NSPS DEVELOPMENT
PARTICULATE AND PARTICLE SIZING EMISSIONS TESTING
PERLITE EXPANSION FURNACE

W. R. GRACE AND COMPANY
IRONDALE, ALABAMA
FEBRUARY 1, 1984

Compiled by:

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OFFICE OF AIR QUALITY PLANNING AND STANDARDS
OFFICE OF AIR, NOISE, AND RADIATION
U. S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, N. C., 27711

REPORT CERTIFICATION

The sampling and analysis performed for this report was carried out under my direction and supervision.

Date April 25, 1984

Signature

Frank J. Phoenix, P.E.

I have reviewed all testing details and results in this test report and hereby certify that the test report is authentic and accurate.

Date April 25, 1984

Signature

D. James Grove, P.E.

DISCLAIMER

Although the research described in this report has been funded wholly or in part by the United States Environmental Protection Agency through Contract 68-02-3852 to Entropy, it has not been subject to the Agency's peer and administrative review and therefore does not necessarily reflect the views of the Agency, and no official endorsement should be inferred.

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1. INTRODUCTION

1.1 Background. The Emission Measurement Branch of the U.S. EPA (EPA EMB) is directing a project designed to generate support data for New Source Performance Standards (NSPS) for calciners and dryers in the mineral industries. Emission standards for the various industries will be developed based upon process-related emission factors determined from the testing of controlled sources.

1.2 Scope of the Project. The U.S. EPA EMB is responsible for coordinating the efforts of Entropy and Midwest Research Institute (MRI) to achieve the goals of the testing program. Entropy has been retained under EMB Contract No. 68-02-3852, Work Assignment No. 2 to conduct testing programs at designated industrial facilities. Entropy is to perform emission measurements at the recommended sampling locations, obtain process feed and product samples, and, in conjunction with Research Triangle Institute (RTI), conduct sample analyses. MRI will monitor process and operating conditions in order to designate suitable testing conditions for the respective processes and to provide a record of process and operational data during the testing.

1.3 W. R. Grace Source Testing Program. The present report covers stationary source sampling performed at the W.R. Grace & Company manufacturing plant in Irondale, Alabama on February 1, 1984 to characterize emissions from the perlite expansion pollution control equipment. Clarence Duckworth of W. R. Grace and Company and Frank Clay of EPA EMB were present to coordinate the testing. Amy J. Kowalski and Butch Smith of MRI monitored the plant process and recorded operational data during the testing.

1.3.1 Source Applicability. W. R. Grace and Company operates a high temperature perlite expansion furnace. This furnace has the capability of processing NA-79 crushed perlite which has a density of about sixty pounds per cubic foot (60 lbs/ft^3). Emissions from the perlite expansion system are controlled by a baghouse, which represents the best available control technology (BACT).

1.3.2 Outline of Testing Program. Three sets of EPA Method 5 runs were performed concurrently at the baghouse east and west stacks to determine the particulate emissions from the perlite expansion process. The impinger reagents from one Method 5 run at each location were analyzed for trace metals. Concurrent with two sets of the Method 5 runs, Method 9 opacity readings were taken at the baghouse east and west stacks, and Method 22 readings for fugitive emissions were taken at the ore feed belt. One particle sizing run was done at the baghouse west stack, while a simultaneous reactivity run* was performed as a control measure at the baghouse east stack. Feed and product samples were taken for moisture content and sieve analysis. Table 1-1 presents a test log which summarizes the test dates, sampling locations, run or sample numbers, and the types of testing performed.

TABLE 1-1

TESTING LOG OF 2/1/84

Sampling Location	Sampling Objective	Method	Run Numbers
Baghouse West Stack	particulate	5	1,2,3
	trace metals	5	2
	particle size	impactor	S1
	opacity	9	1 & 2
Ore Feed Belt	fugitive emissions	22	1 & 2
Furnace Inlet Feed	sieving & moisture	grab sample	1,2,3
Cyclones Product Outlet	sieving & moisture	grab sample	1,2,3
Baghouse East Stack	particulate	5	4,5,6
	trace metals	5	5
	reactivity	impactor	R1
	opacity	9	4 & 5

* A reactivity run is a simultaneous duplicate run using a filter prior to the impactor stages to collect all the particulate in the gas stream. The purpose of the run is to determine if gases in the stack effluent are reacting with the impactor stages and creating a high bias on the weights of the normal particle size run. No weight gain on the impactor stages of the reactivity run indicates no reactivity bias on the normal particle size run.

1.4 Report Organization. Immediately following is the "Summary of Results" section. Appendix 7.1 presents the complete results of each run; field data can be found in Appendix 7.2. The source and the process are described in the "Process Description and Operation" section. The next section, "Sampling Locations" provides a comprehensive description and illustration for each location; "Sampling and Analytical Procedures" follows, describing the sampling strategy used. Descriptions of the equipment and procedures can be found in Appendix 7.3, while Appendix 7.4 presents analytical documentation. The final section, "Quality Assurance," notes the procedures used to ensure the integrity of the sampling program; Appendix 7.6 provides pertinent calibration data. Appendix 7.5 contains a listing of the Entropy test participants and their roles in the testing program.

2. SUMMARY AND DISCUSSION OF RESULTS

2.1 Summary. Table 2-1 presents the total baghouse emission rates and concentrations and visible emissions summary for the particulate testing performed at the baghouse west and east stacks. A run-by-run summary of the particulate results for the west and east baghouse stacks is presented in Tables 2-2 and 2-3, respectively. Detailed results for the testing program appear in Appendix 7.1.

2.2 Discussion of Results. Particle sizing Run S1 data indicate a mass median diameter of approximately 4 microns; however, due to the low concentrations, the catches on some stages are extremely low so, caution should be used in interpreting the particle sizing data. The results appear in Appendix 7.1.3. Due to process upsets, the particle sizing testing scheduled for February 2 was not completed; limited data from the aborted runs show the mass median diameter to be consistant with Run S1.

Only the first set of two-hour visible and fugitive emissions runs was completed. The second set of readings was interrupted after one hour due to the onset of darkness; the scheduled third set was not performed.

Visible emissions plume opacity was negligible except during the cleaning cycles. Fugitive emissions were observed only when the conveyer belt was operating.

TABLE 2-1

BAGHOUSE TOTAL EMISSION RATES & CONCENTRATIONS

	Run Numbers			
	1 & 4	2 & 5	3 & 6	Average
Emission Rates, lb/hr:				
Baghouse West Stack	0.256	0.298	0.239	0.264
Baghouse East Stack	0.321	0.338	0.338	0.332
Sum Total	0.577	0.636	0.577	0.596
Emission Rates, kg/hr:				
Baghouse West Stack	0.116	0.135	0.108	0.120
Baghouse East Stack	0.146	0.153	0.153	0.151
Sum Total	0.262	0.288	0.261	0.271
Air Flow Rates, SCFM:				
Baghouse West Stack	2,702	2,601	2,607	2,637
Baghouse East Stack	1,986	1,986	1,997	1,990
Sum Total	4,688	4,587	4,604	4,627
Concentration, Gn/DSCF:				
Baghouse West Stack	0.0110	0.0134	0.0105	0.0116
Baghouse East Stack	0.0189	0.0198	0.0198	0.0195
Weighted Average*	0.0144	0.0162	0.0146	0.0150
Concentration, mg/DSCM:				
Baghouse West Stack	25.280	30.598	23.944	26.607
Baghouse East Stack	43.142	45.409	45.225	44.592
Weighted Average**	32.948	37.067	33.406	34.550
Average Opacity, Percent:				
Baghouse West Stack	0.16	0.04	-	-
Baghouse East Stack	0.14	0.35	-	-
Fugitive Emissions:				
Observation Time, min.	95.00	45.00	-	-
Duration of Emissions, min.	10.60	35.63	-	

$$* \text{ Weighted Gn/DSCF} = \frac{\text{lb/hr } (7000)}{\text{SCFM } (60)}$$

$$** \text{ Weighted mg/DSCM} = \frac{453{,}592}{7000\ (0.02832)} * \text{ Weighted Gn/DSCF}$$

TABLE 2-2

PARTICULATE TESTS SUMMARY OF RESULTS

Expansion Furnace Baghouse West Stack

	1	2	3
Run Date	02/01/84	02/01/84	02/01/84
Test Train Parameters:			
Volume of Dry Gas Sampled, SCF*	90.792	89.090	90.990
Percent Isokinetic	99.1	101.0	100.5
Stack Parameters:			
Temperature, Deg. F	370	383	378
Air Flow Rates			
SCFM*, Dry	2,702	2,601	2,670
ACFM, Wet	4,525	4,463	4,568
Method 5 Test Results:			
Catch, Milligrams	65.0	77.2	61.7
Concentration,			
Grains Per DSCF*	0.0110	0.0134	0.0105
Milligrams Per DSCM	25.280	30.598	23.944
Emission Rate,			
Pounds Per Hour	0.256	0.298	0.239
Kilograms Per Hour	0.116	0.135	0.108

* 68 Deg. F. - 29.92 in. Hg.

TABLE 2-3

PARTICULATE TESTS SUMMARY OF RESULTS

Expansion Furnace Baghouse East Stack

	4	5	6
Run Date	02/01/84	02/01/84	02/01/84
<u>Test Train Parameters:</u>			
Volume of Dry Gas Sampled, SCF*	106.647	108.400	107.826
Percent Isokinetic	104.6	106.3	105.2
<u>Stack Parameters:</u>			
Temperature, Deg. F	371	376	372
Air Flow Rates			
SCFM*, Dry	1,986	1,986	1,997
ACFM, Wet	3,346	3,380	3,389
<u>Method 5 Test Results:</u>			
Catch, Milligrams	130.3	139.4	138.1
Concentration,			
Grains Per DSCF*	0.0189	0.0198	0.0198
Milligrams Per DSCM	43.142	45.409	45.225
Emission Rate,			
Pounds Per Hour	0.321	0.338	0.338
Kilograms Per Hour	0.146	0.153	0.153

* 68 Deg. F. - 29.92 in. Hg.

3. PROCESS DESCRIPTION AND OPERATION

3.1 Introduction. Source emission tests were conducted on the perlite expansion furnace at the W. R. Grace & Co. (Grace) plant in Irondale, Alabama from January 30 through February 2, 1984. Mr. Frank Clay of EPA/EMB was present during the testing to observe emission testing procedures. The tests were conducted by an eight-person test crew headed by Mr. Frank Phoenix of Entropy. The process was monitored by Stacy Smith and Amy Kowalski from MRI. Mr. Clarence Duckworth of Grace coordinated the testing with plant personnel and provided process information.

3.2 Pollutants/Sampling Points. The primary objectives of the emission test were to obtain the following data for the outlet of the perlite expansion furnace baghouse: (1) particulate matter (PM) concentrations, (2) PM mass emission rates, and (3) particle size distributions (PS) for the PM. Visible emission (VE) observations were made at the two outlet stacks simultaneously with the emission testing. VE measurements were also made of the process fugitive emissions at the expansion furnace feed inlet. The feed inlet consists of a covered belt conveyer which dumps into a bucket elevator. No VE measurements were taken on the product outlet because the system was totally enclosed with no visible leaks. Grab samples of the feed and product material and of the baghouse fines were taken for particle size sieve and moisture content analyses. Table 1 presents the tests conducted at this facility.

TABLE 3-1. EMISSION TESTS CONDUCTED AT W. R. GRACE & CO.[a]

Sampling point	Test type	Test method(s)	No. of samples/run
Furnace feed inlet	Visible emissions	EPA-9,22	1
	Moisture content	ASTM D2216	1
	Particle size sieve	ASTM D422	1
Furnace product outlet	Moisture content	ASTM D2216	1
	Particle size sieve	ASTM D422	1
Baghouse outlet stacks (2)	Particle concentration	EPA-5	1
	Particle size	EPA draft method	1
	Visible emissions	EPA-9	1

[a] EPA Method 5 tests consisted of three runs, all on February 1, 1984. Particle size testing consisted of one run also on February 1, 1984. Additional particle size runs were not possible because of fan malfunctions. Simultaneous particle size and particulate testing was not feasible because of the small stack diameter.

3.3 Process Description

3.3.1 General. Grace expands one size of perlite ore, for horticultural uses, in its Perlite Corporation Model VS-450 vertical expansion furnace. During emission testing, Grefco NA 79 ore was processed. The pre-sized perlite concentrate is fed into the 0.7-m (28-in.) -diameter stainless steel furnace through a surge preheater at a rate of about 0.91 mg/h (1 ton/h). Four variable speed screw feeders on the side of the furnace inject the perlite 1.5 to 1.8 m (5 to 6ft) above the natural gas-fired combustion burner. The fuel usage rate for this furnace is 198 to 227 m^3/h (7,000 to 8,000 ft^3/h).

The perlite is expanded 4 to 20 times its original volume in the hot zone of the furnace at temperatures of 982 degrees to 1093 degrees Celsius (1800 to 2000 degrees Fahrenheit). The four baghouse exhaust fans convey the expanded perlite particles through 30.5-cm (1-ft) -diameter circular ductwork to a 1.75-m (69-in.) -diameter product collection cyclone. The collected perlite falls through a cooler/classifier unit prior to bagging. The air stream from the product cyclone and cooler/classifier cyclone passes through a four-compartment Perlite Corporation baghouse prior to being emitted to the atmosphere. Figure 1 shows an expansion furnace with the Perlite Corporation cyclone and baghouse that is similiar to the system used at Grace. The controlled expansion temperature of the furnace, as indicated by the control panel monitor, ranges from 799 to 832 degrees Celsius (1470 to 1530 degrees Fahrenheit). The furnace has a retention time of two to three seconds. Table 2 presents the design and operating parameters for the furnace. Table 3 presents the specifications for the feed and product material provided by Mr. Frederick Eaton of Grace.

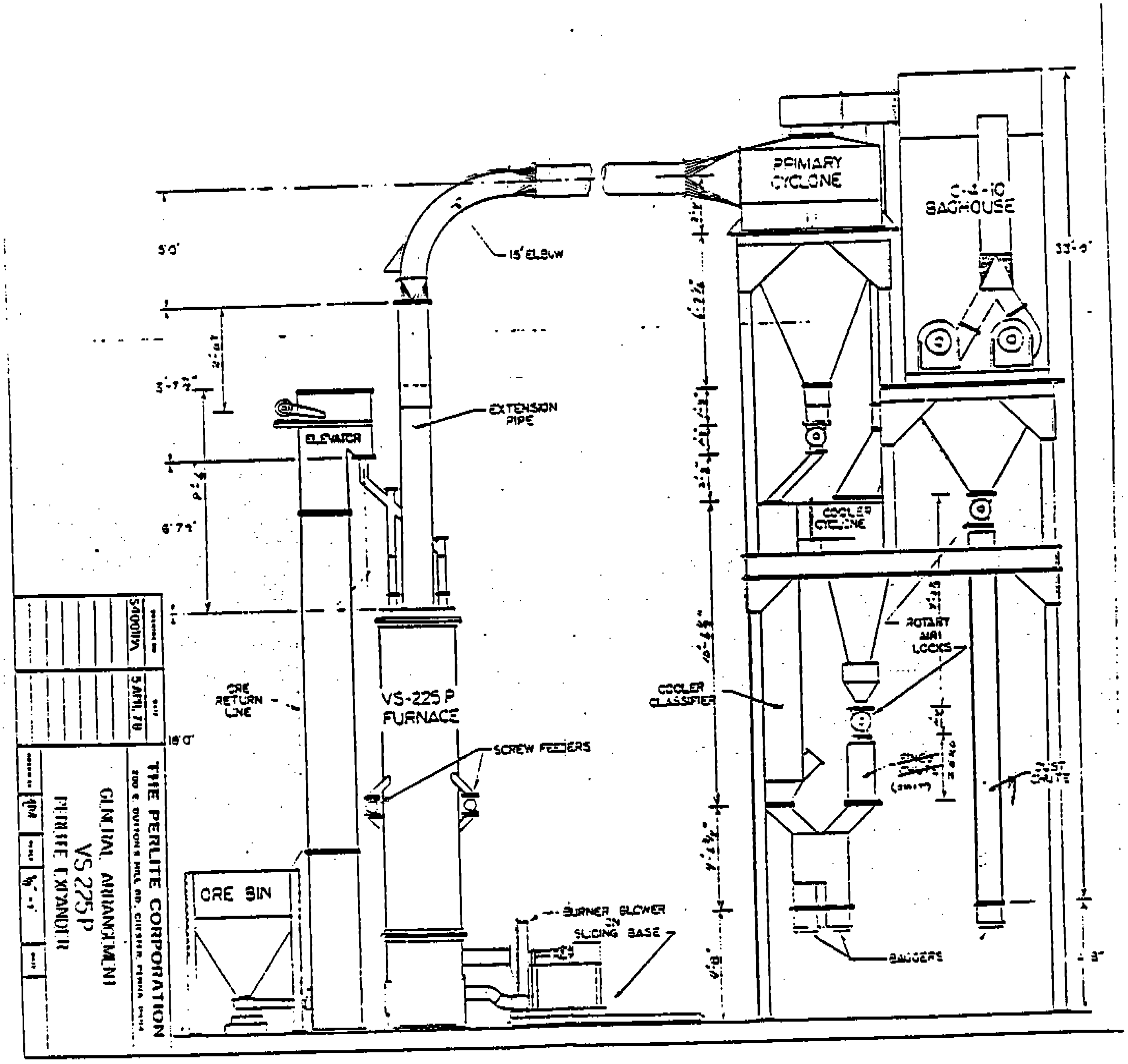


Figure 3-1. Perlite expansion system
W. R. Grace & Co.

TABLE 3-2. DATA FOR PERLITE EXPANSION
FURNACE AT W. R. GRACE & CO., IRONDALE, ALABAMA

Manufacturer	Perlite Corporation
Model	VS-450
Date of installation	1977
Design production rate, Mg/h (ton/h)	1.09 (1.20)
Actual production rate, Mg/h (ton/h)	See Confidential Addendum Item No. 2
Hours of operation	
hours/day	8-16
days/week	5
Retention time, s	2-3
Maximum gas temperature, °C (°F)	982-1093 (1800-2000)
Fuel used	Natural gas
Fuel usage rate, m^3/h (ft^3/h)	See Confidential Addendum Item No. 3
Feed moisture content, %	2-5
Feed particle size	90 percent ≥20 mesh
Feed density, kg/m^3 (lb/ft^3)	881+ (55+)
Product moisture content, %	0
Product density, kg/m^3 (lb/ft^3)	64-112 (4-7)

TABLE 3-3. FEED AND PRODUCT SPECIFICATIONS FOR GREFCO NA79 PERLITE[a]

Mesh size	Cumulative percent retained Raw ore	Cumulative percent retained Expanded product[b]
+4	0	--
+8	20	50% minimum
+12	60	--
+16	85	--
+20	90	90% minimum
+50	--	--
+100	--	96% minimum

[a] Telecons. A. J. Kowalski, MRI, with Mr. Frederick Eaton, W. R. Grace & Co. on February 1 and April 4, 1984.

[b] W. R. Grace & Co. quality control purchase specifications.

TABLE 3-4. DATA FOR PERLITE CORPORATION BAGHOUSE W. R. GRACE & COMPANY, IRONDALE, ALABAMA[a]

Manufacturer	Perlite Corporation
Bag material	Glass graphite
Air-to-cloth ratio	2.6:1
Inlet temp., °C (°F)	232-243 (450-470)
Actual gas flow rate, m^3/s (acfm)	170 @ 177°C (6,000 @ 350°F)[b]
Pressure drop, kPa (in. w.c.)	1.5 (6)
Number of stacks	2
Stack height (from roof), m (ft)	11.3 (27)
Stack diameter, m (ft)	0.4 (1.25)
Number of compartments	4
Design outlet grain loading, g/dsm^3 (gr/dscf)	1.8×10^{-5} (0.01)
Design efficiency	>99%

[a] Telecon, 6/7/83 with Mohammed Huda, Jefferson County Dept. of Health, Birmingham, Ala., and Section 114 response.

[b] Stack temperature.

3.3.2 Control Equipment. Particulate emissions from the perlite expansion furnace are controlled by a baghouse. Data for the baghouse are shown in Table 4. The baghouse was manufactured by the Perlite Corporation. It has four compartments and is equipped with 100 glass graphite bags. The design air-to-cloth ratio is 2.6:1. The temperature of the inlet gas is 232 to 243 degrees Celsius (450 to 470 degrees Fahrenheit). The collected material from the baghouse is bagged separately and landfilled. The baghouse is equipped with four fans, one on each compartment. The baghouse is cleaned by compartment when the respective fan is shut off for a few seconds. The cleaning cycle is set on seven minutes per compartment.

3.4 Process Conditions During Testing. All processes were operating normally during the emission testing. The furnace operation is monitored from a control panel that contains gauges for the furnace outlet temperature, the baghouse internal temperature, and the ore feeder speed. To achieve the required amount of exfoliation for final product quality, the hot section of the furnace must be 982 to 1093 degrees Celsius (1800 to 2000 degrees Fahrenheit). This corresponds to a furnace control temperature of approximately 816 degrees Celsius (1500 degrees Fahrenheit) according to Mr. Duckworth. Throughout the testing the furnace control temperature was 799 to 832 degrees Celsius (1470 to 1530 degrees Fahrenheit) indicating normal furnace operation.

The design capacity of the vertical expansion furnace is 1.09 mg/h (1.2 ton/h). The normal actual production rate is 0.9 mg/h (1 ton/h). Natural gas with a heating value of 1,000 Btu/ft^3 was used to fire the furnace during the testing. The gas firing system was operating normally during the test.

Additional information about the process operation during testing is provided in a Confidential Addendum to this report.

3.5 Discussion. Due to the small diameter of the baghouse outlet stacks [0.4 m (1.25 ft)], simultaneous particle size and Method 5 testing was not possible. In addition, two of the four baghouse fans malfunctioned on three separate occasions. None of the malfunctions affected any of the testing runs. As a result of these breakdowns, however, Method 5 Run No. 3 was performed at night, and VE readings could not be taken. Also, only one 2-hour particle size run was completed due to the fan breakdowns.

Additional particle size testing was scheduled on Thursday, February 2, 1984, to complete the testing requirements. Originally, the three particle size runs were to be performed in only one stack. Due to time constraints, EMB personnel approved simultaneous particle size testing using both stacks. After approximately one hour of testing, the third fan malfunction occurred, and testing was suspended. Because acceptable Method 5 runs had already been obtained and because the outlet particle size data could not be obtained concurrently and were not critical to the calciners and dryers project, it was decided that the testing would be terminated without the final two particle size runs.

Confidential Attachment

4. SAMPLING LOCATIONS

4.1 Suitability of Sampling Sites. The primary goal of the testing program was to characterize emissions from the perlite expansion pollution control equipment. Additionally, physical properties of the process feed stock and the product were investigated. Sampling sites appropriate to these objectives were approved prior to testing. Each sampling location is discussed individually, and the position of each site within the system is illustrated in Figure 4-1.

4.2 Perlite Expansion Furnace Inlet (Sampling Location A). Grab samples of the feed to the expansion furnace were collected for sieve analysis and moisture content determination. Samples were taken during each set of simultaneous Method 5 runs.

4.3 Ore Feed Belt (Observation Location E). Fugitive emissions were determined at the ore feed belt according to EPA Reference Method 22.

4.4 Cyclones Product Outlet (Sampling Location B). Grab samples of product from the cyclones product outlet were collected for sieve analysis and moisture content determination. Samples were taken during each set of simultaneous Method 5 runs.

4.5 Baghouse Exhaust Stacks (Sampling Locations C and C'). Measures of particulate emissions were made at the identical baghouse east and west stacks. A determination of particle size distribution was made only at the baghouse west stack, while a reactivity particle size run was conducted for reference at the baghouse east stack. Figure 4-2 illustrates the dimensions and sampling points which are typical for both stacks.

Both stacks are vertical with inside diameters of 15 inches. Each stack has two sampling ports spaced 90° apart and located 12 inches (0.8 stack diameters) upstream from the stack outlet and 60 inches (4 stack diameters) downstream from the nearest flow disturbance. In accordance with EPA Method 1 (promulgated on September 30, 1983), 24 sampling points were used,

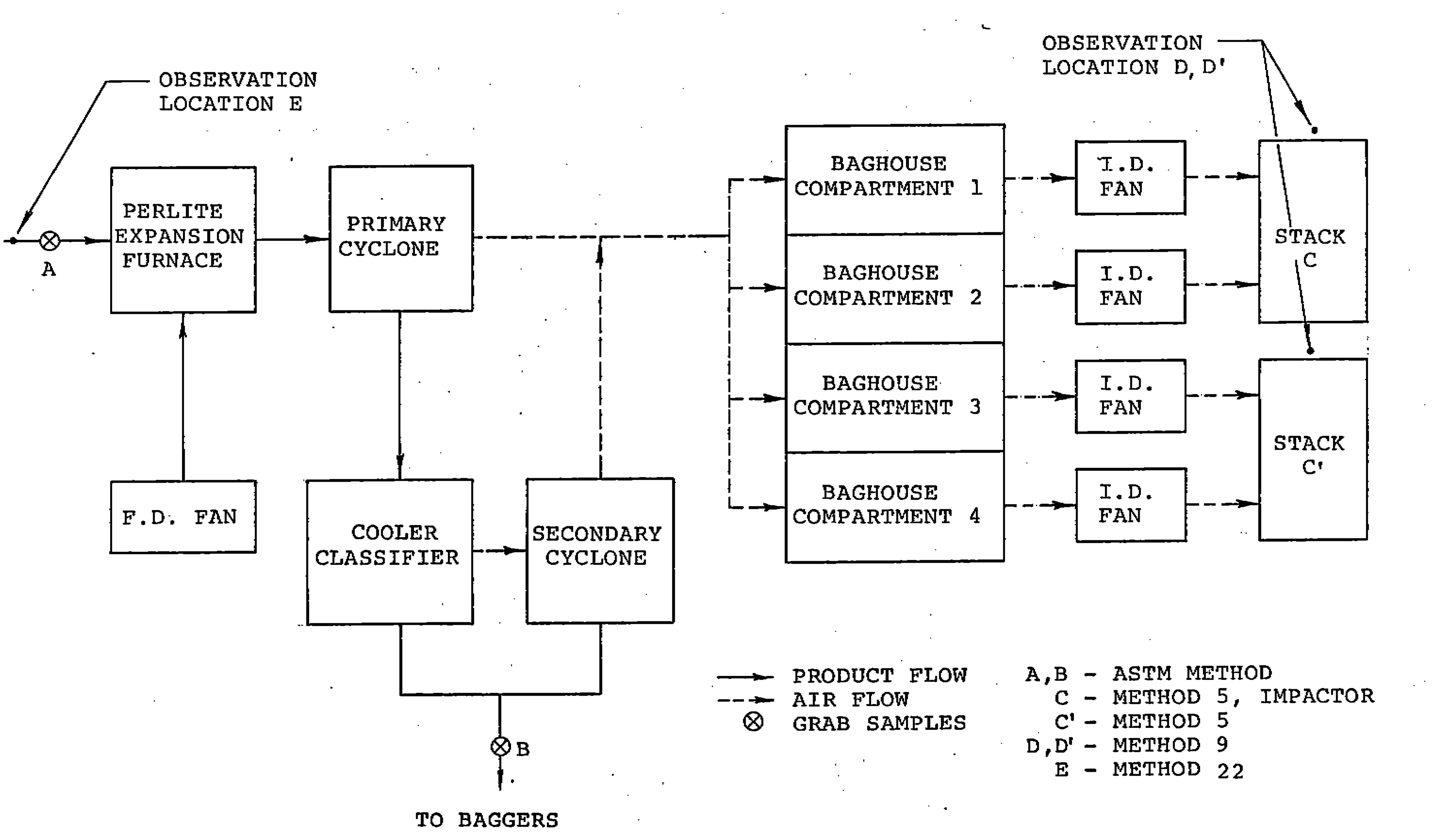


FIGURE 4-1. PERLITE EXPANSION PROCESS SAMPLING LOCATIONS
W. R. GRACE, IRONDALE, ALABAMA

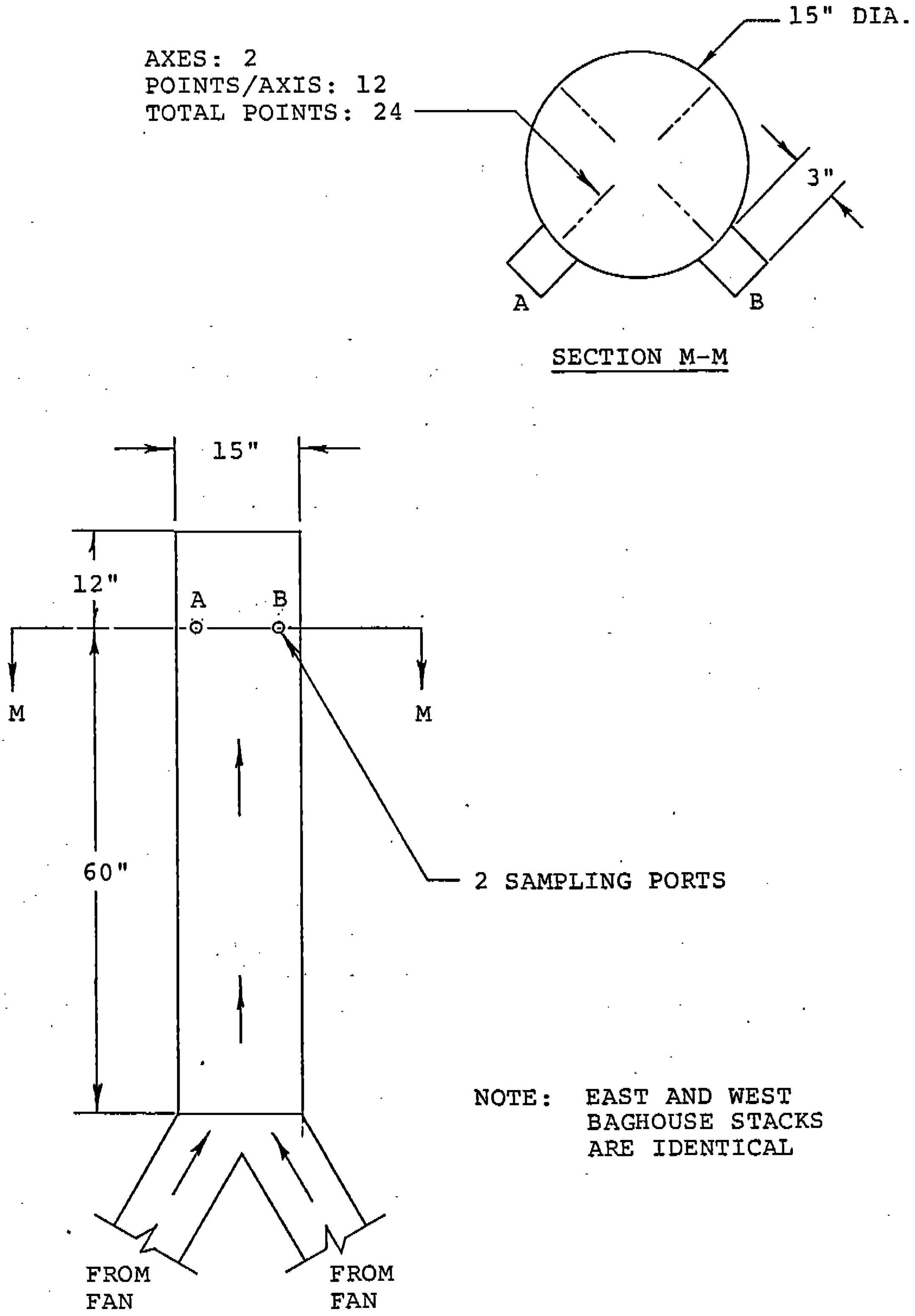


FIGURE 4-2. EAST OR WEST BAGHOUSE OUTLET STACK DIMENSIONS WITH SAMPLING PORT AND POINT LOCATIONS

i.e., 12 sampling points on each of two traverse axes (labeled A and B). Each point was sampled for five minutes resulting in a net test time of 120 minutes.

Particle size determination at the baghouse west stack was performed using the four-point scheme recommended by the Industrial Environmental Research Laboratory (IERL). For the particle size testing the stack cross section was divided into four equal areas, i.e., two traverse axes with two sample points per axis. The centroid of each equal area was sampled for 30 minutes resulting in a net sample time of 120 minutes.

4.6 Baghouse Exhaust Stacks (Observation Locations D and D'). Plume opacity observations for both baghouse exhaust stacks were performed according to procedures outlined in EPA Reference Method 9.

5. SAMPLING AND ANALYTICAL METHODS

5.1 Sampling Objectives. This section describes the sampling and analytical procedures which were employed at the W. R. Grace plant in order to gather data concerning emissions from the perlite expansion pollution control equipment and to investigate physical properties of the process feed stock and the product. The sampling program included outlet tests for particulate emissions, plume opacity, and, at the baghouse west stack only, particle size distribution.

5.2 Particulate Emissions Testing. Particulate emissions sampling conformed to the standards and procedures set forth by EPA Reference Methods 1-5 and described in 40 CFR Part 60, Appendix 7.3.

5.3 Trace Metals Analysis. For one run at each location, the Method 5 particulate catch and the distilled water reagent from the impingers were analyzed for trace metals by using atomic absorption or inductively coupled Plasma Spectrometry. These metals are zinc, nickel, iron, manganese, vanadium, calcium, silicon, aluminum, magnesium, fluorine, beryllium, uranium, lead, and mercury.

5.4 Sieve Analysis and Moisture Content. Sieve analysis and moisture content determinations were performed on all feed and product samples. ASTM Method D 2216 was used to analyze the samples for moisture content, while ASTM Method D 422 was used for sieve analysis.

5.5 Plume Opacity. Visible emissions observations were performed in accordance with EPA Reference Method 9 as described in 40 CFR Part 60.

5.6 Fugitive Emissions. Fugitive emissions were determined in accordance with EPA Reference Method 22 as described in 40 CFR Part 60.

5.7 Particle Size Tests. Particle size determinations were made using a right angle inlet preseparator, followed by an Andersen Mark III cascade impactor. The test procedures were based upon the publication, "Procedures for Cascade Impactor Calibration and Operation in Process Streams - Revised 1979," developed by the Industrial Environmental Research Laboratory (IERL) and Southern Research Institute.

6. QUALITY ASSURANCE

6.1 Introduction. The goal of quality assurance for the project was to ensure the accuracy of all data collected. The procedures used are contained in Entropy's "Quality Assurance Program Plan," which was approved by the U.S. EPA EMB in the contract agreement governing the project.

In order to ensure continuity among field testing personnel, daily meetings were held before each day of the field testing. At the meetings, results from the testing conducted on the previous day were reviewed. Responsibilities were clearly delineated for each member of the testing team, and questions were addressed and resolved immediately. In situations where more than one person was performing similar activities, consistency was ensured through communication at the meetings.

In addition to the general quality assurance measures, specific quality assurance activities were conducted for several of the individual test methods performed.

6.2 Sampling Train Components. Entropy's sampling equipment, including nozzles, pitot tubes, dry gas meters, orifices, and thermocouples, was uniquely identified and calibrated in accordance with documented procedures and acceptance criteria prior to and at the completion of the field testing program. All sampling equipment was manufactured by Nutech Corporation, Andersen 2000 or by Entropy. Calibration data for the sampling equipment are contained in Appendix 7.6.

6.3 Preseparator and Cascade Impactors. All internal components and surfaces of the impactors were cleaned in an ultrasonic bath to ensure that all surface impurities were removed, and visual inspections for cleanliness were made prior to shipment to the field. After each sample recovery, the preseparator, the impactor body, and the plates were rinsed with acetone to ensure that all organic residuals and/or particulate matter were removed.

6.4 Sample Collection Substrates. Schleicker & Schuell #30 glass fiber sample collection substrates were used for particle size testing. To prevent contamination of the substrate surface, all filters were handled with laboratory tweezers. This procedure was used during impactor assembly, sample recovery, and weighing of the substrates.

6.5 Substrate Weighing. An analytical balance capable of weighing to the nearest 0.01 milligram (mg) was used. To ensure that no weight bias was produced from the preparation, transportation, recovery, or weighing procedures, two control samples were obtained during the test program. A reactivity run was performed to ensure that the flue gases did not interact with the substrate to produce extraneous results. For the reactivity run, a solid filter was placed in the front section of the impactor, and the impactor was introduced into the stack, and a sample was pulled through the head using the parameters outlined for a normal particle sizing run. The average difference between the pre- and post-test weights, as shown in Appendix 7.6., was 0.08 milligrams, based upon weight differences ranging from 0.01 to 0.19 milligrams. A blank run was also performed to demonstrate that the impactor could be assembled and disassembled without affecting the weight of the substrate. The average difference between the pre- and post-assembly weights was 0.03 milligrams, based upon a difference ranging from 0.0 to 0.03 milligrams.

6.6 Sample Analysis. In order to reduce the probability of errors or inconsistent results, one member of the field crew had sole responsibility for the sample analysis procedure. Sample analysis was performed in a room dedicated exclusively to filter weighing.

6.7 EPA Method 3. All Method 3 analyses were performed in triplicate. Each analyzer was checked for leaks prior to any analysis as specified in the method. Samples were analyzed within four hours of collection.

6.8 EPA Method 9. The visible emissions observers held current certifications issued within the last 6 months. Documentation verifying the observer's certifications are provided in Appendix 7.2.4.

APPENDICES

APPENDIX 7.1

TEST RESULTS AND EXAMPLE CALCULATIONS

APPENDIX 7.1.1

PARTICULATE TEST RESULTS, BAGHOUSE WEST STACK AND EXAMPLE CALCULATIONS FOR RUN 1

PARTICULATE FIELD DATA & RESULTS TABULATION

PLANT: W. R. Grace & Company, Irondale, Alabama

RUN	SAMPLING LOCATION	TEST TEAM LEADER
1	Expansion Furnace West Baghouse Stack	Gerard M. Carty
2	Expansion Furnace West Baghouse Stack	Gerard M. Carty
3	Expansion Furnace West Baghouse Stack	Willis S. Nesbit

		1	2	3
	RUN DATE	02/01/84	02/01/84	02/01/84
	RUN START TIME	1150	1638	1932
	RUN FINISH TIME	1356	1843	2145
	NET SAMPLING POINTS	24	24	24
Theta	NET RUN TIME, MINUTES	120.00	120.00	120.00
Dia	NOZZLE DIAMETER, INCHES	0.252	0.252	0.252
Cp	PITOT TUBE COEFFICIENT	0.840	0.840	0.840
Y	DRY GAS METER CAL. FACTOR	0.993	0.993	0.993
Pbar	BAROMETRIC PRESSURE, IN. HG.	29.50	29.50	29.50
Delta H	AVG. PRESS. DIFFERENTIAL OF ORIFICE METER, IN. H2O	2.017	1.906	1.953
Vm	VOLUME OF METERED GAS SAMPLE DRY ACTUAL CUBIC FEET	93.181	91.116	92.348
tm	DRY GAS METER TEMP., DEG. F	73	71	67
Vm(std)	VOLUME OF METERED GAS SAMPLE @ DRY STD. COND., DSCF*	90.792	89.090	90.990
Vlc	VOLUME OF WATER CATCH IN IMPINGERS & SIL. GEL.,ML	95.3	111.0	119.0
Vw(std)	VOLUME OF WATER VAPOR, SCF*	4.495	5.225	5.601
%H2O	MOISTURE, PERCENT BY VOLUME	4.7	5.5	5.8
Mfd	DRY MOLE FRACTION	0.953	0.945	0.942

(continued next page)

		1	2	3
%CO2	PERCENT CO2 BY VOLUME, DRY	2.3	2.6	2.9
%O2	PERCENT O2 BY VOLUME, DRY	16.5	15.9	16.0
%CO+N2	PERCENT CO + N2 BY VOLUME, DRY	81.2	81.5	81.1
Md	DRY MOLECULAR WT, LB/LB-MOLE	29.03	29.05	29.10
Ms	WET MOLECULAR WT, LB/LB-MOLE	28.51	28.44	28.46
Pg	STACK STATIC PRESS., IN H2O	-0.2	-0.2	-0.4
Ps	ABSOLUTE STACK PRESS., IN HG	29.49	29.48	29.47
ts	STACK TEMPERATURE, DEG. F	370	383	378
Delta p	AVG VELOCITY HEAD. IN. H2O	0.7418	0.7089	0.7472
vs	STACK GAS VELOCITY, FT/SEC	61.5	60.6	62.0
A	STACK AREA, SQUARE INCHES	176.7	176.7	176.7
Qsd	STACK FLOW RATE, DRY SCFM*	2,702	2,601	2,670
Qaw	STACK FLOW RATE, WET ACFM	4,525	4,463	4,568
%I	PERCENT ISOKINETIC	99.1	101.0	100.5
	METHOD 5 RESULTS:			
mg	CATCH, MILLIGRAMS	65.0	77.2	61.7
	CONCENTRATION			
Gn/DSCF	GRAINS PER DSCF*	0.0110	0.0134	0.0105
mg/DSCM	MILLIGRAMS PER DSCM	25.280	30.598	23.944
	EMISSION RATE			
Lb/Hr	POUNDS PER HOUR	0.256	0.298	0.239
Kg/Hr	KILOGRAMS PER HOUR	0.116	0.135	0.108

* 68 Deg. F - 29.92 in. Hg.

EXAMPLE PARTICULATE TEST CALCULATIONS NO. 1

Expansion Furnace West Baghouse Stack

VOLUME OF DRY GAS SAMPLED AT STANDARD CONDITIONS

$$\text{Vm(std)} = 17.64 * \text{Y} * \text{Vm} * \frac{(\text{Pbar} + \text{Delta H}/13.6)}{(460 + \text{tm})}$$

$$\text{Vm(std)} = 17.64 * 0.993 * 93.181 * \frac{(29.50 + 2.017/13.6)}{(460 + 73)} = 90.792 \text{ DSCF}$$

VOLUME OF WATER VAPOR AT STANDARD CONDITIONS

$$\text{Vw(std)} = 0.04707 * \text{Vlc}$$

$$\text{Vw(std)} = 0.04707 * 95.5 = 4.495 \text{ SCF}$$

PERCENT MOISTURE, BY VOLUME, AS MEASURED IN STACK GAS

$$\%\text{H2O} = 100 * \text{Vw(std)} / (\text{Vw(std)} + \text{Vm(std)})$$

$$\%\text{H2O} = \frac{4.495}{4.495 + 90.792} * 100 = 4.7 \%$$

DRY MOLE FRACTION OF STACK GAS

$$\text{Mfd} = 1 - \%\text{H2O}/100$$

$$\text{Mfd} = 1 - 4.7/100 = 0.953$$

DRY MOLECULAR WEIGHT OF STACK GAS

$$\text{Md} = \%\text{CO2} * 0.44 + \%\text{O2} * 0.32 + \%\text{CO+N2} * 0.28$$

$$\text{Md} = 2.3*0.44 + 16.5*0.32 + 81.2*0.28 = 29.03 \text{ LB/LB-MOLE}$$

WET MOLECULAR WEIGHT OF STACK GAS

$$\text{Ms} = (\text{Md} * \text{Mfd}) + (0.18 * \%\text{H2O})$$

$$\text{Ms} = 29.03 * 0.953 + (0.18 * 4.7) = 28.51 \text{ LB/LB-MOLE}$$

ABSOLUTE STACK GAS PRESSURE

$$Ps = Pbar + Pg / 13.6$$

$$Ps = 29.50 + (-0.1 / 13.6) = 29.49 \text{ IN. HG.}$$

AVERAGE STACK GAS VELOCITY [Note: (Delta p)avg is square of avg sq. root]

$$vs = 85.49 * Cp * SQRT\left[\frac{(\text{Delta } p)avg * (460 + ts)}{Ps * Ms}\right]$$

$$vs = 85.49 * 0.840 * SQRT\left[\frac{0.7418 * (460 + 370)}{29.49 * 28.51}\right] = 61.5 \text{ FT/SEC}$$

DRY VOLUMETRIC STACK GAS FLOW RATE @ STANDARD CONDITIONS

$$Qsd = \frac{60}{144} * Mfd * vs * A * \frac{Tstd}{ts + 460} * \frac{Ps}{Pstd}$$

$$Qsd = \frac{60}{144} * 0.953 * 61.5 * 176.7 * \frac{528}{370 + 460} * \frac{29.49}{29.92}$$

$$Qsd = 2{,}702 \text{ SCFM}$$

WET VOLUMETRIC STACK GAS FLOW RATE @ STACK CONDITIONS

$$Qaw = 60 / 144 * vs * A$$

$$Qaw = 60 / 144 * 61.5 * 176.7 = 4{,}525 \text{ ACFM}$$

PERCENT ISOKINETIC OF SAMPLING RATE

$$\%I = \frac{Pstd}{Tstd} * \frac{100}{60} * \frac{(ts + 460) * Vm(std)}{Ps * vs * Mfd * Theta * \text{Area-nozzle, sq.ft.}}$$

$$\%I = \frac{29.92}{528} * \frac{100}{60} * \frac{(370 + 460) * 90.792}{29.49 * 61.5 * 0.953 * 120.00 * 0.0003464}$$

$$\%I = 99.1 \%$$

GRAINS PER DRY STANDARD CUBIC FOOT

$$\text{Gn/DSCF} = \frac{7{,}000}{453{,}592} * \frac{\text{mgs}}{\text{Vm(std)}}$$

$$\text{Gn/DSCF} = \frac{7{,}000}{453{,}592} * \frac{65.0}{90.792} = 0.0110 \text{ GN/DSCF}$$

MILLIGRAMS PER DRY STANDARD CUBIC METER

mg/DSCM = mg / (Vm(std) * 0.02832)

mg/DSCM = 65.0 / (90.792 * 0.02832) = 25.280 mg/DSCM

POUNDS PER HOUR

Lb/Hr = (60/7000) * Gn/DSCF * Qsd

Lb/Hr = (60/7000) * 0.0110 * 2,702 = 0.26 LB/HR

KILOGRAMS PER HOUR

Kg/Hr = .453592 * Lb/Hr

Kg/Hr = .453592 * 0.256 = 0.116 kg/Hr

APPENDIX 7.1.2

PARTICULATE TEST RESULTS, BAGHOUSE EAST STACK

PARTICULATE FIELD DATA & RESULTS TABULATION

PLANT: W. R. Grace & Company, Irondale, Alabama

RUN	SAMPLING LOCATION	TEST TEAM LEADER
4	Expansion Furnace East Baghouse Stack	Patrick L. Owen
5	Expansion Furnace East Baghouse Stack	Patrick L. Owen
6	Expansion Furnace East Baghouse Stack	Patrick L. Owen

		4	5	6
	RUN DATE	02/01/84	02/01/84	02/01/84
	RUN START TIME	1148	1643	1934
	RUN FINISH TIME	1356	1848	2139
	NET SAMPLING POINTS	24	24	24
Theta	NET RUN TIME, MINUTES	120.00	120.00	120.00
Dia	NOZZLE DIAMETER, INCHES	0.310	0.310	0.310
Cp	PITOT TUBE COEFFICIENT	0.840	0.840	0.840
Y	DRY GAS METER CAL. FACTOR	1.003	1.003	1.003
Pbar	BAROMETRIC PRESSURE, IN. HG.	29.50	29.50	29.50
Delta H	AVG. PRESS. DIFFERENTIAL OF ORIFICE METER, IN. H2O	2.437	2.471	2.492
Vm	VOLUME OF METERED GAS SAMPLE DRY ACTUAL CUBIC FEET	110.483	111.051	110.663
tm	DRY GAS METER TEMP., DEG. F	84	78	79
Vm(std)	VOLUME OF METERED GAS SAMPLE @ DRY STD. COND., DSCF*	106.647	108.400	107.826
Vlc	VOLUME OF WATER CATCH IN IMPINGERS & SIL. GEL.,ML	123.0	135.0	139.5
Vw(std)	VOLUME OF WATER VAPOR, SCF*	5.790	6.354	6.566
%H2O	MOISTURE, PERCENT BY VOLUME	5.1	5.5	5.7
Mfd	DRY MOLE FRACTION	0.949	0.945	0.943

(continued next page)

		4	5	6
%CO2	PERCENT CO2 BY VOLUME, DRY	2.7	2.6	2.8
%O2	PERCENT O2 BY VOLUME, DRY	16.3	15.9	15.9
%CO+N2	PERCENT CO + N2 BY VOLUME, DRY	81.0	81.5	81.3
Md	DRY MOLECULAR WT, LB/LB-MOLE	29.08	29.05	29.08
Ms	WET MOLECULAR WT, LB/LB-MOLE	28.51	28.44	28.45
Ps	STACK STATIC PRESS., IN H2O	-0.2	-0.3	-0.2
Ps	ABSOLUTE STACK PRESS., IN HG	29.49	29.48	29.49
ts	STACK TEMPERATURE, DEG. F	371	376	372
Delta p	AVG VELOCITY HEAD. IN. H2O	0.4052	0.4098	0.4143
vs	STACK GAS VELOCITY, FT/SEC	45.4	45.9	46.0
A	STACK AREA, SQUARE INCHES	176.7	176.7	176.7
Qsd	STACK FLOW RATE, DRY SCFM*	1,986	1,986	1,997
Qaw	STACK FLOW RATE, WET ACFM	3,346	3,380	3,389
%I	PERCENT ISOKINETIC	104.6	106.3	105.2
	METHOD 5 RESULTS:			
mn	CATCH, MILLIGRAMS	130.3	139.4	138.1
Gn/DSCF	CONCENTRATION, GRAINS PER DSCF*	0.0189	0.0198	0.0198
mg/DSCM	MILLIGRAMS PER DSCM	43.142	45.409	45.225
Lb/Hr	EMISSION RATE, POUNDS PER HOUR	0.321	0.338	0.338
Kg/Hr	KILOGRAMS PER HOUR	0.146	0.153	0.153

* 68 Deg. F - 29.92 in. Hg.

APPENDIX 7.1.3

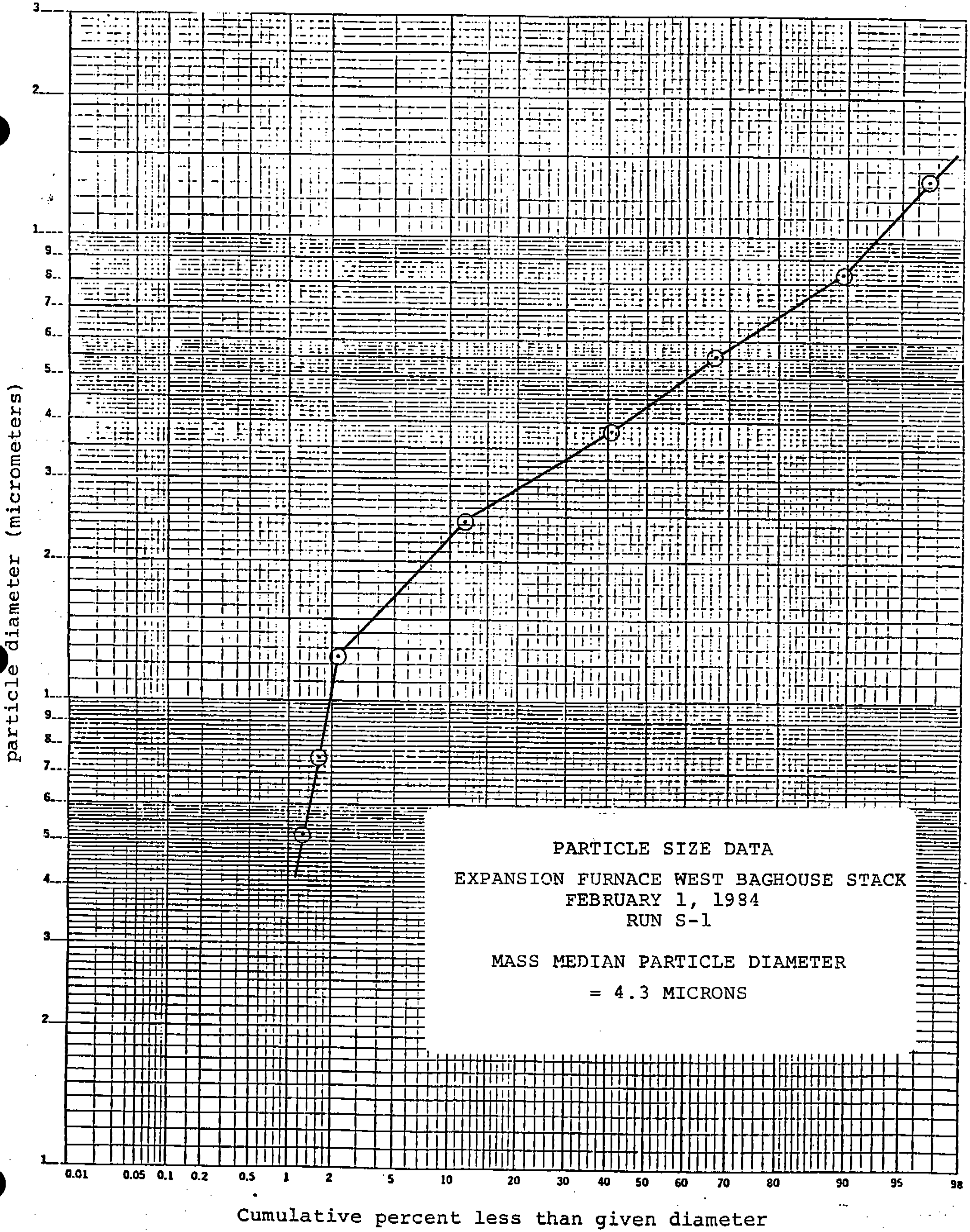
PARTICLE SIZING TEST RESULTS, BAGHOUSE WEST STACK

PARTICLE SIZING TEST SUMMATION

Baghouse West Stack

---------- RUN S1 ----------

AERODYNAMIC DIA.-MICRONS	CUMULATIVE % LESS THAN DIA.
13.3	96.7
8.4	89.8
5.6	67.0
3.9	40.5
2.4	12.0
1.2	2.2
0.8	1.7
0.5	1.3



PARTICLE SIZE DATA

EXPANSION FURNACE WEST BAGHOUSE STACK
FEBRUARY 1, 1984
RUN S-1

MASS MEDIAN PARTICLE DIAMETER

= 4.3 MICRONS

PARTICLE SIZING FIELD DATA & RESULTS TABULATION

RUN S-1

PLANT: W. R. Grace & Company, Irondale, Alabama.

SAMPLING LOCATION: Expansion Furnace West Baghouse Stack   DATE: 020184

	START-FINISH TIME:	0858-1108		VOLUME METERED, ACF:	52.409
SR)	SAMPLING RATE, ACFM	0.718		NOZZLE DIA., INCHES:	0.183
ST)	SAMPLING TIME, MINUTES:	120.00	Y)	METER CAL. FACTOR:	0.993
PB)	BARO. PRESS.,IN.HG.:	29.50	TM)	METER TEMP., DEG F:	69
PSI)	STATIC PRESS., IN. H2O:	-0.10	DH)	DELTA H AVG., IN. H2O:	0.61
TS)	STACK GAS TEMP., DEG F:	368	DEN)	PARTICLE DENSITY, GM/CC:	1.00
PMV)	MOISTURE % BY VOLUME:	5.3	VCF)	VISCOSITY CORR. FACTOR:	1.174
DCF)	DENSITY CORR. FACTOR:	1.000	MD)	MOL WT, DRY LB/LB-MOLE:	29.06
%I)	PERCENT ISOKINETIC	105.7			

STAGE NO.	- PARTICLE DIAMETER - (microns) FROM GRAPH	AERODYNAMIC	CATCH WEIGHT (mgms)	PERCENT OF TOTAL (%)	CUM. % LESS THAN GIVEN DIA
0	11.35	13.32	0.38	3.4	96.7
1	7.13	8.37	0.78	6.9	89.8
2	4.76	5.59	2.58	22.8	67.0
3	3.29	3.86	3.01	26.5	40.5
4	2.08	2.44	3.23	28.5	12.0
5	1.06	1.24	1.11	9.8	2.2
6	0.65	0.76	0.06	0.5	1.7
7	0.44	0.52	0.04	0.4	1.3
FILTER	< 0.44	< 0.52	0.15	1.3	

TOTAL CATCH 11.34

APPENDIX 7.2

FIELD DATA

APPENDIX 7.2.1

PARTICULATE FIELD DATA, BAGHOUSE WEST STACK

Preliminary Field Data

PLANT NAME W. R. GRACE

LOCATION IRONDALE, ALA.

SAMPLING LOCATION BAGHOUSE EAST & WEST STACK

DUCT DEPTH
FROM INSIDE FAR WALL TO OUTSIDE OF PORT 18"

NIPPLE LENGTH 3"

DEPTH OF DUCT 15"

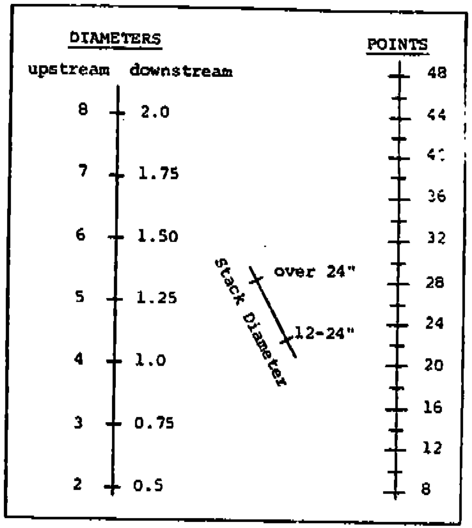
WIDTH (RECTANGULAR DUCT)

EQUIVALENT DIAMETER:

$$D_E = \frac{2 \times \text{DEPTH} \times \text{WIDTH}}{\text{DEPTH} + \text{WIDTH}} = \frac{2(\quad)(\quad)}{(\quad + \quad)} = \times$$

DISTANCE FROM PORTS TO NEAREST FLOW DISTURBANCE:	UPSTREAM	DOWNSTREAM
FEET	5'	1'
STACK DIAMETERS	4	0.[illegible]8

STACK AREA = $(\frac{15}{2})^2 \pi$ = 176.715 IN²



Point	% OF DIAMETER	DISTANCE FROM INSIDE WALL	DISTANCE FROM OUTSIDE OF PORT
1	2.1	[illegible]	3½
2	6.7	1.0	4
3	11.8	1¾	4¾
4	17.7	2⅝	5⅝
5	25.0	3¾	6¾
6	35.6	5⅜	8⅜
7	64.4	9⅝	12⅝
8	75.0	11¼	14¼
9	82.3	12⅜	15⅜
10	88.2	13¼	16¼
11	93.3	14	17
12	97.9	14½	17½
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			

LOCATION OF TRAVERSE POINTS IN CIRCULAR STACKS

	4	6	8	10	12	14	16	18	20	22	24
1	6.7	4.4	3.2	2.6	2.1	1.8	1.6	1.4	1.3	1.1	1.1
2	25.0	14.6	10.5	8.2	6.7	5.7	4.9	4.4	3.9	3.5	3.2
3	75.0	29.6	19.4	14.6	11.8	9.9	8.5	7.5	6.7	6.0	5.5
4	93.3	70.4	32.3	22.6	17.7	14.6	12.5	10.9	9.7	8.7	7.9
5		85.4	67.7	34.2	25.0	20.1	16.9	14.6	12.9	11.6	10.5
6		95.6	80.6	65.8	35.6	26.9	22.0	18.8	16.5	14.6	13.2
7			89.5	77.4	64.4	36.6	28.3	23.6	20.4	18.0	16.1
8			96.8	85.4	75.0	63.4	37.5	29.6	25.0	21.8	19.4
9				91.8	82.3	73.1	62.5	38.2	30.6	26.2	23.0
10				97.4	88.2	79.9	71.7	61.8	38.8	31.5	27.2
11					93.3	85.4	78.0	70.4	61.2	39.3	32.3
12					97.9	90.1	83.1	76.4	69.4	60.7	39.8
13						94.3	87.5	81.2	75.0	68.5	60.2
14						98.2	91.5	85.4	79.6	73.8	67.7
15							95.1	89.1	83.5	78.2	72.8
16							98.4	92.5	87.1	82.0	77.0
17								95.6	90.3	85.4	80.6
18								98.6	93.3	88.4	83.9
19									96.1	91.3	86.8
20									98.7	94.0	89.5
21										96.5	92.1
22										98.9	94.5
23											96.8
24											98.9

LOCATION OF TRAVERSE POINTS IN RECTANGULAR STACKS

	2	3	4	5	6	7	8	9	10	11	12
1	25.0	16.7	12.5	10.0	8.3	7.1	6.3	5.6	5.0	4.5	4.2
2	75.0	50.0	37.5	30.0	25.0	21.4	18.8	16.7	15.0	13.6	12.5
3		83.3	62.5	50.0	41.7	35.7	31.3	27.8	25.0	22.7	20.8
4			87.5	70.0	58.3	50.0	43.8	38.9	35.0	31.8	29.2
5				90.0	75.0	64.3	56.3	50.0	45.0	40.9	37.5
6					91.7	78.6	68.8	61.1	55.0	50.0	45.8
7						92.9	81.3	72.2	65.0	59.1	54.2
8							93.8	83.3	75.0	68.2	62.5
9								94.4	85.0	77.3	70.8
10									95.0	86.4	79.2
11										95.5	87.5
12											95.8

ORSAT FIELD DATA

Plant Name W.R. Grace

Sampling Location Baghouse Stack - West Fuel Type Nat. Gas

Run and/or Sample No. 1 Leak Test? ✓ Date 2-1-84 Operator PLO ~~MLK~~

Time of Sample Collection	Time of Analysis	CO_2 Reading A	O_2 Reading B	CO Reading C	$\%O_2$ B-A	%CO C-B	$\%N_2$ 100-C
1150	1400	2.3	18.8	—	16.5		
↓	↓	2.2	18.9	—	16.7		
1356	1420	2.3	18.8	—	16.5		
	Avg.	2.3		Avg.	16.5		81.2

Run and/or Sample No. 2 Leak Test? ✓ Date 2-1-84 Operator FJP ~~MLK~~

Time of Sample Collection	Time of Analysis	CO_2 Reading A	O_2 Reading B	CO Reading C	$\%O_2$ B-A	%CO C-B	$\%N_2$ 100-C
1638	2030	2.6	18.5	—	15.9		
↓	↓	2.5	18.4	—	15.9		
1843	2100	2.6	18.5	—	15.9		
	Avg.	2.6		Avg.	15.9		81.5

Run and/or Sample No. 3 Leak Test? ✓ Date 2-1-84 Operator MLK

Time of Sample Collection	Time of Analysis	CO_2 Reading A	O_2 Reading B	CO Reading C	$\%O_2$ B-A	%CO C-B	$\%N_2$ 100-C
1932	2315	2.9	18.9	—	16.0		
↓	2330	2.9	18.8	—	15.9		
2145	2345	2.8	18.9	—	16.1		
	Avg.	2.9		Avg.	16.0		81.1

ENTROPY ENVIRONMENTALISTS, INC. SPECIALISTS IN SOURCE SAMPLING

PARTICULATE FIELD DATA

Run # 1

Company Name WR GRACE Time Start 1150
Address IRONDALE, ALA Time Finish 1356
Sampling Location Baghouse STACK WEST
Date 2/1/84 Team Leader GMC Technicians
Barometric Pressure, in. Hg 29.5 Static Pressure, in. H_2O - 0.10
Sampling Train Leak Test Vacuum, in. Hg 15 3
Sampling Train Leak Rate, cu. ft./min. 0.014 0.000

EQUIPMENT CHECKS

- ✓ Pitots, pre-test
- ✓ Pitots, post-test
- ✓ Orsat Sampling System
- ✓ Tedlar Bag
- ✓ Thermocouple @ 370°F

IDENTIFICATION NUMBERS

Reagent Box 0 Nozzle 506 Diameter .252
Meter Box N-5 T/C Readout 009
Umbilical 7 T/C Probe 4-5
Sample Box 8 Orsat Pump 9
Probe 4-1 Tedlar Bag 15

Filter #	Tare
E1517	.5088

NOMOGRAPH SET-UP Nomograph # gmc

$\Delta H_@$ 1.80 C Factor ~~1.01~~ .96
Meter Temp 70 Stack Temp 370
% Moisture 5 Ref. ΔP .68

K= 2.70

	Sample Point	Clock Time, Min.	Dry Gas Meter Reading, Cu. Ft.	Pitot Reading (Δp), In. H_2O	Orifice Setting (ΔH), In. H_2O Ideal	Orifice Setting (ΔH), In. H_2O Actual	Gas Meter Temp. °F	Pump Vacuum In. Hg Gauge	Filter Box Temp. °F	Imp. Exit Temp. °F	Stack Temp. °F	
B	B1	0	339.482	0.57	1.54	1.54	68	1	250	60	340	
	2	5	342.88	0.61	1.65	1.65	70	1.5	250	60	344	
	3	10	346.40	0.65	1.75	1.75	72	2	250	60	346	*
	4	15	350.03	0.70	1.89	1.89	72	2	250	60	350	
	5	20	353.82	0.77	2.08	2.08	72	2	250	60	368	*
	6	25	357.73	0.77	2.08	2.08	72	2	250	60	374	
	7	30	361.67	0.80	2.16	2.16	72	2	250	60	376	
	8	35	365.69	0.80	2.16	2.16	72	2	250	60	376	*
	9	40	369.68	0.83	2.25	2.25	72	2	250	60	374	*
	10	45	373.85	0.86	2.33	2.33	72	2	250	60	374	
	11	50	377.97	0.84	2.27	2.27	73	2	250	60	374	
	12	55	382.11	0.84	2.27	2.27	73	2	250	60	374	
A	A1	60/0	386.240	0.44	1.19	1.19	72	2	250	60	357	
	2	5	389.29	0.65	1.75	1.75	72	2	250	60	355	*
	3	10	392.83	0.66	1.79	1.79	72	2	250	60	356	
	4	15	396.46	0.73	1.98	1.98	73	2	250	60	367	
	5	20	400.31	0.73	1.98	1.98	73	2	250	60	375	
	6	25	404.17	0.75	2.03	2.03	74	2	250	60	380	
	7	30	408.15	0.70	1.89	1.89	74	2	250	60	382	*
	8	35	412.00	0.84	2.27	2.27	75	2	250	60	384	
	9	40	416.06	0.84	2.27	2.27	75	2	250	60	384	
	10	45	420.26	0.86	2.33	2.33	75	2	250	60	386	
	11	50	424.46	0.83	2.25	2.25	75	2.5	250	60	385	
	12	55	428.57	0.83	2.25	2.25	75	2.5	250	60	387	
		60	432.663									

V_m	$(\sqrt{\Delta p})^2$	ΔH	T_m	T_s
93.181	0.7418	2.017	73	370

PARTICULATE FIELD DATA

COMPANY NAME W.R. GRACE
RUN NUMBER 2
ADDRESS IRONDALE, ALABAMA
TIME START 1638
SAMPLING LOCATION BAGHOUSE STACK WEST
TIME FINISH 1843
DATE 2·1·84
TEAM LEADER FJP
TECHNICIANS GMC
BAROMETRIC PRESSURE, IN. HG 29.5
STATIC PRESSURE, IN. H_2O -0.22
SAMPLING TRAIN LEAK TEST VACUUM, IN. HG 15 5
SAMPLING TRAIN LEAK RATE, CU. FT./MIN. 0.011 0.002

EQUIPMENT CHECKS

- ✓ PITOTS, PRE-TEST
- ✓ PITOTS, POST-TEST
- ✓ ORSAT SAMPLING SYSTEM
- ✓ TEDLAR BAG
- ✓ THERMOCOUPLE @ 370 °F

IDENTIFICATION NUMBERS

REAGENT BOX
NOZZLE 506
DIAMETER .252
METER BOX N-5
T/C READOUT 009
UMBILICAL 7
T/C PROBE 4-5
SAMPLE BOX 8
ORSAT PUMP 9
PROBE 4-1
TEDLAR BAG 15

FILTER #	TARE
E1508	.5132

NOMOGRAPH SET-UP

NOMOGRAPH # GMC
ΔH@ 1.80
C FACTOR .96
METER TEMP 70
STACK TEMP 370 / 390
% MOISTURE 5
REF. ΔP .68 / .69

SAMPLE POINT	CLOCK TIME, MIN.	DRY GAS METER READING, CU. FT.	PITOT READING (ΔP), IN. H_2O	ORIFICE SETTING (ΔH), IN. H_2O		GAS METER TEMP. °F	PUMP VACUUM IN. HG GAUGE	FILTER BOX TEMP. °F	IMP. EXIT TEMP. °F	STACK TEMP. °F	
				IDEAL	ACTUAL						
A 1	0/0	433.420	0.67	1.81	1.81	66	3	250	65	358	
2	5	437.07	0.70	1.89	1.89	66	3	250	63	367	
3	10	440.77	0.66	1.79	1.79	67	3	250	60	368	
4	15	444.48	0.64	1.73	1.73	68	3	250	60	372	
5	20	448.02	0.67	1.81	1.81	69	3	250	60	378	*
6	25	451.75	0.76	2.06	2.06	70	4	250	60	389	
7	30	455.71	0.74	2.00	2.00	70	4	250	60	390	
8	35	459.51	0.75	2.03	2.03	70	4	250	60	390	
9	40	463.49	0.76	2.06	2.06	70	4	250	60	393	Changed Nom'o
10	45	467.50	0.75	2.00	2.00	70	4	250	60	396	–
11	50	471.43	0.76	2.03	2.03	70	4	250	60	395	*
12	55	475.36	0.81	2.16	2.16	70	4	250	60	398	
B 1	0/0	479.38	0.50	1.33	1.33	68	3.5	250	60	361	
2	5	482.60	0.56	1.49	1.49	70	3.0	250	60	370	
3	10	485.92	0.58	1.55	1.55	72	3.0	250	60	375	
4	15	489.35	0.66	1.76	1.76	72	3.0	250	60	375	*
5	20	493.00	0.72	1.92	1.92	74	3.5	250	60	387	*
6	25	497.00	0.75	2.00	2.00	75	4.0	250	60	391	
7	30	500.75	0.77	2.05	2.05	75	4.0	250	60	395	
8	35	504.69	0.73	1.93	1.93	75	4.0	250	60	391	
9	40	508.54	0.75	2.00	2.00	75	4.0	250	60	389	
10	45	512.46	0.75	2.00	2.00	75	4.0	250	60	386	*
11	50	516.39	0.80	2.13	2.13	75	4.0	250	60	389	
12	55	520.41	0.83	2.21	2.21	75	4.0	250	60	388	
	60/off	524.536									
	/	9									

V_M	$(\sqrt{\Delta P})^2$	ΔH	T_M	T_S
91.116	0.7089	1.906	71	383

ENTROPY

PARTICULATE FIELD DATA

COMPANY NAME W. R. GRACE
RUN NUMBER 3
ADDRESS IRONDALE, ALABAMA
TIME START 19:32
SAMPLING LOCATION BAGHOUSE STACK WEST
TIME FINISH 21:45
DATE 2·1·84
TEAM LEADER WSN
TECHNICIANS —
BAROMETRIC PRESSURE, IN. HG 29.5
STATIC PRESSURE, IN. H_2O -0.36
SAMPLING TRAIN LEAK TEST VACUUM, IN. HG 15 3 3
SAMPLING TRAIN LEAK RATE, CU. FT./MIN. 0.004 0.000 0.000

EQUIPMENT CHECKS

- ✓ PITOTS, PRE-TEST
- ✓ PITOTS, POST-TEST
- ✓ ORSAT SAMPLING SYSTEM
- ✓ TEDLAR BAG
- ✓ THERMOCOUPLE @ 390 °F

IDENTIFICATION NUMBERS

REAGENT BOX
NOZZLE 506
DIAMETER .252
METER BOX N-5
T/C READOUT 009
UMBILICAL 7
T/C PROBE 4-5
SAMPLE BOX 8
ORSAT PUMP 9
PROBE 4-1
TEDLAR BAG 10

FILTER #	TARE
E1635	.5182

NOMOGRAPH SET-UP

NOMOGRAPH # 9MC
ΔH@ 1.80
C FACTOR 0.97
METER TEMP 70
STACK TEMP 390
% MOISTURE 5
REF. ΔP ~~.69~~ 0.72

SAMPLE POINT	CLOCK TIME, MIN.	DRY GAS METER READING, CU. FT.	PITOT READING (ΔP), IN. H_2O	ORIFICE SETTING (ΔH), IN. H_2O IDEAL	ORIFICE SETTING (ΔH), IN. H_2O ACTUAL	GAS METER TEMP. °F	PUMP VACUUM IN. HG GAUGE	FILTER BOX TEMP. °F	IMP. EXIT TEMP. °F	STACK TEMP. °F
B 1	0/0	524.778	0.63	1.65	1.65	68	2	270	57	360
2	5	528.21	0.70	1.82	1.82	68	2	267	57	372
3	10	532.02	0.67	1.76	1.76	68	2	265	57	374
4	15	535.56	0.70	1.82	1.82	67	2	268	57	368
5	20	539.37	0.72	1.84	1.84	67	2	266	58	377
6	25	543.14	0.76	1.98	1.98	65	2	266	58	386
7	30	546.92	0.76	1.98	1.98	65	2	266	58	382
8	35	550.84	0.76	1.98	1.98	66	2	265	58	385
9	40	554.69	0.78	2.05	2.05	67	2	265	58	382
10	45	558.64	0.82	2.13	2.13	68	2	268	58	381
11	50	562.56	0.82	2.13	2.13	68	2	270	58	379
12	55	566.65	0.80	2.10	2.10	68	2	273	58	381
A 1	60/0	570.570	0.65	1.70	1.70	67	2	270	59	366
2	5	574.40	0.68	1.79	1.79	67	2	272	59	370
3	10	577.87	0.72	1.84	1.84	68	2	272	60	376
4	15	581.65	0.72	1.84	1.84	68	2	275	58	380
5	20	585.43	0.73	1.90	1.90	68	2	272	58	377
6	25	589.35	0.74	1.95	1.95	68	2	272	58	382
7	30	593.15	0.74	1.95	1.95	68	2	272	58	383
8	35	597.09	0.76	1.98	1.98	68	2	272	58	384
9	40	600.85	0.78	2.05	2.05	68	2	272	58	386
10	45	604.84	0.85	2.25	2.25	68	2	270	58	385
11	60	608.86	0.85	2.25	2.25	68	2	268	58	384
12	55	613.14	0.82	2.13	2.13	68	2	266	58	382
	60/off	617.148								

~~570~~.
L.C.
570.548
570.570

V_M	$(\sqrt{\Delta P})^2$	ΔH	T_M	T_S
92.348	0.7472	1.953	67	378

PARTICULATE SAMPLING LABORATORY RESULTS

Plant Name W.R. GRACE EEI Ref. # 3002
Sampling Location EXPANSION FURNACE WEST BAGHOUSE STACK
Date Received 2/3/84 Date Analyzed 2/8/84 Reagent Box(es) 0223

Run Number	1	2	3
Run Date	2/1	2/2	2/2

SUMMARY OF PARTICULATE ANALYSES

Sum of Particulate, mg.	574.3	591.1	580.5
Total Filter Tare mg.	508.8	513.2	518.2
Blank Residue, mg.	(150 ml) 0.5	(200 ml) 0.7	(175 ml) 0.6
TOTAL PARTICULATE CATCH, mg.	65.0	77.2	61.7

ANALYSIS OF MOISTURE CATCH

Reagent 1 (H_2O):			
Final Weight, g.	268.0	280.0	298.0
Tared Weight, g.	200.0	200.0	200.0
Water Catch, g.	68.0	80.0	98.0
Reagent 2 ( ):			
Final Weight, g.	–	–	–
Tared Weight, g.	–	–	–
Water Catch, g.	–	–	–
CONDENSED WATER, g.	68.0	80.0	98.0
Silica Gel:			
Final Weight, g.	227.5	231.0	221.0
Tared Weight, g.	200.0	200.0	200.0
ABSORBED WATER, g.	27.5	31.0	21.0
TOTAL WATER COLLECTED, g.	95.5	111.0	119.0

Blank Beaker #	63
Final wt. mg.	64218.3
Tare wt. mg.	64217.6
Residue, mg.	0.7
Volume, ml.	200
Concen., mg/ml.	.0035

--- Legend ---

✓ = Final Weight
L = Loose Particulate
F = Filter D = Dish
R = Rinse P = Pan

Notes and Comments

LABORATORY SAMPLE WEIGHT CALCULATIONS

Plant Name W.R. GRACE

EEI Ref. # 3002

Run Number	1	2	3
Run Date	2/1	2/2	2/2
Sample ID/Container #	FiR - 134	FiR - 644	FiR - 645
	185.7896 ✓185.7893 185.7897 185.7944	186.2538 ✓186.2537 186.2539 186.2584	185.9207 ✓185.9205 185.9211 185.9260
Tare Wt., g.	185.2150	185.6626	185.3400
SAMPLE WT., g.	.5743	.5911	.5805
Sample ID/Container #			
Tare Wt., g.			
SAMPLE WT., g.			
Sample ID/Container #			
Tare Wt., g.			
SAMPLE WT., g.			
Sample ID/Container #			
Tare Wt., g.			
SAMPLE WT., g.			

CUSTODY SHEET FOR REAGENT BOX # 0223

Date of Makeup 1/25/84 Initials BD Locked? ✓

Individual Tare of Reagent: 200 mls. of Distilled H2O

Individual Tare of Reagent: ______ mls. of ______

Individual Silica Gel Tare Weight 200 gms.

PLANT NAME W.R. Grace - Irondale, Alabama

SAMPLING LOCATION Baghouse St. (West)

Run Number	Date Used	Initials	Locked?	Date Cleanup	% S. Gel Spent	Initials	Locked?
1	2/1/84	WSN	✓	2/1/84	.40	WSN	✓
2	2/2/84	HDL	✓	2/2/84	.95	HDL	✓
3	2/2/84	HDL	✓	2/2/84	.70	HDL	✓

	Date	Initials	Locked?
Received in Lab	2/3/84	MG	✓

Sampling Method: M-5 w/backhalf

Zero & Span Balance Initials MG

Filter #	Tare Weight (mgms)	Used on Test
E 1517	.5088	1
E 1508	.5132	2
E 1635	.5182	3

Remarks:

TRACE METALS ANALYSIS

Baghouse West Stack - Run 2

Element	Molecular Weight	Total Micrograms*	Concen., ppm, dry
Aluminum (Al)	26.98	4,210	1.488
Beryllium (Be)	9.01	ND	-
Calcium (Ca)	40.08	17,780	4.230
Chromium (Cr)	52.00	26.7	0.00490
Fluorine (F)	19.00	1,000	0.502
Iron (Fe)	55.85	985	0.168
Lead (Pb)	207.19	16.1	0.000741
Magnesium (Mg)	24.31	443.9	0.174
Manganese (Mn)	54.94	29.4	0.00510
Mercury (Hg)	200.59	1.27	0.00006
Nichel (Ni)	58.71	45.2	0.00736
Titanium (Ti)	47.90	57.0	0.0114
Uranium (U)	238.03	ND	-
Vanadium (Va)	50.94	ND	-
Zinc (Zn)	65.38	187.8	0.0274

* Sum of catch from filter/probe rinse and impinger reagent.

APPENDIX 7.2.2

PARTICULATE FIELD DATA, BAGHOUSE EAST STACK

ORSAT FIELD DATA

Plant Name W. R. GRACE

Sampling Location BAGHOUSE STACK - EAST Fuel Type NATURAL GAS

Run and/or Sample No. 4 Leak Test? ✓ Date 2/1 Operator PLO

Time of Sample Collection	Time of Analysis	CO_2 Reading A	O_2 Reading B	CO Reading C	$\%O_2$ B-A	%CO C-B	$\%N_2$ 100-C
1148	1410	2.7	19.0 ~~16.3~~	19.0	16.3	0	
↓	1420	2.7	19.0	19.0	16.3	0	
1356	1430	2.7	19.0	19.0	16.3	0	
	Avg.	2.7		Avg.	16.3	0	81.0

Run and/or Sample No. 5 Leak Test? ✓ Date 2/1 Operator FJP

Time of Sample Collection	Time of Analysis	CO_2 Reading A	O_2 Reading B	CO Reading C	$\%O_2$ B-A	%CO C-B	$\%N_2$ 100-C
1643	19:30	2.6	18.5	18.5	15.9	0	
to	19:40	2.7	18.5	18.5	15.8	0	
1848	19:50	2.6	18.5	18.5	15.9	0	
	Avg.	2.6		Avg.	15.9	0	81.5

Run and/or Sample No. 6 Leak Test? ✓ Date 2/1 Operator MLK

Time of Sample Collection	Time of Analysis	CO_2 Reading A	O_2 Reading B	CO Reading C	$\%O_2$ B-A	%CO C-B	$\%N_2$ 100-C
19:34	22:30	2.7	18.7	—	16.0		
↓	22:45	2.8	18.6	—	15.8		
21:39	23:00	2.8	18.7	—	15.9		
	Avg.	2.8		Avg.	15.9		81.3

PARTICULATE FIELD DATA

Run # 4

Company Name W. R. GRACE Time Start 1148
Address IRONDALE, ALA. Time Finish 1356
Sampling Location BAGHOUSE STACK - EAST SIDE
Date 2/1/84 Team Leader Pco Technicians —
Barometric Pressure, in. Hg 29.50 Static Pressure, in. H_2O -.20
Sampling Train Leak Test Vacuum, in. Hg 15 5.0
Sampling Train Leak Rate, cu. ft./min. 0.006 0.000

EQUIPMENT CHECKS	IDENTIFICATION NUMBERS			
✓ Pitots, pre-test	Reagent Box 0219	Nozzle 508	Diameter .310	
✓ Pitots, post-test	Meter Box	N-10	T/C Readout	5
✓ Orsat Sampling System	Umbilical	U-4	T/C Probe	3-9
✓ Tedlar Bag	Sample Box	21-B	Orsat Pump	5
✓ Thermocouple @ 375 °F	Probe	4-1	Tedlar Bag	12

Filter #	Tare	NOMOGRAPH SET-UP		Nomograph # Pco	
E1636	.5205	$\Delta H_@$	1.68	C Factor	0.96
		Meter Temp	80	Stack Temp	375
		% Moisture	4	Ref. ΔP	0.31

K= 5.9354839

Sample Point	Clock Time, Min.	Dry Gas Meter Reading, Cu. Ft.	Pitot Reading (Δp), In. H_2O	Orifice Setting (ΔH), In. H_2O Ideal	Orifice Setting (ΔH), In. H_2O Actual	Gas Meter Temp. °F	Pump Vacuum In. Hg Gauge	Filter Box Temp. °F	Imp. Exit Temp. °F	Stack Temp. °F
A/1	0/0	015.792	0.27	1.60	1.60	76	2.0	240	60	346
2	5	019.634	0.28	1.66	1.66	78	2.0	250	60	351
3	10	023.378	0.29	1.72	1.72	80	2.0	250	58	353
4	15	027.250	0.28	1.66	1.66	80	2.0	245	58	350
5	20	031.039	0.31	1.84	1.84	80	2.0	245	59	364
6	25	035.032	0.37	2.20	2.20	82	2.0	245	60	377
7	30	039.384	0.41	2.43	2.45	82	3.0	250	60	382
8	35	044.010	0.56	3.32	3.32	83	3.0	250	60	384
9	40	049.352	0.58	3.44	3.44	84	3.0	250	61	384
10	45	054.888	0.56	3.32	3.32	85	3.0	250	61	380
11	50	060.326	0.50	2.97	2.97	86	3.0	250	62	377
12	55	065.465	0.50	2.97	2.97	86	3.0	255	62	375
B/1	60/0	070.589	0.36	2.14	2.14	82	2.0	245	65	361
2	5	074.946	0.33	1.96	1.96	84	2.0	245	63	362
3	10	079.093	0.34	2.02	2.02	84	2.0	245	63	374
4	15	083.300	0.36	2.14	2.14	84	2.0	245	62	369
5	20	087.670	0.37	2.20	2.20	85	2.0	245	62	363
6	25	092.046	0.43	2.55	2.55	86	3.0	250	62	380
7	30	096.738	0.48	2.85	2.85	86	3.0	250	62	382
8	35	101.685	0.46	2.73	2.73	86	3.0	250	63	380
9	40	106.723	0.43	2.55	2.55	88	3.0	255	63	378
10	45	111.491	0.43	2.55	2.55	88	3.0	255	63	377
11	50	116.260	0.46	2.73	2.73	86	3.0	250	63	374
12	55	121.121	0.49	2.91	2.91	86	3.0	250	63	377
	120/OFF	126.275								

110.483	0.4052	2437	84	371
V_m	$(\overline{\sqrt{\Delta p}})^2$	$\overline{\Delta H}$	$\overline{T_m}$	$\overline{T_s}$

PARTICULATE FIELD DATA

Run # 5

Company Name W.R. GRACE
Time Start #1643
Address ARONDALE, ALA.
Time Finish 1848
Sampling Location BAGHOUSE STACK -EAST SIDE
Date 2/1/84 Team Leader Pco Technicians
Barometric Pressure, in. Hg 29.50 Static Pressure, in. H_2O -.25
Sampling Train Leak Test Vacuum, in. Hg 15 5.0
Sampling Train Leak Rate, cu. ft./min. 0.014 0.002

EQUIPMENT CHECKS

✓ Pitots, pre-test
✓ Pitots, post-test
✓ Orsat Sampling System
✓ Tedlar Bag
✓ Thermocouple @ 375 °F

IDENTIFICATION NUMBERS

Reagent Box 0219 Nozzle 508 Diameter .310
Meter Box N-10 T/C Readout 5
Umbilical U-4 T/C Probe 3-9
Sample Box 21-B Orsat Pump 5
Probe 4-1 Tedlar Bag 2

Filter #	Tare
E1514	.5156

NOMOGRAPH SET-UP Nomograph # Pco

$\Delta H_@$ 1.68 C Factor 0.95
Meter Temp 80 Stack Temp 375
% Moisture 5 Ref. ΔP 0.31

K = 5.9354839

Sample Point	Clock Time, Min.	Dry Gas Meter Reading, Cu. Ft.	Pitot Reading (Δp), In. H_2O	Orifice Setting (ΔH), In. H_2O Ideal	Orifice Setting (ΔH), In. H_2O Actual	Gas Meter Temp. °F	Pump Vacuum In. Hg Gauge	Filter Box Temp. °F	Imp. Exit Temp. °F	Stack Temp. °F
A/1	0/0	127.584	0.26	1.54	1.54	78	2.0	240	56	338
2	5	131.278	0.26	1.54	1.54	78	2.0	240	55	344
3	10	134.948	0.27	1.60	1.60	80	2.0	250	55	354
4	15	138.684	0.29	1.72	1.72	80	2.0	265	58	358
5	20	142.570	0.36	2.14	2.14	82	3.0	255	58	371
6	25	146.888	0.40	2.37	2.37	82	3.0	255	58	~~446~~ 380
7	30	151.432	0.47	2.79	2.79	82	3.0	250	58	389
8	35	156.298	0.49	2.91	2.91	82	3.0	250	60	390
9	40	161.526	0.54	3.21	3.21	82	4.0	250	60	391
10	45	166.851	0.56	3.32	3.32	82	4.0	250	60	391
11	50	172.300	0.57	3.38	3.38	82	4.0	250	60	393
12	55	177.787	0.52	3.09	3.09	82	4.0	250	60	392
B/1	60/0	183.091	0.30	1.78	1.78	76	2.0	250	56	347
2	5	187.067	0.33	1.96	1.96	76	2.0	245	58	352
3	10	191.191	0.34	2.02	2.02	76	3.0	250	58	359
4	15	195.434	0.38	2.26	2.26	75	3.0	250	58	386
5	20	199.840	0.37	2.20	2.20	74	3.0	250	60	382
6	25	204.284	0.37	2.20	2.20	74	3.0	250	60	388
7	30	208.595	0.44	2.61	2.61	74	3.0	250	60	388
8	35	213.421	0.50	2.97	2.97	74	4.0	250	60	393
9	40	218.356	0.58	3.44	3.44	74	4.0	260	60	391
10	45	223.847	0.54	3.21	3.21	73	4.0	250	59	390
11	50	229.186	0.44	2.61	2.61	72	4.0	250	59	382
12	55	233.975	0.41	2.43	2.43	72	3.0	250	59	380
	120/OFF	238.635								

111.051 V_m

0.4098 $(\overline{\sqrt{\Delta p}})^2$

2.471 $\overline{\Delta H}$

78 $\overline{T_m}$

376 $\overline{T_s}$

PARTICULATE FIELD DATA

Run # 6

Company Name W. R. GRACE
Time Start 1934
Address IRONDALE, ALA.
Time Finish 2139
Sampling Location BAGHOUSE STACK - EAST SIDE
Date 2/1/84
Team Leader Pco
Technicians
Barometric Pressure, in. Hg 29.50
Static Pressure, in. H_2O -.20
Sampling Train Leak Test Vacuum, in. Hg 15 5.0
Sampling Train Leak Rate, cu. ft./min. 0.02 0.008

EQUIPMENT CHECKS

✓ Pitots, pre-test
✓ Pitots, post-test
✓ Orsat Sampling System
✓ Tedlar Bag
✓ Thermocouple @ 375 °F

IDENTIFICATION NUMBERS

Reagent Box 0219
Nozzle 508
Diameter .310
Meter Box N-10
T/C Readout 5
Umbilical U-4
T/C Probe 3-9
Sample Box 21-B
Orsat Pump 5
Probe 4-1
Tedlar Bag

Filter #	Tare
E1634	.5294

NOMOGRAPH SET-UP
Nomograph # Pco

$\Delta H_@$ 1.68
C Factor 0.95
Meter Temp 80
Stack Temp 375
% Moisture 5
Ref. ΔP 0.31

Sample Point	Clock Time, Min.	Dry Gas Meter Reading, Cu. Ft.	Pitot Reading (Δp), In. H_2O	Orifice Setting (ΔH), In. H_2O Ideal	Orifice Setting (ΔH), In. H_2O Actual	Gas Meter Temp. °F	Pump Vacuum In. Hg Gauge	Filter Box Temp. °F	Imp. Exit Temp. °F	Stack Temp. °F
A/1	0/0	238.917	0.24	1.42	1.42	68	2.0	240	60	339
2	5	242.430	0.27	1.60	1.60	69	2.0	240	58	346
3	10	246.117	0.28	1.66	1.66	72	2.0	245	55	343
4	15	249.894	0.31	1.84	1.84	74	2.0	245	65	367
5	20	253.880	0.33	1.96	1.96	75	2.0	245	55	367
6	25	257.985	0.39	2.31	2.31	76	2.0	250	56	383
7	30	262.431	0.45	2.67	2.67	76	2.0	250	56	385
8	35	267.268	0.54	3.21	3.21	78	3.0	255	57	385
9	40	272.474	0.57	3.38	3.38	79	4.0	255	57	389
10	45	277.875	0.58	3.44	3.44	80	4.0	255	57	372
11	50	283.390	0.47	2.79	2.79	80	3.0	255	57	376
12	55	288.384	0.50	2.97	2.97	80	3.0	250	58	372
B/1	60/0	293.462	0.35	2.08	2.08	78	2.0	250	61	355
2	5	297.750	0.36	2.14	2.14	79	2.0	250	60	359
3	10	301.175	0.39	2.31	2.31	80	3.0	250	60	374
4	15	306.460	0.39	2.31	2.31	80	3.0	245	60	377
5	20	310.892	0.37	2.20	2.20	82	3.0	245	60	372
6	25	315.248	0.40	2.37	2.37	82	3.0	250	60	378
7	30	319.700	0.47	2.79	2.79	82	3.0	250	61	384
8	35	324.608	0.57	3.38	3.38	84	4.0	255	61	387
9	40	330.000	0.55	3.26	3.26	84	4.0	255	61	387
10	45	335.368	0.46	2.73	2.73	84	3.0	255	61	378
11	50	340.271	0.43	2.55	2.55	84	3.0	250	61	373
12	55	344.959	0.41	2.43	2.43	82	3.0	250	62	369
	120/OFF	349.580								

110.663	0.4143	2.492	79	372
V_m	$(\sqrt{\Delta p})^2$	ΔH	T_m	T_s

PARTICULATE SAMPLING LABORATORY RESULTS

Plant Name W. R. GRACE EEI Ref. # 3002

Sampling Location EXPANSION FURNACE EAST BAGHOUSE STACK

Date Received 2/3/84 Date Analyzed 2/8/84 Reagent Box(es) 0219

Run Number	4	5	6
Run Date	2/1	2/1	2/1

SUMMARY OF PARTICULATE ANALYSES

Sum of Particulate, mg.	651.2	655.8	668.1
Total Filter Tare mg.	520.5	515.6	529.4
Blank Residue, mg.	(100 ml) 0.4	(225 ml) 0.8	(175 ml) 0.6
TOTAL PARTICULATE CATCH, mg.	130.3	139.4	138.1

ANALYSIS OF MOISTURE CATCH

Reagent 1 (H_2O):			
Final Weight, g.	292.0	298.0	306.0
Tared Weight, g.	200.0	200.0	200.0
Water Catch, g.	92.0	98.0	106.0
Reagent 2 ( ):			
Final Weight, g.	-	-	-
Tared Weight, g.	-	-	-
Water Catch, g.	-	-	-
CONDENSED WATER, g.	92.0	98.0	106.0
Silica Gel:			
Final Weight, g.	231.0	237.0	233.5
Tared Weight, g.	200.0	200.0	200.0
ABSORBED WATER, g.	31.0	37.0	33.5
TOTAL WATER COLLECTED, g.	123.0	135.0	139.5

Blank Beaker # 63

Final wt. mg. 64218.3

Tare wt. mg. 64217.6

Residue, mg. 0.7

Volume, ml. 200

Concen., mg/ml. .0035

--- Legend ---

✓ = Final Weight

L = Loose Particulate

F = Filter D = Dish

R = Rinse P = Pan

Notes and Comments

LABORATORY SAMPLE WEIGHT CALCULATIONS

Plant Name W.R. GRACE

EEI Ref. # 3002

Run Number	4	5	6
Run Date	2/1	2/1	2/1
Sample ID/Container #	F&R-646	F&R-647	F&R-650
	184.5998 ✓184.5996 184.5999	186.0253 ✓186.0249 186.0258 186.0301	186.7404 ✓186.7402 186.7452
Tare Wt., g.	183.9484	185.3691	186.0721
SAMPLE WT., g.	.6512	.6558	.6681
Sample ID/Container #			
Tare Wt., g.			
SAMPLE WT., g.			
Sample ID/Container #			
Tare Wt., g.			
SAMPLE WT., g.			
Sample ID/Container #			
Tare Wt., g.			
SAMPLE WT., g.			

CUSTODY SHEET FOR REAGENT BOX # 0219

Date of Makeup 1/25/84 Initials BD Locked? ✓

Individual Tare of Reagent: 200 mls. of Distilled H2O

Individual Tare of Reagent: ______ mls. of ______

Individual Silica Gel Tare Weight 200 gms.

PLANT NAME WR GRACE

SAMPLING LOCATION BAGHOUSE STACK - EAST SIDE

Run Number	Date Used	Initials	Locked?	Date Cleanup	% S. Gel Spent	Initials	Locked?
4	2/1/84	PLO	✓	2/1/84	100	PLO	✓
5	2/1/84	PLO	✓	2/1/84	100	PLO	✓
6	2/1/84	PLO	✓	2/1/84	95	PLO	✓

Received in Lab Date 2/3/84 Initials WG Locked? ✓

Sampling Method: EPA 5

Remarks:

Zero & Span Balance Initials WG

Filter #	Tare Weight (mgms)	Used on Test
E 1636	.5205	4
E 1514	.5156	5
E 1634	.5294	6

ENTROPY ENVIRONMENTALISTS, INC.

TRACE METALS ANALYSIS

Baghouse East Stack - Run 5

Element	Molecular Weight	Total Micrograms*	Concen., ppm, dry
Aluminum (Al)	26.98	5,340	1.576
Beryllium (Be)	9.01	ND	-
Calcium (Ca)	40.08	13,890	2.760
Chromium (Cr)	52.00	29.5	0.00452
Fluorine (F)	19.00	2,800	1.174
Iron (Fe)	55.85	5,920	0.844
Lead (Pb)	207.19	8.25	0.000317
Magnesium (Mg)	24.31	723.8	0.237
Manganese (Mn)	54.94	54.6	0.00792
Mercury (Hg)	200.59	1.86	0.000074
Nichel (Ni)	58.71	239	0.0324
Titanium (Ti)	47.90	71.8	0.0119
Uranium (U)	238.03	ND	-
Vanadium (Va)	50.94	ND	-
Zinc (Zn)	65.38	54.1	0.00659

* Sum of catch from filter/probe rinse and impinger reagent.

APPENDIX 7.2.3

PARTICLE SIZING FIELD DATA, BAGHOUSE WEST STACK

Preliminary Field Data

PLANT NAME W.R. GRACE

LOCATION IRONDALE, ALABAMA

SAMPLING LOCATION BAGHOUSE STACK

DUCT DEPTH
FROM INSIDE FAR WALL TO OUTSIDE OF PORT 18"

NIPPLE LENGTH 3"

DEPTH OF DUCT 15"

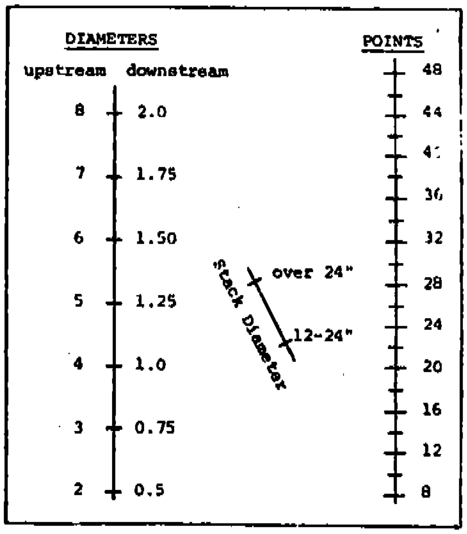
WIDTH (RECTANGULAR DUCT) ____

EQUIVALENT DIAMETER:

$$D_E = \frac{2 \times \text{DEPTH} \times \text{WIDTH}}{\text{DEPTH} + \text{WIDTH}} = \frac{2(\quad)(\quad)}{(\quad + \quad)} = \_\_\_\_$$

DISTANCE FROM PORTS TO NEAREST FLOW DISTURBANCE:	UPSTREAM	DOWNSTREAM
FEET	5'	1'
STACK DIAMETERS	4	0.8

STACK AREA = $(7.5)^2(\pi)$ = 176.7 IN²



PARTICLE SIZING

Point	% OF DIAMETER	DISTANCE FROM INSIDE WALL	DISTANCE FROM OUTSIDE OF PORT
1	.15	2¼"	5¼"
2	.85	12¾"	15¾"
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			

LOCATION OF TRAVERSE POINTS IN CIRCULAR STACKS

	4	6	8	10	12	14	16	18	20	22	24
1	6.7	4.4	3.2	2.6	2.1	1.8	1.6	1.4	1.3	1.1	1.1
2	25.0	14.6	10.5	8.2	6.7	5.7	4.9	4.4	3.9	3.5	3.2
3	75.0	29.6	19.4	14.6	11.8	9.9	8.5	7.5	6.7	6.0	5.5
4	93.3	70.4	32.3	22.6	17.7	14.6	12.5	10.9	9.7	8.7	7.9
5		85.4	67.7	34.2	25.0	20.1	16.9	14.6	12.9	11.6	10.5
6		95.6	80.6	65.8	35.6	26.9	22.0	18.8	16.5	14.6	13.2
7			89.5	77.4	64.4	36.6	28.3	23.6	20.4	18.0	16.1
8			96.8	85.4	75.0	63.4	37.5	29.6	25.0	21.8	19.4
9				91.8	82.3	73.1	62.5	38.2	30.6	26.2	23.0
10				97.4	88.2	79.9	71.7	61.8	38.8	31.5	27.2
11					93.3	85.4	78.0	70.4	61.2	39.3	32.3
12					97.9	90.1	83.1	76.4	69.4	60.7	39.8
13						94.3	87.5	81.2	75.0	68.5	60.2
14						98.2	91.5	85.4	79.6	73.8	67.7
15							95.1	89.1	83.5	78.2	72.8
16							98.4	92.5	87.1	82.0	77.0
17								95.6	90.3	85.4	80.6
18								98.6	93.3	88.4	83.9
19									96.1	91.3	86.8
20									98.7	94.0	89.5
21										96.5	92.1
22										98.9	94.5
23											96.8
24											98.9

LOCATION OF TRAVERSE POINTS IN RECTANGULAR STACKS

	2	3	4	5	6	7	8	9	10	11	12
1	25.0	16.7	12.5	10.0	8.3	7.1	6.3	5.6	5.0	4.5	4.2
2	75.0	50.0	37.5	30.0	25.0	21.4	18.8	16.7	15.0	13.6	12.5
3		83.3	62.5	50.0	41.7	35.7	31.3	27.8	25.0	22.7	20.8
4			87.5	70.0	58.3	50.0	43.8	38.9	35.0	31.8	29.2
5				90.0	75.0	64.3	56.3	50.0	45.0	40.9	37.5
6					91.7	78.6	68.8	61.1	55.0	50.0	45.8
7						92.9	81.3	72.2	65.0	59.1	54.2
8							93.8	83.3	75.0	68.2	62.5
9								94.4	85.0	77.3	70.8
10									95.0	86.4	79.2
11										95.5	87.5
12											95.8

ORSAT FIELD DATA

Plant Name W.R. Grace

Sampling Location Baghouse STACK West Fuel Type NATURAL GAS

Run and/or Sample No. S-1 Leak Test? ✓ Date 2·1·84 Operator 110

Time of Sample Collection	Time of Analysis	CO_2 Reading A	O_2 Reading B	CO Reading C	$\%O_2$ B-A	%CO C-B	$\%N_2$ 100-C
8:58	12:00	2.5	19.4		16.9		
↓	12:10	2.5	19.4		16.9		
11:08	12:25	2.5	19.4		16.9		
	Avg.	2.5		Avg.	16.9		80.6

Run and/or Sample No. ______ Leak Test? ______ Date ______ Operator ______

Time of Sample Collection	Time of Analysis	CO_2 Reading A	O_2 Reading B	CO Reading C	$\%O_2$ B-A	%CO C-B	$\%N_2$ 100-C
	Avg.			Avg.			

Run and/or Sample No. ______ Leak Test? ______ Date ______ Operator ______

Time of Sample Collection	Time of Analysis	CO_2 Reading A	O_2 Reading B	CO Reading C	$\%O_2$ B-A	%CO C-B	$\%N_2$ 100-C
	Avg.			Avg.			

PARTICULATE FIELD DATA

COMPANY NAME W. R. GRACE
RUN NUMBER S-1
ADDRESS IRONDALE, ALABAMA
TIME START 0858
SAMPLING LOCATION BAGHOUSE STACK WEST
TIME FINISH 1108
DATE 2·1·84
TEAM LEADER FJP
TECHNICIANS gmc
BAROMETRIC PRESSURE, IN. HG 29.5
STATIC PRESSURE, IN. H_2O -0.10
SAMPLING TRAIN LEAK TEST VACUUM, IN. HG 10 2
SAMPLING TRAIN LEAK RATE, CU. FT./MIN. .02 .009

EQUIPMENT CHECKS

- ✓ PITOTS, PRE-TEST
- ✓ PITOTS, POST-TEST
- ✓ ORSAT SAMPLING SYSTEM
- ✓ TEDLAR BAG
- ✓ THERMOCOUPLE @ 370 °F

IDENTIFICATION NUMBERS

REAGENT BOX 0218
NOZZLE 5-5
DIAMETER .183
METER BOX N-6
T/C READOUT 009
UMBILICAL 7
T/C PROBE 4-5
SAMPLE BOX 1
ORSAT PUMP 9
PROBE 2-2
TEDLAR BAG 15

FILTER #	TARE
SF 564	
A 996	
B 990	

NOMOGRAPH SET-UP

NOMOGRAPH # gmc
ΔH@ 1.80
C FACTOR 0.95
METER TEMP 70
STACK TEMP 360-368*
% MOISTURE 4-5
REF. ΔP 2.35
K = .714 → K = .730

SAMPLE POINT	CLOCK TIME, MIN.	DRY GAS METER READING, CU. FT.	PITOT READING (ΔP), IN. H_2O	ORIFICE SETTING (ΔH), IN. H_2O IDEAL	ORIFICE SETTING (ΔH), IN. H_2O ACTUAL	GAS METER TEMP. °F	PUMP VACUUM IN. HG GAUGE	IMPACTOR ~~FILTER~~ ~~BOX~~ TEMP. °F	IMP. EXIT TEMP. °F	STACK TEMP. °F
A 2	0/0	286.573	0.84	0.66	0.66	66	1	203	44	369
	5	288.81	0.84	0.66	0.66	68	1	217	44	368 *
	10	291.04	0.86	0.60	0.60	70	1	226	44	367
	15	293.15	0.86	0.61	0.61	70	1	230	44	372
	20	295.34	0.86	0.61	0.61	70	1	231	44	373
	25	297.49	0.86	0.61	0.61	68	1	233	44	376
A1	30/0	299.66	0.70	0.61	0.61	68	1	233	44	375
	5	302.00	0.68	0.61	0.61	68	1	246	44	373
	10	303.96	0.70	0.61	0.61	68	1	243	44	374
	15	306.15	0.65	0.61	0.61	70	1	239	44	379
	20	308.34	0.67	0.61	0.61	70	1	234	48	377
	25	310.54	0.65	0.61	0.61	70	1	228	54	390
B 2	30/0	312.727	0.78	0.61	0.61	70	1	197	60	372
	5	314.88	0.72	0.61	0.61	70	1	197	60	371
	10	317.12	0.72	0.61	0.61	68	1	209	62	372
	15	319.28	0.72	0.61	0.61	68	1	213	62	369
	20	321.46	0.72	0.61	0.61	68	1	214	62	366
	25	323.65	0.72	0.61	0.61	68	1	215	62	365
B1	30/0	325.78	0.76	0.61	0.61	68	1	221	62	360
	5	327.96	0.76	0.61	0.61	68	1	231	62	356
	10	330.15	0.76	0.61	0.61	68	1	224	62	357
	15	332.37	0.76	0.61	0.61	68	1	216	62	353
	20	334.57	0.76	0.61	0.61	68	1	205	62	348
	25	336.78	0.76	0.61	0.61	68	1	199	62	345
OFF	30	338.982	~~0.76~~	~~0.61~~	~~0.61~~	~~68~~	~~1~~			

V_M 52.409
$(\sqrt{\Delta P})^2$ .7531
ΔH .614
T_M 69
T_S 368

ENTROPY

PARTICLE SIZING LABORATORY DATA

CUSTOMER W. R. Grace JOB # 3002 SAMPLING LOCATION Baghouse West Stack

DATE 2/23/84 ANALYST Becky Dorsey

RUN 51 RUN ____ RUN ____

STAGE	FILTER NUMBER	PARTICULATE AND FILTER WEIGHT (mg)	FILTER TARE (mg)	CATCH (mg)	FILTER NUMBER	PARTICULATE AND FILTER WEIGHT (mg)	FILTER TARE (mg)	CATCH (mg)	FILTER NUMBER	PARTICULATE AND FILTER WEIGHT (mg)	FILTER TARE (mg)	CATCH (mg)
0	B990	159.95	159.57	0.38								
1	A990	142.50	141.72	0.78								
2	B991	160.49	157.91	2.58								
3	A991	144.00	140.99	3.01								
4	B992	162.48	159.25	3.23								
5	A992	141.08	139.97	1.11								
6	B993	158.58	158.52	0.06								
7	A993	141.49	141.45	0.04								
BU	SF564	207.75	207.60	0.15								

PI = Pre-impactor

BU = Back-up Filter

APPENDIX 7.2.4

REACTIVITY FIELD DATA, BAGHOUSE EAST STACK

REACTIVITY RUN
QUALITY ASSURANCE

PARTICULATE FIELD DATA

Run # ~~B-1~~ R-1

Company Name WR GRACE
Time Start 0855
Address IRONDALE, ALA.
Time Finish 1055
Sampling Location BAGHOUSE STACK (EAST)
Date 2.1.84
Team Leader π
Technicians
Barometric Pressure, in. Hg 29.50
Static Pressure, in. H_2O -0.12
Sampling Train Leak Test Vacuum, in. Hg 15
Sampling Train Leak Rate, cu. ft./min. 0.006

EQUIPMENT CHECKS

☑ Pitots, pre-test
☐ Pitots, post-test
☐ Orsat Sampling System
☐ Tedlar Bag
☑ Thermocouple @ 350 °F

IDENTIFICATION NUMBERS

Reagent Box
Nozzle ~~56~~1-4 Diameter .252
Meter Box N.10
T/C Readout 0005
Umbilical U.Y
T/C Probe 3.9, 8.3
Sample Box R.6
Orsat Pump
Probe A.1
Tedlar Bag

Filter #	Tare
SF565	
A997-B994	

NOMOGRAPH SET-UP

Nomograph # π

$\Delta H_@$ 1.68
C Factor 0.95
Meter Temp 70
Stack Temp 350
% Moisture 4
Ref. ΔP

Sample Point	Clock Time, Min.	Dry Gas Meter Reading, Cu. Ft.	Pitot Reading (Δp), In. H_2O	Orifice Setting (ΔH), In. H_2O Ideal	Orifice Setting (ΔH), In. H_2O Actual	Gas Meter Temp. °F	Pump Vacuum In. Hg Gauge	Filter ~~Box~~ Temp. °F	Imp. Exit Temp. °F	Stack Temp. °F
A 7	0/0	961.033	0.42	0.62	0.62	70	2.0	297	45	368
	5	963.30		.62	.62	72	2.0	323	48	378
	10	965.57		.62	.62	73	2.5	344	48	378
	15	967.84		.62	.62	72	3.0	356	48	379
	20	970.10		.62	.62	70	3.0	361	49	376
	25	972.36		.62	.62	70	3.0	359	49	378
	30	974.59		62	.62	71	3.5	361	50	378
	35	976.88		.62	.62	73	4.0	364	50	377
	40	979.15		.62	.62	74	4.0	370	52	378
	45	981.38		.62	.62	76	4.5	375	52	378
	50	983.64		.62	.62	76	4.5	378	54	378
	55	985.86		.62	.62	77	4.5	376	54	378
	60	988.10		.62	.62	77	5.0	374	55	377
	65	990.38		.62	.62	77	5.0	374	57	378
	70	992.66		62	.62	78	5.0	377	58	378
	75	994.09		.62	.62	78	5.0	378	60	379
	80	996.38		.62	62	78	5.0	381	60	379
	85	999.54		.62	.62	80	5.5	382	60	377
	-90-	1.00.71		.62	.62	80	5.5	380	62	378
	95	4.00		.62	.62	81	5.5	378	62	378
	100	6.30		.62	.62	81	5.5	375	62	378
	105	8.60		.62	.62	82	5.5	360	62	375
	110	10.89		62	.62	81	5.5	363	62	376
	115	13.16		.62	.62	81	5.5	366	62	378
	120	15.415								

54382	0.42	0.62	76	377
V_m	$(\overline{\sqrt{\Delta p}})^2$	$\overline{\Delta H}$	$\overline{T_m}$	$\overline{T_s}$

PARTICLE SIZING LABORATORY DATA

CUSTOMER W. R. Grace JOB # 3002 SAMPLING LOCATION Baghouse East Stack

DATE 2/23/84 ANALYST Becky Dousey

	RUN R1				RUN ___				RUN ___			
STAGE	FILTER NUMBER	PARTICULATE AND FILTER WEIGHT (mg)	FILTER TARE (mg)	CATCH (mg)	FILTER NUMBER	PARTICULATE AND FILTER WEIGHT (mg)	FILTER TARE (mg)	CATCH (mg)	FILTER NUMBER	PARTICULATE AND FILTER WEIGHT (mg)	FILTER TARE (mg)	CATCH (mg)
0	B994	159.30	159.20	0.10								
1	A994	140.81	140.70	0.11								
2	B995	158.61	158.51	0.10								
3	A995	140.09	140.05	0.04								
4	B996	157.90	157.95	-0.05								
5	A996	142.40	142.59	-0.19								
6	B997	159.60	159.64	-0.04								
7	A997	142.85	142.84	0.01								
BU	SF565	242.00	209.88	32.12								

PI = Pre-impactor

BU = Pre-filter (placed in front of Stage 0)

APPENDIX 7.2.5

METHOD 9, VISIBLE EMISSIONS FIELD DATA

COMPANY W.R. GRACE

LOCATION IRONDALE, ALA.

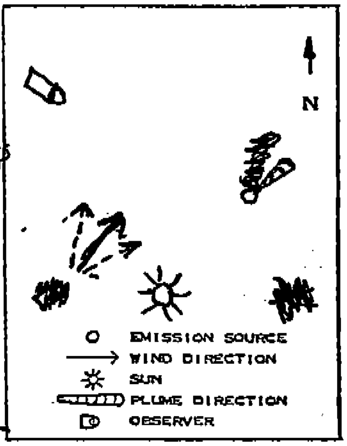
STACK TEST RUN 1 DATE 2.1.84

CONTROL DEVICE CYCLONES / BAGHOUSE WEST STACK

HEIGHT OF DISCHARGE 18' (OFF ROOF)

CONDITION

	START	STOP
CLOCK TIME	1150	1350
OBSERVER LOCATION		
DIST. TO DISCH.	50'	50'
DIREC. FROM DISCH.	W	W
HGT. OF OBSER. PT.	30'	30'
BACKGROUND DESCRIP.	FADED SILVER WITH RUST BLOTCHES	
WEATHER CONDITION	SHADED FROM SUN	
WIND DIREC.	W	W
WIND SPEED.	5-10	5-10
AMBIENT TEMP.		
REL. HUMIDITY		
PLUME COLOR	WHITE	WHITE
DIST. VISIBLE	6-10'	6-10'
SKY CONDITION	CLEAR	CLEAR



	TIME		OPACITY	
SET	START	STOP	SUM	AVG
	1150	1350	75	0.16

READINGS RANGED FROM 5 TO 10 PERCENT OPACITY

OBSERVER SIGNATURE

X

CERTIFICATION DATE

AFFILIATION ENTROPY

		SECONDS				*	
HOUR	MIN	0	15	30	45	A	D
1	0	0	0	0	0		
	1	0	0	0	0		
	2	0	0	0	0		
	3	0	0	0	0		
	4	0	0	0	0		
	5	0	0	0	0		
	6	0	0	0	0		
	7	0	0	0	0		
	8	0	0	0	0		
	9	0	0	0	0		
	10	0	0	0	0		
	11	0	0	0	0		
	12	0	0	0	10		
	13	10	0	0	0		
	14	0	0	0	0		
	15	0	0	0	0		
	16	0	0	0	0		
	17	0	0	0	0		
	18	0	0	0	0		
	19	0	0	0	0		
	20	0	0	0	0		
	21	0	0	0	0		
	22	0	0	0	0		
	23	0	0	0	0		
	24	0	0	0	0		
	25	0	0	0	0		
	26	0	0	0	0		
	27	0	0	0	0		
	28	0	0	0	0		
	29	0	0	0	0		

		SECONDS				*	
HOUR	MIN	0	15	30	45	A	D
	30	0	0	0	0		
	31	0	0	0	0		
	32	0	0	0	0		
	33	0	0	0	0		
	34	0	0	0	0		
	35	0	0	0	0		
	36	0	0	0	0		
	37	0	0	0	0		
	38	0	0	0	0		
	39	0	0	0	0		
	40	0	0	0	0		
	41	0	0	5	10		
	42	0	0	0	0		
	43	0	0	0	0		
	44	0	0	0	0		
	45	0	0	0	0		
	46	0	0	0	0		
	47	0	0	0	0		
	48	0	0	0	5		
	49	10	0	0	0		
	50	0	0	0	0		
	51	0	0	0	0		
	52	0	0	0	0		
	53	0	0	0	0		
	54	0	0	0	0		
	55	0	0	5	0		
	56	0	0	0	0		
	57	0	0	0	0		
	58	0	0	0	0		
	59	0	0	0	0		

* FOR STEAM PLUME IF APPLICABLE, A — ATTACHED, D — DETACHED

ENTROPY
ENVIRONMENTALISTS, INC.

COMPANY WR GRACE

LOCATION IRONDALE, ALA.

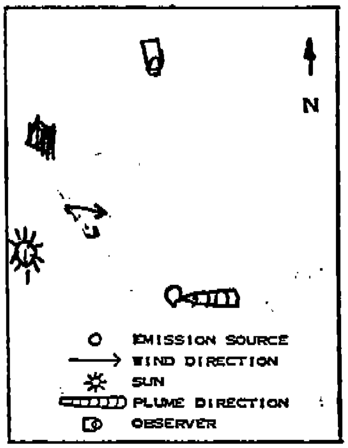
STACK TEST RUN 1 DATE 2-1-84

CONTROL DEVICE BAGHOUSE – WEST STACK

HEIGHT OF DISCHARGE 18'

CONDITION

	START	STOP
CLOCK TIME	1150	1250
OBSERVER LOCATION		
DIST. TO DISCH.		
DIREC. FROM DISCH.		
HGT. OF OBSER. PT.		
BACKGROUND DESCRIP.		
WEATHER CONDITION		
WIND DIREC.	W	W
WIND SPEED.	0-5	
AMBIENT TEMP.		
REL. HUMIDITY		
PLUME COLOR	WHITE	
DIST. VISIBLE	6-10'	
SKY CONDITION	CLEAR	



TIME			OPACITY	
SET	START	STOP	SUM	AVG

READINGS RANGED FROM ____ TO ____ PERCENT OPACITY

OBSERVER SIGNATURE

X

CERTIFICATION DATE

AFFILIATION ENTROPY

		SECONDS				*	
HOUR	MIN	0	15	30	45	A	D
2	0	0	0	0	0		
	1	0	0	0	0		
	2	0	0	0	0		
	3	0	0	0	0		
	4	0	0	0	0		
	5	0	0	0	0		
	6	0	0	0	0		
	7	0	0	0	0		
	8	0	0	0	0		
	9	0	0	0	0		
	10	0	0	0	10		
	11	5	0	0	0		
	12	0	0	0	0		
	13	0	0	0	0		
	14	0	0	0	0		
	15	0	0	0	0		
	16	0	0	0	0		
	17	0	0	0	0		
	18	0	0	0	0		
	19	0	0	0	0		
	20	0	0	0	0		
	21	0	0	0	0		
	22	0	0	0	0		
	23	0	0	0	0		
	24	0	0	0	0		
	25	0	0	0	0		
	26	0	0	0	0		
	27	0	0	0	0		
	28	0	0	0	0		
	29	0	0	0	0		

		SECONDS				*	
HOUR	MIN	0	15	30	45	A	D
	30	0	0	0	0		
	31	0	0	0	0		
	32	0	0	0	0		
	33	0	0	0	0		
	34	0	0	0	0		
	35	0	0	0	0		
	36	0	0	0	0		
	37	0	0	0	0		
	38	0	0	0	0		
	39	0	0	5	0		
	40	0	0	0	0		
	41	0	0	0	0		
	42	0	0	0	0		
	43	0	0	0	0		
	44	0	0	0	0		
	45	0	0	0	0		
	46	0	0	0	0		
	47	5	0	0	0		
	48	0	0	0	0		
	49	0	0	0	0		
	50	0	0	0	0		
	51	0	0	0	0		
	52	0	0	0	0		
	53	0	0	0	0		
	54	0	0	0	0		
	55	0	0	0	0		
	56	0	0	0	0		
	57	0	0	0	0		
	58	0	0	0	0		
	59	0	0	0	0		

* FOR STEAM PLUME IF APPLICABLE, A – ATTACHED, D – DETACHED

ENTROPY
ENVIRONMENTALISTS, INC.

COMPANY WR GRACE

LOCATION IRONDALE, ALA.

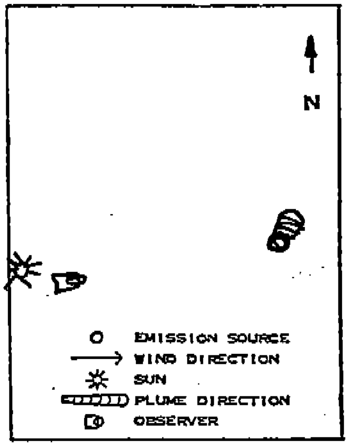
STACK TEST RUN 2 DATE 2·1·83

CONTROL DEVICE BAGHOUSE WEST STACK

HEIGHT OF DISCHARGE 25' (OFF ROOF) 50' OFF GRD.

CONDITION

	START	STOP
CLOCK TIME	1635	1735
OBSERVER LOCATION		
DIST. TO DISCH.	60'	60'
DIREC. FROM DISCH.	W	W
HGT. OF OBSER. PT.	25'	25'
BACKGROUND DESCRIP.	BLUE SKY	
WEATHER CONDITION		
WIND DIREC.	W	W
WIND SPEED.	0-5	0
AMBIENT TEMP.		
REL. HUMIDITY		
PLUME COLOR	WHITE	WHITE
DIST. VISIBLE	6-10'	6-10'
SKY CONDITION	CLEAR	



	TIME		OPACITY	
SET	START	STOP	SUM	AVG
	1635	1735	10	0.04

READINGS RANGED FROM 0 TO 10 PERCENT OPACITY

OBSERVER SIGNATURE X

CERTIFICATION DATE

AFFILIATION ENTROPY

		SECONDS				*	
HOUR	MIN	0	15	30	45	A	D
1	0	0	0	0	0		
	1	0	0	0	0		
	2	0	0	0	0		
	3	0	0	0	0		
	4	0	0	0	0		
	5	0	0	0	0		
	6	0	0	0	0		
	7	0	0	0	0		
	8	0	0	0	0		
	9	0	0	0	0		
	10	0	0	0	0		
	11	0	0	0	0		
	12	0	0	0	0		
	13	0	0	0	0		
	14	0	0	0	0		
	15	0	0	0	0		
	16	0	0	0	0		
	17	0	0	0	0		
	18	0	0	0	0		
	19	0	0	0	0		
	20	0	0	0	0		
	21	0	0	0	0		
	22	0	0	0	0		
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	24	0	0	0	0		
	25	0	0	10	0		
	26	0	0	0	0		
	27	0	0	0	0		
	28	0	0	0	0		
	29	0	0	0	0		

		SECONDS				*	
HOUR	MIN	0	15	30	45	A	D
	30	0	0	0	0		
	31	0	0	0	0		
	32	0	0	0	0		
	33	0	0	0	0		
	34	0	0	0	0		
	35	0	0	0	0		
	36	0	0	0	0		
	37	0	0	0	0		
	38	0	0	0	0		
	39	0	0	0	0		
	40	0	0	0	0		
	41	0	0	0	0		
	42	0	0	0	0		
	43	0	0	0	0		
	44	0	0	0	0		
	45	0	0	0	0		
	46	0	0	0	0		
	47	0	0	0	0		
	48	0	0	0	0		
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	50	0	0	0	0		
	51	0	0	0	0		
	52	0	0	0	0		
	53	0	0	0	0		
	54	0	0	0	0		
	55	0	0	0	0		
	56	0	0	0	0		
	57	0	0	0	0		
	58	0	0	0	0		
	59	0	0	0	0		

* FOR STEAM PLUME IF APPLICABLE, A — ATTACHED, D — DETACHED

ENTROPY
ENVIRONMENTALISTS, INC.

COMPANY W.R. Grace

LOCATION Irondale, Alabama

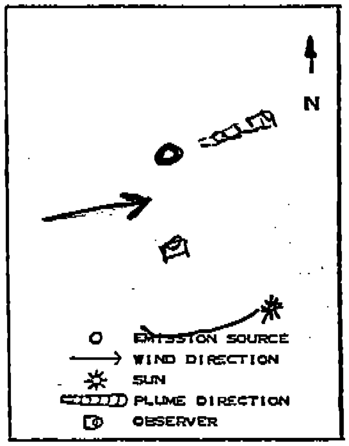
STACK TEST RUN 4 (East St.) DATE 2/1/84

CONTROL DEVICE Baghouse

HEIGHT OF DISCHARGE ~55'

CONDITION normal

	START	STOP
CLOCK TIME	11:45	13:45
OBSERVER LOCATION		
DIST. TO DISCH.	~100'	~100'
DIREC. FROM DISCH.	S	S
HGT. OF OBSER. PT.	GROUND	GROUND
BACKGROUND DESCRIP.		
WEATHER CONDITION		
WIND DIREC.	W	W
WIND SPEED.	5-10	5-10
AMBIENT TEMP.		
REL. HUMIDITY		
PLUME COLOR	WHITE	WHITE
DIST. VISIBLE	~30'	~30'
SKY CONDITION	CLEAR	CLEAR



	TIME		OPACITY	
SET	START	STOP	SUM	AVG
	1145	1345	55	0.14

READINGS RANGED FROM 0 TO 15 PERCENT OPACITY

OBSERVER SIGNATURE

X Willi Sheskt

CERTIFICATION DATE

AFFILIATION Entropy

		SECONDS				*	
HOUR	MIN	0	15	30	45	A	D
0/0	0	0	0	0	0		
	1	0	0	0	0		
	2	0	0	0	0		
	3	0	0	0	0		
	4	0	0	0	0		
	5	0	0	0	0		
	6	0	0	0	0		
	7	0	15	0	0		
	8	0	0	0	0		
	9	0	0	0	0		
	10	0	0	0	0		
	11	0	0	0	0		
	12	0	0	0	0		
	13	0	0	0	0		
	14	0	0	0	0		
	15	0	0	0	0		
	16	0	0	0	0		
	17	0	0	0	0		
	18	0	0	0	0		
	19	0	0	0	0		
	20	0	0	0	0		
	21	0	0	0	0		
	22	0	0	0	0		
	23	0	0	0	0		
	24	0	0	0	0		
	25	0	0	0	0		
	26	0	0	0	0		
	27	0	0	0	0		
	28	0	0	0	10		
	29	0	0	0	0		

		SECONDS				*	
HOUR	MIN	0	15	30	45	A	D
	30	0	0	0	0		
	31	0	0	0	0		
	32	0	0	0	0		
	33	0	0	0	0		
	34	0	0	0	0		
	35	0	0	0	0		
	36	0	0	0	0		
	37	0	0	0	0		
	38	0	0	0	0		
	39	0	0	0	0		
	40	0	0	0	0		
	41	0	0	0	0		
	42	0	0	0	0		
	43	0	0	0	0		
	44	0	0	0	0		
	45	0	0	0	0		
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	48	0	0	0	0		
	49	0	0	0	0		
	50	0	0	0	0		
	51	0	0	0	0		
	52	0	0	0	0		
	53	0	0	0	0		
	54	0	0	0	0		
	55	0	0	0	0		
	56	0	0	0	0		
	57	0	0	0	15		
	58	0	0	0	0		
1/0	59	0	0	0	0		

* FOR STEAM PLUME IF APPLICABLE, A — ATTACHED, D — DETACHED

ENTROPY
ENVIRONMENTALISTS, INC.

COMPANY W. R. Grace

LOCATION Irondale, Alabama

STACK TEST RUN 4 (Cast St.) DATE 2/1/84

CONTROL DEVICE Baghouse

HEIGHT OF DISCHARGE ~55'

CONDITION normal

	START	STOP
CLOCK TIME		
OBSERVER LOCATION		
DIST. TO DISCH.	~100'	
DIREC. FROM DISCH.	S	
HGT. OF OBSER. PT.	GROUND	
BACKGROUND DESCRIP.		
WEATHER CONDITION		
WIND DIREC.	W	
WIND SPEED.	5-10	
AMBIENT TEMP.		
REL. HUMIDITY		
PLUME COLOR	WHITE	
DIST. VISIBLE	~30'	
SKY CONDITION	CLEAR	

N

O EMISSION SOURCE
→ WIND DIRECTION
☼ SUN
PLUME DIRECTION
OBSERVER

SET	TIME START	TIME STOP	OPACITY SUM	OPACITY AVG

READINGS RANGED FROM ____ TO ____ PERCENT OPACITY

OBSERVER SIGNATURE
X

CERTIFICATION DATE

AFFILIATION Entropy

HOUR	MIN	SECONDS 0	15	30	45	* A	D
1/0	0	0	0	0	0		
	1	0	0	0	0		
	2	0	0	0	0		
	3	0	0	0	0		
	4	0	0	0	0		
	5	10	0	0	0		
	6	0	0	0	0		
	7	0	0	0	0		
	8	0	0	0	0		
	9	0	0	0	0		
	10	0	0	0	0		
	11	0	0	0	0		
	12	0	0	0	0		
	13	0	0	0	0		
	14	0	0	0	0		
	15	0	0	0	0		
	16	0	0	0	0		
	17	0	0	0	0		
	18	0	0	0	0		
	19	0	0	0	0		
	20	0	0	0	0		
	21	0	0	0	0		
	22	0	0	0	0		
	23	0	0	0	0		
	24	0	0	0	0		
	25	0	0	0	0		
	26	0	0	0	0		
	27	0	0	0	0		
	28	0	0	0	0		
	29	0	0	0	0		

HOUR	MIN	SECONDS 0	15	30	45	* A	D
	30	0	0	0	0		
	31	0	0	0	0		
	32	0	0	0	0		
	33	0	0	0	0		
	34	0	0	0	0		
	35	0	0	0	0		
	36	0	0	0	0		
	37	0	0	0	0		
	38	0	0	0	0		
	39	0	0	0	0		
	40	0	0	0	0		
	41	0	0	0	0		
	42	0	0	0	0		
	43	0	0	0	0		
	44	0	0	0	0		
	45	0	0	0	0		
	46	0	0	0	0		
	47	0	0	0	0		
	48	0	0	0	0		
	49	0	0	0	0		
	50	0	0	0	0		
	51	0	0	0	0		
	52	0	0	0	0		
	53	0	0	0	0		
	54	0	0	0	0		
	55	0	0	15	0		
	56	0	0	0	0		
	57	0	0	0	0		
	58	0	0	0	0		
	59	0	0	0	0		

* FOR STEAM PLUME IF APPLICABLE, A — ATTACHED, D — DETACHED

COMPANY W.R. Grace

LOCATION Irondale Alabama

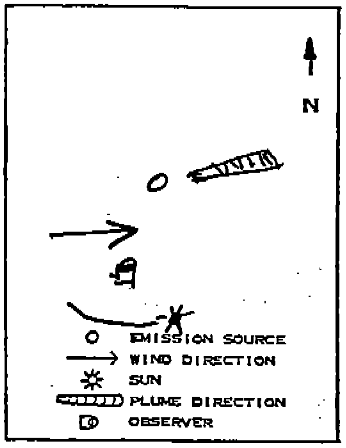
STACK TEST RUN 5 (East St.) DATE 2/1/84

CONTROL DEVICE Baghouse

HEIGHT OF DISCHARGE ~55'

CONDITION normal

	START	STOP
CLOCK TIME	16:31	17:31
OBSERVER LOCATION		
DIST. TO DISCH.	~100'	
DIREC. FROM DISCH.	S	
HGT. OF OBSER. PT.	GROUND	GROUND
BACKGROUND DESCRIP.		
WEATHER CONDITION		
WIND DIREC.	W	
WIND SPEED.	5-10	
AMBIENT TEMP.		
REL. HUMIDITY		
PLUME COLOR	WHITE	WHITE
DIST. VISIBLE	~30'	~30'
SKY CONDITION	CLEAR	CLEAR



SET	TIME START	TIME STOP	OPACITY SUM	OPACITY AVG
	1631	1731	85	0.35

READINGS RANGED FROM 0 TO 20 PERCENT OPACITY

OBSERVER SIGNATURE X

CERTIFICATION DATE

AFFILIATION Entropy

HOUR	MIN	SECONDS 0	15	30	45	* A	D
0/0	0	0	0	0	0		
	1	0	0	0	0		
	2	0	0	0	0		
	3	0	0	0	0		
	4	0	0	0	0		
	5	0	0	0	0		
	6	0	10	0	0		
	7	0	0	0	0		
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	15	0	0	0	0		
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	17	0	0	0	0		
	18	0	0	0	0		
	19	0	0	0	0		
	20	0	0	0	20		
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	24	0	0	0	0		
	25	0	0	0	0		
	26	0	0	0	0		
	27	0	0	0	0		
	28	0	0	0	0		
	29	0	0	0	0		

HOUR	MIN	SECONDS 0	15	30	45	* A	D
	30	0	0	0	0		
	31	0	0	0	0		
	32	0	0	0	0		
	33	0	0	0	0		
	34	0	0	0	0		
	35	10	0	0	0		
	36	0	0	0	0		
	37	0	0	0	0		
	38	0	0	0	0		
	39	0	0	0	0		
	40	0	0	0	0		
	41	0	0	0	0		
	42	0	0	10	0		
	43	0	0	0	0		
	44	0	0	0	0		
	45	0	0	0	0		
	46	0	0	0	0		
	47	0	0	0	0		
	48	0	0	0	0		
	49	0	0	20	0		
	50	0	0	0	0		
	51	0	0	0	0		
	52	0	0	0	0		
	53	0	0	0	0		
	54	0	0	0	0		
	55	0	0	0	0		
	56	0	0	0	0		
	57	0	0	0	0		
	58	0	0	0	0		
1/0	59	0	0	0	0		

* FOR STEAM PLUME IF APPLICABLE, A — ATTACHED, D — DETACHED

End

ENTROPY
ENVIRONMENTALISTS, INC.

APPENDIX 7.2.6

METHOD 22, FUGITIVE EMISSIONS FIELD DATA

FUGITIVE EMISSION INSPECTION
OUTDOOR LOCATION

Run 1

Company W.R. Grace
Location Irondale, Ala.
Company representative Clarence Duckworth

Observer Michael Kirkman
Affiliation Entropy
Date 2-1-84

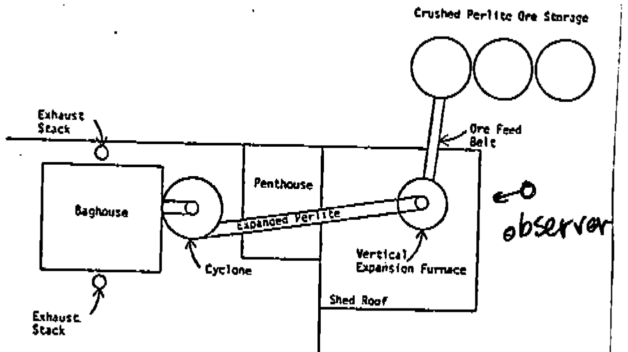
Sky conditions Clear
Precipitation

Wind direction NW
Wind speed 5-10 mph

Industry Perlite

Process unit Perlite Expansion Furnace

Sketch process unit; indicate observer position relative to source and sun; indicate potential emission points and/or actual emission points.



OBSERVATIONS

			Clock time	Observation period duration, min:sec	Accumulated emission time, min:sec	
Begin observation	1152		0	20:00	10:36	10:36
		①	20-0	15:00	0	
	1219	②	15-0	20:00	0	
	1240	③	20-0	20:00	0	
	1310	④	20-0	20:00	0	
	1340	⑤	20-0		0	
	1400	⑥				
				95:00	10:36	
End observation						

ENTROPY

FUGITIVE EMISSION INSPECTION
OUTDOOR LOCATION

Run. 2

Company W. R. Grace
Location Irondale, Ala.
Company representative Clarence Duckworth

Observer Michael Kirkman
Affiliation Entropy
Date 2-1-84

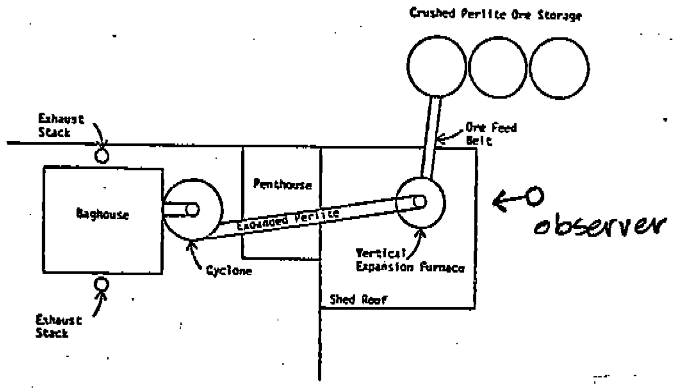
Sky conditions Clear
Precipitation —

Wind direction NW
Wind speed 0-5 mph

Industry Perlite

Process unit Perlite Expansion Furnace

Sketch process unit; indicate observer position relative to source and sun; indicate potential emission points and/or actual emission points.



OBSERVATIONS

Begin observation 1632

Dark quit reading 1732

	Clock time	Observation period duration, min:sec	Accumulated emission time, min:sec	
Begin observation	1 0	20:00	18:1.5	feed belt
	20-0	20:00	9:03	feed elevator
	2020	15:00	8:33	
	25-0			
		45:00	35:38	
End observation				

ENTROPY

APPENDIX 7.3

SAMPLING AND ANALYTICAL PROCEDURES

METHOD 1—SAMPLE AND VELOCITY TRAVERSES FOR STATIONARY SOURCES

1. *Principle and Applicability*

1.1 Principle. To aid in the representative measurement of pollutant emissions and/or total volumetric flow rate from a stationary source, a measurement site where the effluent stream is flowing in a known direction is selected, and the cross-section of the stack is divided into a number of equal areas. A traverse point is then located within each of these equal areas.

1.2 Applicability. This method is applicable to flowing gas streams in ducts, stacks, and flues. The method cannot be used when: (1) flow is cyclonic or swirling (see Section 2.4), (2) a stack is smaller than about 0.30 meter (12 in.) in diameter, or 0.071 m^2 (113 in.^{2}) in cross-sectional area, or (3) the measurement site is less than two stack or duct diameters downstream or less than a half diameter upstream from a flow disturbance.

The requirements of this method must be considered before construction of a new facility from which emissions will be measured; failure to do so may require subsequent alterations to the stack or deviation from the standard procedure. Cases involving variants are subject to approval by the Administrator, U.S. Environmental Protection Agency.

2. *Procedure*

2.1 Selection of Measurement Site. Sampling or velocity measurement is performed at a site located at least eight stack or duct diameters downstream and two diameters upstream from any flow disturbance such as a bend, expansion, or contraction in the stack, or from a visible flame. If necessary, an alternative location may be selected, at a position at least two stack or duct diameters downstream and a half diameter upstream from any flow disturbance. For a rectangular cross section, an equivalent diameter (D_e) shall be calculated from the following equation, to determine the upstream and downstream distances:

$$D_e=\frac{2LW}{L+W}$$

where L=length and W=width.

2.2 Determining the Number of Traverse Points.

2.2.1 Particulate Traverses. When the eight- and two-diameter criterion can be met, the minimum number of traverse points shall be: (1) twelve, for circular or rectangular stacks with diameters (or equivalent diameters) greater than 0.61 meter (24 in.); (2) eight, for circular stacks with diameters between 0.30 and 0.61 meter (12–24 in.); (3) nine, for rectangular stacks with equivalent diameters between 0.30 and 0.61 meter (12–24 in.).

When the eight- and two-diameter criterion cannot be met, the minimum number of traverse points is determined from Figure 1-1. Before referring to the figure, however, determine the distances from the chosen measurement site to the nearest upstream and downstream disturbances, and divide each distance by the stack diameter or equivalent diameter, to determine the distance in terms of the number of duct diameters. Then, determine from Figure 1-1 the minimum number of traverse points that corresponds: (1) to the number of duct diameters upstream; and (2) to the number of diameters downstream. Select the higher of the two minimum numbers of traverse points, or a greater value, so that for circular stacks the number is a multiple of 4, and for rectangular stacks, the number is one of those shown in Table 1-1.

TABLE 1-1. *Cross-sectional layout for rectangular stacks*

Number of traverse points	*Matrix layout*
9	3x3
12	4x3
16	4x4
20	5x4
25	5x5
30	6x5
36	6x6
42	7x6
49	7x7

2.2.2 Velocity (Non-Particulate) Traverses. When velocity or volumetric flow rate is to be determined (but not particulate matter), the same procedure as that for particulate traverses (Section 2.2.1) is followed, except that Figure 1-2 may be used instead of Figure 1-1.

2.3 Cross-Sectional Layout and Location of Traverse Points.

2.3.1 Circular Stacks. Locate the traverse points on two perpendicular diameters according to Table 1-2 and the example shown in Figure 1-3. Any equation (for examples, see Citations 2 and 3 in the Bibliography) that gives the same values as those in Table 1-2 may be used in lieu of Table 1-2.

For particulate traverses, one of the diameters must be in a plane containing the greatest expected concentration variation, e.g., after bends, one diameter shall be in the plane of the bend. This requirement becomes less critical as the distance from the disturbance increases; therefore, other diameter locations may be used, subject to approval of the Administrator.

In addition, for stacks having diameters greater than 0.61 m (24 in.) no traverse points shall be located within 2.5 centimeters (1.00 in.) of the stack walls; and for stack diameters equal to or less than 0.61 m (24 in.), no traverse points shall be located within 1.3 cm (0.50 in.) of the stack walls. To meet these criteria, observe the procedures given below.

2.3.1.1 Stacks With Diameters Greater Than 0.61 m (24 in.). When any of the traverse points as located in Section 2.3.1 fall within 2.5 cm (1.00 in.) of the stack walls, relocate them away from the stack walls to: (1) a distance of 2.5 cm (1.00 in.); or (2) a distance equal to the nozzle inside diameter, whichever is larger. These relocated traverse points (on each end of a diameter) shall be the "adjusted" traverse points.

Whenever two successive traverse points are combined to form a single adjusted traverse point, treat the adjusted point as two separate traverse points, both in the sampling (or velocity measurement) procedure, and in recording the data.

2.3.1.2 Stacks With Diameters Equal to or Less Than 0.61 m (24 in.). Follow the procedure in Section 2.3.1.1, noting only that any "adjusted" points should be relocated away from the stack walls to: (1) a distance of 1.3 cm (0.50 in.); or (2) a distance equal to the nozzle inside diameter, whichever is larger.

2.3.2 Rectangular Stacks. Determine the number of traverse points as explained in Sections 2.1 and 2.2 of this method. From Table 1-1, determine the grid configuration. Divide the stack cross-section into as many equal rectangular elemental areas as traverse points, and then locate a traverse point at the centroid of each equal area according to the example in Figure 1-4.

If the tester desires to use more than the minimum number of traverse points, expand the "minimum number of traverse points" matrix (see Table 1-1) by adding the extra traverse points along one or the other or both legs of the matrix; the final matrix need not be balanced. For example, if a 4x3 "minimum number of points" matrix were expanded to 36 points, the final matrix could be 9x4 or 12x3, and would not necessarily have to be 6x6. After constructing the final matrix, divide the stack cross-section into as many equal rectangular, elemental areas as traverse points, and locate a traverse point at the centroid of each equal area.

The situation of traverse points being too close to the stack walls is not expected to arise with rectangular stacks. If this problem should ever arise, the Administrator must be contacted for resolution of the matter.

2.4 Verification of Absence of Cyclonic Flow. In most stationary sources, the direction of stack gas flow is essentially parallel to the stack walls. However, cyclonic flow may exist (1) after such devices as cyclones and inertial demisters following venturi scrubbers, or (2) in stacks having tangential inlets or other duct configurations which tend to induce swirling; in these instances, the presence or absence of cyclonic flow at the sampling location must be determined. The following techniques are acceptable for this determination.

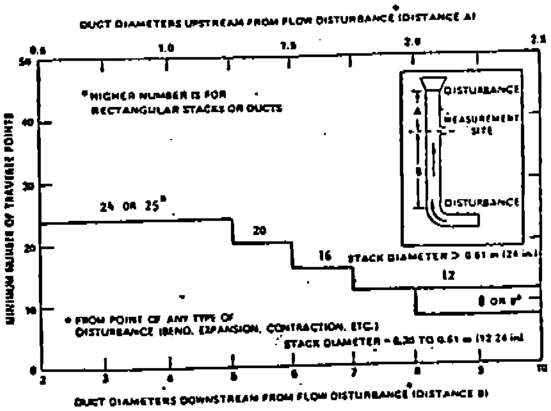


Figure 1-1. Minimum number of traverse points for particulate traverses.

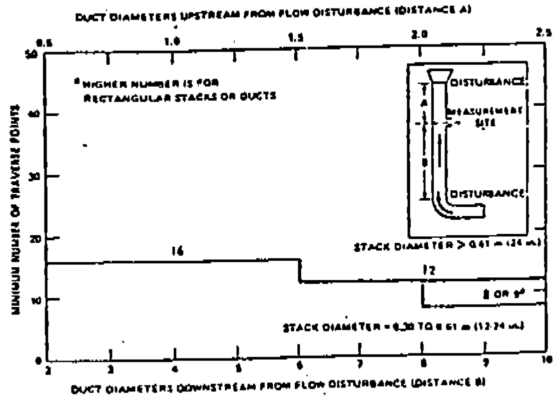


Figure 1-2. Minimum number of traverse points for velocity (nonparticulate) traverses.

METHOD 1—SAMPLE AND VELOCITY TRAVERSES FOR STATIONARY SOURCES

1. *Principle and Applicability*

1.1 Principle. To aid in the representative measurement of pollutant emissions and/or total volumetric flow rate from a stationary source, a measurement site where the effluent stream is flowing in a known direction is selected, and the cross-section of the stack is divided into a number of equal areas. A traverse point is then located within each of these equal areas.

1.2 Applicability. This method is applicable to flowing gas streams in ducts, stacks, and flues. The method cannot be used when: (1) flow is cyclonic or swirling (see Section 2.4), (2) a stack is smaller than about 0.30 meter (12 in.) in diameter, or 0.071 m^2 (113 $in.^2$) in cross-sectional area, or (3) the measurement site is less than two stack or duct diameters downstream or less than a half diameter upstream from a flow disturbance.

The requirements of this method must be considered before construction of a new facility from which emissions will be measured; failure to do so may require subsequent alterations to the stack or deviation from the standard procedure. Cases involving variants are subject to approval by the Administrator, U.S. Environmental Protection Agency.

2. *Procedure*

2.1 Selection of Measurement Site. Sampling or velocity measurement is performed at a site located at least eight stack or duct diameters downstream and two diameters upstream from any flow disturbance such as a bend, expansion, or contraction in the stack, or from a visible flame. If necessary, an alternative location may be selected, at a position at least two stack or duct diameters downstream and a half diameter upstream from any flow disturbance. For a rectangular cross section, an equivalent diameter (D_e) shall be calculated from the following equation, to determine the upstream and downstream distances:

$$D_e=\frac{2LW}{L+W}$$

where L=length and W=width.

2.2 Determining the Number of Traverse Points.

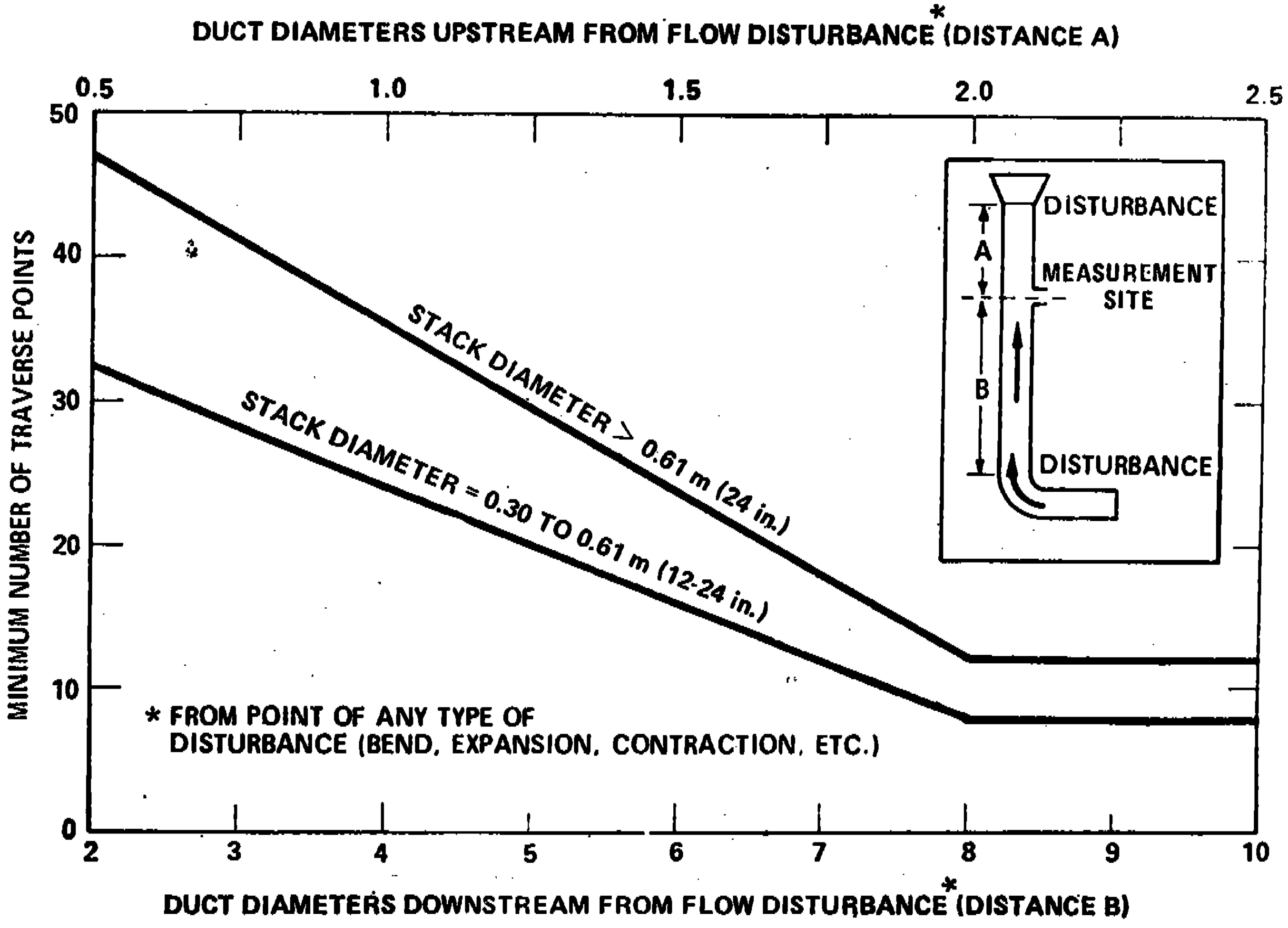
2.2.1 Particulate Traverses. When the eight- and two-diameter criterion can be met, the minimum number of traverse points shall be: (1) twelve, for circular or rectangular stacks with diameters (or equivalent diameters) greater than 0.61 meter (24 in.); (2) eight, for circular stacks with diameters between 0.30 and 0.61 meter (12–24 in.); (3) nine, for rectangular stacks with equivalent diameters between 0.30 and 0.61 meter (12–24 in.).

When the eight- and two-diameter criterion cannot be met, the minimum number of traverse points is determined from Figure 1–1. Before referring to the figure, however, determine the distances from the chosen measurement site to the nearest upstream and downstream disturbances, and divide each distance by the stack diameter or equivalent diameter, to determine the distance in terms of the number of duct diameters. Then, determine from Figure 1–1 the minimum number of traverse points that corresponds: (1) to the number of duct diameters upstream; and (2) to the number of diameters downstream. Select the higher of the two minimum numbers of traverse points, or a greater value, so that for circular stacks the number is a multiple of 4, and for rectangular stacks, the number is one of those shown in Table 1–1.

TABLE 1-1. *Cross-sectional layout for rectangular stacks*

Number of traverse points:	*Matrix layout*
9	3x3
12	4x3
16	4x4
20	5x4
25	5x5
30	6x5
36	6x6
42	7x6
49	7x7

Figure 1-1. Minimum number of traverse points for particulate traverses.



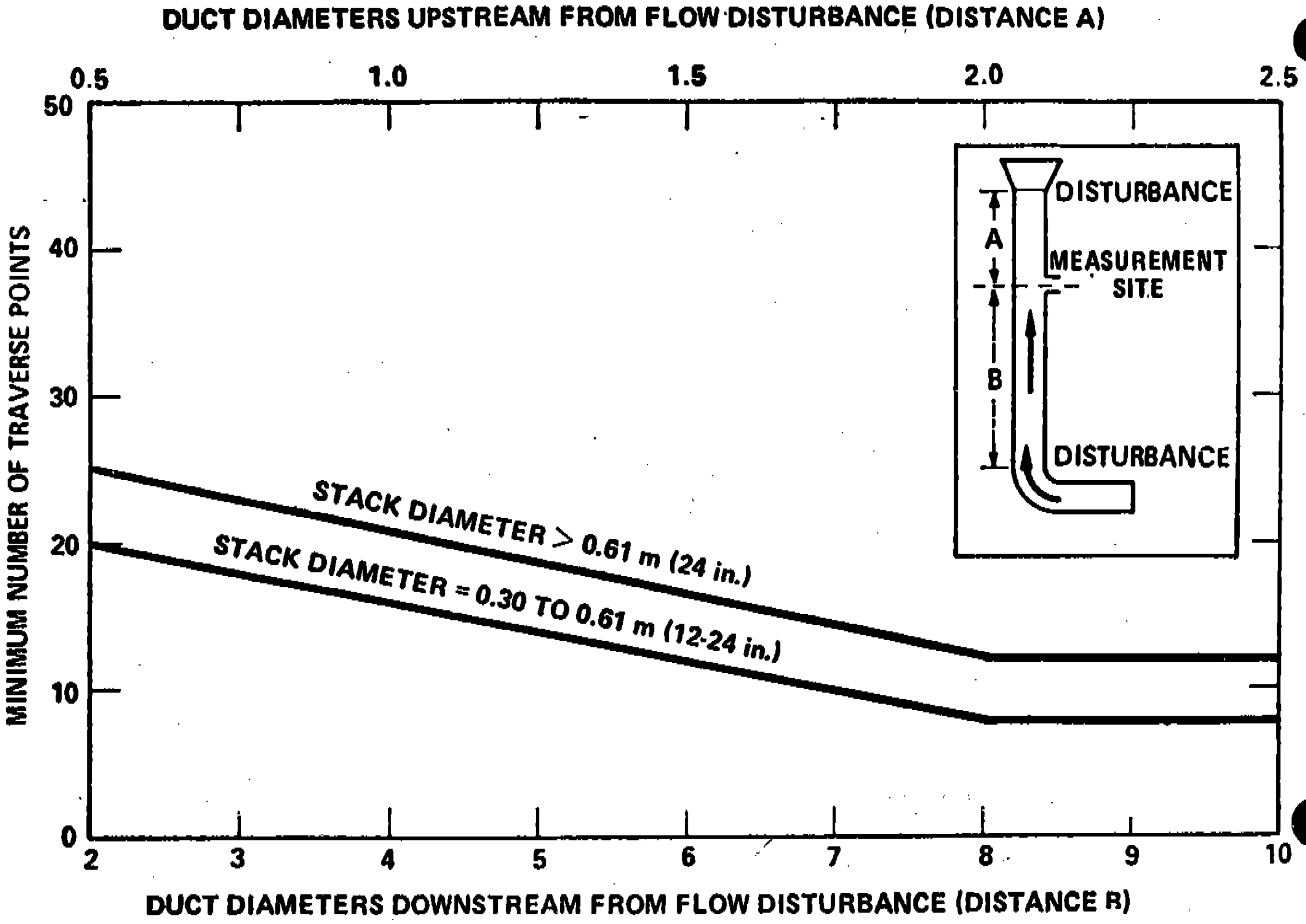


Figure 1-2. Minimum number of traverse points for velocity (nonparticulate) traverses.

2.2.2 Velocity (Non-Particulate) Traverses. When velocity or volumetric flow rate is to be determined (but not particulate matter), the same procedure as that for particulate traverses (Section 2.2.1) is followed, except that Figure 1-2 may be used instead of Figure 1-1.

2.3 Cross-Sectional Layout and Location of Traverse Points.

2.3.1 Circular Stacks. Locate the traverse points on two perpendicular diameters adcording to Table 1-2 and the example shown in Figure 1-3. Any equation (for examples, see Citations 2 and 3 in the Bibliography) that gives the same values as those in Table 1-2 may be used in lieu of Table 1-2.

For particulate traverses, one of the diameters must be in a plane containing the greatest expected concentration variation, e.g., after bends, one diameter shall be in the plane of the bend. This requirement becomes less critical as the distance from the disturbance increases; therefore, other diameter locations may be used, subject to approval of the Administrator.

In addition, for stacks having diameters greater than 0.61 m (24 in.) no traverse points shall be located within 2.5 centimeters (1.00 in.) of the stack walls; and for stack diameters equal to or less than 0.61 m (24 in.), no traverse points shall be located within 1.3 cm (0.50 in.) of the stack walls. To meet these criteria, observe the procedures given below.

2.3.1.1 Stacks With Diameters Greater Than 0.61 m (24 in.). When any of the traverse points as located in Section 2.3.1 fall within 2.5 cm (1.00 in.) of the stack walls, relocate them away from the stack walls to: (1) a distance of 2.5 cm (1.00 in.); or (2) a distance equal to the nozzle inside diameter, whichever is larger. These relocated traverse points (on each end of a diameter) shall be the "adjusted" traverse points.

Whenever two successive traverse points are combined to form a single adjusted traverse point, treat the adjusted point as two separate traverse points, both in the sampling (or velocity measurement) procedure, and in recording the data.

TRAVERSE POINT	DISTANCE, % of diameter
1	4.4
2	14.7
3	29.5
4	70.5
5	85.3
6	95.6

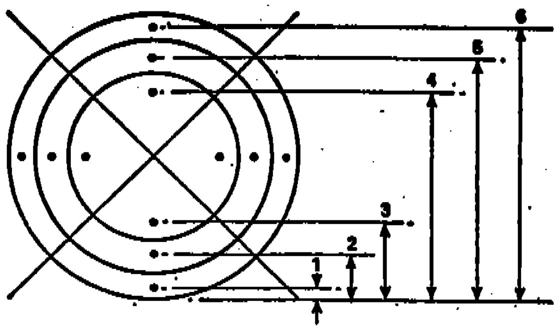


Figure 1-3. Example showing circular stack cross section divided into 12 equal areas, with location of traverse points indicated.

Table 1-2. LOCATION OF TRAVERSE POINTS IN CIRCULAR STACKS

(Percent of stack diameter from inside wall to traverse point)

Traverse point number on a diameter	Number of traverse points on a diameter											
	2	4	6	8	10	12	14	16	18	20	22	24
1	14.6	6.7	4.4	3.2	2.6	2.1	1.8	1.6	1.4	1.3	1.1	1.1
2	85.4	25.0	14.6	10.5	8.2	6.7	5.7	4.9	4.4	3.9	3.5	3.2
3		75.0	29.6	19.4	14.6	11.8	9.9	8.5	7.5	6.7	6.0	5.5
4		93.3	70.4	32.3	22.6	17.7	14.6	12.5	10.9	9.7	8.7	7.9
5			85.4	67.7	34.2	25.0	20.1	16.9	14.6	12.9	11.6	10.5
6			95.6	80.6	65.8	35.6	26.9	22.0	18.8	16.5	14.6	13.2
7				89.5	77.4	64.4	36.6	28.3	23.6	20.4	18.0	16.1
8				96.8	85.4	75.0	63.4	37.5	29.6	25.0	21.8	19.4
9					91.8	82.3	73.1	62.5	38.2	30.6	26.2	23.0
10					97.4	88.2	79.9	71.7	61.8	38.8	31.5	27.2
11						93.3	85.4	78.0	70.4	61.2	39.3	32.3
12						97.9	90.1	83.1	76.4	69.4	60.7	39.8
13							94.3	87.5	81.2	75.0	68.5	60.2
14							98.2	91.5	85.4	79.6	73.8	67.7
15								95.1	89.1	83.5	78.2	72.8
16								98.4	92.5	87.1	82.0	77.0
17									95.6	90.3	85.4	80.6
18									98.6	93.3	88.4	83.9
19										96.1	91.3	86.8
20										98.7	94.0	89.5
21											96.5	92.1
22											98.9	94.5
23												96.8
24												98.9

2.3.1.2 Stacks With Diameters Equal to or Less Than 0.61 m (24 in.). Follow the procedure in Section 2.3.1.1, noting only that any "adjusted" points should be relocated away from the stack walls to: (1) a distance of 1.3 cm (0.50 in.); or (2) a distance equal to the nozzle inside diameter, whichever is larger.

2.3.2 Rectangular Stacks. Determine the number of traverse points as explained in Sections 2.1 and 2.2 of this method. From Table 1-1, determine the grid configuration. Divide the stack cross-section into as many equal rectangular elemental areas as traverse points, and then locate a traverse point at the centroid of each equal area according to the example in Figure 1-4.

The situation of traverse points being too close to the stack walls is not expected to arise with rectangular stacks. If this problem should ever arise, the Administrator must be contacted for resolution of the matter.

2.4 Verification of Absence of Cyclonic Flow. In most stationary sources, the direction of stack gas flow is essentially parallel to the stack walls. However, cyclonic flow may exist (1) after such devices as cyclones and inertial demisters following venturi scrubbers, or (2) in stacks having tangential inlets or other duct configurations which tend to induce swirling; in these instances, the presence or absence of cyclonic flow at the sampling location must be determined. The following techniques are acceptable for this determination.

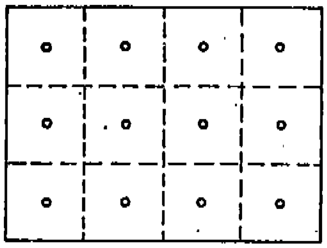


Figure 1-4. Example showing rectangular stack cross section divided into 12 equal areas, with a traverse point at centroid of each area.

Level and zero the manometer. Connect a Type S pitot tube to the manometer. Position the Type S pitot tube at each traverse point, in succession, so that the planes of the face openings of the pitot tube are perpendicular to the stack cross-sectional plane: when the Type S pitot tube is in this position, it is at "0° reference." Note the differential pressure (Δp) reading at each traverse point. If a null (zero) pitot reading is obtained at 0° reference at a given traverse point, an acceptable flow condition exists at that point. If the pitot reading is not zero at 0° reference, rotate the pitot tube (up to ±90° yaw angle), until a null reading is obtained. Carefully determine and record the value of the rotation angle (α) to the nearest degree. After the null technique has been applied at each travrse point, calculate the average of the absolute values of α; assign α values of 0° to those points for which no rotation was required, and include these in the overall average. If the average value of α is greater than 10°, the overall flow condition in the stack is unacceptable and alternative methodology, subject to the approval of the Administrator, must be used to perform accurate sample and velocity traverses.

3. *Bibliography*

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5. Hanson, H. A., et al. Particulate Sampling Strategies for Large Power Plants Including Nonuniform Flow. USEPA, ORD, ESRL, Research Triangle Park, N.C. EPA-600/2-76-170. June 1976.

6. Entropy Environmentalists, Inc. Determination of the Optimum Number of Sampling Points: An Analysis of Method 1 Criteria. Environmental Protection Agency. Research Triangle Park, N.C. EPA Contract No. 68-01-3172, Task 7.

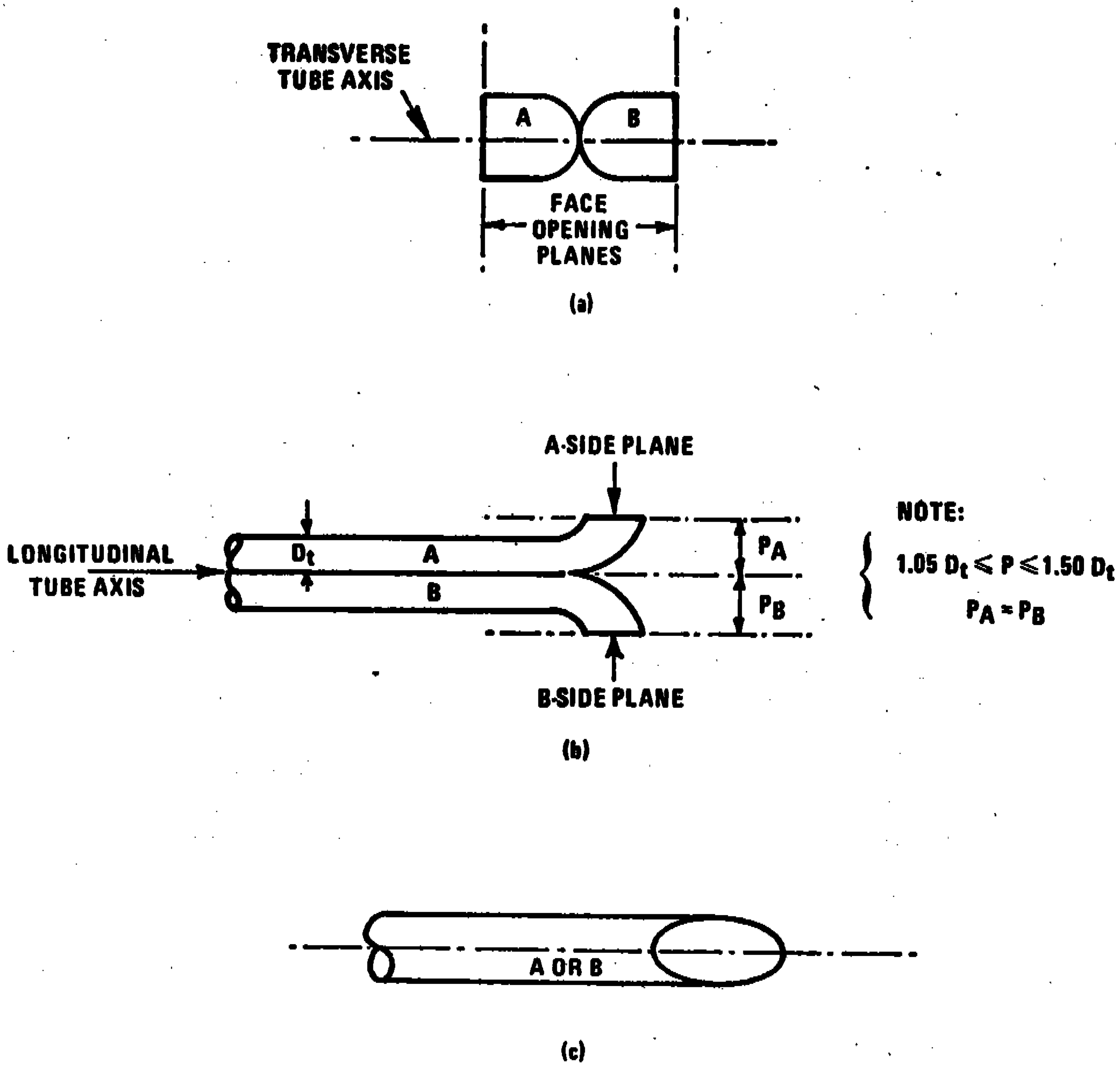


Figure 2-2. Properly constructed Type S pitot tube, shown in: (a) end view; face opening planes perpendicular to transverse axis; (b) top view; face opening planes parallel to longitudinal axis; (c) side view; both legs of equal length and centerlines coincident, when viewed from both sides. Baseline coefficient values of 0.84 may be assigned to pitot tubes constructed this way.

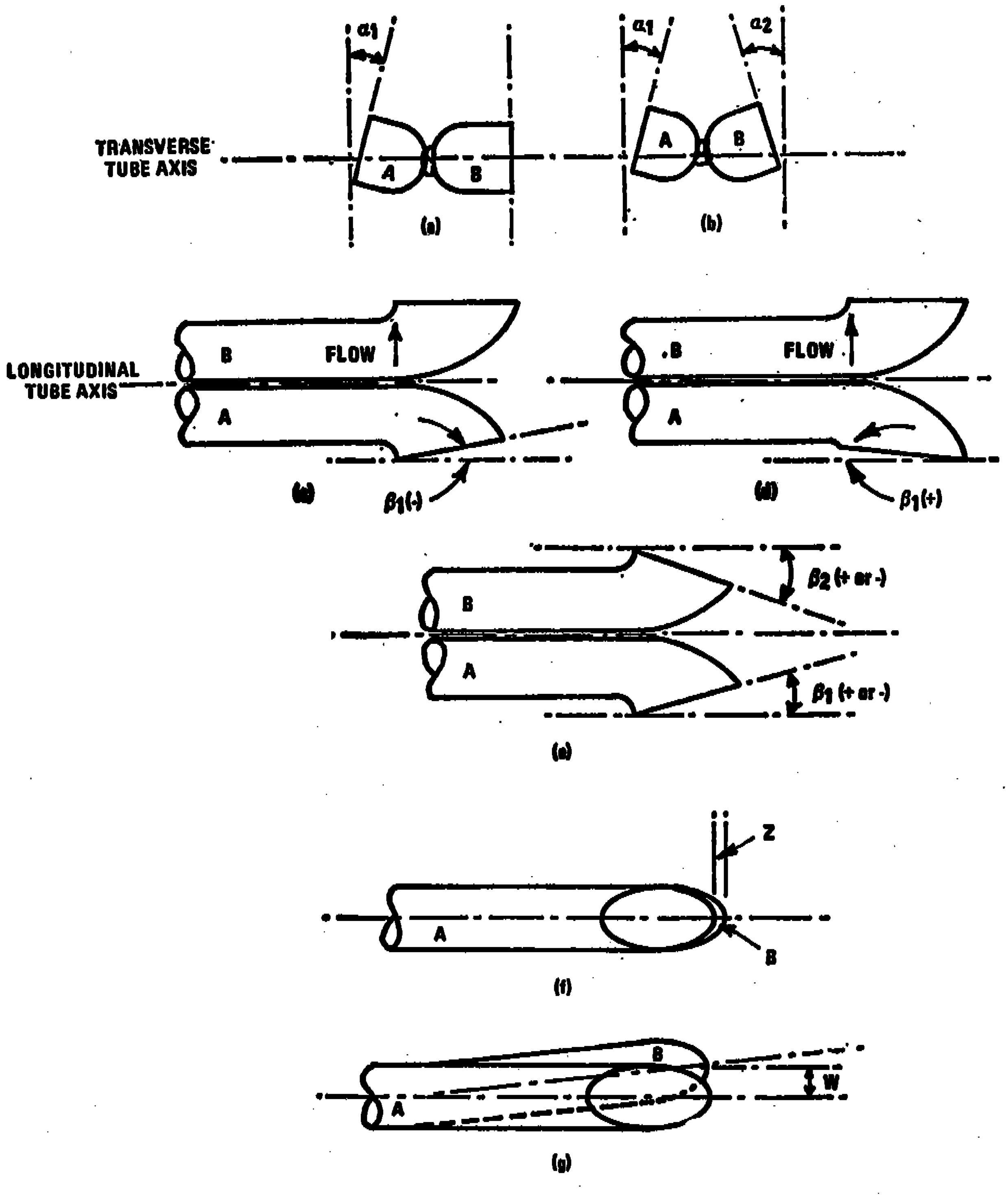


Figure 2-3. Types of face-opening misalignment that can result from field use or improper construction of Type S pitot tubes. These will not affect the baseline value of $\bar{C}p(s)$ so long as α_1 and $\alpha_2 < 10^{\circ}$, β_1 and $\beta_2 < 5^{\circ}$. $z < 0.32$ cm (1/8 in.) and $w < 0.08$ cm (1/32 in.) (citation 11 in Section 6).

A standard pitot tube may be used instead of a Type S, provided that it meets the specifications of Sections 2.7 and 4.2; note, however, that the static and impact pressure holes of standard pitot tubes are susceptible to plugging in particulate-laden gas streams. Therefore, whenever a standard pitot tube is used to perform a traverse, adequate proof must be furnished that the openings of the pitot tube have not plugged up during the traverse period; this can be done by taking a velocity head (Δp) reading at the final traverse point, cleaning out the impact and static holes of the standard pitot tube by "back-purging" with pressurized air, and then taking another Δp reading. If the Δp readings made before and after the air purge are the same (±5 percent), the traverse is acceptable. Otherwise, reject the run. Note that if Δp at the final traverse point is unsuitably low, another point may be selected. If "back-purging" at regular intervals is part of the procedure, then comparative Δp readings shall be taken, as above, for the last two back purges at which suitably high Δp readings are observed.

2.2 Differential Pressure Gauge. An inclined manometer or equivalent device is used. Most sampling trains are equipped with a 10-in. (water column) inclined-vertical manometer, having 0.01-in. H_2O divisions on the 0- to 1-in. inclined scale, and 0.1-in. H_2O divisions on the 1- to 10-in. vertical scale. This type of manometer (or other gauge of equivalent sensitivity) is satisfactory for the measurement of Δp values as low as 1.3 mm (0.05 in.) H_2O. However, a differential pressure gauge of greater sensitivity shall be used (subject to the approval of the Administrator), if any of the following is found to be true: (1) the arithmetic average of all Δp readings at the traverse points in the stack is less than 1.3 mm (0.05 in.) H_2O; (2) for traverses of 12 or more points, more than 10 percent of the individual Δp readings are below 1.3 mm (0.05 in.) H_2O; (3) for traverses of fewer than 12 points, more than one Δp reading is below 1.3 mm (0.05 in.) H_2O. Citation 18 in Section 6 describes commercially available instrumentation for the measurement of low-range gas velocities.

As an alternative to criteria (1) through (3) above, the following calculation may be performed to determine the necessity of using a more sensitive differential pressure gauge:

$$T=\frac{\sum_{i=1}^{n}\sqrt{\Delta p_i+K}}{\sum_{i=1}^{n}\sqrt{\Delta p_i}}$$

where:

Δp_i=Individual velocity head reading at a traverse point, mm H_2O (in. H_2O).

n=Total number of traverse points.

K=0.13 mm H_2O when metric units are used and 0.005 in H_2O when English units are used.

If T is greater than 1.05, the velocity head data are unacceptable and a more sensitive differential pressure gauge must be used.

NOTE.—If differential pressure gauges other than inclined manometers are used (e.g., magnehelic gauges), their calibration must be checked after each test series. To check the calibration of a differential pressure gauge, compare Δp readings of the gauge with those of a gauge-oil manometer at a minimum of three points, approximately representing the range of Δp values in the stack. If, at each point, the values of Δp as read by the differential pressure gauge and gauge-oil manometer agree to within 5 percent, the differential pressure gauge shall be considered to be in proper calibration. Otherwise, the test series shall either be voided, or procedures to adjust the measured Δp values and final results shall be used, subject to the approval of the Administrator.

2.3 Temperature Gauge. A thermocouple, liquid-filled bulb thermometer, bimetallic thermometer, mercury-in-glass thermometer, or other gauge capable of measuring temperature to within 1.5 percent of the minimum absolute stack temperature shall be used. The temperature gauge shall be attached to the pitot tube such that the sensor tip does not touch any metal; the gauge shall be in an interference-free arrangement with respect to the pitot tube face openings (see Figure 2-1 and also Figure 2-7 in Section 4). Alternate positions may be used if the pitot tube-temperature gauge system is calibrated according to the procedure of Section 4. Provided that a difference of not more than 1 percent in the average velocity measurement is introduced, the temperature gauge need not be attached to the pitot tube; this alternative is subject to the approval of the Administrator.

2.4 Pressure Probe and Gauge. A piezometer tube and mercury- or water-filled U-tube manometer capable of measuring stack pressure to within 2.5 mm (0.1 in.) Hg is used. The static tap of a standard type pitot tube or one leg of a Type X pitot tube with the face opening planes positioned parallel to the gas flow may also be used as the pressure probe.

2.5 Barometer. A mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg) may be used. In many cases, the barometric reading may be obtained from a nearby national weather service station, in which case the station value (which is the absolute barometric pressure) shall be requested and an adjustment for elevation differences between the weather station and the sampling point shall be applied at a rate of minus 2.5 mm (0.1 in.) Hg per 30-meter (100 foot) elevation increase, or vice-versa for elevation decrease.

2.6 Gas Density Determination Equipment. Method 3 equipment, if needed (see Section 3.6), to determine the stack gas dry molecular weight, and Reference Method 4 or Method 5 equipment for moisture content determination; other methods may be used subject to approval of the Administrator.

2.7 Calibration Pitot Tube. When calibration of the Type S pitot tube is necessary (see Section 4), a standard pitot tube is used as a reference. The standard pitot tube shall, preferably, have a known coefficient, obtained either (1) directly from the National Bureau of Standards, Route 270, Quince Orchard Road, Gaithersburg, Maryland, or (2) by calibration against another standard pitot tube with an NBS-traceable coefficient. Alternatively, a standard pitot tube designed according to the criteria given in 2.7.1 through 2.7.5 below and illustrated in Figure 2-4 (see also Citations 7, 8, and 17 in Section 6) may be used. Pitot tubes designed according to these specifications will have baseline coefficients of about 0.99±0.01.

2.7.1 Hemispherical (shown in Figure 2-4), ellipsoidal, or conical tip.

2.7.2 A minimum of six diameters straight run (based upon D, the external diameter of the tube) between the tip and the static pressure holes.

2.7.3 A minimum of eight diameters straight run between the static pressure holes and the centerline of the external tube, following the 90 degree bend.

2.7.4 Static pressure holes of equal size (approximately 0.1 D), equally spaced in a piezometer ring configuration.

2.7.5 Ninety degree bend, with curved or mitered junction.

2.8 Differential Pressure Gauge for Type S Pitot Tube Calibration. An inclined manometer or equivalent is used. If the single-velocity calibration technique is employed (see Section 4.1.2.3), the calibration differential pressure gauge shall be readable to the nearest 0.13 mm H_2O (0.005 in. H_2O). For multivelocity calibrations, the gauge shall be readable to the nearest 0.13 mm H_2O (0.005 in H_2O) for Δp values between 1.3 and 25 mm H_2O (0.05 and 1.0 in. H_2O), and to the nearest 1.3 mm H_2O (0.05 in. H_2O) for Δp values above 25 mm H_2O (1.0 in. H_2O). A special, more sensitive gauge will be required to read Δp values below 1.3 mm H_2O [0.05 in. H_2O] (see Citation 18 in Section 6).

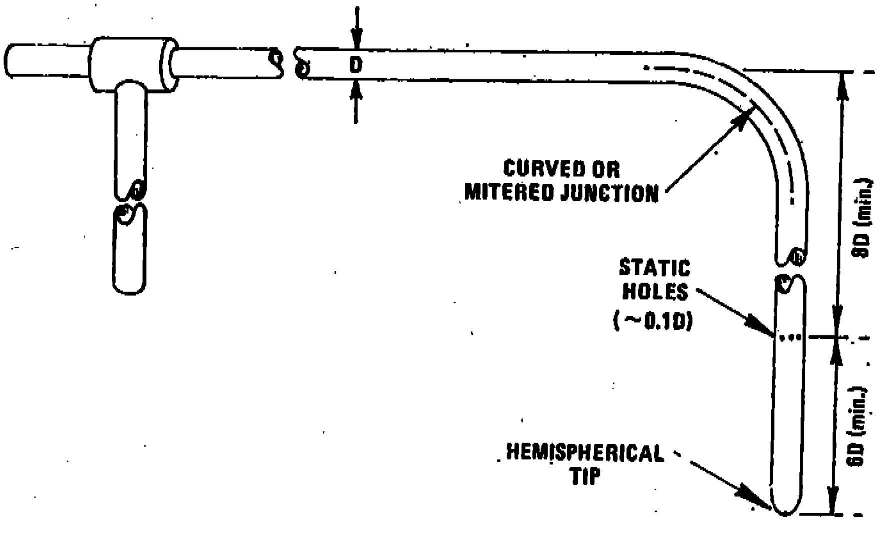


Figure 2-4. Standard pitot tube design specifications.

3. *Procedure*

3.1 Set up the apparatus as shown in Figure 2-1. Capillary tubing or surge tanks installed between the manometer and pitot tube may be used to dampen Δp fluctuations. It is recommended, but not required, that a pretest leak-check be conducted, as follows: (1) blow through the pitot impact opening until at least 7.6 cm (3 in.) H_2O velocity pressure registers on the manometer; then, close off the impact opening. The pressure shall remain stable for at least 15 seconds; (2) do the same for the static pressure side, except using suction to obtain the minimum of 7.6 cm (3 in.) H_2O. Other leak-check procedures, subject to the approval of the Administrator, may be used.

3.2 Level and zero the manometer. Because the manometer level and zero may drift due to vibrations and temperature changes, make periodic checks during the traverse. Record all necessary data as shown in the example data sheet (Figure 2-5).

3.3 Measure the velocity head and temperature at the traverse points specified by Method 1. Ensure that the proper differential pressure gauge is being used for the range of Δp values encountered (see Section 2.2). If it is necessary to change to a more sensitive gauge, do so, and remeasure the Δp and temperature readings at each traverse point. Conduct a post-test leak-check (mandatory), as described in Section 3.1 above, to validate the traverse run.

3.4 Measure the static pressure in the stack. One reading is usually adequate.

3.5 Determine the atmospheric pressure.

PLANT ______________________________
DATE ______________ RUN NO. __________
STACK DIAMETER OR DIMENSIONS, m(in.) __________
BAROMETRIC PRESSURE, mm Hg (in. Hg) __________
CROSS SECTIONAL AREA, m^2(ft^2) __________
OPERATORS ______________________________
PITOT TUBE I.D. NO. ______________________________
AVG. COEFFICIENT, C_p = __________
LAST DATE CALIBRATED __________

SCHEMATIC OF STACK CROSS SECTION

Traverse Pt. No.	Vel. Hd., Δp mm (in.) H_2O	Stack Temperature		P_g mm Hg (in.Hg)	$\sqrt{\Delta p}$
		t_s, °C (°F)	T_s, °K (°R)		
		Average			

Figure 2-5. Velocity traverse data.

3.6 Determine the stack gas dry molecular weight. For combustion processes or processes that emit essentially CO_2, O_2, CO, and N_2, use Method 3. For processes emitting essentially air, an analysis need not be conducted; use a dry molecular weight of 29.0. For other processes, other methods, subject to the approval of the Administrator, must be used.

3.7 Obtain the moisture content from Reference Method 4 (or equivalent) or from Method 5.

3.8 Determine the cross-sectional area of the stack or duct at the sampling location. Whenever possible, physically measure the stack dimensions rather than using blueprints.

4. *Calibration*

4.1 Type S Pitot Tube. Before its initial use, carefully examine the Type S pitot tube in top, side, and end views to verify that the face openings of the tube are aligned within the specifications illustrated in Figure 2-2 or 2-3. The pitot tube shall not be used if it fails to meet these alignment specifications.

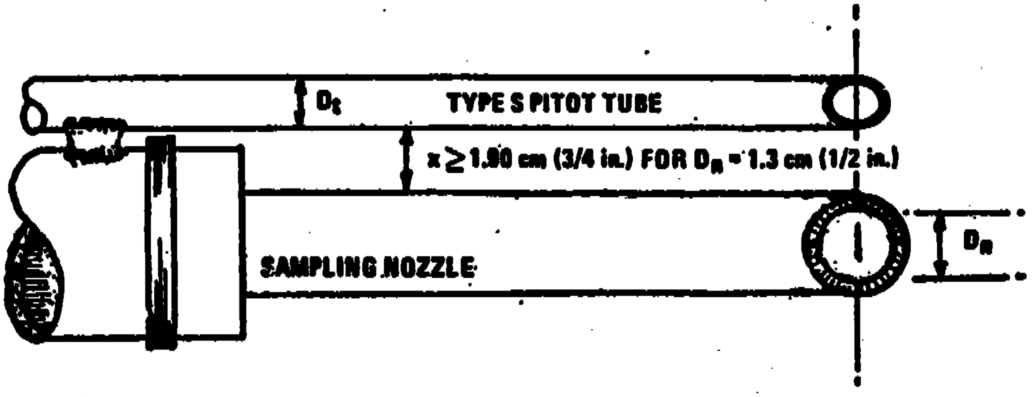
After verifying the face opening alignment, measure and record the following dimensions of the pitot tube: (a) the external tubing diameter (dimension D_t, Figure 2-2b); and (b) the base-to-opening plane distances (dimensions P_A and P_B, Figure 2-2b). If D_t is between 0.48 and 0.95 cm (3/16 and 3/8 in.) and if P_A and P_B are equal and between 1.05 and 1.50 R_t, there are two possible options: (1) the pitot tube may be calibrated according to the procedure outlined in Sections 4.1.2 through 4.1.5 below, or (2) a baseline (isolated tube) coefficient value of 0.84 may be assigned to the pitot tube. Note, however, that if the pitot tube is part of an assembly, calibration may still be required, despite knowledge of the baseline coefficient value (see Section 4.1.1).

If D_t, P_A, and P_B are outside the specified limits, the pitot tube must be calibrated as outlined in 4.1.2 through 4.1.5 below.

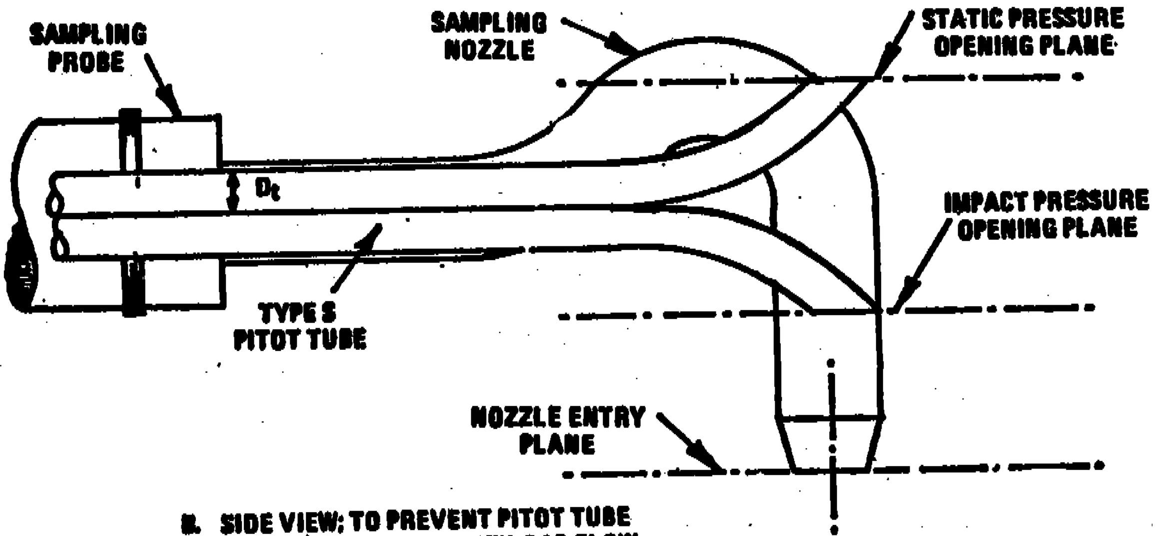
4.1.1 Type S Pitot Tube Assemblies. During sample and velocity traverses, the isolated Type S pitot tube is not always used; in many instances, the pitot tube is used in combination with other source-sampling components (thermocouple, sampling probe, nozzle) as part of an "assembly." The presence of other sampling components can sometimes affect the baseline value of the Type S pitot tube coefficient (Citation 9 in Section 6); therefore an assigned (or otherwise known) baseline coefficient value may or may not be valid for a given assembly. The baseline and assembly coefficient values will be identical only when the relative placement of the components in the assembly is such that aerodynamic interference effects are eliminated. Figures 2-6 through 2-8 illustrate interference-free component arrangements for Type S pitot tubes having external tubing diameters between 0.48 and 0.95 cm (3/16 and 3/8 in.). Type S pitot tube assemblies that fail to meet any or all of the specifications of Figures 2-6 through 2-8 shall be calibrated according to the procedure outlined in Sections 4.1.2 through 4.1.5 below, and prior to calibration, the values of the intercomponent spacings (pitot-nozzle, pitot-thermocouple, pitot-probe sheath) shall be measured and recorded.

NOTE.—Do not use any Type S pitot tube assembly which is constructed such that the impact pressure opening plane of the pitot tube is below the entry plane of the nozzle (see Figure 2-6b).

4.1.2 Calibration Setup. If the Type S pitot tube is to be calibrated, one leg of the tube shall be permanently marked A, and the other, B. Calibration shall be done in a flow system having the following essential design features:



A. BOTTOM VIEW; SHOWING MINIMUM PITOT-NOZZLE SEPARATION.



B. SIDE VIEW; TO PREVENT PITOT TUBE FROM INTERFERING WITH GAS FLOW STREAMLINES APPROACHING THE NOZZLE, THE IMPACT PRESSURE OPENING PLANE OF THE PITOT TUBE SHALL BE EVEN WITH OR ABOVE THE NOZZLE ENTRY PLANE.

Figure 2-6. Proper pitot tube - sampling nozzle configuration to prevent aerodynamic interference; buttonhook - type nozzle; centers of nozzle and pitot opening aligned; D_t between 0.48 and 0.95 cm (3/16 and 3/8 in.).

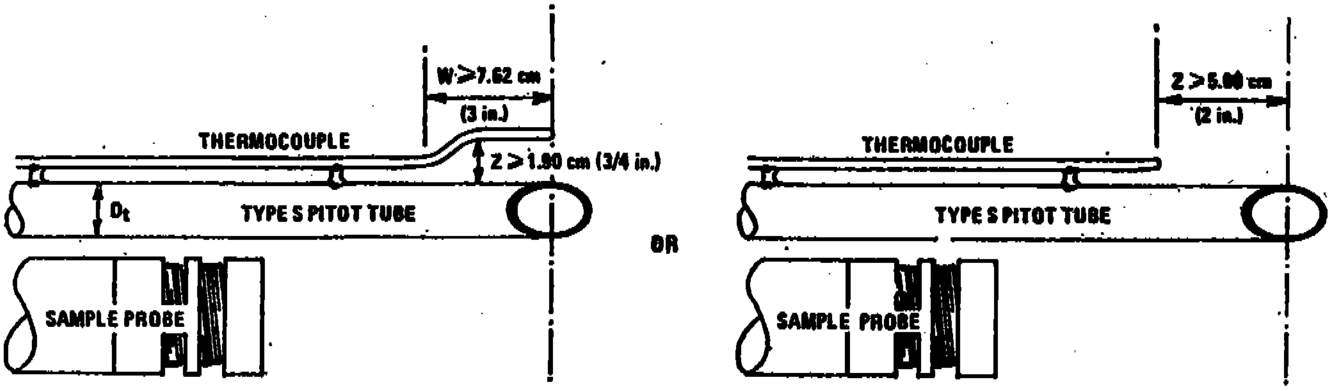


Figure 2-7. Proper thermocouple placement to prevent interference; D_t between 0.48 and 0.95 cm (3/16 and 3/8 in.).

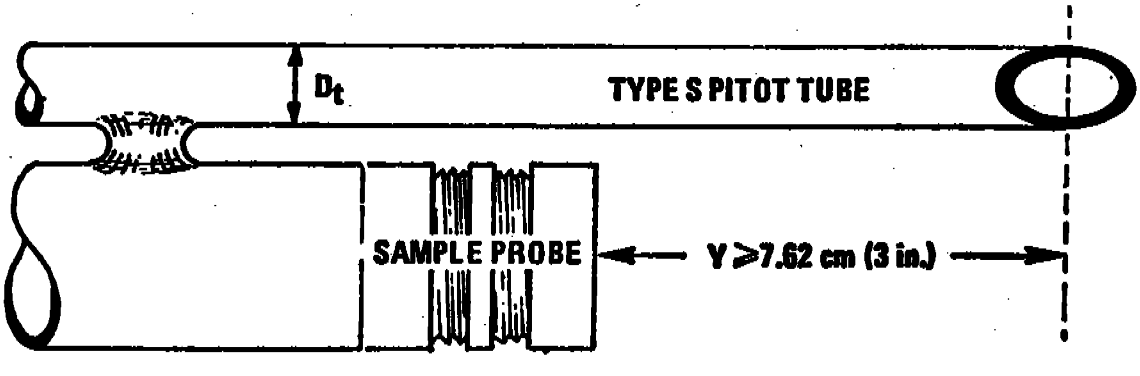


Figure 2-8. Minimum pitot-sample probe separation needed to prevent interference; D_t between 0.48 and 0.95 cm (3/16 and 3/8 in.).

4.1.2.1 The flowing gas stream must be confined to a duct of definite cross-sectional area, either circular or rectangular. For circular cross-sections, the minimum duct diameter shall be 30.5 cm (12 in.); for rectangular cross-sections, the width (shorter side) shall be at least 25.4 cm (10 in.).

4.1.2.2 The cross-sectional area of the calibration duct must be constant over a distance of 10 or more duct diameters. For a rectangular cross-section, use an equivalent diameter, calculated from the following equation, to determine the number of duct diameters:

$$D_e = \frac{2\,LW}{(L+W)}$$

Equation 2-1

where:

D_e = Equivalent diameter
L = Length
W = Width

To ensure the presence of stable, fully developed flow patterns at the calibration site, or "test section," the site must be located at least eight diameters downstream and two diameters upstream from the nearest disturbances.

NOTE.—The eight- and two-diameter criteria are not absolute; other test section locations may be used (subject to approval of the Administrator), provided that the flow at the test site is stable and demonstrably parallel to the duct axis.

4.1.2.3 The flow system shall have the capacity to generate a test-section velocity around 915 m/min (3,000 ft/min). This velocity must be constant with time to guarantee steady flow during calibration. Note that Type S pitot tube coefficients obtained by single-velocity calibration at 915 m/min (3,000 ft/min) will generally be valid to within ±3 percent for the measurement of velocities above 305 m/min (1,000 ft/min) and to within ±5 to 6 percent for the measurement of velocities between 180 and 305 m/min (600 and 1,000 ft/min). If a more precise correlation between C_p and velocity is desired, the flow system shall have the capacity to generate at least four distinct, time-invariant test-section velocities covering the velocity range from 180 to 1,525 m/min (600 to 5,000 ft/min), and calibration data shall be taken at regular velocity intervals over this range (see Citations 9 and 14 in Section 6 for details).

4.1.2.4 Two entry ports, one each for the standard and Type S pitot tubes, shall be cut in the test section; the standard pitot entry port shall be located slightly downstream of the Type S port, so that the standard and Type S impact openings will lie in the same cross-sectional plane during calibration. To facilitate alignment of the pitot tubes during calibration, it is advisable that the test section be constructed of plexiglas or some other transparent material.

4.1.3 Calibration Procedure. Note that this procedure is a general one and must not be used without first referring to the special considerations presented in Section 4.1.5. Note also that this procedure applies only to single-velocity calibration. To obtain calibration data for the A and B sides of the Type S pitot tube, proceed as follows:

4.1.3.1 Make sure that the manometer is properly filled and that the oil is free from contamination and is of the proper density. Inspect and leak-check all pitot lines; repair or replace if necessary.

4.1.3.2 Level and zero the manometer. Turn on the fan and allow the flow to stabilize. Seal the Type S entry port.

4.1.3.3 Ensure that the manometer is level and zeroed. Position the standard pitot tube at the calibration point (determined as outlined in Section 4.1.5.1), and align the tube so that its tip is pointed directly into the flow. Particular care should be taken in aligning the tube to avoid yaw and pitch angles. Make sure that the entry port surrounding the tube is properly sealed.

4.1.3.4 Read Δp_{std} and record its value in a data table similar to the one shown in Figure 2-9. Remove the standard pitot tube from the duct and disconnect it from the manometer. Seal the standard entry port.

4.1.3.5 Connect the Type S pitot tube to the manometer. Open the Type S entry port. Check the manometer level and zero. Insert and align the Type S pitot tube so that its A side impact opening is at the same point as was the standard pitot tube and is pointed directly into the flow. Make sure that the entry port surrounding the tube is properly sealed.

4.1.3.6 Read Δp_s and enter its value in the data table. Remove the Type S pitot tube from the duct and disconnect it from the manometer.

4.1.3.7 Repeat steps 4.1.3.3 through 4.1.3.6 above until three pairs of Δp readings have been obtained.

4.1.3.8 Repeat steps 4.1.3.3 through 4.1.3.7 above for the B side of the Type S pitot tube.

4.1.3.9 Perform calculations, as described in Section 4.1.4 below.

4.1.4 Calculations.

4.1.4.1 For each of the six pairs of Δp readings (i.e., three from side A and three from side B) obtained in Section 4.1.3 above, calculate the value of the Type S pitot tube coefficient as follows:

PITOT TUBE IDENTIFICATION NUMBER: ____________________ **DATE:** __________

CALIBRATED BY: ____

"A" SIDE CALIBRATION

RUN NO.	Δp_{std} cm H_2O (in. H_2O)	$\Delta p_{(s)}$ cm H_2O (in. H_2O)	$C_{p(s)}$	DEVIATION $C_{p(s)} - \bar{C}_p(A)$
1				
2				
3				
		$\bar{C}_p$ (SIDE A)		

"B" SIDE CALIBRATION

RUN NO.	Δp_{std} cm H_2O (in. H_2O)	$\Delta p_{(s)}$ cm H_2O (in. H_2O)	$C_{p(s)}$	DEVIATION $C_{p(s)} - \bar{C}_p(B)$
1				
2				
3				
		$\bar{C}_p$ (SIDE B)		

$$\text{AVERAGE DEVIATION} = \sigma\,(\text{A OR B}) = \frac{\sum_{1}^{3} \left| C_p(s) - \bar{C}_p(\text{A OR B}) \right|}{3} \longleftarrow \text{MUST BE} \leqslant 0.01$$

$$\left| \bar{C}_p\,(\text{SIDE A}) - \bar{C}_p\,(\text{SIDE B}) \right| \longleftarrow \text{MUST BE} \leqslant 0.01$$

Figure 2-9. Pitot tube calibration data.

$$C_{p(s)} = C_{p(std)} \sqrt{\frac{\Delta p_{std}}{\Delta p_s}}$$

Equation 2-2

where:

$C_{p(s)}$ = Type S pitot tube coefficient

$C_{p(std)}$ = Standard pitot tube coefficient; use 0.99 if the coefficient is unknown and the tube is designed according to the criteria of Sections 2.7.1 to 2.7.5 of this method.

Δp_{std} = Velocity head measured by the standard pitot tube, cm H_2O (in. H_2O)

Δp_s = Velocity head measured by the Type S pitot tube, cm H_2O (in. H_2O)

4.1.4.2 Calculate $\bar{C}_p$ (side A), the mean A-side coefficient, and $\bar{C}_p$ (side B), the mean B-side coefficient; calculate the difference between these two average values.

4.1.4.3 Calculate the deviation of each of the three A-side values of $C_{p(s)}$ from $\bar{C}_p$ (side A), and the deviation of each B-side value of $C_{p(s)}$ from $\bar{C}_p$ (side B). Use the following equation:

$$\text{Deviation} = C_{p(s)} - \bar{C}_p(\text{A or B})$$

Equation 2-3

4.1.4.4 Calculate σ, the average deviation from the mean, for both the A and B sides of the pitot tube. Use the following equation:

$$\sigma\,(\text{side A or B}) = \frac{\sum_{1}^{3} \left| C_{p(s)} - \bar{C}_p(A \text{ or } B) \right|}{3}$$

Equation 2-4

4.1.4.5 Use the Type S pitot tube only if the values of σ (side A) and σ (side B) are less than or equal to 0.01 and if the absolute value of the difference between $\bar{C}_p$ (A) and $\bar{C}_p$ (B) is 0.01 or less.

4.1.5 Special considerations.

4.1.5.1 Selection of calibration point.

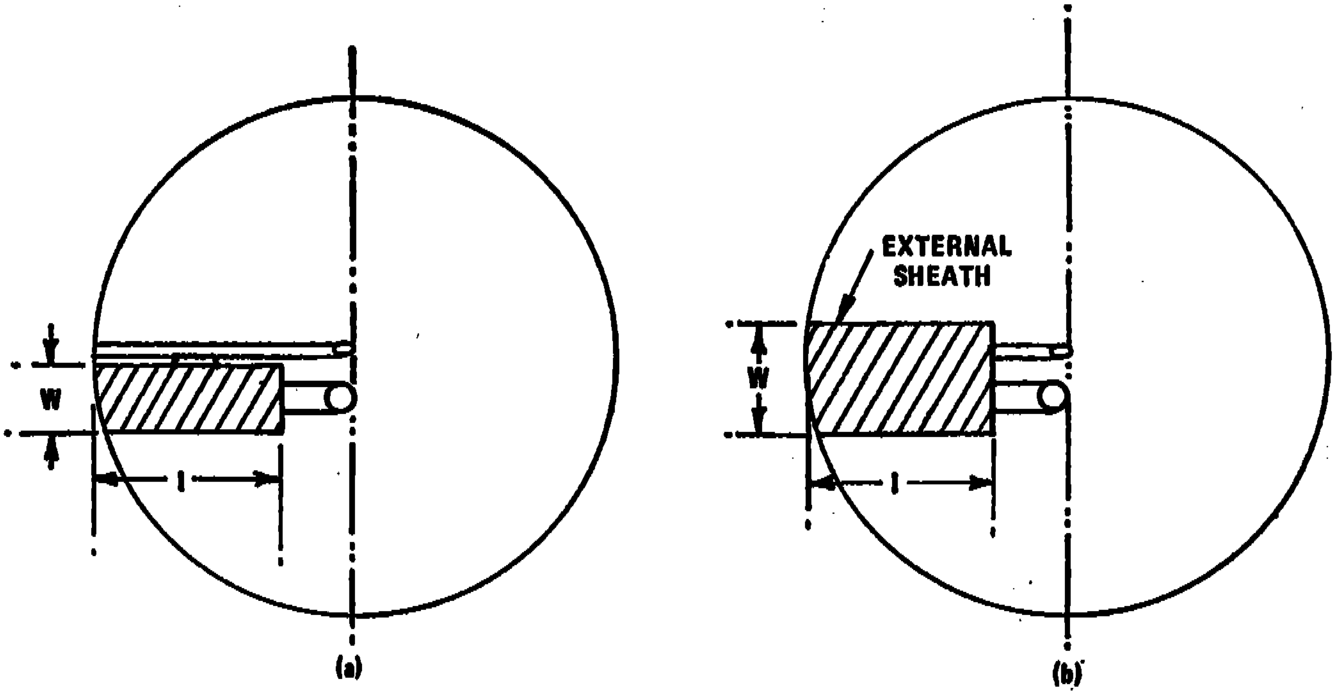
4.1.5.1.1 When an isolated Type S pitot tube is calibrated, select a calibration point at or near the center of the duct, and follow the procedures outlined in Sections 4.1.3 and 4.1.4 above. The Type S pitot coefficients so obtained, i.e., $\bar{C}_p$ (side A) and $\bar{C}_p$ (side B), will be valid, so long as either: (1) the isolated pitot tube is used; or (2) the pitot tube is used with other components (nozzle, thermocouple, sample probe) in an arrangement that is free from aerodynamic interference effects (see Figures 2-6 through 2-8).

4.1.5.1.2 For Type S pitot tube-thermocouple combinations (without sample probe), select a calibration point at or near the center of the duct, and follow the procedures outlined in Sections 4.1.3 and 4.1.4 above. The coefficients so obtained will be valid so long as the pitot tube-thermocouple combination is used by itself or with other components in an interference-free arrangement (Figures 2-6 and 2-8).

4.1.5.1.3 For assemblies with sample probes, the calibration point should be located at or near the center of the duct; however, insertion of a probe sheath into a small duct may cause significant cross-sectional area blockage and yield incorrect coefficient values (Citation 9 in Section 6). Therefore, to minimize the blockage effect, the calibration point may be a few inches off-center if necessary. The actual blockage effect will be negligible when the theoretical blockage, as determined by a projected-area model of the probe sheath, is 2 percent or less of the duct cross-sectional area for assemblies without external sheaths (Figure 2-10a), and 3 percent or less for assemblies with external sheaths (Figure 2-10b).

4.1.5.2 For those probe assemblies in which pitot tube-nozzle interference is a factor (i.e., those in which the pitot-nozzel separation distance fails to meet the specification illustrated in Figure 2-6a), the value of $C_{p(s)}$ depends upon the amount of free-space between the tube and nozzle, and therefore is a function of nozzle size. In these instances, separate calibrations shall be performed with each of the commonly used nozzle sizes in place. Note that the single-velocity calibration technique is acceptable for this purpose, even though the larger nozzle sizes (>0.635 cm or ¼ in.) are not ordinarily used for isokinetic sampling at velocities around 915 m/min (3,000 ft/min), which is the calibration velocity; note also that it is not necessary to draw an isokinetic sample during calibration (see Citation 19 in Section 6).

4.1.5.3 For a probe assembly constructed such that its pitot tube is always used in the same orientation, only one side of the pitot tube need be calibrated (the side which will face the flow). The pitot tube must still meet the alignment specifications of Figure 2-2 or 2-3, however, and must have an average deviation (σ) value of 0.01 or less (see Section 4.1.4.4).



$$\text{ESTIMATED SHEATH BLOCKAGE (\%)} = \left[\frac{l \times W}{\text{DUCT AREA}}\right] \times 100$$

Figure 2-10. Projected-area models for typical pitot tube assemblies.

4.1.6 Field Use and Recalibration.

4.1.6.1 Field Use.

4.1.6.1.1 When a Type S pitot tube (isolated tube or assembly) is used in the field, the appropriate coefficient value (whether assigned or obtained by calibration) shall be used to perform velocity calculations. For calibrated Type S pitot tubes, the A side coefficient shall be used when the A side of the tube faces the flow, and the B side coefficient shall be used when the B side faces the flow; alternatively, the arithmetic average of the A and B side coefficient values may be used, irrespective of which side faces the flow.

4.1.6.1.2 When a probe assembly is used to sample a small duct (12 to 36 in. in diameter), the probe sheath sometimes blocks a significant part of the duct cross-section, causing a reduction in the effective value of $\overline{C}_{p(s)}$. Consult Citation 9 in Section 6 for details. Conventional pitot-sampling probe assemblies are not recommended for use in ducts having inside diameters smaller than 12 inches (Citation 16 in Section 6).

4.1.6.2 Recalibration.

4.1.6.2.1 Isolated Pitot Tubes. After each field use, the pitot tube shall be carefully reexamined in top, side, and end views. If the pitot face openings are still aligned within the specifications illustrated in Figure 2–2 or 2–3, it can be assumed that the baseline coefficient of the pitot tube has not changed. If, however, the tube has been damaged to the extent that it no longer meets the specifications of Figure 2–2 or 2–3, the damage shall either be repaired to restore proper alignment of the face openings or the tube shall be discarded.

4.1.6.2.2 Pitot Tube Assemblies. After each field use, check the face opening alignment of the pitot tube, as in Section 4.1.6.2.1; also, remeasure the intercomponent spacings of the assembly. If the intercomponent spacings have not changed and the face opening alignment is acceptable, it can be assumed that the coefficient of the assembly has not changed. If the face opening alignment is no longer within the specifications of Figures 2–2 or 2–3, either repair the damage or replace the pitot tube (calibrating the new assembly, if necessary). If the intercomponent spacings have changed, restore the original spacings or recalibrate the assembly.

4.2 Standard pitot tube (if applicable). If a standard pitot tube is used for the velocity traverse, the tube shall be constructed according to the criteria of Section 2.7 and shall be assigned a baseline coefficient value of 0.99. If the standard pitot tube is used as part of an assembly, the tube shall be in an interference-free arrangement (subject to the approval of the Administrator).

4.3 Temperature Gauges. After each field use, calibrate dial thermometers, liquid-filled bulb thermometers, thermocouple-potentiometer systems, and other gauges at a temperature within 10 percent of the average absolute stack temperature. For temperatures up to 405° C (761° F), use an ASTM mercury-in-glass reference thermometer, or equivalent, as a reference; alternatively, either a reference thermocouple and potentiometer (calibrated by NBS) or thermometric fixed points, e.g., ice bath and boiling water (corrected for barometric pressure) may be used. For temperatures above 405° C (761° F), use an NBS-calibrated reference thermocouple-potentiometer system or an alternate reference, subject to the approval of the Administrator.

If, during calibration, the absolute temperatures measured with the gauge being calibrated and the reference gauge agree within 1.5 percent, the temperature data taken in the field shall be considered valid. Otherwise, the pollutant emission test shall either be considered invalid or adjustments (if appropriate) of the test results shall be made, subject to the approval of the Administrator.

4.4 Barometer. Calibrate the barometer used against a mercury barometer.

5. *Calculations*

Carry out calculations, retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after final calculation.

5.1 Nomenclature.

A = Cross-sectional area of stack, m² (ft²).

B_{ws} = Water vapor in the gas stream (from Method 5 or Reference Method 4), proportion by volume.

C_p = Pitot tube coefficient, dimensionless.

K_p = Pitot tube constant,

$$34.97\ \frac{\text{m}}{\text{sec}}\left[\frac{(g/g\text{-mole})(\text{mm Hg})}{(°\text{K})(\text{mm H}_2\text{O})}\right]^{1/2}$$

for the metric system and

$$85.49\ \frac{\text{ft}}{\text{sec}}\left[\frac{(\text{lb/lb-mole})(\text{in. Hg})}{(°\text{R})(\text{in. H}_2\text{O})}\right]^{1/2}$$

for the English system.

M_d = Molecular weight of stack gas, dry basis (see Section 3.6) g/g-mole (lb/lb-mole).

M_s = Molecular weight of stack gas, wet basis, g/g-mole (lb/lb-mole).

$= M_d\,(1-B_{ws})+18.0\,B_{ws}$ Equation 2–5

P_{bar} = Barometric pressure at measurement site, mm Hg (in. Hg).

P_g = Stack static pressure, mm Hg (in. Hg).

P_s = Absolute stack gas pressure, mm Hg (in. Hg):

$= P_{bar}+P_g$ Equation 2–6

P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).

Q_{sd} = Dry volumetric stack gas flow rate corrected to standard conditions, dscm/hr (dscf/hr).

t_s = Stack temperature, °C (°F).

T_s = Absolute stack temperature, °K (°R).

$= 273+t_s$ for metric Equation 2–7

$= 460+t_s$ for English Equation 2–8

T_{std} = Standard absolute temperature, 293 °K (528° R)

v_s = Average stack gas velocity, m/sec (ft/sec).

Δp = Velocity head of stack gas, mm H₂O (in. H₂O).

3,600 = Conversion factor, sec/hr.

18.0 = Molecular weight of water, g/g-mole (lb-lb-mole).

5.2 Average stack gas velocity.

$$v_s = K_p C_p (\sqrt{\Delta p})_{avg} \sqrt{\frac{T_{s(avg)}}{P_s M_s}}$$

Equation 2–9

5.3 Average stack gas dry volumetric flow rate.

$$Q_{sd} = 3{,}600(1-B_{ws})v_s A\left(\frac{T_{std}}{T_{s(avg)}}\right)\left(\frac{P_s}{P_{std}}\right)$$

Equation 2–10

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METHOD 3—GAS ANALYSIS FOR CARBON DIOXIDE, OXYGEN, EXCESS AIR, AND DRY MOLECULAR WEIGHT

1. *Principle and Applicability*

1.1 Principle. A gas sample is extracted from a stack, by one of the following methods: (1) single-point, grab sampling; (2) single-point, integrated sampling; or (3) multi-point, integrated sampling. The gas sample is analyzed for percent carbon dioxide (CO_2), percent oxygen (O_2), and, if necessary, percent carbon monoxide (CO). If a dry molecular weight determination is to be made, either an Orsat or a Fyrite[1] analyzer may be used for the analysis; for excess air or emission rate correction factor determination, an Orsat analyzer must be used.

1.2 Applicability. This method is applicable for determining CO_2 and O_2 concentrations, excess air, and dry molecular weight of a sample from a gas stream of a fossil-fuel combustion process. The method may also be applicable to other processes where it has been determined that compounds other than CO_2, O_2, CO, and nitrogen (N_2) are not present in concentrations sufficient to affect the results.

Other methods, as well as modifications to the procedure described herein, are also applicable for some or all of the above determinations. Examples of specific methods and modifications include: (1) a multi-point sampling method using an Orsat analyzer to analyze individual grab samples obtained at each point; (2) a method using CO_2 or O_2 and stoichiometric calculations to determine dry molecular weight and excess air; (3) assigning a value of 30.0 for dry molecular weight, in lieu of actual measurements, for processes burning natural gas, coal, or oil. These methods and modifications may be used, but are subject to the approval of the Administrator.

2. *Apparatus*

As an alternative to the sampling apparatus and systems described herein, other sampling systems (e.g., liquid displacement) may be used provided such systems are capable of obtaining a representative sample and maintaining a constant sampling rate, and are otherwise capable of yielding acceptable results. Use of such systems is subject to the approval of the Administrator.

2.1 Grab Sampling (Figure 3-1).

2.1.1 Probe. The probe should be made of stainless steel or borosilicate glass tubing and should be equipped with an in-stack or out-stack filter to remove particulate matter (a plug of glass wool is satisfactory for this purpose). Any other material inert to O_2, CO_2, CO, and N_2 and resistant to temperature at sampling conditions may be used for the probe; examples of such material are aluminum, copper, quartz glass and Teflon.

2.1.2 Pump. A one-way squeeze bulb, or equivalent, is used to transport the gas sample to the analyzer.

2.2 Integrated Sampling (Figure 3-2).

2.2.1 Probe. A probe such as that described in Section 2.1.1 is suitable.

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[1] Mention of trade names or specific products does not constitute endorsement by the Environmental Protection Agency.

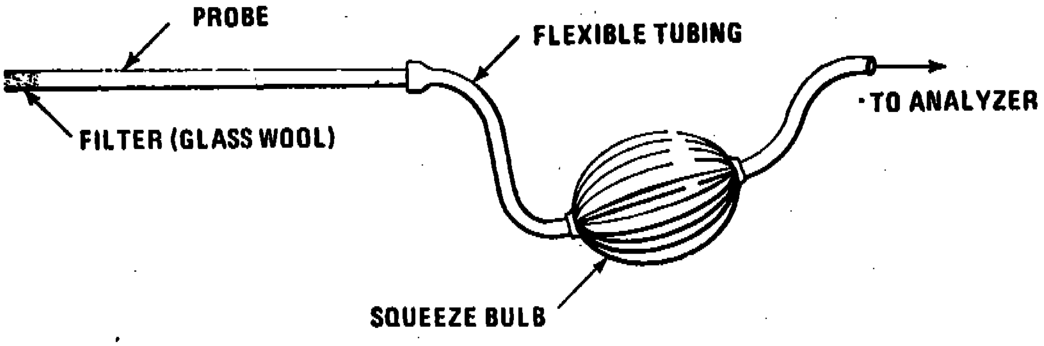

Figure 3-1. Grab-sampling train.

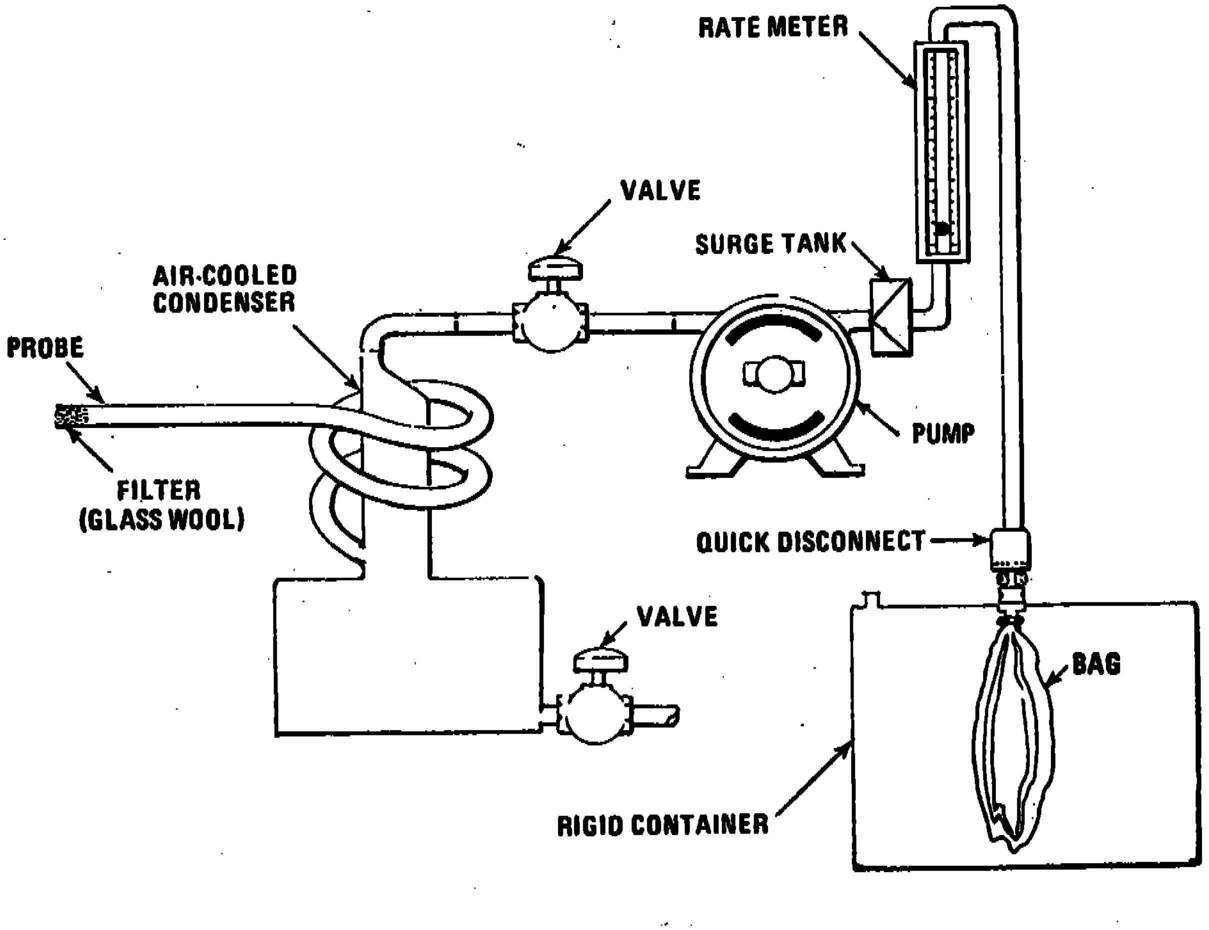

Figure 3-2. Integrated gas-sampling train.

2.2.2 Condenser. An air-cooled or water-cooled condenser, or other condenser that will not remove O_2, CO_2, CO, and N_2, may be used to remove excess moisture which would interfere with the operation of the pump and flow meter.

2.2.3 Valve. A needle valve is used to adjust sample gas flow rate.

2.2.4 Pump. A leak-free, diaphragm-type pump, or equivalent, is used to transport sample gas to the flexible bag. Install a small surge tank between the pump and rate meter to eliminate the pulsation effect of the diaphragm pump on the rotameter.

2.2.5 Rate Meter. The rotameter, or equivalent rate meter, used should be capable of measuring flow rate to within ±2 percent of the selected flow rate. A flow rate range of 500 to 1000 cm^3/min is suggested.

2.2.6 Flexible Bag. Any leak-free plastic (e.g., Tedlar, Mylar, Teflon) or plastic-coated aluminum (e.g., aluminized Mylar) bag, or equivalent, having a capacity consistent with the selected flow rate and time length of the test run, may be used. A capacity in the range of 55 to 90 liters is suggested.

To leak-check the bag, connect it to a water manometer and pressurize the bag to 5 to 10 cm H_2O (2 to 4 in. H_2O). Allow to stand for 10 minutes. Any displacement in the water manometer indicates a leak. An alternative leak-check method is to pressurize the bag to 5 to 10 cm H_2O (2 to 4 in. H_2O) and allow to stand overnight. A deflated bag indicates a leak.

2.2.7 Pressure Gauge. A water-filled U-tube manometer, or equivalent, of about 28 cm (12 in.) is used for the flexible bag leak-check.

2.2.8 Vacuum Gauge. A mercury manometer, or equivalent, of at least 760 mm Hg (30 in. Hg) is used for the sampling train leak-check.

2.3 Analysis. For Orsat and Fyrite analyzer maintenance and operation procedures, follow the instructions recommended by the manufacturer, unless otherwise specified herein.

2.3.1 Dry Molecular Weight Determination. An Orsat analyzer or Fyrite type combustion gas analyzer may be used.

2.3.2 Emission Rate Correction Factor or Excess Air Determination. An Orsat analyzer must be used. For low CO_2 (less than 4.0 percent) or high O_2 (greater than 15.0 percent) concentrations, the measuring burette of the Orsat must have at least 0.1 percent subdivisions.

3. *Dry Molecular Weight Determination*

Any of the three sampling and analytical procedures described below may be used for determining the dry molecular weight.

3.1 Single-Point, Grab Sampling and Analytical Procedure.

3.1.1 The sampling point in the duct shall either be at the centroid of the cross section or at a point no closer to the walls than 1.00 m (3.3 ft), unless otherwise specified by the Administrator.

3.1.2 Set up the equipment as shown in Figure 3-1, making sure all connections ahead of the analyzer are tight and leak-free. If an Orsat analyzer is used, it is recommended that the analyzer be leaked-checked by following the procedure in Section 5; however, the leak-check is optional.

3.1.3 Place the probe in the stack, with the tip of the probe positioned at the sampling point; purge the sampling line. Draw a sample into the analyzer and immediately analyze it for percent CO_2 and percent O_2. Determine the percentage of the gas that is N_2 and CO by subtracting the sum of the percent CO_2 and percent O_2 from 100 percent. Calculate the dry molecular weight as indicated in Section 6.3.

3.1.4 Repeat the sampling, analysis, and calculation procedures, until the dry molecular weights of any three grab samples differ from their mean by no more than 0.3 g/g-mole (0.3 lb/lb-mole). Average these three molecular weights, and report the results to the nearest 0.1 g/g-mole (lb/lb-mole).

3.2 Single-Point, Integrated Sampling and Analytical Procedure.

3.2.1 The sampling point in the duct shall be located as specified in Section 3.1.1.

3.2.2 Leak-check (optional) the flexible bag as in Section 2.2.6. Set up the equipment as shown in Figure 3-2. Just prior to sampling, leak-check (optional) the train by placing a vacuum gauge at the condenser inlet, pulling a vacuum of at least 250 mm Hg (10 in. Hg), plugging the outlet at the quick disconnect, and then turning off the pump. The vacuum should remain stable for at least 0.5 minute. Evacuate the flexible bag. Connect the probe and place it in the stack, with the tip of the probe positioned at the sampling point; purge the sampling line. Next, connect the bag and make sure that all connections are tight and leak free.

3.2.3 Sample at a constant rate. The sampling run should be simultaneous with, and for the same total length of time as, the pollutant emission rate determination. Collection of at least 30 liters (1.00 ft^3) of sample gas is recommended; however, smaller volumes may be collected, if desired.

3.2.4 Obtain one integrated flue gas sample during each pollutant emission rate determination. Within 8 hours after the sample is taken, analyze it for percent CO_2 and percent O_2 using either an Orsat analyzer or a Fyrite-type combustion gas analyzer. If an Orsat analyzer is used, it is recommended that the Orsat leak-check described in Section 5 be performed before this determination; however, the check is optional. Determine the percentage of the gas that is N_2 and CO by subtracting the sum of the percent CO_2 and percent O_2 from 100 percent. Calculate the dry molecular weight as indicated in Section 6.3.

3.2.5 Repeat the analysis and calculation procedures until the individual dry molecular weights for any three analyses differ from their mean by no more than 0.3 g/g-mole (0.3 lb/lb-mole). Average these three molecular weights, and report the results to the nearest 0.1 g/g-mole (0.1 lb/lb-mole).

3.3 Multi-Point, Integrated Sampling and Analytical Procedure.

3.3.1 Unless otherwise specified by the Administrator, a minimum of eight traverse points shall be used for circular stacks having diameters less then 0.61 m (24 in.), a minimum of nine shall be used for rectangular stacks having equivalent diameters less than 0.61 m (24 in.). and a minimum of twelve traverse points shall be used for all other cases. The traverse points shall be located according to Method 1. The use of fewer points is subject to approval of the Administrator.

3.3.2 Follow the procedures outlined in Sections 3.2.2 through 3.2.5, except for the following: traverse all sampling points and sample at each point for an equal length of time. Record sampling data as shown in Figure 3-3.

4. *Emission Rate Correction Factor or Excess Air Determination*

Note.—A Fyrite-type combustion gas analyzer is not acceptable for excess air or emission rate correction factor determination, unless approved by the Administrator. If both percent CO_2 and percent O_2 are measured, the analytical results of any of the three procedures given below may also be used for calculating the dry molecular weight.

Each of the three procedures below shall be used only when specified in an applicable subpart of the standards. The use of these procedures for other purposes must have specific prior approval of the Administrator.

4.1 Single-Point, Grab Sampling and Analytical Procedure.

4.1.1 The sampling point in the duct shall either be at the centroid of the cross-section or at a point no closer to the walls than 1.00 m (3.3 ft), unless otherwise specified by the Administrator.

4.1.2 Set up the equipment as shown in Figure 3-1, making sure all connections ahead of the analyzer are tight and leak-free. Leak-check the Orsat analyzer according to the procedure described in Section 5. This leak-check is mandatory.

TIME	TRAVERSE PT.	Q lpm	% DEV.[a]
	AVERAGE		

$$^{a}\%\,\text{DEV} = \left(\frac{Q - Q_{avg}}{Q_{avg}}\right) 100 \qquad (\text{MUST BE} \leqslant 10\%)$$

Figure 3-3. Sampling rate data.

4.1.3 Place the probe in the stack, with the tip of the probe positioned at the sampling point; purge the sampling line. Draw a sample into the analyzer. For emission rate correction factor determination, immediately analyze the sample, as outlined in Sections 4.1.4 and 4.1.5, for percent CO_2 or percent O_2. If excess air is desired, proceed as follows: (1) immediately analyze the sample, as in Sections 4.1.4 and 4.1.5, for percent CO_2, O_2, and CO; (2) determine the percentage of the gas that is N_2 by subtracting the sum of the percent CO_2, percent O_2, and percent CO from 100 percent; and (3) calculate percent excess air as outlined in Section 6.2.

4.1.4 To ensure complete absorption of the CO_2, O_2, or if applicable, CO, make repeated passes through each absorbing solution until two consecutive readings are the same. Several passes (three or four) should be made between readings. (If constant readings cannot be obtained after three consecutive readings, replace the absorbing solution.)

4.1.5 After the analysis is completed, leak-check (mandatory) the Orsat analyzer once again, as described in Section 5. For the results of the analysis to be valid, the Orsat analyzer must pass this leak test before and after the analysis. Note.—Since this single-point, grab sampling and analytical procedure is normally conducted in conjunction with a single-point, grab sampling and analytical procedure for a pollutant, only one analysis is ordinarily conducted. Therefore, great care must be taken to obtain a valid sample and analysis. Although in most cases only CO_2 or O_2 is required, it is recommended that both CO_2 and O_2 be measured, and that Citation 5 in the Bibliography be used to validate the analytical data.

4.2 Single-Point, Integrated Sampling and Analytical Procedure.

4.2.1 The sampling point in the duct shall be located as specified in Section 4.1.1.

4.2.2 Leak-check (mandatory) the flexible bag as in Section 2.2.6. Set up the equipment as shown in Figure 3-2. Just prior to sampling, leak-check (mandatory) the train by placing a vacuum gauge at the condenser inlet, pulling a vacuum of at least 250 mm Hg (10 in. Hg), plugging the outlet at the quick disconnect, and then turning off the pump. The vacuum shall remain stable for at least 0.5 minute. Evacuate the flexible bag. Connect the probe and place it in the stack, with the tip of the probe positioned at the sampling point; purge the sampling line. Next, connect the bag and make sure that all connections are tight and leak free.

4.2.3 Sample at a constant rate, or as specified by the Administrator. The sampling run must be simultaneous with, and for the same total length of time as, the pollutant emission rate determination. Collect at least 30 liters (1.00 ft^3) of sample gas. Smaller volumes may be collected, subject to approval of the Administrator.

4.2.4 Obtain one integrated flue gas sample during each pollutant emission rate determination. For emission rate correction factor determination, analyze the sample within 4 hours after it is taken for percent CO_2 or percent O_2 (as outlined in Sections 4.2.5 through 4.2.7). The Orsat analyzer must be leak-checked (see Section 5) before the analysis. If excess air is desired, proceed as follows: (1) within 4 hours after the sample is taken, analyze it (as in Sections 4.2.5 through 4.2.7) for percent CO_2, O_2, and CO; (2) determine the percentage of the gas that is N_2 by subtracting the sum of the percent CO_2, percent O_2, and percent CO from 100 percent; (3) calculate percent excess air, as outlined in Section 6.2.

4.2.5 To ensure complete absorption of the CO_2, O_2, or if applicable, CO, make repeated passes through each absorbing solution until two consecutive readings are the same. Several passes (three or four) should be made between readings. (If constant readings cannot be obtained after three consecutive readings, replace the absorbing solution.)

4.2.6 Repeat the analysis until the following criteria are met:

4.2.6.1 For percent CO_2, repeat the analytical procedure until the results of any three analyses differ by no more than (a) 0.3 percent by volume when CO_2 is greater than 4.0 percent or (b) 0.2 percent by volume when CO_2 is less than or equal to 4.0 percent. Average the three acceptable values of percent CO_2 and report the results to the nearest 0.1 percent.

4.2.6.2 For percent O_2, repeat the analytical procedure until the results of any three analyses differ by no more than (a) 0.3 percent by volume when O_2 is less than 15.0 percent or (b) 0.2 percent by volume when O_2 is greater than 15.0 percent. Average the three acceptable values of percent O_2 and report the results to the nearest 0.1 percent.

4.2.6.3 For percent CO, repeat the analytical procedure until the results of any three analyses differ by no more than 0.3 percent. Average the three acceptable values of percent CO and report the results to the nearest 0.1 percent.

4.2.7 After the analysis is completed, leak-check (mandatory) the Orsat analyzer once again, as described in Section 5. For the results of the analysis to be valid, the Orsat analyzer must pass this leak test before and after the analysis. Note: Although in most instances only CO_2 or O_2 is required, it is recommended that both CO_2 and O_2 be measured, and that Citation 5 in the Bibliography be used to validate the analytical data.

4.3 Multi-Point, Integrated Sampling and Analytical Procedure.

4.3.1 Both the minimum number of sampling points and the sampling point location shall be as specified in Section 3.3.1 of this method. The use of fewer points than specified is subject to the approval of the Administrator.

4.3.2 Follow the procedures outlined in Sections 4.2.2 through 4.2.7, except for the following: Traverse all sampling points and sample at each point for an equal length of time. Record sampling data as shown in Figure 3-3.

5. *Leak-Check Procedure for Orsat Analyzers*

Moving an Orsat analyzer frequently causes it to leak. Therefore, an Orsat analyzer should be thoroughly leak-checked on site before the flue gas sample is introduced into it. The procedure for leak-checking an Orsat analyzer is:

5.1.1 Bring the liquid level in each pipette up to the reference mark on the capillary tubing and then close the pipette stopcock.

5.1.2 Raise the leveling bulb sufficiently to bring the confining liquid meniscus onto the graduated portion of the burette and then close the manifold stopcock.

5.1.3 Record the meniscus position.

5.1.4 Observe the meniscus in the burette and the liquid level in the pipette for movement over the next 4 minutes.

5.1.5 For the Orsat analyzer to pass the leak-check, two conditions must be met.

5.1.5.1 The liquid level in each pipette must not fall below the bottom of the capillary tubing during this 4-minute interval.

5.1.5.2 The meniscus in the burette must not change by more than 0.2 ml during this 4-minute interval.

5.1.6 If the analyzer fails the leak-check procedure, all rubber connections and stopcocks should be checked until the cause of the leak is identified. Leaking stopcocks must be disassembled, cleaned, and regreased. Leaking rubber connections must be replaced. After the analyzer is reassembled, the leak-check procedure must be repeated.

6. *Calculations*

6.1 Nomenclature.

M_d = Dry molecular weight, g/g-mole (lb/lb-mole).
%EA = Percent excess air.
$\%CO_2$ = Percent CO_2 by volume (dry basis).
$\%O_2$ = Percent O_2 by volume (dry basis).
%CO = Percent CO by volume (dry basis).
$\%N_2$ = Percent N_2 by volume (dry basis).
0.264 = Ratio of O_2 to N_2 in air, v/v.
0.280 = Molecular weight of N_2 or CO, divided by 100.
0.320 = Molecular weight of O_2 divided by 100.
0.440 = Molecular weight of CO_2 divided by 100.

6.2 Percent Excess Air. Calculate the percent excess air (if applicable), by substituting the appropriate values of percent O_2, CO, and N_2 (obtained from Section 4.1.3 or 4.2.4) into Equation 3-1.

$$\%EA=\left[\frac{\%O_2-0.5\%CO}{0.264\,\%N_2(\%O_2-0.5\,\%CO)}\right]100$$

Equation 3-1

NOTE.—The equation above assumes that ambient air is used as the source of O_2 and that the fuel does not contain appreciable amounts of N_2 (as do coke oven or blast furnace gases). For those cases when appreciable amounts of N_2 are present (coal, oil, and natural gas do not contain appreciable amounts of N_2) or when oxygen enrichment is used, alternate methods, subject to approval of the Administrator, are required.

6.3 Dry Molecular Weight. Use Equation 3-2 to calculate the dry molecular weight of the stack gas

$$M_d=0.440(\%CO_2)+0.320(\%O_2)+0.280(\%N_2+\%CO)$$

Equation 3-2

NOTE.—The above equation does not consider argon in air (about 0.9 percent, molecular weight of 37.7). A negative error of about 0.4 percent is introduced. The tester may opt to include argon in the analysis using procedures subject to approval of the Administrator.

7. *Bibliography*

1. Altshuller, A. P. Storage of Gases and Vapors in Plastic Bags. International Journal of Air and Water Pollution. *6*:75-81. 1963.

2. Conner, William D. and J. S. Nader. Air Sampling Plastic Bags. Journal of the American Industrial Hygiene Association. *25*:291-297. 1964.

3. Burrell Manual for Gas Analysts, Seventh edition. Burrell Corporation, 2223 Fifth Avenue, Pittsburgh, Pa. 15219. 1951.

4. Mitchell, W. J. and M. R. Midgett. Field Reliability of the Orsat Analyzer. Journal of Air Pollution Control Association *26*:491-495. May 1976.

5. Shigehara, R. T., R. M. Neulicht, and W. S. Smith. Validating Orsat Analysis Data from Fossil Fuel-Fired Units. Stack Sampling News. *4*(2):21-26. August, 1976.

than (a) 0.3 percent by volume when O_2 is less than 15.0 percent or (b) 0.2 percent by volume when O_2 is greater than 15.0 percent. Average the three acceptable values of percent O_2 and report the results to the nearest 0.1 percent.

4.2.6.3 For percent CO, repeat the analytical procedure until the results of any three analyses differ by no more than 0.3 percent. Average the three acceptable values of percent CO and report the results to the nearest 0.1 percent.

4.2.7 After the analysis is completed, leak-check (mandatory) the Orsat analyzer once again, as described in Section 5. For the results of the analysis to be valid, the Orsat analyzer must pass this leak test before and after the analysis. Note: Although in most instances only CO_2 or O_2 is required, it is recommended that both CO_2 and O_2 be measured, and that Citation 5 in the Bibliography be used to validate the analytical data.

4.3 Multi-Point, Integrated Sampling and Analytical Procedure.

4.3.1 Both the minimum number of sampling points and the sampling point location shall be as specified in Section 3.3.1 of this method. The use of fewer points than specified is subject to the approval of the Administrator.

4.3.2 Follow the procedures outlined in Sections 4.2.2 through 4.2.7, except for the following: Traverse all sampling points and sample at each point for an equal length of time. Record sampling data as shown in Figure 3-3.

5. *Leak-Check Procedure for Orsat Analyzers*

Moving an Orsat analyzer frequently causes it to leak. Therefore, an Orsat analyzer should be thoroughly leak-checked on site before the flue gas sample is introduced into it. The procedure for leak-checking an Orsat analyzer is:

5.1.1 Bring the liquid level in each pipette up to the reference mark on the capillary tubing and then close the pipette stopcock.

5.1.2 Raise the leveling bulb sufficiently to bring the confining liquid meniscus onto the graduated portion of the burette and then close the manifold stopcock.

5.1.3 Record the meniscus position.

5.1.4 Observe the meniscus in the burette and the liquid level in the pipette for movement over the next 4 minutes.

5.1.5 For the Orsat analyzer to pass the leak-check, two conditions must be met.

5.1.5.1 The liquid level in each pipette must not fall below the bottom of the capillary tubing during this 4-minute interval.

5.1.5.2 The meniscus in the burette must not change by more than 0.2 ml during this 4-minute interval.

5.1.6 If the analyzer fails the leak-check procedure, all rubber connections and stopcocks should be checked until the cause of the leak is identified. Leaking stopcocks must be disassembled, cleaned, and regreased. Leaking rubber connections must be replaced. After the analyzer is reassembled, the leak-check procedure must be repeated.

6. *Calculations*

6.1 Nomenclature.

M_d = Dry molecular weight, g/g-mole (lb/lb-mole).
$\%EA$ = Percent excess air.
$\%CO_2$ = Percent CO_2 by volume (dry basis).
$\%O_2$ = Percent O_2 by volume (dry basis).
$\%CO$ = Percent CO by volume (dry basis).
$\%N_2$ = Percent N_2 by volume (dry basis).
0.264 = Ratio of O_2 to N_2 in air, v/v.
0.280 = Molecular weight of N_2 or CO, divided by 100.
0.320 = Molecular weight of O_2 divided by 100.
0.440 = Molecular weight of CO_2 divided by 100.

6.2 Percent Excess Air. Calculate the percent excess air (if applicable), by substituting the appropriate values of percent O_2, CO, and N_2 (obtained from Section 4.1.3 or 4.2.4) into Equation 3-1.

$$\%EA = \left[\frac{\%O_2 - 0.5\%CO}{0.264\,\%N_2 (\%O_2 - 0.5\,\%CO)} \right] 100$$

Equation 3-1

NOTE.—The equation above assumes that ambient air is used as the source of O_2 and that the fuel does not contain appreciable amounts of N_2 (as do coke oven or blast furnace gases). For those cases when appreciable amounts of N_2 are present (coal, oil, and natural gas do not contain appreciable amounts of N_2) or when oxygen enrichment is used, alternate methods, subject to approval of the Administrator, are required.

6.3 Dry Molecular Weight. Use Equation 3-2 to calculate the dry molecular weight of the stack gas

$$M_d = 0.440(\%CO_2) + 0.320(\%O_2) + 0.280(\%N_2 + \%CO)$$

Equation 3-2

NOTE.—The above equation does not consider argon in air (about 0.9 percent, molecular weight of 37.7). A negative error of about 0.4 percent is introduced. The tester may opt to include argon in the analysis using procedures subject to approval of the Administrator.

7. *Bibliography*

1. Altshuller, A. P. Storage of Gases and Vapors in Plastic Bags. International Journal of Air and Water Pollution. *6*:75-81. 1963.

2. Conner, William D. and J. S. Nader. Air Sampling Plastic Bags. Journal of the American Industrial Hygiene Association. *25*:291-297. 1964.

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METHOD 4—DETERMINATION OF MOISTURE CONTENT IN STACK GASES

1. *Principle and Applicability*

1.1 Principle. A gas sample is extracted at a constant rate from the source; moisture is removed from the sample stream and determined either volumetrically or gravimetrically.

1.2 Applicability. This method is applicable for determining the moisture content of stack gas.

Two procedures are given. The first is a reference method, for accurate determinations of moisture content (such as are needed to calculate emission data). The second is an approximation method, which provides estimates of percent moisture to aid in setting isokinetic sampling rates prior to a pollutant emission measurement run. The approximation method described herein is only a suggested approach; alternative means for approximating the moisture content, e.g., drying tubes, wet bulb-dry bulb techniques, condensation techniques, stoichiometric calculations, previous experience, etc., are also acceptable.

The reference method is often conducted simultaneously with a pollutant emission measurement run; when it is, calculation of percent isokinetic, pollutant emission rate, etc., for the run shall be based upon the results of the reference method or its equivalent; these calculations shall not be based upon the results of the approximation method, unless the approximation method is shown, to the satisfaction of the Administrator, U.S. Environmental Protection Agency, to be capable of yielding results within 1 percent H_2O of the reference method.

NOTE.—The reference method may yield questionable results when applied to saturated gas streams or to streams that contain water droplets. Therefore, when these conditions exist or are suspected, a second determination of the moisture content shall be made simultaneously with the reference method, as follows: Assume that the gas stream is saturated. Attach a temperature sensor [capable of measuring to ±1° C (2° F)] to the reference method probe. Measure the stack gas temperature at each traverse point (see Section 2.2.1) during the reference method traverse; calculate the average stack gas temperature. Next, determine the moisture percentage, either by: (1) using a psychrometric chart and making appropriate corrections if stack pressure is different from that of the chart, or (2) using saturation vapor pressure tables. In cases where the psychrometric chart or the saturation vapor pressure tables are not applicable (based on evaluation of the process), alternate methods, subject to the approval of the Administrator, shall be used.

2. *Reference Method*

The procedure described in Method 5 for determining moisture content is acceptable as a reference method.

2.1 Apparatus. A schematic of the sampling train used in this reference method is shown in Figure 4-1. All components shall be maintained and calibrated according to the procedure outlined in Method 5.

2.1.1 Probe. The probe is constructed of stainless steel or glass tubing, sufficiently heated to prevent water condensation, and is equipped with a filter, either in-stack (e.g., a plug of glass wool inserted into the end of the probe) or heated out-stack (e.g., as described in Method 5), to remove particulate matter.

When stack conditions permit, other metals or plastic tubing may be used for the probe, subject to the approval of the Administrator.

2.1.2 Condenser. The condenser consists of four impingers connected in series with ground glass, leak-free fittings or any similarly leak-free non-contaminating fittings. The first, third, and fourth impingers shall be of the Greenburg-Smith design, modified by replacing the tip with a 1.3 centimeter (½ inch) ID glass tube extending to about 1.3 cm (½ in.) from the bottom of the flask. The second impinger shall be of the Greenburg-Smith design with the standard tip. Modifications (e.g., using flexible connections between the impingers, using materials other than glass, or using flexible vacuum lines to connect the filter holder to the condenser) may be used, subject to the approval of the Administrator.

The first two impingers shall contain known volumes of water, the third shall be empty, and the fourth shall contain a known weight of 6- to 16-mesh indicating type silica gel, or equivalent desiccant. If the silica gel has been previously used, dry at 175° C (350° F) for 2 hours. New silica gel may be used as received. A thermometer, capable of measuring temperature to within 1° C (2° F), shall be placed at the outlet of the fourth impinger, for monitoring purposes.

Alternatively, any system may be used (subject to the approval of the Administrator) that cools the sample gas stream and allows measurement of both the water that has been condensed and the moisture leaving the condenser, each to within 1 ml or 1 g. Acceptable means are to measure the condensed water, either gravimetrically or volumetrically, and to measure the moisture leaving the condenser by: (1) monitoring the temperature and pressure at the exit of the condenser and using Dalton's law of partial pressures, or (2) passing the sample gas stream through a tared silica gel (or equivalent desiccant) trap, with exit gases kept below 20° C (68° F), and determining the weight gain.

If means other than silica gel are used to determine the amount of moisture leaving the condenser, it is recommended that silica gel (or equivalent) still be used between the condenser system and pump, to prevent moisture condensation in the pump and metering devices and to avoid the need to make corrections for moisture in the metered volume.

2.1.3 Cooling System. An ice bath container and crushed ice (or equivalent) are used to aid in condensing moisture.

2.1.4 Metering System. This system includes a vacuum gauge, leak-free pump, thermometers capable of measuring temperature to within 3° C (5.4° F), dry gas meter capable of measuring volume to within 2 percent, and related equipment as shown in Figure 4-1. Other metering systems, capable of maintaining a constant sampling rate and determining sample gas volume, may be used, subject to the approval of the Administrator.

2.1.5 Barometer. Mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg) may be used. In many cases, the barometric reading may be obtained from a nearby national weather service station, in which case the station value (which is the absolute barometric pressure) shall be requested and an adjustment for elevation differences between the weather station and the sampling point shall be applied at a rate of minus 2.5 mm Hg (0.1 in. Hg) per 30 m (100 ft) elevation increase or vice versa for elevation decrease.

2.1.6 Graduated Cylinder and/or Balance. These items are used to measure condensed water and moisture caught in the silica gel to within 1 ml or 0.5 g. Graduated cylinders shall have subdivisions no greater than 2 ml. Most laboratory balances are capable of weighing to the nearest 0.5 g or less. These balances are suitable for use here.

2.2 Procedure. The following procedure is written for a condenser system (such as the impinger system described in Section 2.1.2) incorporating volumetric analysis to measure the condensed moisture, and silica gel and gravimetric analysis to measure the moisture leaving the condenser.

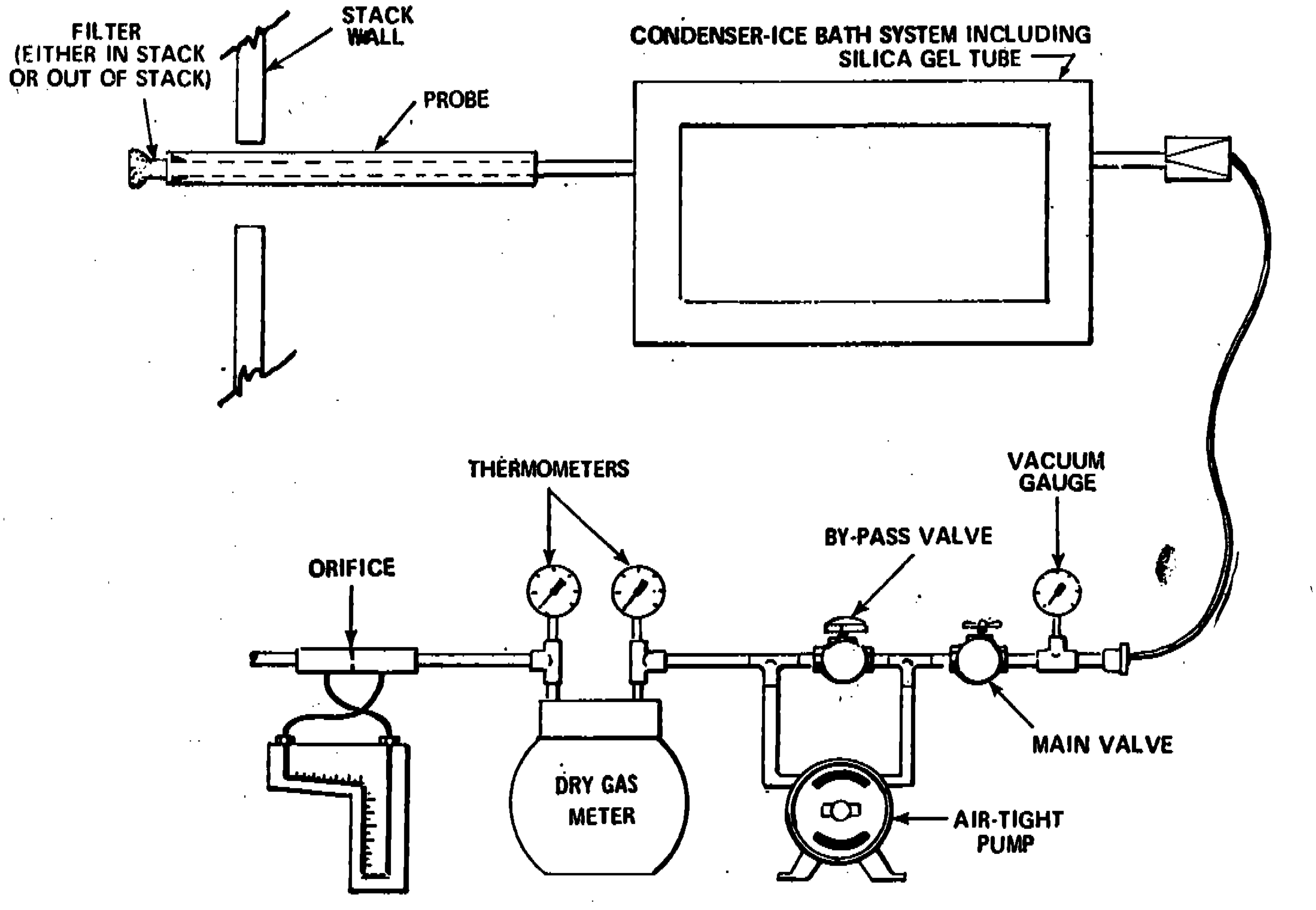

Figure 4-1. Moisture sampling train-reference method.

2.2.1 Unless otherwise specified by the Administrator, a minimum of eight traverse points shall be used for circular stacks having diameters less than 0.61 m (24 in.), a minimum of nine points shall be used for rectangular stacks having equivalent diameters less than 0.61 m (24 in.). and a minimum of twelve travers points shall be used in all other cases. The traverse points shall be located according to Method 1. The use of fewer points is subject to the approval of the Administrator. Select a suitable probe and probe length such that all traverse points can be sampled. Consider sampling from opposite sides of the stack (four total sampling ports) for large stacks, to permit use of shorter probe lengths. Mark the probe with heat resistant tape or by some other method to denote the proper distance into the stack or duct for each sampling point. Place known volumes of water in the first two impingers. Weigh and record the weight of the silica gel to the nearest 0.5 g, and transfer the silica gel to the fourth impinger; alternatively, the silica gel may first be transferred to the impinger, and the weight of the silica gel plus impinger recorded.

2.2.2 Select a total sampling time such that a minimum total gas volume of 0.60 scm (21 scf) will be collected, at a rate no greater than 0.021 m³/min (0.75 cfm). When both moisture content and pollutant emission rate are to be determined, the moisture determination shall be simultaneous with, and for the same total length of time as, the pollutant emission rate run, unless otherwise specified in an applicable subpart of the standards.

2.2.3 Set up the sampling train as shown in Figure 4-1. Turn on the probe heater and (if applicable) the filter heating system to temperatures of about 120° C (248° F), to prevent water condensation ahead of the condenser; allow time for the temperatures to stabilize. Place crushed ice in the ice bath container. It is recommended, but not required, that a leak check be done, as follows: Disconnect the probe from the first impinger or (if applicable) from the filter holder. Plug the inlet to the first impinger (or filter holder) and pull a 380 mm (15 in.) Hg vacuum; a lower vacuum may be used, provided that it is not exceeded during the test. A leakage rate in excess of 4 percent of the average sampling rate or 0.00057 m³/min (0.02 cfm), whichever is less, is unacceptable. Following the leak check, reconnect the probe to the sampling train.

2.2.4 During the sampling run, maintain a sampling rate within 10 percent of constant rate, or as specified by the Administrator. For each run, record the data required on the example data sheet shown in Figure 4-2. Be sure to record the dry gas meter reading at the beginning and end of each sampling time increment and whenever sampling is halted. Take other appropriate readi at each sample point, at least once during each ti increment.

2.2.5 To begin sampling, position the probe tip at the first traverse point. Immediately start the pump and adjust the flow to the desired rate. Traverse the cross section, sampling at each traverse point for an equal length of time. Add more ice and, if necessary, salt to maintain a temperature of less than 20° C (68° F) at the silica gel outlet.

2.2.6 After collecting the sample, disconnect the probe from the filter holder (or from the first impinger) and conduct a leak check (mandatory) as described in Section 2.2.3. Record the leak rate. If the leakage rate exceeds the allowable rate, the tester shall either reject the test results or shall correct the sample volume as in Section 6.3 of Method 5. Next, measure the volume of the moisture condensed to the nearest ml. Determine the increase in weight of the silica gel (or silica gel plus impinger) to the nearest 0.5 g. Record this information (see example data sheet, Figure 4-3) and calculate the moisture percentage, as described in 2.3 below.

2.3 Calculations. Carry out the following calculations, retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after final calculation.

PLANT____________________
LOCATION____________________
OPERATOR____________________
DATE____________________
RUN NO.____________________
AMBIENT TEMPERATURE____________________
BAROMETRIC PRESSURE____________________
PROBE LENGTH m(ft)____________________

SCHEMATIC OF STACK CROSS SECTION

TRAVERSE POINT NUMBER	SAMPLING TIME (θ), min.	STACK TEMPERATURE °C (°F)	PRESSURE DIFFERENTIAL ACROSS ORIFICE METER (ΔH), mm(in.) H_2O	METER READING GAS SAMPLE VOLUME m^3 (ft^3)	ΔV_m m^3 (ft^3)	GAS SAMPLE TEMPERATURE AT DRY GAS METER		TEMPERATURE OF GAS LEAVING CONDENSER OR LAST IMPINGER, °C (°F)
						INLET ($T_{m_{in}}$), °C (°F)	OUTLET ($T_{m_{out}}$), °C (°F)	
TOTAL						Avg.	Avg.	
AVERAGE						Avg.		

Figure 4-2. Field moisture determination-reference method.

	IMPINGER VOLUME, ml	SILICA GEL WEIGHT, g
FINAL		
INITIAL		
DIFFERENCE		

Figure 4-3. Analytical data - reference method.

2.3.1 Nomenclature.

B_{ws} = Proportion of water vapor, by volume, in the gas stream.

M_w = Molecular weight of water, 18.0 g/g-mole (18.0 lb/lb-mole).

P_m = Absolute pressure (for this method, same as barometric pressure) at the dry gas meter, mm Hg (in. Hg).

P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).

R = Ideal gas constant, 0.06236 (mm Hg) (m^3)/(g-mole) (°K) for metric units and 21.85 (in. Hg) (ft^3)/(lb-mole) (°R) for English units.

T_m = Absolute temperature at meter, °K (°R).

T_{std} = Standard absolute temperature, 293° K (528° R).

V_m = Dry gas volume measured by dry gas meter, dcm (dcf).

ΔV_m = Incremental dry gas volume measured by dry gas meter at each traverse point, dcm (dcf).

$V_{m(std)}$ = Dry gas volume measured by the dry gas meter, corrected to standard conditions, dscm (dscf).

$V_{wc(std)}$ = Volume of water vapor condensed corrected to standard conditions, scm (scf).

$V_{wsg(std)}$ = Volume of water vapor collected in silica gel corrected to standard conditions, scm (scf).

V_f = Final volume of condenser water, ml.

V_i = Initial volume, if any, of condenser water, ml.

W_f = Final weight of silica gel or silica gel plus impinger, g.

W_i = Initial weight of silica gel or silica gel plus impinger, g.

Y = Dry gas meter calibration factor.

P_w = Density of water, 0.9982 g/ml (0.002201 lb/ml).

2.3.2 Volume of water vapor condensed.

$$V_{wc(std)} = \frac{(V_f - V_i)\rho_w R T_{std}}{P_{std} M_w}$$

$$= K_1 (V_f - V_i)$$

Equation 4-1

where:

K_1=0.001333 m^3/ml for metric units

=0.04707 ft^3/ml for English units

2.3.3 Volume of water vapor collected in silica gel.

$$V_{wsg(std)} = \frac{(W_f - W_i) R T_{std}}{P_{std} M_w}$$

$$= K_2 (W_f - W_i)$$

Equation 4-2

where:

K_1=0.001335 m^3/g for metric units

=0.04715 ft^3/g for English units

2.3.4 Sample gas volume.

$$V_{m(std)} = V_m Y \frac{(P_m)(T_{std})}{(P_{std})(T_m)}$$

$$= K_3 Y \frac{V_m P_m}{T_m}$$

Equation 4-3

where:

K_3=0.3858 °K/mm Hg for metric units

=17.64 °R/in. Hg for English units

NOTE.—If the post-test leak rate (Section 2.2.6) exceeds the allowable rate, correct the value of V_m in Equation 4-3, as described in Section 6.3 of Method 5.

2.3.5 Moisture Content.

$$B_{ws} = \frac{V_{wc(std)} + V_{wsg(std)}}{V_{wc(std)} + V_{wsg(std)} + V_{m(std)}}$$

Equation 4-4

NOTE.—In saturated or moisture droplet-laden gas streams, two calculations of the moisture content of the stack gas shall be made, one using a value based upon the saturated conditions (see Section 1.2), and another based upon the results of the impinger analysis. The lower of these two values of B_{ws} shall be considered correct.

2.3.6 Verification of constant sampling rate. For each time increment, determine the ΔV_m. Calculate the average. If the value for any time increment differs from the average by more than 10 percent, reject the results and repeat the run.

3. *Approximation Method*

The approximation method described below is presented only as a suggested method (see Section 1.2).

3.1 Apparatus.

3.1.1 Probe. Stainless steel or glass tubing, sufficiently heated to prevent water condensation and equipped with a filter (either in-stack or heated out-stack) to remove particulate matter. A plug of glass wool, inserted into the end of the probe, is a satisfactory filter.

3.1.2 Impingers. Two midget impingers, each with 30 ml capacity, or equivalent.

3.1.3 Ice Bath. Container and ice, to aid in condensing moisture in impingers.

3.1.4 Drying Tube. Tube packed with new or regenerated 6- to 16-mesh indicating-type silica gel (or equivalent desiccant), to dry the sample gas and to protect the meter and pump.

3.1.5 Valve. Needle valve, to regulate the sample gas flow rate.

3.1.6 Pump. Leak-free, diaphragm type, or equivalent, to pull the gas sample through the train.

3.1.7 Volume meter. Dry gas meter, sufficiently accurate to measure the sample volume within 2%, and calibrated over the range of flow rates and conditions actually encountered during sampling.

3.1.8 Rate Meter. Rotameter, to measure the flow range from 0 to 3 lpm (0 to 0.11 cfm).

3.1.9 Graduated Cylinder. 25 ml.

3.1.10 Barometer. Mercury, aneroid, or other barometer, as described in Section 2.1.5 above.

3.1.11 Vacuum Gauge. At least 760 mm Hg (30 in. Hg) gauge, to be used for the sampling leak check.

3.2 Procedure.

3.2.1 Place exactly 5 ml distilled water in each impinger. Assemble the apparatus without the probe as shown in Figure 4-4. Leak check the train by placing a vacuum gauge at the inlet to the first impinger and drawing a vacuum of at least 250 mm Hg (10 in. Hg), plugging the outlet of the rotameter, and then turning off the pump. The vacuum shall remain constant for at least one minute. Carefully release the vacuum gauge before unplugging the rotameter end.

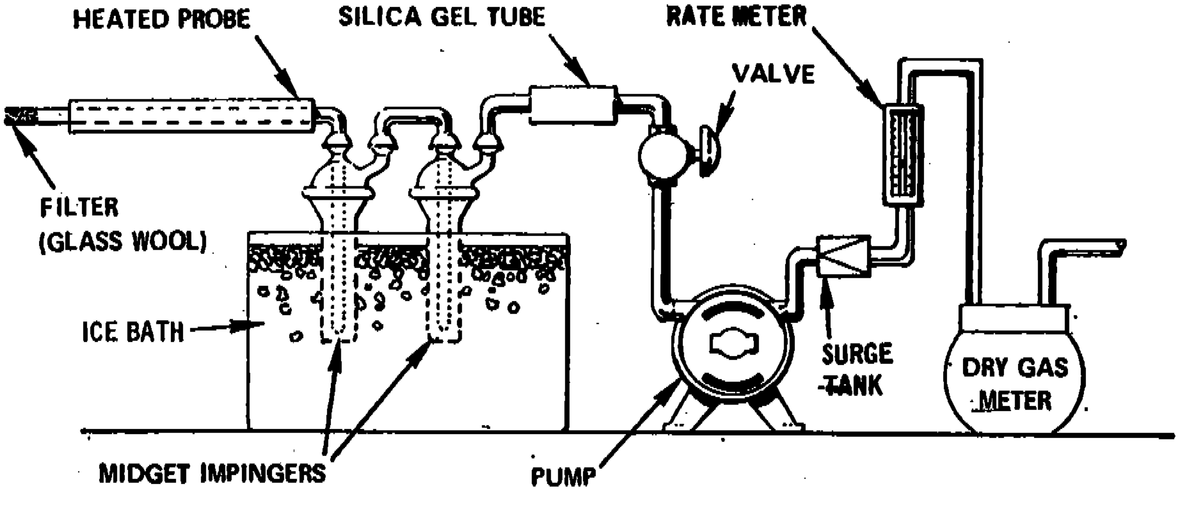

Figure 4-4. Moisture-sampling train - approximation method.

LOCATION______________________________ **COMMENTS**

TEST______________________________

DATE______________________________

OPERATOR______________________________

BAROMETRIC PRESSURE____________________

CLOCK TIME	GAS VOLUME THROUGH METER, (Vm), m^3 (ft^3)	RATE METER SETTING m^3/min. (ft^3/min.)	METER TEMPERATURE, °C (°F)

Figure 4-5. Field moisture determination - approximation method.

3.2.2 Connect the probe, insert it into the stack, and sample at a constant rate of 2 lpm (0.071 cfm). Continue sampling until the dry gas meter registers about 30 liters (1.1 ft^3) or until visible liquid droplets are carried over from the first impinger to the second. Record temperature, pressure, and dry gas meter readings as required by Figure 4–5.

3.2.3 After collecting the sample, combine the contents of the two impingers and measure the volume to the nearest 0.5 ml.

3.3 Calculations. The calculation method presented is designed to estimate the moisture in the stack gas; therefore, other data, which are only necessary for accurate moisture determinations, are not collected. The following equations adequately estimate the moisture content, for the purpose of determining isokinetic sampling rate settings.

3.3.1 Nomenclature.

B_{wm}=Approximate proportion, by volume, of water vapor in the gas stream leaving the second impinger, 0.025.

B_{ws}=Water vapor in the gas stream, proportion by volume.

M_w=Molecular weight of water, 18.0 g/g-mole (18.0 lb/lb-mole)

P_m=Absolute pressure (for this method, same as barometric pressure) at the dry gas meter.

P_{std}=Standard absolute pressure, 760 mm Hg (29.92 in. Hg).

R=Ideal gas constant, 0.06236 (mm Hg) (m^3)/(g-mole) (°K) for metric units and 21.85 (in. Hg) (ft^3)/lb-mole) (°R) for English units.

T_m=Absolute temperature at meter, °K (°R)

T_{std}=Standard absolute temperature, 293° K (528° R)

V_f=Final volume of impinger contents, ml.

V_i=Initial volume of impinger contents, ml.

V_m=Dry gas volume measured by dry gas meter, dcm (dcf).

$V_{m(std)}$=Dry gas volume measured by dry gas meter, corrected to standard conditions, dscm (dscf).

$V_{wc(std)}$=Volume of water vapor condensed, corrected to standard conditions, scm (scf).

ρ_w=Density of water, 0.9982 g/ml (0.002201 lb/ml).

3.3.2 Volume of water vapor collected.

$$V_{wc}=\frac{(V_f-V_i)\rho_w RT_{std}}{P_{std}M_w}$$

$$=K_1(V_f-V_i)$$

Equation 4–5

where:
K_1=0.001333 m^3/ml for metric units
=0.04707 ft^3/ml for English units.

3.3.3 Gas volume.

$$V_{m\,(std)}=V_m\left(\frac{P_m}{P_{std}}\right)\left(\frac{T_{std}}{T_m}\right)$$

$$=K_2\,\frac{V_m P_m}{T_m}$$

Equation 4–6

where:
K_2=0.3858 °K/mm Hg for metric units
=17.64 °R/in. Hg for English units

3.3.4 Approximate moisture content.

$$B_{ws}=\frac{V_{wc}}{V_{wc}+V_{m\,(std)}}+B_{wm}$$

$$=\frac{V_{wc}}{V_{wc}+V_{m\,(std)}}+(0.025)$$

Equation 4–7

4. *Calibration*

4.1 For the reference method, calibrate equipment as specified in the following sections of Method 5: Section 5.3 (metering system); Section 5.5 (temperature gauges); and Section 5.7 (barometer). The recommended leak check of the metering system (Section 5.6 of Method 5) also applies to the reference method. For the approximation method, use the procedures outlined in Section 5.1.1 of Method 6 to calibrate the metering system, and the procedure of Method 5, Section 5.7 to calibrate the barometer.

5. *Bibliography*

1. Air Pollution Engineering Manual (Second Edition). Danielson, J. A. (ed.). U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park, N.C. Publication No. AP-40. 1973.

2. Devorkin, Howard, et al. Air Pollution Source Testing Manual. Air Pollution Control District, Los Angeles, Calif. November, 1963.

3. Methods for Determination of Velocity, Volume, Dust and Mist Content of Gases. Western Precipitation Division of Joy Manufacturing Co., Los Angeles, Calif. Bulletin WP-50. 1968.

METHOD 5—DETERMINATION OF PARTICULATE EMISSIONS FROM STATIONARY SOURCES

1. *Principle and Applicability*

1.1 Principle. Particulate matter is withdrawn isokinetically from the source and collected on a glass fiber filter maintained at a temperature in the range of 120±14° C (248±25° F) or such other temperature as specified by an applicable subpart of the standards or approved by the Administrator, U.S. Environmental Protection Agency, for a particular application. The particulate mass, which includes any material that condenses at or above the filtration temperature, is determined gravimetrically after removal of uncombined water.

1.2 Applicability. This method is applicable for the determination of particulate emissions from stationary sources.

2. *Apparatus*

2.1 Sampling Train. A schematic of the sampling train used in this method is shown in Figure 5-1. Complete construction details are given in APTD-0581 (Citation 2 in Section 7); commercial models of this train are also available. For changes from APTD-0581 and for allowable modifications of the train shown in Figure 5-1, see the following subsections.

The operating and maintenance procedures for the sampling train are described in APTD-0576 (Citation 3 in Section 7). Since correct usage is important in obtaining valid results, all users should read APTD-0576 and adopt the operating and maintenance procedures outlined in it, unless otherwise specified herein. The sampling train consists of the following components:

2.1.1 Probe Nozzle. Stainless steel (316) or glass with sharp, tapered leading edge. The angle of taper shall be ≤30° and the taper shall be on the outside to preserve a constant internal diameter. The proble nozzle shall be of the button-hook or elbow design, unless otherwise specified by the Administrator. If made of stainless steel, the nozzle shall be constructed from seamless tubing; other materials of construction may be used, subject to the approval of the Administrator.

A range of nozzle sizes suitable for isokinetic sampling should be available; e.g., 0.32 to 1.27 cm (⅛ to ½ in.)—or larger if higher volume sampling trains are used—inside diameter (ID) nozzles in increments of 0.16 cm (1/16 in.). Each nozzle shall be calibrated according to the procedures outlined in Section 5.

2.1.2 Probe Liner. Borosilicate or quartz glass tubing with a heating system capable of maintaining a gas temperature at the exit end during sampling of 120±14° C (248±25° F), or such other temperature as specified by an applicable subpart of the standards or approved by the Administrator for a particular application. (The tester may opt to operate the equipment at a temperature lower than that specified.) Since the actual temperature at the outlet of the probe is not usually monitored during sampling, probes constructed according to APTD-0581 and utilizing the calibration curves of APTD-0576 (or calibrated according to the procedure outlined in APTD-0576) will be considered acceptable.

Either borosilicate or quartz glass probe liners may be used for stack temperatures up to about 480° C (900° F); quartz liners shall be used for temperatures between 480 and 900° C (900 and 1,650° F). Both types of liners may be used at higher temperatures than specified for short periods of time, subject to the approval of the Administrator. The softening temperature for borosilicate is 820° C (1,508° F), and for quartz it is 1,500° C (2,732° F).

Whenever practical, every effort should be made to use borosilicate or quartz glass probe liners. Alternatively, metal liners (e.g., 316 stainless steel, Incoloy 825,[2] or other corrosion resistant metals) made of seamless tubing may be used, subject to the approval of the Administrator.

2.1.3 Pitot Tube. Type S, as described in Section 2.1 of Method 2, or other device approved by the Administrator. The pitot tube shall be attached to the probe (as shown in Figure 5-1) to allow constant monitoring of the stack gas velocity. The impact (high pressure) opening plane of the pitot tube shall be even with or above the nozzle entry plane (see Method 2, Figure 2-6b) during sampling. The Type S pitot tube assembly shall have a known coefficient, determined as outlined in Section 4 of Method 2.

2.1.4 Differential Pressure Gauge. Inclined manometer or equivalent device (two), as described in Section 2.2 of Method 2. One manometer shall be used for velocity head (Δp) readings, and the other, for orifice differential pressure readings.

2.1.5 Filter Holder. Borosilicate glass, with a glass frit filter support and a silicone rubber gasket. Other materials of construction (e.g., stainless steel, Teflon, Viton) may be used, subject to approval of the Administrator. The holder design shall provide a positive seal against leakage from the outside or around the filter. The holder shall be attached immediately at the outlet of the probe (or cyclone, if used).

2.1.6 Filter Heating System. Any heating system capable of maintaining a temperature around the filter holder during sampling of 120±14° C (248±25° F), or such other temperature as specified by an applicable subpart of the standards or approved by the Administrator for a particular application. Alternatively, the tester may opt to operate the equipment at a temperature lower than that specified. A temperature gauge capable of measuring temperature to within 3° C (5.4° F) shall be installed so that the temperature around the filter holder can be regulated and monitored during sampling. Heating systems other than the one shown in APTD-0581 may be used.

2.1.7 Condenser. The following system shall be used to determine the stack gas moisture content: Four impingers connected in series with leak-free ground glass fittings or any similar leak-free non-contaminating fittings. The first, third, and fourth impingers shall be of the Greenburg-Smith design, modified by replacing the tip with 1.3 cm (½ in.) ID glass tube extending to about 1.3 cm (½ in.) from the bottom of the flask. The second impinger shall be of the Greenburg-Smith design with the standard tip. Modifications (e.g., using flexible connections between the impingers, using materials other than glass, or using flexible vacuum lines to connect the filter holder to the condenser) may be used, subject to the approval of the Administrator. The first and second impingers shall contain known quantities of water (Section 4.1.3), the third shall be empty, and the fourth shall contain a known weight of silica gel, or equivalent desiccant. A thermometer, capable of measuring temperature to within 1° C (2° F) shall be placed at the outlet of the fourth impinger for monitoring purposes.

Alternatively, any system that cools the sample gas stream and allows measurement of the water condensed and moisture leaving the condenser, each to within 1 ml or 1 g may be used, subject to the approval of the Administrator. Acceptable means are to measure the condensed water either gravimetrically or volumetrically and to measure the moisture leaving the condenser by: (1) monitoring the temperature and pressure at the exit of the condenser and using Dalton's law of partial pressures; or (2) passing the sample gas stream through a tared silica gel (or equivalent desiccant) trap with exit gases kept below 20° C (68° F) and determining the weight gain.

If means other than silica gel are used to determine the amount of moisture leaving the condenser, it is recommended that silica gel (or equivalent) still be used between the condenser system and pump to prevent moisture condensation in the pump and metering devices and to avoid the need to make corrections for moisture in the metered volume.

NOTE.—If a determination of the particulate matter collected in the impingers is desired in addition to moisture content, the impinger system described above shall be used, without modification. Individual States or control agencies requiring this information shall be contacted as to the sample recovery and analysis of the impinger contents.

2.1.8 Metering System. Vacuum gauge, leak-free pump, thermometers capable of measuring temperature to within 3° C (5.4° F), dry gas meter capable of measuring volume to within 2 percent, and related equipment, as shown in Figure 5-1. Other metering systems capable of maintaining sampling rates within 10 percent of isokinetic and of determining sample volumes to within 2 percent may be used, subject to the approval of the Administrator. When the metering system is used in conjunction with a pitot tube, the system shall enable checks of isokinetic rates.

Sampling trains utilizing metering systems designed for higher flow rates than that described in APTD-0581 or APTD-0576 may be used provided that the specifications of this method are met.

2.1.9 Barometer. Mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg). In many cases, the barometric reading may be obtained from a nearby national weather service station, in which case the station value (which is

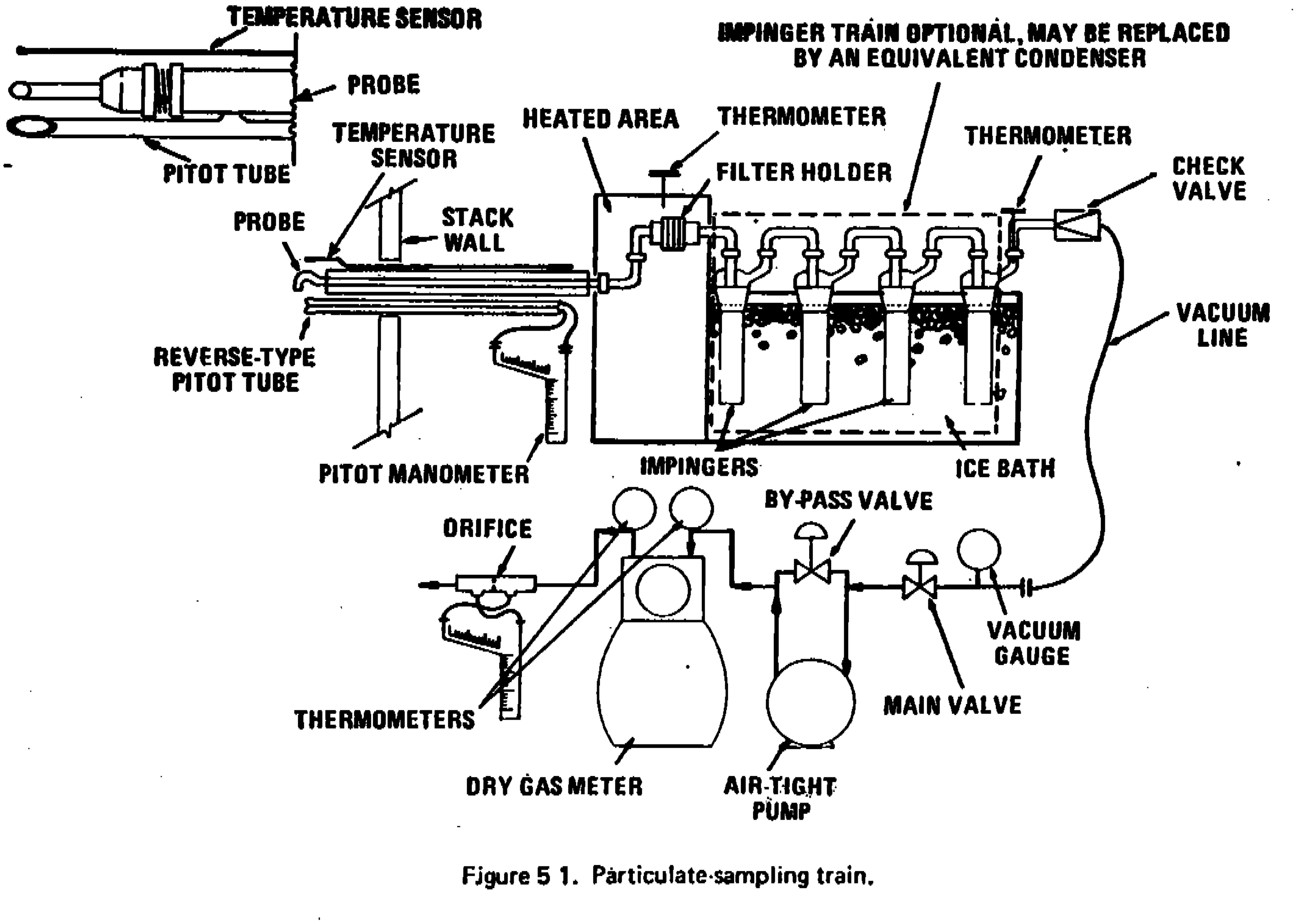

Figure 5 1. Particulate-sampling train.

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[2] Mention of trade names or specific products does not constitute endorsement by the Environmental Protection Agency.

the absolute barometric pressure) shall be requested and an adjustment for elevation differences between the weather station and sampling point shall be applied at a rate of minus 2.5 mm Hg (0.1 in. Hg) per 30 m (100 ft) elevation increase or vice versa for elevation decrease.

2.1.10 Gas Density Determination Equipment. Temperature sensor and pressure gauge, as described in Sections 2.3 and 2.4 of Method 2, and gas analyzer, if necessary, as described in Method 3. The temperature sensor shall, preferably, be permanently attached to the pitot tube or sampling probe in a fixed configuration, such that the tip of the sensor extends beyond the leading edge of the probe sheath and does not touch any metal. Alternatively, the sensor may be attached just prior to use in the field. Note, however, that if the temperature sensor is attached in the field, the sensor must be placed in an interference-free arrangement with respect to the Type S pitot tube openings (see Method 2, Figure 2–7). As a second alternative, if a difference of not more than 1 percent in the average velocity measurement is to be introduced, the temperature gauge need not be attached to the probe or pitot tube. (This alternative is subject to the approval of the Administrator.)

2.2 Sample Recovery. The following items are needed.

2.2.1 Probe-Liner and Probe-Nozzle Brushes. Nylon bristle brushes with stainless steel wire handles. The probe brush shall have extensions (at least as long as the probe) of stainless steel, Nylon, Teflon, or similarly inert material. The brushes shall be properly sized and shaped to brush out the probe liner and nozzle.

2.2.2 Wash Bottles—Two. Glass wash bottles are recommended; polyethylene wash bottles may be used at the option of the tester. It is recommended that acetone not be stored in polyethylene bottles for longer than a month.

2.2.3 Glass Sample Storage Containers. Chemically resistant, borosilicate glass bottles, for acetone washes, 500 ml or 1000 ml. Screw cap liners shall either be rubber-backed Teflon or shall be constructed so as to be leak-free and resistant to chemical attack by acetone. (Narrow mouth glass bottles have been found to be less prone to leakage.) Alternatively, polyethylene bottles may be used.

2.2.4 Petri Dishes. For filter samples, glass or polyethylene, unless otherwise specified by the Administrator.

2.2.5 Graduated Cylinder and/or Balance. To measure condensed water to within 1 ml or 1 g. Graduated cylinders shall have subdivisions no greater than 2 ml. Most laboratory balances are capable of weighing to the nearest 0.5 g or less. Any of these balances is suitable for use here and in Section 2.3.4.

2.2.6 Plastic Storage Containers. Air-tight containers to store silica gel.

2.2.7 Funnel and Rubber Policeman. To aid in transfer of silica gel to container; not necessary if silica gel is weighed in the field.

2.2.8 Funnel. Glass or polyethlene, to aid in sample recovery.

2.3 Analysis. For analysis, the following equipment is needed.

2.3.1 Glass Weighing Dishes.

2.3.2 Desiccator.

2.3.3 Analytical Balance. To measure to within 0.1 mg.

2.3.4 Balance. To measure to within 0.5 g.

2.3.5 Beakers. 250 ml.

2.3.6 Hygrometer. To measure the relative humidity of the laboratory environment.

2.3.7 Temperature Gauge. To measure the temperature of the laboratory environment.

3. *Reagents*

3.1 Sampling. The reagents used in sampling are as follows:

3.1.1 Filters. Glass fiber filters, without organic binder, exhibiting at least 99.95 percent efficiency ($\leq$0.05 percent penetration) on 0.3-micron dioctyl phthalate smoke particles. The filter efficiency test shall be conducted in accordance with ASTM standard method D 2986–71. Test data from the supplier's quality control program are sufficient for this purpose.

3.1.2. Silica Gel. Indicating type, 6 to 16 mesh. If previously used, dry at 175° C (350° F) for 2 hours. New silica gel may be used as received. Alternatively, other types of desiccants (equivalent or better) may be used, subject to the approval of the Administrator.

3.1.3 Water. When analysis of the material caught in the impingers is required, distilled water shall be used. Run blanks prior to field use to eliminate a high blank on test samples.

3.1.4 Crushed Ice.

3.1.5 Stopcock Grease. Acetone-insoluble, heat-stable silicone grease. This is not necessary if screw-on connectors with Teflon sleeves, or similar, are used. Alternatively, other types of stopcock grease may be used, subject to the approval of the Administrator.

3.2 Sample Recovery. Acetone—reagent grade, $\leq$0.001 percent residue, in glass bottles—is required. Acetone from metal containers generally has a high residue blank and should not be used. Sometimes, suppliers transfer acetone to glass bottles from metal containers; thus, acetone blanks shall be run prior to field use and only acetone with low blank values ($\leq$0.001 percent) shall be used. In no case shall a blank value of greater than 0.001 percent of the weight of acetone used be subtracted from the sample weight.

3.3 Analysis. Two reagents are required for the analysis:

3.3.1 Acetone. Same as 3.2.

3.3.2 Desiccant. Anhydrous calcium sulfate, indicating type. Alternatively, other types of desiccants may be used, subject to the approval of the Administrator.

4. *Procedure*

4.1 Sampling. The complexity of this method is such that, in order to obtain reliable results, testers should be trained and experienced with the test procedures.

4.1.1 Pretest Preparation. All the components shall be maintained and calibrated according to the procedure described in APTD–0576, unless otherwise specified herein.

Weigh several 200 to 300 g portions of silica gel in air-tight containers to the nearest 0.5 g. Record the total weight of the silica gel plus container, on each container. As an alternative, the silica gel need not be preweighed, but may be weighed directly in its impinger or sampling holder just prior to train assembly.

Check filters visually against light for irregularities and flaws or pinhole leaks. Label filters of the proper diameter on the back side near the edge using numbering machine ink. As an alternative, label the shipping containers (glass or plastic petri dishes) and keep the filters in these containers at all times except during sampling and weighing.

Desiccate the filters at 20±5.6° C (68±10° F) and ambient pressure for at least 24 hours and weigh at intervals of at least 6 hours to a constant weight, i.e., <0.5 mg change from previous weighing; record results to the nearest 0.1 mg. During each weighing the filter must not be exposed to the laboratory atmosphere for a period greater than 2 minutes and a relative humidity above 50 percent. Alternatively (unless otherwise specified by the Administrator), the filters may be oven dried at 105° C (220° F) for 2 to 3 hours, desiccated for 2 hours, and weighed. Procedures other than those described, which account for relative humidity effects, may be used, subject to the approval of the Administrator.

4.1.2 Preliminary Determinations. Select the sampling site and the minimum number of sampling points according to Method 1 or as specified by the Administrator. Determine the stack pressure, temperature, and the range of velocity heads using Method 2; it is recommended that a leak-check of the pitot lines (see Method 2, Section 3.1) be performed. Determine the moisture content using Approximation Method 4 or its alternatives for the purpose of making isokinetic sampling rate settings. Determine the stack gas dry molecular weight, as described in Method 2, Section 3.6; if integrated Method 3 sampling is used for molecular weight determination, the integrated bag sample shall be taken simultaneously with, and for the same total length of time as, the particulate sample run.

Select a nozzle size based on the range of velocity heads, such that it is not necessary to change the nozzle size in order to maintain isokinetic sampling rates. During the run, do not change the nozzle size. Ensure that the proper differential pressure gauge is chosen for the range of velocity heads encountered (see Section 2.2 of Method 2).

Select a suitable probe liner and probe length such that all traverse points can be sampled. For large stacks, consider sampling from opposite sides of the stack to reduce the length of probes.

Select a total sampling time greater than or equal to the minimum total sampling time specified in the test procedures for the specific industry such that (1) the sampling time per point is not less than 2 min (or some greater time interval as specified by the Administrator), and (2) the sample volume taken (corrected to standard conditions) will exceed the required minimum total gas sample volume. The latter is based on an approximate average sampling rate.

It is recommended that the number of minutes sampled at each point be an integer or an integer plus one-half minute, in order to avoid timekeeping errors.

In some circumstances, e.g., batch cycles, it may be necessary to sample for shorter times at the traverse points and to obtain smaller gas sample volumes. In these cases, the Administrator's approval must first be obtained.

4.1.3 Preparation of Collection Train. During preparation and assembly of the sampling train, keep all openings where contamination can occur covered until just prior to assembly or until sampling is about to begin.

Place 100 ml of water in each of the first two impingers, leave the third impinger empty, and transfer approximately 200 to 300 g of preweighed silica gel from its container to the fourth impinger. More silica gel may be used, but care should be taken to ensure that it is not entrained and carried out from the impinger during sampling. Place the container in a clean place for later use in the sample recovery. Alternatively, the weight of the silica gel plus impinger may be determined to the nearest 0.5 g and recorded.

Using a tweezer or clean disposable surgical gloves, place a labeled (identified) and weighed filter in the filter holder. Be sure that the filter is properly centered and the gasket properly placed so as to prevent the sample gas stream from circumventing the filter. Check the filter for tears after assembly is completed.

When glass liners are used, install the selected nozzle using a Viton A O-ring when stack temperatures are less than 260° C (500° F) and an asbestos string gasket when temperatures are higher. See APTD–0576 for details. Other connecting systems using either 316 stainless steel or Teflon ferrules may be used. When metal liners are used, install the nozzle as above or by a leak-free direct mechanical connection. Mark the probe with heat resistant tape or by some other method to denote the proper distance into the stack or duct for each sampling point.

Set up the train as in Figure 5–1, using (if necessary) a very light coat of silicone grease on all ground glass joints, greasing only the outer portion (see APTD–0576) to avoid possibility of contamination by the silicone grease. Subject to the approval of the Administrator, a glass cyclone may be used between the probe and filter holder when the total particulate catch is expected to exceed 100 mg or when water droplets are present in the stack gas.

Place crushed ice around the impingers.

4.1.4 Leak-Check Procedures.

4.1.4.1 Pretest Leak-Check. A pretest leak-check is recommended, but not required. If the tester opts to conduct the pretest leak-check, the following procedure shall be used.

After the sampling train has been assembled, turn on and set the filter and probe heating systems at the desired operating temperatures. Allow time for the temperatures to stabilize. If a Viton A O-ring or other leak-free connection is used in assembling the probe nozzle to the probe liner, leak-check the train at the sampling site by plugging the nozzle and pulling a 380 mm Hg (15 in. Hg) vacuum.

NOTE.—A lower vacuum may be used, provided that it is not exceeded during the test.

If an asbestos string is used, do not connect the probe to the train during the leak-check. Instead, leak-check the train by first plugging the inlet to the filter holder (cyclone, if applicable) and pulling a 380 mm Hg (15 in. Hg) vacuum (see Note immediately above). Then connect the probe to the train and leak-check at about 25 mm Hg (1 in. Hg) vacuum; alternatively, the probe may be leak-checked with the rest of the sampling train, in one step, at 380 mm Hg (15 in. Hg) vacuum. Leakage rates in excess of 4 percent of the average sampling rate or 0.00057 m^3/min (0.02 cfm), whichever is less, are unacceptable.

The following leak-check instructions for the sampling train described in APTD–0576 and APTD–0581 may be helpful. Start the pump with bypass valve fully open and coarse adjust valve completely closed. Partially open the coarse adjust valve and slowly close the bypass valve until the desired vacuum is reached. Do not reverse direction of bypass valve; this will cause water to back up into the filter holder. If the desired vacuum is exceeded, either leak-check at this higher vacuum or end the leak check as shown below and start over.

When the leak-check is completed, first slowly remove the plug from the inlet to the probe, filter holder, or cyclone (if applicable) and immediately turn off the vaccum pump. This prevents the water in the impingers from being forced backward into the filter holder and silica gel from being entrained backward into the third impinger.

4.1.4.2 Leak-Checks During Sample Run. If, during the sampling run, a component (e.g., filter assembly or impinger) change becomes necessary, a leak-check shall be conducted immediately before the change is made. The leak-check shall be done according to the procedure outlined in Section 4.1.4.1 above, except that it shall be done at a vacuum equal to or greater than the maximum value recorded up to that point in the test. If the leakage rate is found to be no greater than 0.00057 m^3/min (0.02 cfm) or 4 percent of the average sampling rate (whichever is less), the results are acceptable, and no correction will need to be applied to the total volume of dry gas metered; if, however, a higher leakage rate is obtained, the tester shall either record the leakage rate and plan to correct the sample volume as shown in Section 6.3 of this method, or shall void the sampling run.

Immediately after component changes, leak-checks are optional; if such leak-checks are done, the procedure outlined in Section 4.1.4.1 above shall be used.

4.1.4.3 Post-test Leak-Check. A leak-check is mandatory at the conclusion of each sampling run. The leak-check shall be done in accordance with the procedures outlined in Section 4.1.4.1, except that it shall be conducted at a vacuum equal to or greater than the maximum value reached during the sampling run. If the leakage rate is found to be no greater than 0.00057 m^3/min (0.02 cfm) or 4 percent of the average sampling rate (whichever is less), the results are acceptable, and no correction need be applied to the total volume of dry gas metered. If, however, a higher leakage rate is obtained, the tester shall either record the leakage rate and correct the sample volume as shown in Section 6.3 of this method, or shall void the sampling run.

4.1.5 Particulate Train Operation. During the sampling run, maintain an isokinetic sampling rate (within 10 percent of true isokinetic unless otherwise specified by the Administrator) and a temperature around the filter of 120±14° C (248±25° F), or such other temperature as specified by an applicable subpart of the standards or approved by the Administrator.

For each run, record the data required on a data sheet such as the one shown in Figure 5–2. Be sure to record the initial dry gas meter reading. Record the dry gas meter readings at the beginning and end of each sampling time increment, when changes in flow rates are made, before and after each leak check, and when sampling is halted.

Take other readings required by Figure 5–2 at least once at each sample point during each time increment and additional readings when significant changes (20 percent variation in velocity head readings) necessitate additional adjustments in flow rate. Level and zero the manometer. Because the manometer level and zero may drift due to vibrations and temperature changes, make periodic checks during the traverse.

Clean the portholes prior to the test run to minimize the chance of sampling deposited material. To begin sampling, remove the nozzle cap, verify that the filter and probe heating systems are up to temperature, and that the pitot tube and probe are properly positioned. Position the nozzle at the first traverse point with the tip pointing directly into the gas stream. Immediately start the pump and adjust the flow to isokinetic conditions. Nomographs are available, which aid in the rapid adjustment of the isokinetic sampling rate without excessive computations. These nomographs are designed for use when the Type S pitot tube coefficient is 0.85±0.02, and the stack gas equivalent density (dry molecular weight) is equal to 29±4. APTD–0576 details the procedure for using the nomographs. If C_p and M_d are outside the above stated ranges do not use the nomographs unless appropriate steps (see Citation 7 in Section 7) are taken to compensate for the deviations.

PLANT ____________________
LOCATION ____________________
OPERATOR ____________________
DATE ____________________
RUN NO. ____________________
SAMPLE BOX NO. ____________________
METER BOX NO. ____________________
METER ΔH@ ____________________
C FACTOR ____________________
PITOT TUBE COEFFICIENT, C_p ____________

SCHEMATIC OF STACK CROSS SECTION

AMBIENT TEMPERATURE ____________________
BAROMETRIC PRESSURE ____________________
ASSUMED MOISTURE, % ____________________
PROBE LENGTH, m (ft) ____________________
NOZZLE IDENTIFICATION NO. ____________________
AVERAGE CALIBRATED NOZZLE DIAMETER, cm (in.) ____________
PROBE HEATER SETTING ____________________
LEAK RATE, m^3/min.(cfm) ____________________
PROBE LINER MATERIAL ____________________
STATIC PRESSURE, mm Hg (in. Hg) ____________________
FILTER NO. ____________________

TRAVERSE POINT NUMBER	SAMPLING TIME (θ), min.	VACUUM mm Hg (in. Hg)	STACK TEMPERATURE (T_S) °C (°F)	VELOCITY HEAD (ΔP_S), mm(in.)H_2O	PRESSURE DIFFERENTIAL ACROSS ORIFICE METER mm H_2O (in. H_2O)	GAS SAMPLE VOLUME m^3 (ft^3)	GAS SAMPLE TEMPERATURE AT DRY GAS METER		FILTER HOLDER TEMPERATURE, °C (°F)	TEMPERATURE OF GAS LEAVING CONDENSER OR LAST IMPINGER, °C (°F)
							INLET, °C (°F)	OUTLET °C (°F)		
TOTAL							Avg.	Avg.		
AVERAGE							Avg.			

Figure 5-2. Particulate field data.

When the stack is under significant negative pressure (height of impinger stem), take care to close the coarse adjust valve before inserting the probe into the stack to prevent water from backing into the filter holder. If necessary, the pump may be turned on with the coarse adjust valve closed.

When the probe is in position, block off the openings around the probe and porthole to prevent unrepresentative dilution of the gas stream.

Traverse the stack cross-section, as required by Method 1 or as specified by the Administrator, being careful not to bump the probe nozzle into the stack walls when sampling near the walls or when removing or inserting the probe through the portholes; this minimizes the chance of extracting deposited material.

During the test run, make periodic adjustments to keep the temperature around the filter holder at the proper level; add more ice and, if necessary, salt to maintain a temperature of less than 20° C (68° F) at the condenser/silica gel outlet. Also, periodically check the level and zero of the manometer.

If the pressure drop across the filter becomes too high, making isokinetic sampling difficult to maintain, the filter may be replaced in the midst of a sample run. It is recommended that another complete filter assembly be used rather than attempting to change the filter itself. Before a new filter assembly is installed, conduct a leak-check (see Section 4.1.4.2). The total particulate weight shall include the summation of all filter assembly catches.

A single train shall be used for the entire sample run, except in cases where simultaneous sampling is required in two or more separate ducts or at two or more different locations within the same duct, or, in cases where equipment failure necessitates a change of trains. In all other situations, the use of two or more trains will be subject to the approval of the Administrator.

Note that when two or more trains are used, separate analyses of the front-half and (if applicable) impinger catches from each train shall be performed, unless identical nozzle sizes were used on all trains, in which case, the front-half catches from the individual trains may be combined (as may the impinger catches) and one analysis of front-half catch and one analysis of impinger catch may be performed. Consult with the Administrator for details concerning the calculation of results when two or more trains are used.

At the end of the sample run, turn off the coarse adjust valve, remove the probe and nozzle from the stack, turn off the pump, record the final dry gas meter reading, and conduct a post-test leak-check, as outlined in Section 4.1.4.3. Also, leak-check the pitot lines as described in Method 2, Section 3.1; the lines must pass this leak-check, in order to validate the velocity head data.

4.1.6 Calculation of Percent Isokinetic. Calculate percent isokinetic (see Calculations, Section 6) to determine whether the run was valid or another test run should be made. If there was difficulty in maintaining isokinetic rates due to source conditions, consult with the Administrator for possible variance on the isokinetic rates.

4.2 Sample Recovery. Proper cleanup procedure begins as soon as the probe is removed from the stack at the end of the sampling period. Allow the probe to cool.

When the probe can be safely handled, wipe off all external particulate matter near the tip of the probe nozzle and place a cap over it to prevent losing or gaining particulate matter. Do not cap off the probe tip tightly while the sampling train is cooling down as this would create a vacuum in the filter holder, thus drawing water from the impingers into the filter holder.

Before moving the sample train to the cleanup site, remove the probe from the sample train, wipe off the silicone grease, and cap the open outlet of the probe. Be careful not to lose any condensate that might be present. Wipe off the silicone grease from the filter inlet where the probe was fastened and cap it. Remove the umbilical cord from the last impinger and cap the impinger. If a flexible line is used between the first impinger or condenser and the filter holder, disconnect the line at the filter holder and let any condensed water or liquid drain into the impingers or condenser. After wiping off the silicone grease, cap off the filter holder outlet and impinger inlet. Either ground-glass stoppers, plastic caps, or serum caps may be used to close these openings.

Transfer the probe and filter-impinger assembly to the cleanup area. This area should be clean and protected from the wind so that the chances of contaminating or losing the sample will be minimized.

Save a portion of the acetone used for cleanup as a blank. Take 200 ml of this acetone directly from the wash bottle being used and place it in a glass sample container labeled "acetone blank."

Inspect the train prior to and during disassembly and note any abnormal conditions. Treat the samples as follows:

Container No. 1. Carefully remove the filter from the filter holder and place it in its identified petri dish container. Use a pair of tweezers and/or clean disposable surgical gloves to handle the filter. If it is necessary to fold the filter, do so such that the particulate cake is inside the fold. Carefully transfer to the petri dish any particulate matter and/or filter fibers which adhere to the filter holder gasket, by using a dry nylon bristle brush and/or a sharp-edged blade. Seal the container.

Container No. 2. Taking care to see that dust on the outside of the probe or other exterior surfaces does not get into the sample, quantitatively recover particulate matter or any condensate from the probe nozzle, probe fitting, probe liner, and front half of the filter holder by washing these components with acetone and placing the wash in a glass container. Distilled water may be used instead of acetone when approved by the Administrator and shall be used when specified by the Administrator; in these cases, save a water blank and follow the Administrator's directions on analysis. Perform the acetone rinses as follows:

Carefully remove the probe nozzle and clean the inside surface by rinsing with acetone from a wash bottle and brushing with a nylon bristle brush. Brush until the acetone rinse shows no visible particles, after which make a final rinse of the inside surface with acetone.

Brush and rinse the inside parts of the Swagelok fitting with acetone in a similar way until no visible particles remain.

Rinse the probe liner with acetone by tilting and rotating the probe while squirting acetone into its upper end so that all inside surfaces will be wetted with acetone. Let the acetone drain from the lower end into the sample container. A funnel (glass or polyethylene) may be used to aid in transferring liquid washes to the container. Follow the acetone rinse with a probe brush. Hold the probe in an inclined position, squirt acetone into the upper end as the probe brush is being pushed with a twisting action through the probe; hold a sample container underneath the lower end of the probe, and catch any acetone and particulate matter which is brushed from the probe. Run the brush through the probe three times or more until no visible particulate matter is carried out with the acetone or until none remains in the probe liner on visual inspection. With stainless steel or other metal probes, run the brush through in the above prescribed manner at least six times since metal probes have small crevices in which particulate matter can be entrapped. Rinse the brush with acetone, and quantitatively collect these washings in the sample container. After the brushing, make a final acetone rinse of the probe as described above.

It is recommended that two people be used to clean the probe to minimize sample losses. Between sampling runs, keep brushes clean and protected from contamination.

After ensuring that all joints have been wiped clean of silicone grease, clean the inside of the front half of the filter holder by rubbing the surfaces with a nylon bristle brush and rinsing with acetone. Rinse each surface three times or more if needed to remove visible particulate. Make a final rinse of the brush and filter holder. Carefully rinse out the glass cyclone, also (if applicable). After all acetone washings and particulate matter have been collected in the sample container, tighten the lid on the sample container so that acetone will not leak out when it is shipped to the laboratory. Mark the height of the fluid level to determine whether or not leakage occurred during transport. Label the container to clearly identify its contents.

Container No. 3. Note the color of the indicating silica gel to determine if it has been completely spent and make a notation of its condition. Transfer the silica gel from the fourth impinger to its original container and seal. A funnel may make it easier to pour the silica gel without spilling. A rubber policeman may be used as an aid in removing the silica gel from the impinger. It is not necessary to remove the small amount of dust particles that may adhere to the impinger wall and are difficult to remove. Since the gain in weight is to be used for moisture calculations, do not use any water or other liquids to transfer the silica gel. If a balance is available in the field, follow the procedure for container No. 3 in Section 4.3.

Impinger Water. Treat the impingers as follows; Make a notation of any color or film in the liquid catch. Measure the liquid which is in the first three impingers to within ±1 ml by using a graduated cylinder or by weighing it to within ±0.5 g by using a balance (if one is available). Record the volume or weight of liquid present. This information is required to calculate the moisture content of the effluent gas.

Discard the liquid after measuring and recording the volume or weight, unless analysis of the impinger catch is required (see Note, Section 2.1.7).

If a different type of condenser is used, measure the amount of moisture condensed either volumetrically or gravimetrically.

Whenever possible, containers should be shipped in such a way that they remain upright at all times.

4.3 Analysis. Record the data required on a sheet such as the one shown in Figure 5–3. Handle each sample container as follows:

Container No. 1. Leave the contents in the shipping container or transfer the filter and any loose particulate from the sample container to a tared glass weighing dish. Desiccate for 24 hours in a desiccator containing anhydrous calcium sulfate. Weigh to a constant weight and report the results to the nearest 0.1 mg. For purposes of this Section, 4.3, the term "constant weight" means a difference of no more than 0.5 mg or 1 percent of total weight less tare weight, whichever is greater, between two consecutive weighings, with no less than 6 hours of desiccation time between weighings.

Plant____________________

Date____________________

Run No.____________________

Filter No.____________________

Amount liquid lost during transport ____________________

Acetone blank volume, ml____________________

Acetone wash volume, ml____________________

Acetone blank concentration, mg/mg (equation 5-4)____________________

Acetone wash blank, mg (equation 5-5)____________________

CONTAINER NUMBER	WEIGHT OF PARTICULATE COLLECTED, mg		
	FINAL WEIGHT	TARE WEIGHT	WEIGHT GAIN
1			
2			
TOTAL			
		Less acetone blank	
		Weight of particulate matter	

	VOLUME OF LIQUID WATER COLLECTED	
	IMPINGER VOLUME, ml.	SILICA GEL WEIGHT, g
FINAL		
INITIAL		
LIQUID COLLECTED		
TOTAL VOLUME COLLECTED		g* ml

* CONVERT WEIGHT OF WATER TO VOLUME BY DIVIDING TOTAL WEIGHT INCREASE BY DENSITY OF WATER (1g/ml):

$$\frac{\text{INCREASE, g}}{1\ \text{g/ml}} = \text{VOLUME WATER, ml}$$

Figure 5-3. Analytical data.

Alternatively, the sample may be oven dried at 105° C (220° F) for 2 to 3 hours, cooled in the desiccator, and weighed to a constant weight, unless otherwise specified by the Administrator. The tester may also opt to oven dry the sample at 105 ° C (220 ° F) for 2 to 3 hours, weigh the sample, and use this weight as a final weight.

Container No. 2. Note the level of liquid in the container and confirm on the analysis sheet whether or not leakage occurred during transport. If a noticeable amount of leakage has occurred, either void the sample or use methods, subject to the approval of the Administrator, to correct the final results. Measure the liquid in this container either volumetrically to ±1 ml or gravimetrically to ±0.5 g. Transfer the contents to a tared 250-ml beaker and evaporate to dryness at ambient temperature and pressure. Desiccate for 24 hours and weigh to a constant weight. Report the results to the nearest 0.1 mg.

Container No. 3. Weigh the spent silica gel (or silica gel plus impinger) to the nearest 0.5 g using a balance. This step may be conducted in the field.

"Acetone Blank" Container. Measure acetone in this container either volumetrically or gravimetrically. Transfer the acetone to a tared 250-ml beaker and evaporate to dryness at ambient temperature and pressure. Desiccate for 24 hours and weigh to a contsant weight. Report the results to the nearest 0.1 mg.

NOTE.—At the option of the tester, the contents of Container No. 2 as well as the acetone blank container may be evaporated at temperatures higher than ambient. If evaporation is done at an elevated temperature, the temperature must be below the boiling point of the solvent; also, to prevent "bumping," the evaporation process must be closely supervised, and the contents of the beaker must be swirled occasionally to maintain an even temperature. Use extreme care, as acetone is highly flammable and has a low flash point.

5. *Calibration*

Maintain a laboratory log of all calibrations.

5.1 Probe Nozzle. Probe nozzles shall be calibrated before their initial use in the field. Using a micrometer, measure the inside diameter of the nozzle to the nearest 0.025 mm (0.001 in.). Make three separate measurements using different diameters each time, and obtain the average of the measurements. The difference between the high and low numbers shall not exceed 0.1 mm (0.004 in.). When nozzles become nicked, dented, or corroded, they shall be reshaped, sharpened, and recalibrated before use. Each nozzle shall be permanently and uniquely identified.

5.2 Pitot Tube. The Type S pitot tube assembly shall be calibrated according to the procedure outlined in Section 4 of Method 2.

5.3 Metering System. Before its initial use in the field, the metering system shall be calibrated according to the procedure outlined in APTD–0576. Instead of physically adjusting the dry gas meter dial readings to correspond to the wet test meter readings, calibration factors may be used to mathematically correct the gas meter dial readings to the proper values. Before calibrating the metering system, it is suggested that a leak-check be conducted. For metering systems having diaphragm pumps, the normal leak-check procedure will not detect leakages within the pump. For these cases the following leak-check procedure is suggested: make a 10-minute calibration run at 0.00057 m³/min (0.02 cfm); at the end of the run, take the difference of the measured wet test meter and dry gas meter volumes; divide the difference by 10, to get the leak rate. The leak rate should not exceed 0.00057 m³/min (0.02 cfm).

After each field use, the calibration of the metering system shall be checked by performing three calibration runs at a single, intermediate orifice setting (based on the previous field test), with the vacuum set at the maximum value reached during the test series. To adjust the vacuum, insert a valve between the wet test meter and the inlet of the metering system. Calculate the average value of the calibration factor. If the calibration has changed by more than 5 percent, recalibrate the meter over the full range of orifice settings, as outlined in APTD–0576.

Alternative procedures, e.g., using the orifice meter coefficients, may be used, subject to the approval of the Administrator.

NOTE.—If the dry gas meter coefficient values obtained before and after a test series differ by more than 5 percent, the test series shall either be voided, or calculations for the test series shall be performed using whichever meter coefficient value (i.e., before or after) gives the lower value of total sample volume.

5.4 Probe Heater Calibration. The probe heating system shall be calibrated before its initial use in the field according to the procedure outlined in APTD–0576. Probes constructed according to APTD–0581 need not be calibrated if the calibration curves in APTD–0576 are used.

5.5 Temperature Gauges. Use the procedure in Section 4.3 of Method 2 to calibrate in-stack temperature gauges. Dial thermometers, such as are used for the dry gas meter and condenser outlet, shall be calibrated against mercury-in-glass thermometers.

5.6 Leak Check of Metering System Shown in Figure 5–1. That portion of the sampling train from the pump to the orifice meter should be leak checked prior to initial use and after each shipment. Leakage after the pump will result in less volume being recorded than is actually sampled. The following procedure is suggested (see Figure 5–4): Close the main valve on the meter box. Insert a one-hole rubber stopper with rubber tubing attached into the orifice exhaust pipe. Disconnect and vent the low side of the orifice manometer. Close off the low side orifice tap. Pressurize the system to 13 to 18 cm (5 to 7 in.) water column by blowing into the rubber tubing. Pinch off the tubing and observe the manometer for one minute. A loss of pressure on the manometer indicates a leak in the meter box; leaks, if present, must be corrected.

5.7 Barometer. Calibrate against a mercury barometer.

6. *Calculations*

Carry out calculations, retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after the final calculation. Other forms of the equations may be used as long as they give equivalent results.

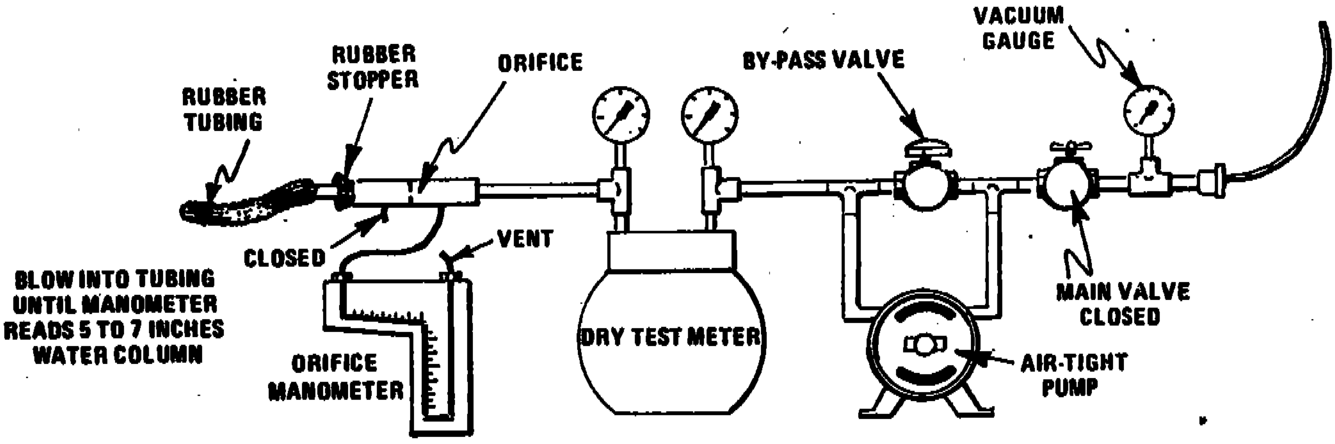

Figure 5-4. Leak check of meter box.

6.1 Nomenclature

A_n = Cross-sectional area of nozzle, m² (ft²).
B_{ws} = Water vapor in the gas stream, proportion by volume.
C_a = Acetone blank residue concentrations, mg/g.
c_s = Concentration of particulate matter in stack gas, dry basis, corrected to standard conditions, g/dscm (g/dscf).
I = Percent of isokinetic sampling.
L_a = Maximum acceptable leakage rate for either a pretest leak check or for a leak check following a component change; equal to 0.00057 m³/min (0.02 cfm) or 4 percent of the average sampling rate, whichever is less.
L_i = Individual leakage rate observed during the leak check conducted prior to the "i^{th}" component change (i=1, 2, 3 . . . . n), m³/min (cfm).
L_p = Leakage rate observed during the post-test leak check, m³/min (cfm).
m_n = Total amount of particulate matter collected, mg.
M_w = Molecular weight of water, 18.0 g/g-mole (18.0 lb/lb-mole).
m_a = Mass of residue of acetone after evaporation, mg.
P_{bar} = Barometric pressure at the sampling site, mm Hg (in. Hg).
P_s = Absolute stack gas pressure, mm Hg (in. Hg).
P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).
R = Ideal gas constant, 0.06236 mm Hg-m³/°K-g-mole (21.85 in. Hg-ft³/°R-lb-mole).
T_m = Absolute average dry gas meter temperature (see Figure 5–2), °K (°R).
T_s = Absolute average stack gas temperature (see Figure 5–2), °K (°R).
T_{std} = Standard absolute temperature, 293° K (528° R).
V_a = Volume of acetone blank, ml.
V_{aw} = Volume of acetone used in wash, ml.
V_{lc} = Total volume of liquid collected in impingers and silica gel (see Figure 5–3), ml.
V_m = Volume of gas sample as measured by dry gas meter, dcm (dcf).
$V_{m(std)}$ = Volume of gas sample measured by the dry gas meter, corrected to standard conditions, dscm (dscf).
$V_{w(std)}$ = Volume of water vapor in the gas sample, corrected to standard conditions, scm (scf).
V_s = Stack gas velocity, calculated by Method 2, Equation 2–9, using data obtained from Method 5, m/sec (ft/sec).
W_a = Weight of residue in acetone wash, mg.
Y = Dry gas meter calibration factor.
ΔH = Average pressure differential across the orifice meter (see Figure 5–2), mm H_2O (in. H_2O).
ρ_a = Density of acetone, mg/ml (see label on bottle).
ρ_w = Density of water, 0.9982 g/ml (0.002201 lb/ml).
θ = Total sampling time, min.
θ_1 = Sampling time interval, from the beginning of a run until the first component change, min.
θ_i = Sampling time interval, between two successive component changes, beginning with the interval between the first and second changes, min.
θ_p = Sampling time interval, from the final (n^{th}) component change until the end of the sampling run, min.
13.6 = Specific gravity of mercury.
60 = Sec/min.
100 = Conversion to percent.

6.2 Average dry gas meter temperature and average orifice pressure drop. See data sheet (Figure 5–2).

6.3 Dry Gas Volume. Correct the sample volume measured by the dry gas meter to standard conditions (20° C, 760 mm Hg or 68° F, 29.92 in. Hg) by using Equation 5–1.

$$V_{m(std)} = V_m Y \left(\frac{T_{std}}{T_m}\right) \left[\frac{P_{bar} + \frac{\Delta H}{13.6}}{P_{std}}\right]$$

$$= K_1 V_m Y \frac{P_{bar} + (\Delta H/13.6)}{T_m}$$

Equation 5–1

where;
$m_j = 0.3858$ °K/mm Hg for metric units
$= 17.64$ °R/in. Hg for English units

NOTE.—Equation 5-1 can be used as written unless the leakage rate observed during any of the mandatory leak checks (i.e., the post-test leak check or leak checks conducted prior to component changes) exceeds L_a. If L_p or L_i exceeds L_a, Equation 5-1 must be modified as follows;

(a) Case I. No component changes made during sampling run. In this case, replace V_m in Equation 5-1 with the expression;

$$V_m - (L_p - L_a)\theta]$$

(b) Case II. One or more component changes made during the sampling run. In this case, replace V_m in Equation 5-1 by the expression:

$$\left[V_m - (L_1 - L_a)\theta_1 - \sum_{i=2}^{n} (L_i - L_a)\theta_i - (L_p - L_a)\theta_p\right]$$

and substitute only for those leakage rates (L_i or L_p) which exceed L_a.

6.4 Volume of water vapor.

$$V_{w(std)} = V_{1c}\left(\frac{\rho_w}{M_w}\right)\left(\frac{RT_{std}}{P_{std}}\right) = K_2 V_{1c}$$

Equation 5-2

where:
$K_2 = 0.001333$ m³/ml for metric units
$= 0.04707$ ft³/ml for English units.

6.5 Moisture Content.

$$B_{ws} = \frac{V_{w(std)}}{V_{m(std)} + V_{w(std)}}$$

Equation 5-3

NOTE.—In saturated or water droplet-laden gas streams, two calculations of the moisture content of the stack gas shall be made, one from the impinger analysis (Equation 5-3), and a second from the assumption of saturated conditions. The lower of the two values of B_{ws} shall be considered correct. The procedure for determining the moisture content based upon assumption of saturated conditions is given in the Note of Section 1.2 of Method 4. For the purposes of this method, the average stack gas temperature from Figure 5-2 may be used to make this determination, provided that the accuracy of the in-stack temperature sensor is ± 1° C (2° F).

6.6 Acetone Blank Concentration.

$$C_a = \frac{m_a}{V_a \rho_a}$$

Equation 5-4

6.7 Acetone Wash Blank.

$$W_a = C_a V_{aw} \rho_a$$

Equation 5-5

6.8 Total Particulate Weight. Determine the total particulate catch from the sum of the weights obtained from containers 1 and 2 less the acetone blank (see Figure 5-3). NOTE.—Refer to Section 4.1.5 to assist in calculation of results involving two or more filter assemblies or two or more sampling trains.

6.9 Particulate Concentration.

$$c_s = (0.001\ g/mg)\ (m_n / V_{m(std)})$$

Equation 5-6

6.10 Conversion Factors:

From	To	Multiply by
scf	m³	0.02832
g/ft³	gr/ft³	15.43
g/ft³	lb/ft³	2.205×10⁻³
g/ft³	g/m³	35.31

6.11 Isokinetic Variation.

6.11.1 Calculation From Raw Data.

$$I = \frac{100\ T_s[K_3 V_{1c} + (V_m/T_m)\ (P_{bar} + \Delta H/13.6)]}{60\ \theta v_s P_s A_n}$$

Equation 5-7

where:
$K_3 = 0.003454$ mm Hg−m³/ml−°K for metric units.
$= 0.002669$ in. Hg−ft³/ml−°R for English units.

6.11.2 Calculation From Intermediate Values.

$$I = \frac{T_s V_{m(std)} P_{std}\, 100}{T_{std} v_s \theta A_n P_s 60 (1 - B_{ws})}$$

$$= K_4 \frac{T_s V_{m(std)}}{P_s V_s A_n \theta (1 - B_{ws})}$$

Equation 5-8

where:
$K_4 = 4.320$ for metric units
$= 0.09450$ for English units.

6.12 Acceptable Results. If 90 percent $\leq I \leq 110$ percent, the results are acceptable. If the results are low in comparison to the standard and I is beyond the acceptable range, or, if I is less than 90 percent, the Administrator may opt to accept the results. Use Citation 4 to make judgments. Otherwise, reject the results and repeat the test.

7. *Bibliography*

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OPERATING INSTRUCTIONS FOR ANDERSEN STACK SAMPLING EQUIPMENT

1.0 INTRODUCTION

In the past, an accurate evaluation of the particulate sample collected from a stack has been difficult because the collection devices were designed mainly to be used exterior to the stack. In addition, there has been a lack of instrumentation capable of giving meaningful particle sizing information.

Now, however, the Andersen Stack Sampler is available which provides a reliable particulate sample that is collected and sized aerodynamically in the stack at isokinetic conditions simultaneously with the collection of gaseous samples. Isokinetic sampling requires that the stack gases are drawn into the sampling nozzle at the same velocity and in the same direction as they occur in the stack. This method of stack effluent analysis is easier and more economical for the simultaneous determination of grain loading, particle sizing, and gaseous content than any other technique.

There are two types or classes of stack sampling equipment. One class (external probe) has the solids-collecting device mounted outside the flue at the exit end of the probe tube and usually requires heating the probe tube and collection device to prevent condensation of water vapor. The other class (internal probe) has the solids-collecting device mounted inside the flue to provide sample collection done under actual stack conditions. The Andersen Stack Sampler is an internal collector and differs from more conventional devices in that it does not operate by means of filtration or impingement, but rather by means of inertial impaction.

A brief description of general stack sampling procedures follows. The unique characteristics and points to be considered when using the Andersen Stack Sampler will be covered in detail.

The particulate matter in stack gases is seldom distributed uniformly over the cross section of a flue; however, by a proper selection of sampling points, a representative sample can be obtained. Also, the quantity seldom remains steady over a substantial period of time because of the difficulty of maintaining uniform plant operating conditions. Therefore, it is necessary to know the operating cycles and cycle conditions in order to obtain representative samples during steady plant conditions. Peak loading times, temperatures, and humidity will all affect the sample.

It should be clearly understood that the result of a test can give only an average value of emission during the period of sampling and can be representative only of the conditions during that period. Therefore, it is recommended that duplicate samples be taken whenever sampling flues.

Since it is not possible to collect all of the material emitted from a stack, it is necessary to obtain a representative sample. This requires the selection of a suitable sampling position, the collection of several samples and the conversion of the data obtained into a reliable estimate of total emission.

Sampling points in the stack should be selected to avoid gas turbulence as much as possible. When selecting a site, the general rule is for measurements to be made eight to ten diameters downstream or three to five diameters upstream from a disturbance. Disturbances are usually caused by inlets, outlets, bends, constrictions, dampers, etc. Often, it is physically impossible to sample in a uniform gas mixture and compromises must be made. Whenever this occurs, all measurements and techniques must be carefully applied to ensure reasonable accuracy.

After the selection of a suitable sampling site, one is ready to make a preliminary survey including gas velocity, temperature, and combustion efficiency determinations. A preliminary traverse is made with a pitot tube connected to an inclined/vertical manometer.

The S pitot tube measures velocity head at the point in the gas stream where it is placed. Temperature, pressure, and humidity determinations must also be made on the sampling plane since these parameters may affect the stack gas density significantly. When making this traverse, the process cycle must be kept in mind because the stack gas velocity is dependent upon the cycle fluctuations. Also, at this time, an Orsat Analyzer is normally used to determine the efficiency of combustion. The acceptable level of CO_2 is 12 percent. It may be necessary to make several preliminary traverses in order to find an area which will conform to the previously discussed requirements. With the velocity information obtained, it is now possible to select a nozzle and flow rate that will be required for isokinetic sampling.

The sampling site selected must be able to safely accommodate two men during the taking of velocity, temperature, and humidity measurements in addition to collecting the samples. A probe tube clamp is provided in the Andersen Sampling Train to hold the stack head, probe tube, and condenser in place. The clamp has a standard 3 inch pipe thread for easy insertion into the access hole. When sampling for non-condensible particulates only, the probe tube may be screwed into the condenser for the removal of entrapped water. In this manner, the impinger may be eliminated entirely from the sampling apparatus. Whenever sampling for particulates and gases simultaneously, four Greenburg-Smith impingers in an ice bath will replace the condenser. Provisions are made so that the impinger case may be used with a rail. If a rail is not used to support the impinger case, a teflon-lined heated hose connecting the probe tube to the inlet part of the impinger case so that the case can be placed on the platform or ground could be used. In this manner, the temperature of the sample gases would be maintained above the dew point to prevent condensation upstream from the impinger case. The impinger case will replace the condenser also whenever one is concerned with collecting condensible particulates.

2.0 EQUIPMENT (SEE DRAWING 10048)

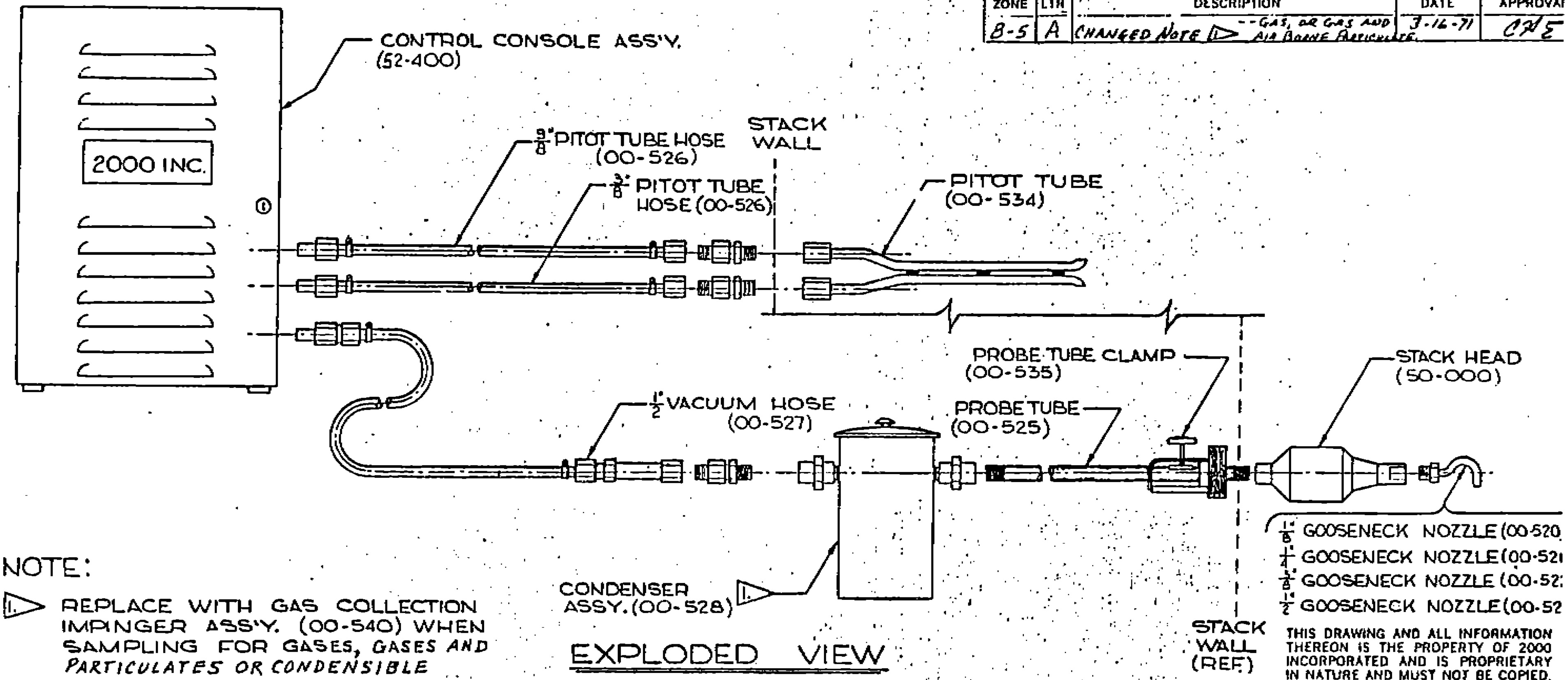
2.1 ANDERSEN STACK SAMPLING HEAD

The Andersen Stack Sampling Head consists of a stainless steel case and 1/2" female pipe fittings. It is designed to be inserted directly into the stack (standard 3 inch opening) where high temperature and/or corrosive conditions may exist.

The Sampler contains nine jet plates each having a pattern of precision-drilled orifices. The nine plates, separated by 2.5 millimeter stainless steel spacers, divide the sample into eight fractions or particle size ranges. The jets on each plate are arranged in concentric circles which are offset on each succeeding plate. The size of the orifices is the same on a given plate, but is smaller for each succeeding downstream plate. Therefore, as the sample is drawn through the Sampler

10048

ZONE	LTR	DESCRIPTION	DATE	APPROVAI
B-5	A	CHANGED NOTE ⚠1 --GAS, OR GAS AND AIR BORNE PARTICULATE.	3-16-71	CHE



NOTE:

⚠1 REPLACE WITH GAS COLLECTION IMPINGER ASS'Y. (00-540) WHEN SAMPLING FOR GASES, *GASES AND PARTICULATES OR CONDENSIBLE PARTICULATE.*

NEXT ASSY	USED ON
APPLICATION	

TOLERANCES
Unless Otherwise Specified
Dimension In Inches
Fractional ±
2 Place Decimal ±
3 Place Decimal ±
4 Place Decimal ±
Angular ±
MATERIAL: —

CONTRACT NO.

DRAWN	G.E.N.	2-26-71
CHECKED		
ENGR.		
PROJ.	C. ERICKSON	3-4-71

APPROVED, DESIGN ACTIVITY.
APPROVEC

2000 INC.

ANDERSEN STACK TRAIN BLOCK DIAGRAM

CATALOG No. 52-000

SIZE	CODE IDENT. NO.	DWG NO.	RE
B		10048	A

SCALE NONE
SHEET 1 OF 1

Rel. CHE Date 3-4-71 Proj. STACK 7

at a constant flow rate, the jets of air flowing through any particluar plate direct the particulates toward the collection area on the downstream plate directly below the circles of jets on the plate above. Since the jet diameters decrease from plate to plate, the velocities increase such that whenever the velocity imparted to a particle is sufficiently great, its inertia will overcome the aerodynamic drag of the turning airstream and the particle will be impacted on the collection surface. Otherwise, the particle remains in the airstream and proceeds to the next plate. Since the particle deposit areas are directly below the jets, seven of the plates act as both a jet stage and a collection plate. Thus, No. 0 plate is only a jet stage and No. 8 plate is only a collection plate. The types of plates available are stainless steel and nickel-plated brass. The case is made of 304 stainless steel. The temperature limitation of the Sampler is approximately 1500 degrees fahrenheit with the stainless steel plates.

The Andersen Stack Sampler has been calibrated by several independent laboratories in order to arrive at the current respective size cuts for each stage. The calibrations were referenced to unit density (1 g/cc), spherical particles so that the aerodynamically equivalent sized particles collected on each stage are always identical for any given flow rate. For this reason, a stack sample containing a mixture of shapes and densities is fractionated and collected according to its aerodynamic characteristics and is aerodynamically equivalent in size to the unit density spheres collected on each specific stage during calibration. For example, consider a golf ball and ping-pong ball of identical shape and physical size. Undoubtedly, they will not behave similarly in any environment because of the large differences in density. In other words, the aerodynamic size of a particle gives information relating to the physical size, shape, and density of the particle and indicates how the particle will behave in any environment. If the aerodynamic size distribution of the particulates in a stack sample is known, then the following pertinent information can be determined:

1. Particle behavior after leaving the stack.
2. Approximate area of environmental deposition.
3. Probable point of respiratory deposition.
4. Type of control equipment needed to collect the particles.

This type of information is impossible to obtain with only physical sizing data which is normally obtained by means of microscopic sizing or wet and/or dry screening.

Figure 1 is a plot of D_p' versus flow rate through the Stack Sampler at 70° F. D_p' is the effective aerodynamic diameter of a spherical, unit density particle. The efficiency of collection for polydisperse material as encountered under actual stack sampling conditions for any given effective cutoff diameter (ECD) is 95 plus percent.*

Figure 2 shows the correction factor for determining the physical diameter of spherical particles having other than unit density. Extreme caution should be exercised

*In Figure 1 it can be seen that the ECD for Stage 4 at 0.8 cfm is 2.0 microns (μ). For data presentation purposes, this means that essentially all of the 2.0 μ particles are separated by Stage 4 and collected on Stage 5. In reality, however, a small amount of the 2.1 μ particles that should be on Stage 5 pass on through to Stage 6. Likewise, a compensating small amount of the 1.9 μ particles that should be on Stage 6 land on Stage 5. The same correlation applies to the 2.2 μ and 1.8 μ particles, etc. In other words, the amount of overlapping on each stage is self-compensating.[1]

F[illegible]1. A[illegible]namic [illegible]meter [illegible] [illegible]te th[illegible] Andersen Stack Sampler

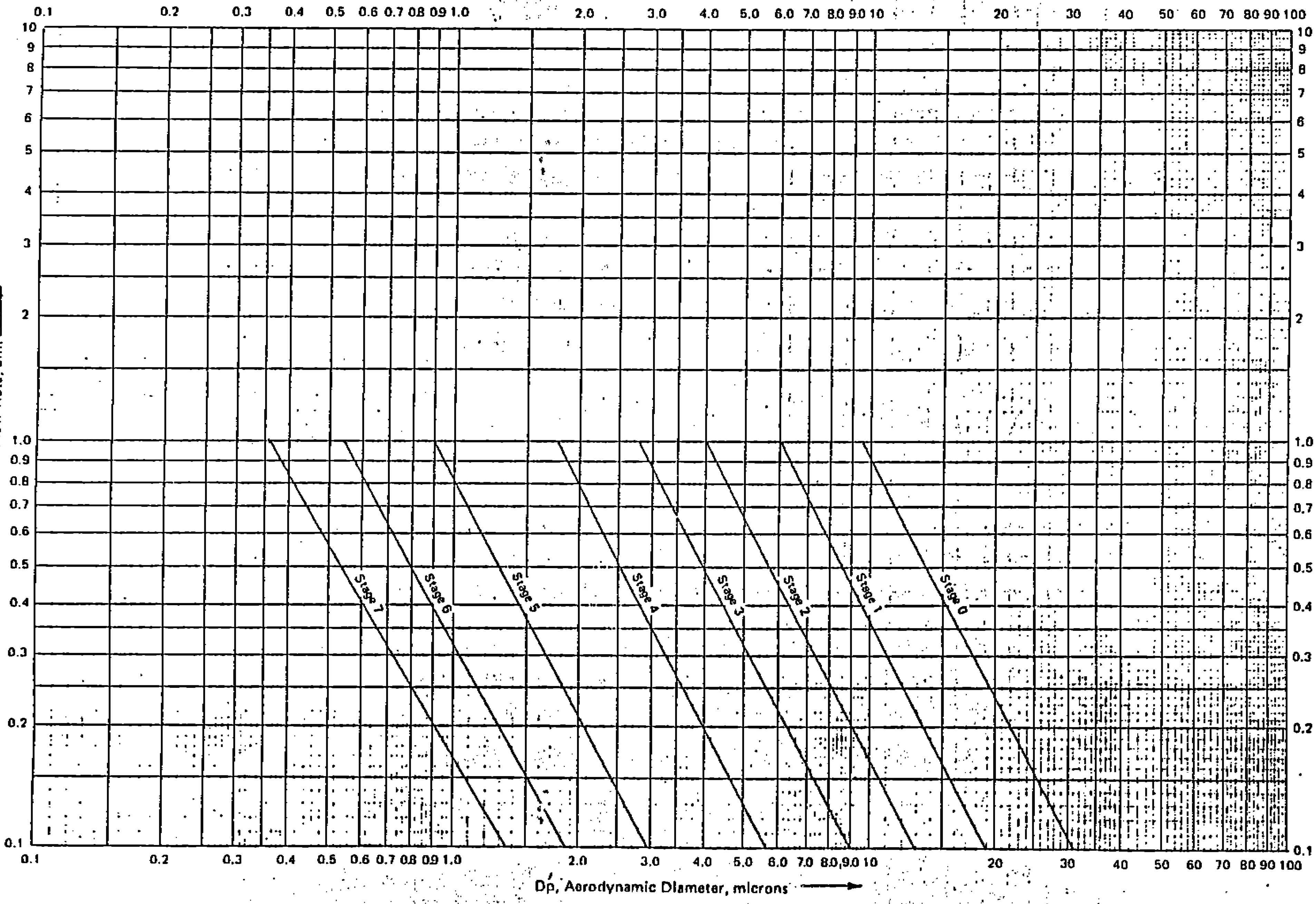
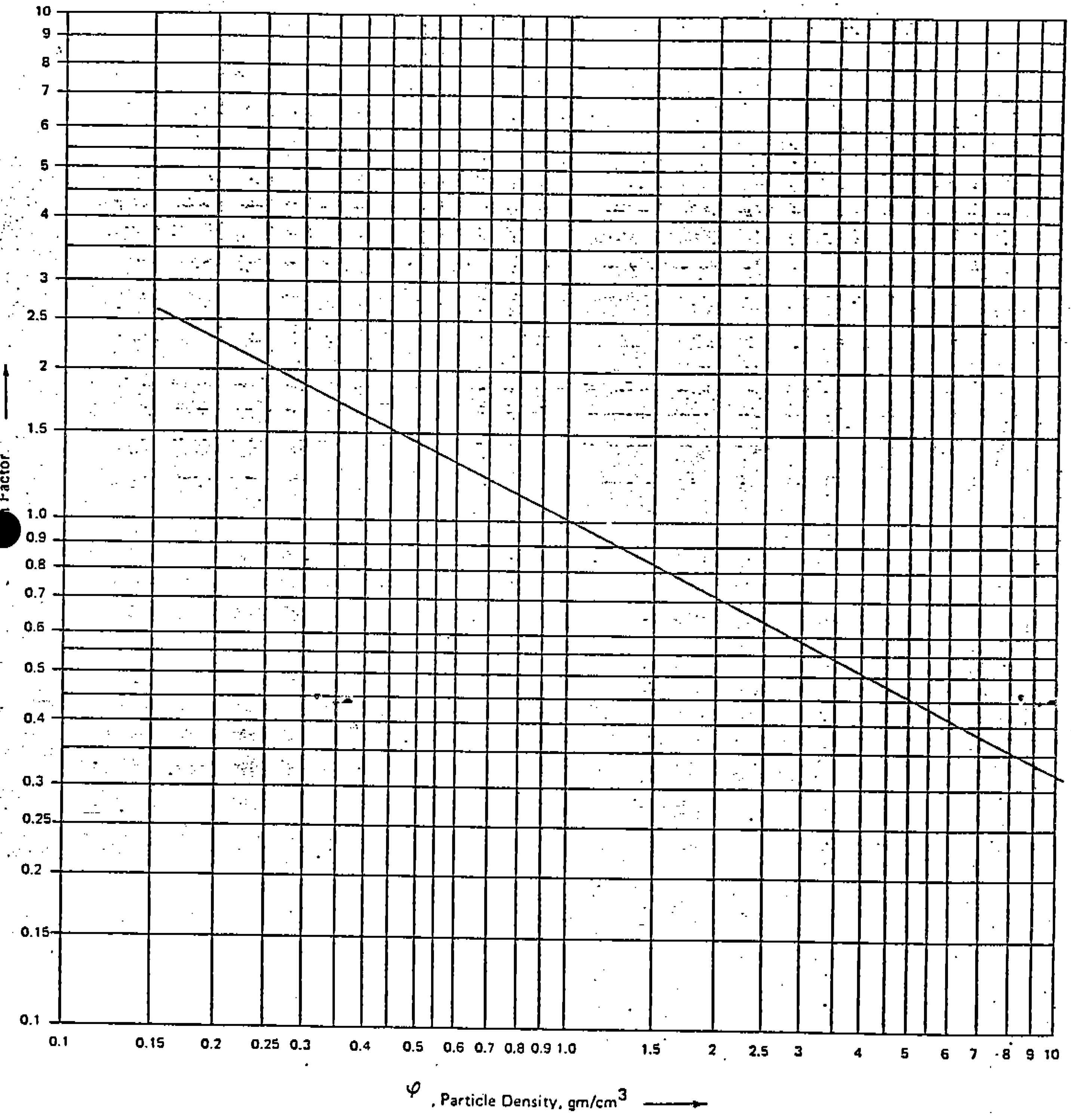
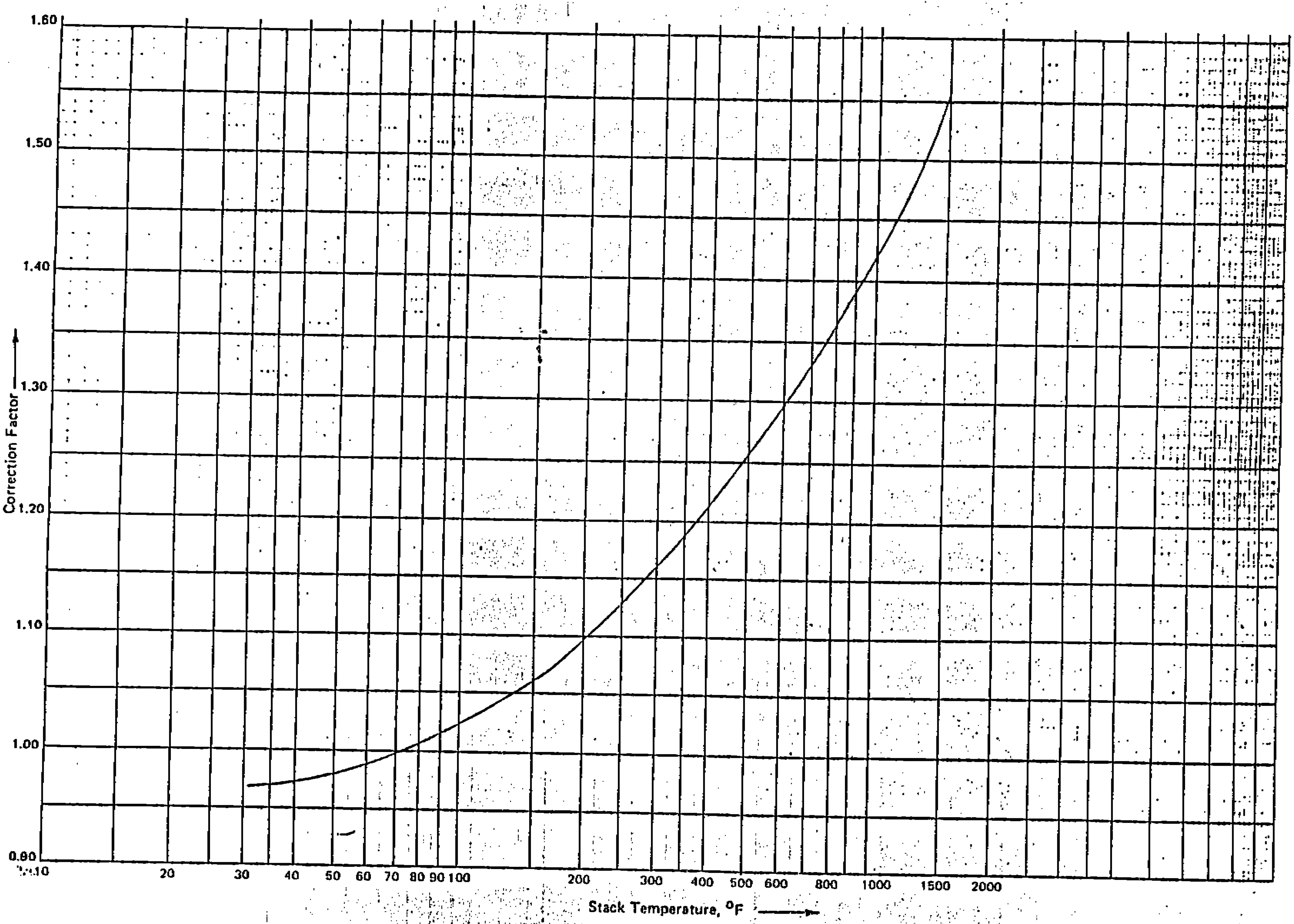


Figure 2. Density Correction Factor for Physical Size of Particles Captured in Andersen Stack Sampler



e 3. [illegible]eratu[illegible] actor for Aerodynamic
Size of Particles Captured [illegible] ersen Stack Sampler



when using Figure 2 because it is valid only if the assumption is made that the particles are spherical in shape. Normally this assumption is not valid. Multiply the effective aerodynamic diameter as determined from Figure 1 by the correction factor from Figure 2 to determine the physical diameter for that density.

Figure 3 shows the correction factor for determining the effective aerodynamic particle diameter for elevated temperatures. Multiply the effective aerodynamic diameter as determined from Figure 1 by the correction factor from Figure 3 to determine the diameter for that temperature.

3.3 END-TO-END CALIBRATION

Before actual sampling is begun, it is strongly recommended that an end-to-end calibration be performed at ambient conditions with a dry gas meter which has already been calibrated against a primary standard. As is, the flowmeter provides 95% accuracy for full scale reading; however, this accuracy will decrease at lower flow rates. For this reason, an end-to-end calibration at 3 or 4 points with a dry gas meter will provide extremely accurate flow information at any desired flow rate and can be accomplished in 10 - 15 minutes. Simply plot Flow Rate (as determined with the dry gas meter and stop watch) vs. flowmeter reading. Draw a line through the points and in this manner accurate, instantaneous flow measurements at any rate can be accomplished with only the flowmeter during actual stack sampling. The above calibration to be performed as quickly as possible to avoid any collection in stack head.

4.0 STACK SAMPLING PROCEDURE

Stack Sampling is simple in principle, but in practice it is complicated by the need to ensure that the collected particulates are representative of the particulates flowing at any one sampling point and also at all possible points in the cross section of the flue at the sampling position. The first requirement is satisfied by isokinetic sampling in which the inlet sampling nozzle velocity is equal and in the same direction as the flue gas velocity. The weight of particulates collected is then equal to the weight of particulates flowing through an area in the flue equal to the area of the sampling nozzle. If sampling is not isokinetic, the gas flow lines are disturbed by the presence of the nozzle and either too few or too many particles are collected.

The second requirement, ensuring that the sample is representative of the average particle flow past the sampling position, presents no problem when the distribution of solids flow is uniform over the area of the flue. Samples taken at all points will be identical and any chosen point will give a representative sample. The weight of solids E passing through the flue per unit time is then found by multiplying the weight w/t collected per unit time at the sampling point (w being the weight collected during the time t) by the ratio of the area A of the flue to the area a of the nozzle:

$$E = \frac{w}{t} \cdot \frac{A}{a}$$

However, the particulates are not usually distributed uniformly over the cross-sectional area of the flue and it is necessary to collect the sample in increments taken separately at each point and the average weight calculated from the separate observations, which is called incremental sampling. Or a single gross sample may be collected by moving the sampling nozzle from point to point which is called cumulative sampling. The incremental method is recommended for the beginner because it is easier to spot mistakes. Also, it is preferred by research investigators and is recommended for those who require the best accuracy because it gives information on the reliability of the average. The cumulative method may be slightly quicker and may be preferred by those doing routine testing not requiring the highest degree of accuracy. Incremental sampling is recommended when using the Andersen Stack Sampler. The cumulative method may be used on occasion and will be discussed later.

The accuracy of the measurements is dependent upon the proper choice of sampling points. The area of the flue is divided into a number of imaginary equal areas and the sample is made up of increments taken from the center point of each area. The greater the number of areas (greater number of sampling points) the more accurate the measurement will be.

In a circular duct, a traverse is made by dividing the duct into equal concentric areas and sampling in the center of each area on four sides of center. No sample is taken in the exact center. The number of equal areas chosen depends on the size of the duct and the accuracy desired. In a rectangular duct, a sample traverse is made by dividing the duct into equal areas and sampling at the center of each area. The number of areas used depends on the flow pattern and size of the duct. See Figure 4 for drawings and tables.

The Andersen Stack Head should be kept clean and assembled when not in use. Before using, examine the jet plates by holding them up to the light. If any hole is plugged, blow out with air or wash with a detergent-water solution and sponge. Rubbing back and forth across the holes usually suffices. The quickest and most economical way for cleaning the jet plates is to place the plates in an inexpensive ultrasonic cleaner with a solvent for a few seconds after each use to insure that the orifices are clean.

Under normal conditions, the orifices do not become plugged if proper sampling and handling techniques are followed. After the plates are cleaned, avoid touching the orifices to prevent oil and/or dirt from plugging the jet holes. If this precaution is taken, there are only two other causes of hole pluggage: (1) collecting too much sample and (2) collecting a sample when the stack head temperature is below the dew point of the flue gases so that condensation occurs. These problems are easily eliminated by taking a sample of proper size and ensuring that the stack head temperature is maintained above the dew point during the sampling period.

With the jet plates in proper sequence, the sampler is ready to operate on the end of the probe tube. The appropriate nozzle is attached to the inlet end of the sampler to achieve the desire isokinetic sampling rate. The zero numbered plate is on the upstream end of the stack head followed by plates 1 through 8 respectively. Downstream from Stage 8 a backup filter and filter holder may be inserted if there is sub-micron material in the stack sample below the lower limit of the last collection stage. Glass fiber webs are recommended as backup filters if elevated stack gas temperatures are encountered.

The sampling head will operate efficiently in any position such as vertical or horizontal. Ideally, the collection head should be used with a straight inlet nozzle and an elbow on the downstream end connecting to the probe tube. This arrangement will work with any thin-walled stack (such as metal) and eliminates the possibility of particles being impinged in any bends or probe lines. If it is necessary to sample a thick-walled stack (such as brick) it will be impossible to insert the right angled elbow through a three inch sampling hole. In this case, the stack head will have to be connected in line with the probe tube and a standard gooseneck nozzle used.

After determining the average velocity pressure along the sampling line, the stack gas temperature is measured and the gas density is calculated. If the stack gases contain an appreciable amount of water vapor, a significant error will result if not taken into consideration. With this data, the flue gas velocity is determined which also is the required inlet nozzle velocity. Choose the appropriate nozzle size to give the approximate velocity required for the flow range that is available. Then calculate the needed flow rate through the stack head at stack conditions (temperature and pressure) to give the correct nozzle velocity. Q = AV

Where: Q = actual flow rate in cubic feet per minute.
A = Area of the nozzle in square feet.
V = Velocity in feet per minute.

Next, determine what flow rate is needed through the flowmeter at flowmeter conditions to give the required flow rate through the stack head at stack conditions.

EXAMPLE: Cross Section Traverse

VP	$\sqrt{VP}$
.20	.448
.18	.424
.17	.413
.23	.480
.25	.500
.24	.491
.28	.530
.17	.413
.25	.500
.26	.510
.26	.510
.26	.510
.26	.510
.24	.491
.24	.491
.22	.470
.21	.459
	8.150

Stack Temperature = 1115° F
Barometric Pressure = 26.0" Hg
Stack gases are dry.
Stack gas density at 32° F and 29.92" Hg = 0.0807 lbs/cu. ft.
VP = velocity pressure in inches of water
W = stack gas density in lbs/ft^3

$$\text{Average V P} = \left(\frac{8.150}{17}\right)^2 = 0.230$$

$$\text{Stack gas density} = 0.0807 \times \frac{26.0}{29.9} \times \frac{460 + 32}{460 + 1115} = 0.0310 \text{ lbs/cu. ft.}$$

$$\text{Stack gas velocity} = 18.27 \sqrt{\frac{VP}{W}} = 18.27 \sqrt{\frac{.230}{.0310}} = 49.8 \text{ feet per second}$$

$$= 49.8 \times 60 = 2988 \text{ feet per minute (fpm)}$$

Therefore, we need 2988 fpm inlet nozzle velocity.
1/4 inch nozzle area = 0.000341 ft^2

$$Q = AV = (0.000341)\ (2988) = 1.02 \text{ cfm}$$

We need 1.02 cfm through the stack head at 1115° F and 26.0 inches Hg. At the flowmeter the pressure is 26.0" Hg since it is downstream from the vacuum pump and exposed to the atmosphere. The flowmeter temperature is 85° F. Therefore, we need

$$Q \times \frac{460 + 85}{460 + 1115} = 0.353 \text{ cfm at the flowmeter to}$$

give the desired inlet nozzle velocity for isokinetic sampling.

If the velocity profile along the sample line is relatively flat (±15%) or if all of the particulates are 5 microns or less in size, then cumulative sampling may be performed without introducing significant errors (see Figure 5 for correcting to isokinetic rate). However, if the velocity profile is not uniform or if the particle size spectrum goes above 5 microns, then incremental sampling is recommended. This requires a clean set of plates at each point with a different flow rate to maintain isokinetic sampling. An alternate technique is to change nozzle diameters at the various sampling points while keeping the flow constant to adjust the inlet nozzle velocity. It is imperative that the flow rate does not change significantly while collecting a sample on a particular set of plates; otherwise, the particle size range collected on each plate will shift an unacceptably large amount with the changing flow rate.

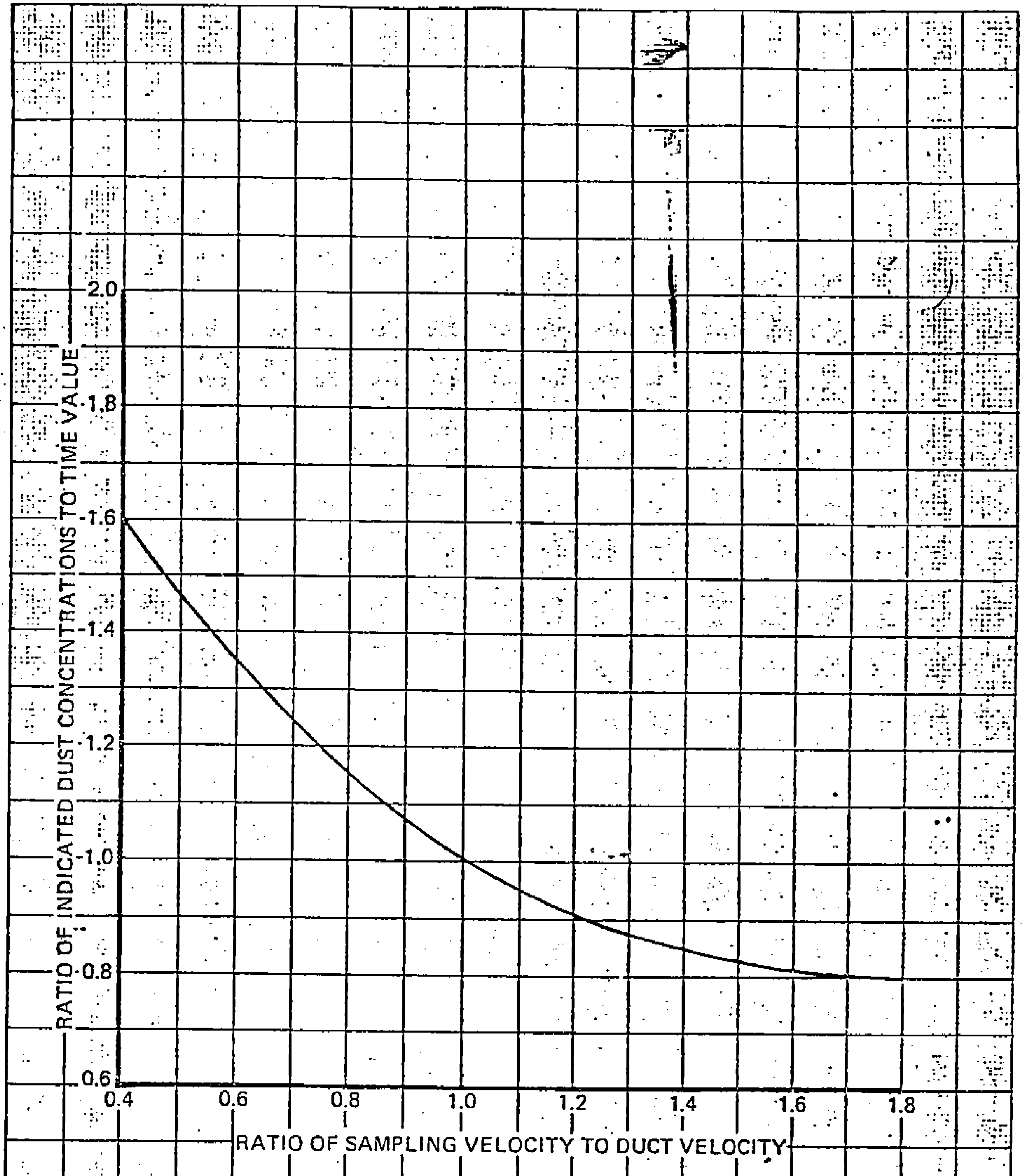
Whenever collecting a sample, always turn the inlet nozzle away from the oncoming gas stream until the vacuum source is applied. At the same instant the pump is turned on, the sample nozzle may be turned into the oncoming flue gases. Also turn the inlet nozzle away from the oncoming gases as the pump is turned off. If the pump is turned on or off with the inlet nozzle facing the oncoming particulates, an error in collected sizes on each stage will be introduced. Before sampling, however, the pump should be turned on with the stack head out of the flue and the flow rate adjusted to the desired valve as read on the flowmeter.

A unique feature of the Andersen Stack Sampler is that there is always a constant pressure drop across the entire system. Therefore, once the proper flow rate is adjusted, it will not change during the sampling period. This is particularly useful when sampling wet plumes. The Andersen Stack Sampler may be inserted directly into plumes saturated with water. The only point to keep in mind is that the stack head temperature must be maintained above the dew point to allow collection of dry samples on the plates with the vaporized water condensing out downstream in the condenser or impingers. An easy way to effect this is to wrap a constant temperature heat tape around the stack head and probe line. It will take 5 - 10 minutes for the stack head temperature to reach equilibrium. Of course, the gas temperature in the stack head must be monitored for flow rate determinations.

Good weighing accuracy is of primary concern during gravimetric analyses and is determined by the ratio of the quantity of sample collected to the sensitivity of the balance being used. A balance with four decimal place reading and sensitivity of 0.10 milligram is recommended. Normal samples vary from one to 10 milligrams per plate. Stage loadings in excess of 10 milligrams are not recommended because of re-entrainment problems.

Only with experience can an operator determine the optimum sampling time for a specific grain loading situation. The deposit areas should be discrete and there should be no material deposited between the sample piles which would indicate oversampling.

It is also suggested that tare weights be made on the plates after chemical and/or physical analyses and the plates have been cleaned. This eliminates the possibility of a change in tare weight taking place during the sampling period whenever sampling in hot and corrosive gases.



2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
RATIO OF INDICATED DUST CONCENTRATIONS TO TIME VALUE
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
RATIO OF SAMPLING VELOCITY TO DUCT VELOCITY

FIGURE 5

Some types of material become charged when passing through the orifices on the lower stages resulting in part of the sample adhering to the bottom side of the plates. This problem is easily remedied simply by grounding the probe line.

Whenever sampling for gases and/or condensible particulates, it is necessary to rinse the sampling train after the sampling is complete. Distilled water may be used as a wash for inorganic material. Organic constituents may be rinsed with acetone or another suitable organic solvent. The rinsing material should be poured into a beaker and retained for analysis.

When sampling for particulates only, the first two impingers are filled with exactly 250 and 150 ml of deionized water respectively. The quantity of water vapor in the stack can be determined by subtracting these initial volumes from the final volume. When sampling for a specific gas, the first impinger is left dry and the second is filled with 150 ml of the appropriate reagent. A precise volume is critical since condensation may occur in this impinger.

The third and fourth impingers trap any moisture leaving the first two impingers. The silica gel must be precisely weighed, as the difference in its weight after sampling will have to be taken into account.

To determine the weight of soluble and insoluble solids from the liquid impingers it is necessary to evaporate the liquid in a tarred beaker. Then re-weigh the beaker to find total solids. If volatile organic particulate matter is collected, an extraction in some organic reagent such as chloroform or carbon tetrachloride is required. This reagent is then evaporated with a stream of dry air in a preweighed beaker and the difference in beaker weight before and after evaporation is the organic's weight.

The total weight of particulate matter collected is the sum of the aqueous and solvent residues.

5.0 DATA PRESENTATION

To determine the concentration of particulates for any specific size or size range first calculate the percentage of total particles for each stage. Then the cumulative percentage is determined beginning with either end of the impactor. Thus, if one starts with the first stage, 100% of the particles will be above 0 microns, some lesser percentage above the last stage, a lesser percentage yet above the next to last stage and so on.

Plot the cumulative percentage determined above against the corrected aerodynamic diameter of the particles corresponding to the same stage. Draw a smooth curve connecting the points. The curve will be hyperbolic in shape if standard arithmetic graph paper is used or a straight line will result if probability logrithmic graph paper is used. It is not uncommon for the curves to contain bulges whenever abnormal distributions occur. From the graph the particle concentration for any size range can be determined. Following in Table No. 1 and Figure 6 data from an actual sample is shown. Approximately 55% of the particles are below 0.59 microns. 100% of the particles are below 15.0 microns.

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1. Personal communication, Dr. Andrew McFarland, University of Notre Dame, South Bend, Indiana - 1971.

Figure 6

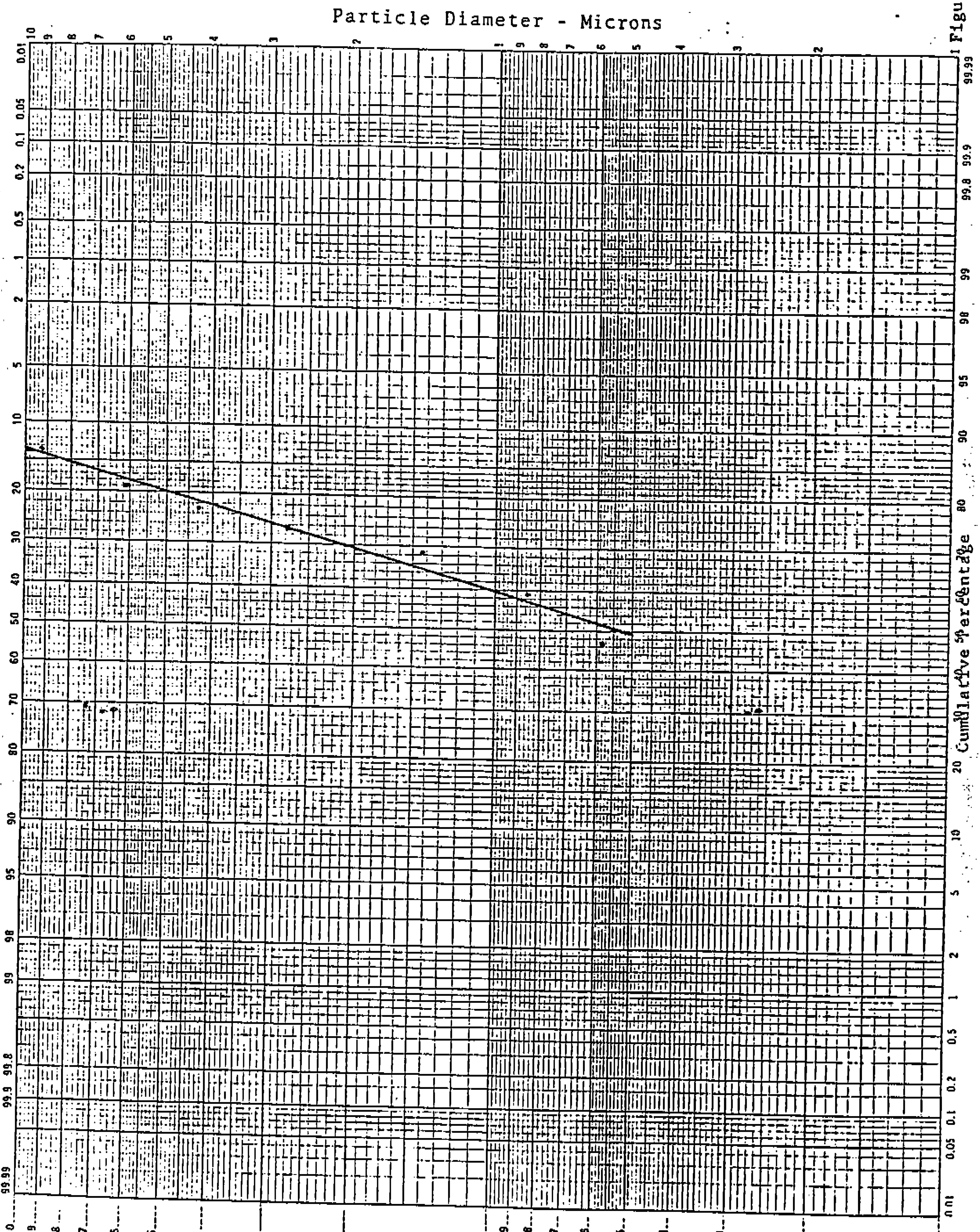
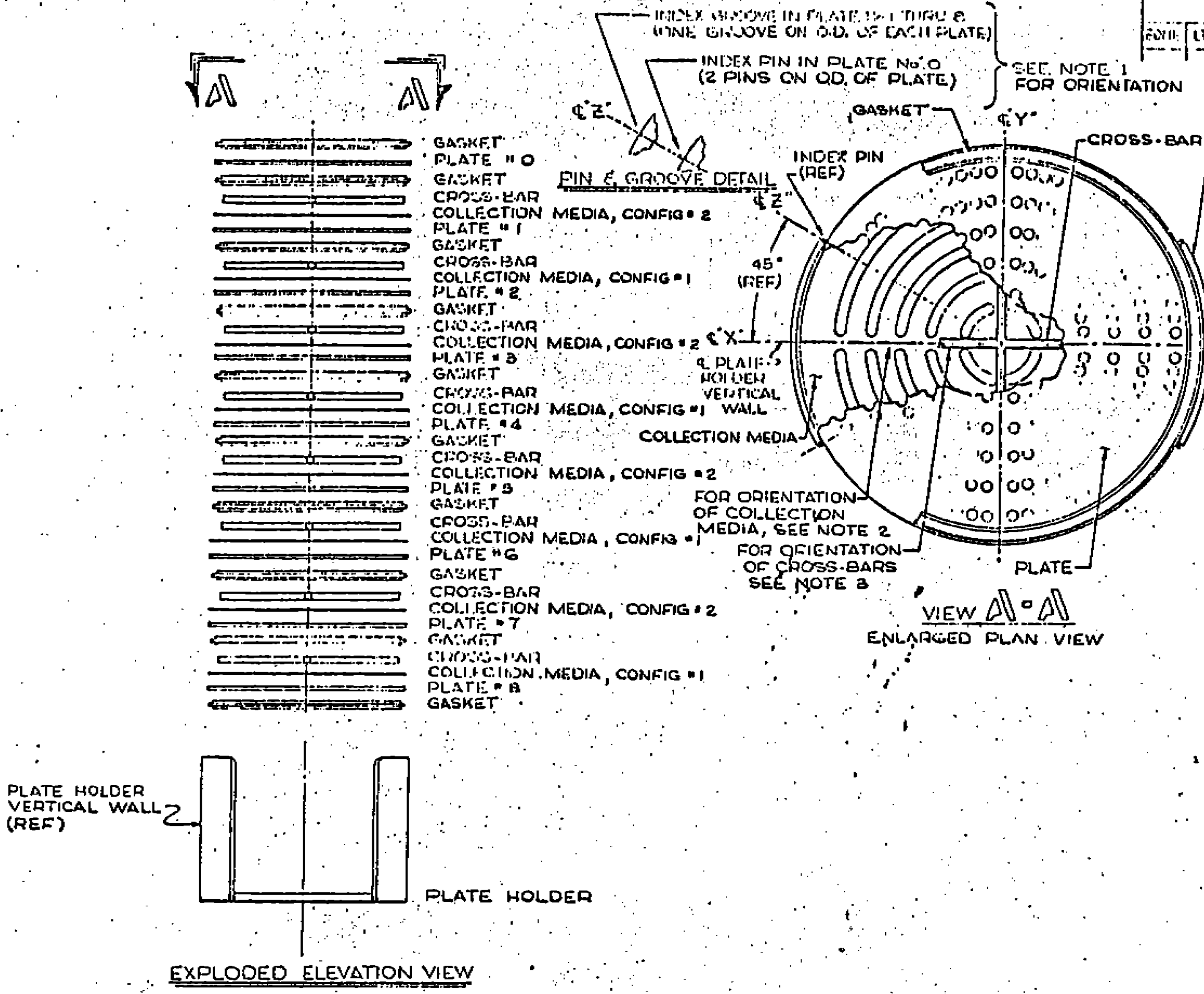

Particle Diameter - Microns
Cumulative Percentage
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99
KEUFFEL & ESSER CO.
2 LOG CYCLES

TABLE 1

Plate	Tare (g)	Final (g)	Net (mg)	%	Cum. %	ECD (Microns)
1	20.48484	20.48628	1.34	13.4	100.0	15.0
2	21.38338	21.38394	.56	5.6	86.7	9.5
3	21.92025	21.92066	.41	4.1	81.1	6.3
4	21.55775	21.55817	.42	4.2	77.0	4.4
5	11.40815	11.40854	.39	3.9	72.8	2.86
6	11.61862	11.61961	.99	9.9	68.9	1.43
7	11.76540	11.76664	1.24	12.4	59.0	.87
8	20.99617	20.99737	1.20	12.0	46.6	.59
Back Up Filter	0.20810	0.21156	3.46	34.6	34.6	
		Total	10.01			

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROV



NOTES:

ORIENTION OF ALL PLATES No. "0" THRU "8", CROSS-BARS AND COLLECTION MEDIAE MUST BE AS SHOWN IN VIEW A-A & AS NOTED BELOW

(1) INDEX PIN IN PLATE No. 0, AND INDEX GROOVE IN PLAT No. 1 THRU 8 MUST ALL B ORIENTED ON SAME ℄, ℄"Z

(2) COLLECTION MEDIA MUST B ORIENTED WITH RADIAL SPOKES CENTERED ON ℄"X" AND ℄"Y". TYPICAL FOR ALL COLLECTION MEDIAE.

3 CROSS-BARS MUST BE ORIENTED WITH BARS CENTERED ON ℄"X" AND ℄"Y TYPICAL FOR ALL CROSS-BARS.

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STACK SAMPLER	
NEXT ASSY	USED
APPL	

TOLERANCES
Unless Otherwise Specified
Dimensions in Inches
Fractional ±
2 Place Decimal ±
3 Place Decimal ±
4 Place Decimal ±
Angular ±
MATERIAL: STAINLESS

CONTRACT NO.
DRAWN
CHECKED
ENGR.
PROJ. C. ERICKSON 7-15-83
APPROVED, DESIGN ACTIVITY
APPROVED

2000 INC.

Salt Lake City, Utah

STACK SAMPLER – MK-III PLATES
INSTRUCTION DRAWINGS

SIZE	CODE IDENT. NO.	DWG NO	REV
C	51125	38	

SCALE

METHOD 9—VISUAL DETERMINATION OF THE OPACITY OF EMISSIONS FROM STATIONARY SOURCES

Many stationary sources discharge visible emissions into the atmosphere; these emissions are usually in the shape of a plume. This method involves the determination of plume opacity by qualified observers. The method includes procedures for the training and certification of observers, and procedures to be used in the field for determination of plume opacity. The appearance of a plume as viewed by an observer depends upon a number of variables, some of which may be controllable and some of which may not be controllable in the field. Variables which can be controlled to an extent to which they no longer exert a significant influence upon plume appearance include: Angle of the observer with respect to the plume; angle of the observer with respect to the sun; point of observation of attached and detached steam plume; and angle of the observer with respect to a plume emitted from a rectangular stack with a large length to width ratio. The method includes specific criteria applicable to these variables.

Other variables which may not be controllable in the field are luminescence and color contrast between the plume and the background against which the plume is viewed. These variables exert an influence upon the appearance of a plume as viewed by an observer, and can affect the ability of the observer to accurately assign opacity values to the observed plume. Studies of the theory of plume opacity and field studies have demonstrated that a plume is most visible and presents the greatest apparent opacity when viewed against a contrasting background. It follows from this, and is confirmed by field trials, that the opacity of a plume, viewed under conditions where a contrasting background is present can be assigned with the greatest degree of accuracy. However, the potential for a positive error is also the greatest when a plume is viewed under such contrasting conditions. Under conditions presenting a less contrasting background, the apparent opacity of a plume is less and approaches zero as the color and luminescence contrast decrease toward zero. As a result, significant negative bias and negative errors can be made when a plume is viewed under less contrasting conditions. A negative bias decreases rather than increases the possibility that a plant operator will be cited for a violation of opacity standards due to observer error.

Studies have been undertaken to determine the magnitude of positive errors which can be made by qualified observers while reading plumes under contrasting conditions and using the procedures set forth in this method. The results of these studies (field trials) which involve a total of 769 sets of 25 readings each are as follows:

(1) For black plumes (133 sets at a smoke generator), 100 percent of the sets were read with a positive error[1] of less than 7.5 percent opacity; 99 percent were read with a positive error of less than 5 percent opacity.

(2) For white plumes (170 sets at a smoke generator, 168 sets at a coal-fired power plant, 298 sets at a sulfuric acid plant), 99 percent of the sets were read with a positive error of less than 7.5 percent opacity; 95 percent were read with a positive error of less than 5 percent opacity.

The positive observational error associated with an average of twenty-five readings is therefore established. The accuracy of the method must be taken into account when determining possible violations of applicable opacity standards.

1. *Principle and applicability.*

1.1 Principle. The opacity of emissions from stationary sources is determined visually by a qualified observer.

1.2 Applicability. This method is applicable for the determination of the opacity of emissions from stationary sources pursuant to § 60.11(b) and for qualifying observers for visually determining opacity of emissions.

2. *Procedures.* The observer qualified in accordance with paragraph 3 of this method shall use the following procedures for visually determining the opacity of emissions:

2.1 Position. The qualified observer shall stand at a distance sufficient to provide a clear view of the emissions with the sun oriented in the 140° sector to his back. Consistent with maintaining the above requirement, the observer shall, as much as possible, make his observations from a position such that his line of vision is approximately perpendicular to the plume direction, and when observing opacity of emissions from rectangular outlets (e.g. roof monitors, open baghouses, noncircular stacks), approximately perpendicular to the longer axis of the outlet. The observer's line of sight should not include more than one plume at a time when multiple stacks are involved, and in any case the observer should make his observations with his line of sight perpendicular to the longer axis of such a set of multiple stacks (e.g. stub stacks on baghouses).

2.2 Field records. The observer shall record the name of the plant, emission location, type facility, observer's name and affiliation, and the date on a field data sheet (Figure 9–1). The time, estimated distance to the emission location, approximate wind direction, estimated wind speed, description of the sky condition (presence and color of clouds), and plume background are recorded on a field data sheet at the time opacity readings are initiated and completed.

2.3 Observations. Opacity observations shall be made at the point of greatest opacity in that portion of the plume where condensed water vapor is not present. The observer shall not look continuously at the plume, but instead shall observe the plume momentarily at 15-second intervals.

2.3.1 Attached steam plumes. When condensed water vapor is present within the plume as it emerges from the emission outlet, opacity observations shall be made beyond the point in the plume at which condensed water vapor is no longer visible. The observer shall record the approximate distance from the emission outlet to the point in the plume at which the observations are made.

2.3.2 Detached steam plume. When water vapor in the plume condenses and becomes visible at a distinct distance from the emission outlet, the opacity of emissions should be evaluated at the emission outlet prior to the condensation of water vapor and the formation of the steam plume.

2.4 Recording observations. Opacity observations shall be recorded to the nearest 5 percent at 15-second intervals on an observational record sheet. (See Figure 9–2 for an example.) A minimum of 24 observations shall be recorded. Each momentary observation recorded shall be deemed to represent the average opacity of emissions for a 15-second period.

2.5 Data Reduction. Opacity shall be determined as an average of 24 consecutive observations recorded at 15-second intervals. Divide the observations recorded on the record sheet into sets of 24 consecutive observations. A set is composed of any 24 consecutive observations. Sets need not be consecutive in time and in no case shall two sets overlap. For each set of 24 observations, calculate the average by summing the opacity of the 24 observations and dividing this sum by 24. If an applicable standard specifies an averaging time requiring more than 24 observations, calculate the average for all observations made during the specified time period. Record the average opacity on a record sheet. (See Figure 9–1 for an example.)

3. *Qualifications and testing.*

3.1 Certification requirements. To receive certification as a qualified observer, a candidate must be tested and demonstrate the ability to assign opacity readings in 5 percent increments to 25 different black plumes and 25 different white plumes, with an error not to exceed 15 percent opacity on any one reading and an average error not to exceed 7.5 percent opacity in each category. Candidates shall be tested according to the procedures described in paragraph 3.2. Smoke generators used pursuant to paragraph 3.2 shall be equipped with a smoke meter which meets the requirements of paragraph 3.3.

The certification shall be valid for a period of 6 months, at which time the qualification procedure must be repeated by any observer in order to retain certification.

3.2 Certification procedure. The certification test consists of showing the candidate a complete run of 50 plumes—25 black plumes and 25 white plumes—generated by a smoke generator. Plumes within each set of 25 black and 25 white runs shall be presented in random order. The candidate assigns an opacity value to each plume and records his observation on a suitable form. At the completion of each run of 50 readings, the score of the candidate is determined. If a candidate fails to qualify, the complete run of 50 readings must be repeated in any retest. The smoke test may be administered as part of a smoke school or training program, and may be preceded by training or familiarization runs of the smoke generator during which candidates are shown black and white plumes of known opacity.

3.3 Smoke generator specifications. Any smoke generator used for the purposes of paragraph 3.2 shall be equipped with a smoke meter installed to measure opacity across the diameter of the smoke generator stack. The smoke meter output shall display in-stack opacity based upon a pathlength equal to the stack exit diameter, on a full 0 to 100 percent chart recorder scale. The smoke meter optical design and performance shall meet the specifications shown in Table 9–1. The smoke meter shall be calibrated as prescribed in paragraph 3.3.1 prior to the conduct of each smoke reading test. At the completion of each test, the zero and span drift shall be checked and if the drift exceeds ±1 percent opacity, the condition shall be corrected prior to conducting any subsequent test runs. The smoke meter shall be demonstrated, at the time of installation, to meet the specifications listed in Table 9–1. This demonstration shall be repeated following any subsequent repair or replacement of the photocell or associated electronic circuitry including the chart recorder or output meter, or every 6 months, whichever occurs first.

3.3.1 Calibration. The smoke meter is calibrated after allowing a minimum of 30 minutes warmup by alternately producing simulated opacity of 0 percent and 100 percent. When stable response at 0 percent or 100 percent is noted, the smoke meter is adjusted to produce an output of 0 percent or 100 percent, as appropriate. This calibration shall be repeated until stable 0 percent and 100 percent readings are produced without adjustment. Simulated 0 percent and 100 percent opacity values may be produced by alternately switching the power to the light source on and off while the smoke generator is not producing smoke.

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[1] For a set, positive error=average opacity determined by observers' 25 observations—average opacity determined from transmissometer's 25 recordings.

Method 22—Visual Determination of Fugitive Emissions From Material Processing Sources

1. *Introduction.*

This method involves the visual determination of fugitive emissions, i.e., emissions not emitted directly from a process stack or duct. Fugitive emissions include emissions that (1) escape capture by process equipment exhaust hoods; (2) are emitted during material transfer; (3) are emitted from buildings housing material processing or handling equipment; and (4) are emitted directly from process equipment.

This method determines the amount of time that any visible emissions occur during the observation period, i.e., the accumulated emission time. This method does not require that the opacity of emissions be determined. Since this procedure requires only the determination of whether a visible emission occurs and does not require the determination of opacity levels, observer certification according to the procedures of Reference Test Method 9 are not required. However, it is necessary that the observer is educated on the general procedures for determining the presence of visible emissions. As a minimum, the observer must be trained and knowledgeable regarding the effects on the visibility of emissions caused by background contrast, ambient lighting, observer position relative to lighting, wind, and the presence of uncombined water (condensing water vapor). This training is to be obtained from written materials found in References 7.1 and 7.2 or from the lecture portion of the Method 9 certification course.

2. *Applicability and Principle.*

2.1 *Applicability.* This method applies to the determination of the frequency of fugitive emissions from stationary sources (located indoors or outdoors) when specified as the test method for determining compliance with new source performance standards.

2.2 *Principle.* Fugitive emissions produced during material processing, handling, and transfer operations are visibly determined by an observer without the aid of instruments.

3. *Definitions.*

3.1 *Emission Frequency.* Percentage of time that emissions are visible during the observation period.

3.2 *Emission Time.* Accumulated amount of time that emissions are visible during the observation period.

3.3 *Fugitive Emissions.* Pollutant generated by an affected facility which is not collected by a capture system and is released to the atmosphere.

3.4 *Observation Period.* Accumulated time period during which observations are conducted, not to be less than 6 minutes.

4. *Equipment.*

4.1 *Stopwatches.* Accumulative type with unit divisions of at least 0.5 seconds; two required.

4.2 *Light Meter.* Light meter capable of measuring illuminance in the 50- to 200-lux range; required for indoor observations only.

5. *Procedure.*

5.1 *Position.* Survey the affected facility or building or structure housing the process to be observed and determine the locations of potential emissions. If the affected facility is located inside a building, determine an observation location that is consistent with the requirements of the applicable regulation (i.e., outside observation of emissions escaping the building/structure or inside observation of emissions directly emitted from the affected facility process unit). Then select a position that enables a clear view of the potential emission point(s) of the affected

Designation: D 2216 – 80

An American National Standard

Standard Method for
LABORATORY DETERMINATION OF WATER (MOISTURE) CONTENT OF SOIL, ROCK, AND SOIL-AGGREGATE MIXTURES[1]

This standard is issued under the fixed designation D 2216; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This method covers the laboratory determination of the water (moisture) content of soil, rock, and soil-aggregate mixtures by weight. For simplicity, the word "material" hereinafter refers to either soil, rock, or soil-aggregate mixtures, whichever is most applicable.

1.2 The water content of a material is defined as the ratio, expressed as a percentage, of the mass of "pore" or "free" water in a given mass of material to the mass of the solid material particles.

1.3 This method does not give true representative results for: materials containing significant amounts of halloysite, montmorillonite or gypsum minerals; highly organic soils; or materials in which the pore water contains dissolved solids (such as salt in the case of marine deposits). For a material of the previously mentioned types, a modified method of testing or data calculation may be established to give results consistent with the purpose of the test.

2. Summary of Method

2.1 The practical application in determining the water content of a material is to determine the mass of water removed by drying the moist material (test specimen) to a constant mass in a drying oven controlled at 110 ± 5°C and to use this value as the mass of water in the test specimen. The mass of material remaining after oven-drying is used as the mass of the solid particles.

3. Significance and Use

3.1 For many soil types, the water content is one of the most significant index properties used in establishing a correlation between soil behavior and an index property.

3.2 The water content of a soil is used in almost every equation expressing the phase relationships of air, water, and solids in a given volume of material.

3.3 In fine-grained (cohesive) soils, the consistency of a given soil type depends on its water content. The water content of a soil, along with its liquid and plastic limit, is used to express its relative consistency or liquidity index.

3.4 The term "water" as used in geotechnical engineering, is typically assumed to be "pore" or "free" water and not that which is hydrated to the mineral surfaces. Therefore, the water content of materials containing significant amounts of hydrated water at in-situ temperatures or less than 110°C can be misleading.

3.5 The term "solid particles" as used in geotechnical engineering, is typically assumed to mean naturally occurring mineral particles that are not readily soluble in water. Therefore, the water content of materials containing extraneous matter (such as cement, etc), water-soluble matter (such as salt) and highly organic matter typically require special treatment or a qualified definition of water content.

4. Apparatus

4.1 *Drying Oven*, thermostatically-controlled, preferably of the forced-draft type, and maintaining a uniform temperature of 110 ± 5°C throughout the drying chamber.

4.2 *Balances*, having a precision (repeatability) of ±0.01 g for specimens having a mass of 200 g or less, ±0.1 g for specimens having a mass of between 200 and 1000 g, or ± 1 g for specimens having a mass greater than 1000 g.

4.3 *Specimen Containers*—Suitable containers made of material resistant to corrosion and a change in mass upon repeated heating, cooling, and cleaning. Containers with close-fitting lids shall be used for testing specimens having a mass of less than about 200 g; while for specimens having a mass greater than about 200 g, containers without lids may be used (Note 1). One container is needed for each water content determination.

NOTE 1—The purpose of close-fitting lids is to prevent loss of moisture from specimens before initial weighing and to prevent absorption of moisture from the atmosphere following drying and before final weighing.

4.4 *Desiccator*—A desiccator of suitable size (a convenient size is 200 to 250-mm diameter) containing a hydrous silica gel. This equipment is only recommended for use when containers having close-fitting lids are not used. See 7.4.1.

5. Samples

5.1 Keep the samples that are stored prior to testing in noncorrodible airtight containers at a temperature between approximately 3 and 30°C and in an area that prevents direct contact with sunlight.

5.2 The water content determination should be done as soon as practicable after sampling, especially if potentially corrodible containers (such as steel thin-walled tubes, paint cans, etc.) or sample bags are used.

6. Test Specimen

6.1 For water contents being determined in conjunction with another ASTM method, the method of specimen selection specified in that method controls.

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[1] This method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity and Density Characteristics of Soils.

Current edition approved May 30, 1980. Published July 1980. Originally published as D 2216 – 63 T. Last previous edition D 2216 – 71.

An American National Standard

TION OF WATER (MOISTURE)
, AND SOIL-AGGREGATE

number immediately following the designation indicates the st revision. A number in parentheses indicates the year of last ge since the last revision or reapproval.

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3.1 For many soil types, the water content is one of the most significant index properties used in establishing a correlation between soil behavior and an index property.

3.2 The water content of a soil is used in almost every equation expressing the phase relationships of air, water, and solids in a given volume of material.

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4.1 *Drying Oven*, thermostatically-controlled, preferably of the forced-draft type, and maintaining a uniform temperature of 110 ± 5°C throughout the drying chamber.

4.2 *Balances*, having a precision (repeatability) of ±0.01 g for specimens having a mass of 200 g or less, ±0.1 g for specimens having a mass of between 200 and 1000 g, or ± 1 g for specimens having a mass greater than 1000 g.

4.3 *Specimen Containers*—Suitable containers made of material resistant to corrosion and a change in mass upon repeated heating, cooling, and cleaning. Containers with close-fitting lids shall be used for testing specimens having a mass of less than about 200 g; while for specimens having a mass greater than about 200 g, containers without lids may be used (Note 1). One container is needed for each water content determination.

Note 1—The purpose of close-fitting lids is to prevent loss of moisture from specimens before initial weighing and to prevent absorption of moisture from the atmosphere following drying and before final weighing.

4.4 *Desiccator*—A desiccator of suitable size (a convenient size is 200 to 250-mm diameter) containing a hydrous silica gel. This equipment is only recommended for use when containers having close-fitting lids are not used. See 7.4.1.

5. Samples

5.1 Keep the samples that are stored prior to testing in noncorrodible airtight containers at a temperature between approximately 3 and 30°C and in an area that prevents direct contact with sunlight.

5.2 The water content determination should be done as soon as practicable after sampling, especially if potentially corrodible containers (such as steel thin-walled tubes, paint cans, etc.) or sample bags are used.

6. Test Specimen

6.1 For water contents being determined in conjunction with another ASTM method, the method of specimen selection specified in that method controls.

6.2 The manner in which the test specimen is selected and its required mass is basically dependent on the purpose (application) of the test, type of material being tested, and the type of sample (specimen from another test, bag, tube, split-barrel, etc.). In all cases, however, a representative portion of the total sample shall be selected. If a layered soil or more than one soil type is encountered, select an average portion or individual portions or both, and note which portion(s) was tested in the report of the results.

6.2.1 For bulk samples, select the test specimen from the material after it has been thoroughly mixed. The mass of moist material selected shall be in accordance with the following table:

Sieve Retaining More Than About 10 % of Sample	Recommended Minimum Mass of Moist Specimen, g
2.0 mm (No. 10) sieve	100 to 200
4.75 mm (No. 4) sieve	300 to 500
19 mm	500 to 1000
38 mm	1500 to 3000
76 mm	5000 to 10 000

6.2.2 For small (jar) samples, select a representative portion in accordance with the following procedure:

6.2.2.1 For cohesionless soils, thoroughly mix the material, then select a test specimen having a mass of moist material in accordance with the table in 6.2.1. See Note 2.

6.2.2.2 For cohesive soils, remove about 3 mm of material from the exposed periphery of the sample and slice it in half (to check if the material is layered) prior to selecting the test specimen. If the soil is layered see 6.2. The mass of moist material selected should not be less than 25 g or should be in accordance with the table in 6.2.1 if coarse-grained particles are noted. (Note 2).

6.3 Using a test specimen smaller than the minimum mass indicated previously requires discretion, though it may be adequate for the purpose of the test. A specimen having a mass less than the previously indicated value shall be noted in the report of the results.

Note 2—In many cases, when working with a small sample containing a relatively large coarse-grained particle, it is appropriate not to include this particle in the test specimen. If this occurs, it should be noted in the report of the results.

7. Procedure

7.1 Select representative test specimens in accordance with Section 6.

7.2 Place the moist specimen in a clean, dry container of known mass (Note 3), set the lid securely in position, and determine the mass of the container and moist material using an appropriate balance (4.2). Record these values.

7.3 Remove the lid and place the container with moist material in a drying oven maintained at 110 ± 5°C and dry to a constant mass (Notes 4, 5, and 6).

NOTE 3—To assist in the oven-drying of large test specimens, they should be placed in containers having a large surface area (such as pans) and the material broken up into smaller aggregations.

NOTE 4–The time required to obtain constant ss will vary depending on the type of material, of specimen, oven type and capacity, and other tors. The influence of these factors generally can established by good judgment, and experience th the materials being tested and the apparatus being used. In most cases, drying a test specimen over ight (about 16 h) is sufficient. In cases where there is doubt concerning the adequacy of drying, drying should be continued until the mass after two successive periods (greater than ½ h) of drying indicate an nsignificant change (less than about 0.1 %). Specimens of sand may often be dried to constant mass in a period of about 4 h, when a forced-draft oven is used.

NOTE 5—Oven-drying at 110 ± 5°C does not lways result in water content values related to the ntended use or the basic definition especially for materials containing gypsum or other minerals having significant amounts of hydrated water or for soil ontaining a significant amount of organic material. n many cases, and depending on the intended use r these types of materials, it might be more applicable to maintain the drying oven at 60 ± 5°C or use a vacuum desiccator at a vacuum of approximately 33 Pa (10 mm Hg) and at a temperature ranging etween 23 and 60°C for drying. If either of these rying methods are used, it should be noted in the report of the results.

NOTE 6—Since some dry materials may absorb oisture from moist specimens, dried specimens hould be removed before placing moist specimens the oven. However, this requirement is not applicable if the previously dried specimens will remain in the drying oven for an additional time period of bout 16 h.

7.4 After the material has dried to constant remove the container from the oven and lace the lid. Allow the material and coner to cool to room temperature or until the container can be handled comfortably with bare hands and the operation of the balance will not be affected by convection currents. Determine the mass of the container and oven-dried material using the same balance as used in 7.2. Record this value.

7.4.1 If the container does not have a lid weigh the container and material right after their temperatures are such that the operation of the balance will not be affected by convection currents or after cooling in a desiccator.

NOTE 7—Cooling in a desiccator is recommended since it prevents absorption of moisture from the atmosphere during cooling.

8. Calculation

8.1 Calculate the water content of the material as follows:

$$w = [(W_1 - W_2)/(W_2 - W_c)] \times 100 = \frac{W_w}{W_s} \times 100$$

where:

w = water content, %,

W_1 = mass of container and moist specimen, g,

W_2 = mass of container and oven-dried specimen, g,

W_c = mass of container, g,

W_w = mass of water, g, and

W_s = mass of solid particles, g.

9. Report

9.1 The report (data sheet) shall include the following:

9.1.1 Identification of the sample (material) being tested, by boring number, sample number, test number, etc.

9.1.2 Water content of the specimen to the nearest 0.1 % or 1 %, depending on the purpose of the test.

9.1.3 Indication of test specimen having a mass less than the minimum indicated in Section 6.

9.1.4 Indication of test specimen containing more than one soil type (layered, etc).

9.1.5 Indication of the method of drying if different from oven-drying at 110 ± 5°C.

9.1.6 Indication of any material (size and amount) excluded from the test specimen.

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10. Precision and Accuracy

10.1 Requirements for the precision and acbare hands and the operation of the balance will not be affected by convection currents. Determine the mass of the container and oven-dried material using the same balance as used in 7.2. Record this value.

7.4.1 If the container does not have a lid, weigh the container and material right after their temperatures are such that the operation of the balance will not be affected by convection currents or after cooling in a desiccator.

NOTE 7—Cooling in a desiccator is recommended since it prevents absorption of moisture from the atmosphere during cooling.

8. Calculation

8.1 Calculate the water content of the material as follows:

$$w = [(W_1 - W_2)/(W_2 - W_c)] \times 100 = \frac{W_w}{W_s} \times 100$$

where:

w = water content, %,
W_1 = mass of container and moist specimen, g,
W_2 = mass of container and oven-dried specimen, g,
W_c = mass of container, g,
W_w = mass of water, g, and
W_s = mass of solid particles, g.

9. Report

9.1 The report (data sheet) shall include the following:

9.1.1 Identification of the sample (material) being tested, by boring number, sample number, test number, etc.

9.1.2 Water content of the specimen to the nearest 0.1 % or 1 %, depending on the purpose of the test.

9.1.3 Indication of test specimen having a mass less than the minimum indicated in Section 6.

9.1.4 Indication of test specimen containing more than one soil type (layered, etc).

9.1.5 Indication of the method of drying if different from oven-drying at 110 ± 5°C.

9.1.6 Indication of any material (size and amount) excluded from the test specimen.

10. Precision and Accuracy

10.1 Requirements for the precision and accuracy of this test method have not yet been developed.

6. Test Sample for Soil Constants

6.1 Separate the remaining portion of the material passing the No. 10 (2.00-mm) sieve into two parts by means of a No. 40 (425-μm) sieve. Discard the fraction retained on the No. 40 sieve. Use the fraction passing the No. 40 sieve for the determination of the soil constants.

Designation: D 422 – 63 (Reapproved 1972)

An American National Standard

Standard Method for
PARTICLE-SIZE ANALYSIS OF SOILS[1]

This standard is issued under the fixed designation D 422; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This method covers the quantitative determination of the distribution of particle sizes in soils. The distribution of particle sizes larger than 75 μm (retained on the No. 200 sieve) is determined by sieving, while the distribution of particle sizes smaller than 75 μm is determined by a sedimentation process, using a hydrometer to secure the necessary data (Notes 1 and 2).

NOTE 1—Separation may be made on the No. 4 (4.75-mm), No. 40 (425-μm), or No. 200 (75-μm) sieve instead of the No. 10. For whatever sieve used, the size shall be indicated in the report.

NOTE 2—Two types of dispersion devices are provided: (*1*) a high-speed mechanical stirrer, and (*2*) air dispersion. Extensive investigations indicate that air-dispersion devices produce a more positive dispersion of plastic soils below the 20-μm size and appreciably less degradation on all sizes when used with sandy soils. Because of the definite advantages favoring air dispersion, its use is recommended. The results from the two types of devices differ in magnitude, depending upon soil type, leading to marked differences in particle size distribution, especially for sizes finer than 20 μm.

2. Apparatus

2.1 *Balances*—A balance sensitive to 0.01 g for weighing the material passing a No. 10 (2.00-mm) sieve, and a balance sensitive to 0.1 percent of the mass of the sample to be weighed for weighing the material retained on a No. 10 sieve.

2.2 *Stirring Apparatus*—Either apparatus A or B may be used.

2.2.1 Apparatus A shall consist of a mechanically operated stirring device in which a suitably mounted electric motor turns a vertical shaft at a speed of not less than 10,000 rpm without load. The shaft shall be equipped with a replaceable stirring paddle made of metal, plastic, or hard rubber, as shown in Fig. 1. The shaft shall be of such length that the stirring paddle will operate not less than ¾ in. (19.0 mm) nor more than 1½ in. (38.1 mm) above the bottom of the dispersion cup. A special dispersion cup conforming to either of the designs shown in Fig. 2 shall be provided to hold the sample while it is being dispersed.

2.2.2 Apparatus B shall consist of an air-jet dispersion cup[2] (Note 3) conforming to the general details shown in Fig. 3 (Notes 4 and 5).

NOTE 3—The amount of air required by an air-jet dispersion cup is of the order of 2 ft^3/min; some small air compressors are not capable of supplying sufficient air to operate a cup.

NOTE 4—Another air-type dispersion device, known as a dispersion tube, developed by Chu and Davidson at Iowa State College, has been shown to give results equivalent to those secured by the air-jet dispersion cups. When it is used, soaking of the sample can be done in the sedimentation cylinder, thus eliminating the need for transferring the slurry. When the air-dispersion tube is used, it shall be so indicated in the report.

NOTE 5—Water may condense in air lines when not in use. This water must be removed, either by using a water trap on the air line, or by blowing the water out of the line before using any of the air for dispersion purposes.

2.3 *Hydrometer*—An ASTM hydrometer, graduated to read in either specific gravity of the suspension or grams per litre of suspension, and conforming to the requirements for

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[1] This method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock.

Current edition accepted Nov. 21, 1963. Originally issued 1935. Replaces D 422 - 62.

[2] Detailed working drawings for this cup are available at a nominal cost from the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103. Order Adjunct No. 12-404220-00.

hydrometers 151H or 152H in ASTM Specification E 100, for ASTM Hydrometers.[3] Dimensions of both hydrometers are the same, the scale being the only item of difference.

2.4 *Sedimentation Cylinder*—A glass cylinder essentially 18 in. (457 mm) in height and 2½ in. (63.5 mm) in diameter, and marked for a volume of 1000 ml. The inside diameter shall be such that the 1000-ml mark is 36 ± 2 cm from the bottom on the inside.

2.5 *Thermometer*—A thermometer accurate to 1 F (0.5 C).

2.6 *Sieves*—A series of sieves, of square-mesh woven-wire cloth, conforming to the requirements of ASTM Specification E 11, for Wire-Cloth Sieves for Testing Purposes.[3] A full set of sieves includes the following (Note 6):

3-in. (75-mm)
2-in. (50-mm)
1½-in. (37.5-mm)
1-in. (25.0-mm)
¾-in. (19.0-mm)
⅜-in. (9.5-mm)
No. 4 (4.75-mm)
No. 10 (2.00-mm)
No. 20 (850-μm)
No. 40 (425-μm)
No. 60 (250-μm)
No. 140 (106-μm)
No. 200 (75-μm)

NOTE 6—A set of sieves giving uniform spacing of points for the graph, as required in Section 16, may be used if desired. This set consists of the following sieves:

3-in. (75-mm)
1½-in. (37.5-mm)
¾-in. (19.0-mm)
⅜-in. (9.5-mm)
No. 4 (4.75-mm)
No. 8 (2.36-mm)
No. 16 (1.18-mm)
No. 30 (600-μm)
No. 50 (300-μm)
No. 100 (150-μm)
No. 200 (75-μm)

2.7 *Water Bath or Constant-Temperature Room*—A water bath or constant-temperature room for maintaining the soil suspension at a constant temperature during the hydrometer analysis. A satisfactory water tank is an insulated tank that maintains the temperature of the suspension at a convenient constant temperature at or near 68 F (20 C). Such a device is illustrated in Fig. 4. In cases where the work is performed in a room at an automatically controlled constant temperature, the water bath is not necessary.

2.8 *Beaker*—A beaker of 250-ml capacity.

2.9 *Timing Device*—A watch or clock with a second hand.

3. Dispersing Agent

3.1 A solution of sodium hexametaphosphate (sometimes called sodium metaphosphate) shall be used in distilled or demineralized water, at the rate of 40 g of sodium hexametaphosphate/litre of solution (Note 7).

NOTE 7—Solutions of this salt, if acidic, slowly revert or hydrolyze back to the orthophosphate form with a resultant decrease in dispersive action. Solutions should be prepared frequently (at least once a month) or adjusted to pH of 8 or 9 by means of sodium carbonate. Bottles containing solutions should have the date of preparation marked on them.

3.2 All water used shall be either distilled or demineralized water. The water for a hydrometer test shall be brought to the temperature that is expected to prevail during the hydrometer test. For example, if the sedimentation cylinder is to be placed in the water bath, the distilled or demineralized water to be used shall be brought to the temperature of the controlled water bath; or, if the sedimentation cylinder is used in a room with controlled temperature, the water for the test shall be at the temperature of the room. The basic temperature for the hydrometer test is 68 F (20 C). Small variations of temperature do not introduce differences that are of practical significance and do not prevent the use of corrections derived as prescribed.

4. Test Sample

4.1 Prepare the test sample for mechanical analysis as outlined in ASTM Method D 421, Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants.[4] During the preparation procedure the sample is divided into two portions. One portion contains only particles retained on the No. 10 (2.00-mm) sieve while the other portion contains only particles passing the No. 10 sieve. The mass of air-dried soil selected for purpose of tests, as prescribed in Method D 421, shall be sufficient to yield quantities for mechanical analysis as follows:

4.1.1 The size of the portion retained on the No. 10 sieve shall depend on the maximum size of particle, according to the following schedule:

Nominal Diameter of Largest Particles, in. (mm)	Approximate Minimum Mass of Portion, g
⅜ (9.5)	500
¾ (19.0)	1000
1 (25.4)	2000
1½ (38.1)	3000
2 (50.8)	4000
3 (76.2)	5000

4.1.2 The size of the portion passing the No. 10 sieve shall be approximately 115 g for sandy soils and approximately 65 g for silt and clay soils.

4.2 Provision is made in Section 4 of Method D 421 for the weighing of the air-dry soil selected for purpose of tests, the separation of the soil on the No. 10 sieve by dry-sieving and washing, and the weighing of the washed and dried fraction retained on the No. 10 sieve. From these two masses the percentages retained and passing the No. 10 sieve can be calculated in accordance with 11.1.

NOTE 8—A check on the mass values and the thoroughness of pulverization of the clods may be secured by weighing the portion passing the No. 10 sieve and adding this value to the mass of the washed and oven-dried portion retained on the No. 10 sieve.

SIEVE ANALYSIS OF PORTION RETAINED ON NO. 10 (2.00-mm) SIEVE

5. Procedure

5.1 Separate the portion retained on the No. 10 (2.00-mm) sieve into a series of fractions using the 3-in. (75-mm), 2-in. (50-mm), 1½-in. (37.5-mm), 1-in. (25.0-mm), ¾-in. (19.0-mm), ⅜-in. (9.5-mm), No. 4 (4.75-mm), and No. 10 sieves, or as many as may be needed depending on the sample, or upon the specifications for the material under test.

5.2 Conduct the sieving operation by means of a lateral and vertical motion of the sieve, accompanied by a jarring action in order to keep the sample moving continuously over the surface of the sieve. In no case turn or manipulate fragments in the sample through the sieve by hand. Continue sieving until not more than 1 mass percent of the residue on a sieve passes that sieve during 1 min of sieving. When mechanical sieving is used, test the thoroughness of sieving by using the hand method of sieving as described above.

5.3 Determine the mass of each fraction on a balance conforming to the requirements of 2.1. At the end of weighing, the sum of the masses retained on all the sieves used should

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[3] *1982 Annual Book of ASTM Standards*, Part 41.
[4] *1983 Annual Book of ASTM Standards*, Vol 04.08.

eralized water, at the rate of 40 g of sodium hexametaphosphate/litre of solution (Note 7).

NOTE 7—Solutions of this salt, if acidic, slowly revert or hydrolyze back to the orthophosphate form with a resultant decrease in dispersive action. Solutions should be prepared frequently (at least once a month) or adjusted to pH of 8 or 9 by means of sodium carbonate. Bottles containing solutions should have the date of preparation marked on them.

3.2 All water used shall be either distilled or demineralized water. The water for a hydrometer test shall be brought to the temperature that is expected to prevail during the hydrometer test. For example, if the sedimentation cylinder is to be placed in the water bath, the distilled or demineralized water to be used shall be brought to the temperature of the controlled water bath; or, if the sedimentation cylinder is used in a room with controlled temperature, the water for the test shall be at the temperature of the room. The basic temperature for the hydrometer test is 68 F (20 C). Small variations of temperature do not introduce differences that are of practical significance and do not prevent the use of corrections derived as prescribed.

4. Test Sample

4.1 Prepare the test sample for mechanical analysis as outlined in ASTM Method D 421, Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants.[4] During the preparation procedure the sample is divided into two portions. One portion contains only particles retained on the No. 10 (2.00-mm) sieve while the other portion contains only particles passing the No. 10 sieve. The mass of air-dried soil selected for purpose of tests, as prescribed in Method D 421, shall be sufficient to yield quantities for mechanical analysis as follows:

4.1.1 The size of the portion retained on the No. 10 sieve shall depend on the maximum size of particle, according to the following schedule:

Nominal Diameter of Largest Particles, in. (mm)	Approximate Minimum Mass of Portion, g
⅜ (9.5)	500
¾ (19.0)	1000
1 (25.4)	2000
1½ (38.1)	3000
2 (50.8)	4000
3 (76.2)	5000

4.1.2 The size of the portion passing the No. 10 sieve shall be approximately 115 g for sandy soils and approximately 65 g for silt and clay soils.

4.2 Provision is made in Section 4 of Method D 421 for the weighing of the air-dry soil selected for purpose of tests, the separation of the soil on the No. 10 sieve by dry-sieving and washing, and the weighing of the washed and dried fraction retained on the No. 10 sieve. From these two masses the percentages retained and passing the No. 10 sieve can be calculated in accordance with 11.1.

NOTE 8—A check on the mass values and the thoroughness of pulverization of the clods may be secured by weighing the portion passing the No. 10 sieve and adding this value to the mass of the washed and oven-dried portion retained on the No. 10 sieve.

SIEVE ANALYSIS OF PORTION RETAINED ON NO. 10 (2.00-mm) SIEVE

5. Procedure

5.1 Separate the portion retained on the No. 10 (2.00-mm) sieve into a series of fractions using the 3-in. (75-mm), 2-in. (50-mm), 1½-in. (37.5-mm), 1-in. (25.0-mm), ¾-in. (19.0-mm), ⅜-in. (9.5-mm), No. 4 (4.75-mm), and No. 10 sieves, or as many as may be needed depending on the sample, or upon the specifications for the material under test.

5.2 Conduct the sieving operation by means of a lateral and vertical motion of the sieve, accompanied by a jarring action in order to keep the sample moving continuously over the surface of the sieve. In no case turn or manipulate fragments in the sample through the sieve by hand. Continue sieving until not more than 1 mass percent of the residue on a sieve passes that sieve during 1 min of sieving. When mechanical sieving is used, test the thoroughness of sieving by using the hand method of sieving as described above.

5.3 Determine the mass of each fraction on a balance conforming to the requirements of 2.1. At the end of weighing, the sum of the masses retained on all the sieves used should equal closely the original mass of the quantity sieved.

HYDROMETER AND SIEVE ANALYSIS OF PORTION PASSING THE NO. 10 (2.00-mm) SIEVE

6. Determination of Composite Correction for Hydrometer Reading

6.1 Equations for percentages of soil remaining in suspension, as given in 13.3, are based on the use of distilled or demineralized water. A dispersing agent is used in the water, however, and the specific gravity of the resulting liquid is appreciably greater than that of distilled or demineralized water.

6.1.1 Both soil hydrometers are calibrated at 68 F (20 C), and variations in temperature from this standard temperature produce inaccuracies in the actual hydrometer readings. The amount of the inaccuracy increases as the variation from the standard temperature increases.

6.1.2 Hydrometers are graduated by the manufacturer to be read at the bottom of the meniscus formed by the liquid on the stem. Since it is not possible to secure readings of soil suspensions at the bottom of the meniscus, readings must be taken at the top and a correction applied.

6.1.3 The net amount of the corrections for the three items enumerated is designated as the composite correction, and may be determined experimentally.

6.2 For convenience, a graph or table of composite corrections for a series of 1-deg temperature differences for the range of expected test temperatures may be prepared and used as needed. Measurement of the composite corrections may be made at two temperatures spanning the range of expected test temperatures, and corrections for the intermediate temperatures calculated assuming a straight-line relationship between the two observed values.

6.3 Prepare 1000 ml of liquid composed of distilled or demineralized water and dispersing agent in the same proportion as will prevail in the sedimentation (hydrometer) test. Place the liquid in a sedimentation cylinder and the cylinder in the constant-temperature water bath, set for one of the two temperatures to be used. When the tempera-

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[3] *1982 Annual Book of ASTM Standards*, Part 41.

[4] *1983 Annual Book of ASTM Standards*, Vol 04.08.

ture of the liquid becomes constant, insert the hydrometer, and, after a short interval to permit the hydrometer to come to the temperature of the liquid, read the hydrometer at the top of the meniscus formed on the stem. For hydrometer 151H the composite correction is the difference between this reading and one; for hydrometer 152H it is the difference between the reading and zero. Bring the liquid and the hydrometer to the other temperature to be used, and secure the composite correction as before.

7. Hygroscopic Moisture

7.1 When the sample is weighed for the hydrometer test, weigh out an auxiliary portion of from 10 to 15 g in a small metal or glass container, dry the sample to a constant mass in an oven at 230 ± 9 F (110 ± 5 C), and weigh again. Record the masses.

8. Dispersion of Soil Sample

8.1 When the soil is mostly of the clay and silt sizes, weigh out a sample of air-dry soil of approximately 50 g. When the soil is mostly sand the sample should be approximately 100 g.

[illegible]2 Place the sample in the 250-ml beaker and cover with 125 ml of sodium hexametaphosphate solution (40 g/litre). Stir until the soil is thoroughly wetted. Allow to soak for at least 16 h.

[illegible]3 At the end of the soaking period, disperse the sample further, using either stirring apparatus A or B. If stirring apparatus A is used, transfer the soil - water slurry from the beaker into the special dispersion cup shown in Fig. 2, washing any residue from the beaker into the cup with distilled or demineralized water (Note 9). Add distilled or demineralized water, if necessary, so that the cup is more than half full. Stir for a period of 1 min.

NOTE 9—A large size syringe is a convenient device for handling the water in the washing operation. Other devices include the wash-water bottle and a hose with nozzle connected to a pressurized [illegible] water tank.

[illegible] If stirring apparatus B (Fig. 3) is used, remove the cover cap and connect the cup to a compressed air supply by means of a rubber hose. An air gage must be on the line between the cup and the control valve. Open the control valve so that the gage indicates 1 psi (7 kPa) pressure (Note 10). Transfer the soil-water slurry from the beaker to the air-jet dispersion cup by washing with distilled or demineralized water. Add distilled or demineralized water, if necessary, so that the total volume in the cup is 250 ml, but no more.

NOTE 10—The initial air pressure of 1 psi is required to prevent the soil - water mixture from entering the air-jet chamber when the mixture is transferred to the dispersion cup.

8.5 Place the cover cap on the cup and open the air control valve until the gage pressure is 20 psi (140 kPa). Disperse the soil according to the following schedule:

Plasticity Index	Dispersion Period, min
Under 5	5
6 to 20	10
Over 20	15

Soils containing large percentages of mica need be dispersed for only 1 min. After the dispersion period, reduce the gage pressure to 1 psi preparatory to transfer of soil - water slurry to the sedimentation cylinder.

9. Hydrometer Test

9.1 Immediately after dispersion, transfer the soil - water slurry to the glass sedimentation cylinder, and add distilled or demineralized water until the total volume is 1000 ml.

9.2 Using the palm of the hand over the open end of the cylinder (or a rubber stopper in the open end), turn the cylinder upside down and back for a period of 1 min to complete the agitation of the slurry (Note 11). At the end of 1 min set the cylinder in a convenient location and take hydrometer readings at the following intervals of time (measured from the beginning of sedimentation), or as many as may be needed, depending on the sample or the specification for the material under test: 2, 5, 15, 30, 60, 250, and 1440 min. If the controlled water bath is used, the sedimentation cylinder should be placed in the bath between the 2- and 5-min readings.

NOTE 11—The number of turns during this minute should be approximately 60, counting the turn upside down and back as two turns. Any soil remaining in the bottom of the cylinder during the first few turns should be loosened by vigorous shaking of the cylinder while it is in the inverted position.

9.3 When it is desired to take a hydrometer reading, carefully insert the hydrometer about

20 to 25 s before the reading is due to approximately the depth it will have when the reading is taken. As soon as the reading is taken, carefully remove the hydrometer and place it with a spinning motion in a graduate of clean distilled or demineralized water.

NOTE 12—It is important to remove the hydrometer immediately after each reading. Readings shall be taken at the top of the meniscus formed by the suspension around the stem, since it is not possible to secure readings at the bottom of the meniscus.

9.4 After each reading, take the temperature of the suspension by inserting the thermometer into the suspension.

10. Sieve Analysis

10.1 After taking the final hydrometer reading, transfer the suspension to a No. 200 (75-μm) sieve and wash with tap water until the wash water is clear. Transfer the material on the No. 200 sieve to a suitable container, dry in an oven at 230 ± 9 F (110 ± 5 C) and make a sieve analysis of the portion retained, using as many sieves as desired, or required for the material, or upon the specification of the material under test.

CALCULATIONS AND REPORT

11. Sieve Analysis Values for the Portion Coarser than the No. 10 (2.00-mm) Sieve

11.1 Calculate the percentage passing the No. 10 sieve by dividing the mass passing the No. 10 sieve by the mass of soil originally split on the No. 10 sieve, and multiplying the result by 100. To obtain the mass passing the No. 10 sieve, subtract the mass retained on the No. 10 sieve from the original mass.

11.2 To secure the total mass of soil passing the No. 4 (4.75-mm) sieve, add to the mass of the material passing the No. 10 sieve the mass of the fraction passing the No. 4 sieve and retained on the No. 10 sieve. To secure the total mass of soil passing the ⅜-in (9.5-mm) sieve, add to the total mass of soil passing the No. 4 sieve, the mass of the fraction passing the ⅜-in. sieve and retained on the No. 4 sieve. For the remaining sieves continue the calculations in the same manner.

11.3 To determine the total percentage passing for each sieve, divide the total mass passing (see 11.2) by the total mass of sample and multiply the result by 100.

kPa) pressure (Note 10). Transfer the soil-water slurry from the beaker to the air-jet dispersion cup by washing with distilled or demineralized water. Add distilled or demineralized water, if necessary, so that the total volume in the cup is 250 ml, but no more.

NOTE 10—The initial air pressure of 1 psi is required to prevent the soil - water mixture from entering the air-jet chamber when the mixture is transferred to the dispersion cup.

8.5 Place the cover cap on the cup and open the air control valve until the gage pressure is 20 psi (140 kPa). Disperse the soil according to the following schedule:

Plasticity Index	Dispersion Period, min
Under 5	5
6 to 20	10
Over 20	15

Soils containing large percentages of mica need be dispersed for only 1 min. After the dispersion period, reduce the gage pressure to 1 psi preparatory to transfer of soil - water slurry to the sedimentation cylinder.

9. Hydrometer Test

9.1 Immediately after dispersion, transfer the soil - water slurry to the glass sedimentation cylinder, and add distilled or demineralized water until the total volume is 1000 ml.

9.2 Using the palm of the hand over the open end of the cylinder (or a rubber stopper in the open end), turn the cylinder upside down and back for a period of 1 min to complete the agitation of the slurry (Note 11). At the end of 1 min set the cylinder in a convenient location and take hydrometer readings at the following intervals of time (measured from the beginning of sedimentation), or as many as may be needed, depending on the sample or the specification for the material under test: 2, 5, 15, 30, 60, 250, and 1440 min. If the controlled water bath is used, the sedimentation cylinder should be placed in the bath between the 2- and 5-min readings.

NOTE 11—The number of turns during this minute should be approximately 60, counting the turn upside down and back as two turns. Any soil remaining in the bottom of the cylinder during the first few turns should be loosened by vigorous shaking of the cylinder while it is in the inverted position.

9.3 When it is desired to take a hydrometer reading, carefully insert the hydrometer about

20 to 25 s before the reading is due to approximately the depth it will have when the reading is taken. As soon as the reading is taken, carefully remove the hydrometer and place it with a spinning motion in a graduate of clean distilled or demineralized water.

NOTE 12—It is important to remove the hydrometer immediately after each reading. Readings shall be taken at the top of the meniscus formed by the suspension around the stem, since it is not possible to secure readings at the bottom of the meniscus.

9.4 After each reading, take the temperature of the suspension by inserting the thermometer into the suspension.

10. Sieve Analysis

10.1 After taking the final hydrometer reading, transfer the suspension to a No. 200 (75-μm) sieve and wash with tap water until the wash water is clear. Transfer the material on the No. 200 sieve to a suitable container, dry in an oven at 230 ± 9 F (110 ± 5 C) and make a sieve analysis of the portion retained, using as many sieves as desired, or required for the material, or upon the specification of the material under test.

CALCULATIONS AND REPORT

11. Sieve Analysis Values for the Portion Coarser than the No. 10 (2.00-mm) Sieve

11.1 Calculate the percentage passing the No. 10 sieve by dividing the mass passing the No. 10 sieve by the mass of soil originally split on the No. 10 sieve, and multiplying the result by 100. To obtain the mass passing the No. 10 sieve, subtract the mass retained on the No. 10 sieve from the original mass.

11.2 To secure the total mass of soil passing the No. 4 (4.75-mm) sieve, add to the mass of the material passing the No. 10 sieve the mass of the fraction passing the No. 4 sieve and retained on the No. 10 sieve. To secure the total mass of soil passing the ⅜-in. (9.5-mm) sieve, add to the total mass of soil passing the No. 4 sieve, the mass of the fraction passing the ⅜-in. sieve and retained on the No. 4 sieve. For the remaining sieves, continue the calculations in the same manner.

11.3 To determine the total percentage passing for each sieve, divide the total mass passing (see 11.2) by the total mass of sample and multiply the result by 100.

12. Hygroscopic Moisture Correction Factor

12.1 The hygroscopic moisture correction factor is the ratio between the mass of the oven-dried sample and the air-dry mass before drying. It is a number less than one, except when there is no hygroscopic moisture.

13. Percentages of Soil in Suspension

13.1 Calculate the oven-dry mass of soil used in the hydrometer analysis by multiplying the air-dry mass by the hygroscopic moisture correction factor.

13.2 Calculate the mass of a total sample represented by the mass of soil used in the hydrometer test, by dividing the oven-dry mass used by the percentage passing the No. 10 (2.00-mm) sieve, and multiplying the result by 100. This value is the weight W in the equation for percentage remaining in suspension.

13.3 The percentage of soil remaining in suspension at the level at which the hydrometer is measuring the density of the suspension may be calculated as follows (Note 13):

For hydrometer 151H:

$$P = [(100{,}000/W) \times G/(G - G_1)]\,(R - G_1)$$

NOTE 13—The bracketed portion of the equation for hydrometer 151H is constant for a series of readings and may be calculated first and then multiplied by the portion in the parenthesis.

For hydrometer 152H:

$$P = (Ra/W) \times 100$$

where:

a = correction faction to be applied to the reading of hydrometer 152H. (Values shown on the scale are computed using a specific gravity of 2.65. Correction factors are given in Table 1),

P = percentage of soil remaining in suspension at the level at which the hydrometer measures the density of the suspension,

R = hydrometer reading with composite correction applied (Section 6),

W = oven-dry mass of soil in a total test sample represented by mass of soil dispersed (see 13.2), g,

G = specific gravity of the soil particles and

G_1 = specific gravity of the liquid in which soil particles are suspended. Use numerical value of one in both instances in the equation. In the first instance any possible variation produces no significant effect, and in the second instance, the composite correction for R is based on a value of one for G_1.

14. Diameter of Soil Particles

14.1 The diameter of a particle corresponding to the percentage indicated by a given hydrometer reading shall be calculated according to Stokes' law (Note 14), on the basis that a particle of this diameter was at the surface of the suspension at the beginning of sedimentation and had settled to the level at which the hydrometer is measuring the density of the suspension. According to Stokes' law:

$$D = \sqrt{[30n/980(G - G_1)] \times L/T}$$

where:

D = diameter of particle, mm,
n = coefficient of viscosity of the suspending medium (in this case water) in poises (varies with changes in temperature of the suspending medium),
L = distance from the surface of the suspension to the level at which the density of the suspension is being measured, cm. (For a given hydrometer and sedimentation cylinder, values vary according to the hydrometer readings. This distance is known as effective depth (Table 2),
T = interval of time from beginning of sedimentation to the taking of the reading, min,
G = specific gravity of soil particles, and
G_1 = specific gravity (relative density) of suspending medium (value may be used as 1.000 for all practical purposes).

NOTE 14—Since Stokes' law considers the terminal velocity of a single sphere falling in an infinity of liquid, the sizes calculated represent the diameter of spheres that would fall at the same rate as the soil particles.

14.2 For convenience in calculations the above equation may be written as follows:

$$D = K\sqrt{L/T}$$

where:

K = constant depending on the temperature of the suspension and the specific gravity of the soil particles. Values of K for a range of temperatures and specific gravities are given in Table 3. The value of K does not change for a series of readings constituting a test, while values of L and T do vary.

14.3 Values of D may be computed with sufficient accuracy, using an ordinary 10-in. slide rule.

NOTE 15—The value of L is divided by T using the A- and B-scales, the square root being indicated on the D-scale. Without ascertaining the value of the square root it may be multiplied by K, using either the C- or CI-scale.

15. Sieve Analysis Values for Portion Finer than No. 10 (2.00-mm) Sieve

15.1 Calculation of percentages passing the various sieves used in sieving the portion of the sample from the hydrometer test involves several steps. The first step is to calculate the mass of the fraction that would have been retained on the No. 10 sieve had it not been removed. This mass is equal to the total percentage retained on the No. 10 sieve (100 minus total percentage passing) times the mass of the total sample represented by the mass of soil used (as calculated in 13.2), and the result divided by 100.

15.2 Calculate next the total mass passing the No. 200 sieve. Add together the fractional masses retained on all the sieves, including the No. 10 sieve, and subtract this sum from the mass of the total sample (as calculated in 13.2).

15.3 Calculate next the total masses passing each of the other sieves, in a manner similar to that given in 11.2.

15.4 Calculate last the total percentages passing by dividing the total mass passing (as calculated in 15.3) by the total mass of sample (as calculated in 13.2), and multiply the result by 100.

16. Graph

16.1 When the hydrometer analysis is performed, a graph of the test results shall be made, plotting the diameters of the particles on a logarithmic scale as the abscissa and the percentages smaller than the corresponding diameters to an arithmetic scale as the ordinate. When the hydrometer analysis is not made on a portion of the soil, the preparation of the graph is optional, since values may be secured directly from tabulated data.

17. Report

17.1 The report shall include the following:

17.1.1 Maximum size of particles,

17.1.2 Percentage passing (or retained on) each sieve, which may be tabulated or presented by plotting on a graph (Note 16),

17.1.3 Description of sand and gravel particles:

17.1.3.1 Shape—rounded or angular,

17.1.3.2 Hardness—hard and durable, soft, or weathered and friable,

17.1.4 Specific gravity, if unusually high or low,

17.1.5 Any difficulty in dispersing the fraction passing the No. 10 (2.00-mm) sieve, indicating any change in type and amount of dispersing agent, and

17.1.6 The dispersion device used and the length of the dispersion period.

NOTE 16—This tabulation of graph represents the gradation of the sample tested. If particles larger than those contained in the sample were removed before testing, the report shall so state giving the amount and maximum size.

17.2 For materials tested for compliance with definite specifications, the fractions called for in such specifications shall be reported. The fractions smaller than the No. 10 sieve shall be read from the graph.

17.3 For materials for which compliance with definite specifications is not indicated and when the soil is composed almost entirely of particles passing the No. 4 (4.75-mm) sieve, the results read from the graph may be reported as follows:

gravity of the soil particles. Values of *K* for a range of temperatures and specific gravities are given in Table 3. The value of *K* does not change for a series of readings constituting a test, while values of *L* and *T* do vary.

14.3 Values of *D* may be computed with sufficient accuracy, using an ordinary 10-in. slide rule.

Note 15—The value of *L* is divided by *T* using the *A*- and *B*-scales, the square root being indicated on the *D*-scale. Without ascertaining the value of the square root it may be multiplied by *K*, using either the *C*- or *CI*-scale.

15. Sieve Analysis Values for Portion Finer than No. 10 (2.00-mm) Sieve

15.1 Calculation of percentages passing the various sieves used in sieving the portion of the sample from the hydrometer test involves several steps. The first step is to calculate the mass of the fraction that would have been retained on the No. 10 sieve had it not been removed. This mass is equal to the total percentage retained on the No. 10 sieve (100 minus total percentage passing) times the mass of the total sample represented by the mass of soil used (as calculated in 13.2), and the result divided by 100.

15.2 Calculate next the total mass passing the No. 200 sieve. Add together the fractional masses retained on all the sieves, including the No. 10 sieve, and subtract this sum from the mass of the total sample (as calculated in 13.2).

15.3 Calculate next the total masses passing each of the other sieves, in a manner similar to that given in 11.2.

15.4 Calculate last the total percentages passing by dividing the total mass passing (as calculated in 15.3) by the total mass of sample (as calculated in 13.2), and multiply the result by 100.

16. Graph

16.1 When the hydrometer analysis is performed, a graph of the test results shall be made, plotting the diameters of the particles on a logarithmic scale as the abscissa and the percentages smaller than the corresponding diameters to an arithmetic scale as the ordinate. When the hydrometer analysis is not made on a portion of the soil, the preparation of the graph is optional, since values may be secured directly from tabulated data.

17. Report

17.1 The report shall include the following:

17.1.1 Maximum size of particles,

17.1.2 Percentage passing (or retained on) each sieve, which may be tabulated or presented by plotting on a graph (Note 16),

17.1.3 Description of sand and gravel particles:

17.1.3.1 Shape—rounded or angular,

17.1.3.2 Hardness—hard and durable, soft, or weathered and friable,

17.1.4 Specific gravity, if unusually high or low,

17.1.5 Any difficulty in dispersing the fraction passing the No. 10 (2.00-mm) sieve, indicating any change in type and amount of dispersing agent, and

17.1.6 The dispersion device used and the length of the dispersion period.

Note 16—This tabulation of graph represents the gradation of the sample tested. If particles larger than those contained in the sample were removed before testing, the report shall so state giving the amount and maximum size.

17.2 For materials tested for compliance with definite specifications, the fractions called for in such specifications shall be reported. The fractions smaller than the No. 10 sieve shall be read from the graph.

17.3 For materials for which compliance with definite specifications is not indicated and when the soil is composed almost entirely of particles passing the No. 4 (4.75-mm) sieve, the results read from the graph may be reported as follows:

(*1*) Gravel, passing 3-in. and retained on No. 4 sieve ......percent
(*2*) Sand, passing No. 4 sieve and retained on No. 200 sieve ......percent
    (*a*) Coarse sand, passing No. 4 sieve and retained on No. 10 sieve ......percent
    (*b*) Medium sand, passing No. 10 sieve and retained on No. 40 sieve ......percent
    (*c*) Fine sand, passing No. 40 sieve and retained on No. 200 sieve ......percent
(*3*) Silt size, 0.074 to 0.005 mm ......percent
(*4*) Clay size, smaller than 0.005 mm ......percent
    Colloids, smaller than 0.001 mm ......percent

17.4 For materials for which compliance with definite specifications is not indicated and when the soil contains material retained on the No. 4 sieve sufficient to require a sieve analysis on that portion, the results may be reported as follows (Note 17):

Sieve Analysis

Sieve Size	Percentage Passing
3-in.	....
2-in.	....
1½-in.	....
1-in.	....
¾-in.	....
⅜-in.	....
No. 4 (4.75-mm)	....
No. 10 (2.00-mm)	....
No. 40 (425-μm)	....
No. 200 (75-μm)	....

Hydrometer Analysis

0.074 mm	....
0.005 mm	....
0.001 mm	....

Note 17—No. 8 (2.36-mm) and No. 50 (300-μm) sieves may be substituted for No. 10 and No. 40 sieves.

TABLE 1 Values of Correction Factor, *a*, for Different Specific Gravities of Soil Particles[a]

Specific Gravity	Correction Factor[a]
2.95	0.94
2.90	0.95
2.85	0.96
2.80	0.97
2.75	0.98
2.70	0.99
2.65	1.00
2.60	1.01
2.55	1.02
2.50	1.03
2.45	1.05

[a] [illegible]r use in equation for percentage of soil remaining in suspension when using Hydrometer 152H.

TABLE 2 Values of Effective Depth Based on Hydro[illegible]nd Sedimentation Cylinder of Specified Sizes[a]

Hydrometer 151H		Hydrometer 152H			
Actual Hydrometer Reading	Effective Depth, *L*, cm	Actual Hydrometer Reading	Effective Depth, *L*, cm	Actual Hydrometer Reading	Effective Depth, *L*, cm
[illegible]00	16.3	0	16.3	31	11.2
[illegible]01	16.0	1	16.1	32	11.1
[illegible]02	15.8	2	16.0	33	10.9
1.003	15.5	3	15.8	34	10.7
1.004	15.2	4	15.6	35	10.6
[illegible]05	15.0	5	15.5		
[illegible]06	14.7	6	15.3	36	10.4
1.007	14.4	7	15.2	37	10.2
1.008	14.2	8	15.0	38	10.1
[illegible]09	13.9	9	14.8	39	9.9
[illegible]10	13.7	10	14.7	40	9.7
1.011	13.4	11	14.5	41	9.6
1.012	13.1	12	14.3	42	9.4
[illegible]13	12.9	13	14.2	43	9.2
[illegible]14	12.6	14	14.0	44	9.1
[illegible]15	12.3	15	13.8	45	8.9
1.016	12.1	16	13.7	46	8.8
[illegible]17	11.8	17	13.5	47	8.6
[illegible]18	11.5	18	13.3	48	8.4
[illegible]19	11.3	19	13.2	49	8.3
1.020	11.0	20	13.0	50	8.1
[illegible]21	10.7	21	12.9	51	7.9
[illegible]22	10.5	22	12.7	52	7.8
[illegible]23	10.2	23	12.5	53	7.6
1.024	10.0	24	12.4	54	7.4
[illegible]	9.7	25	12.2	55	7.3
[illegible]6	9.4	26	12.0	56	7.1
[illegible]	9.2	27	11.9	57	7.0
[illegible]8	8.9	28	11.7	58	6.8
1.029	8.6	29	11.5	59	6.6
[illegible]30	8.4	30	11.4	60	6.5

Table 2 *Continued*

Hydrometer 151H		Hydrometer 152H			
Actual Hydrometer Reading	Effective Depth, *L*, cm	Actual Hydrometer Reading	Effective Depth, *L*, cm	Actual Hydrometer Reading	Effective Depth, *L*, cm
1.031	8.1				
1.032	7.8				
1.033	7.6				
1.034	7.3				
1.035	7.0				
1.036	6.8				
1.037	6.5				
1.038	6.2				

[a] Values of effective depth are calculated from the equation:

$$L = L_1 + \tfrac{1}{2}\left[L_2 - (V_B/A)\right]$$

where:

L = effective depth, cm,

L_1 = distance along the stem of the hydrometer from the top of the bulb to the mark for a hydrometer reading, cm,

L_2 = overall length of the hydrometer bulb, cm,

V_B = volume of hydrometer bulb, cm^3, and

A = cross-sectional area of sedimentation cylinder, cm^2

Values used in calculating the values in Table 2 are as follows:

For both hydrometers, 151H and 152H:

L_2 = 14.0 cm

V_B = 67.0 cm^3

A = 27.8 cm^2

For hydrometer 151H:

L_1 = 10.5 cm for a reading of 1.000

= 2.3 cm for a reading of 1.031

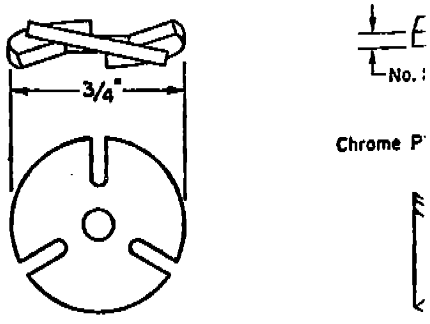
For hydrometer 152H:

L_1 = 10.5 cm for a reading of 0 g/litre

= 2.3 cm for a reading of 50 g/litre

TABLE 3 Values of *K* for Use in Equation for Computi

Temperature, deg C	Specific Gravi				
	2.45	2.50	2.55	2.60	
16	0.01510	0.01505	0.01481	0.01457	0
17	0.01511	0.01486	0.01462	0.01439	0
18	0.01492	0.01467	0.01443	0.01421	0
19	0.01474	0.01449	0.01425	0.01403	0
20	0.01456	0.01431	0.01408	0.01386	0
21	0.01438	0.01414	0.01391	0.01369	0
22	0.01421	0.01397	0.01374	0.01353	0
23	0.01404	0.01381	0.01358	0.01337	0.
24	0.01388	0.01365	0.01342	0.01321	0
25	0.01372	0.01349	0.01327	0.01306	0.
26	0.01357	0.01334	0.01312	0.01291	0
27	0.01342	0.01319	0.01297	0.01277	0
28	0.01327	0.01304	0.01283	0.01264	0
29	0.01312	0.01290	0.01269	0.01249	0.
30	0.01298	0.01276	0.01256	0.01236	0.



(a)

Metric Equival

in.	0.001	0.049	0.
mm	0.03	1.24	5.

FIG. 1 Detail of Stir

Table 2 *Continued*

Hydrometer 151H		Hydrometer 152H			
Actual Hydrometer Reading	Effective Depth, L, cm	Actual Hydrometer Reading	Effective Depth, L, cm	Actual Hydrometer Reading	Effective Depth, L, cm
1.031	8.1				
1.032	7.8				
1.033	7.6				
1.034	7.3				
1.035	7.0				
1.036	6.8				
1.037	6.5				
1.038	6.2				

[a] Values of effective depth are calculated from the equation:

$$L = L_1 + \frac{1}{2}\left[L_2 - (V_B/A)\right]$$

where:

L = effective depth, cm,

L_1 = distance along the stem of the hydrometer from the top of the bulb to the mark for a hydrometer reading, cm,

L_2 = overall length of the hydrometer bulb, cm,

V_B = volume of hydrometer bulb, cm^3, and

A = cross-sectional area of sedimentation cylinder, cm^2.

Values used in calculating the values in Table 2 are as follows:

For both hydrometers, 151H and 152H:

L_2 = 14.0 cm

V_B = 67.0 cm^3

A = 27.8 cm^2

For hydrometer 151H:

$_1$ = 10.5 cm for a reading of 1.000

= 2.3 cm for a reading of 1.031

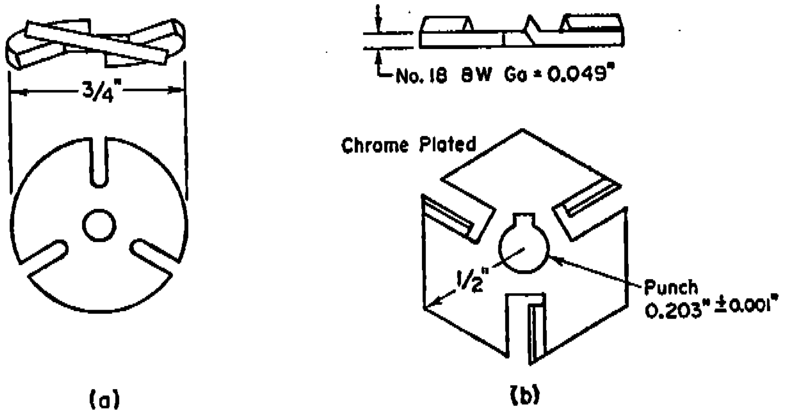
For hydrometer 152H:

L_1 = 10.5 cm for a reading of 0 g/litre

= 2.3 cm for a reading of 50 g/litre

TABLE 3 Values of K for Use in Equation for Computing Diameter of Particle in Hydrometer Analysis

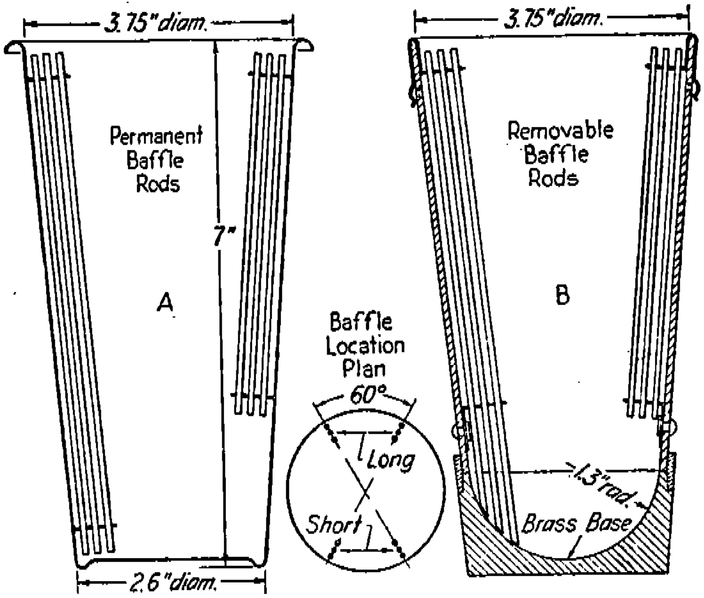
Temperature, deg C	Specific Gravity of Soil Particles								
	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
16	0.01510	0.01505	0.01481	0.01457	0.01435	0.01414	0.01394	0.01374	0.01356
17	0.01511	0.01486	0.01462	0.01439	0.01417	0.01396	0.01376	0.01356	0.01338
18	0.01492	0.01467	0.01443	0.01421	0.01399	0.01378	0.01359	0.01339	0.01321
19	0.01474	0.01449	0.01425	0.01403	0.01382	0.01361	0.01342	0.01323	0.01305
20	0.01456	0.01431	0.01408	0.01386	0.01365	0.01344	0.01325	0.01307	0.01289
21	0.01438	0.01414	0.01391	0.01369	0.01348	0.01328	0.01309	0.01291	0.01273
22	0.01421	0.01397	0.01374	0.01353	0.01332	0.01312	0.01294	0.01276	0.01258
23	0.01404	0.01381	0.01358	0.01337	0.01317	0.01297	0.01279	0.01261	0.01243
24	0.01388	0.01365	0.01342	0.01321	0.01301	0.01282	0.01264	0.01246	0.01229
25	0.01372	0.01349	0.01327	0.01306	0.01286	0.01267	0.01249	0.01232	0.01215
26	0.01357	0.01334	0.01312	0.01291	0.01272	0.01253	0.01235	0.01218	0.01201
27	0.01342	0.01319	0.01297	0.01277	0.01258	0.01239	0.01221	0.01204	0.01188
28	0.01327	0.01304	0.01283	0.01264	0.01244	0.01225	0.01208	0.01191	0.01175
29	0.01312	0.01290	0.01269	0.01249	0.01230	0.01212	0.01195	0.01178	0.01162
30	0.01298	0.01276	0.01256	0.01236	0.01217	0.01199	0.01182	0.01165	0.01149



Metric Equivalents

in.	0.001	0.049	0.203	½	¾
mm	0.03	1.24	5.16	12.7	19.0

FIG. 1 Detail of Stirring Paddles.



Metric Equivalents

in.	1.3	2.6	3.75
mm	33	66	95.2

FIG. 2 Dispersion Cups of Apparatus A.

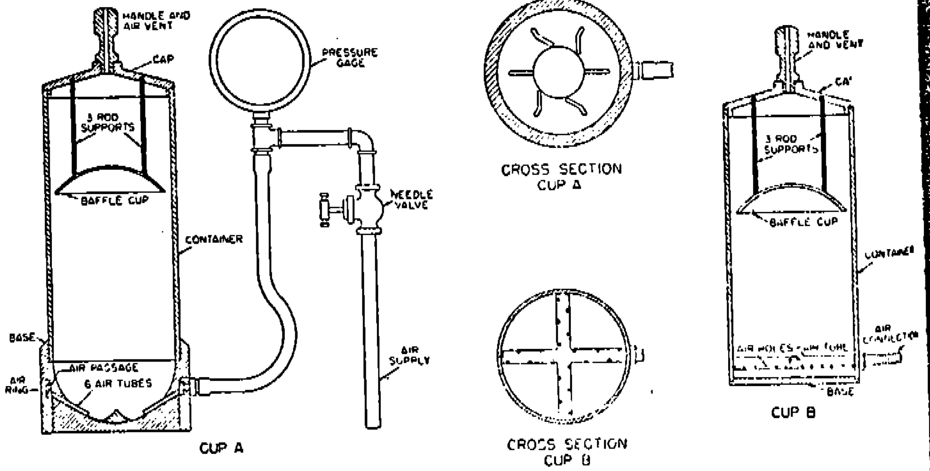
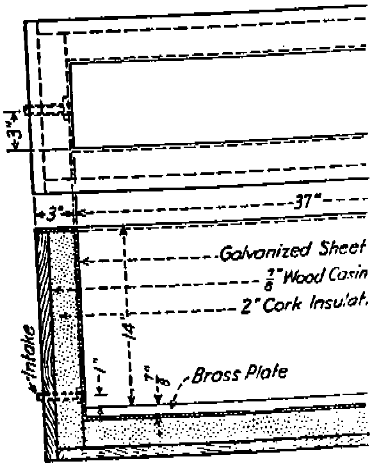


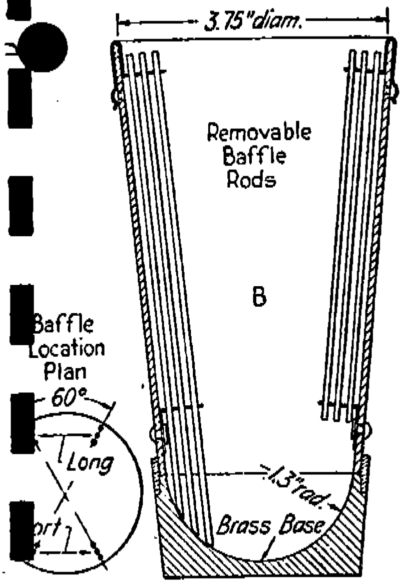
FIG. 3 Air-Jet Dispersion Cups of Apparatus B.



Metric Equival

in.	7/8	1	3
mm	22.2	25.4	76.2

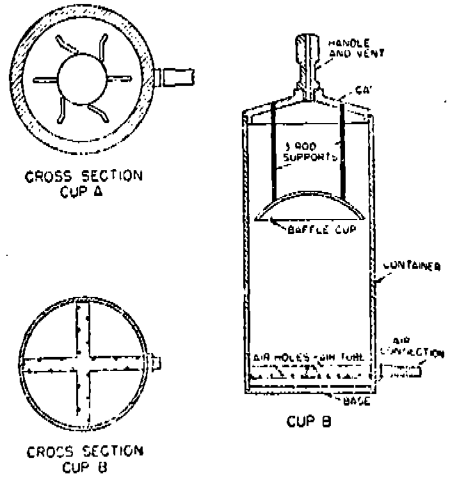
FIG. 4 Insulated W



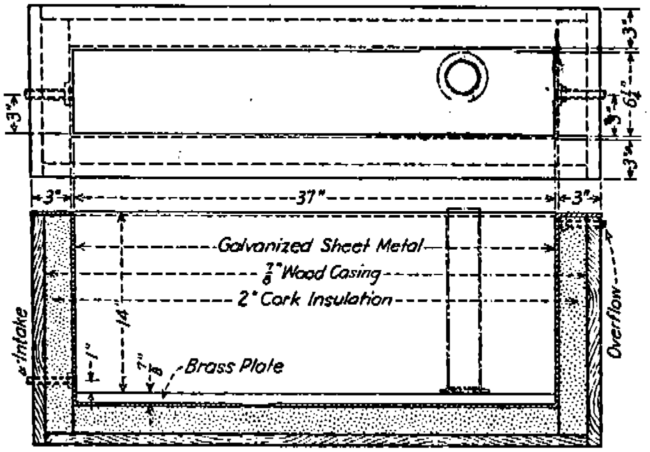
Equivalents

2.6	3.75
66	95.2

n Cups of Apparatus A.



rsion Cups of Apparatus B.



Metric Equivalents

in.	⅞	1	3	6¼	14	37
mm	22.2	25.4	76.2	158.2	356	940

FIG. 4 Insulated Water Bath.

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APPENDIX 7.4

FEED AND PRODUCT ANALYTICAL DATA

MOISTURE ANALYSIS RESULTS

Feed & Product Samples

	---- Moisture Content ----		
	Sample 1	Sample 2	Sample 3
Furnace Inlet Feed	< 0.1	< 0.1	< 0.1
Cyclones Product Outlet	< 0.5	1.0	< 0.5
Baghouse Fines	< 0.5		

LAW ENGINEERING TESTING COMPANY
SOIL SAMPLE DATA

PROJECT NAME & NO. ARE J47784-0105 Enthropy
BORING NUMBER IS Grace Run 1
SAMPLE IDENTIFICATION IS Feed 2-1-84

SPECIFIC GRAVITY = 2.23

* SIEVE ANALYSIS

Note
Sieved Mechanically for 15 minutes

SIEVE NUMBER	#CUM WT RETAINED	PERCENT FINER
4	0.0	100.0
10	71.5	64.5
20	86.1	21.7
40	105.2	12.2
60	112.7	8.5
100	118.4	5.7
200	123.2	3.3

HYDROMETER ANALYSIS ON SOIL PASSING NO. 10 SIEVE

ELAPSED TIME	HYDRO READING	CORR HYDRO	TEMP	DIA IN MM	PERCENT FINER
0.5	11.0	7.6	22.	0.0835	4.2
1.0	9.0	5.6	22.	0.0597	3.1
2.0	8.0	4.6	22.	0.0424	2.6
5.0	8.0	4.6	22.	0.0268	2.6
15.0	6.0	2.6	22.	0.0157	1.4
30.0	6.0	2.6	22.	0.0111	1.4
60.0	5.0	1.6	22.	0.0079	0.9
250.0	4.0	0.8	23.	0.0038	0.5
1440.0	4.0	0.8	23.	0.0016	0.5

PLASTICITY PROPERTIES OF MAT. PASSING NO. 40 SIEVE

SOIL SAMPLE IS NON-PLASTIC

GRAIN SIZE DISTRIBUTION
0.0% GRAVEL 96.7% SAND 2.8% SILT 0.5% CLAY
UNIFORMITY COEF = 5.89 COEF OF CURVATURE = 1.89

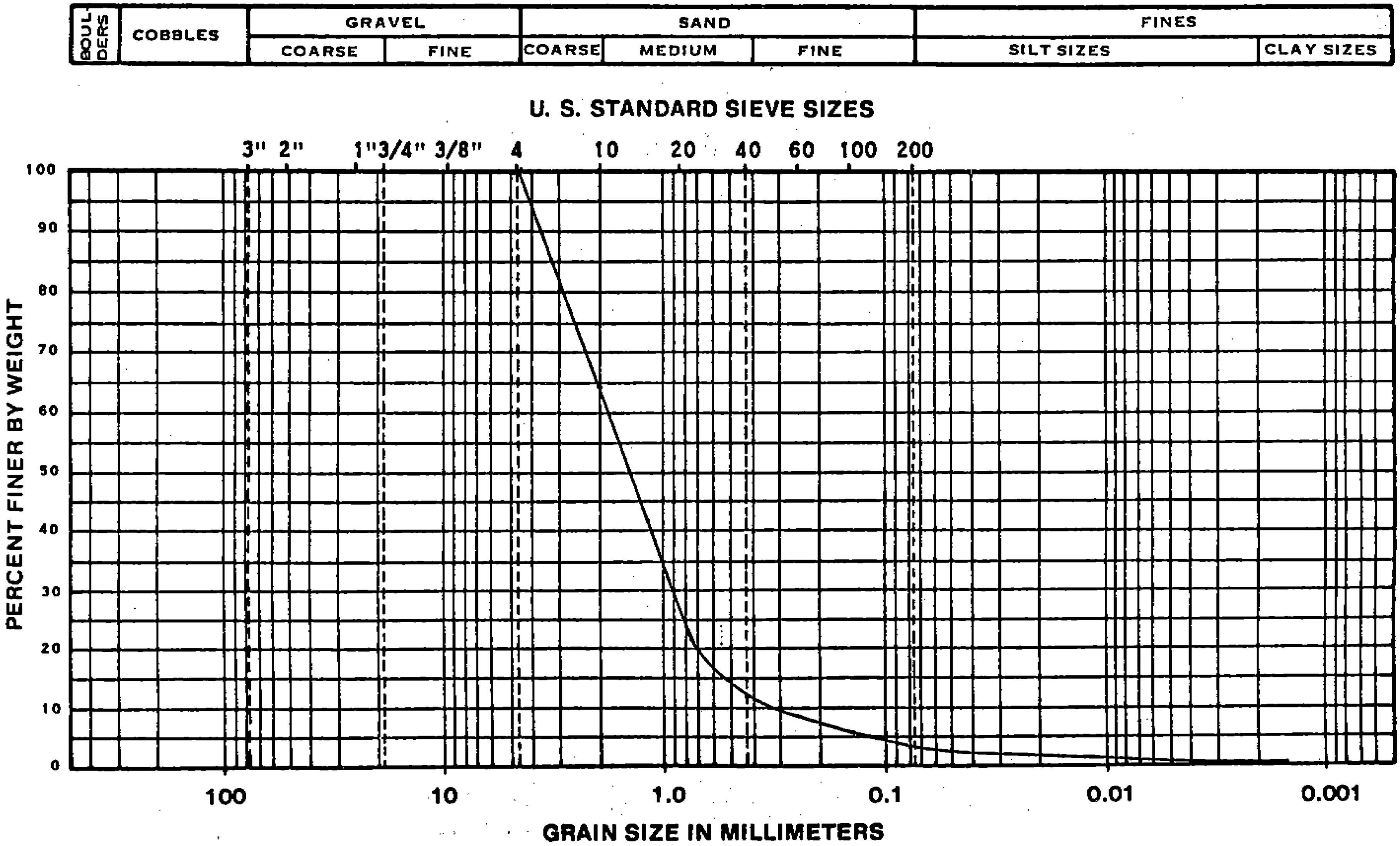
UNIFIED SOIL CLASSIFICATION IS SP

AASHTO SOIL CLASSIFICATION IS A1 WITH A GROUP INDEX OF 0

ROUGH ESTIMATES OF VARIOUS SOIL PROPERTIES

MAX AND MIN DRY DENSITY = 101 AND 77 PCF
PERMEABILITY COEFF. =0.10E+00 CM/SEC

* Tested in General Accordance with ASTM D854



Law Engineering Testing Company

Grain Size Distribution

BORING NO.	DEPTH	NAT WC	LL	PL	PI	DESCRIPTION OR CLASSIFICATION
						Entropy W.R.Grace Run 1 Feed 2-1-84

JOB NO.
J47784
0105

LAW ENGINEERING TESTING COMPANY
SOIL SAMPLE DATA

PROJECT NAME & NO. ARE J47784-0105 Entropy
BORING NUMBER IS Grace Run 2
SAMPLE IDENTIFICATION IS Feed 2-1-84

* SPECIFIC GRAVITY = 2.23

SIEVE ANALYSIS

Note
Sieved Mechanically For 15 Minutes

SIEVE NUMBER	#CUM WT RETAINED	PERCENT FINER
4	0.0	100.0
10	105.3	52.5
20	88.8	12.4
40	100.1	7.4
60	104.6	5.3
100	108.5	3.6
200	111.9	2.0

HYDROMETER ANALYSIS ON SOIL PASSING NO. 10 SIEVE

ELAPSED TIME	HYDRO READING	CORR HYDRO	TEMP	DIA IN MM	PERCENT FINER
0.5	9.0	5.6	22.	0.0844	2.8
1.0	7.0	3.6	22.	0.0603	1.8
2.0	7.0	3.6	22.	0.0427	1.8
5.0	7.0	3.6	22.	0.0270	1.8
15.0	6.0	2.6	22.	0.0157	1.3
30.0	5.0	1.6	22.	0.0111	0.8
60.0	5.0	1.6	22.	0.0079	0.8
250.0	4.0	0.8	23.	0.0038	0.4
1440.0	4.0	0.8	23.	0.0016	0.4

PLASTICITY PROPERTIES OF MAT. PASSING NO. 40 SIEVE

SOIL SAMPLE IS NON-PLASTIC

GRAIN SIZE DISTRIBUTION
0.0% GRAVEL 98.0% SAND 1.6% SILT 0.4% CLAY
UNIFORMITY COEF = 3.82 COEF OF CURVATURE = 1.17

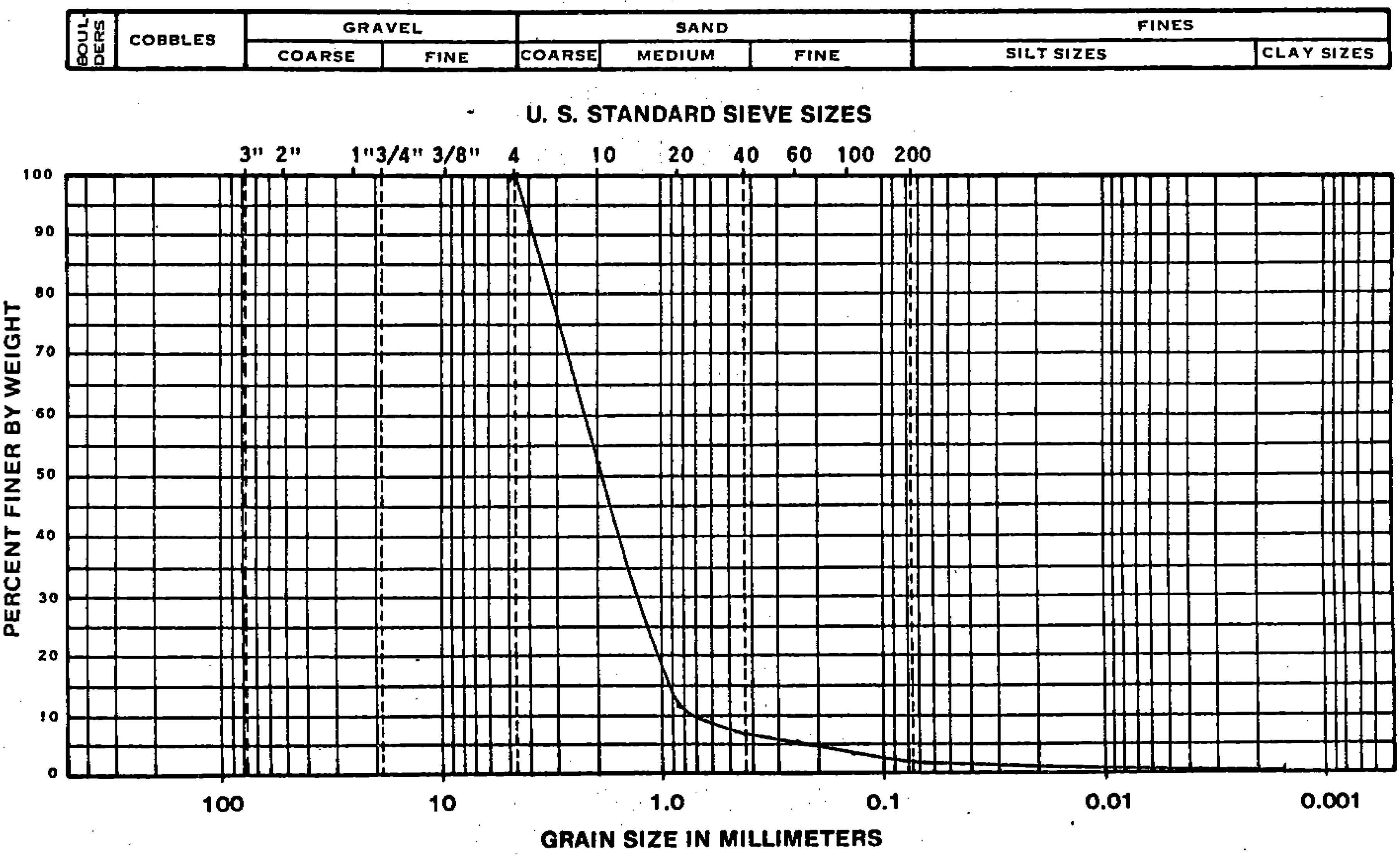
UNIFIED SOIL CLASSIFICATION IS SP

AASHTO SOIL CLASSIFICATION IS A1 WITH A GROUP INDEX OF 0

ROUGH ESTIMATES OF VARIOUS SOIL PROPERTIES

MAX AND MIN DRY DENSITY = 96 AND 72 PCF
PERMEABILITY COEFF. =0.41E+00 CM/SEC

* TESTED IN GENERAL ACCORDANCE WITH ASTM D854



Law Engineering Testing Company

Grain Size Distribution

BORING NO.	DEPTH	NAT WC	LL	PL	PI	DESCRIPTION OR CLASSIFICATION
JOB NO. J47784 0105	-	-	-	-	-	Entropy W.R.Grace Run 2 Feed 2-1-84

LAW ENGINEERING TESTING COMPANY
SOIL SAMPLE DATA

PROJECT NAME & NO. ARE J47784-0105 Enthropy
BORING NUMBER IS Grace Run 3
SAMPLE IDENTIFICATION IS Feed 2-1-84

*SPECIFIC GRAVITY = 2.23

<u>Note</u>
Sieved Mechanically for 15 minutes

SIEVE ANALYSIS

SIEVE NUMBER	#CUM WT RETAINED	PERCENT FINER
4	0.0	100.0
10	88.0	51.5
20	68.3	13.8
40	79.2	7.8
60	83.0	5.7
100	86.5	3.8
200	89.3	2.3

HYDROMETER ANALYSIS ON SOIL PASSING NO. 10 SIEVE

ELAPSED TIME	HYDRO READING	CORR HYDRO	TEMP	DIA IN MM	PERCENT FINER
0.5	8.0	4.6	22.	0.0849	2.8
1.0	7.0	3.6	22.	0.0603	2.2
2.0	6.0	2.6	22.	0.0429	1.6
5.0	6.0	2.6	22.	0.0271	1.6
15.0	6.0	2.6	22.	0.0157	1.6
30.0	6.0	2.6	22.	0.0111	1.6
60.0	5.0	1.6	22.	0.0079	1.0
250.0	4.0	0.8	23.	0.0038	0.5
1440.0	4.0	0.8	23.	0.0016	0.5

PLASTICITY PROPERTIES OF MAT. PASSING NO. 40 SIEVE

SOIL SAMPLE IS NON-PLASTIC

GRAIN SIZE DISTRIBUTION
0.0% GRAVEL 97.7% SAND 1.7% SILT 0.5% CLAY
UNIFORMITY COEF = 4.34 COEF OF CURVATURE = 1.26

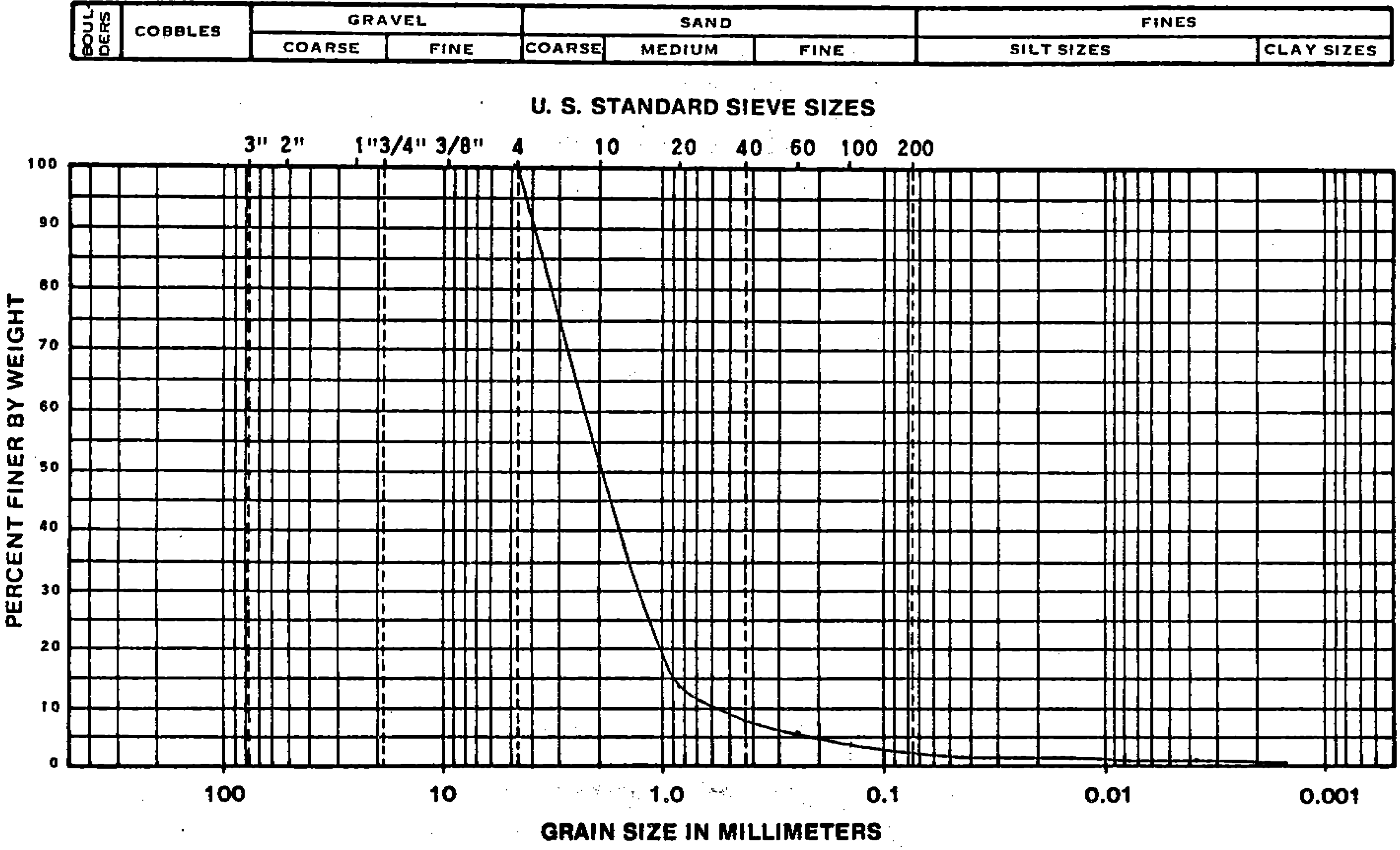
UNIFIED SOIL CLASSIFICATION IS SP

AASHTO SOIL CLASSIFICATION IS A1 WITH A GROUP INDEX OF 0

ROUGH ESTIMATES OF VARIOUS SOIL PROPERTIES

MAX AND MIN DRY DENSITY = 98 AND 74 PCF
PERMEABILITY COEFF. =0.33E+00 CM/SEC

*TESTED IN GENERAL ACCORDANCE WITH ASTM D854



Law Engineering Testing Company

Grain Size Distribution

BORING NO.	DEPTH	NAT WC	LL	PL	PI	DESCRIPTION OR CLASSIFICATION
JOB NO. J47784 0105						Entropy W.R.Grace Run 3 Feed 2-1-84

1400001

Product sieve analysis data are considered confidential by W. R. Grace and Company and these data are kept in a confidential file in the Division Office of the Emission Standards and Engineering Division, Office of Air Quality, Planning, and Standards, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711.

LAW ENGINEERING TESTING COMPANY
SOIL SAMPLE DATA

PROJECT NAME & NO. ARE J47784-0105 Enthropy
BORING NUMBER IS Grace
SAMPLE IDENTIFICATION IS Baghouse Fines

SPECIFIC GRAVITY = 2.27

* SIEVE ANALYSIS

Note
Sieved Mechanically for 15 minutes

SIEVE NUMBER	#CUM WT RETAINED	PERCENT FINER
10	0.0	100.0
20	0.1	99.8
40	0.1	99.8
60	0.1	99.8
100	0.2	99.6
200	0.4	99.1

HYDROMETER ANALYSIS ON SOIL PASSING NO. 10 SIEVE

ELAPSED TIME	HYDRO READING	CORR HYDRO	TEMP	DIA IN MM	PERCENT FINER
0.5	47.0	43.6	22.	0.0632	107.7
1.0	46.0	42.6	22.	0.0451	105.2
2.0	46.0	42.6	22.	0.0319	105.2
5.0	45.0	41.6	22.	0.0204	102.8
15.0	38.0	34.6	22.	0.0125	85.5
30.0	34.0	30.6	22.	0.0091	75.6
60.0	24.0	20.6	22.	0.0069	50.8
250.0	6.0	2.8	23.	0.0037	7.0
1440.0	5.0	1.8	23.	0.0016	4.5

Possible Bulking of Sample
Particles in Suspension

PLASTICITY PROPERTIES OF MAT. PASSING NO. 40 SIEVE

SOIL SAMPLE IS NON-PLASTIC

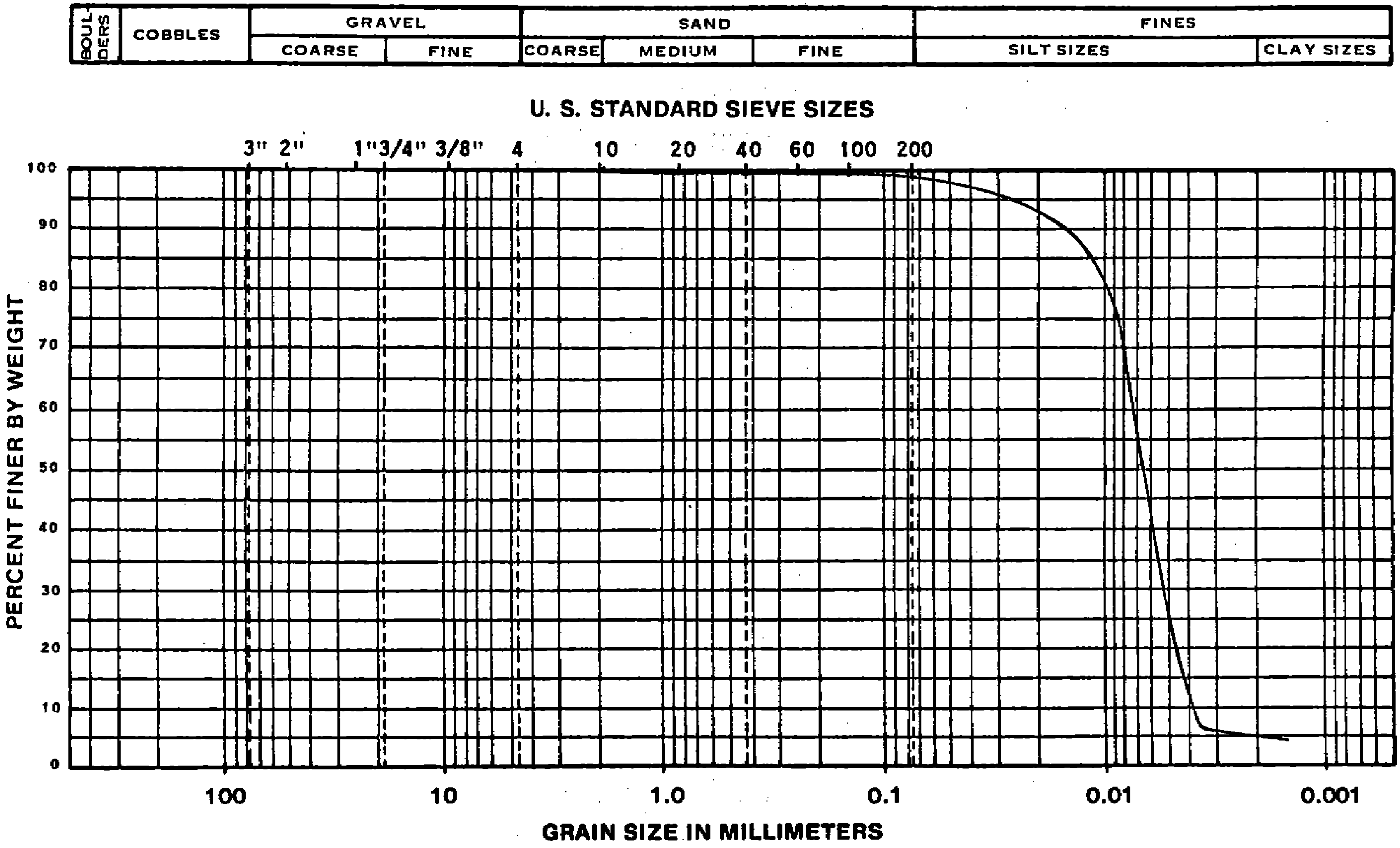
GRAIN SIZE DISTRIBUTION
0.0% GRAVEL 0.9% SAND 94.1% SILT 5.0% CLAY
UNIFORMITY COEF = 1.96 COEF OF CURVATURE = 0.96

UNIFIED SOIL CLASSIFICATION IS ML

AASHTO SOIL CLASSIFICATION IS A-4 WITH A GROUP INDEX OF 7

ROUGH ESTIMATES OF VARIOUS SOIL PROPERTIES

* TESTED IN GENERAL ACCORDANCE WITH ASTM D854



Law Engineering Testing Company

Grain Size Distribution

BORING NO.	DEPTH	NAT WC	LL	PL	PI	DESCRIPTION OR CLASSIFICATION
JOB NO. J47784 0105	-	-	-	-	-	Entropy W.R.Grace Baghouse Fines

APPENDIX 7.5

ENTROPY TEST PARTICIPANTS

FRANK J. PHOENIX	PROJECT DIRECTOR
GERARD M. CARTY	SAMPLING TEAM LEADER
PATRICK L. OWEN	SAMPLING TEAM LEADER
MICHAEL M. KIRKMAN	VISIBLE EMISSIONS OBSERVER
WILLIS S. NESBIT	VISIBLE EMISSIONS OBSERVER
THOMAS E. THOMPSON	VISIBLE EMISSIONS OBSERVER
HENRY B. LONG	ENGINEERING TECHNICIAN
REBECCA S. DORSEY	LABORATORY TECHNICIAN

APPENDIX 7.6

CALIBRATION DATA

CALIBRATIONS

GENERAL

All measuring equipment Entropy uses is initially calibrated before use. Equipment which can change calibration is both checked upon return from each field use and is also periodically recalibrated in full. When an instrument is found out of calibration, it is so noted in the report and appropriate adjustments are made to the final results. The equipment is then repaired and recalibrated or retired as needed. Specific equipment is handled as follows:

PITOT TUBE

All pitot tubes used by Entropy, whether separate or attached to a sampling probe, are constructed in-house or by Nutech Corporation. Prior to their initial usage, they are calibrated using EPA geometry standards. In general, if a type "S" pitot tube is assembled correctly, and positioned properly in relation to the probe nozzle, it will have an average Cp of 0.84. As long as it is not damaged, it should not change its calibration. The recalibration schedule for pitot tubes is related to the physical condition and usage of the pitot tube, not a fixed time schedule. Each pitot tube is inspected upon return to the laboratory from each field use.

DRY GAS METER AND ORIFICE METER

All Entropy meter boxes are calibrated upon purchase and at least once every six months against a secondary test meter (one calibrated against a wet test meter) according to their usage history. Basic procedures are outlined in the EPA Publication No. APTD-0576. The only differences are in the choice of flow rates used and the volumes metered at each flow rate. After each field use, quick checks are performed to insure delta H@ changes of less than 5%. These checks compare the orifice against the dry gas meter. If greater than 5% changes occur, recalibration and repair are instituted.

NOZZLES

Each nozzle is calibrated upon purchase, and thereafter whenever it becomes apparent that the nozzle has become damaged. Each nozzle is inspected upon return to laboratory from each field use. The diameter is measured on five different axes, with the high and low readings differing by no more than 0.004 inches as a tolerance.

TEMPERATURE MEASURING INSTRUMENTS

After each field use, the thermocouples or thermometers are calibrated against an ASTM precision mercury-in-glass thermometer across a wide range of temperatures. If the initial reading is not within ± 1.5% of the absolute temperature reading of the standard thermometer, the instrument is adjusted until it is in the acceptable range.

MAGNEHELIC GAUGES

After each field use, each magnehelic gauge is calibrated against an inclined manometer at three different settings (low, medium, high) over the range of the individual gauges. If the readings differ more than ± 5% from the manometer readings, the magnehelics are recalibrated.

BAROMETER

After each field use, each barometer is checked against a mercury barometer.

Dry Gas Meter Identification: 1017057 Calibration by: Bruce Hawks

Date: October 14, 1982 Barometric Pressure (P_b): 29.77 in. Hg

*Date: October 15, 1982 *Barometric Pressure (P_b): 29.71 in. Hg

ENTROPY ENVIRONMENTALISTS, INC.

Approx. Flow Rate (Q) cfm	Spirometer		Dry Gas Meter		Pressure (Δp) in. H_2O	Time (Θ) min.	Flow Rate (Q) cfm	Meter Meter Coeff. (Y_{ds})	Avg. Meter Coeff. ($\bar{Y}_{ds}$)
	Gas Volume (V_s) ft^3	Temp. (t_s) °F	Gas Volume (V_{ds}) ft^3	Temp. (t_{ds}) °F					
*1.20	15.046	75.2	15.006	73.0	0.90	12.897	1.142	0.9963	
	14.809	72.5	15.003	74.0	0.90	12.970	1.124	0.9876	
	14.754	70.7	15.011	75.0	0.90	12.991	1.122	0.9886	
	14.736	71.6	15.004	75.0	0.90	13.003	1.117	0.9862	
*1.40	14.791	74.3	15.002	76.0	1.40	10.919	1.329	0.9857	
	14.882	74.3	15.202	76.0	1.40	11.013	1.325	0.9787	
	14.709	74.3	15.002	77.0	1.40	10.864	1.328	0.9820	

$$Y_{ds} = \frac{(V_s)\ (t_{ds} + 460)\ (P_b)}{(V_{ds})\ (t_s + 460)\ (P_b + (\ p\ /\ 13.6))}$$

$$Q = (17.64)\ \frac{(P_b)\ (V_s)}{(t_s + 460)\ (\Theta)}$$

Dry Gas Meter Identification: 1017057 Calibration by: Bruce Hawks

Date: October 14, 1982 Barometric Pressure (P_b): 29.77 in. Hg

*Date: October 15, 1982 *Barometric Pressure (P_b): 29.71 in. Hg

ENTROPY ENVIRONMENTALISTS, INC.

Approx. Flow Rate (Q) cfm	Spirometer		Dry Gas Meter		Pressure (Δp) in. H_2O	Time (Θ) min.	Flow Rate (Q) cfm	Meter Meter Coeff. (Y_{ds})	Avg. Meter Coeff. ($\bar{Y}_{ds}$)
	Gas Volume (V_s) ft^3	Temp. (t_s) °F	Gas Volume (V_{ds}) ft^3	Temp. (t_{ds}) °F					
*0.20	2.004	75.2	2.001	76.0	0.00	14.585	0.135	1.0030	
	2.008	75.2	2.000	76.0	0.00	14.418	0.136	1.0055	
	2.013	76.1	2.000	76.0	0.00	14.426	0.136	1.0063	
0.40	5.036	75.2	5.001	74.0	0.13	12.892	0.383	1.0044	
	5.005	77.0	5.000	74.5	0.13	12.954	0.378	0.9960	
	4.909	74.3	5.000	77.0	0.13	13.080	0.369	0.9864	
	5.005	77.0	5.000	77.0	0.13	12.995	0.377	1.0007	
0.60	4.968	75.2	5.000	77.0	0.30	8.680	0.562	0.9962	
	4.945	75.2	5.000	77.0	0.30	8.665	0.560	0.9916	
	4.982	75.2	5.000	770	0.30	8.694	0.562	0.9990	
0.80	8.821	73.4	9.002	76.0	0.47	11.643	0.744	0.9835	
	6.967	73.4	7.001	76.0	0.50	8.869	0.772	0.9988	
	8.852	72.5	8.997	76.0	0.50	11.373	0.768	0.9891	
1.00	9.845	72.5	10.001	76.0	0.70	10.304	0.942	0.9892	
	9.886	72.5	9.998	76.0	0.70	10.301	0.946	0.9936	
	9.854	71.6	9.997	76.0	0.70	10.295	0.946	0.9921	

$$Y_{ds} = \frac{(V_s)\ (t_{ds} + 460)\ (P_b)}{(V_{ds})\ (t_s + 460)\ (P_b + (\ p\ /\ 13.6))}$$

$$Q = (17.64)\ \frac{(P_b)\ (V_s)}{(t_s + 460)\ (\Theta)}$$

Meter Box Number: N5

Standard Meter Number: 1017057

Calibration by: BDK

Date: 8/29/83

Barometric Pressure (P_b): 29.40 in. Hg

*Date: 8/30/83

*Barometric Pressure (P_b): 29.50 in. Hg

ENTROPY ENVIRONMENTALISTS, INC.

Standard Dry Gas Meter					Meter Box Metering System						
Gas Volume (V_{ds}) ft^3	Temp. (t_{ds}) °F	Flow Rate (Q_{ds}) cfm	Coeff. at Q_{ds} (Y_{ds})	Time (Θ) min.	Orifice Setting (ΔH) in. H_2O	Gas Volume (V_d) ft^3	Temp. (t_d) °F	Flow Rate (Q_d) cfm	Orifice Factor (OF)	Coeff. (Y_d)	$\Delta H@$ in. H_2O
4.088	73	0.398	0.9985	10.00	0.50	4.107	74	0.3972	3.014	0.9945	1.721
4.073	73	0.396	0.9985	10.00	0.50	4.128	77	0.3957	3.022	0.9914	1.724
8.066	73	0.785	0.9925	10.00	2.10	8.139	82	0.7790	6.222	0.9950	1.852
8.077	73	0.786	0.9925	10.00	2.10	8.205	85	0.7800	6.239	0.9938	1.837
* 12.289	72	1.202	0.9860	10.00	4.80	12.205	79	1.1853	9.365	0.9940	1.845
* 12.266	72	1.200	0.9861	10.00	4.80	12.285	82	1.1831	9.391	0.9912	1.841
								AVERAGE		0.993	1.80

$$\Delta H_@ = \frac{0.0317 * \Delta H}{P_b * (t_d + 460)} * \left[\frac{(t_{ds} + 460) * \Theta}{Y_{ds} * V_{ds}}\right]^2$$

$$Y_d = \frac{Y_{ds} * V_{ds} * (t_d + 460) * P_b}{V_d * (t_{ds} + 460) * (P_b + \Delta H/13.6)}$$

DATE PRINTED: 01/12/84

INTER-LABORATORY STUDY RESULTS

(SEPTEMBER 1983)

POLLUTANT - DGM

C18009
MR. BRUCE HAWKS
ENTROPY ENVIRONMENTALISTS, INC.
P.O. BOX 12291
RESEARCH TRIANGLE PARK, NC 27709

N5

UNITS - CUBIC METERS

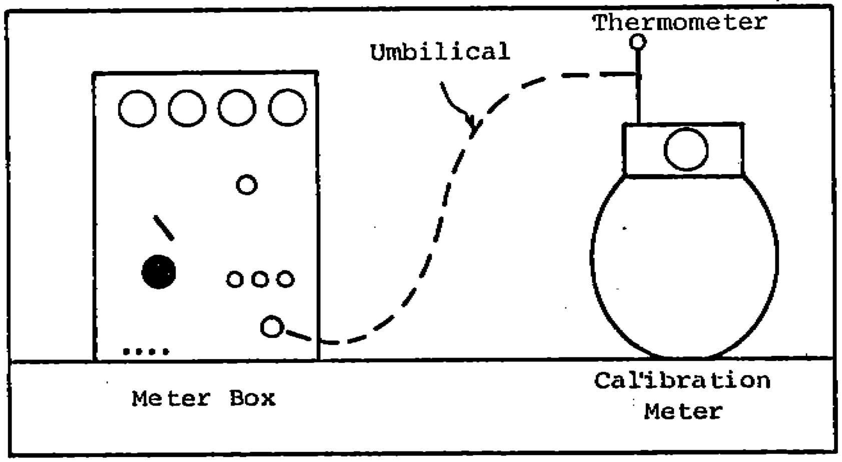
SITE - 005

ORIFICE NUMBER	REPORTED VALUE	EPA VALUE	PERCENT DIFFERENCE
267	0.2020	0.2029	-.4
267	0.1826	0.1835	-.4
267	0.1760	0.1766	-.3

Meter Box Number: N5
Standard Meter Number: 1017057
Calibration By: Mf
Date: 7-20-84
Barometric Pressure (P_b): 29.51 in. Hg.
Vacuum: 4 in. Hg.
*Date: ______
*Barometric Pressure (P_b): ______ in. Hg.

POST-TEST METERBOX CALIBRATION

Standard Dry Gas Meter					Meter Box Metering System						
Gas Volume (V_{ds}) ft^3	Temp. (t_{ds}) °F	Flow Rate (Q_{ds}) cfm	Coeff. at Q_{ds} (Y_{ds})	Time (Θ) min	Orifice Setting (ΔH) in. H_2O	Gas Volume (V_d) ft^3	Temp. (t_d) °F	Flow Rate (Q_d) cfm	Orifice factor (OF)	Coeff. (Y_d)	ΔH@ in. H_2O
7.815	65	0.775	0.9927	10:00	2.00	7.841	76	0.7692	6.027	1.0051	1.836
7.803	66	.772	.9927	10:00	2.00	7.904	82	.7666	6.061	1.0048	1.828
7.767	67	.767	.9928	10:00	2.00	7.939	86	.7617	6.038	1.0013	1.838
								AVERAGE		1.004	1.83



Schematic of equipment set-up for full and post-test meterbox calibrations.

$$\Delta H@ = \frac{0.0317 * \Delta H}{P_b * (t_d + 460)} * \left[\frac{(t_{ds} + 460) * 0}{Y_{ds} * V_{ds}}\right]^2$$

$$Y_d = \frac{Y_{ds} * V_{ds} * (t_d + 460) * P_b}{V_d * (t_{ds} + 460) * (P_b + \Delta H/13.6)}$$

ENTROPY ENVIRONMENTALISTS, INC.

Meter Box Number: N10

Date: 2-20-84

*Date: ______

Standard Meter Number: 1017057

Barometric Pressure (P_b): 29.51 in. Hg

*Barometric Pressure (P_b): ______ in. Hg

Calibration by: NMH

ENTROPY ENVIRONMENTALISTS, INC.

Standard Dry Gas Meter					Meter Box Metering System						
Gas Volume (V_{ds}) ft^3	Temp. (t_{ds}) °F	Flow Rate (Q_{ds}) cfm	Coeff. at Q_{ds} (Y_{ds})	Time (Θ) min.	Orifice Setting (ΔH) in. H_2O	Gas Volume (V_d) ft^3	Temp. (t_d) °F	Flow Rate (Q_d) cfm	Orifice Factor (OF)	Coeff. (Y_d)	ΔH@ in. H_2O
3.967	66	0.393	0.9986	10.00	0.5	3.986	76	0.3920	3.014	1.0115	1.767
3.985	66	0.394	0.9986	10.00	0.5	4.070	82	0.3938	3.030	1.0062	1.731
8.233	66	0.815	0.9920	10.00	2.1	8.440	83	0.8093	6.216	0.9938	1.723
8.242	66	0.816	0.9920	10.00	2.1	8.469	84	0.8092	6.222	0.9933	1.716
12.700	66	1.257	0.9852	10.00	4.8	12.792	81	1.2382	9.381	0.9941	1.685
12.637	66	1.251	0.9853	10.00	4.8	12.809	84	1.2322	9.407	0.9934	1.692
								AVERAGE		0.999	1.72

$$\Delta H_@ = \frac{0.0317 * \Delta H}{P_b * (t_d + 460)} * \left[\frac{(t_{ds} + 460) * \Theta}{Y_{ds} * V_{ds}}\right]^2$$

$$Y_d = \frac{Y_{ds} * V_{ds} * (t_d + 460) * P_b}{V_d * (t_{ds} + 460) * (P_b + \Delta H/13.6)}$$

INTER-LABORATORY STUDY RESULTS

DATE PRINTED: 01/12/84

(SEPTEMBER 1983)

POLLUTANT - DGM

C18009
MR. BRUCE HAWKS
ENTROPY ENVIRONMENTALISTS, INC.
P.O. BOX 12291
RESEARCH TRIANGLE PARK, NC 27709

NIO

UNITS - CUBIC METERS

SITE - 010

ORIFICE NUMBER	REPORTED VALUE	EPA VALUE	PERCENT DIFFERENCE
267	0.1863	0.1852	.6
267	0.1857	0.1842	.8
267	0.1850	0.1839	.6

Meter Box Number: N10

Standard Meter Number: 1017057

Calibration by: NMH

Date: 2-20-84

Barometric Pressure (P_b): 29.51 in. Hg

ENTROPY ENVIRONMENTALISTS, INC.

*Date: ______

*Barometric Pressure (P_b): ______ in. Hg

Standard Dry Gas Meter					Meter Box Metering System						
Gas Volume (V_{ds}) ft³	Temp. (t_{ds}) °F	Flow Rate (Q_{ds}) cfm	Coeff. at Q_{ds} (Y_{ds})	Time (Θ) min.	Orifice Setting (ΔH) in. H_2O	Gas Volume (V_d) ft³	Temp. (t_d) °F	Flow Rate (Q_d) cfm	Orifice Factor (OF)	Coeff. (Y_d)	ΔH@ in. H_2O
3.967	66	0.393	0.9986	10.00	0.5	3.986	76	0.3920	3.014	1.0115	1.767
3.985	66	0.394	0.9986	10.00	0.5	4.070	82	0.3938	3.030	1.0062	1.731
8.233	66	0.815	0.9920	10.00	2.1	8.440	83	0.8083	6.216	0.9938	1.723
8.242	66	0.816	0.9920	10.00	2.1	8.469	84	0.8092	6.222	0.9933	1.716
12.700	66	1.257	0.9852	10.00	4.8	12.792	81	1.2382	9.381	0.9941	1.685
12.637	66	1.251	0.9853	10.00	4.8	12.809	84	1.2322	9.407	0.9934	1.692
								AVERAGE		0.999	1.72

$$\Delta H_@ = \frac{0.0317 * \Delta H}{P_b * (t_d + 460)} * \left[\frac{(t_{ds} + 460) * \Theta}{Y_{ds} * V_{ds}}\right]^2$$

$$Y_d = \frac{Y_{ds} * V_{ds} * (t_d + 460) * P_b}{V_d * (t_{ds} + 460) * (P_b + \Delta H/13.6)}$$

ANDERSEN AND FLOW SENSOR HOLE DIAMETER SPECIFICATIONS

	HOLE DIAMETER (INCHES)	
Plate #	Andersen	Flow Sensor
0	0.0635	
1	0.0465	0.0635
2	0.0360	0.0390
3	0.0280	0.0292
4	0.0210	0.0240
5	0.0135	0.0180
6	0.0100	0.0135
7	0.0100	0.0135

PARTICLE SIZING LABORATORY DATA

CUSTOMER W.R. Grace JOB # 3002 SAMPLING LOCATION ______

DATE 2/23/84 ANALYST Becky Dorsey

RUN B1 RUN ____ RUN ____

STAGE	FILTER NUMBER	PARTICULATE AND FILTER WEIGHT (mg)	FILTER TARE (mg)	CATCH (mg)	FILTER NUMBER	PARTICULATE AND FILTER WEIGHT (mg)	FILTER TARE (mg)	CATCH (mg)	FILTER NUMBER	PARTICULATE AND FILTER WEIGHT (mg)	FILTER TARE (mg)	CATCH (mg)
0	B986	159.00	158.91	0.09								
1	A986	141.15	141.12	0.03								
2	B987	160.00	160.02	-0.02								
3	A987	141.30	141.30	0								
4	B988	160.22	160.22	0								
5	A988	141.68	141.70	-0.02								
6	B989	160.80	160.82	-0.02								
7	A989	141.12	141.15	-0.03								
BU	SF563	207.29	207.20	0.09								

PI = Pre-impactor

BU = Back-up Filter

NOZZLE NUMBER: 506

Date	Initials	Dia. 1	Dia. 2	Dia. 3	Dia. 4	Dia. 5	Average
12-2-82	ST	.254	.251	.250	.252	.251	0.252

NOTE: All diameters measured in inches.

ENTROPY
ENVIRONMENTALISTS,INC.

NOZZLE NUMBER: 508

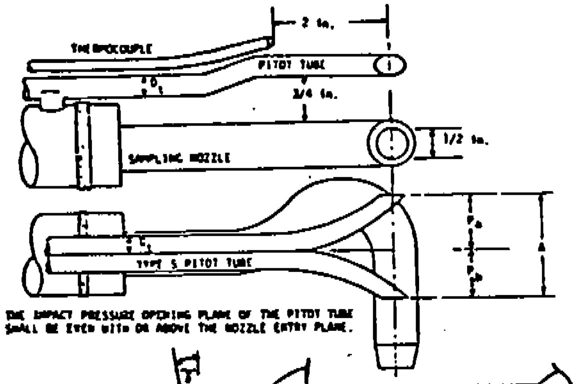
Date	Initials	Dia. 1	Dia. 2	Dia. 3	Dia. 4	Dia. 5	Average
12-2-82	ST	.306	.303	.305	.304	.306	0.305
11-14-83	PLD	.309	.309	.312	.310	.312	0.310

NOTE: All diameters measured in inches.

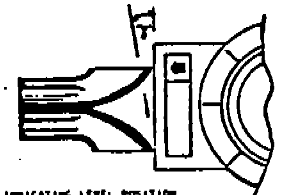
ENTROPY
ENVIRONMENTALISTS, INC.

PITOT TUBE INSPECTION DATA SHEET

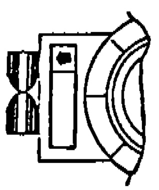
Pre-sample		Post Sample
Date 1/18/84		Date 2-20-84



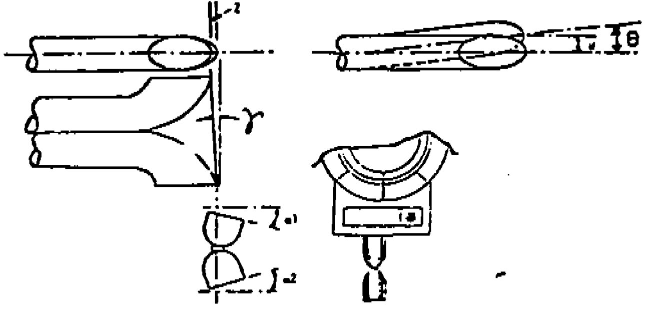
THE IMPACT PRESSURE OPENING PLANE OF THE PITOT TUBE SHALL BE EVEN WITH OR ABOVE THE NOZZLE ENTRY PLANE.



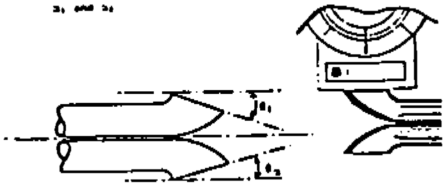
DEGREE INDICATING LEVEL POSITION FOR DETERMINING γ, THEN CALCULATING Z.



DEGREE INDICATING LEVEL POSITION FOR DETERMINING θ



DEGREE INDICATING LEVEL POSITION FOR DETERMINING Z_1 and Z_2



DEGREE INDICATING LEVEL POSITION FOR DETERMINING α_1 and β_1

YES	level?	YES
No	obstructions?	No
No	damaged?	No
1°	$-10° < \alpha_1 < +10°$	1°
1°	$-10° < \alpha_2 < +10°$	2°
0°	$-5° < \beta_1 < +5°$	0°
0°	$-5° < \beta_2 < +5°$	1°
0°	γ	1°
0°	θ	0°
.843	A	.842
.415	$1.05\ D_t < P_a < 1.5\ D_t$	.417
.428	$1.05\ D_t < P_b < 1.5\ D_t$	.425
.375	$3/16" \leqslant D_t \leqslant 3/8"$	.375
0	$A \tan \gamma < 0.125"$	.017
0	$A \tan \theta < 0.03125"$	0
YES	$P_a = P_b \pm 0.063"$	YES

GJC

Comments: ______________________

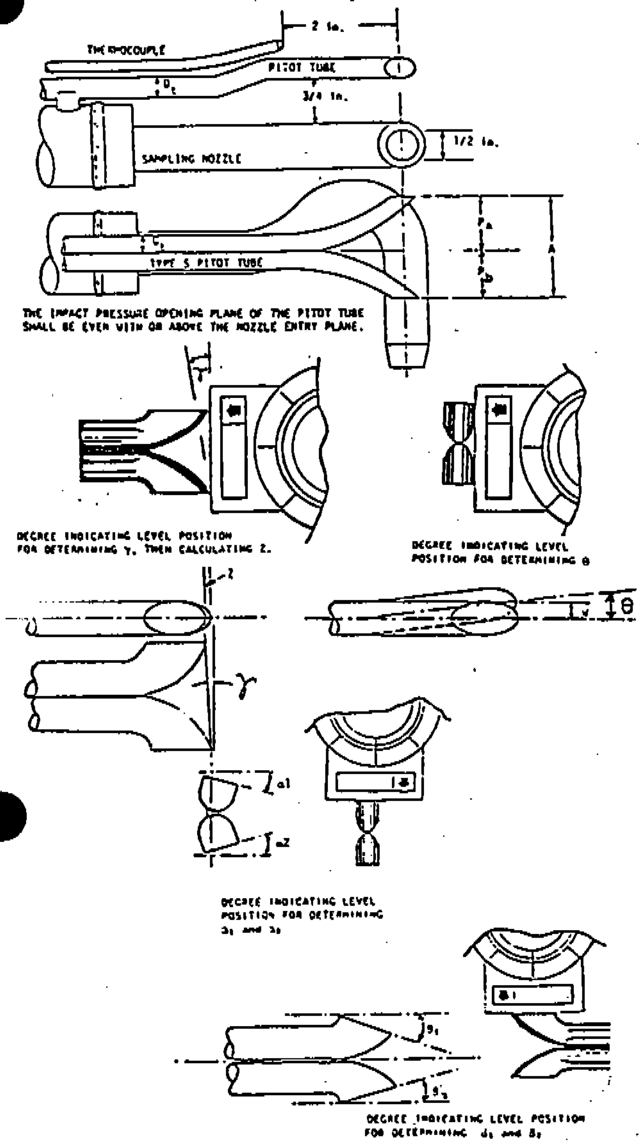
I certify that pitot tube/probe number Z-Z meets or exceeds all specifications, criteria and/or applicable design features* and is hereby assigned a pitot tube calibration factor of 0.84.

Signature Patrick L. Owen

Date 1/18/84

*See 40 CFR 60, Vol. 42, No. 160, Method 2. Verify the minimum 2 inch setback of the thermocouple and the minimum 3/4 inch separation between the pitot tube and the nozzle as shown at the top of this page.

PITOT TUBE INSPECTION DATA SHEET



THE IMPACT PRESSURE OPENING PLANE OF THE PITOT TUBE SHALL BE EVEN WITH OR ABOVE THE NOZZLE ENTRY PLANE.

DEGREE INDICATING LEVEL POSITION FOR DETERMINING γ, THEN CALCULATING Z.

DEGREE INDICATING LEVEL POSITION FOR DETERMINING θ

DEGREE INDICATING LEVEL POSITION FOR DETERMINING α_1 and α_2

DEGREE INDICATING LEVEL POSITION FOR DETERMINING β_1 and β_2

Pre-sample Date 1/19/84

Post Sample Date 2-20-84

Pre-sample		Post Sample
YES	level?	YES
No	obstructions?	No
No	damaged?	No
2°	$-10° < \alpha_1 < +10°$	2°
1°	$-10° < \alpha_2 < +10°$	0°
1°	$-5° < \beta_1 < +5°$	1°
2°	$-5° < \beta_2 < +5°$	1°
1°	γ	1°
0	θ	0
.891	A	.890
.459	$1.05\ D_t < P_a < 1.5\ D_t$	.458
.432	$1.05\ D_t < P_b < 1.5\ D_t$	.432
.375	$3/16" \leq D_t \leq 3/8"$	.375
.016	$A \tan \gamma < 0.125"$	.016
0	$A \tan \theta < 0.03125"$	0
YES	$P_a = P_b \pm 0.063"$	YES

Comments:

I certify that pitot tube/probe number 4-1 meets or exceeds all specifications, criteria and/or applicable design features* and is hereby assigned a pitot tube calibration factor of 0.84.

Signature Patrick L. Owen

Date 1/19/84

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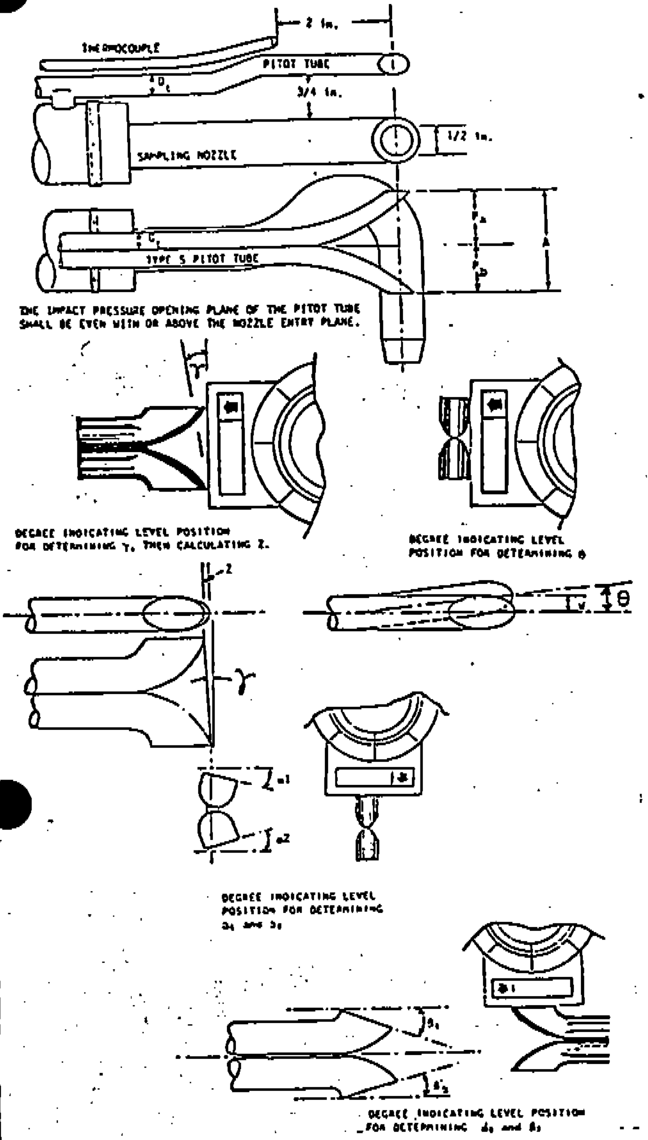
*See 40 CFR 60, Vol. 42, No. 160, Method 2. Verify the minimum 2 inch setback of the thermocouple and the minimum 3/4 inch separation between the pitot tube and the nozzle as shown at the top of this page.

PITOT TUBE INSPECTION DATA SHEET

Pre-sample Date 1-27-84

Post Sample Date 2-20-84



YES	level?	YES
NO	obstructions?	NO
NO	damaged?	NO
3°	$-10° < \alpha_1 < +10°$	3°
-3°	$-10° < \alpha_2 < +10°$	-2°
0	$-5° < \beta_1 < +5°$	0°
1°	$-5° < \beta_2 < +5°$	1°
2°	γ	1°
0	θ	0
.940	A	.942
.475	$1.05\ D_t < P_a < 1.5\ D_t$	.475
.465	$1.05\ D_t < P_b < 1.5\ D_t$	.467
.374	$3/16" \leq D_t \leq 3/8"$	.374
.033	$A \tan \gamma < 0.125"$	.017
0	$A \tan \theta < 0.03125"$	0
YES	$P_a = P_b \pm 0.063"$	YES

Comments:

I certify that pitot tube/probe number A-1 meets or exceeds all specifications, criteria and/or applicable design features* and is hereby assigned a pitot tube calibration factor of 0.84.

Signature Neill M. Harden

Date 1-27-84

*See 40 CFR 60, Vol. 42, No. 160, Method 2. Verify the minimum 2 inch setback of the thermocouple and the minimum 3/4 inch separation between the pitot tube and the nozzle as shown at the top of this page.

TEMPERATURE SENSING EQUIPMENT CALIBRATION DATA

ROMETRIC PRESSURE: 29.44 DATE: 2/20/84 CALIBRATED BY: GJC

MERCURY-IN-GLASS REFERENCE NUMBER: 1962175 AMBIENT TEMP.: 67°F

CALIBRATION SYSTEM USED	POTENTIOMETER I.D. NUMBER	THERMOCOUPLE/ THERMOMETER I.D. NUMBER	REFERENCE THERMOMETER TEMPERATURE T_o (°F)	T_c (°F)	MEAN TEMPERATURE OF Hg COLUMN T_m (°F)	THERMOCOUPLE/ THERMOMETER TEMPERATURE T_t (°F)	ΔT^B $\leq 1.5\%$
Boiling H_2O	DS-1	4-5	212	214	96	213	0.15
〃	〃	8-3	212	214	97	213	0.15
〃	〃	4-11	212	214	96	213	0.15
〃	〃	3-9	212	214	96	214	0.0
〃	〃	4-3	212	214	97	213	0.15
〃	009	4-11	212	214	97	213	0.15
〃	005	4-11	212	214	96	214	0.0

CORRECTED TEMPERATURE = $T_c = T_o + -.00009\ (T_o - 20)(T_o - T_m)$

EMPERATURE DIFFERENCE = $\Delta T = \dfrac{[(T_c, {}^\circ F + 460) - (T_t, {}^\circ F + 460)]}{T_c, {}^\circ F + 460} \times 100 \leq 1.5\%$

ENTROPY