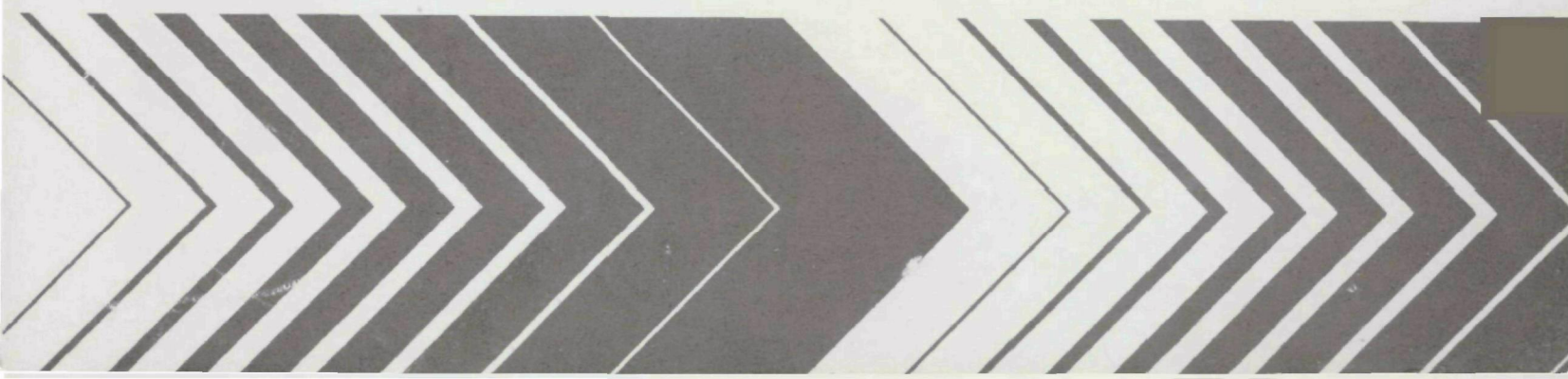




Evaluation of Wood-fired Boilers and Wide-Bodied Cyclones in the State of Vermont



EVALUATION OF WOOD-FIRED
BOILERS AND WIDE-BODIED CYCLONES
IN THE STATE OF VERMONT

Prepared By:

Cedric R. Sanborn

FOR:

THE ENVIRONMENTAL PROTECTION AGENCY
REGION I
BOSTON, MASSACHUSETTS 02203

AND

THE AIR POLLUTION CONTROL SECTION
AGENCY OF ENVIRONMENTAL CONSERVATION
DIVISION OF ENVIRONMENTAL ENGINEERING
MONTPELIER, VERMONT 05602

MARCH 1, 1979

ABSTRACT

A two part emissions testing program for the evaluation of wood-fired boilers and wide-bodied cyclones was conducted by the Vermont Agency of Environmental Conservation during the summer of 1977. The first part consisted of testing for particulate, gaseous, and organic matter from small (less than 25×10^6 BTU input) industrial wood-fired boilers. Tests were conducted on 10 boilers for total particulates, sulfur dioxide (SO_2), nitrogen oxides (NO_x), and particle sizing of the exhaust gases. The second part of the program consisted of testing particulate emissions from wide-bodied cyclones which are used by the wood products industry to collect and/or transport wood "wastes".

The primary purpose of the testing program was to qualify and quantify particulate and gaseous emissions from wood-fired boilers and to acquire a workable knowledge of the combustion characteristics of wood-fired boilers. The results of the testing program were used to develop specific regulations for emissions from wood-fired boilers and wide-bodied cyclones.

The average SO_2 emission rate was less than the minimum detectable limit of 3.4 mg/DSCM (2.12×10^{-7} lb/DSCF). NO_x emissions averaged 4.97 mg/DSCM (3.1×10^{-7} lb/DSCF), with a high concentration of 30.44 mg/DSCM (1.9×10^{-6} lb/DSCF). The low sulfur dioxide (SO_2) and nitrogen oxides (NO_x) emissions were most likely due to both the low sulfur and nitrogen content of the fuel and low firebox temperatures.

Results of particle sizing indicated that up to 40% of the particles emitted by an uncontrolled wood-fired boiler and up to 80% of the particles emitted by a controlled boiler are one (1) micron or less in diameter. There may be a potential health problem associated with wood-fired boilers, since a high percentage of the particles emitted are in the respirable range (0.1 - 1.0 microns).

The particulate emissions ranged from 0.073 - 1.142 g/DSCM (0.032 - 0.499 gr/DSCF) @ 12% CO_2 (excluding boiler H), with an average rate of 0.684 g/DSCM (0.299 gr/DSCF).

The results of comparison testing between EPA Method 5 and the high-volume test method indicates that statistically there is no significant difference in the overall means between the two methods. However, it was found on a case by case basis there may be a substantial difference (up to 53%).

Results of the wide-bodied cyclone tests indicate that if the amount of sanderdust introduced to the unit is kept to a minimum, the unit will be able to meet a particulate emission standard of 0.137 g/DSCM (0.06 gr/DSCF). The average emission rate was found to be 0.114 g/DSCM (0.05 gr/DSCF) with a low rate of .009 g/DSCM (0.004 gr/DSCF). Based on field observations, if the opacity of the cyclone exceeds 20%, the unit is probably incapable of meeting the 0.137 g/DSCM (0.06 gr/DSCF) standard.

	<u>Page</u>
FIGURES	iii
TABLES.	iv
NOMENCLATURE.	v
ACKNOWLEDGEMENT	vi
INTRODUCTION.	1
CONCLUSIONS	2
Part I - WOOD-FIRED BOILERS	5
SECTION	
2. BACKGROUND	6
3. TEST METHODS	7
4. TYPES OF BOILERS	17
5. FUEL	24
6. CONTROLS	27
7.0 EMISSIONS.	28
7.10 GENERAL DISCUSSION	28
7.20 CALCULATION TECHNIQUES	34
7.21 $1\text{b}/10^6$ BTU INPUT	34
7.22 gr/DSCF @ 12% CO ₂	35
7.23 EMISSION RATES	42
7.30 COMPARISON OF HIGH VOLUME & METHOD 5 TESTS	44
7.40 PARTICLE SIZING.	58
8. GASEOUS EMISSIONS.	62
9. ASH ANALYSIS	66
Part II - WIDE-BODIED CYCLONES.	71
INTRODUCTION.	72
1. TEST METHODS	73

	<u>Page</u>
2. DISCUSSION	74
3. PARTICLE SIZING.	79
4. WOOD FUEL SIEVE ANALYSIS	84
REFERENCES.	86
APPENDICES	
A. REFERENCE METHODS 1-5.	A - 1
B. HIGH VOLUME TEST METHODS	B - 1
C. REFERENCE METHOD 6	C - 1
D. REFERENCE METHOD 7	D - 1
E. COMPLETE RESULTS OF METHOD 5 SAMPLING.	E - 1
F. STATE OF VERMONT WOOD BOILER REGULATIONS	F - 1
G. STATE OF VERMONT - CYCLONE REGULATIONS	G - 1

FIGURES

<u>Number</u>		<u>Page</u>
1	Particulate Sample Train	10
2	Schematic Diagram of Typical High-Volume Train	11
3	SO ₂ Sample Train	12
4	NO _x Sample Train	13
5	A & B Schematic Andersen Sample Head	14 - 15
6	Collection Substrate for Andersen Sampler.	16
7	Dutch Oven and HRT Boiler.	21
8	Small Spreader - Stoker Boiler	22
9	Pneumatic Wood Feeder For Pneumatic Stoker	23
10	Regression Analysis - Method 5 vs. High Volume (Vermont Data).	56
11	Regression Analysis - Method 5 vs. High Volume (Vermont-Boube1 Data)	57
12	Particle Size Distribution - Wood-Fired Boilers.	61
13a.	Particle Size Distribution - Wide-Bodied Cyclone	82
13b.	Particle Size Distribution - Wide-Bodied Cyclone	83

TABLES

<u>Number</u>		<u>Page</u>
1	Boiler Capacities.	19
2	Type of Fuel & Firing	20
3	Chemical Analysis of Wood Boiler Feed	26
4	Excess Air Vs. Color of Filter	30
5	Color of High-Volume Filters	31
6	Color of Impinger Water.	32
7	"F" Factors.	37
8	Emission Rate (E_C), Wood Boilers - Calculated.	38
9	Emission Rate (E_F), Wood Boilers - "F" Factor.	39
10	Comparison of Emission Rates ⁺ , E_C & E_F , Wood Boilers	40
11	Overall Comparison, E_C , E_F	41
12	Comparison of Particulate Emission Standards	43
13	Grain Loadings Corrected to 12% CO ₂ - Method 5	46
14	Grain Loadings Corrected to 12% CO ₂ - High-Volume.	48
15	Comparison of Grain Loadings Corrected to 12% CO ₂ , Method 5 Vs. High-Volume.	50
16	Overall Comparison of Method 5 and High-Volume, Corrected to 12% CO ₂	51
17	Impactor Data - Boilers.	59
18	Results of NO _x Sampling.	63
19	Vermont Wood Ash Analysis by AA.	68
20	Vermont Wood Ash Analysis by XRF	69
21	Ash Sample Location.	21
22	Material Handled by Cyclones During Test	76
23	Cyclone Emission Data.	77
24	Impactor Data - Cyclones	80
25	Sieves Analysis.	85

NOMENCLATURE

- \bar{d} - Difference of population mean
 dF - Degree of freedom
 DSCF - Dry Standard Cubic Feet
 DSCM - Dry Standard Cubic Meter
 g - Gram
 gr - Grain
 H_a - Research Hypothesis
 H_0 - Null Hypothesis
 H.P. - Horse Power
 H-V - High-Volume Test Method
 M-5 - EPA Reference Method 5
 mg - Milligram
 N - Population (sample) Size
 NO_x - Oxides of Nitrogen
 R^2 - Coefficient Correlation
 S - Standard Deviation
 SO_2 - Sulfur Dioxide
 S_d - Standard Deviation of the Differences
 S_x - Standard Error of the Mean
 T - Test statistic
 T_α - T Distribution
 u - Mean Grain Loading
 \bar{x} - Population Mean
 XRF - X-ray Fluorescence
 α - Probability (Type I)
 β - Probability (Type II)

ACKNOWLEDGEMENT

Chief Technician for the Vermont Field Testing was Lawrence McGill. Assistance was also provided by George Apgar, Lena Blaise, Richard Cambio, Richard Couture, James Feeley, Harold Garabedian, Christian Jones and Paul Wishinski. Sample preparation and laboratory analysis were conducted by the Vermont Industrial Hygiene Laboratory under the supervision of Benjamine Levadie. Analysis were performed by Michael Blanchet, Cindy Parks, and Debbie Volland.

Graphical assistance was provided by Gary Durkee.

The x-ray fluorescence analysis was done by Dr. Thomas Spittler, United States Environmental Protection Agency, Lexington, Massachusetts.

Fuel analysis were made by Schwartzkopf Microanalytical Laboratory, Woodside, New York.

INTRODUCTION

A two part emissions testing program for the evaluation of wood-fired boilers and wide-bodied cyclones was conducted by the Vermont Agency of Environmental Conservation and the GCA/Technology Division during the summer of 1977. The first part consisted of testing for particulate, gaseous, and organic matter from small (less than 25×10^6 BTU input) industrial wood-fired boilers. The State of Vermont conducted tests on 10 boilers for total particulates, sulfur dioxide (SO_2), nitrogen oxides (NO_x), and particle sizing of the exhaust gases. The GCA tests were for evaluation of the organic compounds of the flue gas. GCA tested five of the above mentioned boilers. The second part of the program which was done by the State of Vermont consisted of testing particulate emissions from wide-bodied cyclones which are used by the wood products industry to collect and/or transport wood "wastes".

The primary purpose of the testing program was to qualify and quantify particulate and gaseous emissions from wood-fired boilers and to acquire a workable knowledge of the combustion characteristics of wood-fired boilers. As more and more facilities turn to the burning of wood as a primary fuel, the need for specific emission regulations for wood-fired boilers becomes apparent. The results of the program were used to develop these regulations for Vermont.

Additional boiler tests were made by the State of Vermont during the summer of 1978. Some of the data generated from these tests have been included in this report.

In order to maintain the confidentiality of the results, each facility has been coded with a letter (A,B,C, etc.). The boilers in the original study are coded as A, B, C, D, E, F, G, H, I, and J, with boilers N and O added in 1978. The cyclones are designated as B, D, E, F, I, J, K, L, and M. Each cyclone at a facility was also assigned a number (1, 2, 3 etc.).

SECTION 1

CONCLUSIONS

Both sulfur dioxide (SO_2) and nitrogen oxides (NO_x) emissions are relatively low. This is due to both the low sulfur and nitrogen content of the fuel and a low firebox temperature. The average SO_2 emission rate was less than the minimum detectable limit of 3.4 mg/DSCM (2.12×10^{-7} lb/DSCF). NO_x emissions averaged 4.97 mg/DSCM (3.1×10^{-7} lb/DSCF), with a high concentration of 30.44 mg/DSCM (1.9×10^{-6} lb/DSCF) and a low concentration of 1.59 mg/DSCM (9.9×10^{-8} lb/DSCF).

Results of particle sizing indicated that up to 40% of the particles emitted by an uncontrolled wood-fired boiler are one (1) micron or less in diameter. The single unit (N) that was equipped with a multiclone collector had a particulate size distribution showing 80% of the particles to be less than one (1) micron. There may be a potential health problem associated with wood-fired boilers, since a high percentage of the particles emitted are in the respirable range (0.1 - 1.0 microns).

The particulate emissions ranged from 0.073-3.549 g/DSCM (0.032 - 1.551 gr/DSCF) @ 12% CO_2 . However boiler (H), with the high emission rate of 3.549 g/DSCM (1.551 gr/DSCF) @ 12% CO_2 is not considered to be representative of normal boiler operation. The second highest emission rate was 1.142 g/DSCM (0.499 gr/DSCF) @ 12% CO_2 . The average particulate emission rate for boilers (excluding H and A) was 0.684 g/DSCM (0.299 gr/DSCF) @ 12% CO_2 . It is interesting to note that the four boilers which are hand fired had the lowest particulate emission rates.

It was found that the majority of the boilers operated with 250-400 percent excess combustion air. This leads to excess particulate (fly ash and unburned carbon) carryover, as well as reduced combustion and boiler efficiency. Both the placement and amount of combustion air is critical to proper operation of wood-fired boilers. Since wood is approximately 80% volatiles, the majority of the required air is needed to provide a secondary combustion zone for the volatiles which are driven off as the wood first starts to burn. Only a minimum amount of air is needed to maintain combustion of the

fixed carbon. Not only is the fly ash carried over, but it is also possible to carry out unburned carbon particles which are lifted from the bed, as well as the fines in the fuel which may not even reach the primary combustion zone. Two of the boilers, E and F, which had emission rates in excess of the Vermont standard of 1.03 g/DSCM (0.45 gr/DSCF) @ 12% CO₂, have had their air systems modified to reduce the amount of combustion air. The two units were both retested (1978) after modification, and in both cases the particulate emission rate was reduced by more than 50%. Not only were the particulate emissions reduced but the overall combustion efficiency and firebox temperature increased, while the fuel usage was reduced. Therefore, in most cases for boilers similar to the ones that were tested, a reduction of excess air and proper placement of the air, will reduce emissions to meet standards. It will not be necessary in most cases to install add on control equipment.

The results of the comparison testing between EPA Method 5 and the high-volume test method indicates that there is no significant difference in the overall means between the two methods. However, it was found on a case by case basis there may be a substantial difference (up to 53%). The most likely reason for the difference is the overall test times. A Method 5 test is run for a minimum of one hour, while a high volume test is run for twenty (20) minutes or less. Because of its shorter test period, the high volume method is more apt to reflect any short term cycle in boiler operation. Disparity between the two methods can be reduced if five or more high volume tests are run per set. The high volume sampler is the preferred test method since it is simple and therefore easier and less expensive to use. Since it is statistically comparable to a Method 5 test, it can be used as a screening test to determine if a Method 5 test would be required or perhaps as a compliance test.

Results of the wide-bodied cyclone tests indicate that if the amount of sanderdust introduced to the unit is kept to a minimum, the unit will be able to meet a particulate emission standard of 0.137 g/DSCM (0.06 gr/DSCF). The average emission rate was found to be 0.114 g/DSCM (0.05 gr/DSCF) with a low rate of .009 g/DSCM (0.004 gr/DSCF). A cyclone that handles hardwood waste has the potential for higher emissions, since hardwood

particles have a lower resin content than softwood particles and therefore do not have a tendency to agglomerate. A unit that handles large amounts of sander or planer dust will probably not be able to meet a 0.137 g/DSCM (0.06 gr/DSCF) standard. Based on field observations, if the opacity of the cyclone exceeds 20%, the unit is probably incapable of meeting the 0.137 g/DSCM (0.06 gr/DSCF) standard.

PART 1

WOOD-FIRED BOILERS

SECTION 2

BACKGROUND

There are approximately 45 industrial wood-fired boilers in Vermont at the present time. The largest of these is rated at 30.2 million K cal/hr. (120×10^6 BTU/hr), although the average size is 1.6 million K cal/hr (6.5×10^6 BTU/hr). The largest boiler tested during the original program was rated at 5.5 million K cal/hr (22×10^6 BTU/hr.). A wide range of emission rates will be found due to variations in boiler design, feed system, type of wood fuel, and most importantly the degree of operator control. Several of the boilers have been modified at least once and may bear little resemblance to the original unit. Less than 10% of the boilers are equipped with emission control equipment. The collectors used for the older boilers (pre 1975) are instack fly ash collectors, with the newer units equipped with multi-clones. The maximum steam pressure that the pre-1975 boilers operate at is 150 psi.

Extensive testing has been done on large, high pressure (200-600 psi) boilers in the Northwest to determine particulate and gaseous emissions. These units burn Western woods (Douglas Fir, Redwood, etc.), with the majority of them burning a bark and wood mixture, with a high percentage of bark. The boilers in Vermont primarily burn Eastern kiln-dried hardwoods, with little or no bark content. Thus, the results of the Western studies may not be applicable to boilers in the Northeast, Vermont in particular.

SECTION 3
TEST METHODS

3.10 Particulates

Testing for particulates was performed using two different test methods: a) EPA Method 5, which is the standard test method, and b) a high-volume test method, which is being considered as an alternate and comparative test method. The original scope of work called for simultaneous testing with the two methods, however due to the small size of the stacks (0.81 - 1.22 meters diameter) it was felt that the high volume method would cause undue interference with the Method 5 test, therefore the two methods were not run simultaneously.

3.11 Method 5

The Method 5 tests were performed in accordance with 40 CFR 60, Appendix A, Reference Methods 1-5, as specified prior to the August 18, 1977 revisions. Due to time restrictions, the sampling time was reduced from five minutes to three minutes per point for those locations where the number of required sampling points exceeded 24.

For a Method 5 test, particulate matter is withdrawn isokinetically from the stack and passed through a heated box containing a fiberglass filter. The gas is then cooled in an impinger box to 70°F or less, before it enters a dry gas meter which measures the total gas flow in dry cubic feet. The filter is removed and placed in a sample dish. The nozzle, probe, and any glassware preceeding the filter are washed with acetone and the wash placed in a sample bottle. The total amount of moisture collected in the impingers is measured. In determining the separate particulate weight gains of the filter and acetone wash, each must be dried, desiccated and weighed. See Appendix A for a copy of the reference methods. See Figure 1 for schematic of test train.

3.12 High-Volume

Testing for particulates was also performed using a manual Rader high-volume sampler. Testing was performed in accordance with methods (Modified slightly for boiler application) outlined in the Oregon Air Pollution Control Regulations (See Appendix B). The Oregon test

was used since at the time of the test program no formal ASTM or EPA test method had been developed for this test method.

For the high volume tests, from three to six sample points were used on each stack depending on the size of the stack and accessibility. In all cases the sample was drawn isokinetically for a total test time of 15-18 minutes. The test time was dependant upon the temperature of the stack, amount of particulate collected, and the moisture content of the exhaust gas. Unlike a Method 5 test train, the high volume train does not have a heated probe, glassware, or a dry gas meter. The flow through the system is controlled by a butterfly valve, while the total flow is determined using the recorded orifice pressure. After the test, the filter is removed and placed in a sample envelope. The nozzle, probe and filter housing are washed with acetone and the wash placed in a sample bottle. See Figure 2 for schematic of high volume test train.

3.20 Gaseous

3.21 Sulfur Dioxide:

Three tests for sulfur dioxide (SO_2) were performed on each boiler in accordance with EPA Reference Method 6 (See Appendix C). A gas sample was extracted from a single sampling point in the stack at a rate proportional to the stack gas velocity. The gas sample passes through a midget bubbler containing fifteen (15) milliliters (ml) of 80 percent isopropanol, which retains any acid mist and sulfur trioxide. The SO_2 in the gas stream is captured in a three (3) percent hydrogen peroxide solution in two midget impingers. A fourth and final midget impinger is left dry.

After the sample has been taken, the probe is removed from the stack and the sample train is purged with ambient air fifteen (15) minutes. After purging, the contents of the midget bubbler is discarded, and the contents of the three midget impingers placed in a sample bottle. The midget impinger and the connecting glassware are washed with distilled water and the wash added to the sample bottle. See Figure 3 for schematic of SO_x sample train.

3.22 Oxides of Nitrogen (NO_x):

Testing for NO_x was performed on each of the boilers, following test procedures outlined in EPA Reference Method 7. A grab sample is collected in an evacuated flask containing a dilute sulfuric acid - hydrogen peroxide absorbing solution. The nitrogen oxides, except nitrous oxide, are measured colorimetrically using the phenoldisulfuric acid (PSD) procedure. See Appendix D for complete testing and analytical procedures and Figure 4 for schematic.

3.30 Particle Sizing

In-stack particle sizing of the particulates was performed on each of the boilers, using an Anderson Mark III eight stage cascade impactor. The sample was withdrawn isokinetically from a single point in the stack. A single point and constant orifice pressure drop was used in order to maintain a constant velocity through the sizer. If the velocity is changed then the size of the particles collected on each plate would also change. Slotted fiberglass filters were used as the collection media (the backup filter is not slotted). Boilers C, D and F were tested without a backup filter. This will bias the results, since the particles in the <0.6 micron range were not collected. See Figure 5 a, b, and c for schematic of sampler and collection substrate.

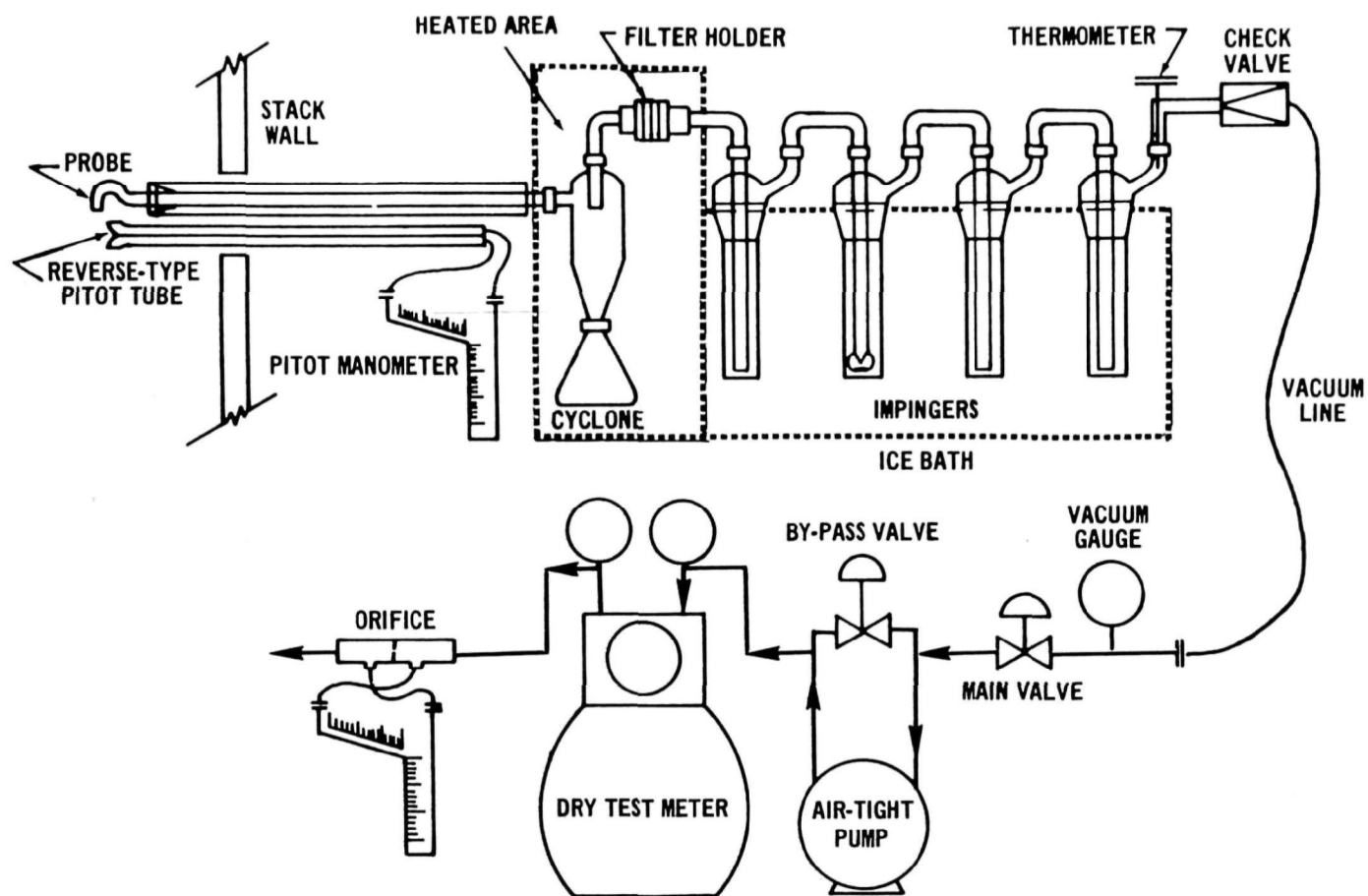
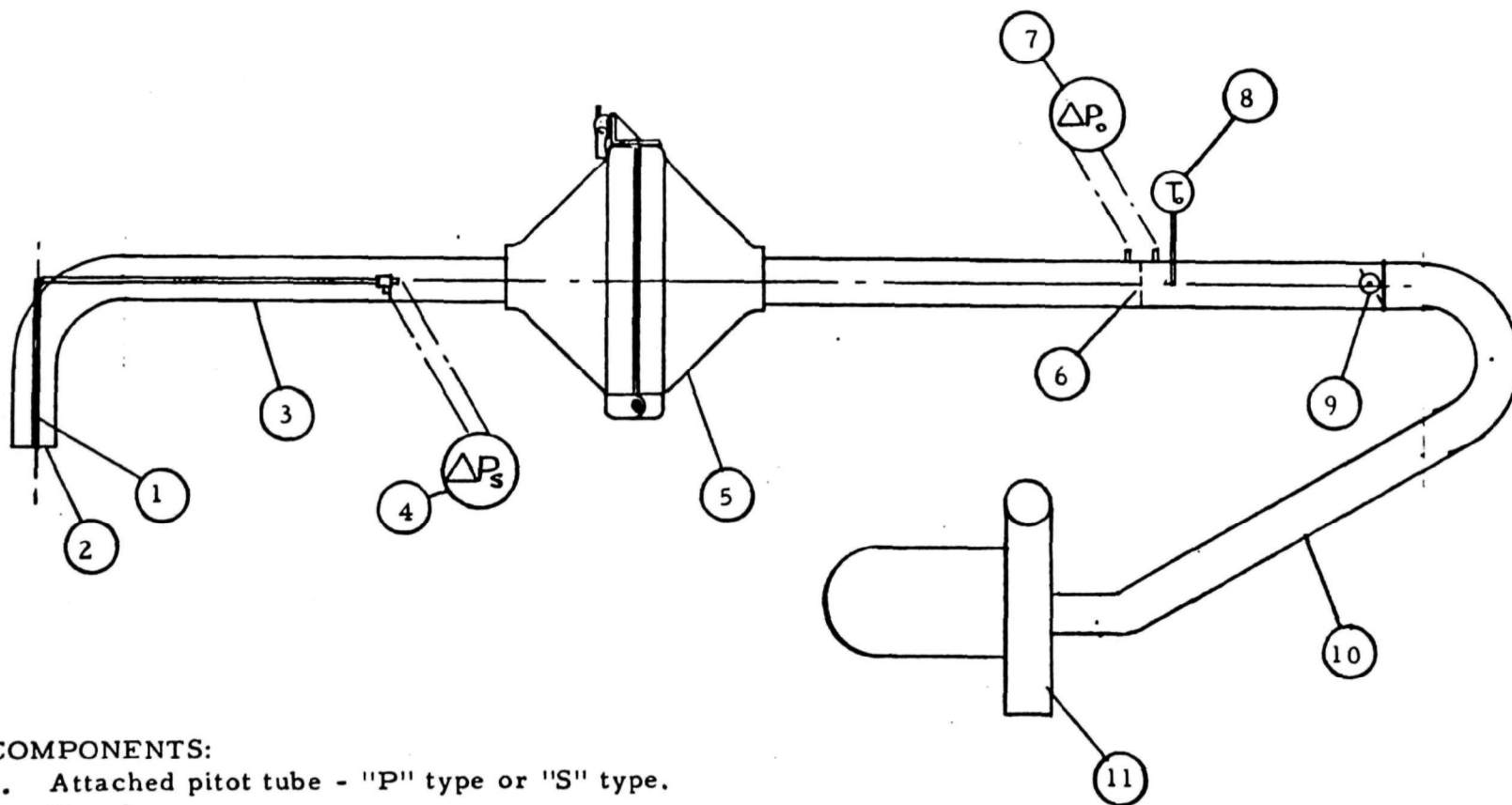


Figure 1. Particulate sampling train.

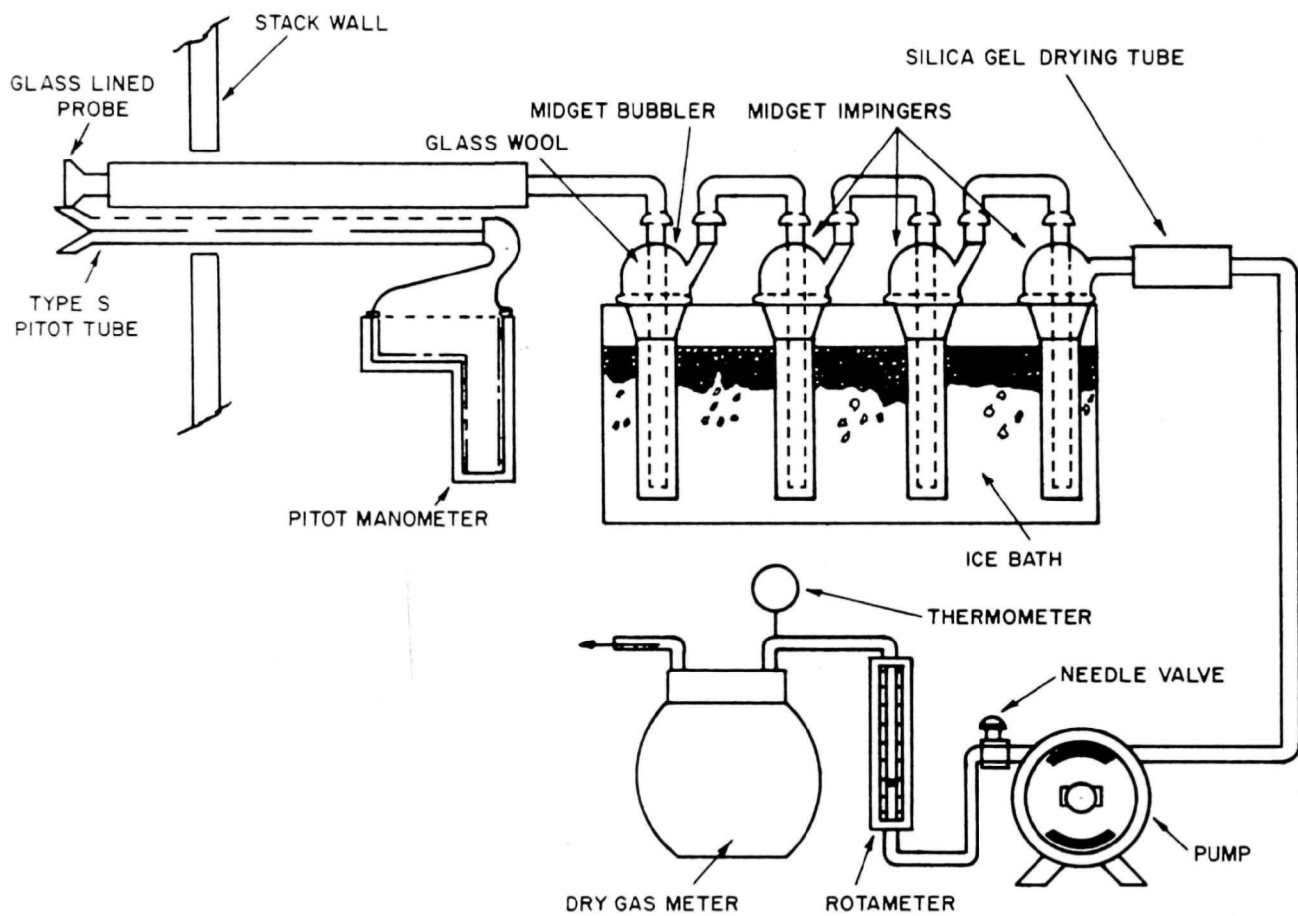
FIGURE 2
SCHEMATIC DIAGRAM
TYPICAL HIGH VOLUME PARTICULATE SAMPLING TRAIN⁸



COMPONENTS:

1. Attached pitot tube - "P" type or "S" type.
2. Nozzle
3. Probe
4. Differential pressure gauge or manometer
5. Filter holder
6. Calibrated orifice
7. Differential pressure gauge or manometer
8. Thermometer or thermocouple
9. Control valve or damper
10. Optional flexible coupling
11. High volume blower

FIGURE 3
SO₂ SAMPLING TRAIN



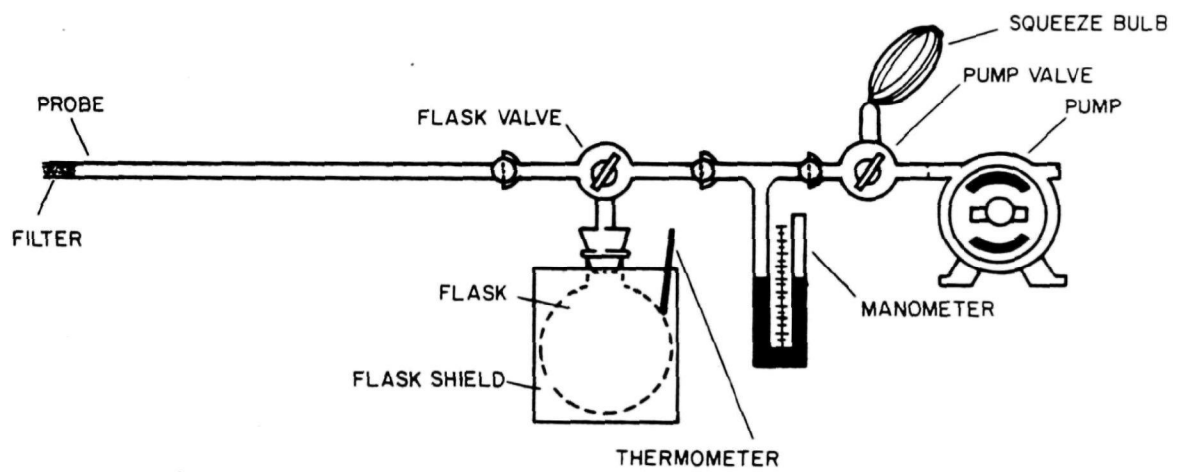


FIGURE 4
NO_x SAMPLING TRAIN

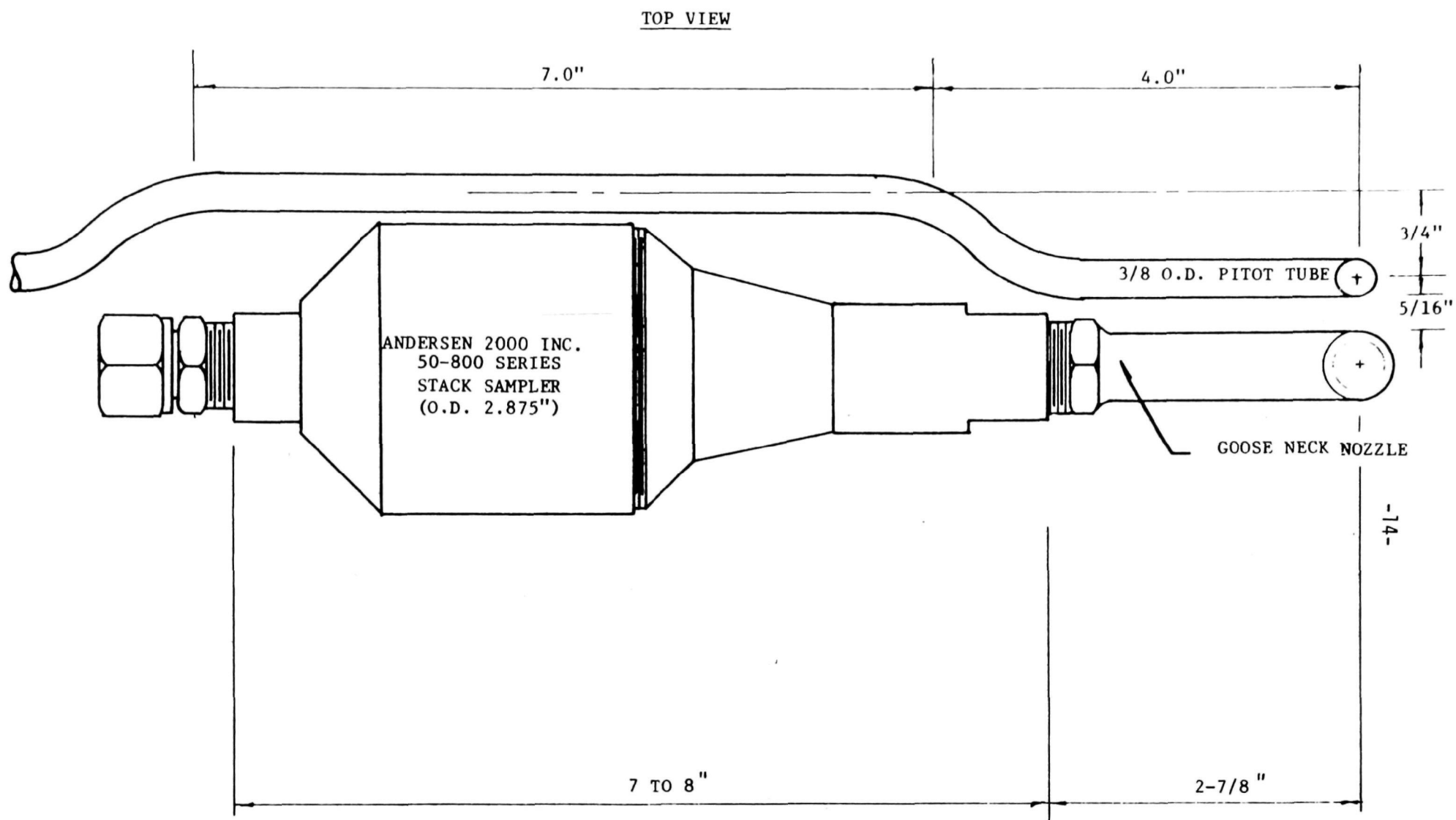


FIGURE 5A Sampler Adaptation to "EPA type" Pitot tube.⁹

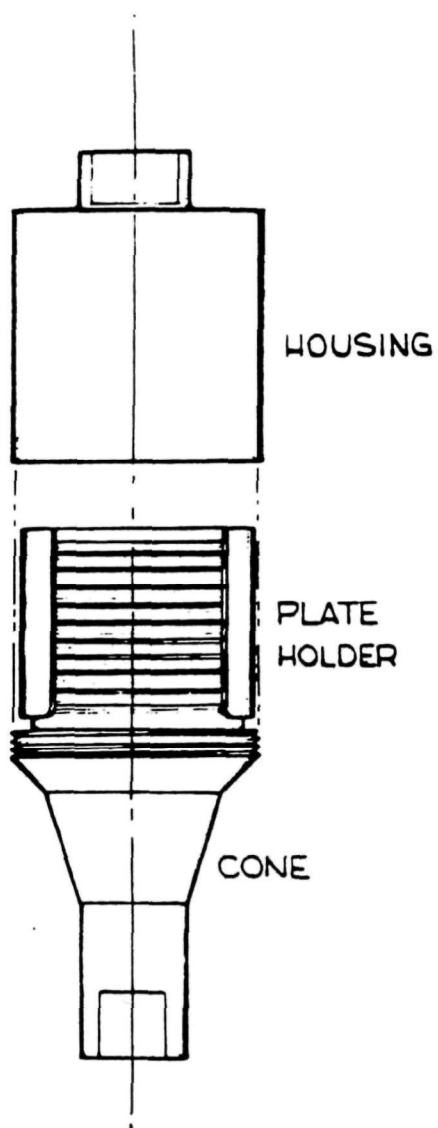
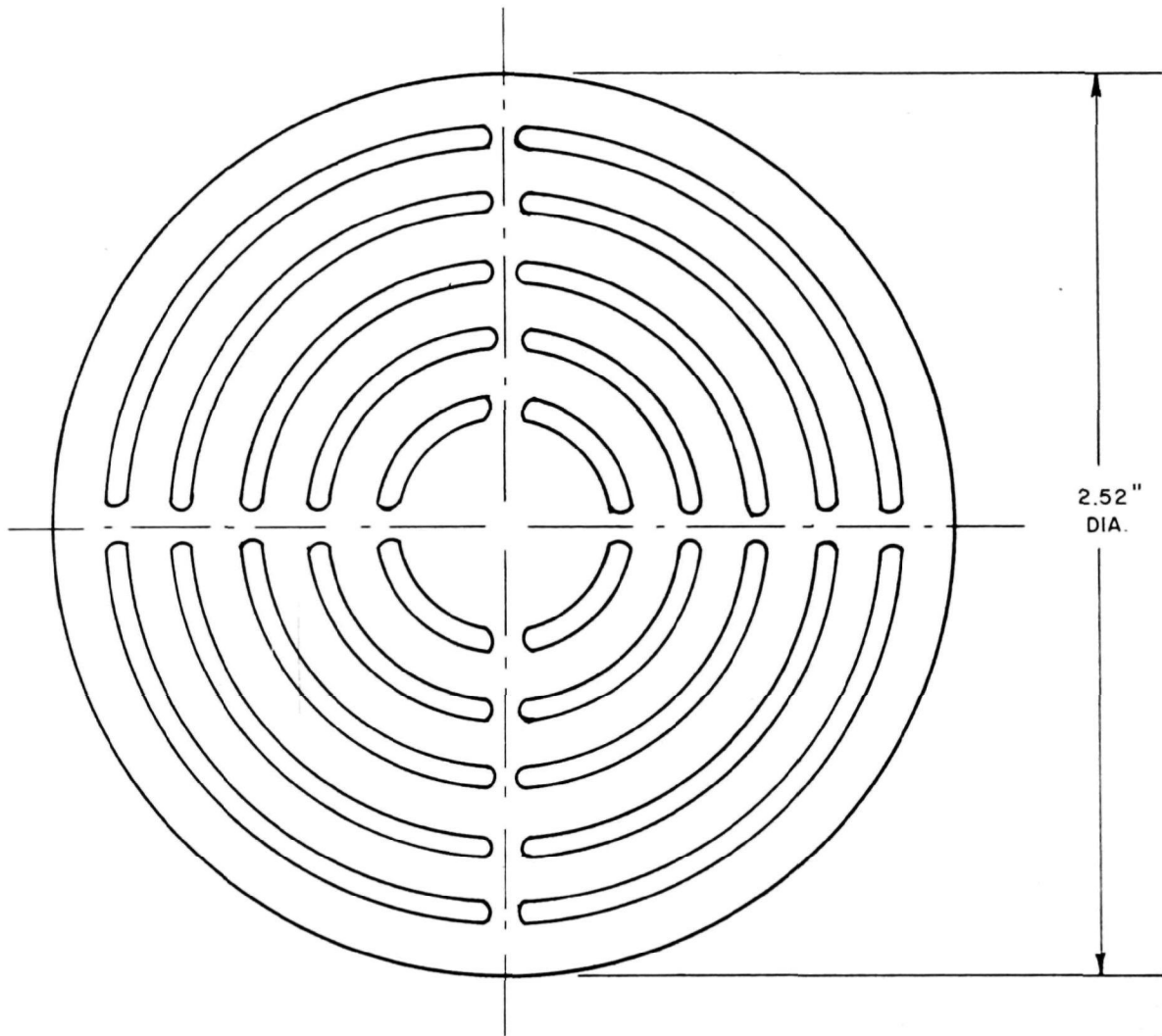


FIGURE 5B
ANDERSON SAMPLE HEAD⁹

FIGURE 6
COLLECTION SUBSTRATE PLATE⁹



SECTION 4 TYPES OF BOILERS

The two main boiler configurations that are used in Vermont are a firetube/Dutch oven and a watertube/pneumatic stoker.

The firetube boilers operate at a relatively low pressure (less than 150 psi) and generally involve pile burning of the fuel in the Dutch oven. The fuel, either fed by hand or gravity, forms a pile on the grates. The height of the pile is maintained by visual inspection and the feed rate is determined by the plant's steam demand. Underfire air passes through the grates either by forced draft or natural draft through the ash doors. Overfire air is either drawn in through the oven doors and/or through air jets in the bridge wall.

The majority of the firetube/Dutch oven boilers were manufactured prior to 1930. On some units, attempts have been made to reduce the size of the pile by feeding the fuel pneumatically. However, this method does not seem to adapt itself readily to Dutch ovens and higher particulate emissions occur (Plant C).

The Dutch oven acts as a primary combustion chamber, burning the fixed carbon in the fuel while it is in the pile. The volatiles that are driven off are combusted in the secondary combustion zone, provided adequate over-fire air is supplied. Generally the over-fire air is injected through jets in the bridge wall itself.

One interesting note is that almost no soot blowing is done on firetube boilers. The tubes are generally cleaned once a year, during the July shutdown. What effect this has on boiler efficiency has yet to be determined.

The watertube boilers generally utilize a pneumatic stoker to distribute the fuel over the fixed grates. The fuel is blown in pneumatically and forms a thin layer over the grates. Many of the smaller particles will burn while still in suspension. Underfire air comes through the grates, which helps promote primary combustion and keeps the ash and fuel from plugging the grates. Overfire air is added above the grates to form the secondary

combustion zone for the combustion of the volatiles. The rate of feed is generally controlled by a screw conveyor whose speed is controlled by the steam demand from the plant. Once the speed of the screw conveyor has been set to correspond with steam demand, a watertube/spreader stoker setup (unlike a firetube/Dutch oven) may be almost totally independent, needing little operator control. However this type of operation may actually lead to higher particulate emission rates, since the automatic controls cannot make adjustments to compensate for variations within the fuel.

The boilers that were tested ranged from a rated capacity of 150 HP to 425 HP. The State of Vermont Air Pollution Control Regulations define one (1) boiler horsepower (H.P.) as a unit that is equal to ten (10) square feet of boiler heating surface. It is common for a watertube boiler to operate at a rate that is 200% over the rated horsepower, while firetube boilers may operate at 150% of rated horsepower. Of ten boilers, five utilize pneumatic firing and five are manually fired. The type of fuel ranged from kiln dried sawdust and shavings to hogged fuel to large chunks and scraps. The boiler at Plant D burns hogged kiln dried maple which is wetted with water prior to firing. This technique increases retention time and minimizes carry over. A complete description of each boiler, and the feed system used is contained in Tables 1 & 2.

TABLE 1 - BOILER CAPACITIES

<u>PLANT</u>	<u>H.P. RATING</u>	<u>NO. BOILERS AT PLANT</u>	<u>NO. TESTED</u>	<u>MANUFACTURER OF BOILER</u>	<u>APPROXIMATE⁺ FEED RATE - Tn/Hr</u>
A	425	2	1	Riley	1.1
B	150	2	1	D. M. Dillon	0.40
C	167	2	2*	D. M. Dillon	0.40
D	150	2	1	D. M. Dillon	0.36
E	250	1	1	Keeler	0.50
F	200	1	1	D. M. Dillon	0.44
G	257	1	1	D. M. Dillon	0.62
H	300	1	1	Erie City	1.29
I	150	1	1	Dillon	0.33
J	150	1	1	D. M. Dillon	0.40

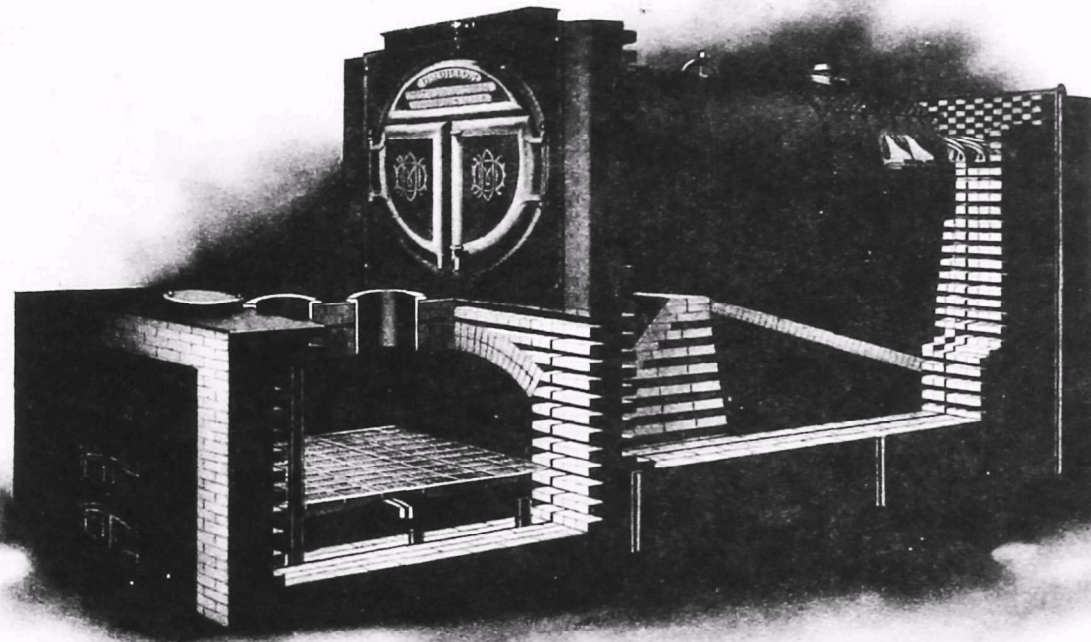
*Test done in common stack with both units in operation

⁺Feed rate during test - since tests were conducted in summer, this rate does not represent the maximum possible feed rate.

TABLE 2 - TYPE OF FUEL & FIRING

<u>PLANT</u>	<u>TYPE OF FUEL</u>	<u>CONDITION OF FUEL</u>	<u>METHOD OF FIRING</u>
A	Maple, Birch & Pine (Kiln Dried)	Hogged, shavings, sawdust	Pneumatic stoker
B	Ash Mixture Kiln Dried & Green	Shavings, sawdust, occasional hand firing	Gravity feed to pile on grates
C	Mixture of Hard & Softwoods	Sanderdust, sawdust-some hogged fuel	Pneumatic feed to pile on grates
D	Maple - Most Kiln Dried	Hogged fuel, shavings, saw- dust-material wetted before firing-occasionally wet sawdust & bark used	Hand fired
E	Oak - Maple & Pine (Kiln Dried)	Hogged, shavings, sawdust, sanderdust	Pneumatic stoker
F	Maple (Kiln Dried)	Hogged, shavings, sawdust,	Pneumatic stoker
G	Mixture of Hard & Softwoods	Edgings-Plywood scrap	Hand fired
H	Mixture of Hard & Softwoods	Hogged-Plywood scrap, cores, bark, veneer scraps	Pneumatic stoker
I	Mixture of Maple & Pine - Mostly Kiln Dried	Shavings, sawdust, hogged fuel, occasional hand firing	Gravity feed from collector to pile on grates
J	Mixture of Hard & Softwoods	Cores, plywood trimmings, sanderdust, sawdust, veneer scraps	Hand fired & gravity feed from collectors

D. M. DILLON STEAM BOILER WORKS INC., FITCHBURG, MASS.



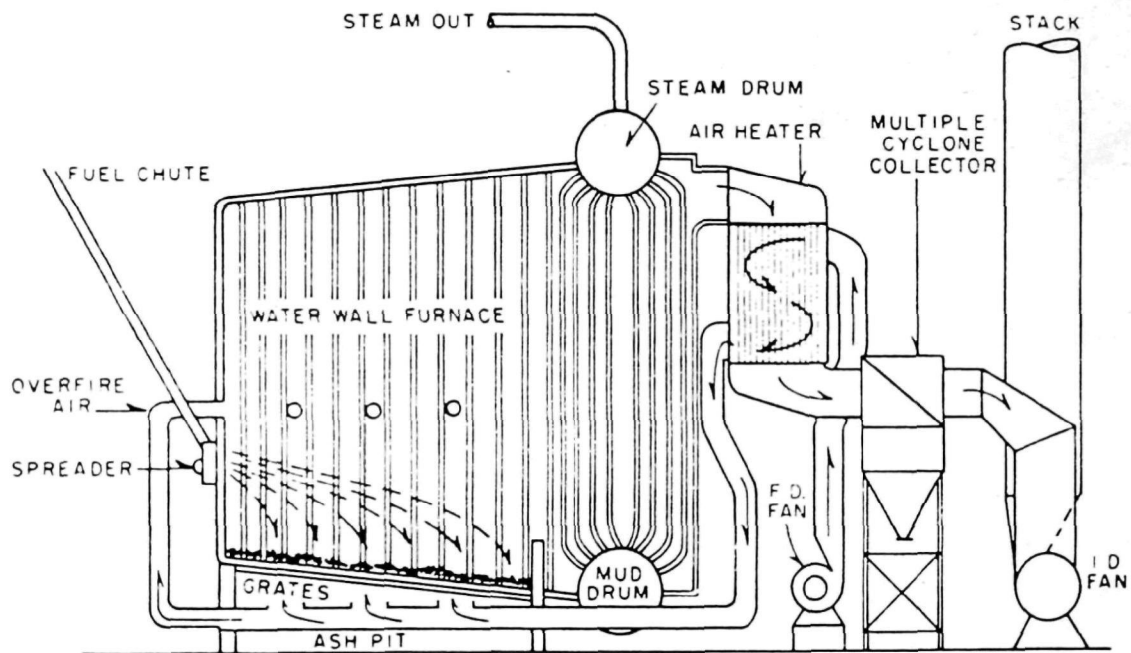
Setting of Horizontal Return Tubular Boiler

Showing Extension Front or Dutch Oven

This form of setting is used in sawmills and other plants where sawdust, shavings and slabs constitute the bulk of fuel. Sawdust and shavings are fed through the openings on top of furnace, while the regular fire doors are used for coal and large slabs. On account of the large grate which is installed with this form of setting, the full rating of the boiler is obtained when green fuel is used.

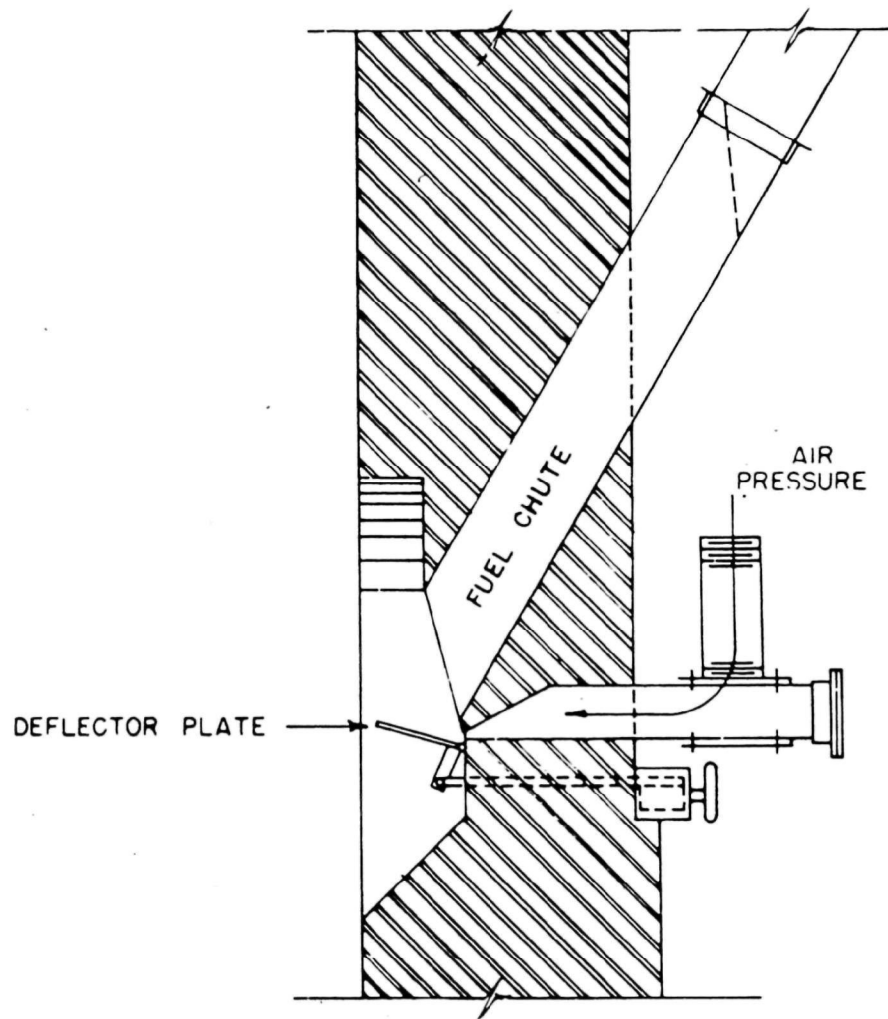
FIGURE 7

FIGURE 8



Small spreader-stoker furnace.

FIGURE 9
PNEUMATIC WOOD FEEDER FOR PNEUMATIC STOKER



PNEUMATIC STOKER

SECTION 5

FUEL

Most of the wood fuel that is burned is generated as waste within the plant, and has a moisture content that varies from 6% (kiln dried) to approximately 60% (green). The furniture manufacturers use primarily kiln dried fuel consisting of sawdust, shavings, hogged fuel, and limited quantities of sanderdust. The use of sanderdust is limited, due to the fact that it can be highly explosive. The species, size, and moisture content of the fuel varies, depending on the type of wood processed at a given facility, the type of operation, the availability of the wood waste and the boiler feed systems. (See Table 2) A spreader stoker requires that the larger pieces be hogged, while a Dutch oven can be hand fired with chunks and large pieces.

One of the main advantages of wood is that its composition (based on an ultimate analysis) is relatively constant from species to species, which is beneficial to good combustion control. Its main disadvantage is that the fuel mixture as it is fed to the boiler is not uniform. This lack of uniformity may cause a temporary or periodic "smokey" condition which requires an operator to correct. Wood has low sulfur (less than 0.05%) and ash (less than 5%) content.

The average S_2 , N_2 and ash content (by weight) was 0.02 percent, 0.18, and 0.72 respectively, excluding plants G, H, and J. These three have been excluded since the fuel used at each plant contains large quantities of plywood scraps. It was felt that the glue in the plywood adversely affected the results of the analysis. For example the fuel used at Plant G, which burns exclusively plywood scraps, had an ash content of eight (8) percent, while the average for raw wood was 0.72 percent. Due to its overall low S_2 , N_2 and ash content, wood is desirable as fuel. Wood fuel contains 70-80 percent volatiles with the remainder of it being ash and fixed carbon. Due to the high volatile content, wood has burning characteristics similar to those of a gaseous fuel, rather than a solid fuel such as coal. Because the volatiles are driven off as the wood starts to burn, a secondary combustion zone must be provided above the bed in order to utilize these gases.

The BTU value for hardwoods is less than 8,500 BTU per dry pound of wood. Bark and softwoods have a slightly higher BTU value per pound since they contain more resins than the hardwood. However, particulate emissions from bark are higher since they usually contain large amounts of dirt, sand, etc. Bark also has a higher sulfur content (up to 0.1%). Dry, resin-free wood has a high heat value (hhv) of 8,300 BTU/lb., while the hhv of resin alone is 16,900 BTU/lb.³ Thus a high resin content will increase the overall hhv of the fuel.

Less than 10% of the wood-fired steam generators in Vermont utilize bark, keeping potential emissions to a minimum. There is only one boiler that uses fly ash re-injection which provides an opportunity for additional combustion of any unburned carbon particles. However, re-injection may also lead to higher particulate emission rates.

TABLE 3 - CHEMICAL ANALYSIS OF WOOD BOILER FEED

<u>FACILITY</u>	<u>H</u>	<u>C</u>	<u>S</u>	<u>N</u>	<u>O</u>	<u>ASH</u>	<u>HEATING VALUE, BTU/DRY LB.</u>	<u>PERCENT MOISTURE</u>
A	6.19	48.57	0.005	0.086	41.70	0.23	8,360	5.5
B	6.10	47.78	0.025	0.10	38.74	0.85	8,440	23.4
C	6.12	48.45	0.019	0.88	38.47	0.32	8,392	10.8
D	6.11	47.36	0.007	0.074	41.36	1.12	8,430	8.3
E	6.24	47.57	0.004	0.065	41.54	0.33	8,220	5.9
F	6.26	47.73	0.018	0.083	41.14	0.44	8,387	5.3
G	5.93	46.30	0.057	2.00	39.44	8.25 7.71	8,400	11.4
H	5.36	45.11	0.032	0.34	39.44	2.80 2.08	8,056	27.8
I	6.30	49.51	0.014	0.094	39.69	0.79	8,856	5.8
J	6.14	47.16	0.032	1.77	39.21	1.17	8,300	10.5
N	6.34	48.52	0.021	0.10	42.46	0.72	8,264	50.3
O	6.44	47.51	0.027	0.15	41.84	1.43	8,241	46.4

SECTION 6

CONTROLS

The primary control device presently used on most boilers is an optical opacity monitor. When the opacity reaches a preset point, usually 20% opacity, the operator is alerted and can then make the necessary changes to combustion conditions to reduce the visible emissions. In some cases an additional overfire air fan also comes on automatically when the preset point is reached.

An add-on control device that is used most often for pre-1975 boilers is an instack fly ash collector. Three of these are in use at this time.

The boiler at Plant E is the only unit equipped with an instack collector that was tested. The ash that is collected by this system is not reinjected to the boiler. The newer boilers are all equipped with multiclone type collectors.

While both the instack collector and the multiclone effectively capture the larger particles (greater than 10 microns), they do nothing to reduce visible emissions caused by smoke. Only an operator can make the necessary adjustments to the boiler feed and air systems to reduce visible emissions, making him the most important control factor. Also an automatic feed system cannot compensate for changes in the fuel mixture which may significantly alter the combustion characteristics causing a temporary smoking condition.

SECTION 7

EMISSIONS

7.10 General Discussion

As discussed previously, there are two main types of boiler configurations in Vermont. Each unit has its own distinct and unique set up for providing underfire air, overfire air, and damper control. The primary responsibility of the fireman has not been to provide maximum combustion efficiency, but to operate the boiler in a manner that provides the required steam load and at the same time keeps visible emissions to a minimum. Since the majority of the plants have an excess of wood waste, which is used for fuel, maintaining a high combustion efficiency has been of little concern. However, with the cost of fuel oil increasing, and excess wood "waste" becoming a saleable item, most facilities are now trying to increase combustion efficiency.

The amount of particulates emitted is dependent upon the percent excess air, fly ash carryover, condition of the fuel, and the combustion efficiency of the system. The amount of excess air required to reduce carryover should be limited to 125% for an underfired system and 50% for a primarily overfired system. As the underfire air reaches 125% or more excess air, the rate of carryover increases. On the other hand, when the percent excess air provided thru overfire air exceeds 50%, no significant change in particulate emission has been observed.⁴ The matter that is carried out by the gas is a combination of fly ash and unburned carbon.

In a system that is equipped with both overfire and underfire air, it is essential that less than 20% of the total air be underfire air. Recent studies of Junge⁴ have shown that for the best combustion efficiency with minimum particulate emissions, the percent excess air should be held between 100-130%, with an overfire air to underfire air ratio of 9 to 1.

This helps to reduce carryover, and allows the fuel to remain in the primary combustion zone longer. The high percentage of over-fire air provides the air necessary to promote combustion of the volatiles in the secondary combustion zone.

Average excess air observed during the Vermont study was approximately 300%. High excess air rates indicate that gas velocities through the boiler are too high, thus reducing retention time and increasing carryover of fly ash and unburned carbon particles. Boiler efficiency is further reduced because excess air must be raised from ambient temperature to boiler temperature, an increase that could be as much as 1800-2000°F. The placement of the combustion air is just as important as the percent excess air.

In order to burn the pile of wood in Dutch ovens, larger amounts of underfire air are needed to keep the pile from settling on the grate and smothering the fire. In the case of a spreader stoker, less underfire air will be needed, since the fuel forms only a thin bed that is readily lifted by the incoming air.

Different types of particulate carryover are apparent from a visual inspection of the test filters. In cases where high rates of underfire were used the material on the filter is black, indicating partially burned solid carbon which was lifted from the bed. This condition was more prevalent on the Dutch oven systems. For systems using a spreader stoker and large amounts of excess underfire air, the filters are brownish in color, indicating that the fines were being carried out without any combustion. This condition also exists for boilers that have the overfire air jets located immediately above the grates. The jets must be far enough above the grates so that the burning bed is not disrupted. The overfire air should also be introduced such that the fines (from a pneumatic stoker) are not carried out without ever entering the combustion zone. Where the excess air was kept to a minimum (100-200%), material on the filter appeared light grey, indicative of only fly ash carryover.

A further indication of the combustion efficiency is the color of the impinger water. Dark brown discoloration indicated high levels of volatiles which were not subjected to a proper secondary combustion zone.

Even though the percent excess air was found to be high, the stack gas velocities were found to be fairly low (less than fifteen (15) feet per second). Therefore the velocities through the boiler itself should also be relatively low, minimizing carryover.

TABLE 4 - EXCESS AIR VS. COLOR OF FILTER

<u>PLANT</u>	<u>TEST</u>	<u>% EXCESS AIR</u>	<u>COLOR OF FILTER</u>
A	1	447	Brown
	2	1121	Grey
	3	649	Brown
B	1	317	Black
	2	328	Lt. Brown
	3	327	Lt. Brown
C	1	232	Black
	2	298	Black
	3	261	Black
D	1	219	Grey
	2	269	Black
	3	249	Lt. Grey
E	1	685	Black
	2	532	Dk. Brown
	3	385	Dk. Grey
F	1	416	Black w/wood
	2	374	Dk. Brown
	3	505	Dk. Brown
G	1	159	Lt. Grey
	2	131	Lt. Grey
	3	112	Lt. Grey
H	1	132	Dk. Grey
	2	201	Dk. Grey
	3	184	Dk. Grey
I	1	370	Black
	2	311	Dk. Brown (2)
	3	399	Black w/wood
J	1	215	Grey
	2	174	Lt. Grey
	3	177	Lt. Grey
E*	1	294	Grey
	2	279	Dk. Grey
	3	294	Grey

TABLE 5 : COLOR OF HIGH VOLUME FILTERS

<u>PLANT</u>	<u>TEST</u>	<u>COLOR</u>
A	1	Grey
	2	Brown
	3	Brown
B	1	Black
	2	Grey
	3	Dark Grey
C	1	Black
	2	Black
	3	Black
D	1	Grey
	2	Dark Grey
	3	Black
E	1	Grey with Wood Particles
	2	Dark Grey with Wood Particles
	3	Dark Grey with Wood Particles
F	1	Brown
	2	Brown with Fly Ash
	3	Light Grey
	4	Dark Brown
G	1	Light Grey
	2	Light Grey
	3	Light Grey
H	1	Grey
	2	Grey
	3	Grey
I	1	Dark Grey
	2	Black with Wood Particles
	3	Black with Wood Particles
	4	Grey with Wood Particles

TABLE 6 : COLOR OF IMPINGER WATER

<u>PLANT</u>	<u>TEST</u>	<u>COLOR</u>
A	1 - 3	Clear
B	1 - 3	Clear
C	1 2 - 3	Slightly Discolored Clear
D	1 - 3	Clear
E	1 - 3	Slightly Discolored
F	1 - 3	Brown
G	1 - 3	Clear
H	1 - 2 3	Clear Slightly Discolored
I	1 2 3	Brown Dark Brown Light Brown
J	1 - 3	Slightly Discolored
E*	1 - 3	Clear

*1978 Retest

The results of instack particle sizing show that the majority of the particles emitted are less than five (5) microns in size. As much as half of the particles were one (1) micron or less. The carryover generally seemed to be limited to the smaller size particles, another indication of low velocities through the system, even though the excess air rate was high. There is also a possibility that the fly ash particles break up relatively easy, which would increase the percent of fines emitted. The rate of break up would be increased significantly with high rates of excess air.

Another factor to be considered was the variations in the feed rate due to steam demands. If the speed of a screw conveyor is dependent upon steam pressure, a sharp increase in demand may cause temporary smothering of the fire and increase in emissions. Units that are fired independent of actual steam demand, such as those that are hand fired, may also undergo temporary smothering if the fuel is improperly charged.

The estimated particulate emission rate for a wood boiler burning bark-free fuel (5-50% moisture is 2.3 - 6.80 kg (5 - 15 lb) per ton of fuel on an as-fired basis. In cases where the fuel is kiln dried, the estimated emission rate should be closer to 2.3 kg (5 lb) per ton of fuel.¹ In most cases the emission rates from the boilers tested fell within the 2.3 - 6.8 kg (5 - 15 lb) per ton range. The main exception to this was boiler H which had severe combustion problems, as well as improperly placed overfire air jets.

7.20 Calculation Techniques

7.21 (lb/10⁶ BTU Input)

The particulate emission rate (lb/10⁶ BTU input) was calculated using both the pollutant mass rate (PMR) and the "F" factor technique.

The problem associated with using the PMR approach was that, in most cases for small industrial boilers, the BTU input to the boiler was not known, nor was the steam output known. Thus several assumptions had to be made in order to calculate the BTU input, these assumptions included boiler capacity, percent of boiler capacity in use at time of test, and overall boiler efficiency. The amount of fuel fed to the boiler may be measured directly or estimated. Depending on the feed system in use, the estimate may be based on production figures from the plant or by weighing an average charge. If the amount of steam produced can be obtained from a chart or integrator reading, it must be assumed that the chart or integrator is calibrated. If the output is known, a boiler efficiency must be assumed in order to calculate the BTU input. In any event the BTU value of the fuel must be determined, either by estimate or analysis. However, even with all the assumptions, a workable estimate of the total BTU input can be made.

An alternate method of calculating the emission rate in pounds per million (lb/10⁶) BTU input is the "F" factor approach. This approach gives an emission rate (E) using the following equation:

$$E = CF \frac{20.9}{20.9 - \%O_2} \quad (7.1)$$

where C is the concentration of the particulates in pounds per standard cubic foot of flue gas (lb/DSCF), O₂ is the percent oxygen of the flue gas and F is the ratio of the volume of dry flue gases generated to the gross calorific value (GCV) of the fuel combusted (DSCF/10⁶ BTU).

The value for C is obtained using:

$$C = 2.205 \times 10^{-6} \frac{M_n}{V_{m_{std}}} \quad (7.2)$$

where M_n is the particulate collected in mg, and V_{m_{std}} is the volume of gas sampled at standard condition (DSCF).

The value of F is determined using an ultimate analysis of the fuel and the equation:

$$F = \frac{106 \quad 3.64\% H + 1.53\% + 0.14\% H - 0.46\% O}{GCV} \quad (7.3)$$

where GCV is the gross calorific value of the fuel.

Equation 7-1 utilizes the particulate concentration determined at the stack (C), the percent O₂ at the test location, and a BTU analysis of the fuel. All of these values are readily available and the calculations fairly straight forward. In the event that an ultimate analysis is not available, a standard "F" factor of 9223 has been developed. A list of the calculated "F" factor for each test is contained in Table 7. The calculated factors are based on an ultimate analysis (Table 3) and equation 7-3. The critical factor in determining the emission rate using the "F" factor is the percent O₂. Tables 8 and 9 contain the calculated emission rates using both the "F" factor and the PMR techniques.

A comparison of the results obtained using the "F" factor and PMR approach is contained in Tables 10-11. There was no difference in the two averages, however differences of up to 50% were observed (Plant D - Table 10). Test I-2 has been excluded since it was felt, based on Tests I-1 and I-3, not to be a representative test. Plant A has been excluded from the comparison analysis between E_C and E_F, since the gas sample was not valid. This will bias the results obtained using the "F" factor approach, since the percent O₂ is a critical part of the equation. At this point it was felt that the "F" factor technique was the more appropriate method and would yield a number that was more representative of the actual emission rate. This was because no assumptions had to be made as was necessary for the PMR approach.

7.22 gr/DSCF @ 12% CO₂

An alternate approach to quantifying the particulate emission rate is grain loading. In this case the emission rate was given as grains per dry standard cubic foot of exhaust gas (gr/DSCF). Since the amount of excess air was not the same for all boilers, then a baseline had to be made so that all grain loadings were compared equally. Therefore all

measured grain loadings were corrected to 12% CO₂. This correction was made using the following equation:

$$C_c = \frac{12 C_m}{\% CO_2} \quad (7.4)$$

Where:

C_c = corrected grain loading (gr/DSCF) at 12% CO₂

C_m = measured gain loading (gr/DSCF) at stack conditions

% CO₂ = percent CO₂ measured at the sampling point.

The concentration in the stack, C_m , was determined as follows:

$$C_m = 0.0154 \frac{(MN)}{VMSTD} \quad (7.5)$$

Where:

MN = total particulate catch in milligrams

VMSTD = volume of gas sampled (FT³) at standard conditions (68°F and 29.92 in. H₂) on a dry basis.

For the grain loading technique, no assumptions regarding the boiler operation in BTU input had to be made when determining the emission rate.

TABLE 7 - "F" FACTORS

<u>PLANT</u>	<u>DSCM/J</u>	<u>DSCF/10⁶ BTU</u>
A	1.045	9291.5
B	1.033	9184.3
C	1.056	9395.1
D	1.009	8978.6
E	1.045	9294.2
F	1.041	9170.2
G	0.998	8880.3
H	0.983	8745.3
I	1.021	9083.3
J	1.041	9245.1
N	1.059	9415.2
O	1.049	9334.2
*	1.038	9233

*EPA-40 CFR 60.45 (F) (4) (v)

TABLE 8 - EMISSION RATE (E_c), WOOD BOILERS - CALCULATED

<u>PLANT</u>	<u>\bar{x}, 1b/10⁶ BTU</u>	<u>S</u>	<u>$S_{\bar{x}}$</u>
B	0.258	0.008	0.005
C	0.716	0.337	0.194
D	0.134	0.059	0.034
E	0.836	0.064	0.037
F	1.035	0.193	0.111
G	0.348	0.026	0.015
H	2.724	0.573	0.331
I	1.533	1.287	0.742
I*	0.791*	0.742*	0.524*
J	1.194	0.256	0.148

*Excluding Test No. 2

TABLE 9 - EMISSION RATE (E_F), WOOD BOILERS - "F" FACTOR

<u>PLANT</u>	<u>\bar{x}, lb/10⁶ BTU</u>	<u>S</u>	<u>$S_{\bar{x}}$</u>
B	0.167	0.006	0.003
C	0.755	0.319	0.184
D	0.068	0.024	0.014
E	1.058	0.331	0.191
F	0.923	0.304	0.175
G	0.238	0.026	0.015
H	2.981	0.610	0.352
I	1.684	1.193	0.844
I*	0.996*	0.047*	0.027*
J	0.702	0.004	0.002

*Excluding Test No. 2

TABLE 10 - COMPARISON OF EMISSION RATES⁺, E_C AND E_F , WOOD BOILERS

<u>PLANT</u>	<u>E_C, lb/10⁶ BTU</u>	<u>E_F, lb/10⁶ BTU</u>	<u>DIFFERENCE, d</u>
B	0.258	0.167	0.091
C	0.716	0.755	-0.039
D	0.134	0.068	0.066
E	0.836	1.058	-0.222
F	1.035	0.923	0.112
G	0.348	0.238	0.110
H	2.724	2.981	-0.257
I	1.533	1.684	-0.151
I*	0.791*	0.996*	-.205*
J	1.194	0.702	0.492
	<hr/>	<hr/>	<hr/>
	0.957 AVE.	0.957 AVE.	0.000 AVE.

*Excludes Test No. I-2

+Excludes Plant A

TABLE 11 - OVERALL COMPARISON* E_C & E_F

<u>Method</u>	<u>\bar{x}</u>	<u>S</u>	<u>$S_{\bar{x}}$</u>
E _F	0.957	0.861	0.272
E _C	0.957	0.757	0.239

*Excludes Plant A

7.23 Emission Rates

For discussion purposes, Plant A is excluded wherever the results are corrected to 12% CO₂. Plant H is used only for determining the high average for particulate emissions and for comparison analysis between Method 5 and the high volume method, since this boiler is not felt to be representative of normal or proper operation.

The average emission rate, using the "F" factor approach and excluding Plants A and H is 329 nanogram/J (0.76 lb/10⁶ BTU) or 2.43 Kg/hr (5.36 lb/hr).

Based on the Method 5 tests the average particulate emission rate is 0.684 g/DSCM (0.299 gr/DSCF) at 12% CO₂ which is well below the Vermont standard of 1.029 g/DSCM (0.45 gr/DSCF) @ 12% CO₂. This corresponds approximately to 5.44 Kg/hr (12 lb) per ton of fuel.

The lowest particulate emission rate was 0.073 g/DSCM (0.032 gr/DSCF) @ 12% CO₂ and 1.055 g/DSCM (0.461 gr/DSCF) at 12% CO₂ respectively, both had their air feed systems modified in early 1978. These boilers were retested in August 1978, and the emission rates were then found to be 0.398 g/DSCM (0.174 gr/DSCF) at 12% CO₂ and 0.599 g/DSCM (0.262 gr/DSCF) at 12% CO₂. This represents a 35% reduction in emissions for boiler E and a 43% reduction in emissions for boiler F. These reductions are due to reducing and reappportioning the flow of combustion air. Therefore it is possible to substantially reduce emissions by utilizing proper combustion air placement and quantities. For boilers of the type tested, add-on control equipment may not be necessary.

TABLE 12 - COMPARISON OF PARTICULATE EMISSION STANDARDS

<u>Plant</u>	EXISTING, lb/10 ⁶ BTU		PROPOSED*, GRAINS/DSCF (12% CO ₂)	
	<u>Actual</u>	<u>Allowable</u>	<u>Actual</u>	<u>Allowable</u>
A	0.382	0.34	+	0.450
B	0.258	0.50	0.081	0.450
C	0.716	0.50	0.380	0.450
D	0.134	0.50	0.032	0.450
E	0.836	0.32	0.493	0.450
F	1.035	0.50	0.461	0.450
G	0.348	0.50	0.119	0.450
H	2.724	0.26	1.551	0.450
I	0.791	0.50	0.499	0.450
J	1.194	0.50	0.330	0.450
E*	0.395	0.32	0.174	0.450
F*	0.586	0.50	0.261	0.450

*Gas Analysis not valid, emission rate (gr/DSCF) not known.

*Proposed regulations adopted, August 1978.

*Retested 1978

7.30 Comparison of High Volume and Method 5 Tests

7.31 Emission Rates

Comparison testing was originally performed on nine of the boilers, although the tests were not always run simultaneously due to limitations of the locations and/or stack size. Boiler J was not tested with the high volume sampler due to the high (greater than 500°F) stack temperature, which adversely affects the operation of the sampler. From Table 15 it can be seen that the overall grain loadings corrected to 12% CO₂ determined using Method 5 average 6.6 percent higher than the loadings determined using the high-volume sampler. For purposes of this comparison, the results of Plants A & H were included since only a comparison of the results obtained using each test method is being made. However the results of Plant A are not representative of actual emissions when corrected to 12% CO₂ due to an invalid gas sample. The average grain loading for Method 5 and the high-volume method were 1.007 g/DSCM (0.440 gr/DSCF) at 12% CO₂ and 0.940 g/DSCM (0.411 gr/DSCF) at 12% CO₂ respectively. In both cases the standard deviation (S) and the standard error of the mean (S_x) were essentially the same. A comparison of the two methods is contained in Tables 15 and 16. Although the overall difference is only 6.6 percent, it should be noted that differences of up to 53% were observed on a test by test basis. In order for the short-term high-volume sampler to produce results similar to those of Method 5, more than three runs will be needed per test site. A set of at least five runs would help to minimize the bias obtained using the high-volume sampler. The bias is due to the fact that high volume tests may reflect short-term cycles in the boiler operation, since the test period is 20 minutes or less. A Method 5 test will have less bias since the test must be conducted over a period of at least one hour. It may also be advantageous to increase the high-volume test time.

The high-volume sampling was performed using a manual Rader high-volume sampler. The major drawback of using this system to test boilers is that control of flow through the sampler is extremely difficult when stack temperature exceeds 350°F. Under such high temperatures, the sampler butterfly valve is affected. Therefore, it is possible that the total volume reported may not be equal to the actual volume sampled because the

flow must be adjusted constantly. This could account for, in part, the overall 6.6 difference in grain loading as shown in Table 15.

An automatic high volume sampler is available which, among other things, records the total amount of air sampled. This would remove most of the doubt about the total volume of air used for the calculations. It would be worthwhile to do some comparison testing between the automatic and manual samplers in order to determine if there is a significant difference in results.

TABLE 13 GRAIN LOADINGS CORRECTED TO
12% CO₂ - METHOD 5

<u>PLANT</u>	<u>TEST</u>	<u>% CO₂</u>	<u>RECORDED LOADING (gr/DSCF)</u>	<u>CORRECTED LOADING (gr/DSCF)</u>
A	1	2.2	0.083	0.453
	2	1.8	0.093	0.620
	3	1.4	0.087	0.746
	Average		0.087	0.606
B	1	4.6	0.030	0.078
	2	4.2	0.031	0.089
	3	4.6	0.029	0.076
	Average		0.030	0.081
C	1	5.0	0.237	0.569
	2	4.2	0.083	0.237
	3	5.2	0.145	0.335
	Average		0.155	0.380
D	1	6.2	0.014	0.027
	2	5.8	0.022	0.046
	3	5.4	0.011	0.024
	Average		0.016	0.032
E	1	2.2	0.129	0.704
	2	3.2	0.113	0.424
	3	4.2	0.123	0.351
	Average		0.122	0.493
F	1	3.4	0.136	0.480
	2	4.0	0.094	0.282
	3	2.8	0.145	0.621
	Average		0.125	0.461
G	1	6.8	0.078	0.138
	2	8.2	0.071	0.104
	3	9.0	0.087	0.116
	Average		0.076	0.119
H	1	7.4	0.901	1.461
	2	5.8	0.654	1.353
	3	6.6	0.012	1.840
	Average		0.856	1.551
I	1	3.8	0.163	0.515
	2	4.2	0.552	1.577
	3	3.6	0.145	0.483
	Average		0.154*	0.499*
	Average		0.287	0.858
J	1	6.0	0.164	0.328
	2	7.0	0.191	0.327
	3	6.6	0.185	0.336
	Average		0.180	0.330

*Excludes Test No. 2

Table 13 (continued)

-47-

<u>PLANT</u>	<u>TEST</u>	<u>% CO₂</u>	<u>RECORDED LOADING (gr/DSCF)</u>	<u>CORRECTED LOADING (gr/DSCF)</u>
E ⁺	1	5.2	0.071	0.165
	2	5.4	0.098	0.217
	3	5.2	0.061	0.141
	Average			0.174

+1978 Retest

TABLE 14. GRAIN LOADINGS CORRECTED
TO 12% CO₂ - HIGH-VOLUME

<u>PLANT</u>	<u>TEST</u>	<u>% CO₂</u>	<u>RECORDED LOADING (gr/DSCF)</u>	<u>CORRECTED LOADING (gr/DSCF)</u>
A	1	2.2	0.128	0.698
	2	1.8	0.070	0.4767
	3	1.4	0.061	0.523
	Average		0.086	0.563
B	1	4.6	0.048	0.125
	2	4.2	0.037	0.106
	3	4.6	0.013	0.034
	Average		0.033	0.088
C	1	5.0	0.097	0.233
	2	4.2	0.090	0.257
	3	5.2	0.086	0.198
	Average		0.091	0.229
D	1	6.2	0.027	0.052
	2	5.8	0.018	0.037
	3	5.4	0.026	0.058
	Average		0.024	0.049
E	1	2.2	0.094	0.513
	2	3.2	0.084	0.315
	3	4.2	0.089	0.254
	Average		0.089	0.361
F	1	3.4	0.156	0.551
	2	3.4	0.110	0.388
	3	4.0	0.073	0.219
	4	2.8	0.210	0.900
	Average		0.137	0.515
G	1	6.8	0.068	0.120
	2	8.2	0.056	0.082
	3	9.0	0.060	0.080
	Average		0.061	0.094
H	1	7.4	0.535	0.868
	2	5.8	1.167	2.414
	3	6.6	0.809	1.471
	Average		0.837	1.584
I	1	3.8	0.093	0.294
	2	3.8	0.190	0.600
	3	4.2	0.251	0.717
	4	3.6	0.086	0.287
	Average		0.155	0.474

<u>PLANT</u>	<u>TEST</u>	<u>% CO₂</u>	<u>RECORDED LOADING (gr/DSCF)</u>	<u>CORRECTED LOADING (gr/DSCF)</u>
E*	1	5.2	0.069	0.159
	2	5.2	0.054	0.124
	3	5.5	0.071	0.154
	4	5.1	0.069	0.162
	5	4.9	0.062	0.151
	Average			0.150

*1978 Retest

TABLE 15 - COMPARISON OF GRAIN LOADINGS
CORRECTED TO 12% CO₂. METHOD 5
VS. HIGH-VOLUME

<u>PLANT</u>	<u>\bar{x}</u> <u>METHOD 5</u>	<u>\bar{x}</u> <u>HIGH-VOLUME</u>	<u>x</u>	<u>% DIFFERENCE</u>
A	0.606	0.563	0.043	7.1
B	0.081	0.088	-0.007	-8.6
C	0.380	0.229	0.151	39.7
D	0.032	0.049	-0.017	-53.1
E	0.493	0.361	0.132	26.8
F	0.461	0.515	-0.054	-11.7
G	0.119	0.094	0.025	21.0
H	1.551	1.584	-0.033	-2.1
I*	0.499*	0.474	0.025	5.0
E ⁺	<u>0.174</u>	<u>0.150</u>	<u>0.024</u>	<u>14.0</u>
	0.440 Ave.	0.411 Ave.	0.029 Ave.	6.6 Ave.

*Excluding Test No. 2

⁺Retested 1978

TABLE 16 - OVERALL COMPARISON OF METHOD 5
AND HIGH-VOLUME, CORRECTED TO 12% CO₂

<u>METHOD</u>	<u>x, gr/DSCF</u>	<u>S Ave.</u>	<u>S_x</u>
High Volume	0.411	0.454	0.144
Method 5	0.440	0.440	0.139

7.32 Statistical Analysis

In order to determine if there is a significant difference between the particulate emission rate determined using Method 5 and the emission rate determined using the Rader high volume method, a statistical analysis of the overall results of the two test methods was made. In the event there was a significant difference between the two methods, it was hoped that a correlation between the Method 5 tests and the high volume test could be made by using linear regression techniques. A paired sample analysis of the Vermont data was made to determine if the results obtained using the two methods were statistically equivalent. Additionally, data from the Boubel Study⁵ was added to the Vermont data for purposes of performing a linear regression analysis. The combined data base should generate a line that better represents the differences, if any, in the two test methods.

STATISTICAL ANALYSIS OF METHOD 5 VS. HIGH VOLUME. CONCENTRATIONS GIVEN IN GRAINS PER DRY STANDARD CUBIC FOOT CORRECTED TO 12% CO₂.

Vermont Data

<u>PLANT</u>	<u>M-5</u>	<u>H-V</u>	<u>DIFFERENCE</u> <u>d</u>
A	0.606	0.563	0.043
B	0.081	0.088	-0.007
C	0.380	0.229	0.151
D	0.032	0.049	-0.017
E	0.493	0.361	0.132
F	0.461	0.515	-0.054
G	0.119	0.094	0.025
H	1.551	1.584	-0.033
I	0.499	0.474	0.025
E*	0.175	0.150	0.025

*1978 Retest

PAIRED SAMPLE ANALYSIS

$N = 10$ $df = 9$ $\bar{d} = 0.029$ $S_d = 0.066$ $\alpha = 0.05$

U_1 = mean grain loading (gr/DSCF) of Method 5

U_2 = mean grain loading (gr/DSCF) of high volume method

$H_0: U_1 = U_2$

$H_a: U_1 \neq U_2$

REJECT H_0 IF $|T| > T_{\alpha}$

$$T = \frac{\bar{d}}{S_d/\sqrt{N}} = \frac{0.029}{0.066/\sqrt{10}} = 1.389 \quad (7.6)$$

$T_{\alpha/2}$ from T Tables = 2.262

Since $2.262 > 1.389$ Accept Null Hypothesis (H_0)

95% Confidence Interval For Difference in Means ($U_1 - U_2 = 0$)

$$d = \bar{d} \pm T_{\alpha/2} \frac{S_d}{\sqrt{N}} \quad (7.7)$$

$$d = 0.029 \pm 2.262 \frac{(0.066)}{\sqrt{10}}$$

$$d = 0.029 \pm 0.047$$

B Analysis of Null Hypothesis (H_0)

$\alpha = 0.05$ Two-sided T Test

$$d = \frac{|d_0 - d_a|}{S_d} = \frac{|0 - 0.047|}{0.066} \quad (7.8)$$

$$d = 0.71$$

From OC Curves

$$B = 0.30$$

Linear Regression (Vermont only)

$$\hat{Y} = \hat{B}_0 + \hat{B}_1 X_1 \quad (7.9)$$

From HP-25 Program

$$\hat{B}_0 = -0.038$$

$$\hat{B}_1 = 1.021$$

$$\hat{Y} = -0.038 + 1.021 X$$

Where:

X = Grain Loading Determined Using Method 5

Y = Grain Loading Determined Using High-Volume

$$R^2 = 0.979$$

Linear Regression (Vermont & Boubel)

Additional data points (Boubel)

<u>Modified M-5</u>	<u>High-Volume</u>	<u>Difference</u>
0.138	0.204	-0.066
0.263	0.223	0.040
0.186	0.265	-0.079
0.234	0.240	-0.006
0.116	0.106	0.010
0.086	0.113	0.027
0.254	0.246	0.008

$$\hat{Y} = \hat{B}_0 + \hat{B}_1 X_1$$

From HP-25 Program

$$\hat{Y} = -0.007 + 0.990 X$$

$$R^2 = 0.971$$

From the paired sample analysis of the Vermont data, using a significance level of $\alpha = 0.05$, it can be seen that the critical T value (T_{α}) of 2.262 is greater than the test statistic (T) of 1.389. Since the value of T does not exceed the T_{α} value, the null hypothesis (H_0), that the values of the two mean grain loadings U_1 and U_2 are not significantly different (i.e., $U_1 = U_2$) can be accepted.

However there is still some risk or probability that the null hypothesis (H_0) is incorrectly accepted using the above technique. This is known as the B risk. From the results of the B test above, it can be seen that there is a 30% probability of incorrectly accepting the null hypothesis (H_0) that there is no significant difference in the means. Therefore, there is a possibility that 30% of the time the two means (U_1 and U_2) may be significantly different even though the T test indicates no difference. This difference can be seen from the results of Table 15, where the following differences in the means are observed; Plant C-40%, Plant E-27%, and Plant D-53%.

A linear regression was done in order to correlate the values obtained using the high volume method and Method 5. For the first regression analysis, the ten data points from the Vermont Study only were used (See Figure 10). The calculated equation for the line ($y = 0.038 + 1.021x$) shows almost a one to one relationship between the two test methods. The R^2 value of 0.979 reflects minimal scattering of the data and indicates a good fit of the line to the data points.

For the second linear regression, the results of the Boubel⁵ study were added to the Vermont data. The calculated equation of the line ($y = 0.007 + 0.990x$) changed slightly due to the overall effect of the additional data points. (See Figure 11). Again, a relatively high R^2 value (0.971) was obtained.

It can be shown statistically that at a significance level of 0.05 there is no significant difference between the results obtained by the two test methods. It would appear in the case of wood-fired boilers that the shorter and easier high volume test method could be used in place of the more complex Method 5. However, it can be seen from the results of the Vermont study that the actual differences may be as much as 50% on a case by case basis. This should be kept in mind if the high volume test is substituted for the Method 5 test.

One possible way to minimize the difference would be to conduct a series of at least five (5) high volume tests per test set rather than the customary three. Because the high volume test is generally only 15-18 minutes, it is possible to bias the test due to fluctuations in the boiler load and feed rate which may cause a corresponding change in the emission rate. By performing more than three tests, the overall test time will be increased and the bias minimized. Currently, more comparison testing is being conducted by the State of Vermont to substantiate the hypothesis that the two test methods are not significantly different. In any event, the high volume test method can be used as a relatively inexpensive screening method to see if the more complex Method 5 test is required. With a sufficient number of tests (5 or more) per test location, the results obtained using the high volume test method should be equivalent to those obtained using the Method 5 tests.

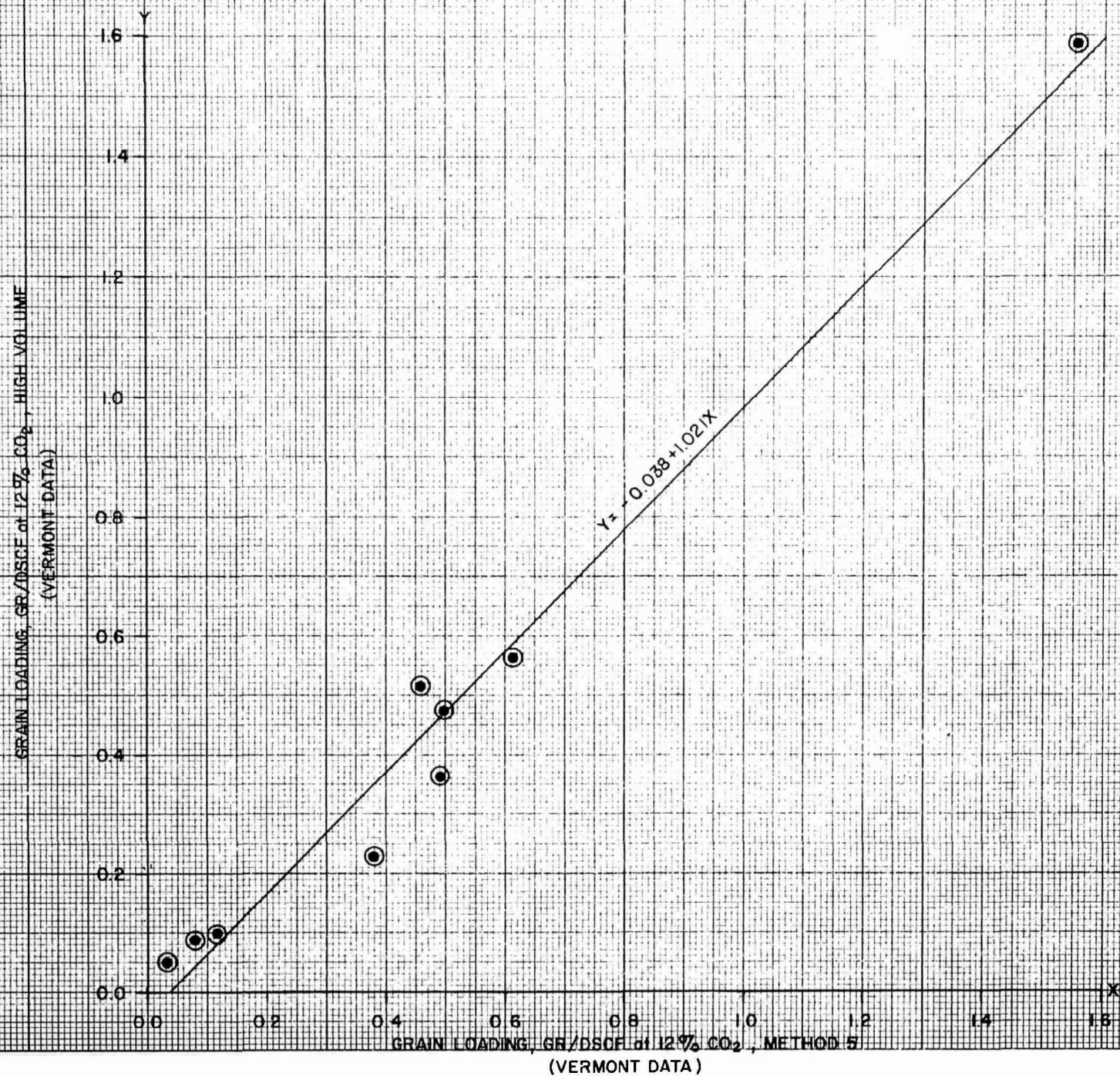


FIGURE 10

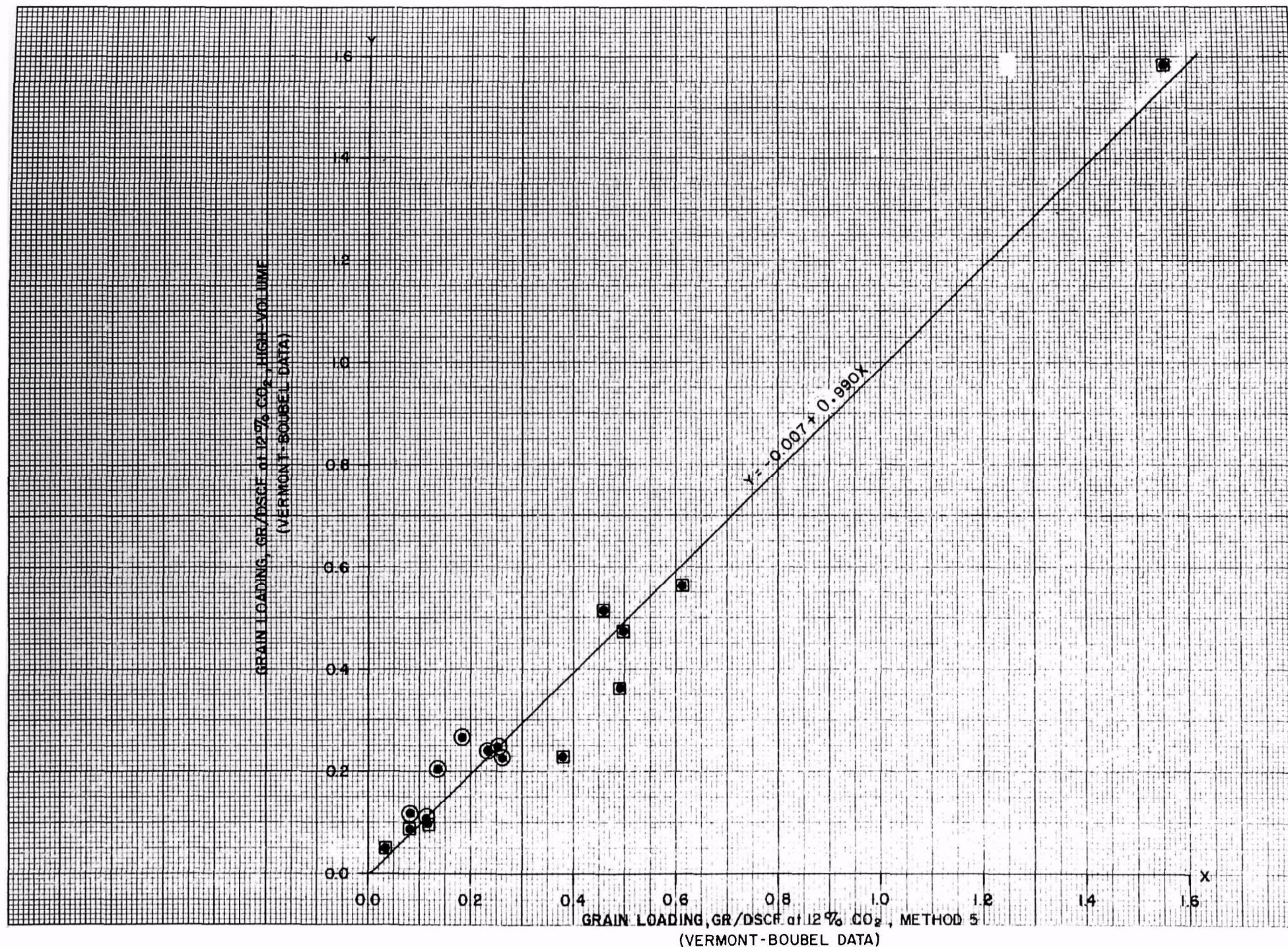


FIGURE II

7.40 Particle Sizing.

The results of the instack particle sizing is shown in Figure 12 and in Table 17. Boilers C, D, and F were tested without a backup filter. It should also be noted that boiler N was equipped with a multi-clone collector which significantly reduces the amount of large particles ($> 5\mu$) that are emitted. This effect can be seen from Figure 12. Boiler E was equipped with an instack fly ash collector. However the collector does not seem to substantially alter the particle size distribution, when the results are compared to the size distribution of the other boilers. All of the remaining boilers did not have particulate control devices.

There was the possibility that some of the larger particles would break up when either entering the impactor or moving through the collection plates. This would indicate that the percent of small particles (less than 5 microns) actually emitted was less than indicated by the impactor. In order to verify the cascade impacted results, an alternate method of sizing should be performed. Assuming the results were unbiased, for an uncontrolled small industrial wood-fired boiler, it would appear that 40% (by weight) of the particles emitted were less than one (1) micron in size, while only 20% (by weight) were larger than 10 microns. For a boiler controlled with a multiclone, the size distribution will be similar to that of boiler N.

TABLE 17 - IMPACTOR DATA - BOILERS

<u>BOILER</u>	<u>TEST</u>	PERCENT (BY WT)		
		<u>≤ 1.0 u</u>	<u>≤ 5.0 u</u>	<u>≤ 10.0 u</u>
C ⁺	1	21.9	45.9	74.77
	2	37.0	65.6	86.1
	3	24.6	57.0	84.2
D ⁺	1	0.0	5.9	42.0
	2	6.4	24.5	71.4
E	1	56.7	67.5	79.5
	2	49.6	69.4	82.6
	3	38.3	57.7	72.5
F ⁺	1	9.5	20.7	36.6
	2	48.8	61.6	71.8
	3	38.4	58.1	69.9
G	1	76	92	96
	2	68	87.8	92.6
	3	56.5	87.4	94.3
H	1	4.4	10.6	21.3
	2	3.6	9.2	25.5
	3	1.9	9.9	25.4
I	1	34.4	38.3	45.5
	2	30.0	33.0	39.6
	3	≅ 40.0	47.1	57.5
J	1	50.5	58.3	68.7
	2	58	62.5	68.6
	3	52.5	68.4	77.4

⁺Back Up Filter Not Used

Table 17 (continued)

-60-

<u>BOILER</u>	<u>TEST</u>	PERCENT (BY WT)		
		<u>≤ 1.0 u</u>	<u>≤ 5.0 u</u>	<u>≤ 10.0 u</u>
N*	1	85	98.5	99
	2	81	93.3	99

*Equipped With Multi-Clone

G ⁺	1	63.0	80.0	87.9
	2	57.5	76.0	83.0

⁺ 1978 Retest

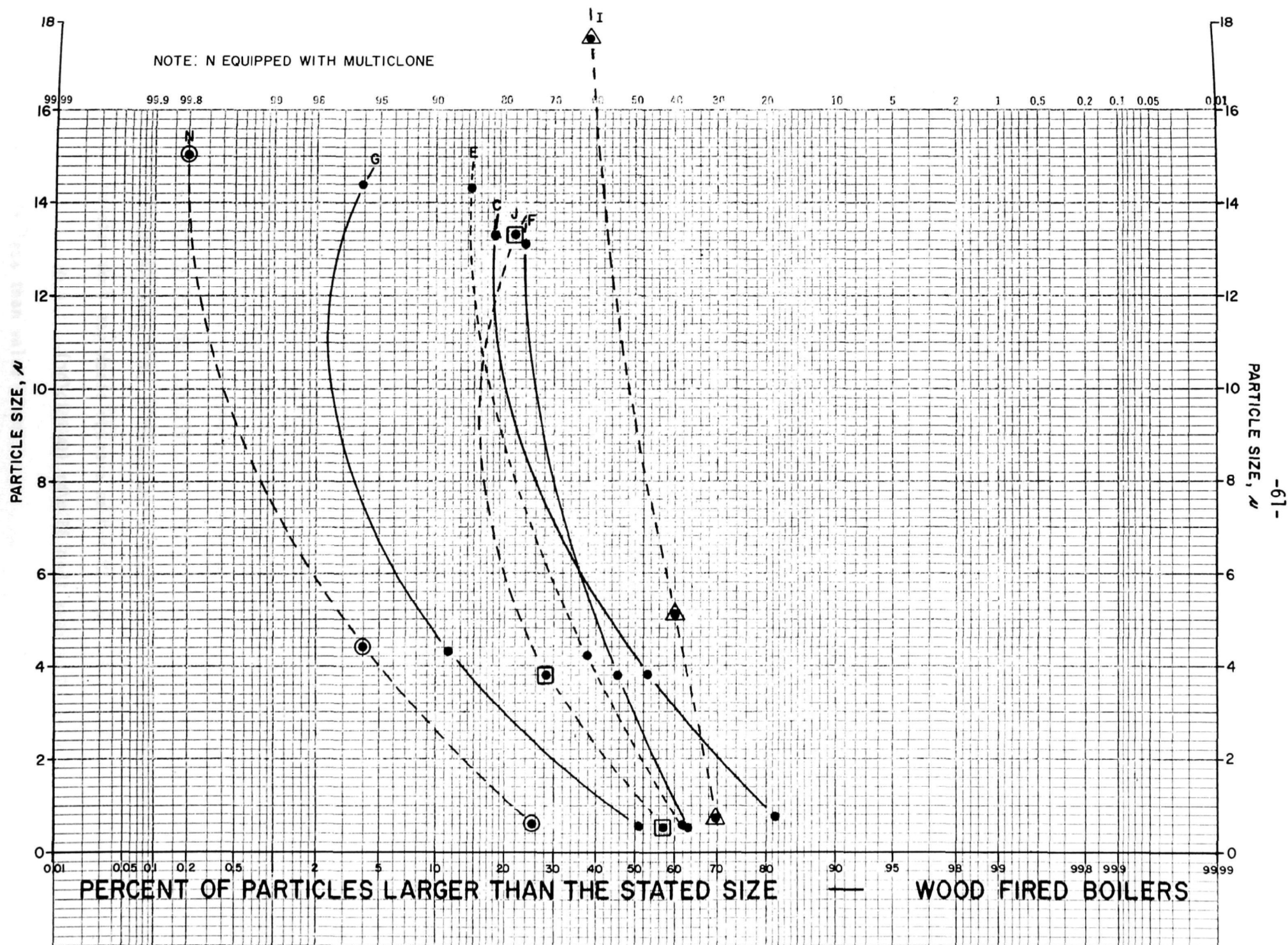


FIGURE 12

SECTION 8
GASEOUS EMISSIONS

NO_x

The samples from boilers J and D were contaminated in the laboratory and samples A and C were stored improperly making these four sample sets invalid. In most cases there was less than one microgram of NO_x detected in the sample. The maximum calculated emission rate was 0.32 kg/hr (0.718 lb/hr). The average emissions rate was 4.97 mg/DSCM with a high concentration of 30.44 mg/DSCM and a low of 1.59 mg/DSCM. The NO_x emission rate was determined using the concentration determined from the laboratory analysis in conjunction with the stack gas flow rate.

An elemental analysis was performed for each wood fuel sample (Table 3). The nitrogen present ranged from 0.065-2.00 percent by weight. Thus, the amount of nitrogen available for NO_x formation from the fuel itself was minimal. Using a Leeds & Northrup optical pyrometer, the fire box temperatures ranged from 1800-2200°F, with the average temperature being 1900°F. A low fire box temperature minimizes NO_x formation from the free nitrogen in the combustion air. As a contrast, the fire box temperature in boiler H was 2200°F, (the highest value recorded) which corresponded with the higher NO_x emission rate (0.32 Kg/hr). Due to overall low fire box temperatures and low nitrogen content of the fuel, relatively low emission rates of NO_x were expected.

SO_x

A laboratory analysis of the sample for the sulfur dioxide fraction was done by the barium-thorin titration method. The analysis showed the SO₂ content in all of the samples to be less than the minimum detectable limit of 3.4 mg/DSCM (Method 6). It can be seen from Table 3 that the average sulfur content of the wood fuel is less than 0.022 percent by weight, with a maximum sulfur content of 0.057 percent. Because of the small quantities of sulfur present in the fuel, a low quantity of SO₂ was emitted. Using the minimum detectable limit of 3.4 mg/DSCM and an average stack gas flow rate of 9905 m³/hr, the amount of SO₂ emitted would be less than 33 g/hr (0.1 lb/hr).

TABLE 18- RESULTS OF NO_x SAMPLING

PLANT: F

T_F - 66°F

P_F - (30.09 - ΔP) in Hg

August 18, 1977

T_I - 250°F

P_I - 29.97 in. Hg

Flask No.	ΔP, in. H ₂ O	Vol. Flask, ml	No _x , ug	Concentration lb/DSCF	Emission Rate, Lb/hr
102	+1.2	2032	2.5	3.4 x 10 ⁻⁷	0.141
103	-38.1	2034	<1.0	1.4*	0.058*
107	-18.6	2031	<1.0	1.4*	0.058*
108	-26.8	2014	<1.0	1.4*	0.058*
109	-37.2	2051	<1.0	1.4*	0.058*
111	VOID	----	----	----	-----
121	-25.8	2034	2.5	3.4	0.141
105	VOID	----	----	----	-----
104	VOID	----	----	----	-----

*NO_x present is less than value given

PLANT: B

T_F - 68°F

P_F - (29.40 - ΔP) in. Hg

August 31, 1977

T_I - 205°F

P_I - 30.21 in. Hg

Flask No.	ΔP, in. H ₂ O	Vol. Flask, ml	No _x , ug	Concentration lb/DSCF	Emission Rate, Lb/hr
102	-40.2	2032	<1.0	2.2 x 10 ⁻⁷	0.075
103	-15.0	2034	<1.0	2.2	0.075
104	+1.2	2041	<1.0	2.2	0.075
105	+0.4	2049	<1.0	2.2	0.075
107	-13.7	2031	<1.0	2.2	0.075
108	-13.4	2014	<1.0	2.4	0.075
109	-12.2	2051	<1.0	2.2	0.075
111	-0.2	2031	<1.0	2.2	0.075
121	-39.3	2034	<1.0	2.2	0.075

*NO_x present is less than value given

Table 18 (continued)

-64-

PLANT: I

 $T_F - 70^{\circ}\text{F}$ $P_F - (29.55 - \Delta P) \text{ in. Hg}$

September 7, 1977

 $T_I - 360^{\circ}\text{F}$ $P_I - 30.08 \text{ in. Hg}$

<u>Flask No.</u>	<u>ΔP, in. H_2O</u>	<u>Vol. Flask, ml</u>	<u>NO_x, ug</u>	<u>Concentration lb/DSCF</u>	<u>Emission Rate, Lb/hr</u>
102	-29.8	2032	<1.0	1.15×10^{-7}	0.023
103	-28.5	2034	<1.0	1.17	0.023
104	-31.2	2041	<1.0	1.17	0.023
105	-34.3	2049	<1.0	1.16	0.023
107	-35.3	2031	<1.0	1.17	0.023
108	-33.7	2014	<1.0	1.18	0.023
109	-32.9	2051	<1.0	1.16	0.023
111	-10.1	2031	<1.0	1.17	0.023
121	-33.1	2034	<1.0	1.17	0.023

* NO_x present is less than the value given

PLANT: E

 $T_F - 68^{\circ}\text{F}$ $P_F - (29.45 - \Delta P) \text{ in. Hg}$

September 30, 1977

 $T_I - 330^{\circ}\text{F}$ $P_I - 29.70 \text{ in. Hg}$

<u>Flask No.</u>	<u>ΔP, in. H_2O</u>	<u>Vol. Flask, ml</u>	<u>NO_x, ug</u>	<u>Concentration lb/DSCF</u>	<u>Emission Rate, Lb/hr</u>
102	-25.9	2032	5	4.9×10^{-7}	0.170
103	-19.2	2032	<1	$9.8 \times 10^{-8*}$	0.034*
104	-17.5	2041	5	4.9×10^{-7}	0.170
105	-20.9	2049	2.5	2.4×10^{-7}	0.083
107	-16.5	2031	10	9.8×10^{-7}	0.339
108	-19.4	2014	<1	$9.9 \times 10^{-8*}$	0.034*
109	-16.7	2051	<1	$9.7 \times 10^{-8*}$	0.034*
111	-18.6	2031	<1	$9.8 \times 10^{-8*}$	0.034*
121	-19.4	2034	<1	$9.8 \times 10^{-8*}$	0.034*

* NO_x present is less than the value given

Table 18 (continued)

-65-

PLANT: G

 $T_F - 75^{\circ}\text{F}$ $P_F - (29.35 - \Delta P) \text{ in. Hg}$

October 4, 1977

 $T_I - 400^{\circ}\text{F}$ $P_I - 29.31 \text{ in. Hg}$

<u>Flask No.</u>	<u>$\Delta P, \text{ in. H}_2\text{O}$</u>	<u>Vol. Flask, ml</u>	<u>$\text{NO}_x, \text{ ug}$</u>	<u>Concentration lb/DSCF</u>	<u>Emission Rate, Lb/hr</u>
102	-10.6	2032	8	6.7×10^{-7}	0.218
103	+1.6	2034	5	4.2×10^{-7}	0.137
108	-5.7	2014	3	2.5×10^{-7}	0.082
109	+6.5	2051	<1	$8.2 \times 10^{-8*}$	0.027*

* NO_x present is less than the value given

PLANT: H

 $T_F - 75^{\circ}\text{F}$ $P_F - (29.35 - \Delta P) \text{ in. Hg}$

October 5, 1977

 $T_I - 240^{\circ}\text{F}$ $P_I - 29.98$

<u>Flask No.</u>	<u>$\Delta P, \text{ in. H}_2\text{O}$</u>	<u>Vol. Flask, ml</u>	<u>$\text{NO}_x, \text{ ug}$</u>	<u>Concentration lb/DSCF</u>	<u>Emission Rate, Lb/hr</u>
104	-6.9	2041	7.5	1.1×10^{-6}	0.416
105	+6.7	2049	13	1.9×10^{-6}	0.718
107	+1.5	2031	<1	$1.5 \times 10^{-7*}$	0.057*
111	+1.5	2031	3	4.4×10^{-7}	0.166
121	+9.2	2034	11.5	1.7×10^{-7}	0.064
140	-2.0	2026	8	1.2×10^{-6}	0.454

* NO_x present is less than the value given

SECTION 9

ASH SAMPLES

Samples of wood ash were collected from the fire box of each of the boilers that were sampled. Some additional samples were taken in the breeching area, and at the base of the stack where possible. A preliminary analysis of thirteen ash samples was made using both atomic adsorption (AA) and x-ray/fluorescence (XRF) techniques. Fourteen elements were analyzed for using the AA, with the major emphasis on heavy metals, while eleven elements were analyzed for using the XRF. The results of these analyses are contained in Tables 19 and 20.

Concentrations obtained using XRF may not be representative of actual concentrations due to the lack of sensitivity of the instrument and the fact that no sample preparation is required prior to analysis. Additionally the print out from the unit doesn't lend itself easily to quantification. In most cases, the concentrations determined using XRF were consistantly lower than the concentrations found using AA techniques.

All of the samples which were analyzed on the AA were run in duplicate in order to verify the results. Four of the samples required additional ashing due to a high percentage of unburned material. These samples were analyzed both before and after ashing.

As can be seen from Table 19, the concentration of a given element varied considerably from sample to sample. This variability could result from:

1. The species of wood;
2. The soil characteristics where the tree was cut; or
3. Process or boiler contamination.

From the results of the AA analysis, it can be seen that wood ash contains high concentrations of aluminum, calcium, iron, potassium, and magnesium. However the ash also contained appreciable amounts (greater than 10 ppm) of cobalt, copper, chromium, nickel and lead.

The fourteen elements that were found using the AA represents 40-60 percent of the total ash sample. It is felt that large portions of the remaining ash consists of

silicon compounds. There are also small quantities of heavy metals (such as Vanadium, Titanium, Strontium, etc.) present.

Presently the wood ash is either dumped in a landfill type environment or used on a limited scale as fertilizer for agricultural purposes. At the existing level of use, wood ash disposal is not felt to be a problem. However, the ramifications of increased use of wood and the disposal problems that go with it are unknown and should be fully investigated before long term financial commitments to burn wood on a large scale are made by industry, municipalities and the general public.

TABLE 19 - VERMONT WOOD ASH ANALYSIS BY AA TECHNIQUES

Sample I.D.	ELEMENTS													
	AL	Ca	Cd	Co	CR	Cu	Fe	K	Mg	Mn	Na	Ni	Pb	Zn
176-11179	44.16 ⁺	131.95	0.002	0.613	0.1288	0.1602	39.51	21.265	187.405	3.703	17.53	0.059	0.0762	
177-11204	7.11	19.62	0.0006	0.0030	0.0069	0.0245	0.3715	3.907	5.922	0.808	0.691	0.004	0.0132	0.0177
177-11204*	64.63	178.4	0.005	0.0268	0.0624	0.2224	3.3737	35.50	53.77	7.351	6.281	0.0365	0.1204	0.1608
178-11206	14.02	428.9	0.0023	0.0292	0.0409	0.0690	12.26	15.99	206.15	8.856	2.209	0.079	0.0432	0.1139
179-11207	8.9	231.0	0.0033	0.0256	0.0170	0.5440	5.272	58.51	318.70	0.500	1.674	0.038	0.0380	2.8860
180-11176	21.07	101.81	0.164	0.0232	0.0592	0.5075	27.42	23.03	223.5	7.794	7.595	0.111	0.3164	8.0866
181-11175	16.47	425.6	0.0075	0.0398	0.1131	0.1072	22.01	16.00	391.25	20.809	4.324	0.094	0.0817	0.4166
182-11121	0.154	12.96	0.004	0.0027	0.0110	0.0114	3.8284	1.852	3.258	0.474	1.703	0.0059	0.0053	0.0053
182-11121*	2.56	214.0	0.0059	0.0439	0.1815	0.1885	63.22	30.57	53.79	7.822	28.13	0.0978	0.0874	0.0896
183-11122	21.08	241.45	0.003	0.0868	0.0572	0.5309	113.14	25.06	253.9	16.114	9.829	0.102	0.1187	0.3159
184-11123	4.34	38.23	0.0021	0.0092	0.0237	0.0267	4.3517	1.834	5.934	1.163	2.793	0.0228	0.0228	0.0112
184-11123*	13.61	119.80	0.0067	0.0287	0.0742	0.0837	13.64	5.75	18.60	2.644	8.75	0.0540	0.0716	0.0352
185-11124	11.86	151.4	0.078	0.0621	0.0354	0.0339	122.95	31.13	22.86	17.615	12.112	0.0553	0.2143	2.3894
186-11125	13.54	441.5	0.0024	0.0173	0.0357	0.1775	17.63	11.60	16.91	5.735	11.625	0.148	0.0862	0.1173
187-11126	6.61	60.52	0.0011	0.0040	0.2165	0.0800	41.44	17.897	12.39	1.782	10.980	0.0649	0.0139	0.0033
187-11126*	15.63	142.3	0.0025	0.0304	0.5089	0.1881	97.43	42.07	29.14	4.190	25.81	0.1525	0.0326	0.0078
188-11127	17.46	99.6	0.0019	0.0170	0.0278	0.1647	16.86	4.304	7.40	2.426	0.0365	0.037	0.0299	0.2566

*Sample Completely Ashed

⁺All concentrations are given in mg/g (parts per thousand)

20 - Vermont Wood Ash Analysis by XRF*

	Ti	V	Cr	Mn	Fe	Rb	Ni	Cu	Zn	Pb	Sr
11204	< 100	< 30	<20	760	130	31	< 4	<6	50	< 9	54
11122	200	66	<20	2,180	12,500	33	36	90	20	13	10
11123	200	66	<20	790	1,500	22	< 4	13	37	9	88
11124	1,050	130	22	3,740	3,700	55	< 4	30	210	94	360
11125	< 50	< 30	<20	940	1,040	44	< 4	20	16	27	560
11126	200	< 30	44	1,500	2,300	51	13	30	37	< 9	590
11127	750	100	66	550	4,700	35	< 4	10	50	18	150
11175	400	130	<20	2,960	3,000	44	9	23	50	22	540
11176	850	130	44	1,600	7,000	100	22	60	1,010	76	230
11179	700	100	66	780	5,600	80	7	66	92	18	370
11121	< 50	< 30	<20	600	450	< 7	< 4	16	27	< 9	110
11206	100	< 30	<20	650	400	15	< 4	6	7	< 9	220
11207	200	66	66	62	530	120	< 4	96	370	9	450

1. Samples analyzed directly on XRF.
2. Quantitation performed by standard addition technique. Cr, Cu, Pb and Rb added to sample 11204.
3. Minimum detection limit expressed as $\leq x$ for each metal. In general, lower detection limit for higher atomic number elements.
4. Accuracy estimated to be $\pm 30\%$ for low values, $\pm 15\%$ for high values.
5. Concentrations in parts per million (ppm).

*X-ray Fluorescence

TABLE 21
ASH SAMPLE LOCATIONS

<u>SAMPLE I.D.</u>	<u>PLANT</u>	<u>LOCATION</u>
11204	I	Firebox
11122	E	Firebox
11123	H	Boiler house roof
11124	C	Breeching
11125	J	Firebox
11126	G	Firebox
11127	H	Base of stack
11175	E	Fly ash collector
11176	A	Firebox
11179	F	Firebox
11121	C	Firebox
11206	D	Firebox
11207	B	Firebox

PART II

WIDE-BODIED CYCLONES

INTRODUCTION

The primary purpose of testing the cyclones was to develop particulate emission standards for wide-bodied cyclones. The emission standard is based on the high volume method. Additionally for ease of computation and applicability, the emission standard was to be in grains per dry standard cubic foot of exhaust gas. In order to determine overall particulate size collection efficiency under various load conditions particle sizing was conducted at the cyclone outlet and a sample of the material entering such unit was collected for a sieve analysis.

SECTION 1
TEST METHODS

Particulates

Testing for particulates was performed using a manual Rader high-volume sampler. Testing was performed in accordance with methods outlined in the Oregon Air Pollution Control Regulations (See Appendix B). The Oregon test was used since at the time of the test no formal ASTM or EPA test method had been developed for this test method. The test procedure involves "mapping out" the face (outlet) of the cyclone to determine the flow pattern. The point with the highest flow rate and at least five (5) representative points were selected for testing. Each point was sampled isokinetically for three minutes, for a total test time of at least 18 minutes. After the testing was completed the filter was removed and placed in an envelope. The nozzle probe and filter housing were cleaned with acetone and the acetone wash placed in a sample jar.

Particle Sizing

Particle sizing was performed at the outlet of the cyclone. An Anderson Mark III eight stage cascade impactor was used. The sample is drawn isokinetically from a single sample point maintaining a constant orifice pressure drop in order to keep the velocity through the sizer constant.

SECTION 2
DISCUSSION

A total of twenty-four (24) different cyclones were tested, with two of the cyclones (I-5 and L-1) tested under two different load conditions for a total of twenty-six sets of tests. Cyclone I-5 which was tested once when handling only softwood wastes and again with primarily hardwood wastes, is listed as Cyclone I-5A while handling hardwoods and I-5 for softwood wastes. Cyclone L-1 was tested once when handling only planer dust and shavings and again when handling only hogged material. The cyclone is denoted as L-1P and L-1H respectively. From Table 22 it can be seen that a wide variety of wood species and types of wood waste (hogged, sanderdust, shavings, etc.) were handled by the cyclones that were tested.

The average particulate emission rate for the cyclones was 0.114 grains per dry standard cubic meter (g/DSCM) [0.05 grains per dry standard cubic foot (gr/DSCF)], with a high emission rate of 0.448 g/DSCM (0.196 gr/DSCF) (I-5A) and a low emission rate of .009 g/DSCM (0.004 gr/DSCF) (M-3). (See Table 23) The testing showed that five of the units had an emission rate of 0.137 g/DSCM (0.06 gr/DSCF), the limitation presently set by the State of Vermont. Cyclone No. I-5A had an average emission rate of 0.448 g/DSCM (0.196 gr/DSCF) when carrying mixed kiln dried hardwood waste and an average emission rate of 0.119 g/DSCM (0.052 gr/DSCF) when handling softwood waste. This was probably caused by the fact that hardwood dust (sander, planer, etc) is generally smaller in size than the dust from softwood. Also since the resin content of the hardwood wastes is low, these particles do not readily agglomerate as do the softwood particles. In the case of cyclone I-5, only seven (7) percent of the softwood particles emitted are 10 microns or smaller in size, while 41 percent of the hardwood particles were smaller than 10 microns in size. Therefore it could be expected that wide-bodied cyclones handling hardwood waste would have a higher emission rate and would emit smaller size particles than a similar unit handling only softwood waste.

Sanderdust, due to its small size (2-80 μ) is not effectively collected by a wide-bodied cyclone. Cyclone J-2 handles sanderdust exclusively and had an emission rate of 0.371 g/DSCM (0.162 gr/DSCF) with 68.5 percent of the particles less than 10 microns in size and 26 percent of the particles less than 5.0 microns in size. Cyclone E-6 was also fed a large amount of sanderdust, however there were also planer shavings and hogged material mixed in with the dust which help reduce the number of sanderdust particles emitted. In this case only 40 percent of the particles are less than 10 microns in size.

The average emission rate of those collectors which were meeting the particulate emission standard of 0.137 g/DSCM (0.06 gr/DSCF) was 0.071 g/DSCM (0.031 gr/DSCF). In most cases if there is little or no sanderdust introduced to the collector, a wide-bodied cyclone will be able to operate within standards. A summary of the test results is contained in Table 23.

TABLE 22- MATERIAL HANDLED BY CYCLONES DURING TESTS

<u>CYCLONE ID.</u>	<u>TYPE OF WOOD</u>	<u>CONDITION OF WOOD</u>
E -1 & 6	Oak - Maple	Hogged, sawdust, planer shavings (Kiln dried)
E -4 & 5	Oak - Maple	Sanderdust, shavings, sawdust (Kiln dried)
F-1	Maple	Sanderdust, sawdust (Kiln dried)
F-2	Maple	Sawdust, shavings, planer shavings, sanderdust, hogged (Kiln dried)
D-1	Maple	Shavings (Kiln dried)
D-2	Maple	Sawdust, planer shavings (Kiln dried)
D-4	Maple	Hogged (Kiln dried)
B-1	Ash	Shavings, sawdust (Kiln dried)
B-2	Ash	Shavings, sawdust (Kiln dried & Green)
M-1 & 2	Oak, Birch, White Ash	Hogged, sawdust
M-3	Birch, Oak, White Ash	Chips, sawdust
I 1	Pine	Planer shavings, sawdust (Kiln dried)
I 2	Pine	Sawdust, planer shavings, sanderdust (Kiln dried)
I 3	Pine	Hogged (Kiln dried)
I-5 & 7	Pine	Hogged, sawdust, sanderdust, planer shavings (Kiln dried)
I-5-A	Maple	Hogged, sawdust, sanderdust, planer shavings (Kiln dried)
L 1P	Assorted Hardwoods	Planer shavings (Kiln dried)
L 1-H	Assorted Hardwoods	Hogged (Kiln dried)
J 1	Assorted Hardwoods & Softwoods	Sawdust, shavings
J 2	Assorted Hardwoods & Softwoods	Sanderdust

TABLE 23- CYCLONE EMISSION DATA

<u>Cyclone I.D.</u>	<u>Test No.</u>	<u>Emission Rate gr/DSCF</u>	<u>Average Rate, gr./DSCF</u>
E - 1	1	0.047	0.048
	2	0.049	
	3	0.048	
E - 4	1	0.038	0.036
	2	0.035	
	3	0.035	
E - 5	1	0.075	0.145
	2	0.209	
	3	0.150	
E - 6	1	0.112	0.087
	2	0.076	
	3	0.073	
F- 1	1	0.040	0.055
	2	0.042	
	3	0.074	
	4	0.066	
F- 2	1	0.027	0.030
	2	0.042	
	3	0.021	
D - 1	1	0.009	0.009
	2	0.009	
	3	0.008	
D - 2	1	0.018	0.022
	2	0.029	
	3	0.019	
D - 4	1	0.015	0.019
	2	0.020	
	3	0.023	
B - 1	1	0.020	0.017
	2	0.020	
	3	0.010	
B - 2	1	0.019	0.024
	2	0.026	
	3	0.027	
M - 1	1	0.008	0.099
	2	0.187	
	3	0.102	
M - 2	1	0.027	0.020
	2	0.025	
	3	0.009	

Table 23- Continued

-78-

<u>Cyclone I.D.</u>	<u>Test No.</u>	<u>Emission Rate gr/DSCF</u>	<u>Average Rate, gr./DSCF</u>
M - 3	1	0.003	0.004
	2	0.007	
	3	0.003	
I - 1	1	0.018	0.020
	2	0.020	
	3	0.021	
I - 2	1	0.027	0.014
	2	0.007	
	3	0.009	
I - 3	1	0.010	0.011
	2	0.014	
	3	0.008	
I - 5A	1	0.275	0.196
	2	0.178	
	3	0.134	
I - 5	1	0.041	0.052
	2	0.068	
	3	0.046	
I - 7	1	0.039	0.039
	2	0.039	
	3	0.040	
L - 1 P	1	0.028	0.059
	2	0.070	
	3	0.079	
L 1 H	1	0.020	0.025
	2	0.030	
J - 1	1	0.022	0.018
	2	0.019	
	3	0.013	
J - 2	1	0.209	0.162
	2	0.050	
	3	0.228	
K	1	0.024	0.026
	2	0.022	
	3	0.033	
I -10	1	0.085	0.090
	2	0.090	
	3	0.094	

SECTION 3

PARTICLE SIZING

Particle sizing was performed on nine different cyclones, with Cyclones I-5 and L-1, each tested twice under different conditions for a total of eleven sets of sizing data. The size distribution for the cyclones is presented in Figures 13A and 13B. It can be seen that in the majority of cases less than 35% of the particles (by weight) are smaller than five microns, while 60% of the particles (by weight) are greater than ten microns.

The original scope of work called for sizing to be done in each inlet to the collectors. Due to the high concentrations and generally large size of the material entering the collector, it was not possible to conduct in line tests. However, samples of wood waste entering the collectors was taken for most of the units that were tested. A size distribution by weight of the material entering the cyclones is presented in Table 24.

TABLE 24- IMPACTOR DATA - CYCLONES

<u>CYCLONE I.D.</u>	<u>TEST</u>	PERCENT (BY WT)		
		<u>≤1.0 u</u>	<u>≤5.0 u</u>	<u>>10.0 u</u>
F - 1	1	0.0	3.3	73.6
	2	0.0	4.7	67.8
	3	0.0	7.8	65.0
I - 5 *	1	0.0	47.7	12.9
	2	0.8	0.9	92.2
	3	4.5	5.3	94.7
I - 5A +	1	0.0	35.7	64.3
	2	1.0	25.9	74.1
	3	1.0	23.6	39.0
I - 7	1	2.9	7.7	92.3
	2	5.8	16.3	75.0
	3	2.0	5.5	94.5
J - 2	1	0.0	12.1	40.6
	2	0.0	24.0	28.4
	3	1.1	27.2	25.4
E - 1	1	0.2	25.0	62.2
	2	0.2	31.2	59.0
	3	0.2	44.7	35.3
E - 5	1	0.9	10.4	72.0
	2	0.1	7.4	78.6
	3	0.0	6.1	76.1
E - 6	1	1.6	11.7	66.9
	2	0.0	5.7	51.0
	3	0.3	7.5	63.3
K	1	0.2	13.0	59.8
	2	0.0	4.5	52.4
	3	0.0	0.0	87.1

TABLE 24 - IMPACTOR DATA - CYCLONES (CONTINUED)

<u>CYCLONE I.D.</u>	<u>TEST</u>	PERCENT (BY WT)		
		<u>≤ 1.0 u</u>	<u>≤ 5.0 u</u>	<u>> 10.0 u</u>
L - P	1	1.8	42.7	12.2
	2	2.6	23.6	37.8
L - H	1	14.4	42.1	29.8

* - Handling Softwood

+ - Handling Hardwood

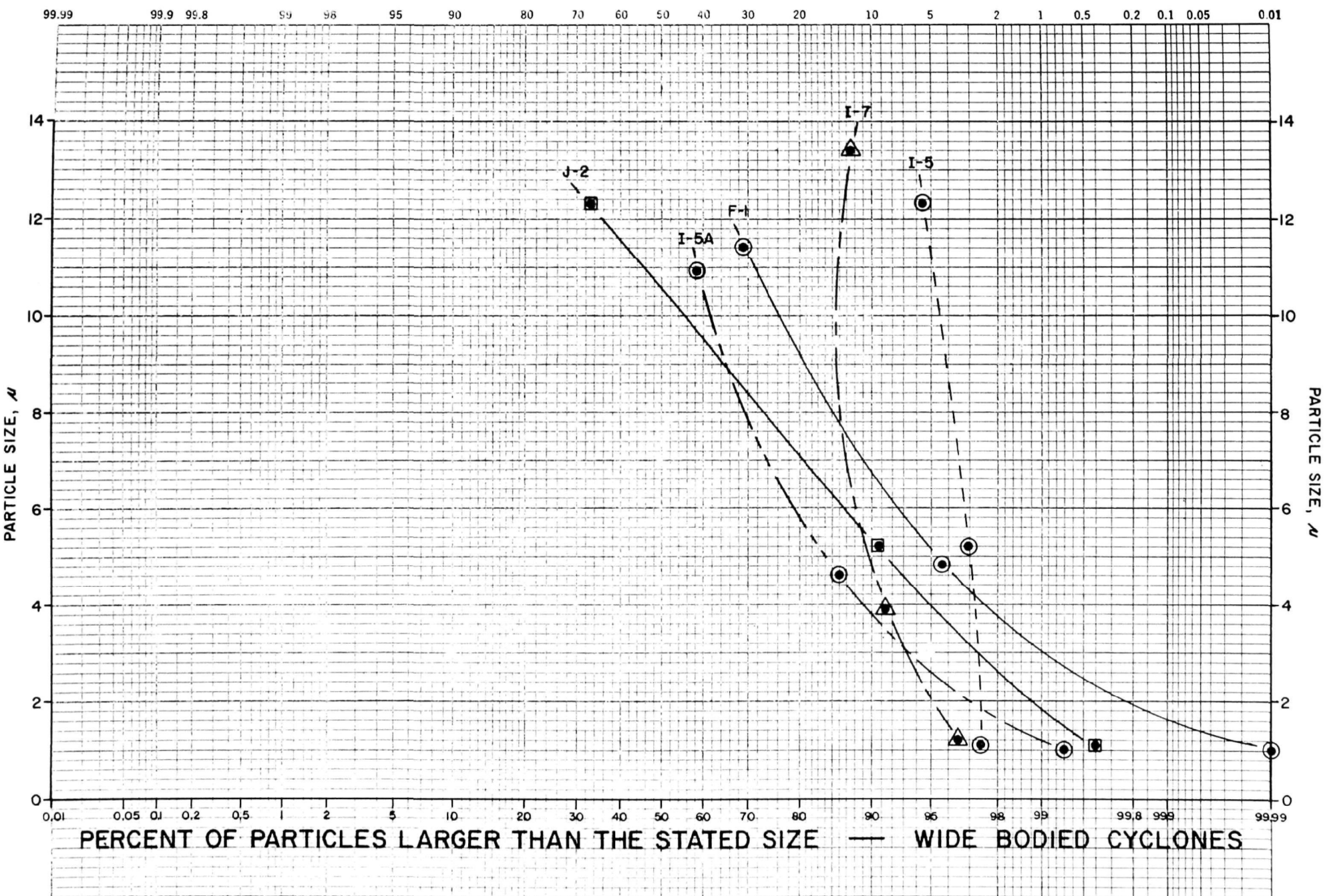


FIGURE 13A

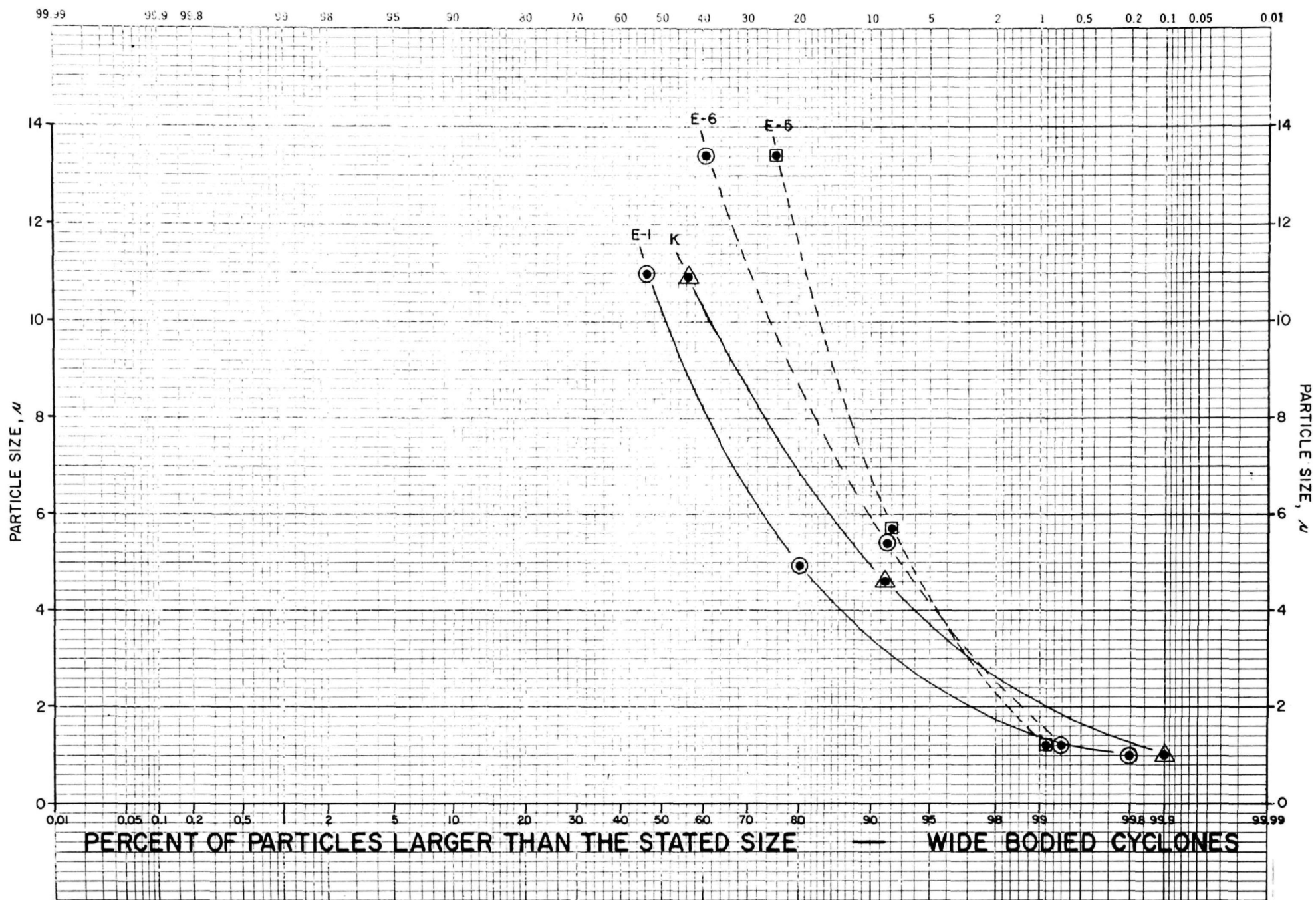


FIGURE 13 B

SECTION 4

WOOD FUEL SIEVE ANALYSIS

An analysis was done on samples of wood fuels taken from various wood-working plants in Vermont. This analysis consisted of quartering samples taken from boiler feeds, cyclones, and the like, and running a known amount (about an ounce) of this material through six sieves on an automatic sieve shaker for 5 minutes. The sieves were then dismantled, and respective weights of collected materials were noted.

Results are exhibited on a percent of total sample basis. Samples were weighed to the nearest 1/10th of a gram. A small amount of material was lost in transfer.

TABLE 2 5 - SIEVE ANALYSIS -85-
SIEVE SIZES

Sample Description	#10 0.0787"	#18 0.0394"	#40 0.0165"	#80 0.0070"	#140 0.004"	#400 0.0015"
E Boiler	51.6%	20.8%	18.7%	6.6%	1.5%	0.8%
E - #1 Cyclone	14.8%	19.7%	32.5%	20.9%	9.1%	6.3%
E - #3 Cyclone	73.7%	14.6%	9.9%	1.4%	0.5%	0.5%
E - #4 Cyclone	2.3%	10.1%	33.0%	26.7%	15.6%	10.4%
E #5 Cyclone	53.8%	25.0%	18.2%	1.8%	0.2%	0.2%
C Main Boiler Feed	37.8%	16.6%	11.4%	8.4%	7.8%	11.2%*
C Hammer Mill	92.5%	7.3%	0.2%	0.2%	0.2%	0.2%
I - - Boiler Feed	28.4%	25.3%	30.4%	9.6%	3.4%	2.9%
I - Cyclone #1	11.3%	17.1%	29.6%	20.3%	14.0%	8.4%
I - Cyclone #2	86.0%	7.3%	4.1%	1.1%	0.4%	0.2%
Rip Saw	32.3%	41.0%	20.3%	5.5%	1.4%	0.5%
#5 and #7 Cyclones	36.1%	24.2%	19.8%	9.8%	5.2%	3.5%
#10 Cyclone	21.1%	75.9%	2.5%	0.2%	0.2%	0.1%
B Boiler Feed	66.3%	22.7%	9.3%	1.0%	0.3%	0.3%
J Boiler Feed - Scrap	(100%) All Pieces Larger Than 1st Sieve					
J - Cyclone #1	0.2%	3.6%	31.3%	34.9%	17.9%	9.8%
K Cyclone #1	41.8%	28.2%	21.6%	5.5%	1.1%	0.7%
L - Cyclone #1-H	98.7%	1.0%	0.2%	0.1%	0.1%	0.1%
L - Cyclone #1-P	49.1%	23.9%	15.7%	7.6%	5.2%	3.4%
D - Boiler Fuel & Cyclone #4	95.7%	3.8%	0.4%	0.2%	0.2%	0.2%
D Cyclone #1	58.4%	31.1%	8.8%	0.5%	0.3%	0.3%
D Cyclone #2	25.6%	24.4%	34.3%	12.4%	2.0%	0.5%
M Boiler Feed	59.0%	20.1%	13.3%	5.2%	1.6%	0.5%
M Shaker #3	96.9%	2.0%	0.4%	0.2%	0.2%	0.2%
M Cyclone #4	6.0%	23.2%	46.1%	14.1%	4.0%	2.6%
F -- Boiler Feed Cyclone	82.5%	10.4%	1.9%	1.1%	1.5%	1.9%
A - Boiler Feed	76.4%	19.4%	3.0%	0.9%	0.2%	0.2%

*6.5% less than last sieve

REFERENCES

- (1) Anonymous, Compilation of Air Pollutant Emission Factors, 2nd edition, United States Environmental Protection Agency.
- (2) Anonymous, Standards of Performance for New Stationary Sources. United States Environmental Protection Agency 40 CFR 60. Appendix A as amended.
- (3) Baumeister, Theodore, Mark's Standard Handbook for Mechanical Engineers, 7th edition. McGraw-Hill Book Co. Chapter 17, pp. 19-19.
- (4) Junge, David C., Investigation of the Rate of Combustion of Wood Residue Fuel. United States Environmental Protection Agency Contract No. EY-76-C-06-2227, TPR No. 1, September 1977.
- (5) Morford, Jerry M., The Comparison of a High-Volume Sampling Method with EPA Method 5 for Particulate Emission from Wood-Fired Boilers. Oregon State University, 1975.
- (6) Brown, O.D., "Energy Generation From Wood Waste", National District Heating Association, French Lick, Indiana, June 1973.
- (7) Boubel, R.W., Control of Particulate Emissions From Wood-Fired Boilers. United States Environmental Protection Agency Contract No. 68-01-3150.
- (8) Supplied by Rader Companies, Inc., Portland Oregon.
- (9) Supplied by Andersen 2000 Inc., Atlanta, Georgia.

A-1

.

APPENDIX A

REFERENCE METHODS 1 - 5

(1) Method 5 for concentration of particulate matter and associated moisture content;

(3) Method 1 for sample and velocity traverses;

(3) Method 2 for velocity and volumetric flow rate; and

(4) Method 3 for gas analysis.

(b) For Method 5, the sampling time for each run shall be at least four hours. When a single EAF is sampled, the sampling time for each run shall also include an integral number of heats. Shorter sampling times, when necessitated by process variables or other factors, may be approved by the Administrator. The minimum sample volume shall be 4.5 dscm (160 dscf).

(c) For the purpose of this subpart, the owner or operator shall conduct the demonstration of compliance with 60.272(a)(3) and furnish the Administrator a written report of the results of the test.

(d) During any performance test required under § 60.8 of this part, no gaseous diluents may be added to the effluent gas stream after the fabric in any pressurized fabric filter collector, unless the amount of dilution is separately determined and considered in the determination of emissions.

(e) When more than one control device serves the EAF(s) being tested, the concentration of particulate matter shall be determined using the following equation:

$$C_s = \frac{\sum_{i=1}^N (C_i Q_i)}{\sum_{i=1}^N (Q_i)}$$

where:

C_s = concentration of particulate matter in mg/dscm (gr/dscf) as determined by method 5.

N = total number of control devices tested.

Q_i = volumetric flow rate of the effluent gas stream in dscm/hr (dscf/hr) as determined by method 2.

$(C_i Q_i)$ or (Q_i) = value of the applicable parameter for each control device tested.

(f) Any control device subject to the provisions of this subpart shall be designed and constructed to allow measurement of emissions using applicable test methods and procedures.

(g) Where emissions from any EAF(s) are combined with emissions from facilities not subject to the provisions of this subpart but controlled by a common capture system and control device, the owner

or operator may use any of the following procedures during a performance test:

(1) Base compliance on control of the combined emissions.

(2) Utilize a method acceptable to the Administrator which compensates for the emissions from the facilities not subject to the provisions of this subpart.

(3) Any combination of the criteria of paragraphs (g) (1) and (g) (2) of this section.

(h) Where emissions from any EAF(s) are combined with emissions from facilities not subject to the provisions of this subpart, the owner or operator may use any of the following procedures for demonstrating compliance with § 60.272 (a) (3):

(1) Base compliance on control of the combined emissions.

(2) Shut down operation of facilities not subject to the provisions of this subpart.

(3) Any combination of the criteria of paragraphs (h) (1) and (h) (2) of this section.

APPENDIX A—REFERENCE METHODS

METHOD 1—SAMPLE AND VELOCITY TRAVERSES FOR STATIONARY SOURCES

1. Principle and Applicability.

1.1 Principle. A sampling site and the number of traverse points are selected to aid in the extraction of a representative sample.

1.2 Applicability. This method should be applied only when specified by the test procedures for determining compliance with the New Source Performance Standards. Unless otherwise specified, this method is not intended to apply to gas streams other than those emitted directly to the atmosphere without further processing.

2. Procedure.

2.1 Selection of a sampling site and minimum number of traverse points.

2.1.1 Select a sampling site that is at least eight stack or duct diameters downstream and two diameters upstream from any flow disturbance such as a bend, expansion, contraction, or visible flame. For rectangular cross section, determine an equivalent diameter from the following equation:

$$\text{equivalent diameter} = 2 \left(\frac{(\text{length})(\text{width})}{\text{length} + \text{width}} \right)$$

equation 1-1

2.1.2 When the above sampling site criteria can be met, the minimum number of traverse points is twelve (12).

2.1.3 Some sampling situations render the above sampling site criteria impractical. When this is the case, choose a convenient sampling location and use Figure 1-1 to de-

termine the minimum number of traverse points. Under no conditions should a sampling point be selected within 1 inch of the stack wall. To obtain the number of traverse points for stacks or ducts with a diameter less than 2 feet, multiply the number of points obtained from Figure 1-1 by 0.67.

2.1.4 To use Figure 1-1 first measure the distance from the chosen sampling location to the nearest upstream and downstream disturbances. Determine the corresponding number of traverse points for each distance

from Figure 1-1. Select the higher of the two numbers of traverse points, or a greater value, such that for circular stacks the number is a multiple of 4, and for rectangular stacks the number follows the criteria of section 2.2.2.

2.2 Cross-sectional layout and location of traverse points.

2.2.1 For circular stacks locate the traverse points on at least two diameters according to Figure 1-2 and Table 1-1. The traverse axes shall divide the stack cross section into equal parts.

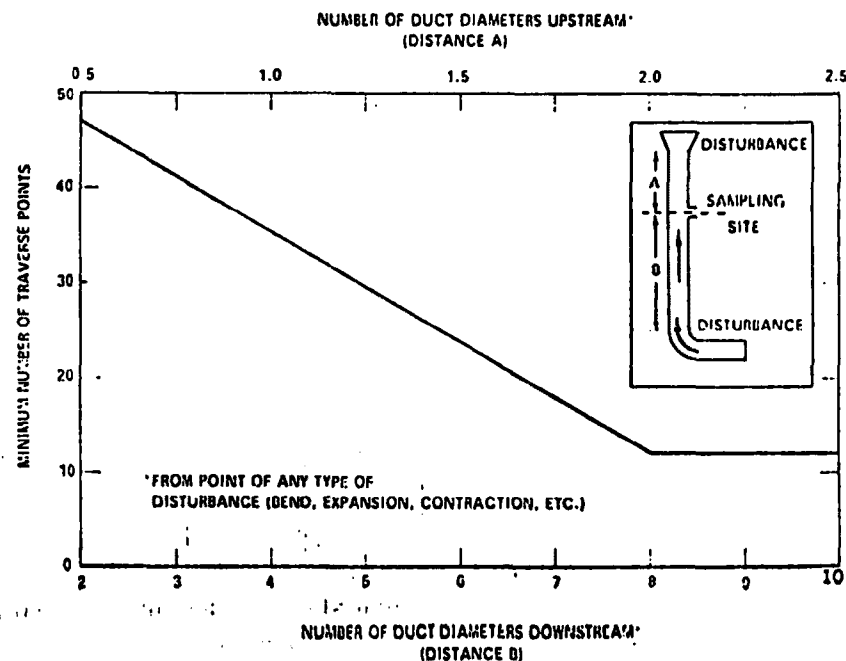


Figure 1-1. Minimum number of traverse points.

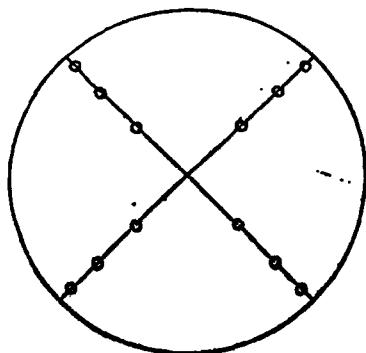


Figure 1-2. Cross section of circular stack divided into 12 equal areas, showing location of traverse points at centroid of each area.

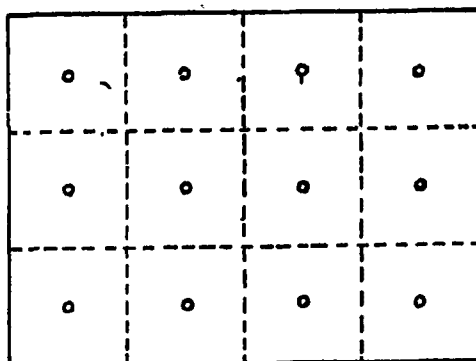


Figure 1-3. Cross section of rectangular stack divided into 12 equal areas, with traverse points at centroid of each area.

Table 1-1. 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	3.3	2.5	2.1	1.8	1.6	1.4	1.3	1.1	1.1
2	85.4	25.0	14.7	10.5	8.2	6.7	5.7	4.9	4.4	3.9	3.5	3.2
3		75.0	29.8	19.4	14.6	11.8	9.9	8.5	7.5	6.7	6.0	5.5
4		93.3	70.5	32.3	22.6	17.7	14.6	12.5	10.9	9.7	8.7	7.9
5			85.3	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	35.5	26.9	22.0	18.8	16.5	14.6	13.2
7				89.5	77.4	64.5	36.6	28.3	23.6	20.4	18.0	16.1
8				96.7	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	26.1	23.0
10					97.5	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	73.9	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

A-3

2.2.3 For rectangular stacks divide the cross section into as many equal rectangular areas as traverse points, such that the ratio of the length to the width of the elemental areas is between one and two. Locate the traverse points at the centroid of each equal area according to Figure 1-3.

3. References.

Determining Dust Concentration in a Gas Stream, ASME Performance Test Code #27, New York, N.Y., 1957.

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

Methods for Determination of Velocity, Volume, Dust and Mist Content of Gases, Western Precipitation Division of Joy Manu-

facturing Co., Los Angeles, Calif. Bulletin WP-50, 1968.

Standard Method for Sampling Stacks for Particulate Matter, In: 1971 Book of ASTM Standards, Part 23, Philadelphia, Pa. 1971, ASTM Designation D-2928-71.

METHOD 2—DETERMINATION OF STACK GAS VELOCITY AND VOLUMETRIC FLOW RATE (TYPE S PITOT TUBE)

1. Principle and applicability.

1.1 Principle. Stack gas velocity is determined from the gas density and from measurement of the velocity head using a Type S (Stauscheibe or reverse type) pitot tube.

1.2 Applicability. This method should be applied only when specified by the test pro-

cedures for determining compliance with the New Source Performance Standards.

2. Apparatus.

2.1 Pitot tube—Type S (Figure 2-1), or equivalent, with a coefficient within $\pm 5\%$ over the working range.

2.2 Differential pressure gauge—Inclined manometer, or equivalent, to measure velocity head to within 10% of the minimum value.

2.3 Temperature gauge—Thermocouple or equivalent attached to the pitot tube to measure stack temperature to within 1.5% of the minimum absolute stack temperature.

2.4 Pressure gauge—Mercury-filled U-tube manometer, or equivalent, to measure stack pressure to within 0.1 in. Hg.

2.5 Barometer—To measure atmospheric pressure to within 0.1 in. Hg.

2.6 Gas analyzer—To analyze gas composition for determining molecular weight.

2.7 Pitot tube—Standard type, to calibrate Type S pitot tube.

3. Procedure.

3.1 Set up the apparatus as shown in Figure 2-1. Make sure all connections are tight and leak free. Measure the velocity head and temperature at the traverse points specified by Method 1.

3.2 Measure the static pressure in the stack.

3.3 Determine the stack gas molecular weight by gas analysis and appropriate calculations as indicated in Method 3.

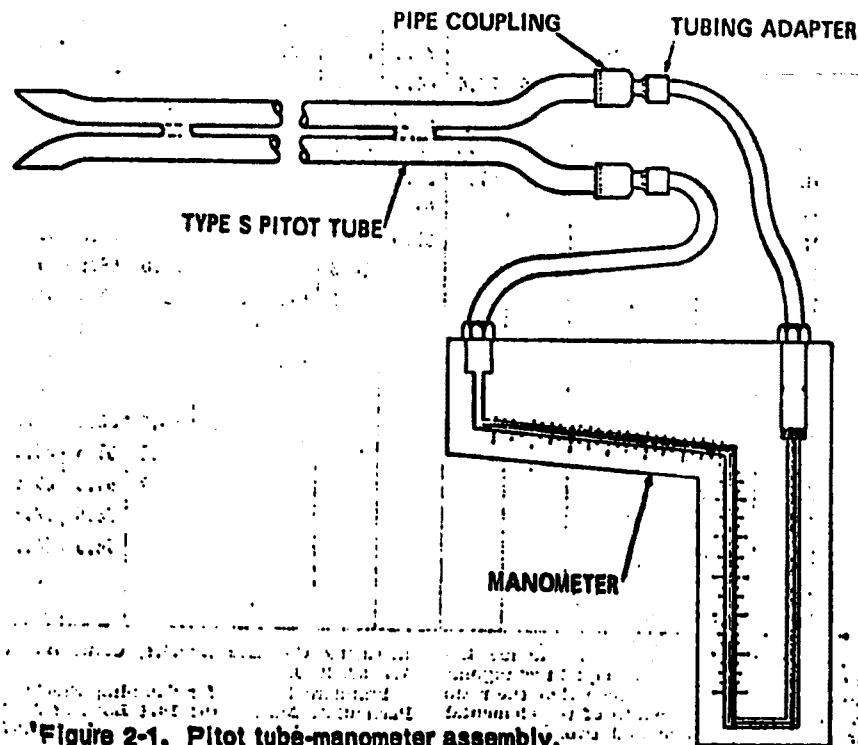


Figure 2-1. Pitot tube-manometer assembly

4. Calibration.

4.1 To calibrate the pitot tube, measure the velocity head at some point in a flowing gas stream with both a Type S pitot tube and a standard type pitot tube with known coefficient. Calibration should be done in the laboratory and the velocity of the flowing gas stream should be varied over the normal working range. It is recommended that the calibration be repeated after use at each field site.

4.2 Calculate the pitot tube coefficient using equation 2-1.

$$C_{p, \text{Type S}} = C_{p, \text{std}} \sqrt{\frac{\Delta p_{\text{std}}}{\Delta p_{\text{Type S}}}} \quad \text{Equation 2-1}$$

where:

$C_{p, \text{Type S}}$ = Pitot tube coefficient of Type S pitot tube.

$C_{p, \text{std}}$ = Pitot tube coefficient of standard type pitot tube (if unknown, use 0.99).

Δp_{std} = Velocity head measured by standard type pitot tube.

$\Delta p_{\text{Type S}}$ = Velocity head measured by Type S pitot tube.

4.3 Compare the coefficients of the Type S pitot tube determined first with one leg and then the other pointed downstream. Use the pitot tube only if the two coefficients differ by no more than 0.01.

5. Calculations.

Use equation 2-2 to calculate the stack gas velocity.

$$(V_s)_{\text{avg}} = K_p C_p (\sqrt{\Delta p})_{\text{avg}} \sqrt{\frac{(T_s)_{\text{avg}}}{P_s M_s}} \quad \text{Equation 2-2}$$

where:

$(V_s)_{\text{avg}}$ = Stack gas velocity, feet per second (f.p.s.).

$K_p = 84.48 \frac{\text{ft.}}{\text{sec.}} \left(\frac{\text{lb.}}{\text{lb. mole} \cdot \text{R}} \right)^{1/4}$ when these units are used.

C_p = Pitot tube coefficient, dimensionless.

$(T_s)_{\text{avg}}$ = Average absolute stack gas temperature, $^{\circ}\text{R}$.

$(\sqrt{\Delta p})_{\text{avg}}$ = Average velocity head of stack gas, inches H_2O (see Fig. 2-2).

P_s = Absolute stack gas pressure, inches Hg.

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

$M_d(1 - B_{ws}) + 18 B_{ws}$

M_d = Dry molecular weight of stack gas (from Method 3).

B_{ws} = Proportion by volume of water vapor in the gas stream (from Method 4).

Figure 2-2 shows a sample recording sheet for velocity traverse data. Use the averages in the last two columns of Figure 2-2 to determine the average stack gas velocity from Equation 2-2.

Use Equation 2-3 to calculate the stack gas volumetric flow rate.

$$Q_s = 3600 (1 - B_{ws}) V_s A \left(\frac{T_{std}}{(T_s)_{\text{avg}}} \right) \left(\frac{P_s}{P_{std}} \right) \quad \text{Equation 2-3}$$

where:

Q_s = Volumetric flow rate, dry basis, standard conditions, ft.³/hr.

A = Cross-sectional area of stack, ft.²

T_{std} = Absolute temperature at standard conditions $^{\circ}\text{R}$.

P_{std} = Absolute pressure at standard conditions, 29.92 inches Hg.

6. References.

Mark, L. S., Mechanical Engineers' Handbook, McGraw-Hill Book Co., Inc., New York, N.Y., 1951.

Perry, J. H., Chemical Engineers' Handbook, McGraw-Hill Book Co., Inc., New York, N.Y., 1950.

Shigohara, R. T., W. F. Todd, and W. S. Smith, Significance of Errors in Stack Sampling Measurements. Paper presented at the Annual Meeting of the Air Pollution Control Association, St. Louis, Mo., June 14-19, 1970.

Standard Method for Sampling Stacks for Particulate Matter, In: 1971 Book of ASTM Standards, Part 23, Philadelphia, Pa., 1971, ASTM Designation D-2028-71.

Vennard, J. K., Elementary Fluid Mechanics, John Wiley & Sons, Inc., New York, N.Y., 1947.

DATE _____

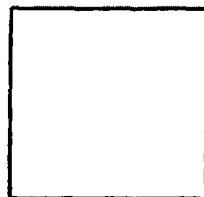
RUN NO. _____

STACK DIAMETER, in._____

BAROMETRIC PRESSURE, in. Hg. _____

STATIC PRESSURE IN STACK (P_g), in. Hg. _____

OPERATORS



SCHEMATIC OF STACK CROSS SECTION

[illegible]

Figure 2-2. Velocity traverse data.

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

1. Principle and applicability.

1.1 Principle. An integrated or grab gas sample is extracted from a sampling point and analysed for its components using an Orsat analyser.

1.2 Applicability. This method should be applied only when specified by the test procedures for determining compliance with the New Source Performance Standards. The test procedure will indicate whether a grab sample or an integrated sample is to be used.

2. Apparatus.

2.1 Grab sample (Figure 3-1).

2.1.1 Probe—Stainless steel or Pyrex¹ glass, equipped with a filter to remove particulate matter.

2.1.2 Pump—One-way squeeze bulb, or equivalent, to transport gas sample to analyzer.

2.2 Integrated sample (Figure 3-2).

2.2.1 Probe—Stainless steel or Pyrex¹ glass, equipped with a filter to remove particulate matter.

2.2.2 Air-cooled condenser or equivalent—
To remove any excess moisture.

2.2.3 Needle valve—To adjust flow rate.
2.2.4 Pump—Leak-free, diaphragm type, or equivalent, to pull gas.

2.2.5 Rate meter—To measure a flow range from 0 to 0.035 cfm.

2.2.6 Flexible bag—Tedar,¹ or equivalent with a capacity of 2 to 3 cu. ft. Leak test the bag in the laboratory before using.

2.2.7 Pitot tube—Type S, or equivalent attached to the probe so that the sampling flow rate can be regulated proportional to the stack gas velocity when velocity is varying with time or a sample traverse is conducted.

2.3 Analysis.

2.3.1 Oresat analyzer, or equivalent.

Trade name.

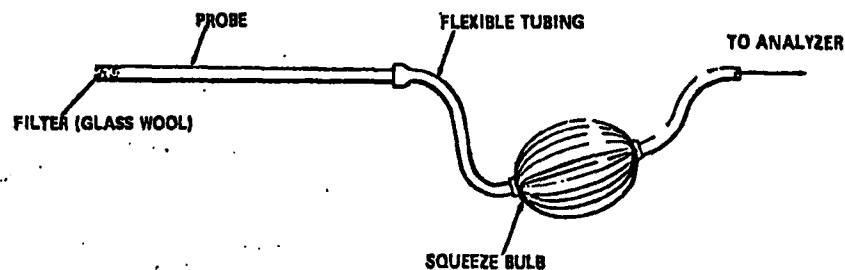


Figure 3-1. Grab-sampling train.

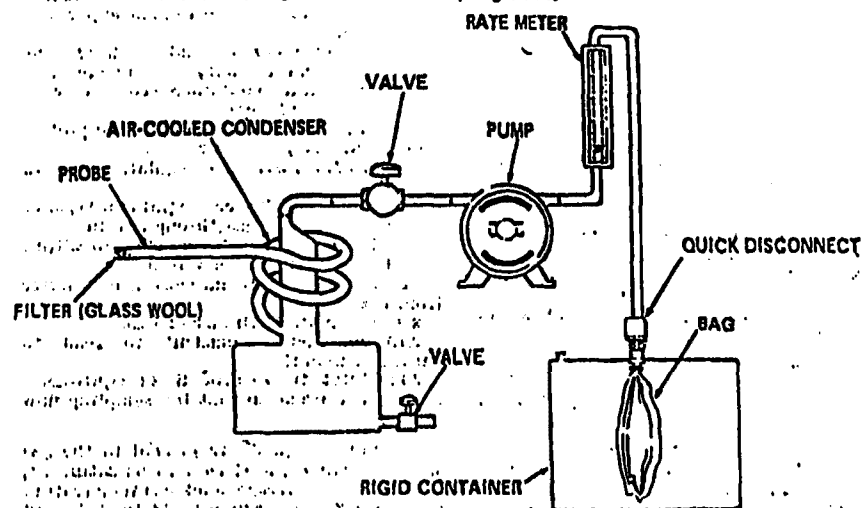


Figure 3-2. Integrated gas - sampling train.

8. Procedure.

3.1 Grab sampling.

3.1.1 Set up the equipment as shown in Figure 3-1, making sure all connections are leak-free. Place the probe in the stack at a sampling point and purge the sampling line.

3.1.2 Draw sample into the analyzer.

3.2 Integrated sampling.

3.2.1 Evacuate the flexible bag. Set up the equipment as shown in Figure 3-2 with the bag disconnected. Place the probe in the stack and purge the sampling line. Connect the bag, making sure that all connections are tight and that there are no leaks.

3.2.2 Sample at a rate proportional to the stack velocity.

3.3 Analysis.

3.3.1 Determine the CO_2 , O_2 , and CO concentrations as soon as possible. Make as many passes as are necessary to give constant readings. If more than ten passes are necessary, replace the absorbing solution.

3.3.2 For grab sampling, repeat the sampling and analysis until three consecutive samples vary no more than 0.5 percent by volume for each component being analyzed.

3.3.3 For integrated sampling, repeat the analysis of the sample until three consecutive analyses vary no more than 0.2 percent by volume for each component being analyzed.

4. Calculations.

4.1 Carbon dioxide. Average the three consecutive runs and report the result to the nearest 0.1% CO_2 .

4.2 Excess air. Use Equation 3-1 to calculate excess air, and average the runs. Report the result to the nearest 0.1% excess air.

% EA =

$$\frac{(\% \text{O}_2) - 0.5(\% \text{CO})}{1.264(\% \text{N}_2) - (\% \text{O}_2) + 0.5(\% \text{CO})} \times 100$$

equation 3-1

where:

% EA = Percent excess air.

% O_2 = Percent oxygen by volume, dry basis.

% N_2 = Percent nitrogen by volume, dry basis.

% CO = Percent carbon monoxide by volume, dry basis.

0.264 = Ratio of oxygen to nitrogen in air by volume.

4.3 Dry molecular weight. Use Equation 2 to calculate dry molecular weight and average the runs. Report the result to the nearest tenth.

$$d_1 = 0.44(\% \text{CO}_2) + 0.32(\% \text{O}_2) + 0.28(\% \text{N}_2 + \% \text{CO})$$

equation 3-2

where:

M = Dry molecular weight, lb./lb.-mole.

% CO_2 = Percent carbon dioxide by volume, dry basis.

% O_2 = Percent oxygen by volume, dry basis.

% N_2 = Percent nitrogen by volume, dry basis.

0.44 = Molecular weight of carbon dioxide divided by 100.

0.32 = Molecular weight of oxygen divided by 100.

0.28 = Molecular weight of nitrogen and CO divided by 100.

5. References.

Altshuler, A. P., et al., Storage of Gases and Vapors in Plastic Bags, Int. J. Air & Water Pollution, 6:75-81, 1963.

Conner, William D., and J. S. Nader, Air Sampling with Plastic Bags, Journal of the American Industrial Hygiene Association, 25:201-207, May-June 1964.

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

METHOD 4—DETERMINATION OF MOISTURE IN STACK GASES

1. Principle and applicability.

1.1 Principle. Moisture is removed from the gas stream, condensed, and determined volumetrically.

1.2 Applicability. This method is applicable for the determination of moisture in stack gas only when specified by test procedures for determining compliance with New Source Performance Standards. This method does not apply when liquid droplets are present in the gas stream¹ and the moisture is subsequently used in the determination of stack gas molecular weight.

Other methods such as drying tubes, wet bulb-dry bulb techniques, and volumetric condensation techniques may be used.

2. Apparatus.

2.1 Probe—Stainless steel or Pyrex[®] glass sufficiently heated to prevent condensation and equipped with a filter to remove particulate matter.

2.2 Impingers—Two midjet impingers, each with 50 ml. capacity, or equivalent.

2.3 Ice bath container—To condense moisture in impingers.

2.4 Silica gel tube (optional)—To protect pump and dry gas motor.

2.5 Needle valve—To regulate gas flow rate.

2.6 Pump—Leak-free, diaphragm type, or equivalent, to pull gas through train.

2.7 Dry gas motor—To measure to within 1% of the total sample volume.

2.8 Rotameter—To measure a flow range from 0 to 0.1 c.f.m.

2.9 Graduated cylinder—25 ml.

2.10 Barometer—Sufficient to read to within 0.1 inch Hg.

2.11 Pitot tube—Type B, or equivalent, attached to probe so that the sampling flow

¹ If liquid droplets are present in the gas stream, assume the stream to be saturated, determine the average stack gas temperature by traversing according to Method 1, and use a psychrometric chart to obtain an approximation of the moisture percentage.

[®] Trade name.

rate can be regulated proportional to the stack gas velocity when velocity is varying with time or a sample traverse is conducted.

3. Procedure.

3.1 Place exactly 5 ml. distilled water in each impinger. Assemble the apparatus without the probe as shown in Figure 4-1. Leak check by plugging the inlet to the first impinger and drawing a vacuum. Insure that flow through the dry gas meter is less than 1% of the sampling rate.

3.2 Connect the probe and sample at a

constant rate of 0.075 c.f.m. or at a rate proportional to the stack gas velocity. Continue sampling until the dry gas meter registers 1 cubic foot 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 4-2.

3.3 After collecting the sample, measure the volume increase to the nearest 0.5 ml.

4. Calculations.

4.1 Volume of water vapor collected.

$$V_w = \frac{(V_i - V_f) p_{H_2O} R T_{std}}{P_{std} M_{H_2O}} = 0.0174 \frac{\text{ft.}^3}{\text{ml.}} (V_i - V_f)$$

equation 4-1

where:

V_w = Volume of water vapor collected (standard conditions), cu. ft.

V_i = Final volume of impinger contents, ml.

V_f = Initial volume of impinger contents, ml.

R = Ideal gas constant, 21.83 inches Hg—cu. ft./lb. mole—°R.

p_{H_2O} = Density of water, 1 g./ml.

T_{std} = Absolute temperature at standard conditions, 530° R.

P_{std} = Absolute pressure at standard conditions, 29.92 inches Hg.

M_{H_2O} = Molecular weight of water, 18 lb./lb.-mole.

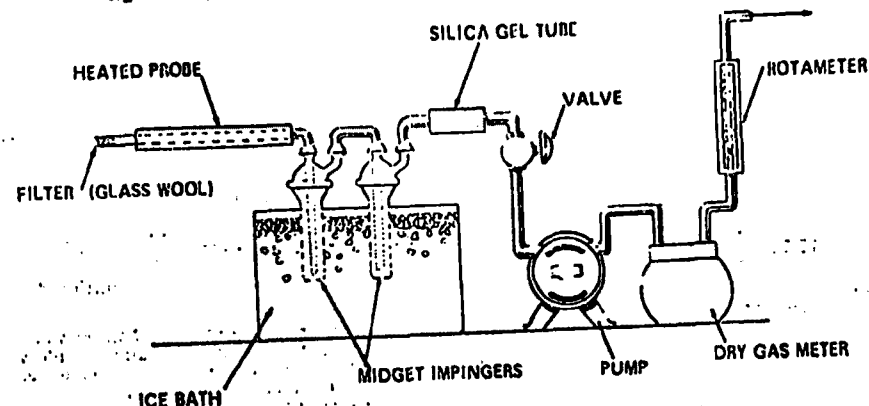


Figure 4-1. Moisture-sampling train.

LOCATION _____ COMMENTS _____
 TEST _____
 DATE _____
 OPERATOR _____
 BAROMETRIC PRESSURE _____

CLOCK TIME	GAS VOLUME THROUGH METER, (V _m), ft ³	ROTAMETER SETTING ft ³ /min	METER TEMPERATURE, °F

Figure 4-2. Field moisture determination.

4.2 Gas volume.

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

$$17.71 \frac{^\circ R}{\text{in. Hg}} \left(\frac{V_m P_m}{T_m} \right) \quad \text{equation 4-2}$$

where:

V_{m,d} = Dry gas volume through meter at standard conditions, cu. ft.V_m = Dry gas volume measured by meter, cu. ft.P_m = Barometric pressure at the dry gas meter, inches Hg.P_{std} = Pressure at standard conditions, 29.92 inches Hg.T_{std} = Absolute temperature at standard conditions, 530° R.T_m = Absolute temperature at meter (°F + 460), °R.

4.3 Moisture content.

$$B_{w,v} = \frac{V_{w,v}}{V_{w,v} + V_{m,d}} + B_{w,m} = \frac{V_{w,v}}{V_{w,v} + V_{m,d}} + (0.025) \quad \text{equation 4-3}$$

where:

B_{w,v} = Proportion by volume of water vapor in the gas stream, dimensionless.V_{w,v} = Volume of water vapor collected (standard conditions), cu. ft.V_{m,d} = Dry gas volume through meter (standard conditions), cu. ft.B_{w,m} = Approximate volumetric proportion of water vapor in the gas stream leaving the impingers, 0.025.

5. References.

Air Pollution Engineering Manual, Danielson, J. A. (ed.), U.S. DHEW, PHS, National Center for Air Pollution Control, Cincinnati, Ohio, PHS Publication No. 999-AP-40, 1967.
 Devorkin, Howard, et al., Air Pollution Source Testing Manual, Air Pollution Control District, Los Angeles, Calif., November 1969.

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 its weight is determined gravimetrically after removal of uncombined water.

1.2 Applicability. This method is applicable for the determination of particulate emissions from stationary sources only when specified by the test procedures for determining compliance with New Source Performance Standards.

2. Apparatus.

2.1 Sampling train. The design specifications of the particulate sampling train used by EPA (Figure 5-1) are described in APTD-0581. Commercial models of this train are available.

2.1.1 Nozzle—Stainless steel (316) with sharp, tapered leading edge.

2.1.2 Probe—Pyrex¹ glass with a heating system capable of maintaining a minimum gas temperature of 250° F. at the exit end during sampling to prevent condensation from occurring. When length limitations (greater than about 8 ft.) are encountered at temperatures less than 600° F., Incoloy 825¹, or equivalent, may be used. Probes for sampling gas streams at temperatures in excess of 600° F. must have been approved by the Administrator.

2.1.3 Pitot tube—Type S, or equivalent, attached to probe to monitor stack gas velocity.

¹ Trade name.

2.1.4 Filter Holder—Pyrex¹ glass with heating system capable of maintaining minimum temperature of 225° F.

2.1.5 Impingers / Condenser—Four impingers connected in series with glass ball joint fittings. The first, third, and fourth impingers are of the Greenburg-Smith design, modified by replacing the tip with a 1/2-inch ID glass tube extending to one-half inch from the bottom of the flask. The second impinger is of the Greenburg-Smith design with the standard tip. A condenser may be used in place of the impingers provided that the moisture content of the stack gas can still be determined.

2.1.6 Metering system—Vacuum gauge, leak-free pump, thermometers capable of measuring temperature to within 5° F., dry gas meter with 2% accuracy, and related equipment, or equivalent, as required to maintain an isokinetic sampling rate and to determine sample volume.

2.1.7 Barometer—To measure atmospheric pressure to ±0.1 inches Hg.

2.2 Sample recovery.

2.2.1 Probe brush—At least as long as probe.

2.2.2 Glass wash bottles—Two.

2.2.3 Glass sample storage containers.

2.2.4 Graduated cylinder—250 ml.

2.3 Analysis.

2.3.1 Glass weighing dishes.

2.3.2 Desiccator.

2.3.3 Analytical balance—To measure to ±0.1 mg.

2.3.4 Trip balance—300 g. capacity, to measure to ±0.05 g.

3. Reagents.

3.1 Sampling.

3.1.1 Filters—Glass fiber, MSA 1105 BH¹, or equivalent, numbered for identification and preweighed.

3.1.2 Silica gel—Indicating type, 6-16 mesh, dried at 175° C. (350° F.) for 2 hours

3.1.3 Water.

3.1.4 Crushed ice.

3.2 Sample recovery.

3.2.1 Acetone—Reagent grade.

3.3 Analysis.

3.3.1 Water.

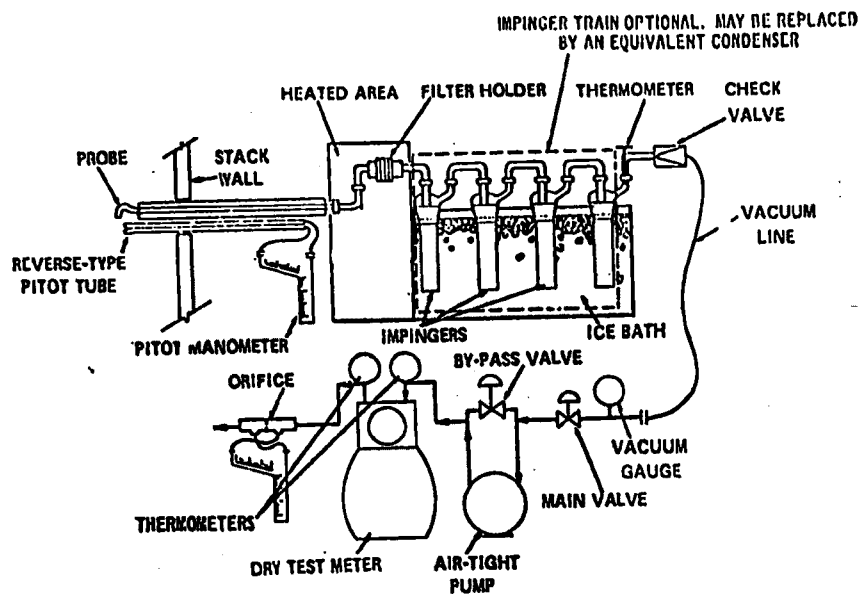


Figure 5-1. Particulate-sampling train.

3.3.2 Desiccant—Drierite,¹ Indicating.

4. Procedure.

4.1 Sampling

4.1.1 After selecting the sampling site and a minimum number of sampling points, determine the stack pressure, temperature, moisture, and range of velocity head.

4.1.2 Preparation of collection train. Weigh to the nearest gram approximately 200 g of silica gel. Label a filter of proper diameter, at least 24 inches in diameter, for use at a relative humidity in a room where the relative humidity is less than 50%. Place 0 ml. of water in each of the first two impingers, leave the third impinger empty.

1 Trade name.

'Dry using Drierite' at 70° F. ± 10° F.

and place approximately 200 g. of preweighed silica gel in the fourth impinger. Set up the train without the probe as in Figure 5-1. Leak check the sampling train at the sampling site by plugging up the inlet to the filter holder and pulling a 15 in. Hg vacuum. A leakage rate not in excess of 0.02 c.f.m. at a vacuum of 15 in. Hg is acceptable. Attach the probe and adjust the heater to provide a gas temperature of about 260° F. at the probe outlet. Turn on the filter heating system. Place crushed ice around the impingers. Add more ice during the run to keep the temperature of the gases leaving the last impinger as low as possible and preferably at 70° F. or less. Temperatures above 70° F. may result in damage to the dry gas meter from either moisture condensation or excessive heat.

4.1.3 Particulate train operation. For each run, record the data required on the example sheet shown in Figure 5-2. Take readings at each sampling point, at least every 5 minutes, and when significant changes in stack conditions necessitate additional adjustments in flow rate. To begin sampling, 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. Sample for at least 5 minutes at each traverse point; sam-

piling time must be the same for each point. Maintain isokinetic sampling throughout the sampling period. Nomographs are available which aid in the rapid adjustment of the sampling rate without other computations. APTD-0576 details the procedure for using these nomographs. Turn off the pump at the conclusion of each run and record the final readings. Remove the probe and nozzle from the stack and handle in accordance with the sample recovery process described in section 4.2.

[illegible]

Figure 5-2. Particulate field data.

4.9 Sample recovery. Exercise care in moving the collection train from the test site to the sample recovery area to minimize the loss of collected sample or the gain of extraneous particulate matter. Set aside a portion of the acetone used in the sample recovery as a blank for analysis. Measure the volume of water from the first three impingers, then discard. Place the samples in containers as follows:

Container No. 1. Remove the filter from its holder, place in this container, and seal.

Container No. 2. Place loose particulate matter and acetone washings from all sample-exposed surfaces prior to the filter in this container and seal. Use a razor blade, brush, or rubber policeman to lose adhering particles.

Container No. 3. Transfer the silica gel from the fourth impinger to the original container and seal. Use a rubber policeman as an aid in removing silica gel from the impinger.

4.3 Analysis. Record the data required on the example sheet shown in Figure 5-3. Handle each sample container as follows:

Container No. 1. Transfer the filter and any loose particulate matter from the sample container to a tared glass weighing dish, desiccate, and dry to a constant weight. Report results to the nearest 0.5 mg.

Container No. 2. Transfer the acetone washings to a tared beaker and evaporate to dryness at ambient temperature and pressure. Desiccate and dry to a constant weight. Report results to the nearest 0.5 mg.

Container No. 3. Weigh the spent silica gel and report to the nearest gram.

5. Calibration.

Use methods and equipment which have been approved by the Administrator to calibrate the orifice meter, pitot tube, dry gas meter, and probe heater. Recalibrate after each test series.

6. Calculations.

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

6.2 Dry gas volume. Correct the sample volume measured by the dry gas meter to standard conditions (70° F., 29.92 inches Hg) by using Equation 5-1.

$$V_{std} = V_m \left(\frac{T_{std}}{T_m} \right) \left(\frac{P_{bar} + \frac{\Delta H}{13.6}}{P_{std}} \right) = (17.71 \frac{in. Hg}{in. Hg}) V_m \left(\frac{P_{bar} + \frac{\Delta H}{13.6}}{T_m} \right)$$

equation 5-1

where:

V_{std} = Volume of gas sample through the dry gas meter (standard conditions), cu. ft.

V_m = Volume of gas sample through the dry gas meter (meter conditions), cu. ft.

T_{std} = Absolute temperature at standard conditions, 530° R.

T_m = Average dry gas meter temperature, °R.

P_{bar} = Barometric pressure at the orifice meter, inches Hg.

ΔH = Average pressure drop across the orifice meter, inches H₂O.

13.6 = Specific gravity of mercury.

P_{std} = Absolute pressure at standard conditions, 29.92 inches Hg.

6.3 Volume of water vapor.

$$V_{std} = V_m \frac{\rho_{H_2O}}{M_{H_2O}} \frac{RT_{std}}{P_{std}} \frac{lb.}{454 gm.} = 0.0474 \frac{cu. ft.}{ml.} V_m$$

equation 5-2

where:

V_{std} = Volume of water vapor in the gas sample (standard conditions), cu. ft.

V_m = Total volume of liquid collected in impingers and silica gel (see Figure 5-3), ml.

ρ_{H_2O} = Density of water, 1 g./ml.

M_{H_2O} = Molecular weight of water, 18 lb./lb.-mole.

R = Ideal gas constant, 21.83 inches Hg-cu. ft./lb.-mole-°R.

T_{std} = Absolute temperature at standard conditions, 530° R.

P_{std} = Absolute pressure at standard conditions, 29.92 inches Hg.

6.4 Moisture content.

$$B_{ws} = \frac{V_{std}}{V_{std} + V_{std}} \quad \text{equation 5-3}$$

where:

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

V_{std} = Volume of water in the gas sample (standard conditions), cu. ft.

V_{std} = Volume of gas sample through the dry gas meter (standard conditions), cu. ft.

6.5 Total particulate weight. Determine the total particulate catch from the sum of the weights on the analysis data sheet (Figure 5-3).

6.6 Concentration.

6.6.1 Concentration in gr./s.c.f.

$$C_g = \left(0.0154 \frac{gr.}{mg.} \right) \left(\frac{M_m}{V_{std}} \right) \quad \text{equation 5-4}$$

where:

C_g = Concentration of particulate matter in stack gas, gr./s.c.f., dry basis.

M_m = Total amount of particulate matter collected, mg.

V_{std} = Volume of gas sample through dry gas meter (standard conditions), cu. ft.

PLANT _____

DATE _____

RUN NO. _____

CONTAINER NUMBER	WEIGHT OF PARTICULATE COLLECTED, mg		
	FINAL WEIGHT	TARE WEIGHT	WEIGHT GAIN
1			
2			
TOTAL			

	VOLUME OF LIQUID WATER COLLECTED	
	IMPINGER VOLUME, ml	SILICA GEL WEIGHT, g
FINAL		
INITIAL		
LIQUID COLLECTED		
TOTAL VOLUME COLLECTED		g ^a ml

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

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

Figure 5-3. Analytical data.

6.6.2 Concentration in lb./cu. ft.

$$c_s = \frac{\left(\frac{1}{453,600} \frac{\text{lb.}}{\text{mg.}} \right) M_s}{V_{s,14}} = 2.205 \times 10^{-4} \frac{M_s}{V_{s,14}} \quad \text{equation 5-5}$$

where:

c_s = Concentration of particulate matter in stack gas, lb./c.c.f., dry basis.
453,600 = Mg/lb.

M_s = Total amount of particulate matter collected, mg.

$V_{s,14}$ = Volume of gas sample through dry gas meter (standard conditions), cu. ft.

6.7 Isokinetic variation.

$$I = T_s \left[\left(\frac{0.00207 \text{ in. Hg-cu. ft.}}{\text{ml-}^\circ\text{R}} \right) V_{t,1} + \frac{V_{t,1}}{T_{t,1}} \left(P_{t,1} + \frac{H}{13.6} \right) \right] \left(\frac{1.067 \text{ min.}}{\text{sec.}} \right) \quad \text{equation 5-6}$$

where:

I = Percent of isokinetic sampling.

$V_{t,1}$ = Total volume of liquid collected in impingers and silica gel (See Fig. 5-3), ml.

$\rho_{w,1}$ = Density of water, g./ml.

R = Ideal gas constant, 21.83 inches Hg-cu. ft./lb. mole- $^\circ\text{R}$.

$M_{w,1}$ = Molecular weight of water, 18 lb./lb.-mole.

$V_{t,1}$ = Volume of gas sample through the dry gas meter (meter conditions), cu. ft.

$T_{t,1}$ = Absolute average dry gas meter temperature (see Figure 5-2), $^\circ\text{F}$.

$P_{t,1}$ = Barometric pressure at sampling site, inches Hg.

ΔH = Average pressure drop across the orifice (see Fig. 5-2), inches Hg.

T_s = Absolute average stack gas temperature (see Fig. 5-2), $^\circ\text{R}$.

θ = Total sampling time, min.

V_s = Stack gas velocity calculated by Method 2, Equation 2-2, ft./sec.

P_s = Absolute stack gas pressure, inches Hg.

A_s = Cross-sectional area of nozzle, sq. ft.

6.8 Acceptable results. The following range sets the limit on acceptable isokinetic sampling results:

If $90\% \leq 110\%$, the results are acceptable; otherwise, reject the results and repeat the test.

7. Reference.

Addendum to Specifications for Incinerator Testing at Federal Facilities, FHS, NCAPC, Dec. 6, 1967.

Martin, Robert M., Construction Details of Isokinetic Source Sampling Equipment, Environmental Protection Agency, APTD-5081.

Rom, Jerome J., Maintenance, Calibration and Operation of Isokinetic Source Sampling Equipment, Environmental Protection Agency, APTD-5078.

Smith, W. S., R. T. Shigehara, and W. F. Todd, A Method of Interpreting Stack Sampling Data, Paper presented at the 63d Annual Meeting of the Air Pollution Control Association, St. Louis, Mo., June 14-19, 1970.

Smith, W. S., et al., Stack Gas Sampling Improved and Simplified with New Equipment, APCA paper No. 67-110, 1967.

Specifications for Incinerator Testing at Federal Facilities, FHS, NCAPC, 1967.

METHOD 6—DETERMINATION OF SULFUR DIOXIDE EMISSIONS FROM STATIONARY SOURCES

1. Principle and applicability.

1.1 Principle. A gas sample is extracted from the sampling point in the stack. The acid mist, including sulfur trioxide, is separated from the sulfur dioxide. The sulfur dioxide fraction is measured by the barium-thorin titration method.

1.2 Applicability. This method is applicable for the determination of sulfur dioxide emissions from stationary sources only when specified by the test procedures for determining compliance with New Source Performance Standards.

2. Apparatus.

2.1 Sampling. See Figures 6-1.

2.1.1 Probe—Pyrex¹ glass, approximately 5 to 6 mm. ID, with a heating system to prevent condensation and a filtering medium to remove particulate matter including sulfuric acid mist.

2.1.2 Midget bubbler—One, with glass wool packed in top to prevent sulfuric acid mist carryover.

2.1.3 Glass wool.

2.1.4 Midget impingers—Three.

2.1.5 Drying tube—Packed with 6 to 16 mesh indicating-type silica gel, or equivalent, to dry the sample.

2.1.6 Valve—Needle valve, or equivalent, to adjust flow rate.

2.1.7 Pump—Leak-free, vacuum type.

2.1.8 Rate meter—Rotameter or equivalent, to measure a 0-10 s.c.f.h. flow range.

2.1.9 Dry gas meter—Sufficiently accurate to measure the sample volume within 1%.

2.1.10 Pitot tube—Type S, or equivalent, necessary only if a sample traverse is required, or if stack gas velocity varies with time.

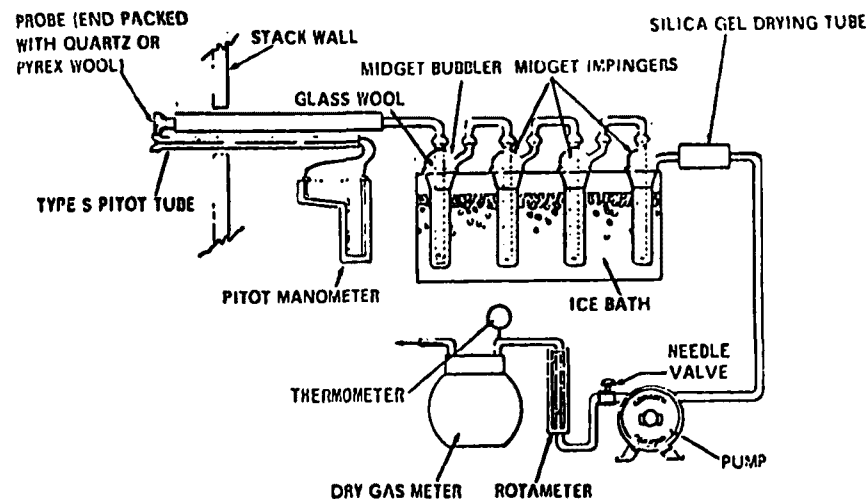
2.2 Sample recovery.

2.2.1 Glass wash bottles—Two.

2.2.2 Polyethylene storage bottles—To store impinger samples.

2.3 Analysis.

¹ Trade names.

Figure 6-1. SO₂ sampling train.

2.3.1 Pipettes—Transfer type, 5 ml. and 10 ml. sizes (0.1 ml. divisions) and 25 ml. size (0.2 ml. divisions).

2.3.2 Volumetric flasks—50 ml., 100 ml., and 1,000 ml.

2.3.3 Burettes—5 ml. and 50 ml.

2.3.4 Erlenmeyer flask—125 ml.

3. Reagents.

3.1 Sampling.

3.1.1 Water—Deionized, distilled.

3.1.2 Isopropanol, 80%—Mix 80 ml. of isopropanol with 20 ml. of distilled water.

3.1.3 Hydrogen peroxide, 3%—dilute 100 ml. of 30% hydrogen peroxide to 1 liter with distilled water. Prepare fresh daily.

3.2 Sample recovery.

3.2.1 Water—Deionized, distilled.

3.2.2 Isopropanol, 80%.

3.3 Analysis.

3.3.1 Water—Deionized, distilled.

3.3.2 Isopropanol.

3.3.3 Thorin indicator—1-(o-arsonophenylazo)-2-naphthol-3,6-disulfonic acid, disodium salt (or equivalent). Dissolve 0.20 g. in 100 ml. distilled water.

3.3.4 Barium perchlorate (0.01 N)—Dissolve 1.05 g. of barium perchlorate [Ba(ClO₄)₂ · 8H₂O] in 200 ml. distilled water and dilute to 1 liter with isopropanol. Standardize with sulfuric acid. Barium chloride may be used.

3.3.5 Sulfuric acid standard (0.01 N)—Purchase or standardize to ± 0.0002 N against 0.01N NaOH which has previously been standardized against potassium acid phthalate (primary standard grade).

4. Procedure.

4.1 Sampling.

4.1.1 Preparation of collection train. Pour 15 ml. of 80% isopropanol into the midget bubbler and 15 ml. of 3% hydrogen peroxide into each of the first two midget impingers. Leave the final midget impinger dry. Assemble the train as shown in Figure 6-1. Leak check the sampling train at the sampling site by plugging the probe inlet and pulling a 10 inches Hg vacuum. A leakage rate not in excess of 1% of the sampling rate is acceptable. Carefully release the probe inlet plug and turn off the pump. Place crushed ice around the impingers. Add more ice during the run to keep the temperature of the gases leaving the last impinger at 70° F. or less.

4.1.2 Sample collection. Adjust the sample flow rate proportional to the stack gas velocity. Take readings at least every five minutes and when significant changes in stack conditions necessitate additional adjustments in flow rate. To begin sampling, position the tip of the probe at the first sampling point and start the pump. Sample proportionally throughout the run. At the conclusion of each run, turn off the pump and record the final readings. Remove the probe from the stack and disconnect it from the train. Drain the ice bath and purge the remaining part of the train by drawing clean ambient air through the system for 15 minutes.

4.2 Sample recovery. Disconnect the impingers after purging. Discard the contents of the midget bubbler. Pour the contents of the midget impingers into a polyethylene shipment bottle. Rinse the three midget impingers and the connecting tubes with dis-

B-1

APPENDIX B

HIGH-VOLUME TEST METHODS

OREGON DEPARTMENT OF ENVIRONMENTAL QUALITY

AIR QUALITY CONTROL DIVISION

May, 1972

STANDARD SAMPLING METHOD

DETERMINATION OF PARTICULATE EMISSIONS FROM CYCLONES
(High Volume Method)

1. Principle and Applicability

- 1.1 Particulate matter is withdrawn from the source under isokinetic conditions as a component of the flowing gas stream. The particulate is removed from the sample stream by filtration through a glass fiber filter. Particulate mass is determined gravimetrically.
- 1.2 This method is applicable for the determination of particulate emissions from cyclones exhausting directly to the atmosphere.
- 1.3 It is recognized that this sampling method is not necessarily consistent with other standard methods of source testing. The Department of Environmental Quality and other agencies may re-evaluate this method in comparison with other methods, as more data becomes available, and will revise this method as required.

2. Range and Sensitivity

- 2.1 The range of the method is dependent upon the sampling time and flowrate. To obtain the minimum required sample weight of 100 mg. on a filter in the minimum acceptable time of 15 minutes, the particulate concentration must be at least .002 gr./scf. when sampling at 50 cfm, or 0.02 gr./scf. at 5 cfm. The maximum practical loading on the filter is not known at this time.
- 2.2 The sensitivity of the method is better than 1.0% of the measured concentration, based on the ability to discriminate an increment of sample weight of 1.0 mg. in a sample of at least 100 mg.

3. Interferences

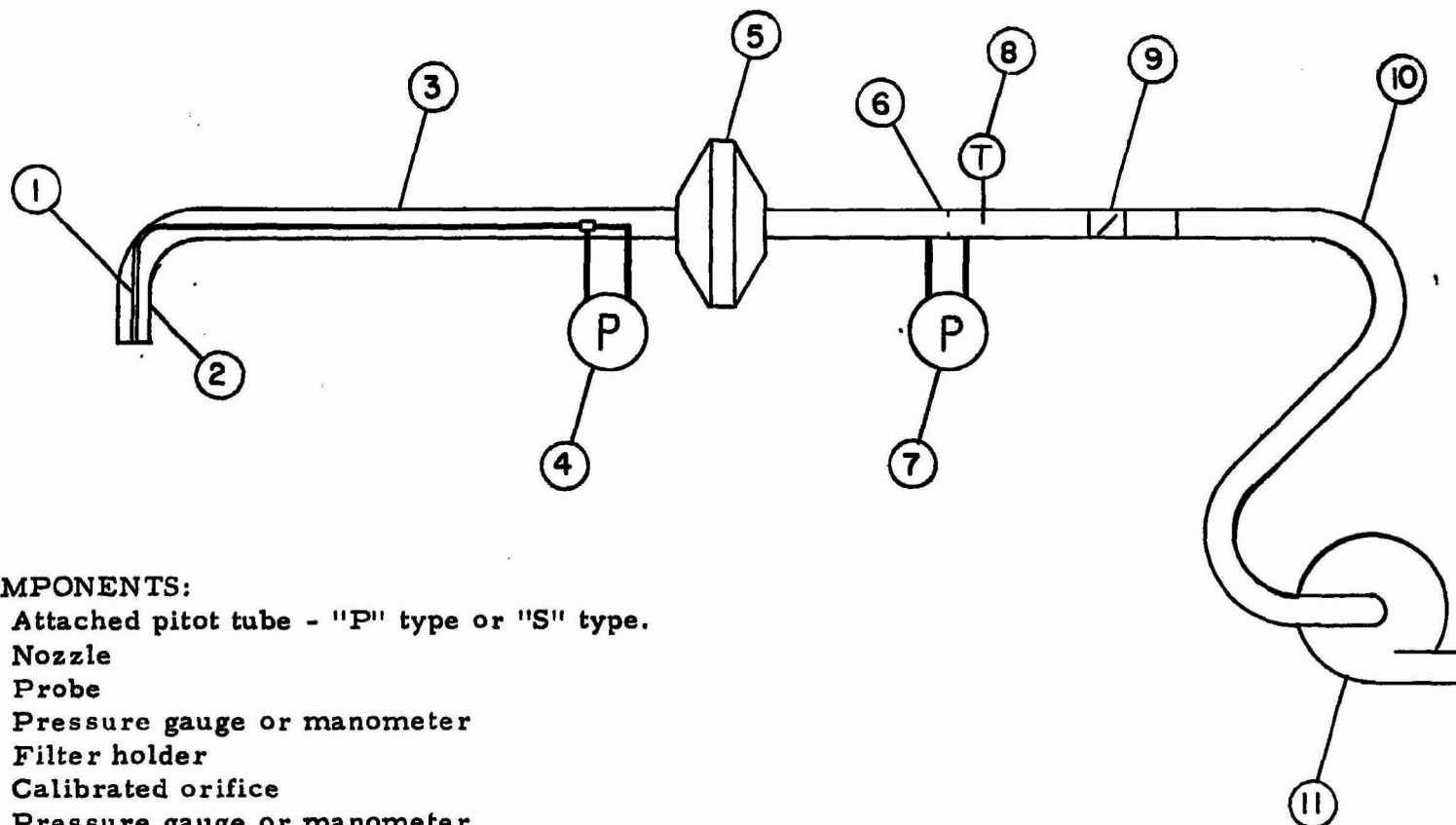
- 3.1 Particulate matter present in a gaseous phase at the filtration temperature will probably not be collected. This method should not be used if significant quantities of condensible particulate matter are expected, unless the temperature of the sample gas can be reduced to approximately 70° prior to filtration.

4. Apparatus

- 4.1 Sampling - A schematic diagram of a typical sampling train is shown in Figure 1. The recommended design of this device is described in Reference 10.1, and commercial models are available.

- 4.1.1 Nozzle - The sampling nozzle shall be made of metal, and shall be sharp-edged. Nozzle diameter shall be such that isokinetic conditions can be maintained at flow rates to be used on each test. The typical range of nozzle sizes is from 1/2 inch to 2 inches in diameter. The nozzle shall be connected to the probe by means such that deposition of particulate matter in threads or joints is minimized.
- 4.1.2 Probe - The probe shall attach to the filter holder either directly or by the shortest possible length of smooth-walled tubing.
- 4.1.3 Filter Holder - The filter holder shall be air tight. A quick disconnect assembly is recommended for ease of changing filters.
- 4.1.4 Metering System - The filter holder shall be followed by a calibrated orifice, a thermometer or thermocouple, a flow control and a high volume blower capable of 60 cfm free air capacity.
- 4.2 Sample Recovery
 - 4.2.1 Probe Brush - It should be of a length at least equal to that of the probe and any tubing connecting it to the filter holder.
 - 4.2.2 Clean manila envelopes for handling and storing filters.
 - 4.2.3 Wash bottles and storage containers for liquid samples.
- 4.3 Analysis - The laboratory in which samples are to be analyzed shall include standard laboratory equipment such as glass weighing dishes, an analytical balance accurate to the nearest milligram, and other necessary equipment.
- 5. Reagents
 - 5.1 Sampling
 - 5.1.1 Filters - Glass fiber filters, type A, type E, or equivalent, shall be used. Prior to sampling, each filter shall be exposed to a light source and inspected for pinholes, particles, or other imperfections. Filters with visible imperfections shall not be used. A small brush is useful for removing particles. Filters shall be pre-conditioned by equilibrating at 20-24° C, 50% relative humidity or less, for a minimum of 2 hours. Filters shall be numbered for identification, and pre-weighed to the nearest 1 milligram. Filters shall not be folded before collection of the sample.
 - 5.2 Sample Recovery - Reagent grade acetone, methanol, or other suitable solvent shall be used for cleaning up the sampling train.
- 6. Procedure
 - 6.1 Determination of Air-Flow Rates and Properties
 - 6.1.1 A sampling site for determining system flow rate shall be selected in the approach-duct to the cyclone. The point selected shall be as close as possible to the ideal location described in standard source sampling literature (e. g., eight diameters downstream, and two diameters upstream, from the nearest obstruction or bend in the duct), keeping in mind the necessity of having an accessible location. The cross section of the duct shall be divided into equal areas and a velocity traverse conducted according to standard sampling methods (Reference 10.2).

F E 1
SCHEMA. DIAGRAM
TYPICAL HIGH VOLUME PARTICULATE SAMPLING TRAIN



COMPONENTS:

1. Attached pitot tube - "P" type or "S" type.
2. Nozzle
3. Probe
4. Pressure gauge or manometer
5. Filter holder
6. Calibrated orifice
7. Pressure gauge or manometer
8. Thermometer or thermocouple
9. Control valve or damper
10. Optional flexible coupling
11. High volume blower

- 6.1.2 Either an S-type or P-type pitot tube may be used in conducting a velocity traverse, according to Reference 10.2.
- 6.1.3 Temperature, static pressure, and moisture of the gas stream shall be measured in order for duct flow rate to be corrected to standard conditions.
- 6.1.4 Record data on Form 2 of Appendix I, or equivalent.
- 6.1.5 A pitot traverse is probably impractical for high pressure pneumatic conveying systems, in which case it is permissible to use manufacturer's data relating air flow to pressure drop and rpm at the blower.
- 6.2 Sampling
 - 6.2.1 Velocity Survey at Cyclone Exhaust
 - 6.2.1.1 Use a pitot tube to roughly map the velocity distribution across the cross section of the cyclone exhaust.
 - 6.2.1.2 At each point at which velocity is measured, measure the flow in the direction that gives maximum deflection on the manometer or pressure gauge. Record data on Form 3, Appendix I.
 - 6.2.1.3 Select six points at which emissions will be sampled. Each of these points shall be in an area of positive (out-going) flow. One point shall be near the point at which maximum velocity occurs. The points shall provide a representative sample of the flow pattern, and shall be numbered and referenced on the sketch of the exit cross section flow pattern. If six points with positive flow cannot be obtained, use the maximum number possible.
 - 6.2.2 Preparation of Sampling Train - The following steps shall be conducted prior to each run.
 - 6.2.2.1 All parts of the sampling train shall be cleaned and properly calibrated as directed in Paragraph 7.
 - 6.2.2.2 Place a filter in the filter holder, coarse side facing the flow, being careful not to damage it.
 - 6.2.2.3 Perform a leak check by plugging the nozzle, turning on the blower, and observing the deflection, if any, on the flow orifice pressure gauge. Leakage shall not exceed 5% of the expected sample flowrate.
 - 6.2.3 Sample Collection
 - 6.2.3.1 With the probe out of the exhaust stream, turn on the blower and adjust the flowrate so that the velocity at the sampling nozzle corresponds with the velocity at first point to be sampled in the cyclone exhaust. When the correct flowrate has been established, turn off the blower. Note This step should not be done if the local environment is extremely dusty and there is danger of extraneous particulate contaminating the sample. The same applies to similar steps below.

- 6. 2. 3. 2 Locate the probe at the first point to be sampled and move it around until the velocity pressure matches that for which the sampling flowrate was pre-set.
- 6. 2. 3. 3 Turn on the blower and sample for the desired period of time. The sampling period at each point should be such that total run time for the cyclone is at least 15 min.
- 6. 2. 3. 4 Continually monitor velocity during the sampling period and move the probe around as required to keep it in an area where the velocity matches the rate needed to match the pre-set sampling flowrate. Record on the data sheet (Form 4, Appendix I) the temperature and pressure drop at the orifice meter.
- 6. 2. 3. 5 At the conclusion of the sampling period for the first point, move the probe to the next point and quickly readjust the flowrate to the previously established isokinetic rate. In the event conditions make it impossible to adjust the flowrate rapidly enough, the probe should be removed from the cyclone exhaust and the rate pre-set as in 6.2.3.1. Note on the data sheet (Form 4, Appendix I) the exact time of the sample period.
- 6. 2. 3. 6 Repeat steps 6.2.3.1 through 6.2.3.5 until all points are sampled. If excessive loading of the filter should occur or the pressure drop should increase such that isokinetic conditions cannot be maintained, replace the filter and continue the test.
- 6. 2. 3. 7 Extreme caution should be taken that the nozzle does not touch the walls of the cyclone. Doing so may dislodge the deposited material from the wall and cause it to enter the sampling nozzle, thus invalidating the sample. If there is reason to believe this has happened, discontinue the sample, clean the train and start over again.

6.3 Sample Recovery

- 6.3.1 Immediately upon removing the probe from the stack after completing the final point, plug the nozzle until it can be cleaned. Take the sampler to a reasonably clean area, turn on the blower, insert the probe brush into the probe and brush the particulate from the nozzle and probe into the filter. *Using a preweighed wash solution, rinse the probe section into a clean container.
- 6.3.2 Open the filter holder, and use a fine brush to brush any particulate matter deposited on the front side of the holder onto the filter. Fold the filter once length-wise, with the dirty side in, and place in a folded manila tagboard, folded edge down. Put a paper clip on the outside edge of the tagboard, and place in a manila envelope.

- 6.3.3 At the conclusion of testing of each cyclone, or more frequently if desired, wash the inside of the nozzle, the probe, the front half of the filter holder and the probe brush with solvent. Place the washings in a labeled container for gravimetric analysis.
- 6.4 Analysis
 - 6.4.1 Filter - Equilibrate the sample for at least 16 hours at 68-75° F (20-24° C) and 50%, or less, relative humidity. In the case of extremely wet particulate, oven drying at 150° F (65° C) may precede equilibration. Weigh the filter to a constant weight to the nearest mg.
 - 6.4.2 Solvent Wash - Transfer the solvent washings to a tared beaker, and evaporate to dryness at room temperature and pressure. Alternatively, the solvent may be evaporated in an oven at 150° F (65° C) or less. Equilibrate for at least 16 hours. Weigh to a constant weight and report the results to the nearest mg.
 - 6.4.3 Blanks - At least one filter for each four filters used in the field shall be inserted in the filter holder, a leak check performed, and removed and returned to the laboratory for analysis as a blank. A portion of the solvent used for field clean-up shall also be analyzed as a blank. Results from field samples shall be adjusted according to the blank values.

calibration

The pitot tube, orifice flowmeter, pressure gauges and temperature measurement devices shall be calibrated at least once a year against a primary standard or a device which has been calibrated against a primary standard. The date and method of calibration of these instruments shall be recorded on Form 1, Appendix I.

8. Calculations

Total particulate emissions from the cyclone shall be calculated by multiplying the particulate concentration measured at the cyclone exhaust by the flow measured at the inlet duct.

- 8.1 Particulate Concentration - The following calculations shall be conducted for each run.
 - 9.1.1 Total Sample Weight - Calculate the total sample weight from laboratory results by adding the net weight gain of filter samples, adjusted for blank value, to the net weight of particulate matter in the acetone washings. If the solvent washings represent more than one run, they should be pro-rated for each run according to the relative net weights of particulate collected on the filters. Record results on Form 4, Appendix I.
 - 8.1.2 Total Sample Air Volume - Calculate the sample volume for each sample point by multiplying the duration of the sample in minutes, times the average flowrate (cfm). Add the volume of all sample points to get the total sample air volume for the run. If each point was sampled for an equal period of time, the total flow can

be calculated as simply the total sample time multiplied by the average flowrate for all sample points. Flowrate for each point shall be determined from the calibration curve for the flow orifice, corrected to standard temperature and pressure. Express the results in the space provided on Form 4, Appendix I to the nearest cubic foot, both on a wet basis (cu. ft.) and on a dry basis (scf.), using 60° F and 29.92 in. Hg. as standard conditions.

8. 1. 3 Calculate the particulate concentration in gr. /scf. by the following equation:

$$C_g = 0.0154 \times \frac{W}{Q}$$

Where C_g = Particulate concentration, gr. /scf.

W = total particulate sample weight, mg.

Q = total volume of gas sample, scf.

Record this result in the space provided on Form 4 and Form 5, Appendix I.

8. 2 Total Flowrate

Use data from the velocity traverse of the approach duct to calculate flow through cyclone in scfm, using the tabular computing equations in Form 5, Appendix I. For some cyclones, the total flow may be adjusted to account for air purposely vented out the bottom of the cyclone.

8. 3 Total Emissions

Calculate the total particulate emission in lb/hr by the following equation, using Form 5, Appendix I:

$$E = .00857 (C_g)(Q_a)$$

Where E = total emission, lb/hr

Q_a = total cyclone flowrate, scfm.

8. 4 Percent Isokinetic

Use the tabular computing equations in Form 5, Appendix I to compute the percent isokinetic (I), defined as the ratio of the average velocity of the sample gas entering the sample nozzle to the average local velocity at the sampling points. In order to achieve acceptable results, the value of this parameter must be between 82% and 120%. Test results falling outside this range shall be discarded and the test repeated.

9. Test Reports

The following outline shall be considered the minimum acceptable contents of a source test report for a cyclone or group of cyclones at a plant site.

- I. Introduction and Summary of Results and Conclusions.
- II. Description of Source(s) - may be in tabular form for a large number of cyclones.
 - A. A plant site plot diagram and a process flow diagram in which each cyclone is clearly identified.
 - B. Process equipment involved - type, size.
 - C. Process material flowrates, fuel rates, etc...include assumptions used in evaluating process variables.
 - D. Cyclone system design, type, size, cfm, etc.
 - E. Special conditions occurring during the source test period.

III. Sampling and Analytical Methods.

- A. Field equipment - include dates of calibrations.
- B. Field procedures - describe deviations from the standard method, if any.
- C. Analytical methods - describe deviations from the standard method, if any.
- D. Special problems or considerations.

IV. Detailed results - may be in tabular form for a large number of cyclones.

- A. Emissions in gr./scf. and in lb/hr.
- B. Gas volume, temperature and moisture content.
- C. Percent isokinetic sample rate.
- D. Other results - particle size analysis, chemical analysis, or other optional data that may have been obtained.

V. Appendix

- A. Forms, 1, 2, 3, 4, and 5, or equivalent.
- B. Other field or laboratory data.

10. References

- 10.1 Boubel, Richard W., "A High Volume Stack Sampler," APCA Journal, Vol. 21, No. 12, December, 1971.
- 10.2 "Methods for Determination of Velocity, Volume, Dust and Mist Content of Gases," Bulletin WP-50, Western Precipitation Group, Joy Manufacturing Company.

C-1

•

APPENDIX C

REFERENCE METHOD 6

tiled water and add these washings to the same storage container.

4.3 Sample analysis. Transfer the contents of the storage container to a 50 ml. volumetric flask. Dilute to the mark with deionized, distilled water. Pipette a 10 ml. aliquot of this solution into a 125 ml. Erlenmeyer flask. Add 40 ml. of isopropanol and two to four drops of thorin indicator. Titrate to a pink endpoint using 0.01 N barium perchlorate. Run a blank with each series of samples.

5. Calibration.

5.1 Use standard methods and equipment which have been approved by the Administrator to calibrate the rotameter, pitot tube, dry gas meter, and probe heater.

5.2 Standardize the barium perchlorate against 25 ml. of standard sulfuric acid containing 100 ml. of isopropanol.

6. Calculations.

6.1 Dry gas volume. Correct the sample volume measured by the dry gas meter to

standard conditions (70° F. and 29.92 inches Hg) by using equation 6-1.

$$V_{std} = V_m \left(\frac{T_{std}}{T_m} \right) \left(\frac{P_{bar}}{P_{std}} \right) = 17.71 \frac{V_m}{\text{in. Hg}} \left(\frac{V_m P_{bar}}{T_m} \right) \quad \text{equation 6-1}$$

where:

V_{std} = Volume of gas sample through the dry gas meter (standard conditions), cu. ft.

V_m = Volume of gas sample through the dry gas meter (meter conditions), cu. ft.

T_{std} = Absolute temperature at standard conditions, 530° R.

T_m = Average dry gas meter temperature, °R.

P_{bar} = Barometric pressure at the orifice meter, inches Hg.

P_{std} = Absolute pressure at standard conditions, 29.92 inches Hg.

6.2 Sulfur dioxide concentration.

$$C_{SO_2} = \left(7.05 \times 10^{-4} \frac{\text{lb.-l.}}{\text{g.-ml.}} \right) \frac{(V_t - V_{th})N \left(\frac{V_{std}}{V_t} \right)}{V_{std}} \quad \text{equation 6-2}$$

where:

C_{SO_2} = Concentration of sulfur dioxide at standard conditions, dry basis, lb./cu. ft.

7.05×10^{-4} = Conversion factor, including the number of grams per gram equivalent of sulfur dioxide (32 g./g.-eq.), 453.6 g./lb., and 1,000 ml./l., lb.-l./g.-ml.

V_t = Volume of barium perchlorate titrant used for the sample, ml.

V_{th} = Volume of barium perchlorate titrant used for the blank, ml.

N = Normality of barium perchlorate titrant, g.-eq./l.

V_{std} = Total solution volume of sulfur dioxide, 50 ml.

V_t = Volume of sample aliquot titrated, ml.

V_{std} = Volume of gas sample through the dry gas meter (standard conditions), cu. ft., see Equation 6-1.

7. References.

Atmospheric Emissions from Sulfuric Acid Manufacturing Processes, U.S. DHEW, PHS, Division of Air Pollution, Public Health Service Publication No. 999-AP-13, Cincinnati, Ohio, 1965.

Corbett, F. F., The Determination of SO_2 and SO_3 in Flue Gases, Journal of the Institute of Fuel, 24:237-243, 1951.

Matty, R. E. and E. K. Diehl, Measuring Flue-Gas SO_2 and SO_3 , Power 102:94-97, November, 1957.

Patton, W. F. and J. A. Brink, Jr., New Equipment and Techniques for Sampling Chemical Process Gases, J. Air Pollution Control Association, 13, 162 (1963).

METHOD 7—DETERMINATION OF NITROGEN OXIDE EMISSIONS FROM STATIONARY SOURCES

1. Principle and applicability.

1.1 Principle. A grab sample is collected in an evacuated flask containing a dilute sulfuric acid-hydrogen peroxide absorbing solution, and the nitrogen oxides, except nitrous oxide, are measured colorimetrically using the phenoldisulfonic acid (PDS) procedure.

1.2 Applicability. This method is applicable for the measurement of nitrogen oxides from stationary sources only when specified by the test procedures for determining compliance with New Source Performance Standards.

2. Apparatus.

2.1 Sampling. See Figure 7-1.

2.1.1 Probe—Pyrex¹ glass, heated, with filter to remove particulate matter. Heating is unnecessary if the probe remains dry during the purging period.

2.1.2 Collection flask—Two-liter, Pyrex¹ round bottom with short neck and 24/40 standard taper opening, protected against implosion or breakage.

2.1.3 Flask valve—T-bore stopcock connected to a 24/40 standard taper joint.

2.1.4 Temperature gauge—Dial-type thermometer, or equivalent, capable of measuring 2° F. intervals from 28° to 125° F.

2.1.5 Vacuum line—Tubing capable of withstanding a vacuum of 3 inches Hg absolute pressure, with "T" connection and T-bore stopcock, or equivalent.

2.1.6 Pressure gauge—U-tube manometer, 36 inches, with 0.1-inch divisions, or equivalent.

¹ Trade name.

2.1.7 Pump—Capable of producing a vacuum of 3 inches Hg absolute pressure.

2.1.8 Squeeze bulb—One way.

2.2 Sample recovery.

2.2.1 Pipette or dropper.

2.2.2 Glass storage containers—Cushioned for shipping.

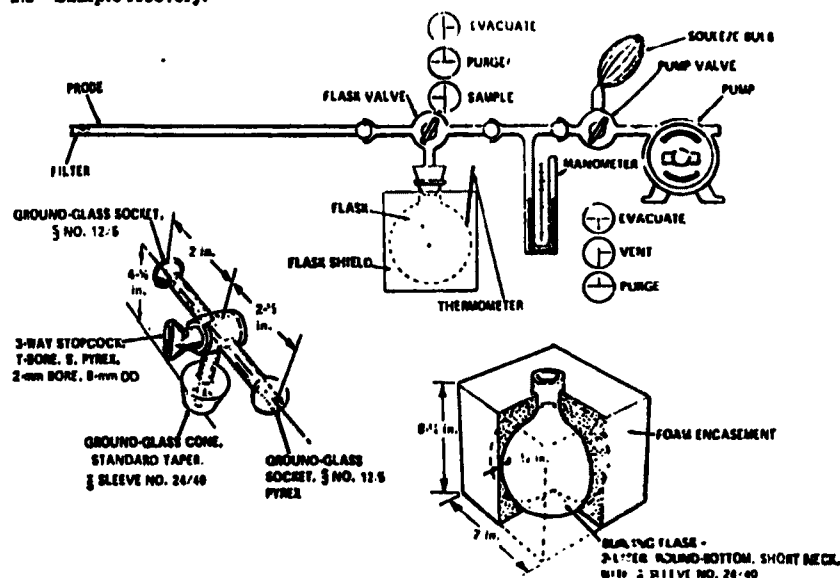


Figure 7-1. Sampling train, flask valve, and flask.

2.2.3 Glass wash bottle.

2.3 Analysis.

2.3.1 Steam bath.

2.3.2 Beakers or casserole—250 ml., one for each sample and standard (blank).

2.3.3 Volumetric pipettes—1, 2, and 10 ml.

2.3.4 Transfer pipette—10 ml. with 0.1 ml. divisions.

2.3.5 Volumetric flask—100 ml., one for each sample, and 1,000 ml. for the standard (blank).

2.3.6 Spectrophotometer—To measure absorbance at 420 nm.

2.3.7 Graduated cylinder—100 ml. with 1.0 ml. divisions.

2.3.8 Analytical balance—To measure to 0.1 mg.

3. Reagents.

3.1 Sampling.

3.1.1 Absorbing solution—Add 2.8 ml. of concentrated H_2SO_4 to 1 liter of distilled water. Mix well and add 6 ml. of 8 percent hydrogen peroxide. Prepare a fresh solution weekly and do not expose to extreme heat or direct sunlight.

3.2 Sample recovery.

3.2.1 Sodium hydroxide (1N)—Dissolve 40 g. NaOH in distilled water and dilute to 1 liter.

3.2.2 Red litmus paper.

3.2.3 Water—Deionized, distilled.

3.3 Analysis.

3.3.1 Fuming sulfuric acid—15 to 18% by weight free sulfur trioxide.

3.3.2 Phenol—White solid reagent grade.

3.3.3 Sulfuric acid—Concentrated reagent grade.

3.3.4 Standard solution—Dissolve 0.5495 g. potassium nitrate (KNO_3) in distilled water and dilute to 1 liter. For the working standard solution, dilute 10 ml. of the resulting solution to 100 ml. with distilled water. One ml. of the working standard solution is equivalent to 25 μ g. nitrogen dioxide.

3.3.5 Water—Deionized, distilled.

3.3.6 Phenoldisulfonic acid solution—Dissolve 25 g. of pure white phenol in 150 ml. concentrated sulfuric acid on a steam bath. Cool, add 75 ml. fuming sulfuric acid, and heat at 100° C. for 2 hours. Store in a dark, stoppered bottle.

4. Procedure.

4.1 Sampling.

4.1.1 Pipette 25 ml. of absorbing solution into a sample flask. Insert the flask valve stopper into the flask with the valve in the "purge" position. Assemble the sampling train as shown in Figure 7-1 and place the probe at the sampling point. Turn the flask valve and the pump valve to their "evacuate" positions. Evacuate the flask to at least 3 inches Hg absolute pressure. Turn the pump

6.6.2 Concentration in lb./cu. ft.

$$c_s = \frac{\left(\frac{1}{453,000} \frac{\text{lb.}}{\text{mg.}}\right) M_s}{V_{m,1d}} = 2.205 \times 10^{-6} \frac{M_s}{V_{m,1d}} \quad \text{equation 5-5}$$

where:

c_s = Concentration of particulate matter in stack gas, lb./s.c.f., dry basis.
453,000 = Mg/lb.

M_s = Total amount of particulate matter collected, mg.

$V_{m,1d}$ = Volume of gas sample through dry gas meter (standard conditions), cu. ft.

6.7 Isokinetic variation.

$$I = T_s \left[\left(\frac{0.00267 \text{ in. Hg-cu. ft.}}{\text{ml} - R} \right) V_1 + \frac{V_2}{T_m} \left(P_{m,1} + \frac{H}{13.6} \right) \right] \left(\frac{1.067 \text{ min.}}{\text{sec.}} \right) \quad \text{equation 5-6}$$

where:

I = Percent of isokinetic sampling.
 V_1 = Total volume of liquid collected in impingers and silica gel (See Fig. 5-3), ml.
 ρ_{H_2O} = Density of water, 1 g./ml.
 R = Ideal gas constant, 21.83 inches Hg-cu. ft./lb.-mole-°K.
 M_{H_2O} = Molecular weight of water, 18 lb./lb.-mole.
 V_2 = Volume of gas sample through the dry gas meter (meter conditions), cu. ft.
 T_m = Absolute average dry gas meter temperature (see Figure 5-3), °K.
 $P_{m,1}$ = Barometric pressure at sampling site, inches Hg.
 ΔH = Average pressure drop across the orifice (see Fig. 5-2), inches Hg.
 T_s = Absolute average stack gas temperature (see Fig. 5-2), °K.
 θ = Total sampling time, min.
 V_2 = Stack gas velocity calculated by Method 2, Equation 2-2, ft./sec.
 P_s = Absolute stack gas pressure, inches Hg.
 A_s = Cross-sectional area of nozzle, sq. ft.

6.8 Acceptable results. The following range sets the limit on acceptable isokinetic sampling results:

If 90% ≤ 110%, the results are acceptable; otherwise, reject the results and repeat the test.

7. Reference.

Addendum to Specifications for Incinerator Testing at Federal Facilities, PHS, NCAPC, Dec. 6, 1967.

Martin, Robert M., Construction Details of Isokinetic Source Sampling Equipment, Environmental Protection Agency, APTD-5081.

Rom, Jerome J., Maintenance, Calibration and Operation of Isokinetic Source Sampling Equipment, Environmental Protection Agency, APTD-5076.

Smith, W. S., R. T. Shigehara, and W. F. Todd, A Method of Interpreting Stack Sampling Data, Paper presented at the 63d Annual Meeting of the Air Pollution Control Association, St. Louis, Mo., June 14-19, 1970.

Smith, W. S., et al., Stack Gas Sampling Improved and Simplified with New Equipment, APCA paper No. 67-110, 1967.

Specifications for Incinerator Testing at Federal Facilities, PHS, NCAPA, 1967.

METHOD 6—DETERMINATION OF SULFUR DIOXIDE EMISSIONS FROM STATIONARY SOURCES

1. Principle and applicability.

1.1 Principle. A gas sample is extracted from the sampling point in the stack. The acid mist, including sulfur trioxide, is separated from the sulfur dioxide. The sulfur dioxide fraction is measured by the barium-thorin titration method.

1.2 Applicability. This method is applicable for the determination of sulfur dioxide emissions from stationary sources only when specified by the test procedures for determining compliance with New Source Performance Standards.

2. Apparatus.

2.1 Sampling. See Figure 6-1.

2.1.1 Probe—Pyrex¹ glass, approximately 5 to 6 mm. ID, with a heating system to prevent condensation and a filtering medium to remove particulate matter including sulfuric acid mist.

2.1.2 Midget bubbler—One, with glass wool packed in top to prevent sulfuric acid mist carryover.

2.1.3 Glass wool.

2.1.4 Midget impingers—Three.

2.1.5 Drying tube—Packed with 6 to 16 mesh indicating-type silica gel, or equivalent, to dry the sample.

2.1.6 Valve—Needle valve, or equivalent, to adjust flow rate.

2.1.7 Pump—Leak-free, vacuum type.

2.1.8 Rate meter—Rotameter or equivalent, to measure a 0-10 s.c.f.h. flow range.

2.1.9 Dry gas meter—Sufficiently accurate to measure the sample volume within 1%.

2.1.10 Pitot tube—Type S, or equivalent, necessary only if a sample traverse is required, or if stack gas velocity varies with time.

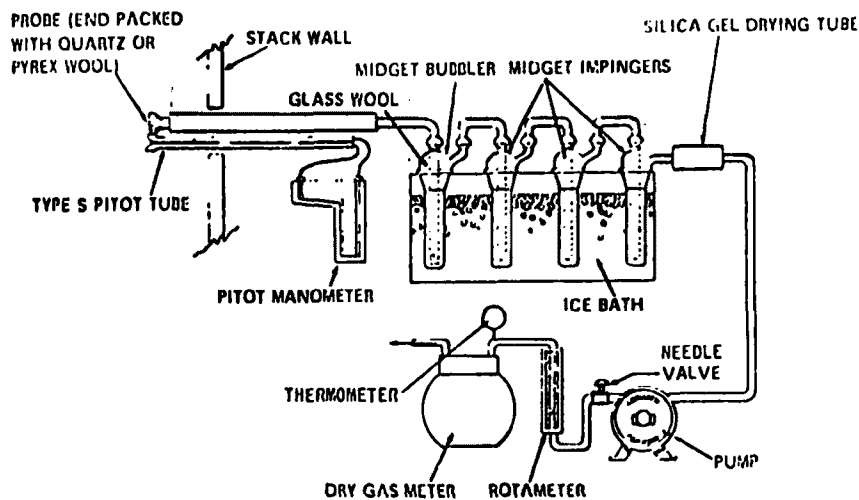
2.2 Sample recovery.

2.2.1 Glass wash bottles—Two.

2.2.2 Polyethylene storage bottles—To store impinger samples.

2.3 Analysis.

¹ Trade names.

Figure 6-1. SO₂ sampling train.

2.8.1 Pipettes—Transfer type, 5 ml. and 10 ml. sizes (0.1 ml. divisions) and 25 ml. size (0.2 ml. divisions).

2.8.2 Volumetric flasks—50 ml., 100 ml., and 1,000 ml.

2.8.3 Burettes—5 ml. and 50 ml.

2.8.4 Erlenmeyer flask—125 ml.

3. Reagents.

3.1 Sampling.

3.1.1 Water—Deionized, distilled.

3.1.2 Isopropanol, 80%—Mix 80 ml. of isopropanol with 20 ml. of distilled water.

3.1.3 Hydrogen peroxide, 3%—dilute 100 ml. of 30% hydrogen peroxide to 1 liter with distilled water. Prepare fresh daily.

3.2 Sample recovery.

3.2.1 Water—Deionized, distilled.

3.2.2 Isopropanol, 80%.

3.3 Analysis.

3.3.1 Water—Deionized, distilled.

3.3.2 Isopropanol.

3.3.3 Thorin indicator—1-(o-arsenophenylazo)-2-naphthol-3,6-disulfonic acid, disodium salt (or equivalent). Dissolve 0.20 g. in 100 ml. distilled water.

3.3.4 Barium perchlorate (0.01 N)—Dissolve 1.95 g. of barium perchlorate [Ba(ClO₄)₂ · 8H₂O] in 200 ml. distilled water and dilute to 1 liter with isopropanol. Standardize with sulfuric acid. Barium chloride may be used.

3.3.5 Sulfuric acid standard (0.01 N)—Purchase or standardize to ±0.0002 N against 0.01N NaOH which has previously been standardized against potassium acid phthalate (primary standard grade).

4. Procedure.

4.1 Sampling.

4.1.1 Preparation of collection train. Pour 15 ml. of 80% isopropanol into the midget bubbler and 15 ml. of 3% hydrogen peroxide into each of the first two midget impingers. Leave the final midget impinger dry. Assemble the train as shown in Figure 6-1. Leak check the sampling train at the sampling site by plugging the probe inlet and pulling a 10 inches Hg vacuum. A leakage rate not in excess of 1% of the sampling rate is acceptable. Carefully release the probe inlet plug and turn off the pump. Place crushed ice around the impingers. Add more ice during the run to keep the temperature of the gases leaving the last impinger at 70° F. or less.

4.1.2 Sample collection. Adjust the sample flow rate proportional to the stack gas velocity. Take readings at least every five minutes and when significant changes in stack conditions necessitate additional adjustments in flow rate. To begin sampling, position the tip of the probe at the first sampling point and start the pump. Sample proportionally throughout the run. At the conclusion of each run, turn off the pump and record the final readings. Remove the probe from the stack and disconnect it from the train. Drain the ice bath and purge the remaining part of the train by drawing clean ambient air through the system for 15 minutes.

4.2 Sample recovery. Disconnect the impingers after purging. Discard the contents of the midget bubbler. Pour the contents of the midget impingers into a polyethylene shipment bottle. Rinse the three midget impingers and the connecting tubes with dis-

D-1

..

APPENDIX D

REFERENCE METHOD 7

filled water and add these washings to the same storage container.

4.3 Sample analysis. Transfer the contents of the storage container to a 50 ml. volumetric flask. Dilute to the mark with de-ionized, distilled water. Pipette a 10 ml. aliquot of this solution into a 125 ml. Erlenmeyer flask. Add 40 ml. of isopropanol and two to four drops of thorin indicator. Titrate to a pink endpoint using 0.01 N barium perchlorate. Run a blank with each series of samples.

5. Calibration.

5.1 Use standard methods and equipment which have been approved by the Administrator to calibrate the rotameter, pitot tube, dry gas meter, and probe heater.

5.2 Standardize the barium perchlorate against 25 ml. of standard sulfuric acid containing 100 ml. of isopropanol.

6. Calculations.

6.1 Dry gas volume. Correct the sample volume measured by the dry gas meter to

$$C_{SO_2} = \left(7.05 \times 10^{-4} \frac{\text{lb.-l.}}{\text{g.-ml.}} \right) \frac{(V_t - V_{15}) N \left(\frac{V_{std}}{V_s} \right)}{V_{std}} \quad \text{equation 6-2}$$

where:

C_{SO_2} —Concentration of sulfur dioxide at standard conditions, dry basis, lb./cu. ft.

7.05×10^{-4} —Conversion factor, including the number of grams per gram equivalent of sulfur dioxide (32 g./g.-eq.), 453.6 g./lb., and 1,000 ml./l., lb.-l./g.-ml.

V_t —Volume of barium perchlorate titrant used for the sample, ml.

V_{15} —Volume of barium perchlorate titrant used for the blank, ml.

N —Normality of barium perchlorate titrant, g.-eq./l.

V_{std} —Total solution volume of sulfur dioxide, 50 ml.

V_s —Volume of sample aliquot titrated, ml.

V_{std} —Volume of gas sample through the dry gas meter (standard conditions), cu. ft., see Equation 6-1.

7. References.

Atmospheric Emissions from Sulfuric Acid Manufacturing Processes, U.S. DEW, PHS, Division of Air Pollution, Public Health Service Publication No. 999-AP-13, Cincinnati, Ohio, 1965.

Corbett, F. F., The Determination of SO_2 and SO_3 in Flue Gases, Journal of the Institute of Fuel, 24:237-243, 1961.

Matty, R. E. and E. K. Diehl, Measuring Flue-Gas SO_2 and SO_3 , Power 101:94-97, November, 1957.

Patton, W. F. and J. A. Brink, Jr., New Equipment and Techniques for Sampling Chemical Process Gases, J. Air Pollution Control Association, 13, 162 (1963).

standard conditions (70° F. and 29.92 inches Hg) by using equation 6-1.

$$V_{std} = V_m \left(\frac{T_{std}}{T_m} \right) \left(\frac{P_{bar}}{P_{std}} \right) = 17.71 \frac{^{\circ}R}{\text{in. Hg}} \left(\frac{V_m P_{bar}}{T_m} \right) \quad \text{equation 6-1}$$

where:

V_{std} —Volume of gas sample through the dry gas meter (standard conditions), cu. ft.

V_m —Volume of gas sample through the dry gas meter (meter conditions), cu. ft.

T_{std} —Absolute temperature at standard conditions, 530° R.

T_m —Average dry gas meter temperature, °R.

P_{bar} —Barometric pressure at the orifice meter, inches Hg.

P_{std} —Absolute pressure at standard conditions, 29.92 inches Hg.

6.2 Sulfur dioxide concentration.

METHOD 7—DETERMINATION OF NITROGEN OXIDE EMISSIONS FROM STATIONARY SOURCES

1. Principle and applicability.

1.1 Principle. A grab sample is collected in an evacuated flask containing a dilute sulfuric acid-hydrogen peroxide absorbing solution, and the nitrogen oxides, except nitrous oxide, are measure colorimetrically using the phenoldisulfonic acid (PDS) procedure.

1.2 Applicability. This method is applicable for the measurement of nitrogen oxides from stationary sources only when specified by the test procedures for determining compliance with New Source Performance Standards.

2. Apparatus.

2.1 Sampling. See Figure 7-1.

2.1.1 Probe—Pyrex¹ glass, heated, with filter to remove particulate matter. Heating is unnecessary if the probe remains dry during the purging period.

2.1.2 Collection flask—Two-liter, Pyrex¹ round bottom with short neck and 24/40 standard taper opening, protected against implosion or breakage.

2.1.3 Flask valve—T-bore stopcock connected to a 24/40 standard taper joint.

2.1.4 Temperature gauge—Dial-type thermometer, or equivalent, capable of measuring 2° F. intervals from 25° to 125° F.

2.1.5 Vacuum line—Tubing capable of withstanding a vacuum of 3 inches Hg absolute pressure, with "T" connection and T-bore stopcock, or equivalent.

2.1.6 Pressure gauge—U-tube manometer, 36 inches, with 0.1-inch divisions, or equivalent.

¹ Trade name.

2.1.7 Pump—Capable of producing a vacuum of 3 inches Hg absolute pressure.

2.1.8 Squeeze bulb—One way.

2.2 Sample recovery.

2.2.1 Pipette or dropper.

2.2.2 Glass storage containers—Cushioned for shipping.

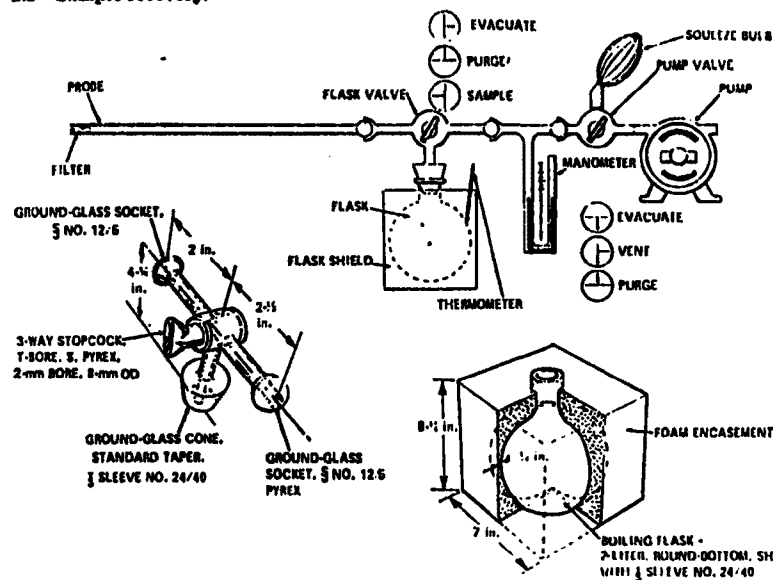


Figure 7-1. Sampling train, flask valve, and flask.

2.2.3. Glass wash bottle.

2.3 Analysis.

2.3.1 Steam bath.

2.3.2 Beakers or casseroles—250 ml., one for each sample and standard (blank).

2.3.3 Volumetric pipettes—1, 2, and 10 ml.

2.3.4 Transfer pipette—10 ml. with 0.1 ml. divisions.

2.3.5 Volumetric flask—100 ml., one for each sample, and 1,000 ml. for the standard (blank).

2.3.6 Spectrophotometer—To measure absorbance at 420 nm.

2.3.7 Graduated cylinder—100 ml. with 1.0 ml. divisions.

2.3.8 Analytical balance—To measure to 0.1 mg.

3. Reagents.

3.1 Sampling.

3.1.1 Absorbing solution—Add 2.8 ml. of concentrated H_2SO_4 to 1 liter of distilled water. Mix well and add 6 ml. of 8 percent hydrogen peroxide. Prepare a fresh solution weekly and do not expose to extreme heat or direct sunlight.

3.2 Sample recovery.

3.2.1 Sodium hydroxide (1N)—Dissolve 40 g. NaOH in distilled water and dilute to 1 liter.

3.2.2 Red litmus paper.

3.2.3 Water—Deionized, distilled.

3.3 Analysis.

3.3.1 Fuming sulfuric acid—15 to 18% by weight free sulfur trioxide.

3.3.2 Phenol—White solid reagent grade.

3.3.3 Sulfuric acid—Concentrated reagent grade.

3.3.4 Standard solution—Dissolve 0.5495 g. potassium nitrate (KNO_3) in distilled water and dilute to 1 liter. For the working standard solution, dilute 10 ml. of the resulting solution to 100 ml. with distilled water. One ml. of the working standard solution is equivalent to 25 µg. nitrogen dioxide.

3.3.5 Water—Deionized, distilled.

3.3.6 Phenoldisulfonic acid solution—Dissolve 25 g. of pure white phenol in 150 ml. concentrated sulfuric acid on a steam bath. Cool, add 75 ml. fuming sulfuric acid, and heat at 100° C. for 2 hours. Store in a dark, stoppered bottle.

4. Procedure.

4.1 Sampling.

4.1.1 Pipette 25 ml. of absorbing solution into a sample flask. Insert the flask valve stopper into the flask with the valve in the "purge" position. Assemble the sampling train as shown in Figure 7-1 and place the probe at the sampling point. Turn the flask valve and the pump valve to their "evacuate" positions. Evacuate the flask to at least 3 inches Hg absolute pressure. Turn the pump

valve to its "vent" position and turn off the pump. Check the manometer for any fluctuation in the mercury level. If there is a visible change over the span of one minute, check for leaks. Record the initial volume, temperature, and barometric pressure. Turn the flask valve to its "purge" position, and then do the same with the pump valve. Purge the probe and the vacuum tube using the squeeze bulb. If condensation occurs in the probe and flask valve area, heat the probe and purge until the condensation disappears. Then turn the pump valve to its "vent" position. Turn the flask valve to its "sample" position and allow sample to enter the flask for about 15 seconds. After collecting the sample, turn the flask valve to its "purge" position and disconnect the flask from the sampling train. Shake the flask for 5 minutes.

4.2 Sample recovery.

4.2.1 Let the flask set for a minimum of 16 hours and then shake the contents for 2 minutes. Connect the flask to a mercury filled U-tube manometer, open the valve from the flask to the manometer, and record the flask pressure and temperature along with the barometric pressure. Transfer the flask contents to a container for shipment or to a 250 ml. beaker for analysis. Rinse the flask with two portions of distilled water (approximately 10 ml.) and add rinse water to the sample. For a blank use 25 ml. of absorbing solution and the same volume of distilled water as used in rinsing the flask. Prior to shipping or analysis, add sodium hydroxide (1*N*) dropwise into both the sample and the blank until alkaline to litmus paper (about 25 to 35 drops in each).

4.3 Analysis.

4.3.1 If the sample has been shipped in a container, transfer the contents to a 250 ml. beaker using a small amount of distilled

$$V_{st} = \frac{T_{st}(V_f - V_v)}{P_{st}} \left(\frac{P_f - P_i}{T_f - T_i} \right) = (17.71 \frac{^{\circ}\text{R}}{\text{in. Hg}}) (V_f - 25 \text{ ml.}) \left(\frac{P_f - P_i}{T_f - T_i} \right) \quad \text{Equation 7-1}$$

where:

V_{st} —Sample volume at standard conditions (dry basis), ml.

T_{st} —Absolute temperature at standard conditions, 530° R.

P_{st} —Pressure at standard conditions, 29.92 inches Hg.

V_f —Volume of flask and valve, ml.

V_v —Volume of absorbing solution, 25 ml.

$$C = \left(\frac{m}{V_{st}} \right) \left(\frac{1 \text{ lb.}}{35.27 \text{ oz.}} \right) \left(\frac{1 \text{ cu. ft.}}{1.6 \times 10^3 \text{ cu. in.}} \right) = (0.2 \times 10^{-4} \frac{\text{lb./s.c.f.}}{\mu\text{g./ml.}}) \left(\frac{m}{V_{st}} \right) \quad \text{equation 7-2}$$

where:

C —Concentration of NO_x as NO_2 (dry basis), lb./s.c.f.

m —Mass of NO_x in gas sample, μg .

V_{st} —Sample volume at standard conditions (dry basis), ml.

water. Evaporate the solution to dryness on a steam bath and then cool. Add 3 ml. phenoldisulfonic acid solution to the dried residue and triturate thoroughly with a glass rod. Make sure the solution contacts all the residue. Add 1 ml. distilled water and four drops of concentrated sulfuric acid. Heat the solution on a steam bath for 3 minutes with occasional stirring. Cool, add 20 ml. distilled water, mix well by stirring, and add concentrated ammonium hydroxide dropwise with constant stirring until alkaline to litmus paper. Transfer the solution to a 100 ml. volumetric flask and wash the beaker three times with 4 to 5 ml. portions of distilled water. Dilute to the mark and mix thoroughly. If the sample contains solids, transfer a portion of the solution to a clean, dry centrifuge tube, and centrifuge, or filter a portion of the solution. Measure the absorbance of each sample at 420 nm. using the blank solution as a zero. Dilute the sample and the blank with a suitable amount of distilled water if absorbance falls outside the range of calibration.

5. Calibration.

5.1 Flask volume. Assemble the flask and flask valve and fill with water to the stopcock. Measure the volume of water to ± 10 ml. Number and record the volume on the flask.

5.2 Spectrophotometer. Add 0.0 to 10.0 ml. of standard solution to a series of beakers. To each beaker add 25 ml. of absorbing solution and add sodium hydroxide (1*N*) dropwise until alkaline to litmus paper (about 25 to 35 drops). Follow the analysis procedure of section 4.3 to collect enough data to draw a calibration curve of concentration in $\mu\text{g. NO}_x$ per sample versus absorbance.

6. Calculations.

6.1 Sample volume.

P_f —Final absolute pressure of flask, inches Hg.

P_i —Initial absolute pressure of flask, inches Hg.

T_f —Final absolute temperature of flask, °R.

T_i —Initial absolute temperature of flask, °R.

6.2 Sample concentration. Read $\mu\text{g. NO}_x$ for each sample from the plot of $\mu\text{g. NO}_x$ versus absorbance.

7. References.

Standard Methods of Chemical Analysis, 6th ed. New York, D. Van Nostrand Co., Inc., 1962, vol. 1, p. 329-330.

Standard Method of Test for Oxides of Nitrogen in Gaseous Combustion Products

(Phenoldisulfonic Acid Procedure), in: 1968 Book of ASTM Standards, Part 23, Philadelphia, Pa, 1968, ASTM Designation D-1000-60, p. 725-729.

Jacob, M. N., The Chemical Analysis of Air Pollutants, New York, N.Y., Interscience Publishers, Inc., 1960, vol. 10, p. 351-360.

METHOD 8—DETERMINATION OF SULFURIC ACID MIST AND SULFUR DIOXIDE EMISSIONS FROM STATIONARY SOURCES

1. Principle and applicability.

1.1 Principle. A gas sample is extracted from a sampling point in the stack and the acid mist including sulfur trioxide is separated from sulfur dioxide. Both fractions are measured separately by the barium-chloride titration method.

1.2 Applicability. This method is applicable to determination of sulfuric acid mist (including sulfur trioxide) and sulfur dioxide from stationary sources only when specified by the test procedures for determining compliance with the New Source Performance Standards.

2. Apparatus.

2.1 Sampling. See Figure 8-1. Many of the design specifications of this sampling train are described in APTD-0581.

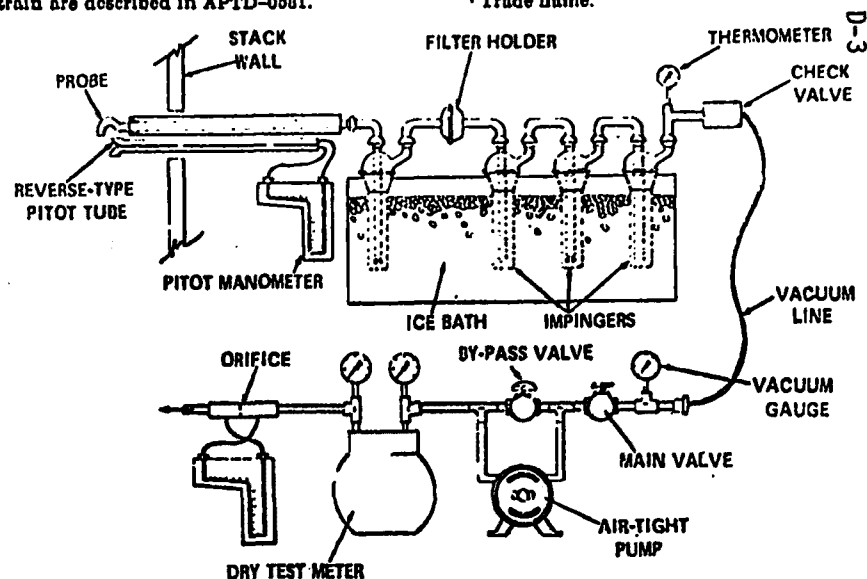


Figure 8-1. Sulfuric acid mist sampling train.

APPENDIX E

COMPLETE SUMMARY OF METHOD 5 SAMPLING

PLANT: A

E-2

	<u>1</u>	TEST	<u>2</u>	<u>3</u>
T _m , °R	536		525	532
T _S , °R	790		785	585
P _B , IN. Hg	29.08		29.12	29.40
P _S , IN. Hg	29.07		29.11	29.39
Q, MIN	80		80	80
A _S , FT ²	28.274		28.274	28.274
A _N , FT ²	1.36 x 10 ⁻³		1.36 x 10 ⁻³	1.36 x 10 ⁻³
C _p	0.78		0.78	0.78
V _I , ml	30.1		32.0	29.3 /
M _N , mg	157.29		175.39	195.8
% O ₂	17.4		19.2	18.4
% CO ₂	2.2		1.8	1.4
% CO	0.2		0.2	0.2
% Ng	80.2		78.8	80.0
√P Ave	0.122		0.122	0.141
ΔH Ave	0.50		0.351	0.69
V _{MStd} , DSCF	29.13		34.61	34.613
V _{WStd} , CF	1.427		1.52	1.389
B _{W0}	0.047		0.042	0.039
EA, %	447		1121.0	649
M _d , lb/lb mole	29.048		29.06	28.960
M _S lb/lb mole	28.529		29.59	28.533
V _S , FPS	7.939		7.91	9.096
Q _S , DSCFH	501,862		505,910	589,935
I, %	90.48		106.7	99.4
C _S , lb/SCF	1.191 x 10 ⁻⁵		1.331 x 10 ⁻⁵	1.247 x 10 ⁻⁵
C _S , gr/SCF	0.083		0.093	0.087
PMR, lb/hr	5.975		6.732	7.358

PLANT: B

E-3

	<u>1</u>	TEST	<u>2</u>	<u>3</u>
T _m , °R	555		555	553
T _S , °R	715		720	725
P _B , IN. Hg	29.97		29.97	29.97
P _S , IN. Hg	29.96		29.96	29.96
Ø, MIN	60		60	60
A _S , FT ²	14.748		14.748	14.748
A _N , FT ²	1.36 x 10 ⁻³		1.36 x 10 ⁻³	1.36 x 10 ⁻³
C _p	0.78		0.78	0.78
V _I , ml	20.9		22.0	26.1
M _N , mg	59.83		65.75	60.46
% O ₂	16.0		16.0	16.0
% CO ₂	4.6		4.2	4.6
% CO	0.2		0.2	0.2
% Ng	79.2		78.6	79.2
√P Ave	0.149		0.146	0.147
ΔH Ave	0.98		0.927	0.94
V _{MStd} , DSCF	31.796		32.751	31.930
V _{WStd} , CF	0.991		1.043	1.237
B _{W0}	0.030		0.031	0.037
EA, %	317		328	317
M _d , lb/lb mole	29.376		29.032	29.376
M _S , lb/lb mole	29.035		28.690	28.955
V _S , FPS	9.007		8.090	8.960
Q _S , DSCFH	344,213.8	337,776.4		337,360.2
I, %	100.2	105.1		103.3
C _S , lb/SCF	4.149 x 10 ⁻⁶	4.427 x 10 ⁻⁶		4.175 x 10 ⁻⁶
C _S , gr/SCF	0.030	0.031		0.029
PMR, lb/hr	1.428	1.495		1.409

PLANT: C.

E-4

	TEST		
	<u>1</u>	<u>2</u>	<u>3</u>
$T_m, ^\circ R$	567	541	550
$T_s, ^\circ R$	950	940	945
$P_B, \text{IN. Hg}$	29.25	29.25	29.25
$P_S, \text{IN. Hg}$	29.22	29.22	29.22
σ, MIN	60	60	60
A_S, FT^2	7.86	7.86	7.86
A_N, FT^2	7.669×10^{-4}	7.669×10^{-4}	7.669×10^{-4}
C_p	0.78	0.78	0.78
V_I, ml	64.90	68.2	52.30
M_N, mg	528.10	213.2	343.9
% O_2	14.8	15.8	15.2
% CO_2	5.0	4.2	5.2
% CO	---	---	---
% Ng	80.2	80.0	79.6
\sqrt{P} Ave	0.373	0.396	0.374
ΔH Ave	1.378	1.539	1.392
V_{MStd}, DSCF	34.277	39.387	36.631
V_{WStd}, CF	3.076	3.233	2.479
B_{W0}	0.082	0.076	0.063
EA, %	232	298	261
$M_d, \text{lb/lb mole}$	29.392	29.304	29.440
$M_s, \text{lb/lb mole}$	28.458	28.445	28.719
V_s, FPS	26.582	28.079	26.462
Q_s, DSCFH	378,124	404,151	384,194
I, %	93.44	99.87	97.77
$C_s, \text{lb/SCF}$	3.397×10^{-5}	1.194×10^{-5}	2.07×10^{-5}
$C_s', \text{gr/SCF}$	0.237	0.083	0.145
PMR, lb/hr	12.778	4.824	7.953

PLANT: D

E-5

	TEST		
	<u>1</u>	<u>2</u>	<u>3</u>
T _m , °R	550	547	535
T _S , °R	720	725	730
P _B , In. Hg	30.12	30.12	30.16
P _S , In. Hg	30.11	20.11	30.15
Q, MIN	60	60	60
A _S , FT ²	12.566	12.566	12.566
A _H , FT ²	1.36 x 10 ⁻³	1.36 x 10 ⁻³	1.36 x 10 ⁻³
C _p	0.78	0.78	0.78
V _I , ml	44.3	51.6	50.8
M _N , mg	29.8	51.84	23.48
% O ₂	14.4	15.2	15.0
% CO ₂	6.2	5.8	5.4
% CO	---	---	---
% Ng	79.4	79.0	79.6
√P Ave	0.155	0.182	0.138
ΔH Ave	1.133	1.45	0.89
V _{MStd} , DSCF	33.199	37.02	32.28
V _{WStd} , CF	2.10	2.446	2.413
B _{W0}	0.059	0.062	0.070
EA, %	219	269	249
M _d , lb/lb mole	29.568	29.536	29.464
M _S , lb/lb mole	28.885	28.82	28.66
V _S , FPS	9.403	11.09	8.46
Q _S , DSCFH	388,080.0	346,166.5	260,238.7
I, %	103.5	98.8	114.5
C _S , lb/SCF	1.979 x 10 ⁻⁶	3.09 x 10 ⁻⁶	1.603 x 10 ⁻⁶
C _S , gr/SCF	0.014	0.072	0.0112
PMR, lb/hr	0.768	1.07	0.417

PLANT: E

E-6

	<u>1</u>	TEST	<u>2</u>	<u>3</u>
Tm, °R	542		546	545
TS, °R	810		835	840
PB, IN. Hg	29.70		29.70	29.70
PS, IN. Hg	29.69		29.69	29.69
Ø, MIN	108		108	108
AS, FT ²	5.585		5.585	5.585
AN, FT ²	3.41 x 10 ⁻⁴		3.41 x 10 ⁻⁴	3.41 x 10 ⁻⁴
Cp	0.78		0.78	0.78
VI, ml	51.0		50.2	48.1
MT, mg	390.94		338.93	369.58
% O ₂	18.4		17.6	16.6
% CO ₂	2.2		3.2	4.2
% CO	0.4		---	---
% Ng	79		79.2	79.2
√P Ave	0.432		0.431	0.437
ΔH Ave	0.61		0.61	0.63
VMStd, DSCF	46.845		46.39	46.20
VWStd, CF	2.42		2.38	2.28
B _{W0}	0.049		0.049	0.047
EA, %	685		532	385
M _d , lb/lb mole	29.088		29.216	29.336
M _S lb/lb mole	28.54		28.67	29.80
VS, FPS	28.159		28.46	28.88
QS, DSCFH	349,516		342,717.5	346,356
I, %	122		123.16	121.3
CS, lb/SCF	1.84 x 10 ⁻⁵		1.611 x 10 ⁻⁵	1.764 x 10 ⁻⁵
CS, gr/SCF	0.129		0.113	0.123
PMR, lb/hr	6.431		5.521	6.109

PLANT: F

E-7

	<u>1</u>	TEST	<u>2</u>	<u>3</u>
T _m , °R	554		553	541
T _S , °R	760		705	650
P _B , IN. Hg	29.97		29.97	29.97
P _S , IN. Hg	29.96		29.96	29.96
σ, MIN	60		60	60
A _S , FT ²	12.57		12.57	12.57
A _N , FT ²	1.36 x 10 ⁻³		1.36 x 10 ⁻³	1.36 x 10 ⁻³
C _p	0.78		0.78	0.78
V _I , ml	32.6		31.3	30.1
M _N ^T , mg	342.1		278.8	414.74
% O ₂	17.0		16.6	17.6
% CO ₂	3.4		4.0	2.8
% CO	0.2		0.2	0.2
% Ng	79.4		79.2	79.4
\sqrt{A} P Ave	0.193		0.227	0.206
Δ H Ave	1.48		2.07	1.83
V _{MStd} , DSCF	38.598		45.465	43.996
V _{WStd} , CF	1.545		1.484	1.427
B _{W0}	0.0385		0.032	0.031
EA, %	416		374	505
M _d , lb/lb mole	29.224		29.304	29.152
M _S , lb/lb mole	29.792		28.942	28.806
V _S , FPS	12.083		13.647	11.920
Q _S , DSCFH	366,839.94	449,911		426,655
I, %	97.2	93.4		95.36
C _S , lb/SCF	1.954 x 10 ⁻⁵	1.352 x 10 ⁻⁵		2.079 x 10 ⁻⁵
C _S ⁱ , gr/SCF	0.136	0.094		0.145
PMR, lb/hr	7.168	6.083		8.868

PLANT: G

E-8

	<u>1</u>	TEST	<u>2</u>	<u>3</u>
T _m , °R	524		535	536
T _S , °R	900		910	910
P _B , IN. Hg	29.31		29.31	29.31
P _S , IN. Hg	29.29		29.29	29.29
σ, MIN	60		60	60
A _S , FT ²	9.33		9.33	9.33
A _N , FT ²	7.67 x 10 ⁻⁴		1.36 x 10 ⁻³	1.36 x 10 ⁻³
C _p	0.78		0.78	0.78
V _I , ml	41.3		77.1	60.5
M _N ^T , mg	150.49		227.05	212.55
% O ₂	13.0		12.0	11.2
% CO ₂	6.8		8.2	9.0
% CO	---		0.2	0.2
% Ng	80.2		79.6	79.6
√ΔP Ave	0.245		0.271	0.195
ΔH Ave	0.75		2.74	1.45
V _{MStd} , DSCF	29.680		49.185	37.58
V _{WStd} , CF	1.958		3.655	2.8677
B _{WO}	0.062		0.069	0.0709
EA, %	159		130.6	112
M _d , lb/lb mole	29.61		29.792	29.83
M _S , lb/lb mole	28.888		28.978	28.99
V _S , FPS	16.847		18.709	13.46
Q _S , DSCFH	305,920.2		333,490	239,435.3
I, %	110.6		101.2	107.7
C _S , lb/SCF	1.118 x 10 ⁻⁵		1.018 x 10 ⁻⁵	1.247 x 10 ⁻⁵
C _S ⁱ , gr/SCF	0.078		0.071	0.087
PMR, lb/hr	3.42		3.395	2.986

PLANT: H

E-9

	TEST		
	<u>1</u>	<u>2</u>	<u>3</u>
Tm, °R	540	542	546
TS, °R	750	750	740
PS, IN. Hg	29.98	29.98	29.98
PS, IN. Hg	29.27	29.27	29.27
σ, MIN	108	108	108
AS, FT ²	12.566	12.566	12.566
AN, FT ²	7.67 x 10 ⁻⁴	7.67 x 10 ⁻⁴	7.67 x 10 ⁻⁴
Cp	0.78	0.78	0.78
VI, ml	102.9	94.9	90.6
MT MN, mg	2697.6	1988.28	2964.37
% O ₂	12.2	14.2	13.7
% CO ₂	7.4	5.8	6.6
% CO	0.4	0.3	0.2
% Ng	80.0	79.7	79.5
√ΔP Ave	0.209	0.208	0.205
ΔH Ave	0.62	0.60	0.59
VMStd, DSCF	46.11	46.853	45.122
VWStd, CF	4.878	4.498	4.294
BWO	0.095	0.088	0.087
EA, %	132	201	184
MD, lb/lb mole	29.56	29.412	29.55
MS lb/lb mole	29.454	28.41	28.54
VS, FPS	13.067	13.02	12.712
QS, DSCFH	378,369.0	380,072	376,628.6
I, %	110	112	109.2
CS, lb/SCF	1.29 x 10 ⁻⁴	9.357 x 10 ⁻⁵	1.449 x 10 ⁻⁴
CS, gr/SCF	0.901	0.654	1.012
PMR, lb/hr	48.81	35.564	54.573

PLANT: I

E-10

	<u>1</u>	TEST	<u>2</u>	<u>3</u>
$T_m, ^\circ R$	551		548	552
$T_S, ^\circ R$	870		860	860
$P_B, \text{IN. Hg}$	30.08		30.08	30.08
$P_S, \text{IN. Hg}$	30.06		30.06	30.06
σ, MIN	120		120	72
A_S, FT^2	7.069		7.069	7.069
A_N, FT^2	1.36×10^{-3}		1.36×10^{-3}	1.36×10^{-3}
C_p	0.78		0.78	0.78
V_I, ml	107.1		104.4	69.6
m_N^T, mg	795.9		2777.55	431.9
% O_2	16.6		16.0	16.8
% CO_2	3.8		4.2	3.6
% CO	0.2		0.2	---
% Ng	79.4		79.6	79.6
$\sqrt{A} P \text{ Ave}$	0.301		0.213	0.201
$\Delta H \text{ Ave}$	1.40		1.46	1.37
V_{MStd}, DSCF	75.265		77.526	45.761
V_{WStd}, CF	5.077		4.949	3.299
B_{H_2O}	0.0632		0.060	0.067
EA, %	370		311	399
$M_d, \text{lb/lb mole}$	29.216		29.312	29.250
$M_S, \text{lb/lb mole}$	28.507		28.633	28.494
V_S, FPS	13.503		14.190	13.43
Q_S, DSCFH	196,981.7		210,123.4	197,731.5
I, %	99.3		95.9	100.4
$C_S, \text{lb/SCF}$	2.331×10^{-5}		7.9×10^{-5}	2.08×10^{-5}
$C_S, \text{gr/SCF}$	0.163		0.552	0.145
PMR, lb/hr	4.593		16.60	4.105

PLANT: J

E-11

	<u>1</u>	TEST	<u>2</u>	<u>3</u>
Tm, °R	556		549	524
TS, °R	970		935	960
PG, IN. Hg	29.25		29.25	29.25
PS, IN. Hg	29.23		29.23	29.13
Q, MIN	60		60	50
AS, FT ²	7.07		7.07	7.07
AN, FT ²	1.36×10^{-3} 7.67×10^{-4}		7.67×10^{-4}	7.67×10^{-4}
Cp	0.78		0.78	0.78
VI, ml	62.4		53.4	83.7
MT, mg	399.78		394.75	401.73
% O ₂	14.4		13.4	13.6
% CO ₂	6.0		7.0	6.6
% CO	0.2		0.2	0.2
% Ng	79.4		79.4	79.6
\sqrt{AP} Ave	0.261		0.281	0.366
ΔH Ave	1.720		0.91	1.11
VMStd, DSCF	37.556		31.803	33.352
VWStd, CF	2.958		2.531	3.967
B _{WO}	0.073		0.074	0.106
EA, %	215		174	177
M _d , lb/lb mole	29.536		29.656	29.544
M _S , lb/lb mole	28.694		29.793	28.320
VS, FPS	18.714		19.747	26.330
QS, DSCFH	235,642.6		257,680	321,957.1
I, %	-----		113.5	95.5
CS, lb/SCF	2.347×10^{-5}		2.737×10^{-5}	2.656×10^{-5}
CS, gr/SCF	0.164		0.191	0.185
PMR, lb/hr	5.53		7.053	8.551

.

APPENDIX F

STATE OF VERMONT WOOD BOILER REGULATIONS

Uniform Adopting Page

VERMONT ADMINISTRATIVE RULE

☒ Adopted Rule

TITLE OR SUBJECT: Air Pollution Control Regulations - Wood-Fired Boilers

AGENCY: Environmental Conservation

AGENCY'S REFERENCE NUMBER FOR RULE (IF ANY): Regulations 5-101, 5-211,
5-231-3 and 5-408-11EFFECT ON EXISTING RULES: New Material: 5-101-10 Amends: 5-211
5-101-22 5-408-11
5-101-45
5-211-3
5-231-3.b.

STATUTORY AUTHORITY: 10 VSA 554 and 558

Effective Date: *Aug. 12, 1978*Expiration Date: *N/A*Action 1. Section 5-101, entitled "Definitions", is amended by adding the following new subsections:5-101 AS USED IN THIS PART, ALL TERMS NOT DEFINED HEREIN SHALL HAVE THE MEANING
GIVEN THEM IN THE ACT.

10. "Commence Operation" means to begin using, on a full time basis, any equipment in a manner that represents normal operational procedures.
22. "Horsepower (H.P.)" is a unit that is equal to 10 square feet of boiler heating surface.
45. "Wood Fuel" for the purposes of these regulations means natural wood, as well as, sawdust or other wood waste generated by wood processing operations.

Action 2. Section 5-211, entitled "Prohibition of Visible Air Contaminants", is amended to read:

5-211 PROHIBITION OF VISIBLE AIR CONTAMINANTS

- 1.
- Installations
- constructed prior to April 30, 1970

No person shall cause, suffer, allow or permit the emission of any visible air contaminant from installations constructed prior to April 30, 1970, for more than a period or periods aggregating six (6) minutes in any hour, which has

a shade, or density, greater than 40% opacity (No. 2 of the Ringelmann Chart).

At no time shall the visible air contaminants have a shade, density, or appearance greater than 60% opacity (No. 3 of the Ringelmann Chart).

2. Installations constructed subsequent to April 30, 1970

No person shall cause, suffer, allow or permit the emission of any visible air contaminant, from installations constructed subsequent to April 30, 1970, [after the effective date of these regulations] for more than a period or periods aggregating six (6) minutes in any hour, which has a shade, or density, greater than 20% opacity (No. 1 of the Ringelmann Chart).

At no time shall the visible air contaminants have a shade, density, or appearance greater than 60% opacity (No. 3 of the Ringelmann Chart).

3. Exceptions - Wood Fuel Burning Equipment

a) During normal startup operations, emissions of visible air contaminants in excess of the limits specified in subsections 1 & 2 above may be allowed for a period not to exceed one (1) hour.

b) During normal soot blowing operations, emissions of visible air contaminants in excess of the limits specified in subsections 1 & 2 above may be allowed for a period not to exceed 30 minutes during any 24 hour period.

c) At no time shall the visible air contaminants allowed under this subsection have a shade, density, or appearance greater than 80% opacity (No. 4 of the Ringelmann Chart).

d) Any wood fuel burning equipment that has a rated output of 40 H.P. or less shall not be subject to this regulation (§5-211).

Action 3. Section 5-231-3, entitled "Prohibition of Particulate Matter - Combustion Contaminants", is amended by adding the following new subsection:

5-231 PROHIBITION OF PARTICULATE MATTER

3. Combustion Contaminants

b. A person shall not discharge, cause, suffer, allow, or permit the emission of particulate matter caused by the combustion of wood fuel in fuel burning equipment from any stack or chimney:

1) in excess of 0.45 grains per dry standard cubic foot (gr/DSCF) of exhaust gas corrected to 12% CO₂ in any combustion installation that has a rated output of greater than 90 H.P. which commenced operation prior to December 5, 1977.

2) in excess of 0.20 gr/DSCF corrected to 12% CO₂ in any combustion installation that has a rated output of greater than 90 H.P., but less than 1300 H.P., which commences operation after December 5, 1977.

3) in excess of 0.10 gr/DSCF corrected to 12% CO₂ in any combustion installation that has a rated output of greater than 1300 H.P. which commences operation after December 5, 1977.

Any wood fuel burning equipment that has a rated output of 90 H.P. or less shall not be subject to these particulate emission standards.

When any fossil fuel is burned in combination with wood fuel, and the fossil fuel contributes less than 50% of the total BTU input, the above particulate standards shall apply. If the fossil fuel contributes more than 50% of the total BTU input, subsection 3.a. of this regulation shall apply.

When a soot blowing cycle exceeds 15 minutes, separate emissions testing for particulate emissions during the soot blowing cycle may be required in addition to emissions testing during normal operating conditions pursuant to Regulation 5-404 below. In this event, the emission rate calculated for the soot blowing cycle shall be prorated over the time period between soot blowing cycles.

Action 4. Section 5-408-11, entitled "Installations Requiring That Information Be Submitted To The State Air Pollution Control Agency Prior To Construction", is amended to read:

5-408 INSTALLATIONS REQUIRING THAT INFORMATION BE SUBMITTED TO THE STATE AIR POLLUTION CONTROL AGENCY PRIOR TO CONSTRUCTION

The following types of installations are required to submit to the State Air Pollution Control Agency information regarding the air pollution potential of their proposed new construction, new installation, or modification:

11. Fuel Burning Installations:

a. Fossil fuel burning equipment of greater than 10 million BTU's per hour rated heat input.

b. Wood fuel burning equipment of greater than 90 H.P. rated output.

[11. Fuel burning installations greater than 10 million BTU's per hour rated heat input]

[] = Deletions

_____ = Additions

APPENDIX G

STATE OF VERMONT - CYCLONE REGULATIONS

5-231 PROHIBITION OF PARTICULATE MATTER

1. Industrial Process Emissions

a. No person shall discharge, cause, suffer, allow, or permit in any one hour from any stack whatsoever particulate matter in excess of the amount shown in Table 1. For purposes of this regulation the total process weight entering a process unit shall be used to determine the maximum allowable emissions of particulate matter which may pass through the stack associated with the process unit. When two or more process units exhaust through a common stack, the combined process weight of all of the process units, served by the common stack, shall be used to determine the allowable particulate emission rate.

b. In cases where process weight is not applicable as determined by the Air Pollution Control Officer, the concentration of solid particulates in the effluent gas stream shall not exceed 0.14 grams per cubic meter (0.06 grains per cubic foot) of undiluted exhaust gas at standard conditions on a dry basis. In the case of wood processing operations, process weight is not applicable and, instead, the concentration standard specified in this subsection shall apply.