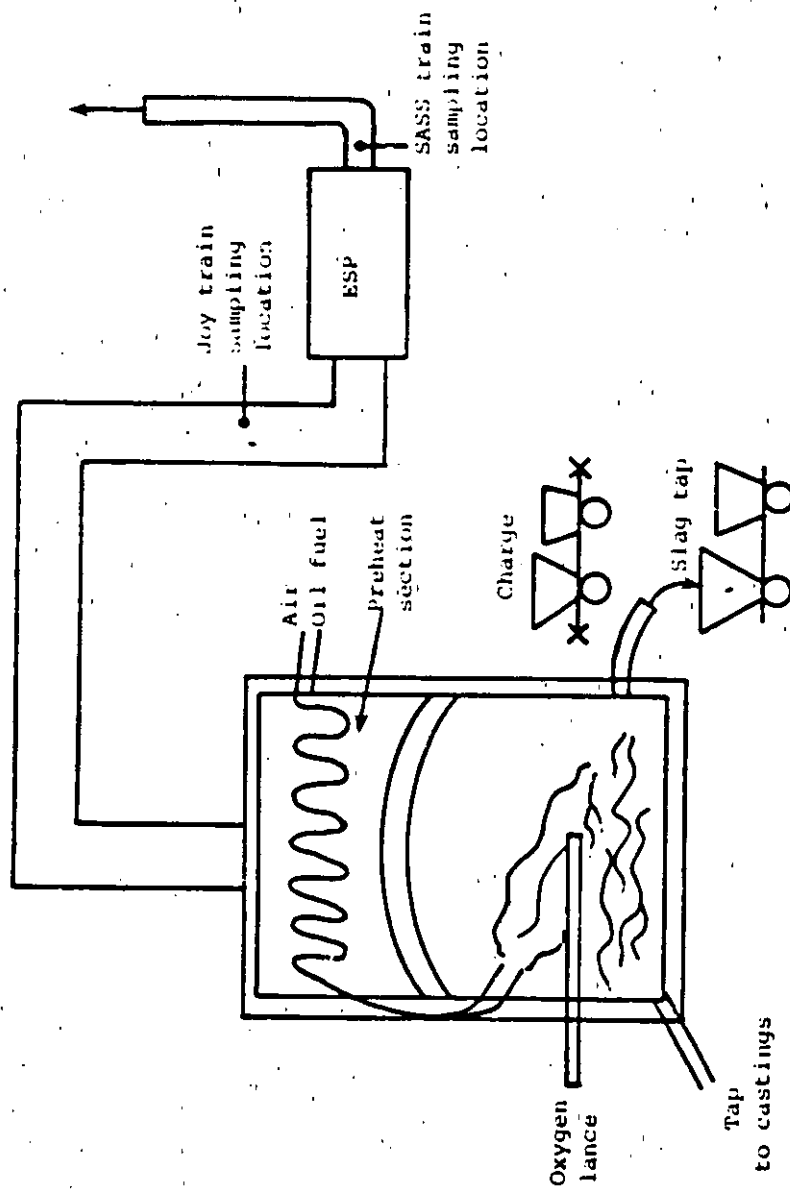


Figure 4-64. Open hearth furnace.

KVH 5806-783

B. Particulate Test Set-up--

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

C. Particulate Test Results--

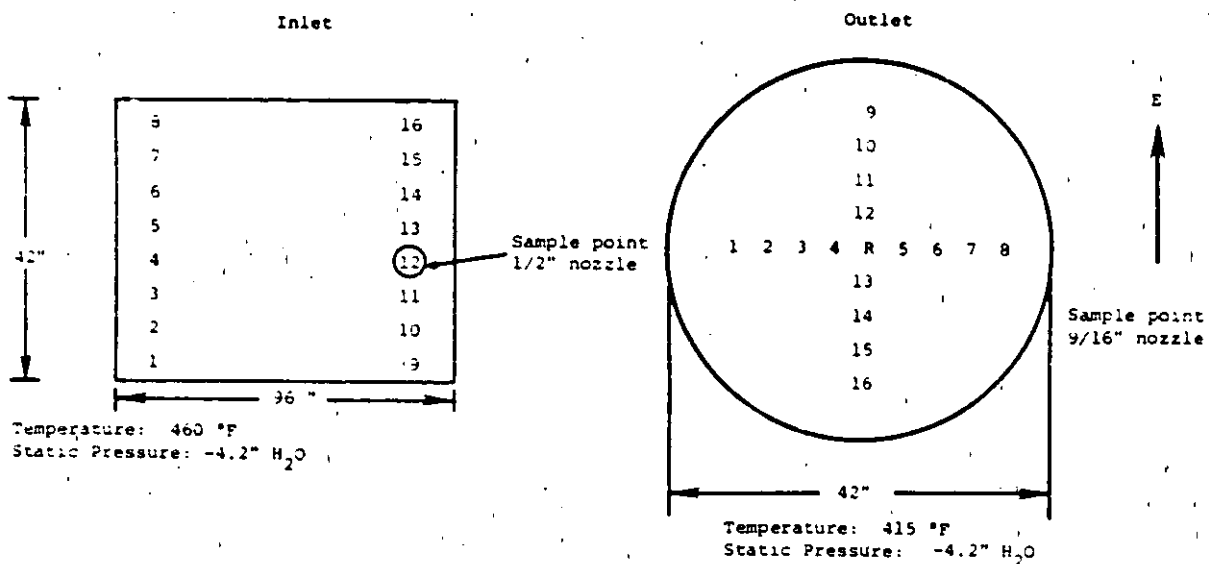
The results of the two tests (Tests 36S and 36J) discussed in this section are listed in Table 4-70. Elemental composition, sulfate, nitrate, and carbon analysis were determined for all fractions of particulate catches which contained weights in excess of 100 mg. The details for these procedures are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

D. Discussion of Test Results--

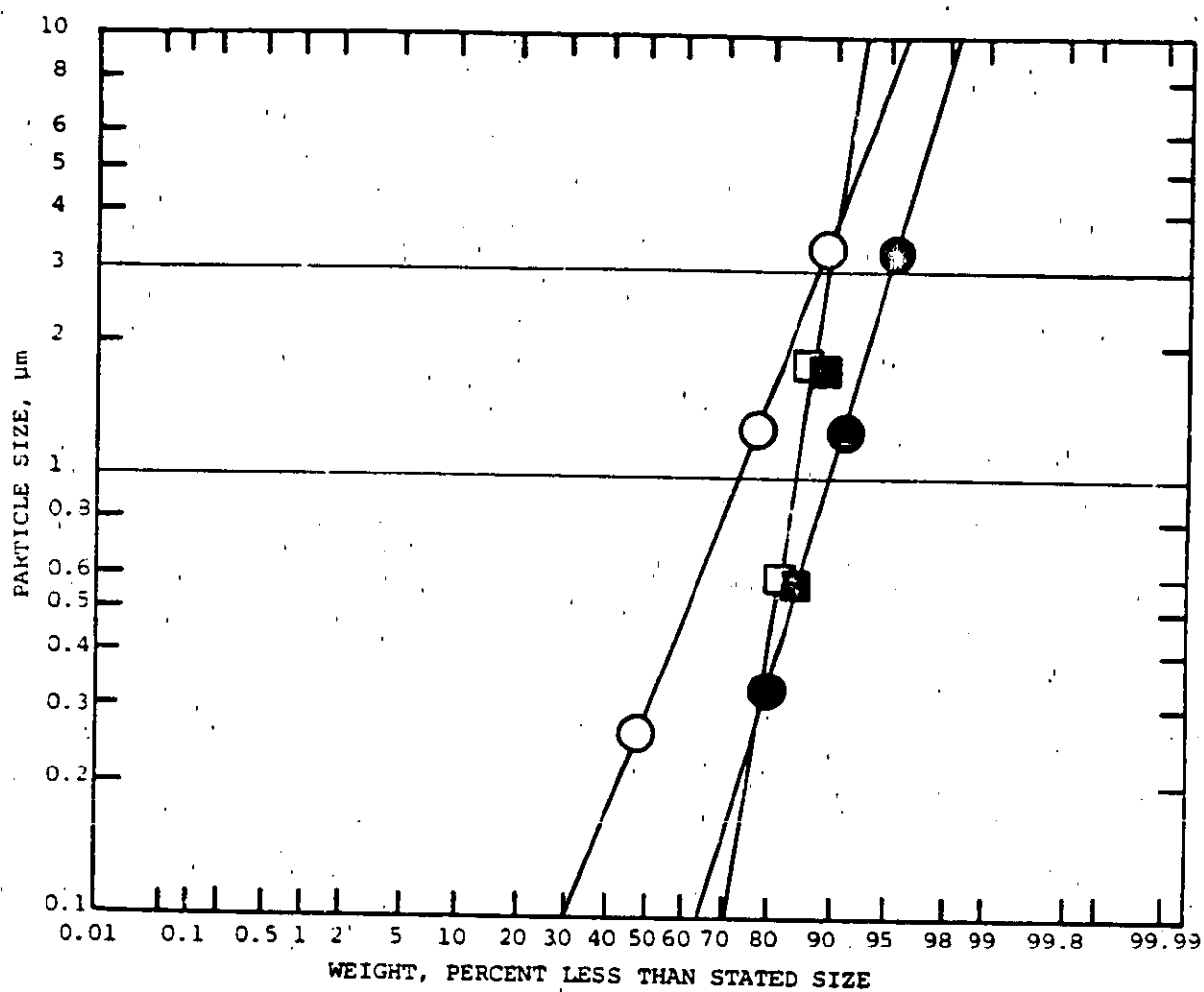
1. Electrostatic precipitator efficiency--The calculated efficiency for the ESP based on the total particulate catch is 84.2%. Neglecting the impinger catch on both trains the efficiency is 90.3%. The EPA Method 5 ignores the impinger catch; therefore, the higher efficiency would apply. Whereas, the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

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

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



Distance from end of port (inches)	Velocity				Distance from end of port (inches)	Velocity			
	Point #	ft/sec.	Point #	ft/sec.		Point #	ft/sec.	Point #	ft/sec.
5-5/8	1	27.3	9	25.3	4-3/8	1	55.3	9	50.5
10-7/8	2	27.3	10	25.3	7-3/8	2	59.7	10	63.8
16-1/8	3	28.3	11	25.3	12-1/4	3	61.8	11	69.6
21-3/8	4	24.3	12	23.1	16-1/2	4	63.8	12	69.6
26-5/8	5	23.1	13	23.1	24	R	63.8	R	67.7
31-7/8	6	24.3	14	14.6	31-5/8	5	63.8	13	22.5
37-1/8	7	23.1	15	14.6	36-3/4	6	63.8	14	22.5
43-3/8	8	20.7	16	14.6	40-5/8	7	63.8	15	22.5
Average: 22.68 ft/sec. 21,539 SCFM					Average: 54.2 ft/sec. 18,584 SCFM				



- Joy Mfg. Sampling Train With Impinger
 - Joy Mfg. Sampling Train Without Impinger
 - SASS Train With Impinger
 - SASS Train Without Impinger
- } Inlet

} Outlet

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

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

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

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

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

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

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

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

SAMPLE #	SASS 1µm Cyclone 36S-4S	SASS Filter 36S-5S	SASS Impinger 36S-1C	Joy 10µm Cyclone 36J-2S	Joy 1µm Cyclone 36J-4S	Joy Filter 36J-5S	Joy Impinger 36J-1C
WT. PERCENT OF CUT	9.7	15	44	12	26	39	9.6
XRF ANALYSIS							
Calcium	t	1.2/0.5	t	2.2/0.4	t	t	t
Chromium	1.1/0.2	1.2/0.3	2.2/0.4	t	t	1.3/0.3	
Copper	t	t	t	t	t	t	t
Iron	15/2	11/2	8.2/1	18/3	13/2	8.2/1	t
Lead	t	t		t	t	t	
Manganese	1.0/0.2	t	t	1.1/0.2	t	t	
Nickel	t	t	1.2/0.2	t	t	t	
Potassium	4.5/1	5.9/1		3.1/0.6	4.3/1	6.1/1	t
(Sulfur)	(27/10)	(30/10)	(18/6)	(25/10)	(20/8)	(30/10)	(16/6)
Vanadium	t	t		t	t	t	
Zinc	11/2	8.9/1		9.0/1	9.3/1	7.4/0.8	t
TOTAL ¹	25	31	13	24	31	26	3
Sulfates, H ₂ O sol ²	38	41	38	32	41	44	32
(Sulfur, from SO ₄) ³	(12.8)	(13.8)	(12.8)	(12.8)	(13.7)	(14.8)	(10.9)
Nitrate (H ₂ O sol) ²	t	t	t	t	t	t	t
Total Carbon ¹	21		23				41
(Volatile Carbon) ¹	(21.82)		(21)				(32)
(Carbonates) ¹							
TOTAL ANALYZED	84	72	74	66	72	70	77
BALANCE	16	28	26	34	28	30	23
	100%	100%	100%	100%	100%	100%	100%

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

CHEMICAL PROCESS

4.2.20 Boric Acid Production

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

Sulfuric acid is reacted with borax to produce boric acid and Glauber salt, (hydrated sodium sulfate, $\text{Na}_2\text{SO}_4 \cdot 10 \text{H}_2\text{O}$). These products are then separated on a vacuum filter. The boric acid cake is redissolved, filtered, crystallized, centrifuged, dried, and screened. The Glauber salt follows a similar circuit except for an additional step of conversion to sodium sulfate. Figure 4-66 is a flow diagram of the process.

B. Particulate Test Setup--

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

C. Test Results--

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

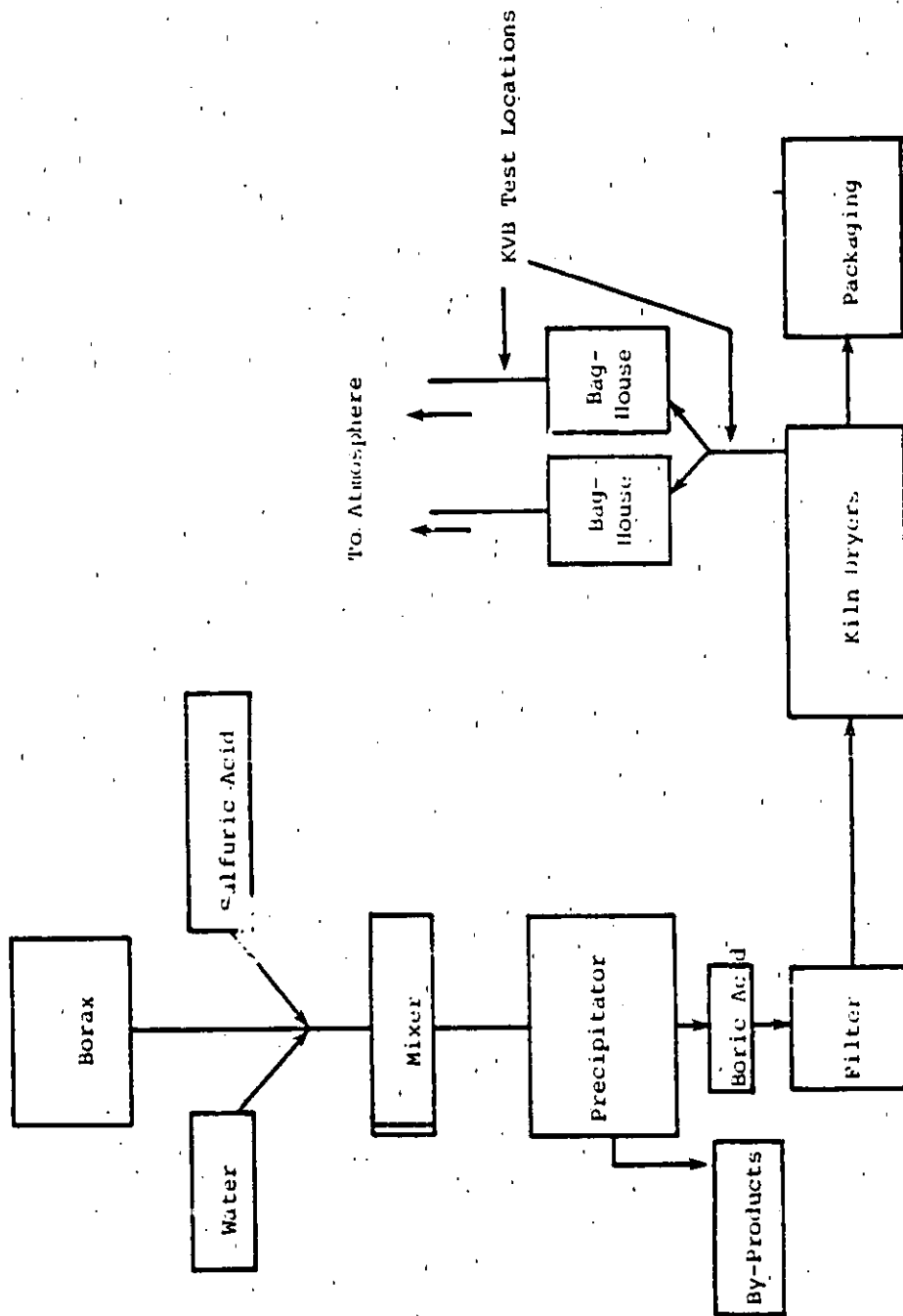
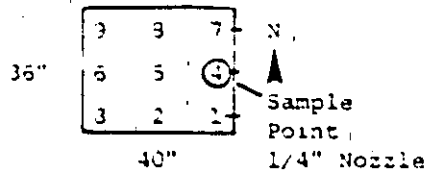


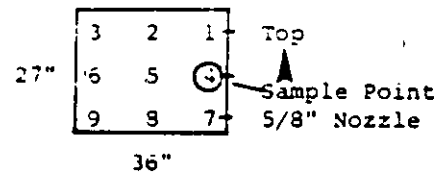
Figure 4-66. Boric acid production flow diagram.

KVB 5806-783

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



Temperature - 150 °F
Static Pressure - 13" H₂O



Temperature - 130 °F
Static Pressure - 16" H₂O

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

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

SAMPLE #	Impinger		10Lr	
	Inlet 17J-1C	Outlet 17S-1C	Inlet 17J-2S	Outlet 17S-24
WT. PERCENT OF CUT	29	84	6	11
XRF ANALYSIS				
Chlorine	t	t		t
Chromium				
Iron		t		
(Sulfur)	(<2.0)	t	t	t
TOTAL ¹	t	t	t	1.3
Sulfates, H_2O sol ²	1.96	t	t	2.20
(Sulfur, from SO_4^{2-}) ³	t	t	t	t
Nitrate (H_2O sol) ²	t	t	1.43	2.43
Total Carbon ³		4.0		
(Volatile Carbon) ³		3.9		
(Carbonates) ³			t	
TOTAL ANALYZED	2	4	2	6
BALANCE Probably HBO_3	98	96	98	94
	100%	100%	100%	100%

- t detected in concentration of $<1\%$
- 1 analyzed by x-ray fluorescence--Section 1.2.2 B
- 2 analyzed by wet chemistry--Section 1.2.2 A
- 3 analyzed by Oceanography carbon analyzer--Section 1.2.2 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. $X \pm Y$)
- () not included in total--sulfur and sulfates are accounted for in sulfur XRF analysis and volatile carbon and carbonate are accounted for in total carbon

D. Discussion of Results--

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

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

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

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

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

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

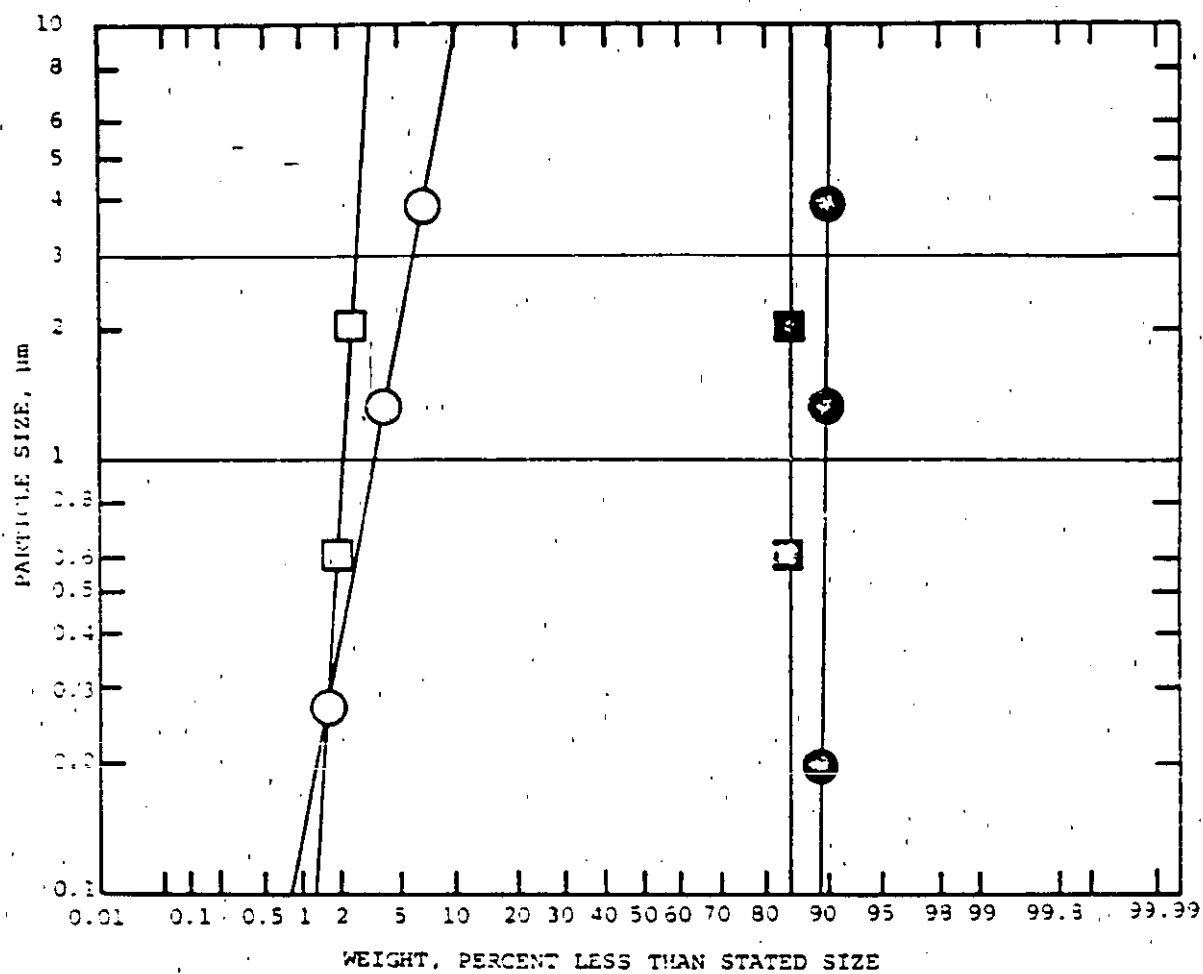


Figure 4-67. Particle size distribution for boric acid plant. (Test 17)

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

4.2.21 Chemical Fertilizer Plants

A. Process Description

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

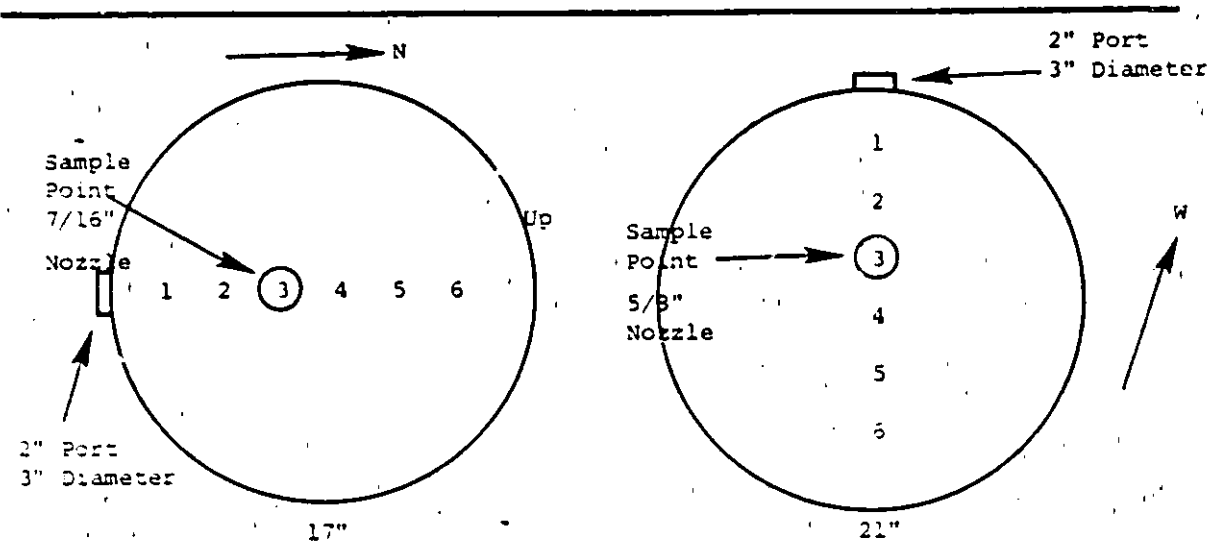
B. Particulate Test Setup--

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

C. Test Results--

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

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



Temperature - 86 °F
Static Pressure - -0.16" H₂O

Temperature - 101 °F
Static Pressure - +0.56

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

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

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

t detected in concentration of <1%

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

2 analyzed by wet chemistry--Section 3.2.2 A

3 analyzed by Oceanography Carbon analyzer--Section 3.2.2 A

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

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

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

D. Discussion of Results--

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

2. Particle size distribution--Figure 4-69 is a plot of particle size (μm) versus accumulated weight percent, the latter plotted on a probability scale as explained in Section 3.2.3B. Two sets of curves are presented, one including the impinger catch, and the other ignoring it. Considering the nature of the gas stream, it would seem that the material collected in the impinger would be attributed to very fine particles and not to pseudo particulates. Therefore, the impinger catch was believed to be properly included in the measurements of the suspended particulates from chemical fertilizer plants for particle size distribution. The breakdown of the particle size distribution, including the impinger catch, is as follows:

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

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

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

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

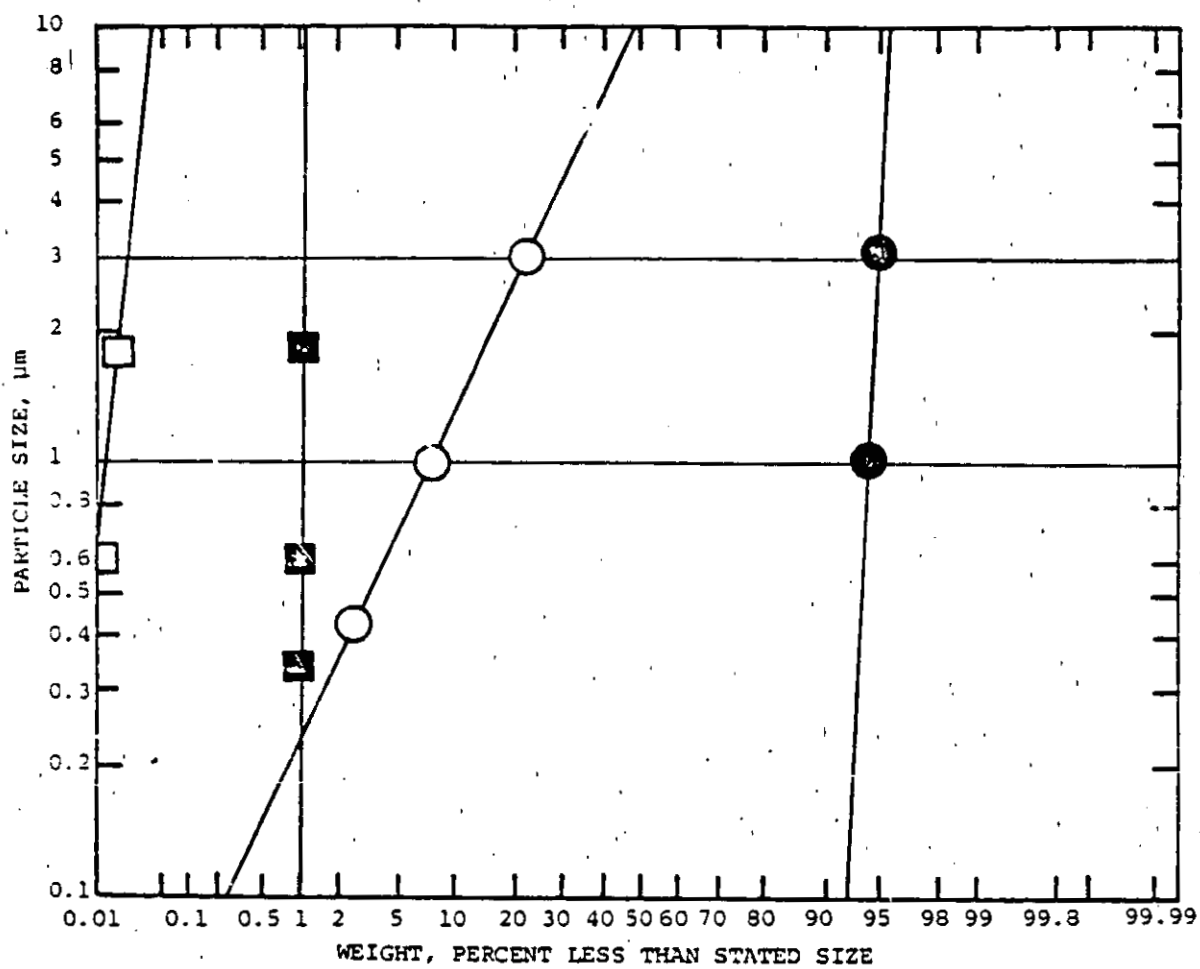


Figure 4-69. Particle size distribution for chemical fertilizer plants. (Test 19)

Units	Controlled	Uncontrolled
SCF	0.0028	0.72
	0.1	12.2
L	0.11	12.6
lb/ton produced	0.02	2.0
lb/ton produced (Ref. 4-37)	0.4	80.0

4.2.22 Paint Spray Booths - Automobile

A. Process Description

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

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

B. Particulate Test Setup

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

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

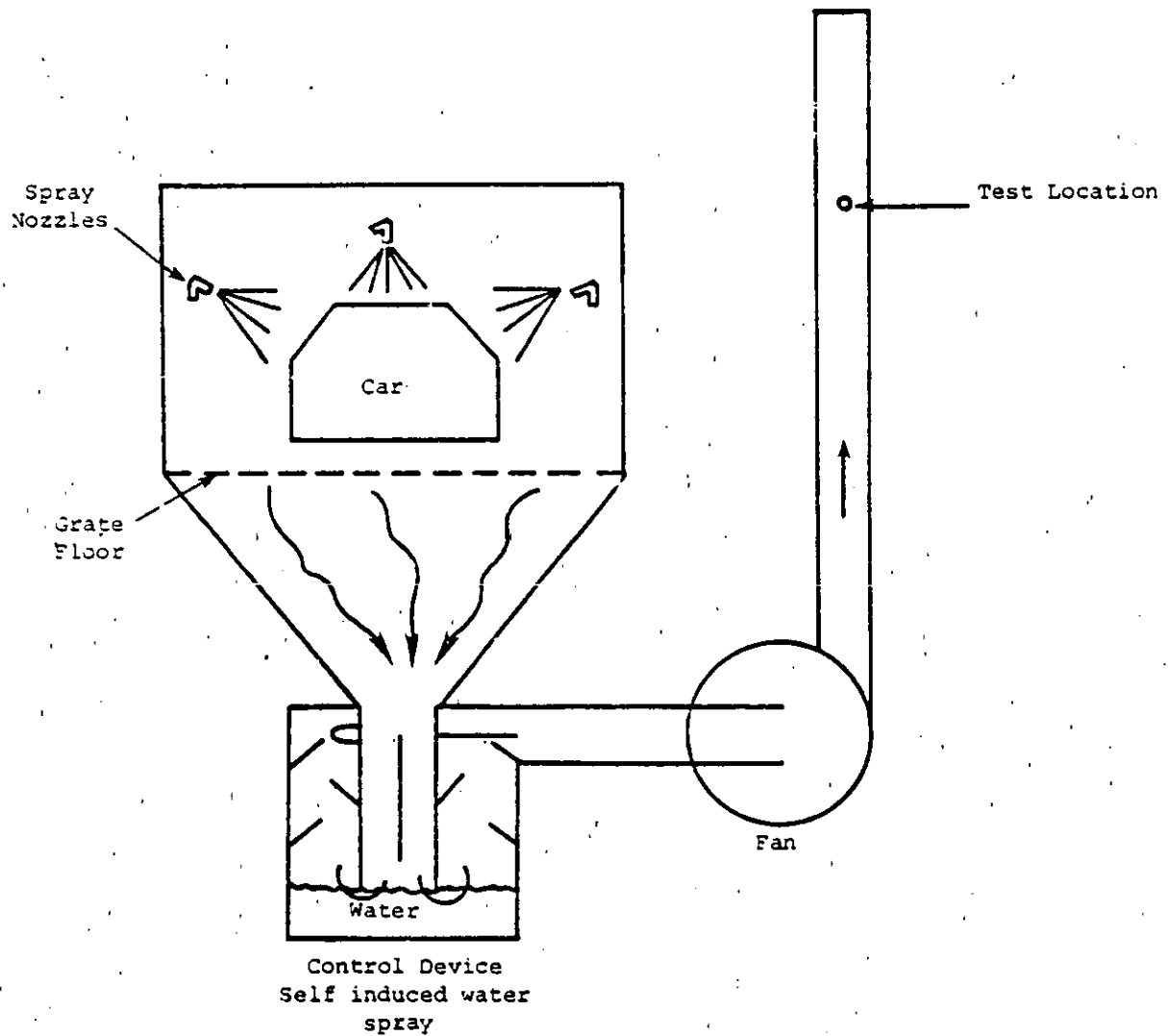
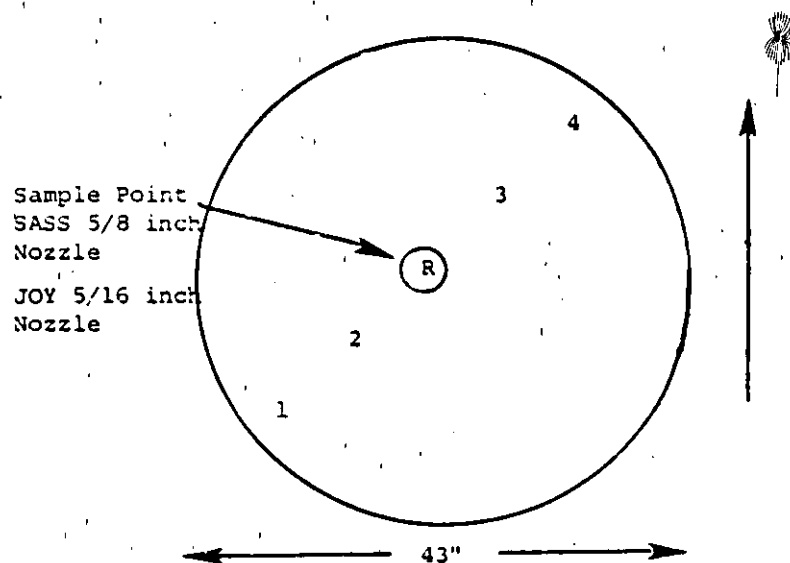


Figure 4-70. Automotive spray booth.

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

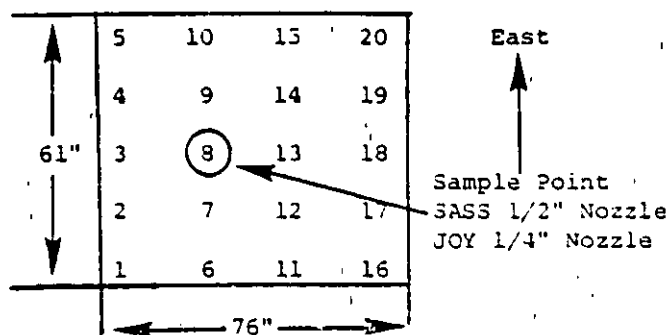


Temperature - 67 °F
Static Pressure - +0.1" H₂O

Stack No. 1
One of Six Stacks

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

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



Temperature - 70 °F
 Static Pressure - +0.2" H₂O

Stack No. 1 of four stacks

Distance From Edge of Duct	Velocity			
	Point No.	ft/sec	Point No.	ft/sec
6"	1	52.0	11	52.6
18	2	51.0	12	46.4
30	3	54.9	13	43.7
42	4	48.0	14	43.0
54	5	49.6	15	42.3
6"	6	55.5	16	60.8
18	7	50.8	17	49.6
30	8	48.4	18	42.3
42	9	42.3	19	40.3
54	10	41.5	20	49.0

Average 48.5 ft/sec
 79,992 SCFM

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

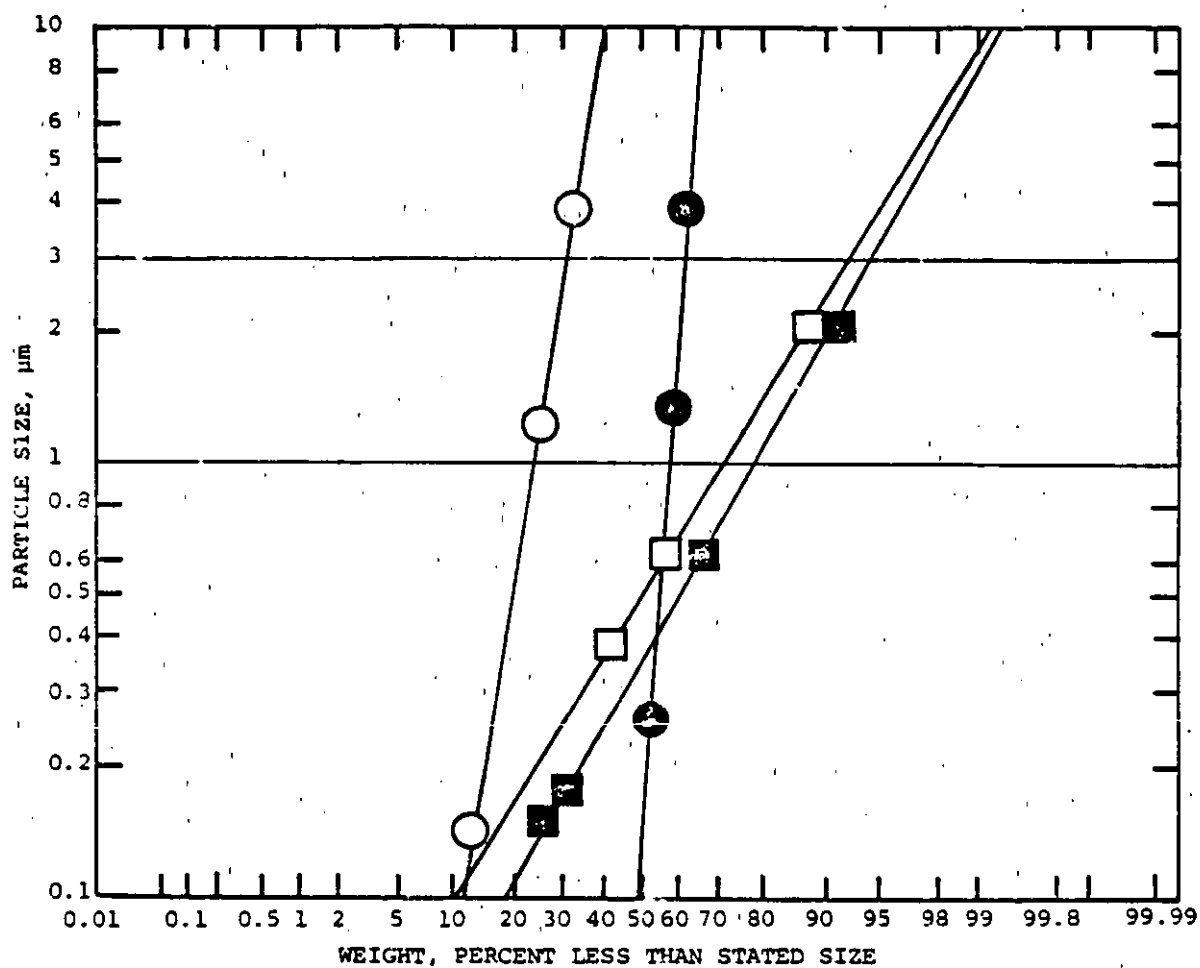
The velocity profile in the duct is listed in Table 4-76. Also listed in Table 4-76 is the average flow, SCFM, for each of the four stacks exhausting the spray booth. The total flow for the spray booth exhaust is 240,000 SCFM. A 1/2 inch nozzle was used with the larger SASS train at velocity point No.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

C. Test Results

The results of the tests (Test 2/S, 27J, 31S, 31J) discussed in this section are listed in Table 4-1. Elemental composition, sulfate, nitrate and carbon analysis were determined for all fraction of particulate catches which contained weights in excess of 100 mg. The details for these procedures are discussed in Section 3.2.2. Table 4-77 lists the results from this analysis. Because of the small particle loading in the exhaust stream, both tests failed to yield sufficient sample for chemical analysis. See Section

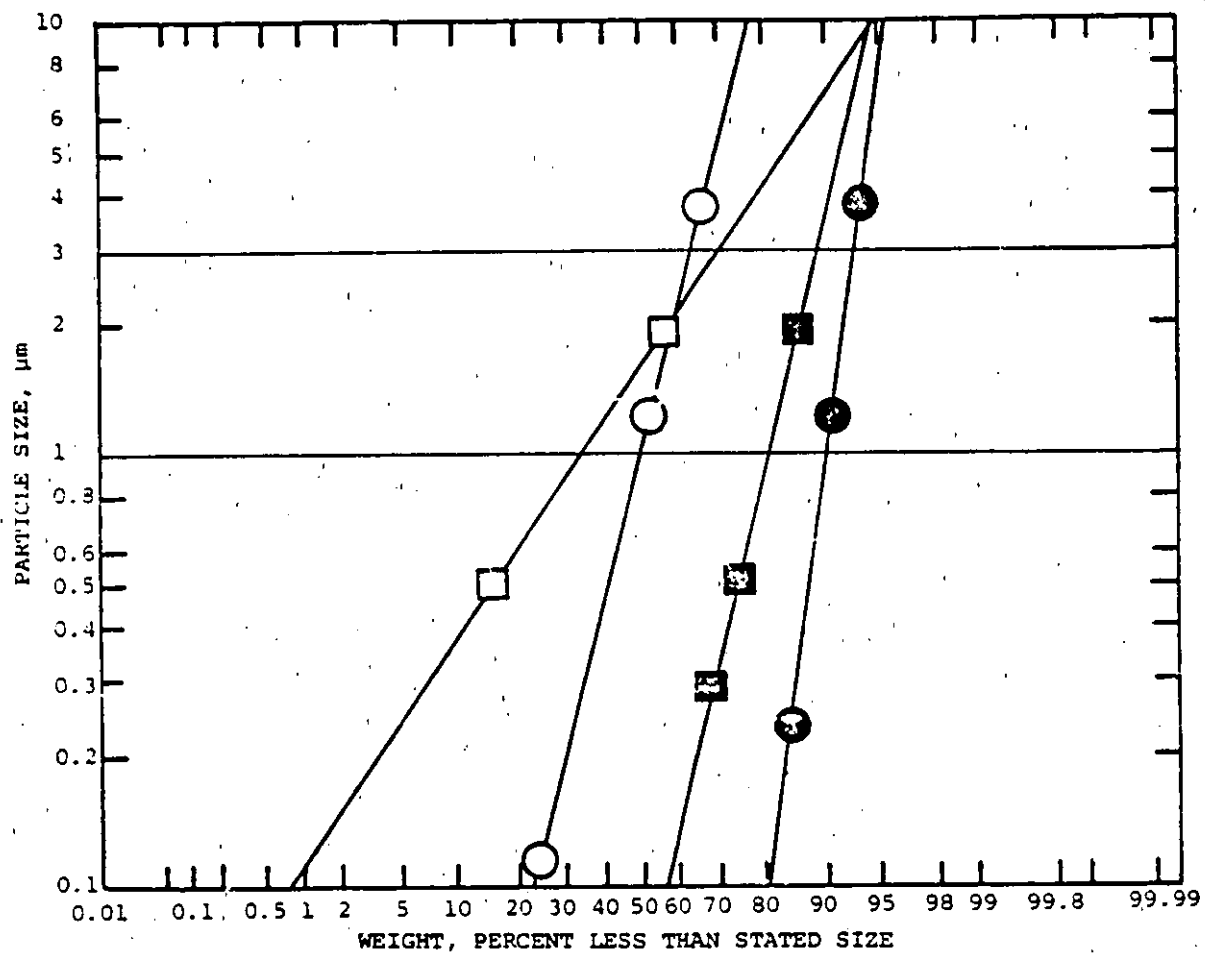
D. Discussion of Results

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



- Joy Mfg. Sampling Train With Impinger
- Joy Mfg. Sampling Train Without Impinger
- SASS Train With Impinger
- SASS Train Without Impinger

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



- Joy Mfg. Sampling Train With Impinger
- Joy Mfg. Sampling Train Without Impinger
- SASS Train With Impinger
- SASS Train Without Impinger

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

PERCENT OF PARTICLES

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

The mean particle size is about 1 μ m.

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

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

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

4.2.23 Wood Processing

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

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

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

t detected in concentration of <1%

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

2 analyzed by wet chemistry--Section 3.2.2 A

3 analyzed by Oceanography carbon analyzer--Section 3.2.2 A

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

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

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

A. Process Description--

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

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

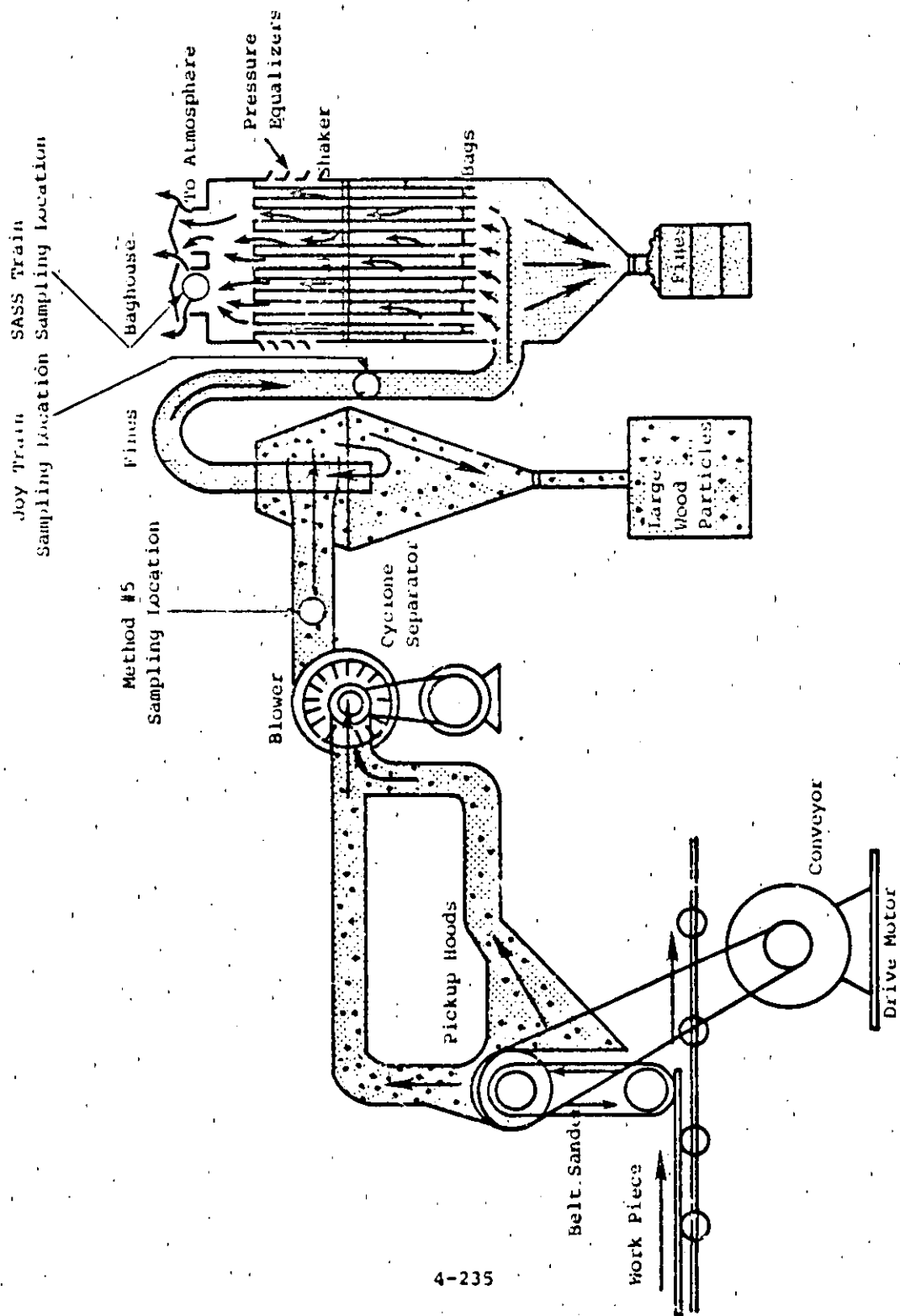
B. Particulate Test Setup--

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

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

C. Test Results--

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



4-235

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

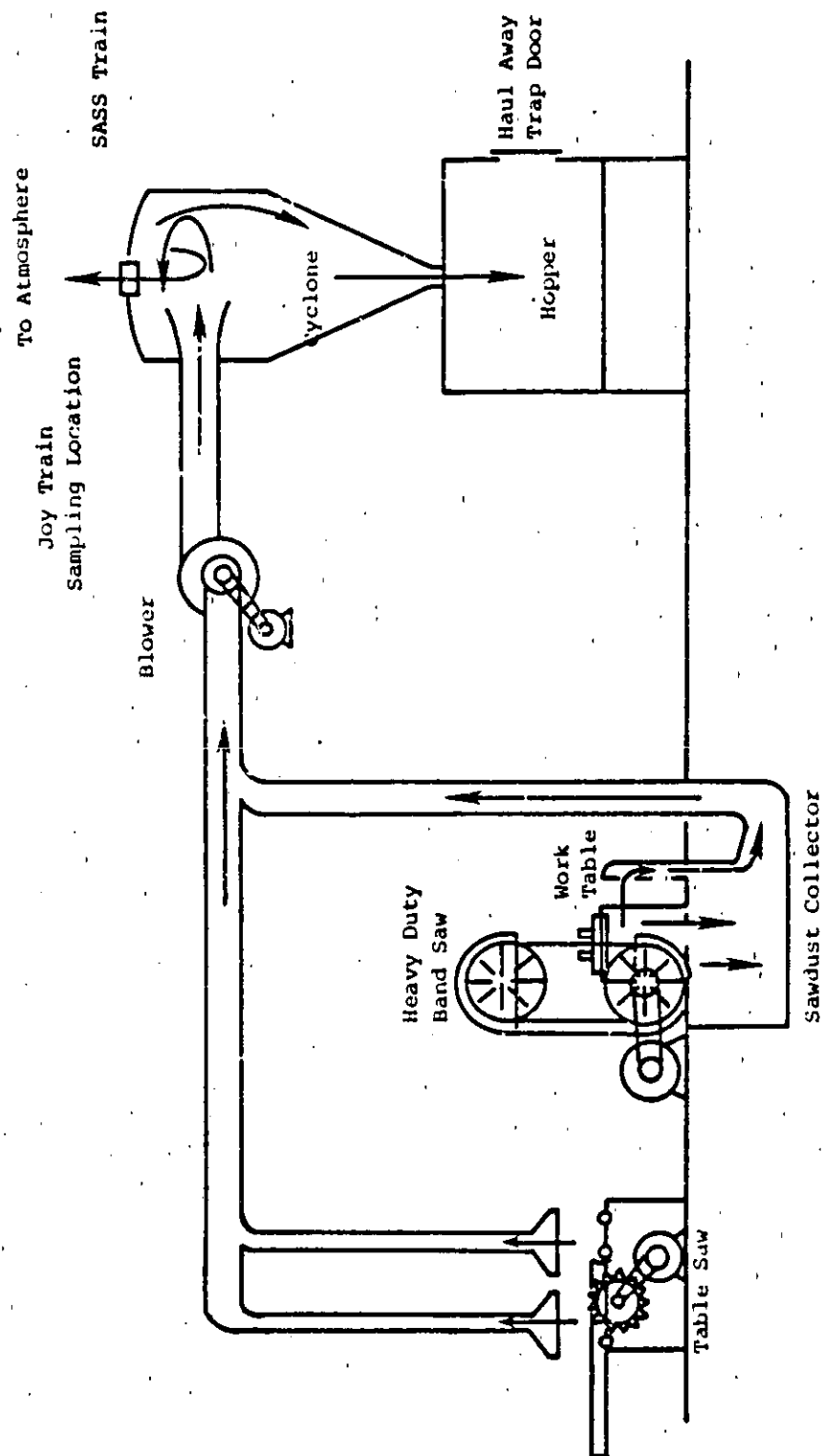


Figure 4-74. Wood resawing with particulate controls.

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

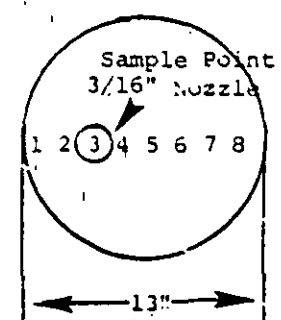
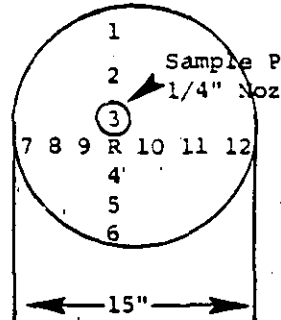
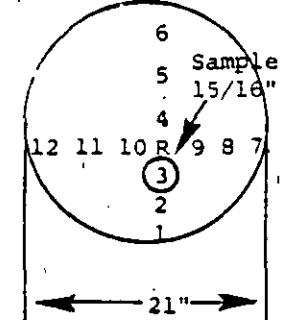
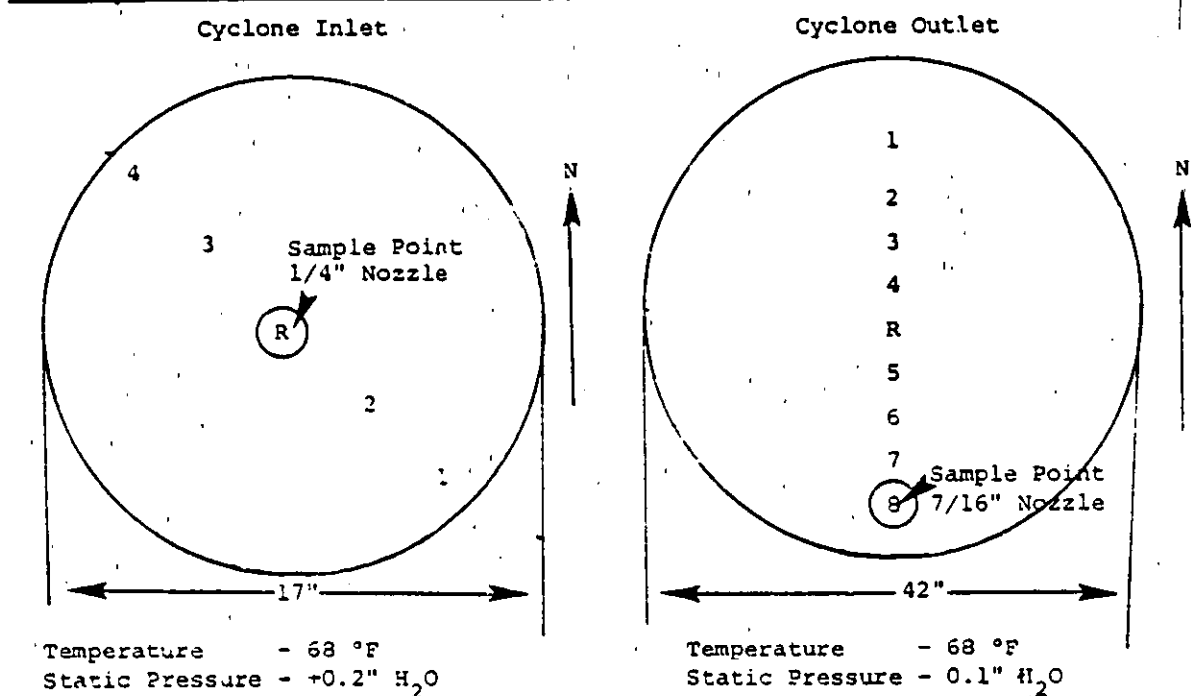
Cyclone Inlet			Cyclone Outlet Baghouse Inlet			Baghouse Outlet One of Two		
								
Temperature - 73 °F			Temperature - 78 °F			Temperature - 79 °F		
Static Pressure - +5.5" H ₂ O			Static Pressure - +2.1" H ₂ O			Static Pressure - Ambient		
Distance From Edge of Duct	Velocity Point No.	ft/ sec	Distance From Edge of Duct	Velocity Point No.	ft/ sec	Distance From Edge of Duct	Velocity Point No.	ft/ sec
0.4"	1	61.4	5/8"	1	38.0	0.1"	1	15
1.4"	2	63.2	2-1/4	2	30.1	3.0"	2	15
2.5"	3	70.2	4-3/8	3	31.6	6-1/8"	3	15
4.5"	4	76.3	7-1/2	R	33.6	10.5"	R	15
6.5"	R	79.2	10-1/2	4	52.5	14.88"	4	15
9.0"	5	73.3	12-3/4	5	51.7	18.0"	5	15
10.5"	6	67.0	14-3/8	6	45.6	20.0"	6	15
11.6"	7	63.5	5/8	7	27.7	0.9"	7	15
12.5"	8	56.8	2-1/4	8	36.8	3.0"	8	15
Average	70.0		4-3/8	9	36.8	6-1/8"	9	15
	4384 SCFM		7-1/2	R	33.6	10.5"	R	15
			10-1/2	10	23.3	14.88"	10	15
			12-3/4	11	24.2	18.0"	11	15
			14-3/8	12	32.9	20.0"	12	15
			Average	58.6		Average	15	
				4180 SCFM			4206 SCFM	

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



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

Distance From Edge of Duct	Point No.	Velocity ft/sec
1.4	1	53.7
4.4	2	47.1
8.0	3	13.3
13.5	4	0
21.0	R	-23.2
28.5	5	0
33.8	6	13.3
37.6	7	44.2
41.4	8	70.4
	Average	26.2
		6546 SCFM

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

D. Discussion of Results

1. Efficiency of particulate control equipment

a. Sanding operation

Using the solid weight data (does not include impinger catch) from both inlet and outlet of the cyclone and inlet and outlet to the baghouse, the efficiency was calculated to be 98.4% for the cyclone and 96.3% for the baghouse. Therefore, the overall efficiency of the system is 99.94%. Using the total catch including the impinger catch the efficiency is 98.2% for the cyclone, 96.9% for the baghouse and for overall efficiency of 99.3%.

b. Resaw operation

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

2. Particle size distribution

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

PERCENT OF PARTICLES

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

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

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

t detected in concentration of <1%

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

2. analyzed by wet chemistry--Section 3.2.2 A

3. analyzed by Oceanography carbon analyzer--Section 3.2.2 A

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

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

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

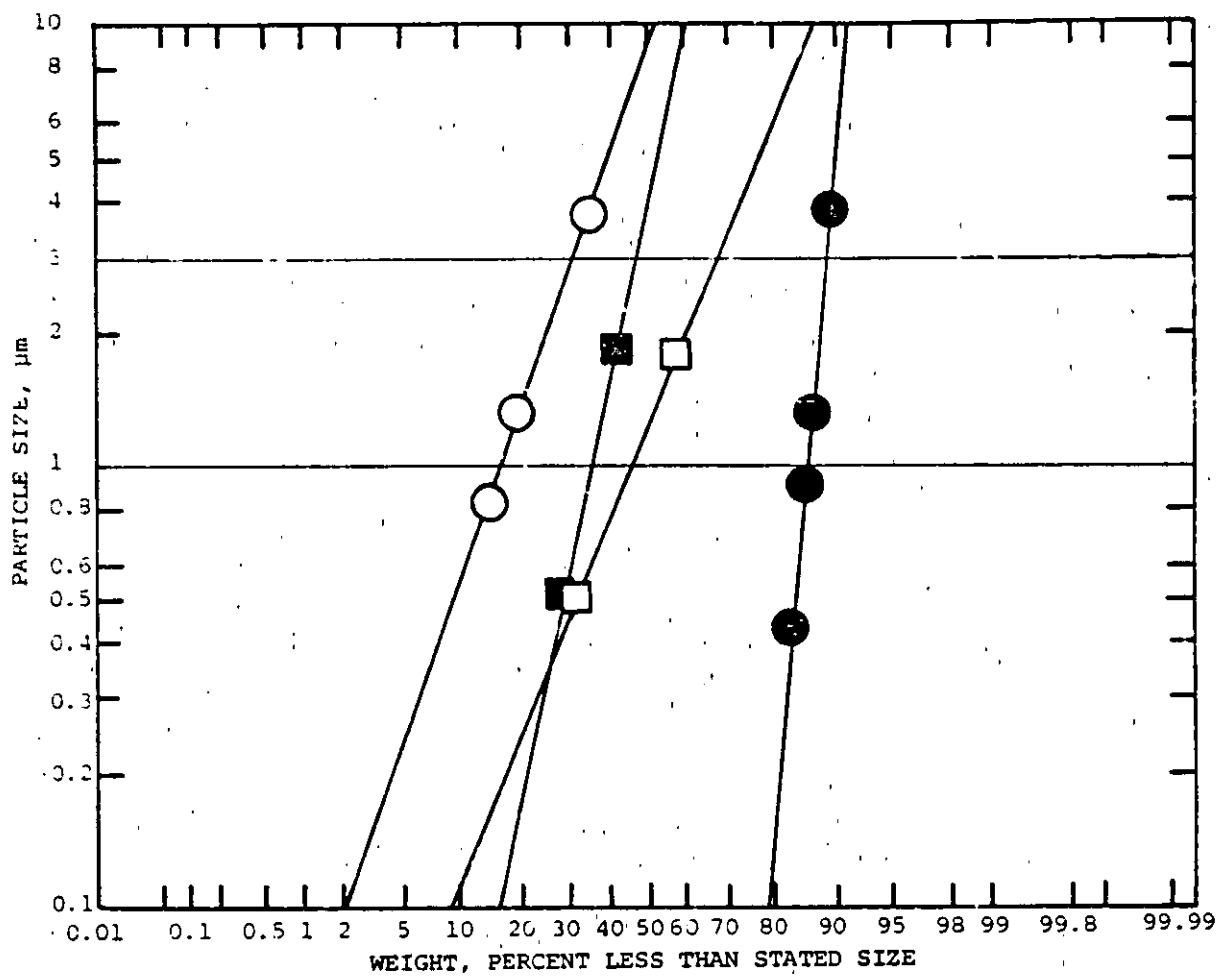
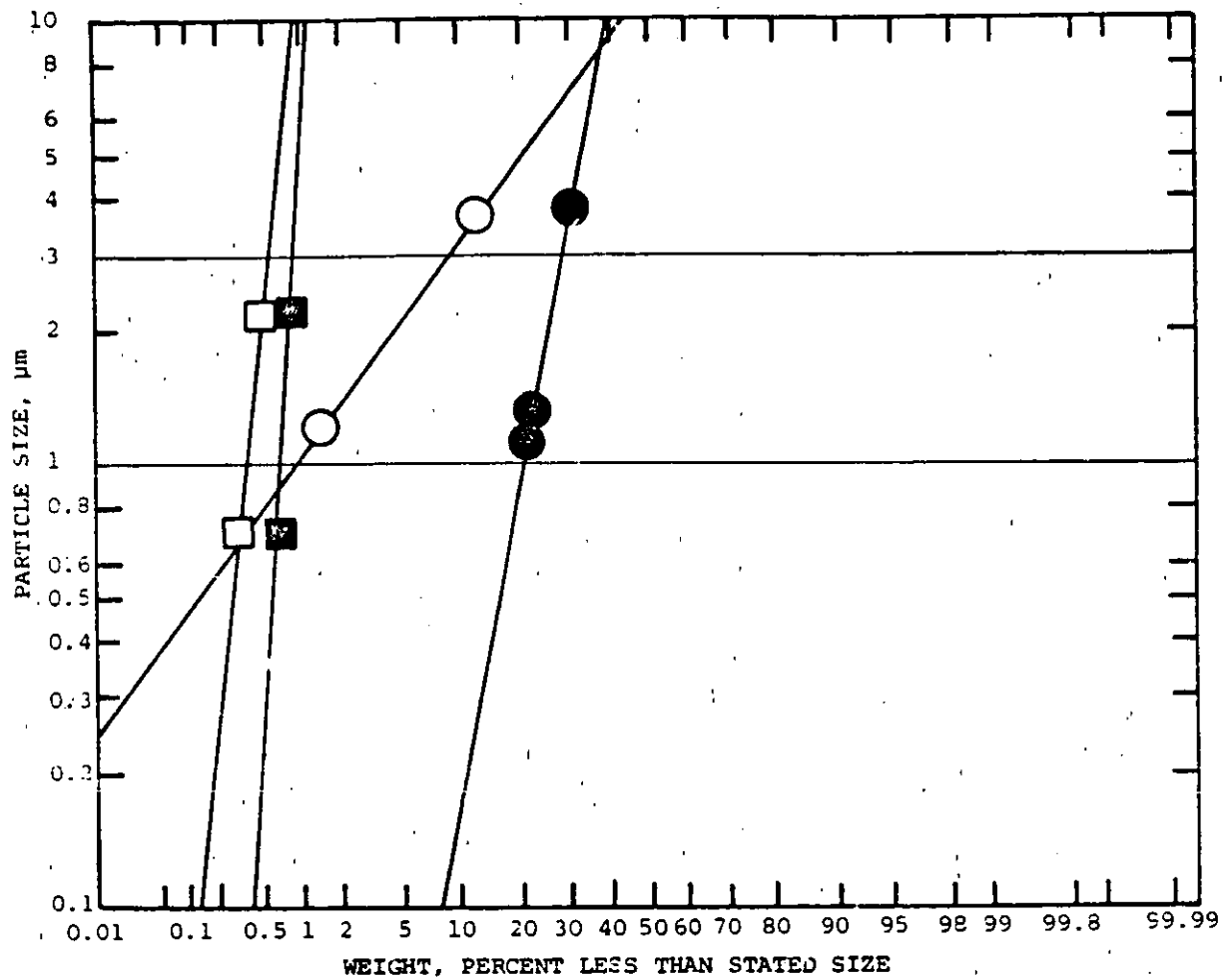


Figure 4-75. Particle size distribution for wood sanding operation (Test 30).



- Joy Mfg. Sampling Train With Impinger
- Joy Mfg. Sampling Train Without Impinger
- SASS Train With Impinger
- SASS Train Without Impinger

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

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

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

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

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

4.2.24 Refinery Process Heaters

A. Process Description (Ref. 4-43)

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

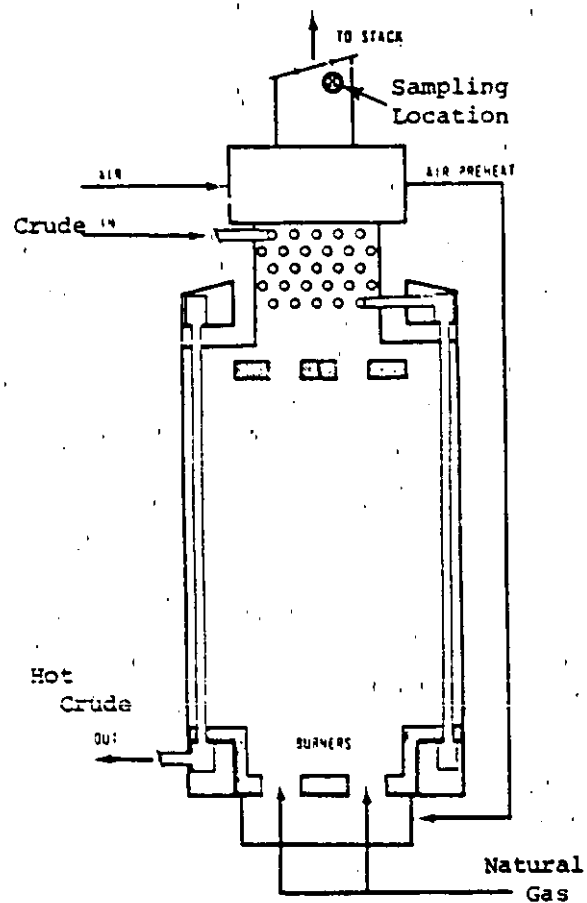


Figure 4-77. A vertical cylindrical refinery heater. (Ref. 4-43)

B. Particulate Test Setup--

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

C. Test Results--

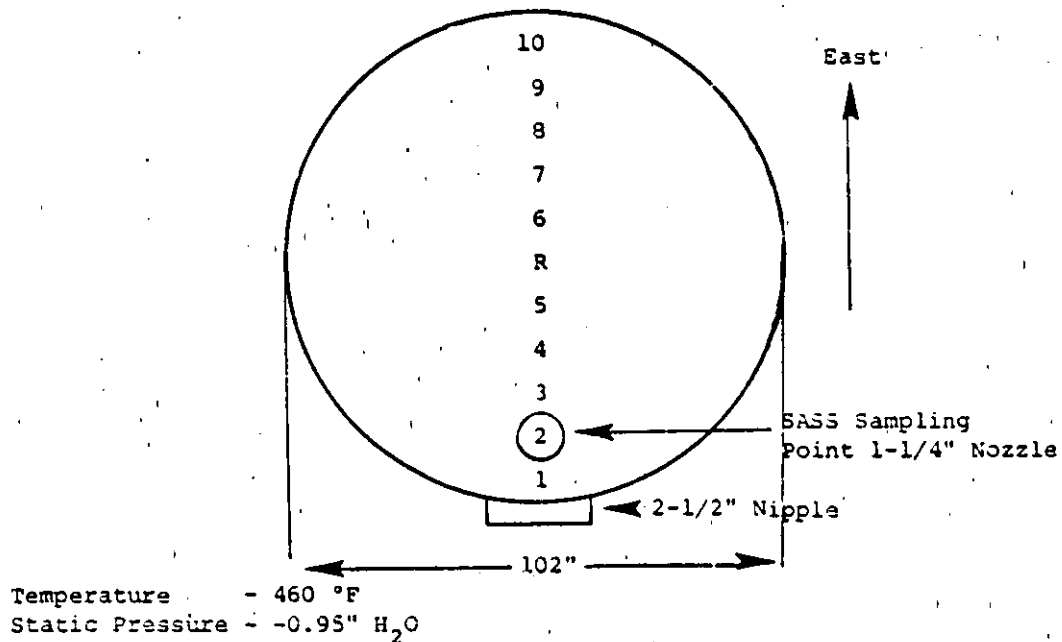
The results of the test (Test 405) discussed in this section are listed in Table 4-1. Elemental composition, sulfate, nitrate, and carbon analysis were determined for all fraction of particulate catches which contained weights in excess of 100 mg. The details for these procedures are discussed in Section 3.2.2. Table 4-82 lists the results from this analysis.

D. Discussion of Results--

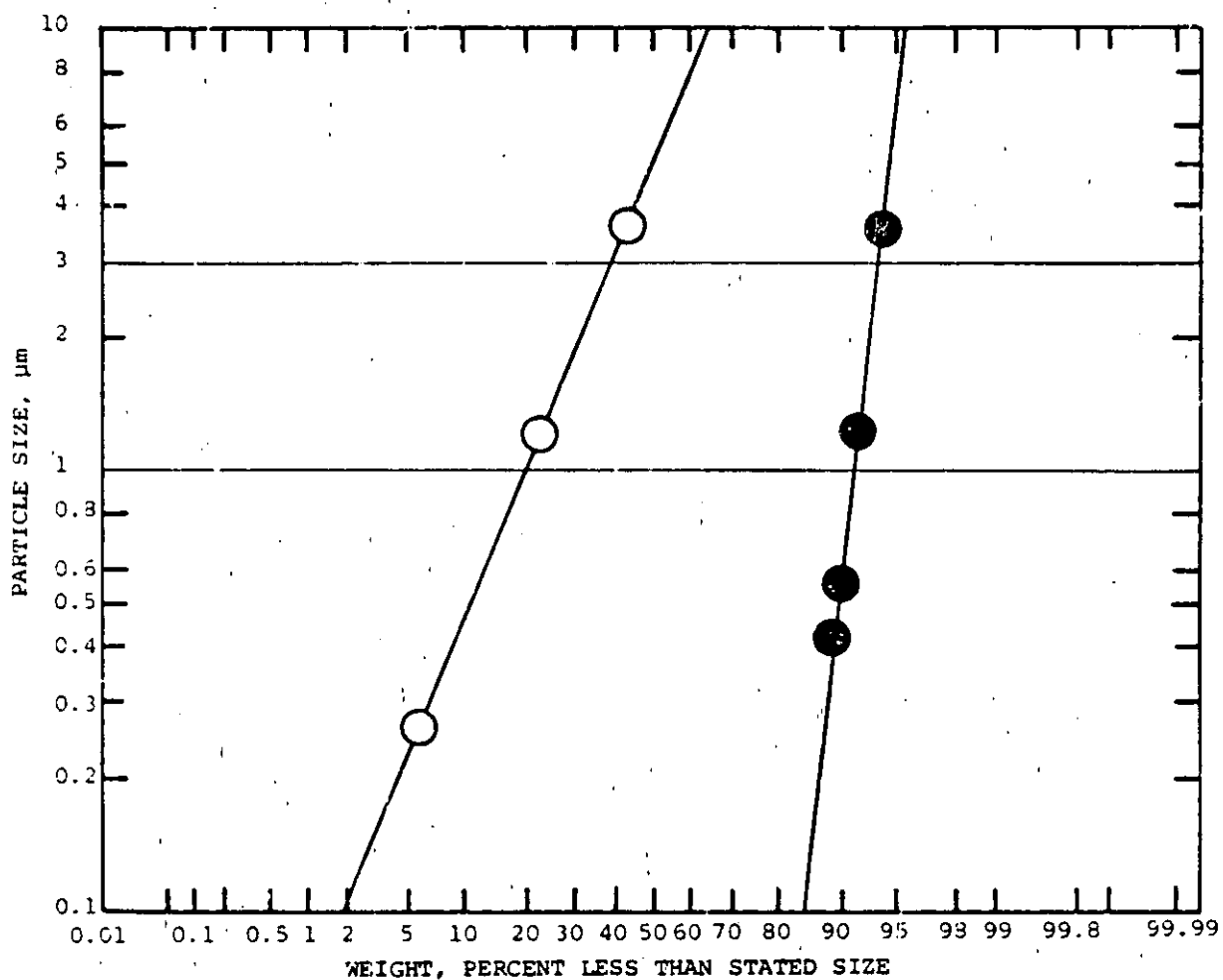
1. Particle size distribution-- Figure 4-78 is a plot of particle size (μm) versus accumulated weight percent, the latter plotted on a probability scale as explained in Section 3.2.3B. Two curves are presented, one including the impinger catch, and the other ignoring it. Considering the large amount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

PERCENT OF PARTICLES				
	>10 μm	10-3 μm	3-1 μm	<1 μm
Test 405	4.5	2	1.5	91

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



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



- Joy Mfg. Sampling Train With Impinger
- Joy Mfg. Sampling Train Without Impinger
- SASS Train With Impinger
- SASS Train Without Impinger

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

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

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

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

4.2.25 Catalytic Cracking

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

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

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

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

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

(Natural Gas Fuel)

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

t detected in concentration of <1%

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

2 analyzed by wet chemistry--Section 3.2.2 A

3 analyzed by Oceanography carbon analyzer--Section 3.2.2 A

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

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

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

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

B. Particulate Test Setup

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

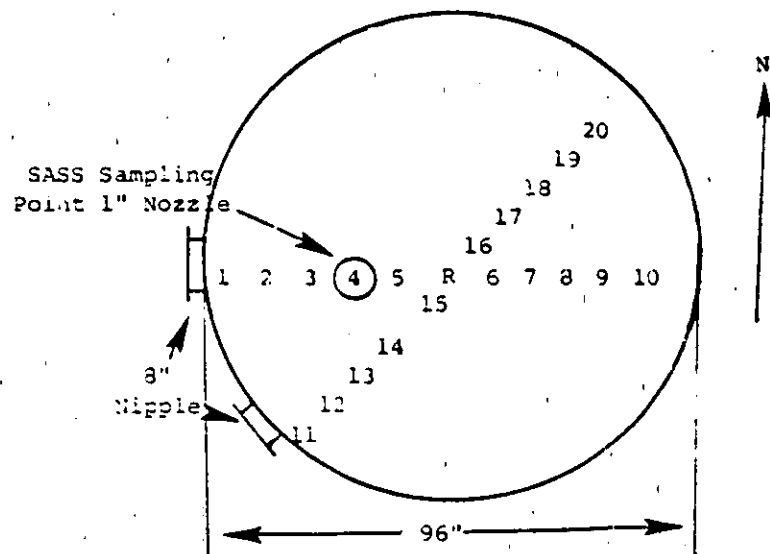
C. Test Results

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

D. Discussion of Results--

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

TABLE 4-83. VELOCITY PROFILE FOR CO BOILER EXHAUST (TEST 413)



Temperature - 565 °F
 Static Pressure - +0.5" H₂O

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

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

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

t detected in concentration of <1%

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

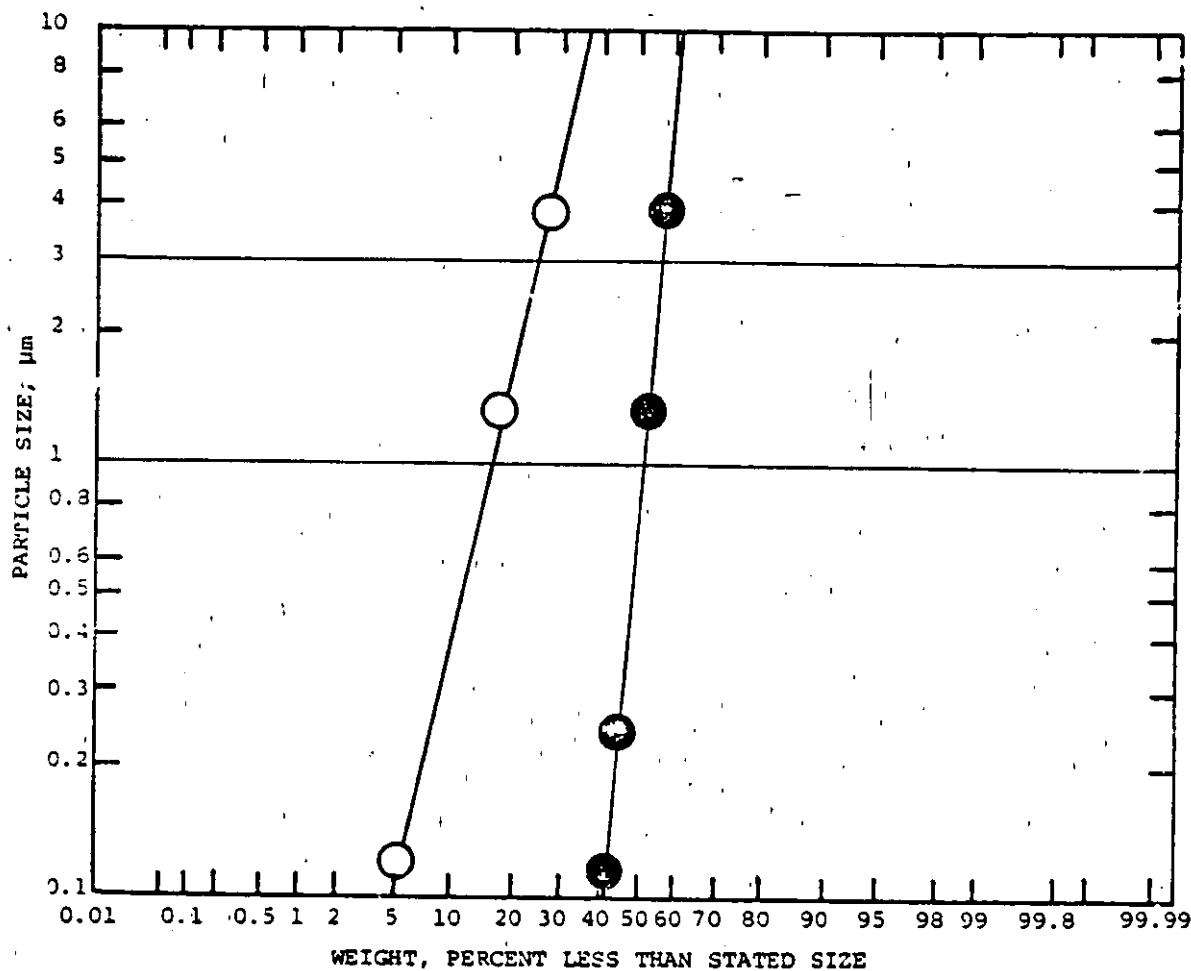
2 analyzed by wet chemistry--Section 3.2.2 A

3 analyzed by Oceanography carbon analyzer--Section 3.2.2 A

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

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

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



- SASS Train With Impinger
- SASS Train Without Impinger

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

PERCENT OF PARTICLES

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

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

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

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

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

4.2.26 Alfalfa Dehydration

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

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

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

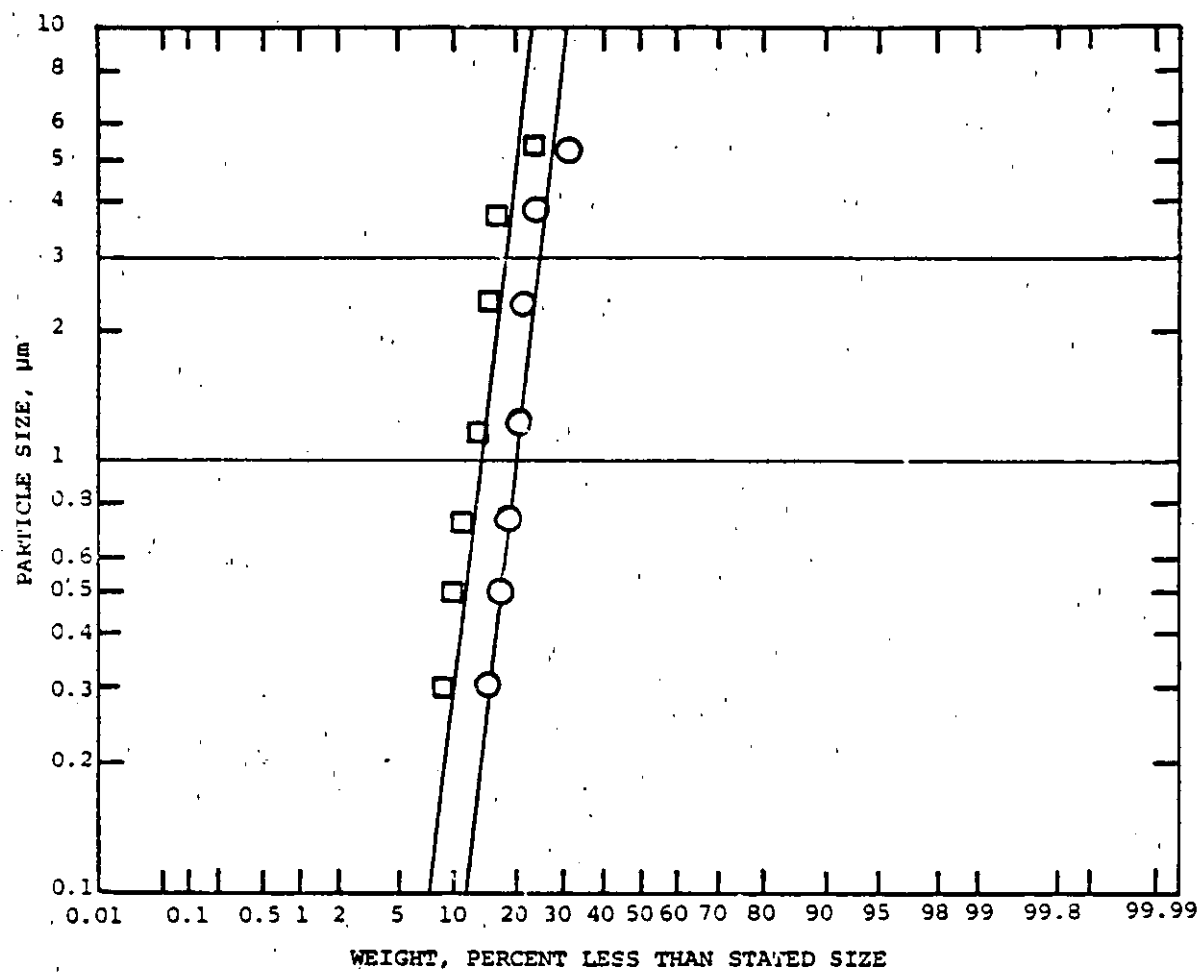
Alfalfa Dehydration	Percent of Particle			
	>10 μm	10-3 μm	3-1 μm	<1 μm
Test 1	68	6	6	20
Test 2	76	6	4	14

The mean particle size is about 60 μm .

TABLE 4-85. ALFALFA DEHYDRATION TEST RESULTS

Test No.	Measured Emissions		
	1	2	Average
Date of Test	11-18-76	11-18-76	
Duration of Test, minutes	60	60	60
Process Weight Rate, lbs/hr	20,000	20,000	20,000
Gas Flow Rate, SCFM (DRY)	9908	9616	9762
Stack Gas Temp., °F	195	183	184
CO ₂ % by vol.	1	1	1
O ₂ % by vol.	20	20	20
CO % by vol.	0	0	0
H ₂ O % by vol.	20	17	18.5
Particulate Concentration, gr/scf	0.11	0.11	0.11
Particulate Weight, lbs/hr	9.02	9.78	9.4

KVB 5806-783



- SASS Train Without Impinger - Test 1
 □ Joy Mfg. Sampling Train Without Impinger - Test 2

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

4.2.27 Cotton Ginning Operations

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

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

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

TABLE 4-86. COTTON GIN TEST RESULTS

Test	A Unclean Notes	B #1 and #2 Incliner Cleans	C Unloading and Dyer	D Unloading Separator	E Condensor & Basket Catch	F Note Cleaner	G #2 Lint Cleaner	H #1 Lint Cleaner	I #2 Lint Cleaner	J Batter Condensor
Flow Rate ACPH	630,000	850,000	721,000	350,500	345,000	143,500	823,660	1,060,000	780,000	1,494,860
Moisture %	0.035	03.3	0.8	0.19	0.35	0.93	0.28	2.0	1.24	1.63
Temperature °F	82	144	115	69	69	71	74	81	76	82
Emission GR/DSCT	0.043	0.0106	0.047	0.102	0.0097	0.087	0.031	0.088	0.041	0.023
Total lb/m	3.82	10.97	4.38	5.05	0.49	1.78	3.63	12.99	4.41	4.61
Front half lb/hr	3.78	10.72	4.34	4.99	0.36	1.71	3.35	11.86	4.41	3.64

KVB 5806-783

4.3 PARTICULATE CONTROL EQUIPMENT EFFICIENCIES

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

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

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

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

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

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

TABLE 4-87. CONTROL EQUIPMENT EFFICIENCY

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

TABLE 4-88. SIZE EFFICIENCY CALCULATION RESULTS

Test	Percent of Particles			gr/DSCP	Control Type	Industrial Type
	10- μ m	3- μ m	1-0.1 μ m			
39J in	0.5	0.3	0.3	0.266	Cyclone	Wood Resaw
39S out	10	9	11.5	0.00317		
Efficiency	82.7	74	66.8			
30J	4	12	20	0.0168	Baghouse	Wood Sanding
30S	3	3	7	0.0022		
Efficiency	90.2	96.7	95.4			
29J	18	18	26	11.483	Baghouse	Asphalt Batch Plant
29S	6	4	7	0.00776		
Efficiency	99.98	99.98	99.98			
34J	3.5	1.7	1.6	1.922	Baghouse	Steel Sand-blasting
34S	6	6	12	0.00088		
Efficiency	99.92	99.8	99.7			
26J	1	1	2	0.205	Baghouse	Sinter Plant
26S	1.2	1.4	3	0.0459		
Efficiency	73.1	68.6	66.4			
20J	0.4	0.5	1.9	0.0364	ESP	Glass Mfg.
20S	0.6	1	2	0.00617		
Efficiency	74.6	66.1	82.2			
19J	0.2	0.01	0.2	0.7154	Baghouse	Chemical Fertilizer
19S	1	1	2	0.0028		
Efficiency	98	60.8	96.1			
17J	1	0.01	1	0.6105	Baghouse	Boric Acid Mfg.
17S	0.5	0.5	1	0.0237		
Efficiency	98.1	94.1	96.12			
14J	7	10	30	0.0593	Baghouse	Steel Heat Treating
14S	8	14	41	0.00283		
Efficiency	94.55	93.3	93.5			
8J	0.85	0.3	0.14	1.169	Baghouse	Brick Mfg.
8S	4	4	8	0.00641		
Efficiency	97.4	92.7	68.7			
36J	3	4	11	0.206	ESP	Steel Open Hearth Furn.
36S	3.8	7	23	0.0366		
Efficiency	77.5	68.9	64.1			

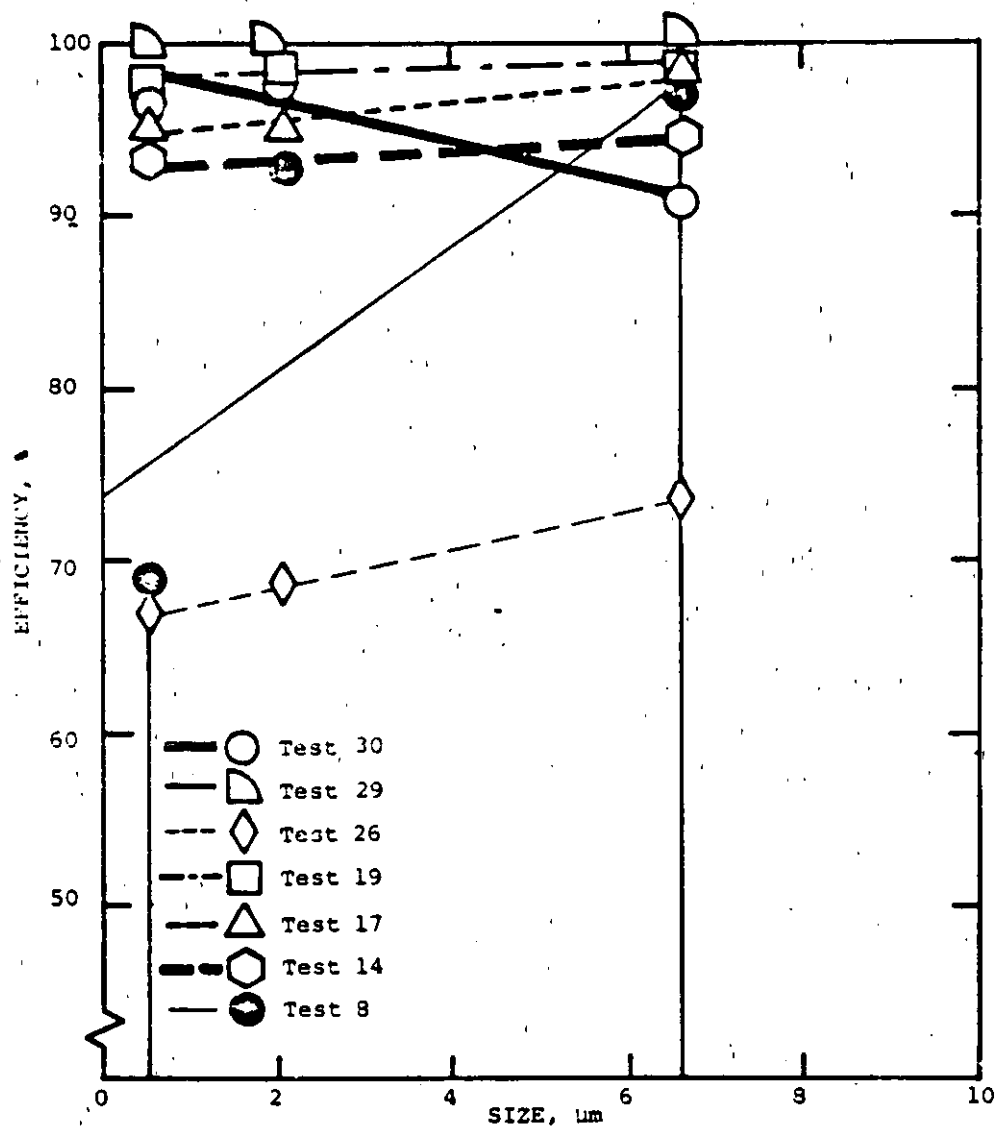


Figure 4-81. Baghouse size includes Impinger.

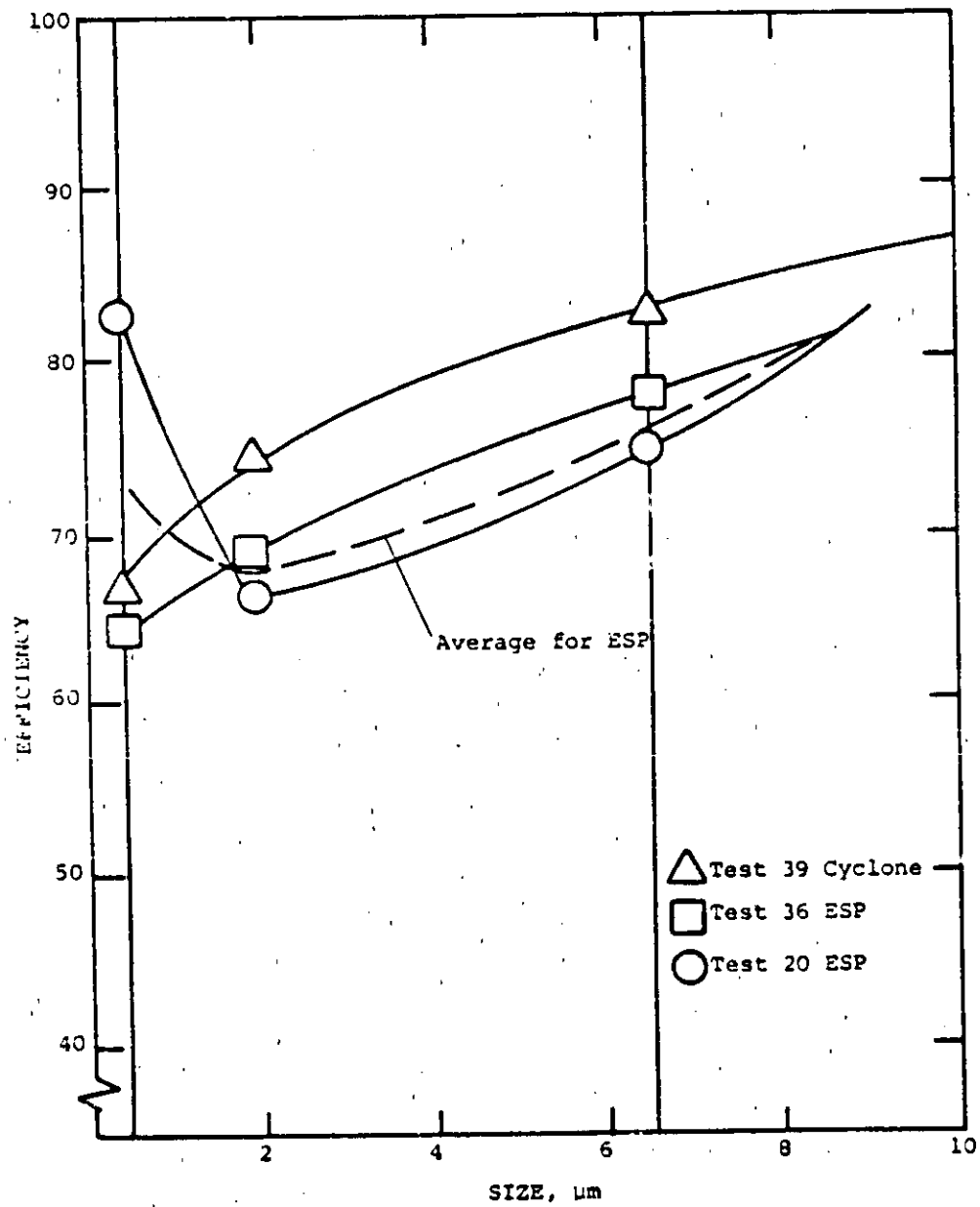


Figure 4-82. Cyclone and electrostatic precipitator efficiency curve.

SECTION 4.0

REFERENCES

- 4-1 Goldstein, H. L., and Cregmund, C. W., Environmental Science & Technology, Vol. 10, No. 12, November 1976.
- 4-2 "Inertial Cascade Impactor Substrate Media for Flue Gas Sampling," EPA (600/7-77-060).
- 4-3 Air Pollution Engineering Manual, Second Edition, EPA, AP-40, 1973, p. 533.
- 4-4 Particulate Test Results by Frederiksen Engineering Co., Long Beach, CA.
- 4-5 Compilation of Air Pollutant Emission Factors, Second Edition, AP-42, EPA, Section 3-1.
- 4-6 Federal Register (Method 5).
- 4-7 Compilation of Air Pollutant Emission Factors, Second Edition, AP-42, EPA, Section 1.3-1.
- 4-8 SCAQMD, Combustion Emission Factors for EIS/EDP, Tech. Memo, 11/9/76.
- 4-9 Compilation of Air Pollutant Emission Factors, Second Edition, AP-42, EPA, Section 3.3.
- 4-10 Kreichelt, T. E. et al., Atmospheric Emissions from the Manufacture of Portland Cement, U.S. DHEW, Public Health Service, Cincinnati, Ohio, PHS Publication Number 999-AP-17, 1967.
- 4-11 Unpublished standards of performance for new and substantially modified portland cement plants, Environmental Protection Agency, Bureau of Stationary Source Pollution Control, Research Triangle Park, NC, August 1971.
- 4-12 "A Study of the Cement Industry in the State of Missouri," Resources Research Inc., Reston, VA, prepared for the Air Conservation Commission of the State of Missouri, December 1967.

- 4-13 Sittig, M., Particulates and Fine Dust Removal, Noyes Data Corp., 1977, p. 56.
- 4-14 Compilation of Air Pollutant Emission Factors, 2nd Edition, EPA AP42, Section 8.6.
- 4-15 Shreve, R. N., The Chemical Process Industries, McGraw-Hill Book Co., 1945, p. 172.
- 4-16 Compilation of Air Pollutant Emission Factors, 2nd Edition, EPA AP42, Section 8.3.
- 4-17 Air Pollution Engineering Manual, 2nd Edition, EPA AP40, p. 775.
- 4-18 Compilation of Air Pollutant Emission Factors, 2nd Edition, EPA AP42, Section 8.11.
- 4-19 Ibid, Section 8.2.
- 4-20 "Asphaltic Concrete Plants Atmospheric Emissions Study," Valentine, Fisher, and Tomlinson, Consulting Engineers, Seattle Washington, prepared for Environmental Protection Agency, Research Triangle Park, NC, under Contract Number 68-02-0076, November 1971.
- 4-21 Guide for Air Pollution Control of Hot Mix Asphalt Plants, National Asphalt Pavement Association, Riverdale, MD, Information Series 17.
- 4-22 Compilation of Air Pollutant Emission Factors, 2nd Edition, EPA AP42, Section 8.10.
- 4-23 Beir, J. M. and Thring, M. W., Measurements in Flames, Vol. 1, Edward Arnold Ltd., London, 1972.
- 4-24 Personal communication with J. Ozanna, Oct. 4, 1977.
- 4-25 Compilation of Air Pollutant Emission Factors, 2nd Edition, EPA AP42, Section 6.2.
- 4-26 Air Pollution Engineering Manual, 2nd Edition, EPA AP40, 1973, p. 320.
- 4-27 Ibid, p. 397.
- 4-28 Hammond, W. F. and Simon, H., "Secondary Aluminum-Melting Processes," in Air Pollution Engineering Manual, Danielson, J. A., ed., U.S. DHEW, PHS, National Center for Air Pollution Control, Cincinnati, Ohio, Publication Number 999-AP-40, 1967, p. 284-290.

- 4-29 Compilation of Air Pollutant Emission Factors, 2nd Edition, EPA AP42, Section 7.1.
- 4-30 Ibid, Section 7.5.2.
- 4031 Considine, D. M., Chemical and Process Technology Encyclopedia, McGraw-Hill Book Co., 1974, p. 641.
- 4-32 Shannon, L. J., et al., "Particulate Pollutant Systems Study II," Fine Particle Emissions, Report PB-203,521, Kansas City, MO, Midwest Research Institute, August 1, 1971.
- 4-33 Sittig, M., Particulates and Fine Dust Removal Processes and Equipment, Noyes Data Corporation, 1977, p. 289.
- 4-34 Compilation of Air Pollutant Emission Factors, 2nd Edition, EPA AP42, Section 7.5.3.
- 4-35 Bramer, Henry C., "Pollution Control in the Steel Industry," Environmental Science and Technology, p. 1004-1008, October 1971.
- 4-36 Celenza, C. J., "Air Pollution Problems Faced by the Iron and Steel Industry," Plant Engineering, April 30, 1970, p. 60-63.
- 4-37 Compilation of Air Pollutant Emission Factors, 2nd Edition, EPA AP42, Section 7.5.5.
- 4-38 Personal correspondence with J. C. Paulsen, June 9, 1978.
- 4-39 Shannon, L. J., et al., "Particulate Pollutant Systems Study II, Fine Particle Emissions," Report PB 203,521, Kansas City, MO, Midwest Research Institute, August 1, 1971.
- 4-40 Sittig, M., Particulate and Fine Dust Removal, Noyes Data Corp., 1977, p. 160.
- 4-41 Compilation of Air Pollutant Emission Factors, 2nd Edition, EPA AP42, Section 6.10.
- 4-42 Ibid, Section 10.3.
- 4-43 Air Pollution Engineering Manual, 2nd Edition, EPA AP40, p. 559.
- 4-44 Compilation of Air Pollutant Emission Factors, 2nd Edition, EPA AP42, Section 9.1.2.
- 4-45 Ibid, Section 9.1.3.

- 4-46 Duprey, R. L. Compilation of Air Pollutant Emission Factors, U.S. DHEW, PHS, National Center for Air Pollution Control, Durham, NC, PHS Publication Number 999-AP-42, 1978, p. 19.
- 4-47 Stern, A., ed., Air Pollution Volume III, "Sources of Air Pollution and their Control," 2nd Ed., New York, Academic Press, 1968.
- 4-48 "Process Flow Sheets and Air Pollution Controls," American Conference of Governmental Industrial Hygienists, Committee on Air Pollution, Cincinnati, OH, 1961.
- 4-49 Billings, C. E., et al, Handbook of Fabric Filter Technology, Vol. 1, Fabric Filter Systems Study, National Technical Information Service, Springfield, VA, PB-200-648, December 1970.
- 4-50 U. S. Department of Health, Education and Welfare, Control Techniques for Particulate Air Pollutants, National Air Pollution Control Administration Publication No. AP-51, 1970.
- 4-51 Danielson, J. A., Air Pollution Engineering Manual, U.S. DHEW Public Health Service, Washington, DC, Government Printing Office, Publication Number 999-AP-40.
- 4-52 Sommerland, R. E., "Baghouse Filters as Applied to Power Plant Effluents," Heat and Fluid Dynamics Department, John Blizard Research Laboratory, Foster Wheeler Corporation, Carteret, NJ, May 1966.
- 4-53 Stairmand, C. J., "The Design and Performance of Cyclone Separators," Trans. Inst. Chem. Engrs., Vol. 29, British, 1951.
- 4-54 Caplan, K. J., "All About Cyclone Collectors," Air Engineering, September 1964, pp. 28-38.
- 4-55 Gallae, C. A. and Schindeler, J. W., "Mechanical Dust Collectors," J.A.P.C.A., Vol. 13, December 1963, pp. 574-580.
- 4-56 Kane, J. M., "Operation, Application, and Effectiveness of Dust Collection Equipment," Heating and Ventilating, August 1952.
- 4-57 Lapple, C. E., "Processes use many Collection Types," Chemical Engineering, Vol. 58, pp. 145-151, May 1951.
- 4-58 Air Pollution Engineering Manual, EPA 999-AP-40, 1967, pp. 91-99.
- 4-59 "The Electrostatic Precipitator Manual," the McIlvaine Company, Northbrook, IL, 1977.

SECTION 5.0

PARTICULATE EMISSION CONTROL TECHNOLOGY

INTRODUCTION

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

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

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

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

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

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

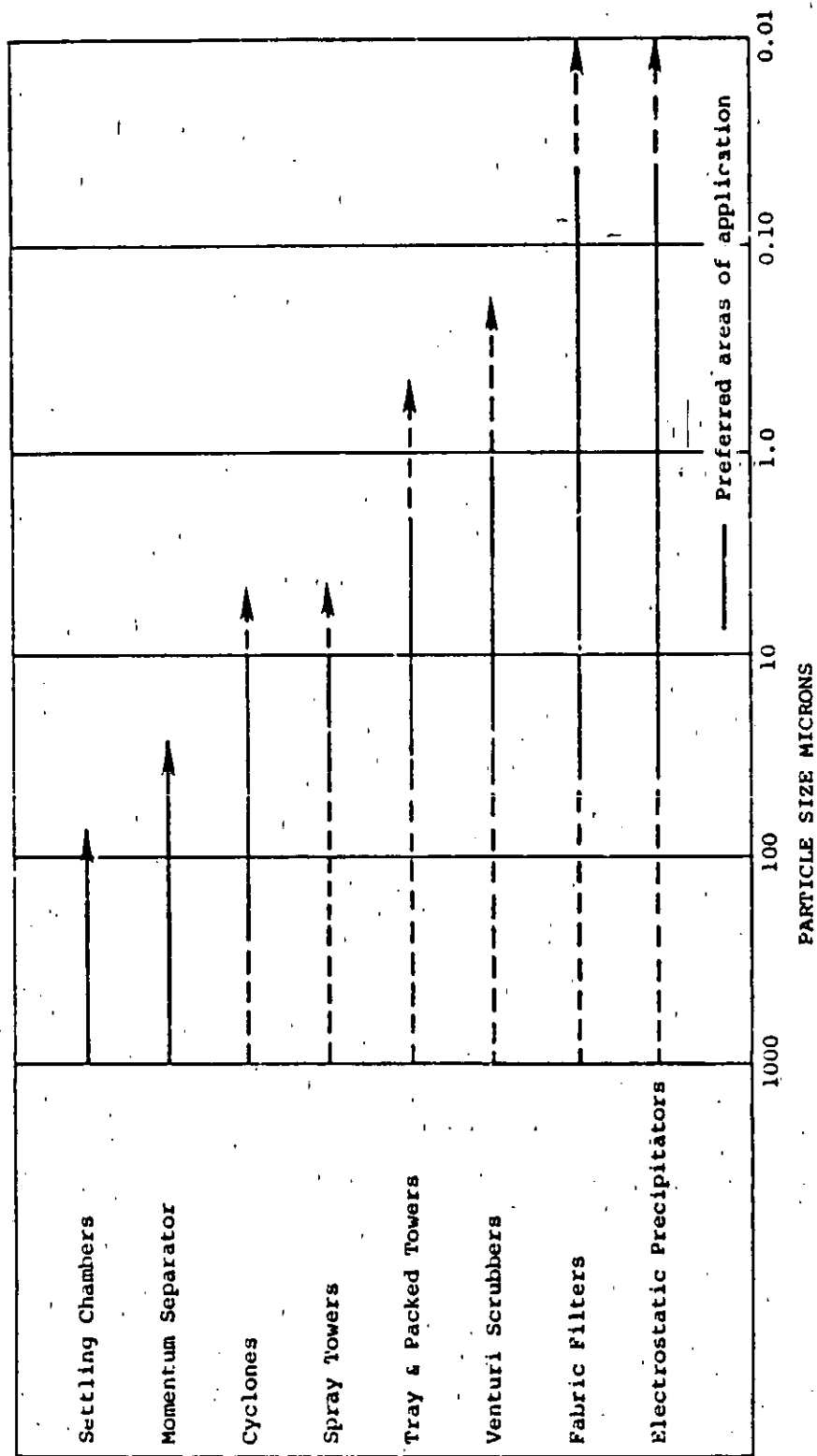


Figure 5-1. Areas of application for particulate control devices (Ref. 5-2).

TABLE 5-1. APPLICATION TABLE

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

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

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

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

5.1 METHODS OF CONTROL

5.1.1 Settling Chambers and Momentum Separators

A. Settling Chambers--

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

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

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

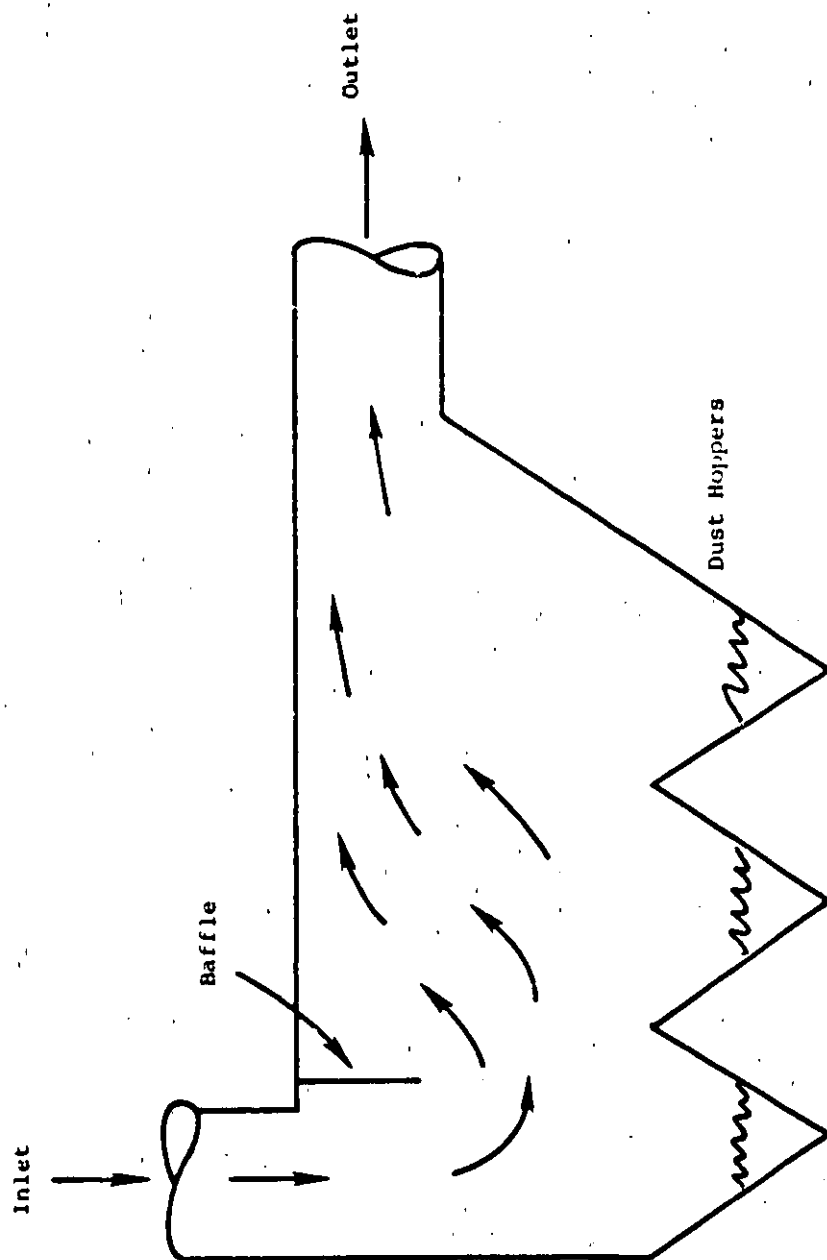


Figure 5-2. Settling chamber. (Ref. 5-1)

KVB 5806-738

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

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

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

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

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

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

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

B. Momentum Separators

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

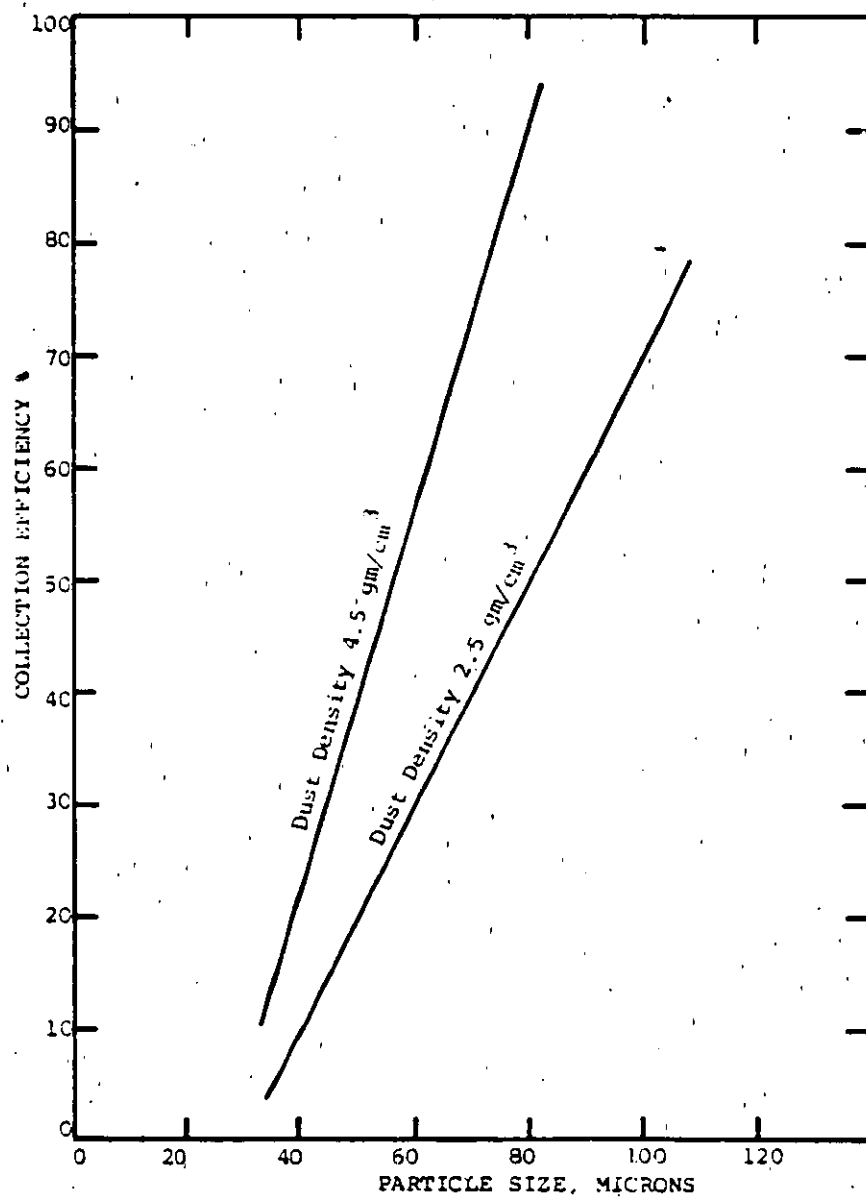


Figure 5-3. Typical settling chamber collection efficiency. (Ref. 5-1)

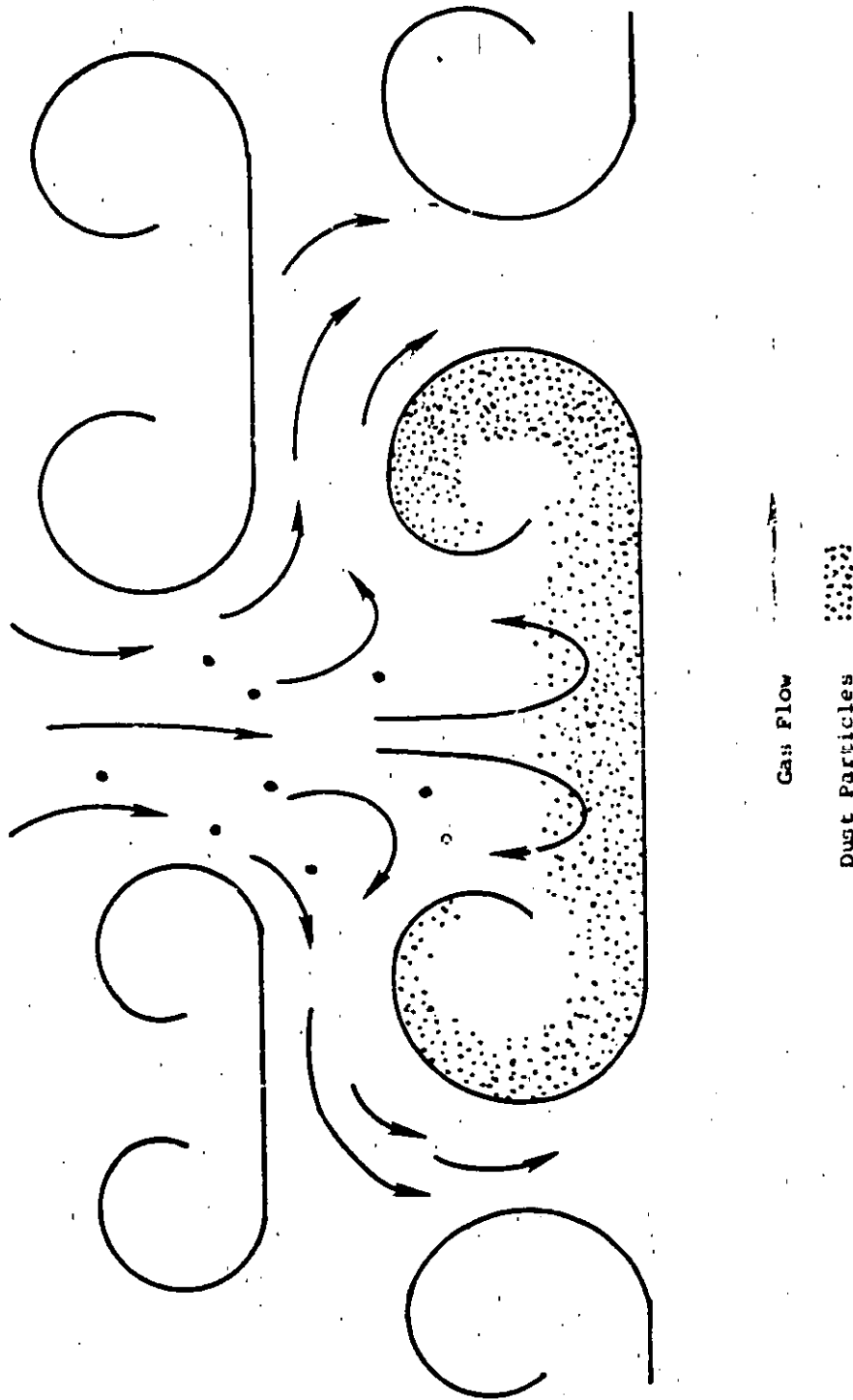


Figure 5-4. Momentum separator (Ref. 5-1).

KVB 5806-783

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

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

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

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

5.1.2 Cyclones

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

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

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

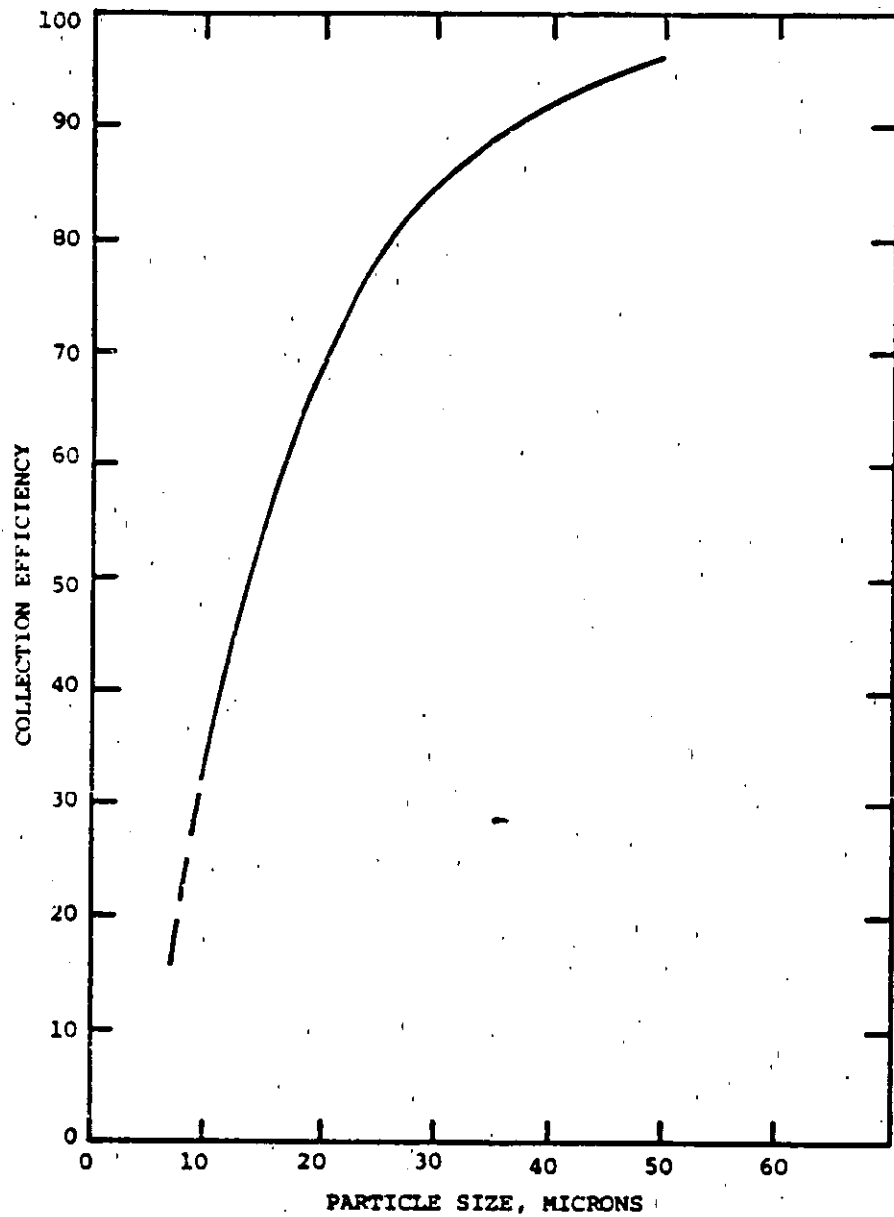


Figure 5-5. Typical momentum separator collection efficiency.
(Ref. 5-1)

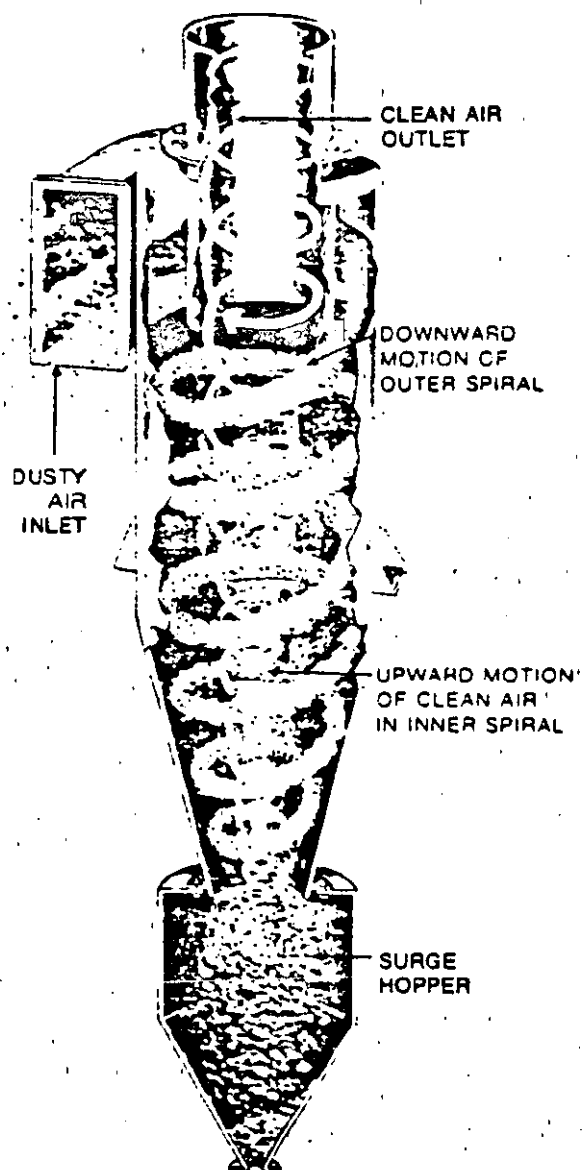


Figure 5-6. Reverse flow cyclone (Research-Cottrell).

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

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

$$F \propto \frac{v^2}{D} \quad (1)$$

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

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

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

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

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

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

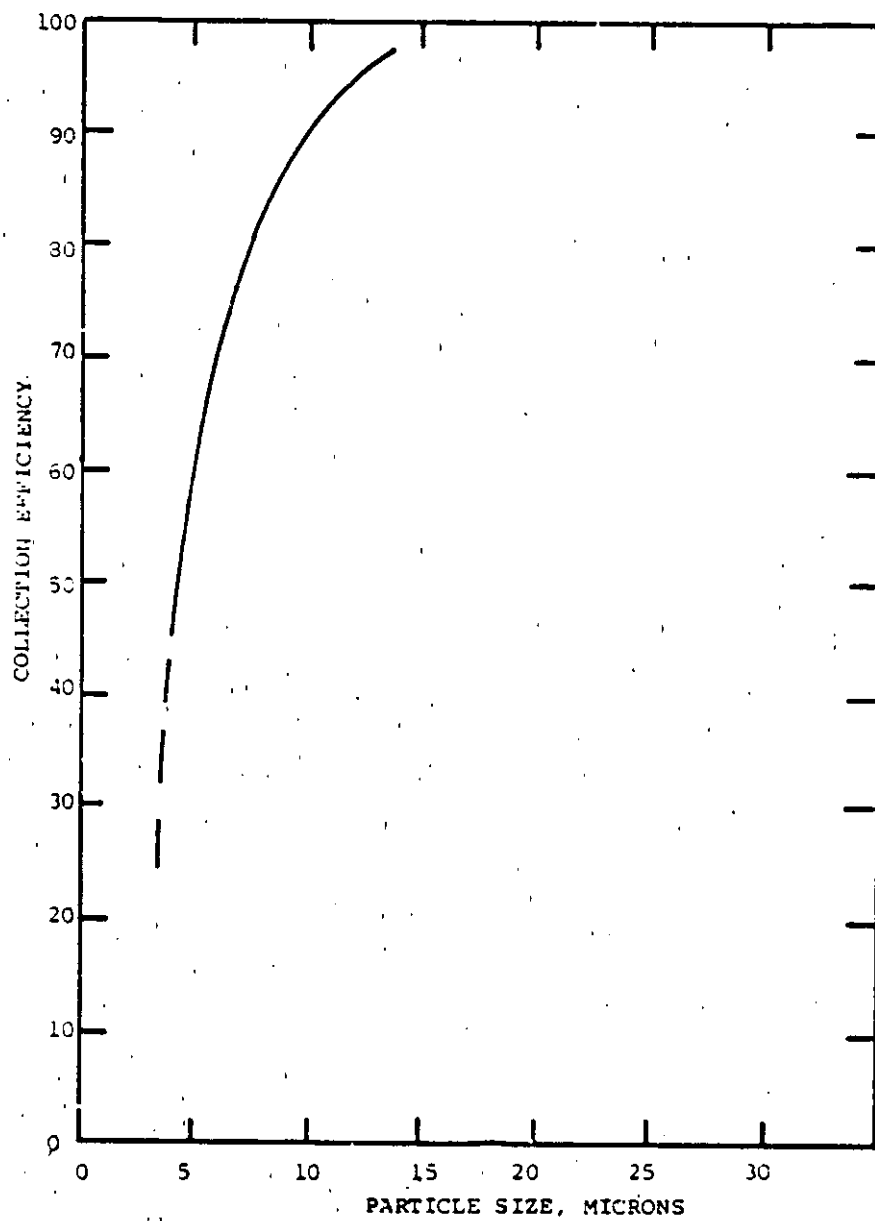


Figure 5-7. Typical multi-cyclone collection efficiency. (Ref. 5-1)

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

5.1.3 Wet Scrubbers

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

A. Spray Towers--

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

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

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

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

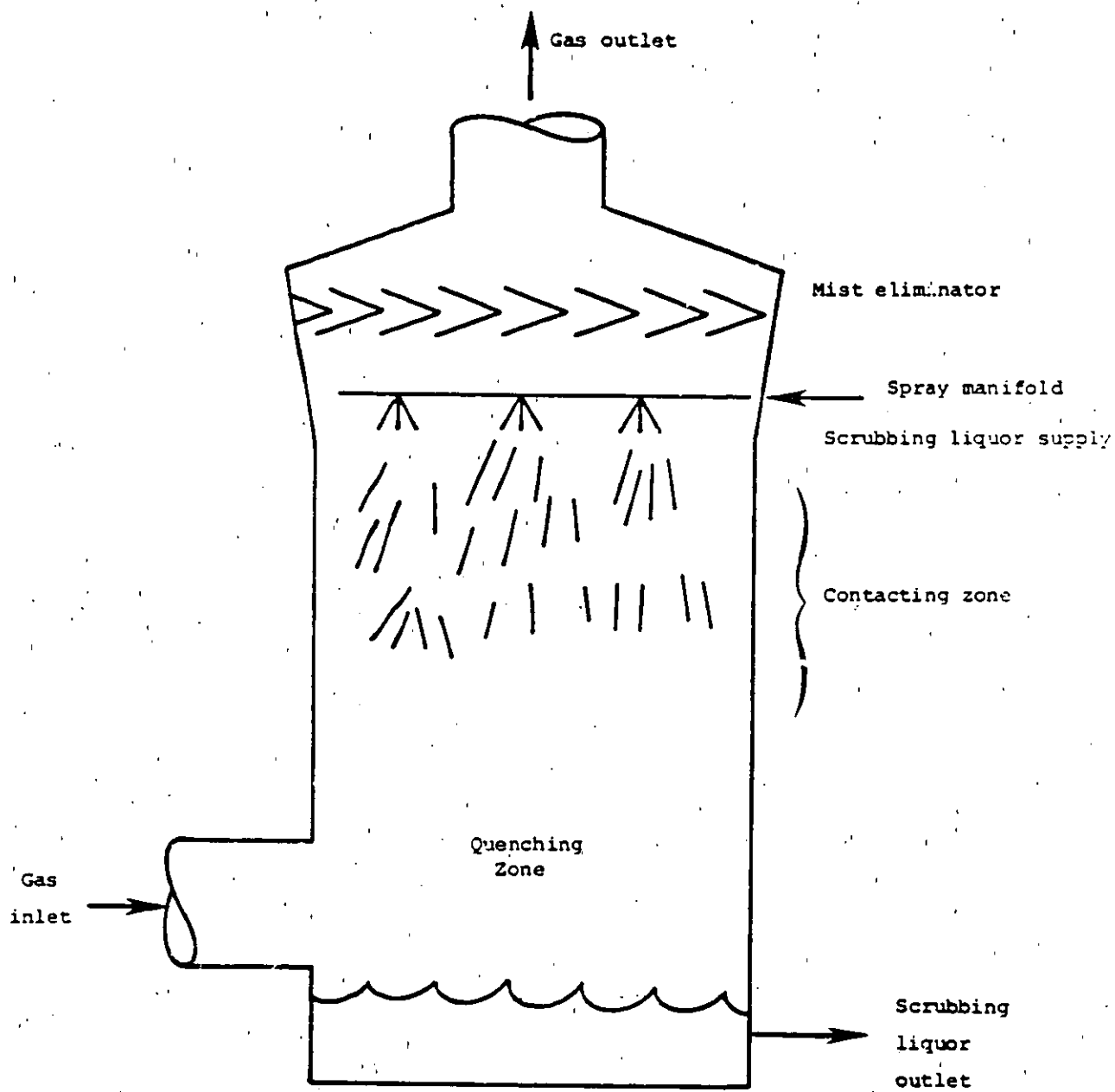


Figure 5-8. Typical spray tower.

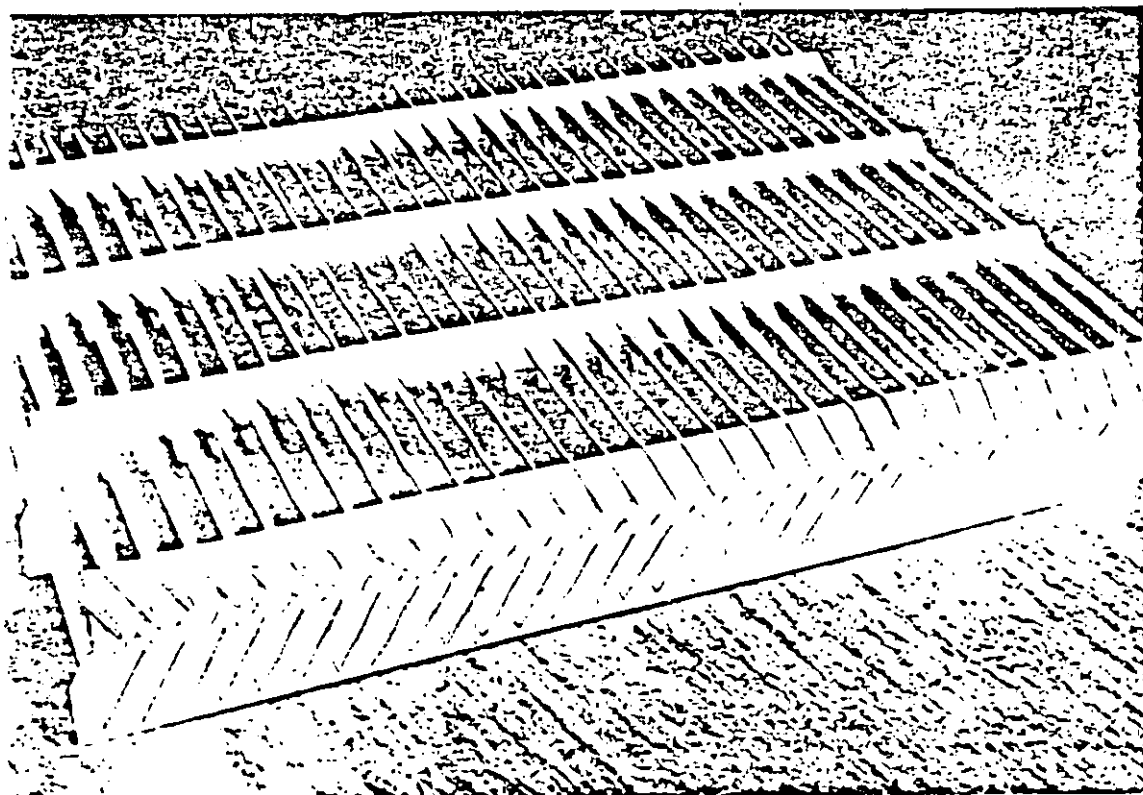
The use of spray nozzles with appropriate manifolds is the most common method of creating droplets of scrubbing liquor in spray towers. The selection of spray nozzles is critical to successful operation. The scrubbing liquor must be uniformly distributed throughout the scrubber and the droplets which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

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

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

2. Investigations of particulate collection in spray towers has shown that there is an optimum droplet size for collecting particles from gas streams via inertial impaction and interception. These investigations have also shown that this droplet size is essentially independent of the size of the dust particles to be collected. For droplets composed mainly of water in gases similar to air the optimum droplet is approximately 300 microns in diameter.

An 300 micron water droplet has a terminal velocity in the air of approximately 10 ft/sec. However, spray nozzles designed to produce a mean droplet size of 800 microns produce substantial numbers of smaller droplets, therefore a maximum velocity of 4 to 5 ft/sec is usually selected. The use of larger droplets permits higher gas velocities, but the loss in collection efficiency, at least above 10 microns, can be offset by increasing scrubber liquor flow rates.



Gas Flow

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

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

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

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

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

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

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

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

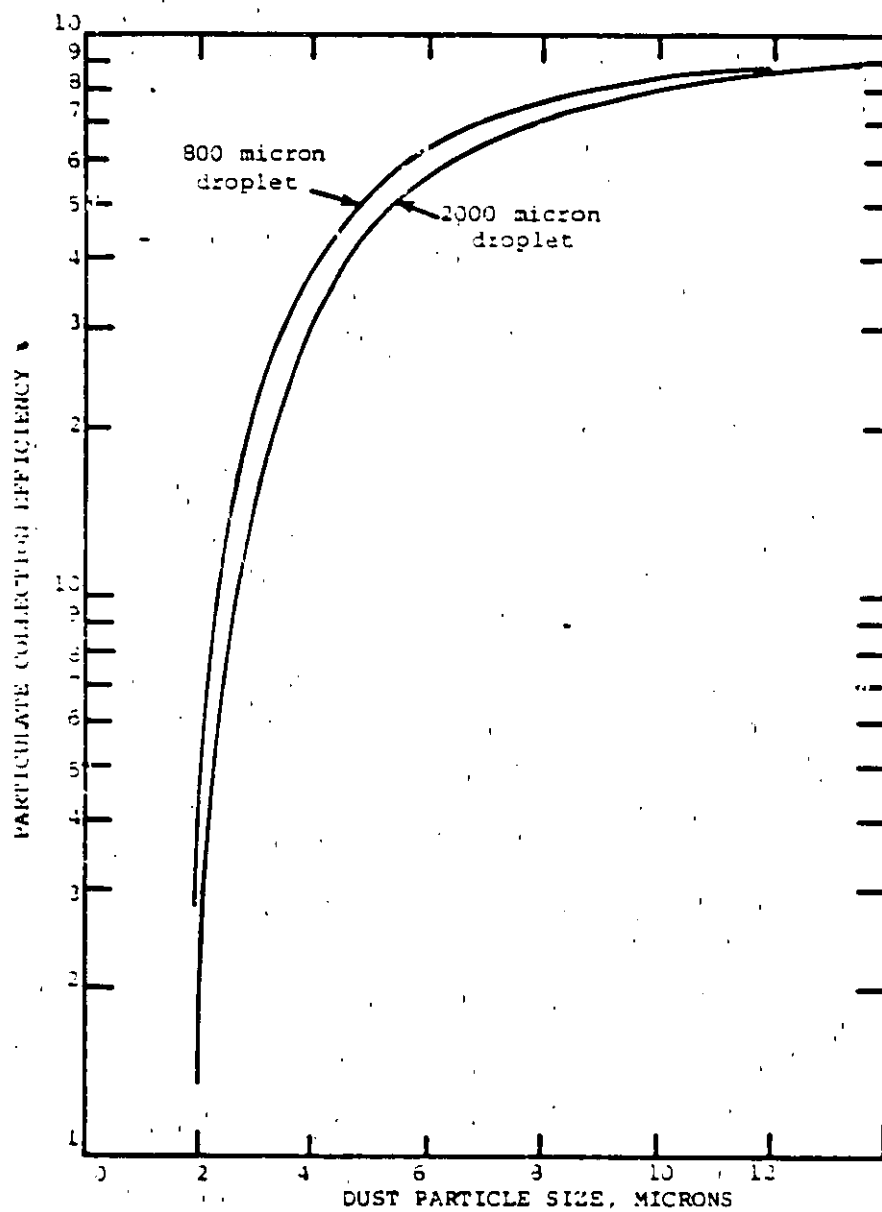


Figure 5-10. Theoretical collection efficiency for various sized droplets in a spray tower. (Ref. 5-1)

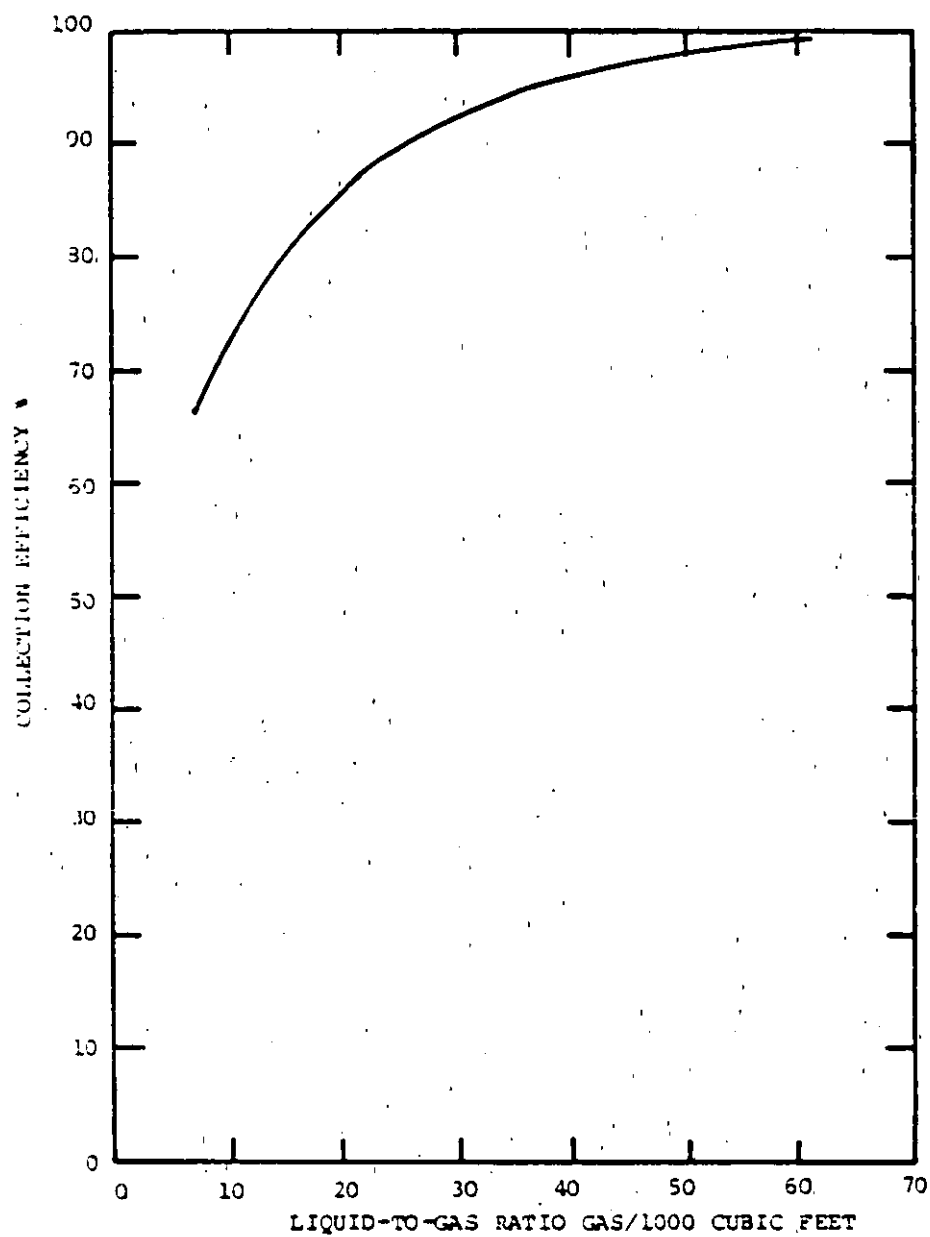


Figure 5-11. The effect of liquid-to-gas ratio on particulate collection in a spray tower. (Ref. 5-1)

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

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

B. Tray and Packed Towers--

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

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

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

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

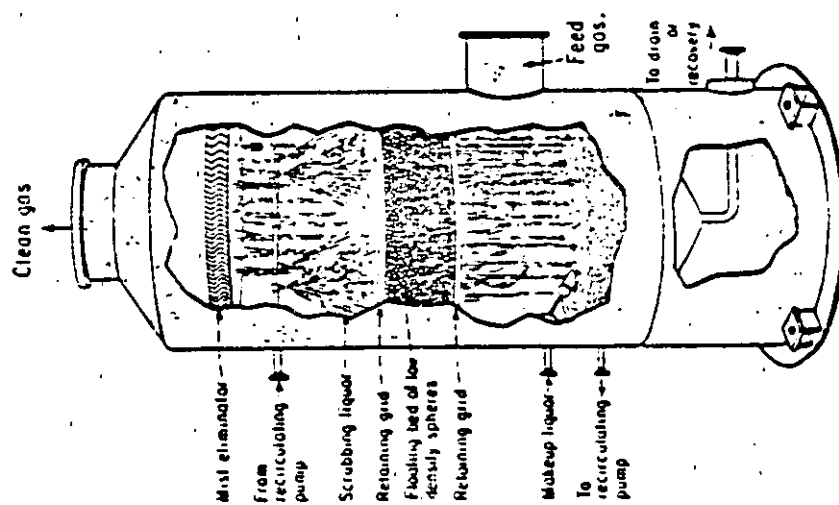


Figure 5-12. Floating-bed scrubber (Ref. 5-1).

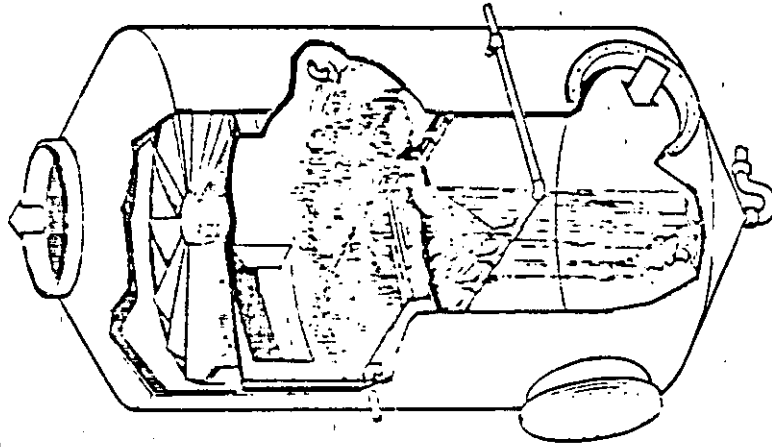


Figure 5-13. Impingement plate scrubber (Impinjet) (Ref. 5-1).

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

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

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

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

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

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

C. Venturi Scrubbers--

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

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

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

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

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

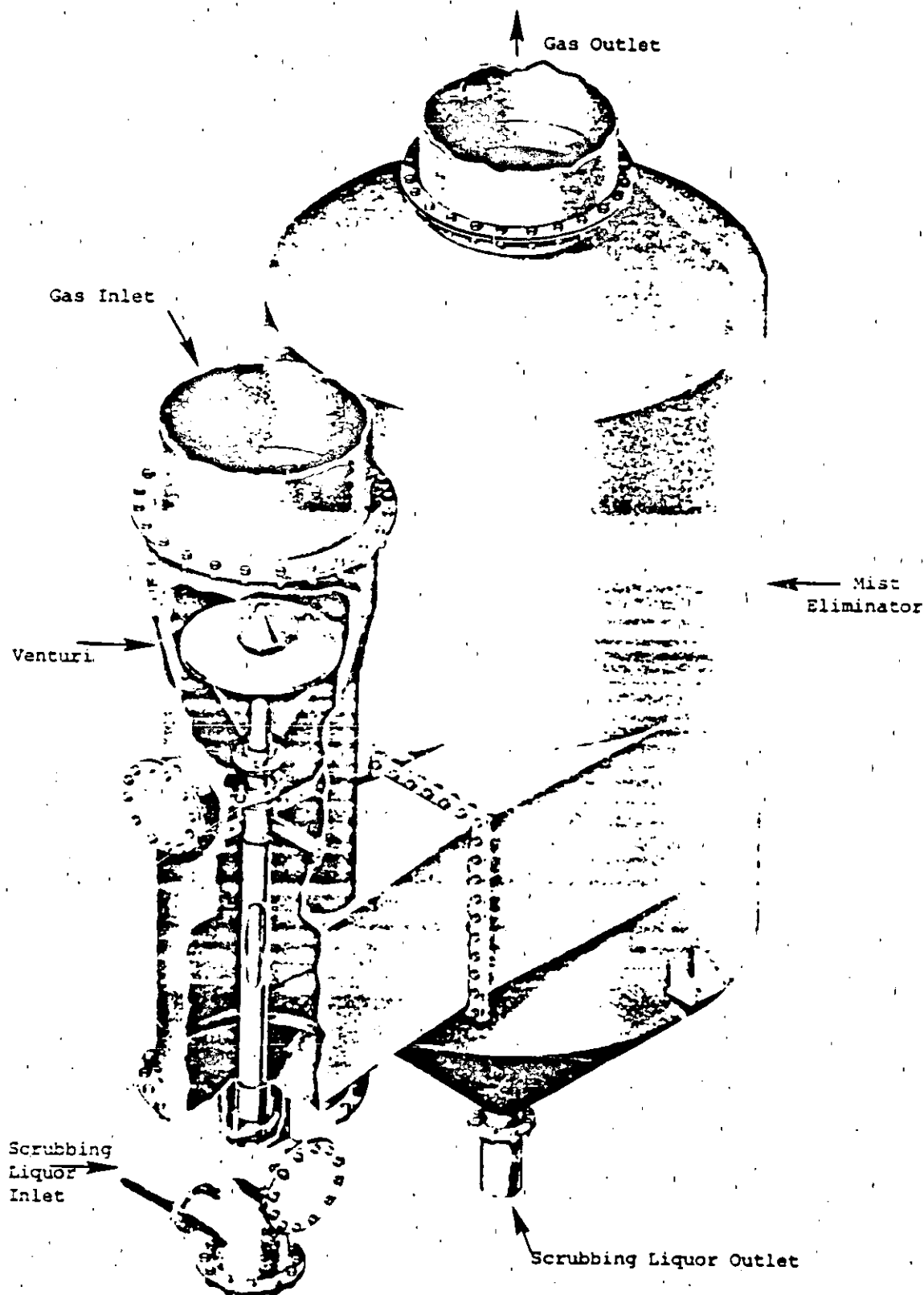


Figure 5-14. Venturi scrubber and mist eliminator (Research-Cottrell).

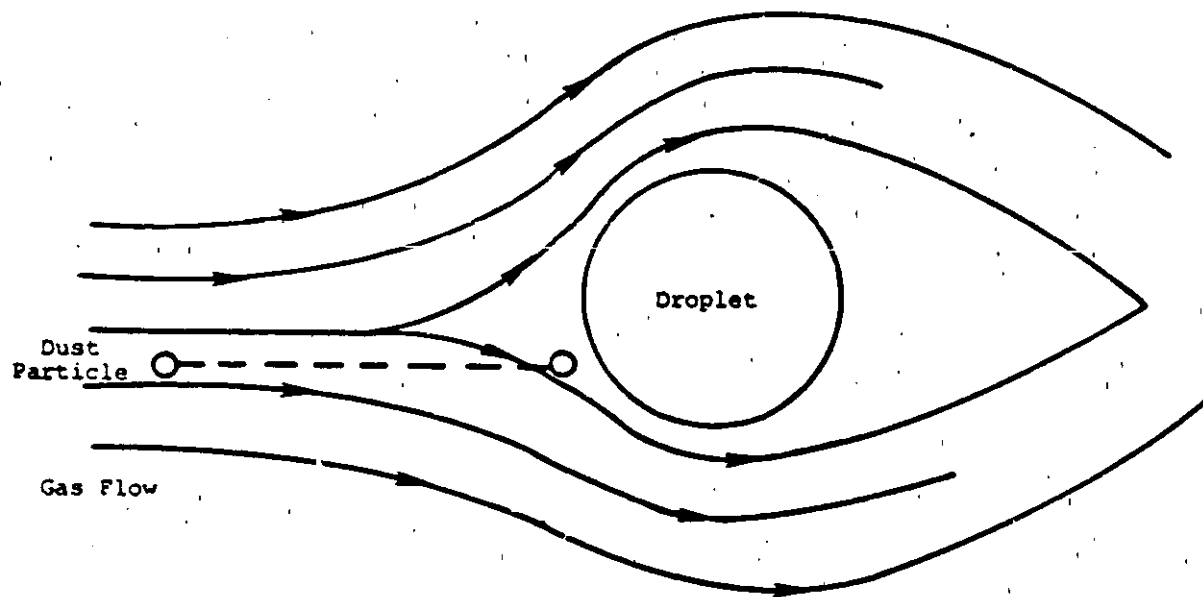


Figure 5-15. Path of dust particles (Ref. 5-1).

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

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

where K is a system related parameter

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

$$\Psi = \frac{C d_p d_p^2 v^2}{18\mu D_L} \quad (3)$$

where C is the Cunningham correction factor

D_p is the particle density

d_p is the particle diameter

v is the throat velocity

μ is the gas viscosity

D_L is the scrubbing liquor droplet diameter

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

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

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

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

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

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

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

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

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

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

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

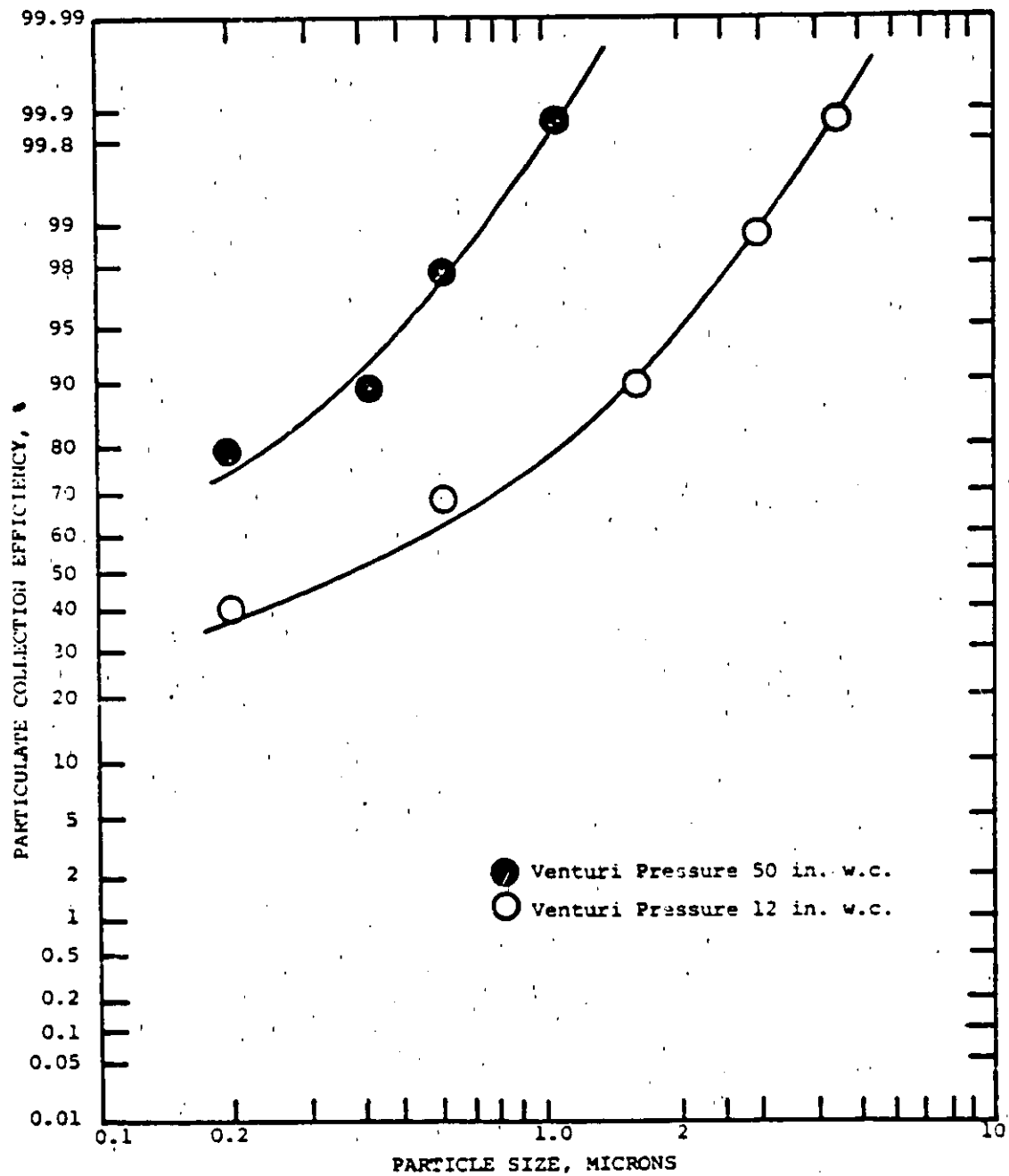


Figure 5-16. Typical venturi scrubber particulate collection efficiency (Research-Cottrell).

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

5.1.4 Fabric Filters

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

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

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

There are two modes of collection possible in a fabric filter, i.e., collection on the inside or outside of the bag. When collection occurs inside the bag, a woven fabric is normally used at relatively low gas rates, i.e., 1.5 to 3.5 ft³/min ft². Woven fabrics are available in a wide range of materials and operation at temperatures up to 500 °F are possible.

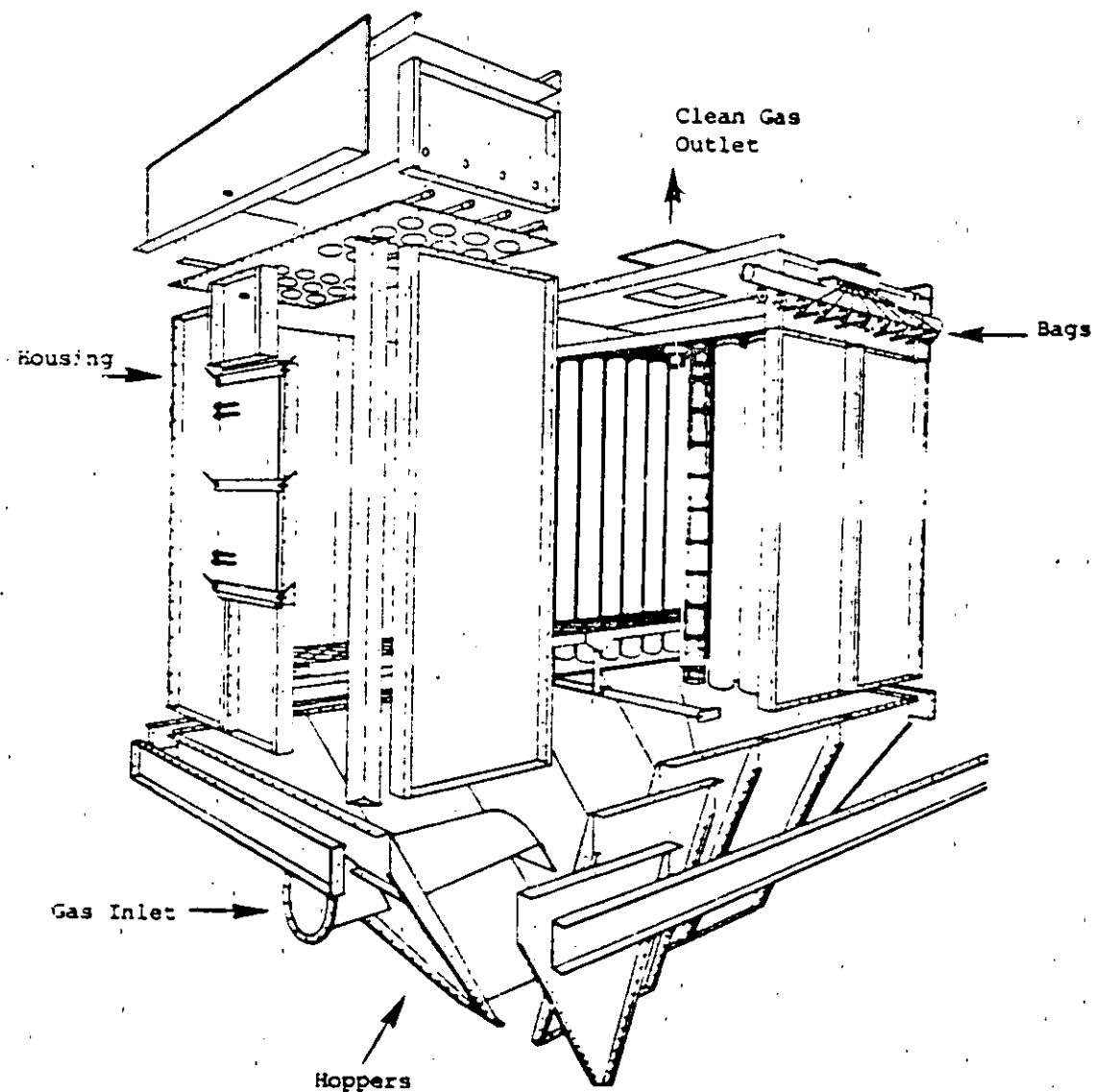


Figure 5-17. Typical pulse jet fabric filter (Research-Cottrell).

Felt fabrics are generally used when collection occurs on the outside of the bag. Since the pressure outside the bag is greater than that inside in this mode of operation, a support is necessary to prevent the bag from collapsing. Gas rates between 5 and 15 cfm/ft² are normal for outside collection applications.

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

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

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

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

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

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

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

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

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

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

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

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

TABLE 5-2. FABRIC CHARACTERISTICS

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

(Ref. 5-3)

KVB 5806-783

Pressure drop in a fabric filter is caused by the combined resistances of the fabric and the accumulated dust layer. The resistance of the fabric alone is affected by the type of cloth and the weave; it varies directly with the air flow. The permeability of various fabrics to clean air is usually specified by the manufacturer as the air flow rate (cfm) through 1 ft² of fabric when the pressure differential is 0.5 in. H₂O in accordance with the American Society for Testing and Materials (ASTM). At normal filtering velocities the resistance of the clean fabric is usually less than 10 percent of the total resistance. The spaces between the fibers are usually larger than the particles that are collected. Thus the efficiency and the pressure drop of a new filter are initially low. After a coating of particles is formed on the surface, the collection efficiency improves and the pressure drop also increases. Even after the first cleaning and subsequent cleaning cycles, collection efficiency remains high because the accumulated dust is not entirely removed.

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

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

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

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

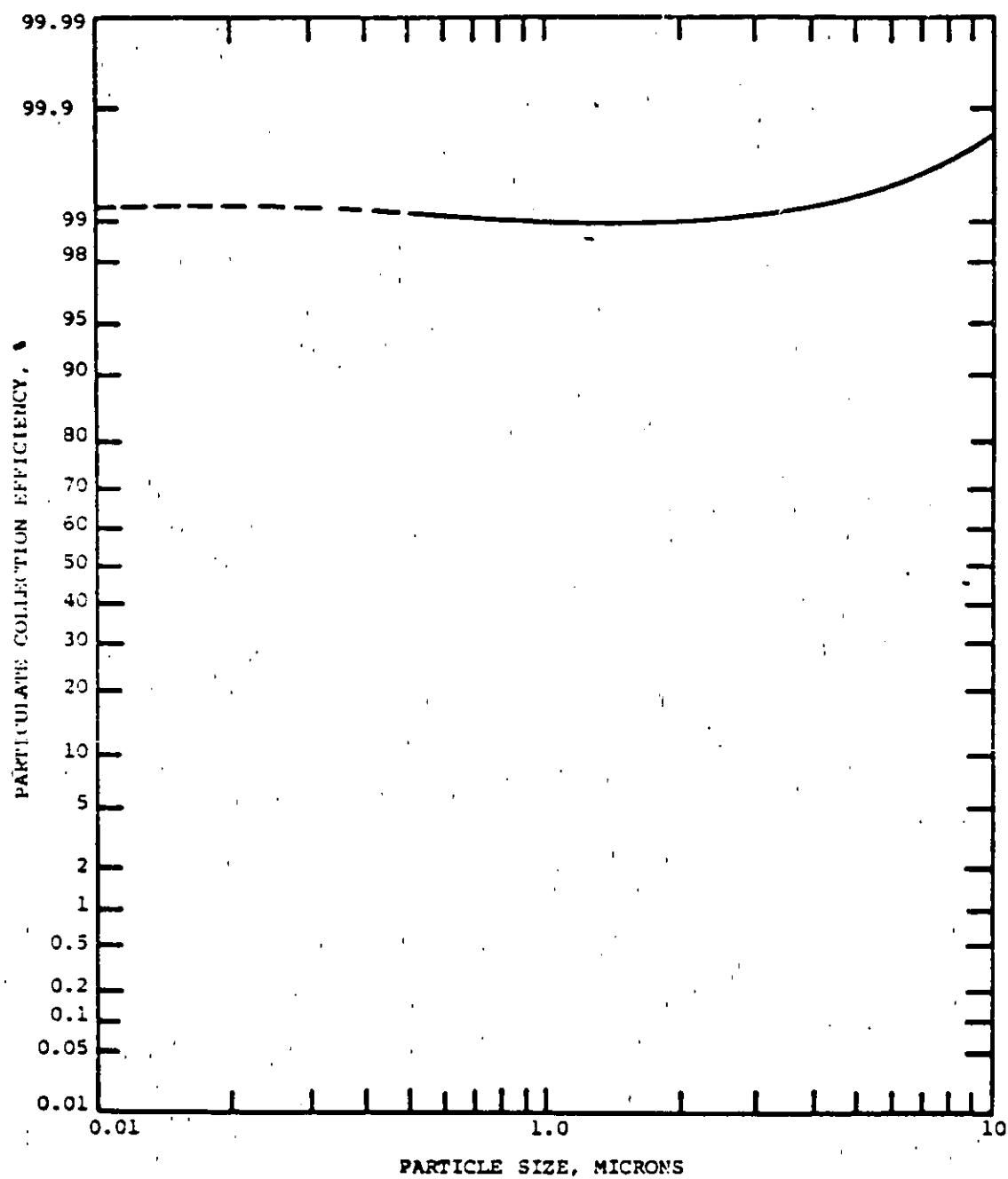


Figure 5-18. Fabric filter particulate collection efficiency (Ref. 5-4).

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

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

During operation each compartment is cleaned in the following manner:

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

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

TABLE 5-3. COMPARISON OF FABRIC FILTER CLEANING METHODS

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

(Ref. 5-3)

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

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

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

5.1.5 Electrostatic Precipitators

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

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

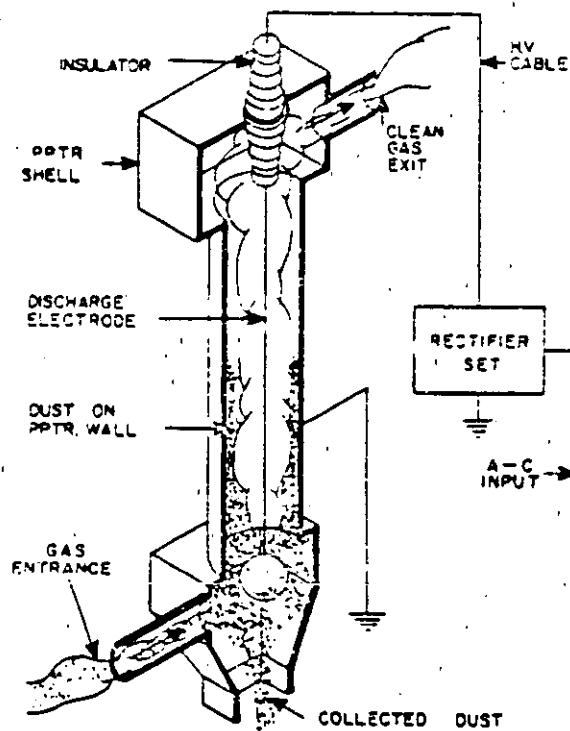


Figure 5-19. Typical precipitation process (courtesy of Research-Cottrell).

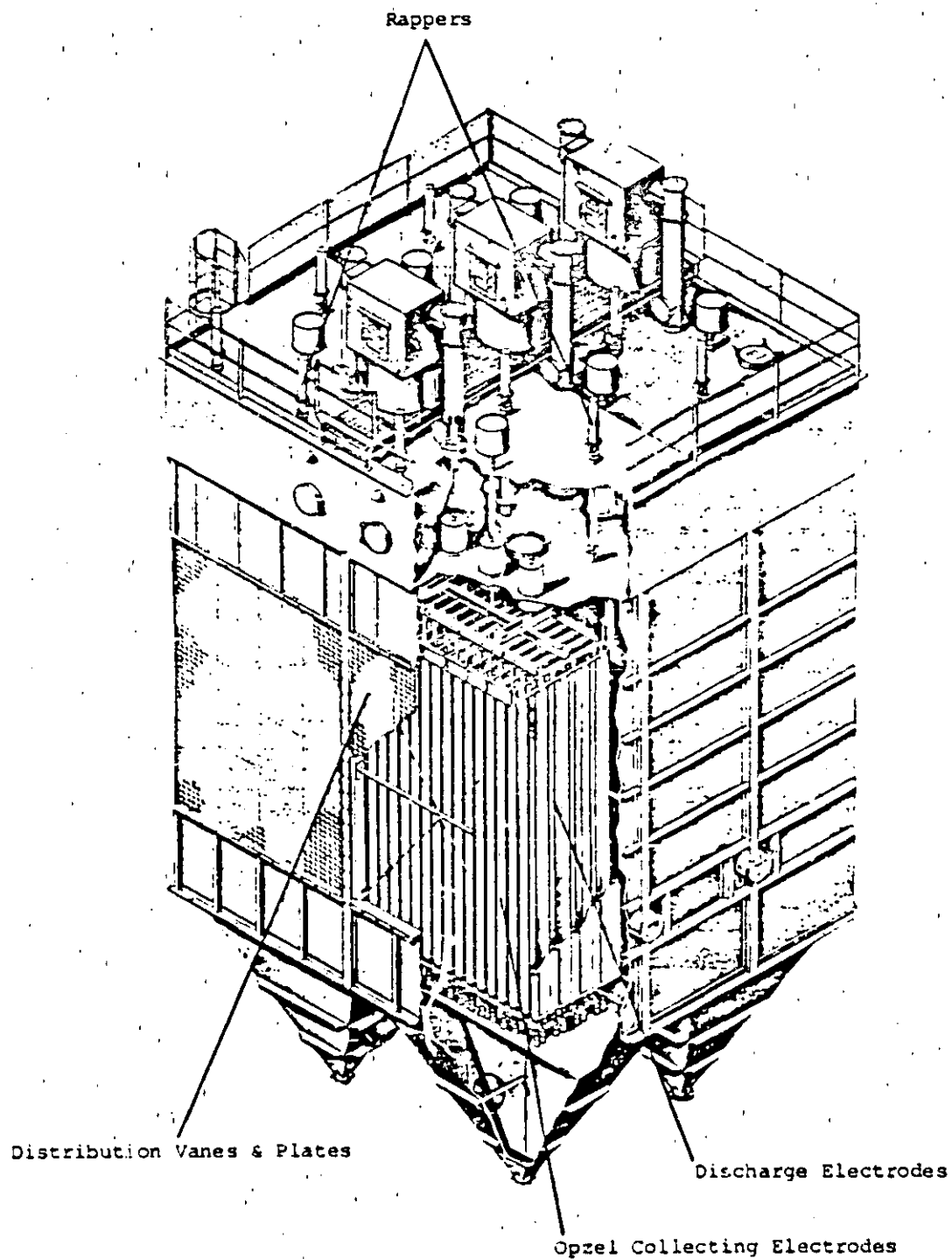


Figure S-20. Typical full-size electrostatic precipitator (Research-Cottrell)

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

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

e = Base of Natural Logarithms

A = Collecting Electrode Area (square feet)

V = Gas Flow Rate (cubic feet/second)

w = Migration Velocity (feet/second)

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

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

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

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

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

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

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

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

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

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

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

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

D. Rappers--

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

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

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

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

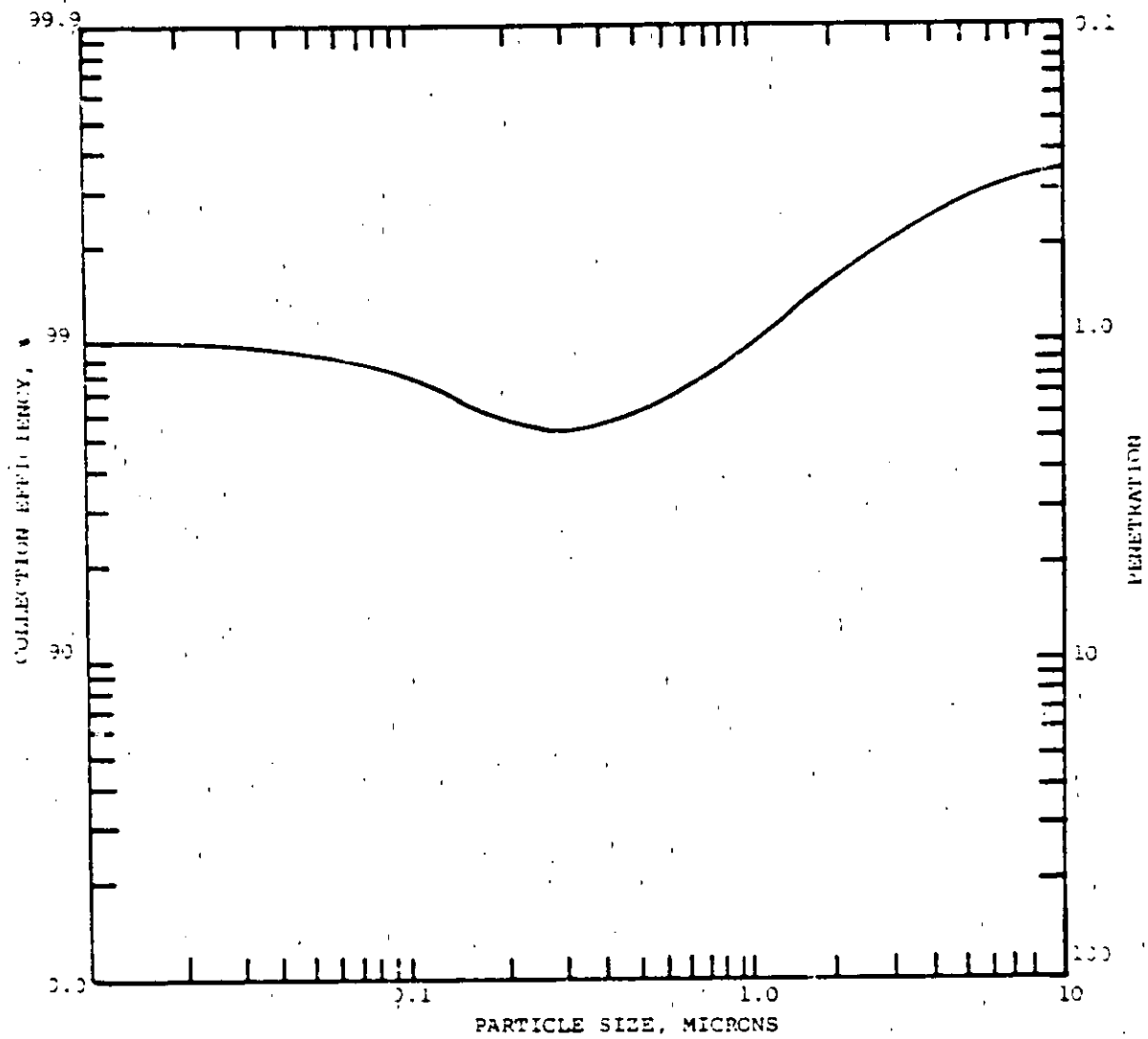


Figure 5-21. ESP collection efficiency (Research-Cottrell).

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

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

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

200 °F	99.9%
325 °F	99%
400 °F	99.5%

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

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

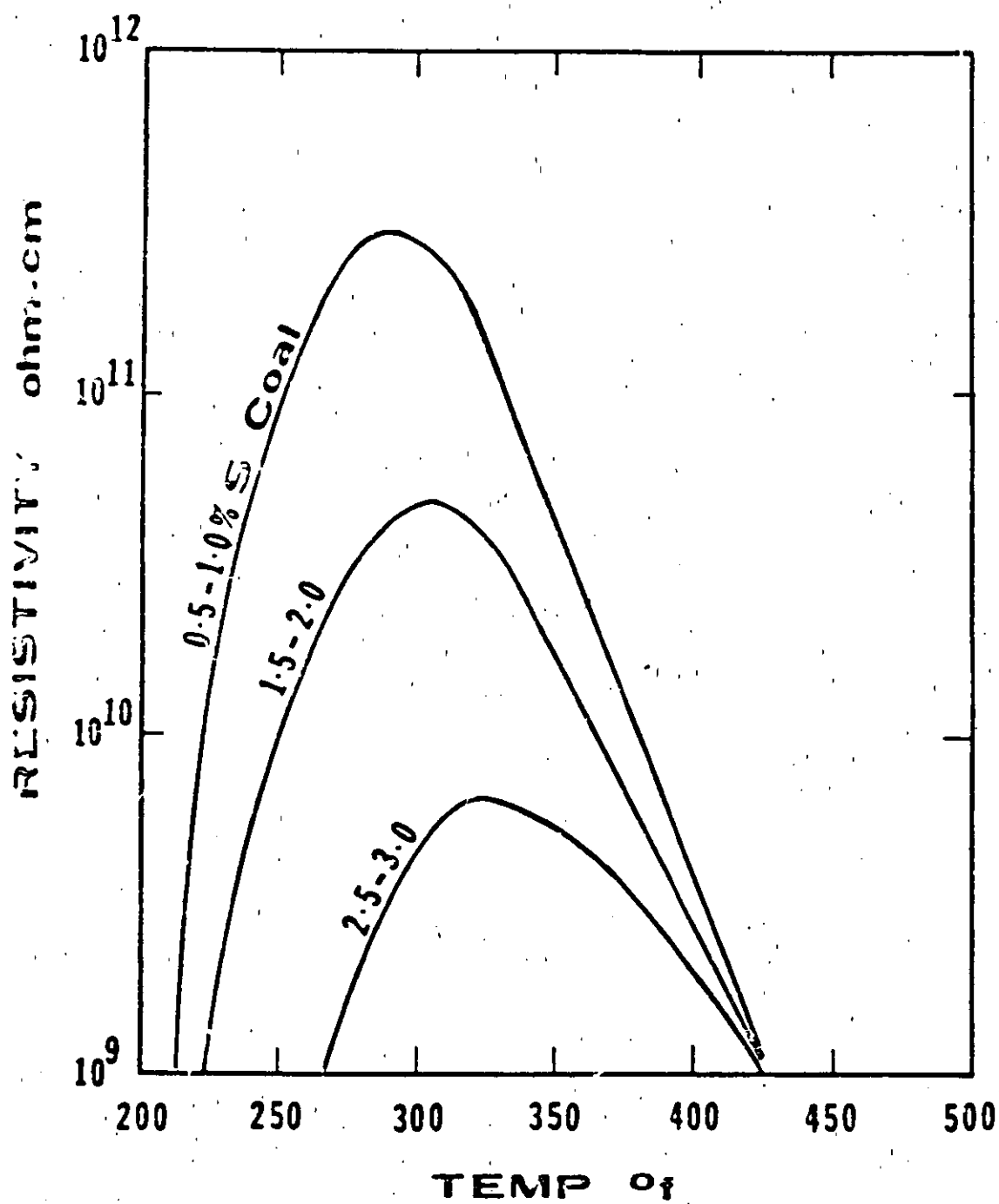


Figure 5-22. Typical fly ash temperature vs. resistivity curve.
(Research-Cottrell)

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

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

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

5.2 COST OF PARTICULATE CONTROL

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

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

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

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

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

5.2.1 Cost Basis

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

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

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

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

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

5.2.2 Cost Data

A. Settling Chamber and Momentum Separators--

Factors Dictating Cost: Figure 5-23

1. Gas Volume
2. Particle Size Distribution

Basic Size Module - 100,000 ACFM

Basic Particulate Loading - 5 gr per SCF

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

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

The following example illustrates the use of the cost curves.

Settling Chamber:

Gas Volume: 250,000 ACFM

Particulate Loading: 8 gr/SCF

Particle Size to be Collected: 40 microns and larger

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

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

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

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

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

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

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

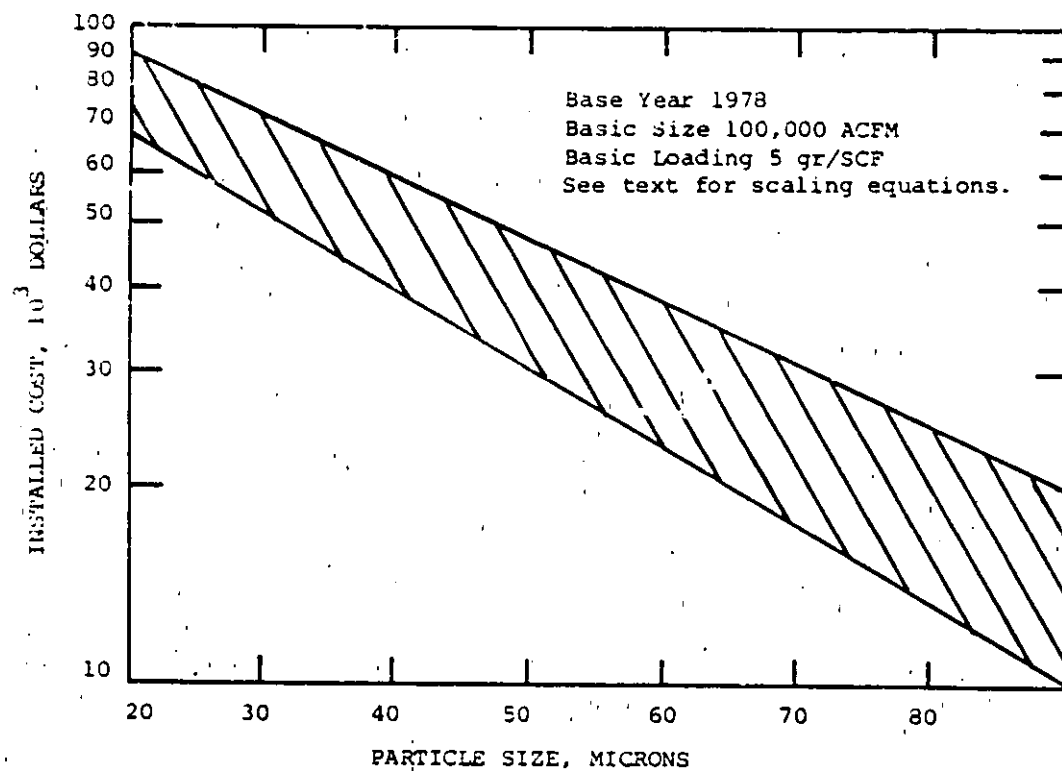


Figure 5-23. Settling chamber and momentum separator cost data.

B. Cyclones--(Figure 5-24)

Factors Dictating Cost:

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

Basic Size Module: 100,000 ACFM

Basic Particulate Loading: 5 gr SCF

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

Particulate Loading Variation:

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

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

Materials of Construction: Carbon Steel

Nominal pressure drop: 3 I.W.C.

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

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

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

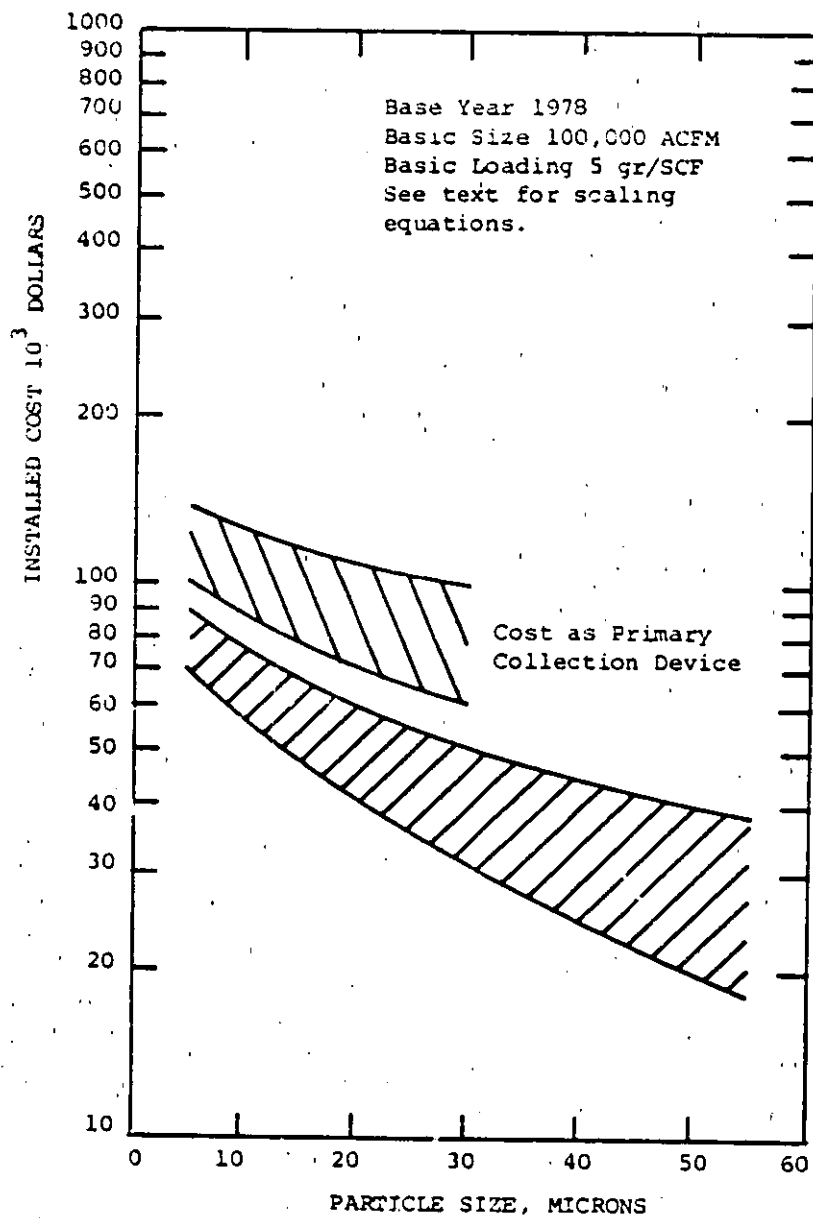


Figure 5-24. Cyclone and multi-cyclone cost data.

C. Wet Scrubber--

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

Factors Dictating Cost:

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

Basic Size Module: 100,000 ACFM

Basic Particulate Loading: 5 gr/SCF

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

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

Particulate Loading Variation:

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

Liquor-to-gas Ratio Variation:

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

Materials of Construction: 316 LSS (stainless steel)

Nominal Pressure Drop:

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

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

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

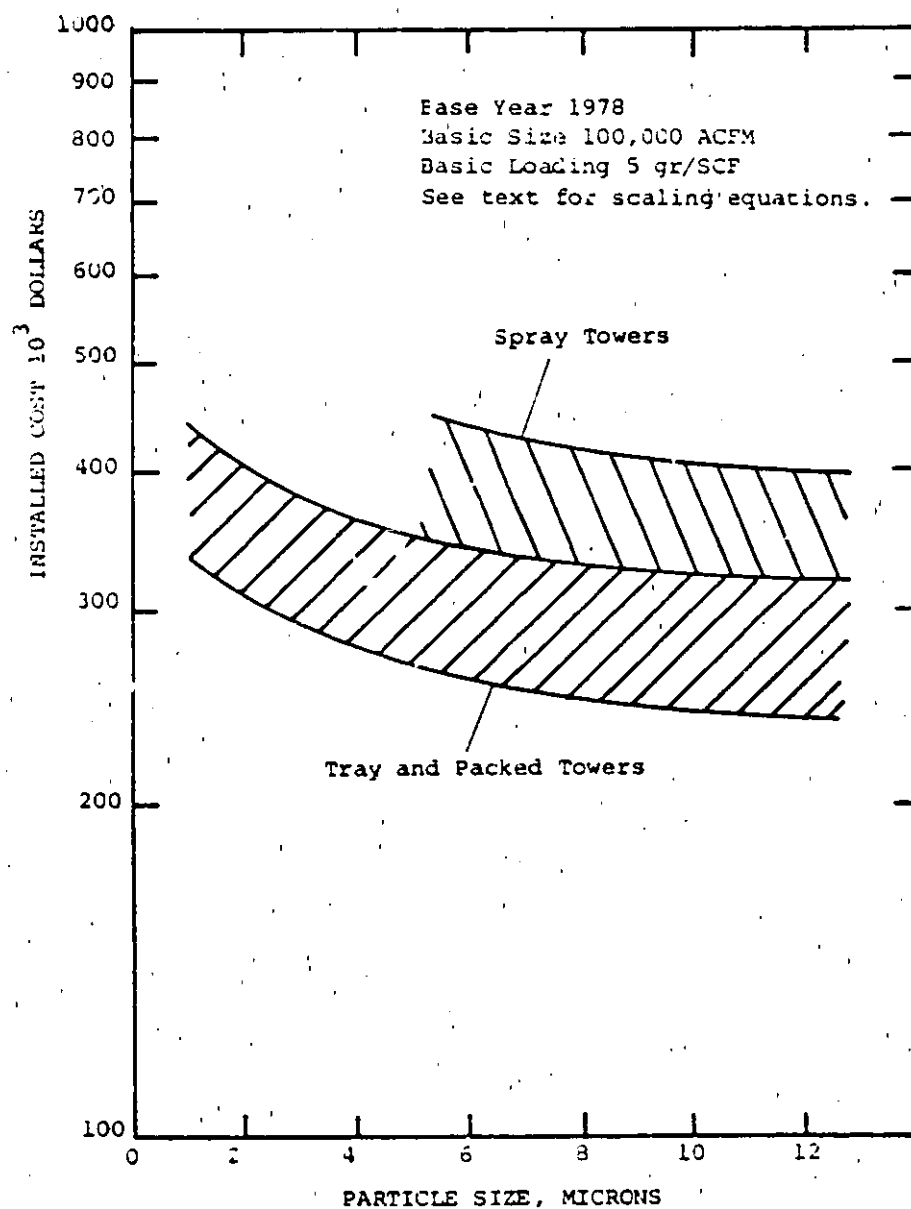


Figure 5-25. Wet scrubber spray, tray and packed tower cost data.

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

Factors Dictating Cost:

1. Gas Volume

Basic Size Module: 100,000 ACFM

Basic Particulate Loading: 5 gr per SCF

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

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

Particulate Loading Variation:

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

Liquor-to-gas Ratio Variation:

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

Materials of Construction: 316 LSS (stainless steel)

Nominal Pressure Drop

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

Medium Efficiency: 25 I.W.C. for collection of particles between 0.3 and 1 μm

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

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

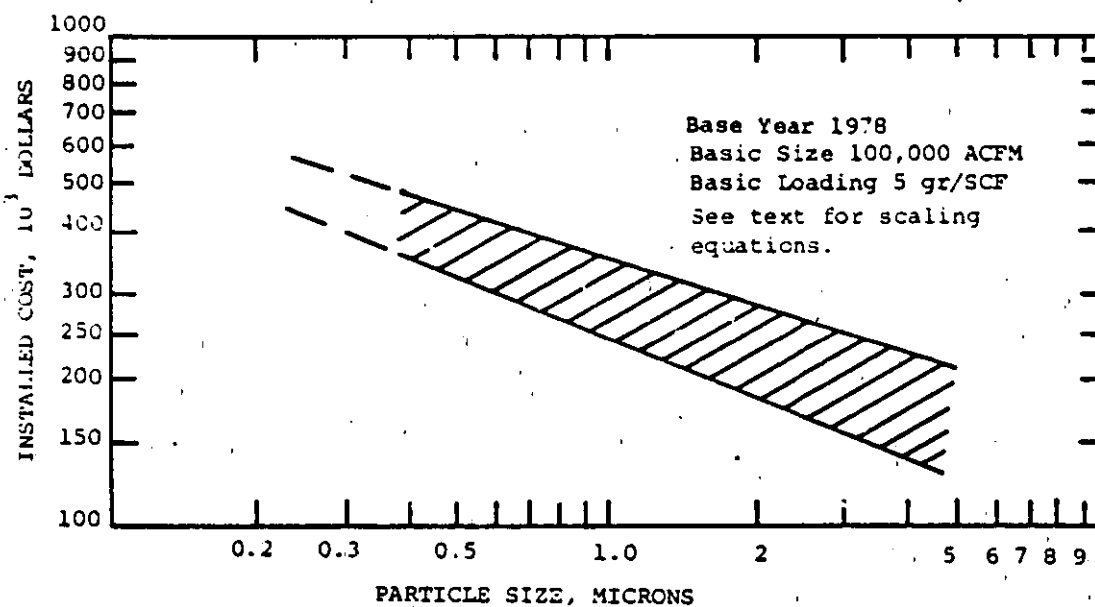


Figure 5-26. Venturi scrubber cost data.

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

Factors Dictating Cost:

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

Basic Size Module: 100,000 ACFM

Basic Particulate Loading: 5 gr/SCF

Basic Gas Temperature: 350 °F

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

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

Particulate Loading Variation:

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

Gas Temperature Variation: $0.95 \times \text{cost} + 0.05 \times \text{cost}$

(Relative Cost of Fabric/2.3)*

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

Materials of Construction: Carbon steel

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

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

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

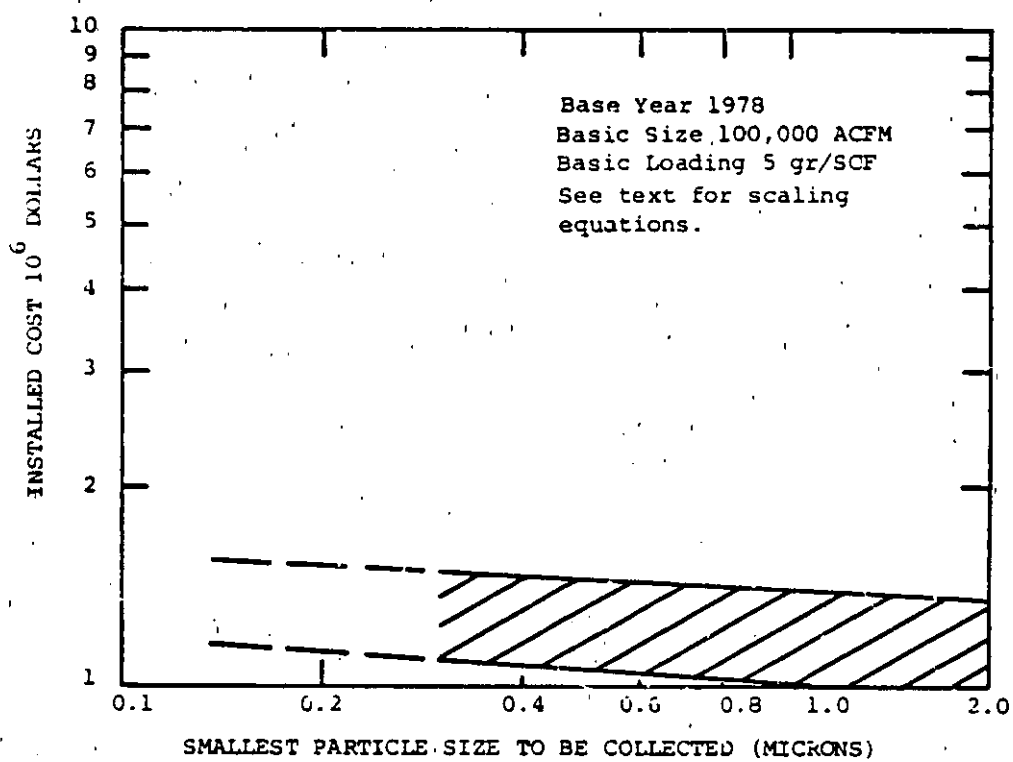


Figure 5-27. Fabric filter cost data. NOTE: 99+% overall collection efficiency.

E. Electrostatic Precipitators--(Figure 5-28)

Factors Dictating Cost:

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

Basic Size Module: 100,000 ACFM

Basic Particulate Loading: 5 gr/SCF

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

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

Particulate Loading Variation:

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

Particulate Resistivity Variation:

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

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

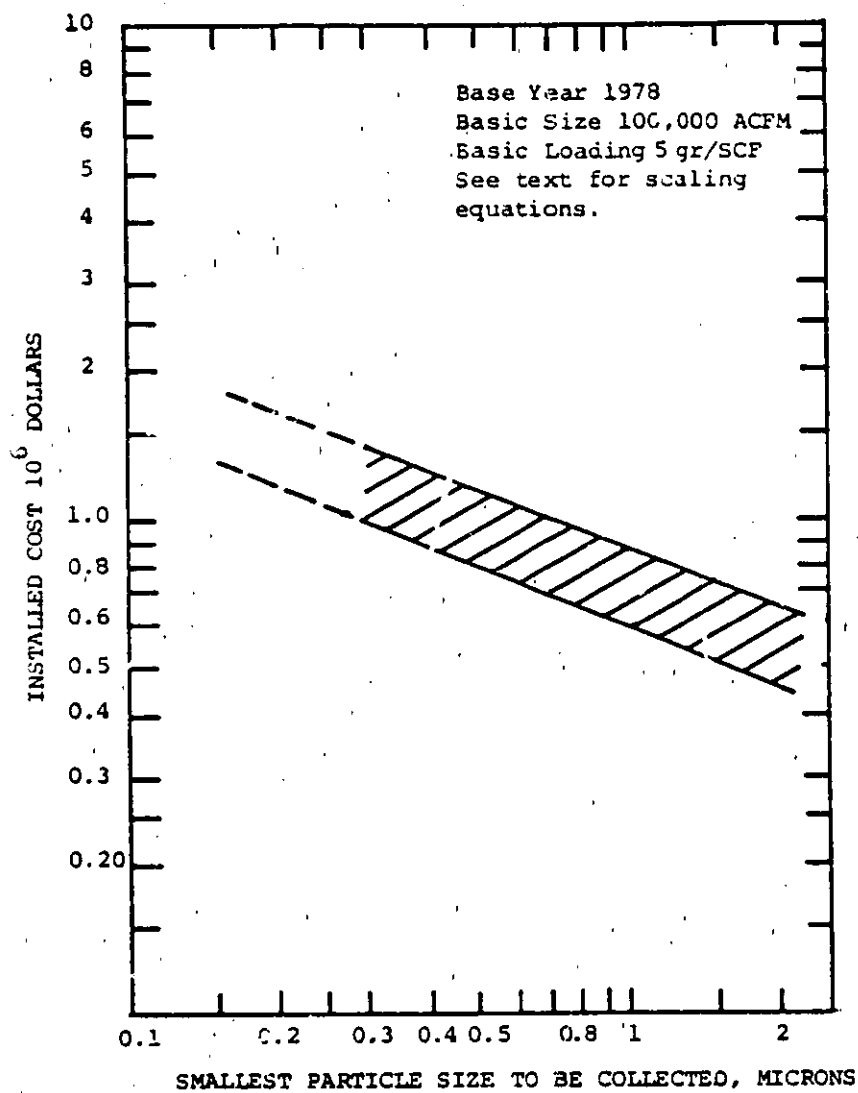


Figure 5-28. Electrostatic precipitator cost data. NOTE: 99% overall collection efficiency.

1326
13

REFERENCES

SECTION 5.0

- 5-1 Strauss, Industrial Gas Cleaning, First Edition, Pergamon Press, 1966.
- 5-2 Perry, John & Robert, Eds., Engineering Manual, McGraw Hill, 1959.
- 5-3 Marchello & Kelly, Eds., Gas Cleaning for Air Quality Control, Dekker, 1975.
- 5-4 EPA Report G00/7-76-010, Symposium Proceedings, "Operating Experience and Performance at Sunbury Station Baghouse," 1976.

BIBLIOGRAPHY FOR SECTION 5.0

- 1. EPA Fine Particulate Scrubber Symposium, EPA 650/2-74-112.
- 2. Calvert, S., Fire Particulate Scrubber Performance Tests, EPA 650/2-74-093.
- 3. Ctvrtnicek, T. E., Application of Foam Scrubbing to Fine Particulate Control, EPA 600/2-76-125 and EPA 600/2-77-110.

