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SANDERS ENGINEERING & ANALYTICAL SERVI

Oxides of Nitrogen, Sulfur Dioxide and Particulate Emissions Test Report

for

Koppers Industry

Dolomite, Alabama

Coke Battery

UNDER FIRE STACK #1



August 21, 1991

1568 LEROY STEVENS ROAD

MOBILE, ALABAMA 36695 • 205/633-4120

SUBJECT : DETERMINATION OF CO₂ COMBUSTION RATE IN ASSOCIATION WITH A PERFORMANCE STACK TEST PERFORMED BY SANDERS ENGINEERING, ON UNDERFIRE STACK #1 DATED AUGUST 21, 1991

BASIS : BY USE OF THE F-FACTOR COMBUSTION GAS CAN BE DETERMINED AND IS AS FOLLOWS;

THE F-FACTOR HAS BEEN USED BY STACK SAMPLING TEAMS AS AN ACCEPTED METHOD OF OBTAINING HEAT INPUT OF COMBUSTION SOURCES THROUGH MEASUREMENT OF GAS VELOCITY AND GAS CONDITIONS TO DETERMINE GAS VOLUME. DURING INSPECTIONS OF COMBUSTION SOURCES IT IS OFTEN ENCOUNTERED THAT BOTH THE HEAT INPUT AND GAS CONDITIONS ARE DETERMINABLE AND THE GAS VOLUME IS THE UNKNOWN FACTOR. TO DETERMINE THIS PARAMETER FOR THE EVALUATION OF CONTROL EQUIPMENT PERFORMANCE THE F-FACTOR METHOD IS USED TO SOLVE FOR THE MISSING VALUE.

F-FACTOR DEFINITION: AN F-FACTOR IS A RELATIONSHIP BETWEEN THE AMOUNT OF FUEL COMBUSTED OR HEAT INPUT RATE AND THE QUANTITY OF COMBUSTION GASES THAT ARE PRODUCED BY THE COMBUSTION PROCESS.

$$\text{THEREFORE: } Q = \text{HEAT INPUT RATE} \times \left[\frac{(F_D \times \text{EXCESS AIR CORRECTION}) + (F_W - F_D)}{528^\circ\text{R (STANDARD TEMP } 68^\circ\text{F @ 1 ATM)}} \right] \times \text{TACT} + 460^\circ\text{R}$$

0 (NOT NECESSARY FOR dsft³)

FOR BITUMINOUS COAL

$$F_D = 9780 \frac{\text{BTU}}{\text{dsft}^3}$$

$$F_W = 10,640 \frac{\text{BTU}}{\text{dsft}^3}$$

SEE ATTACHED F...

EXCESS AIR CORRECTION

$$\% O_2 = 9.6 \text{ (FROM STACK TEST)}$$
$$\frac{20.9}{20.9 - 9.6} = 1.85$$

$$Q = \frac{26100 \text{ SDFT}^3 \text{ (STACK TEST)}}{\text{MIN.}} \times \frac{60 \text{ MIN.}}{\text{HR}} = \frac{1.566 \times 10^6 \text{ SDFT}^3}{\text{HR}}$$

$$\frac{1.566 \times 10^6 \text{ SDFT}^3}{\text{HR}} = \frac{\cancel{K} \text{ BTU}}{\text{HR}} \times \left[\frac{(9780 \text{ SDFT}^3 \times 1.85)}{\text{MMBTU}} + \frac{(10,640 \text{ SDFT}^3)}{\text{MMBTU}} \right]$$

$$\frac{1.566 \times 10^6 \text{ SDFT}^3}{\text{HR}} = \frac{\cancel{K} \text{ BTU}}{\text{HR}} \times \frac{18,954 \text{ SDFT}^3}{\text{MMBTU}}$$

$$\frac{1.566 \times 10^6 \text{ SDFT}^3}{\text{HR}} \times \frac{\text{MMBTU}}{18,954 \text{ SDFT}^3} = \frac{\cancel{K} \text{ BTU}}{\text{HR}}$$

$$82.62 \frac{\text{MMBTU}}{\text{HR}} = \frac{\cancel{K} \text{ BTU}}{\text{HR}}$$

$$\frac{82.62 \times 10^6 \text{ BTU}}{\text{HR}} \times \frac{\text{FT}^3}{500 \text{ BTU}} = 175,787 \text{ (179,608)}$$

$\frac{400}{110}$
HR COMBUSTED

KOPPERS
SUBJECT'S GAS USAGE RATE DETERMINATION BY USE OF THE
F-FACTOR
GIVEN'S AVERAGED VALUES FROM SEPT. 26, 1991 STACK TEST
& AUGUST 21, 1991 STACK TEST.

$$\text{HEAT INPUT RATE} \times \left[(F_d \times \text{EXCESS AIR CORRECTION}) + (F_w - F_d) \right] \times \text{TEMPERATURE CORRECTION}$$
$$\frac{59700}{2} \times 60 \frac{\text{SDFT}^3}{\text{HR}} = \frac{\cancel{K} \text{ BTU}}{\text{HR}} \left[\frac{(9780 \text{ SDFT}^3 \times 2.22)}{\text{MMBTU}} + \frac{(10,640 \text{ SDFT}^3 - 9780 \text{ SDFT}^3)}{\text{MMBTU}} \right] \times 1.86$$

$$\frac{17 \times 10^6 \text{ SDFT}^3}{\text{HR}} = \frac{\cancel{K} \text{ BTU}}{\text{HR}} \times \frac{41,983 \text{ SDFT}^3}{\text{MMBTU}}$$
$$\frac{57 \times 10^6 \text{ SDFT}^3}{\text{HR}} \times \frac{\text{MMBTU}}{41,983 \text{ SDFT}^3} = 85.034 \frac{\text{MMBTU}}{\text{HR}}$$

$$85.034 \text{ MMBTU} \times \frac{\text{FT}^3}{460 \text{ BTU}} = 184,857 \text{ FT}^3 \text{ COG}$$

HR COMBUSTED

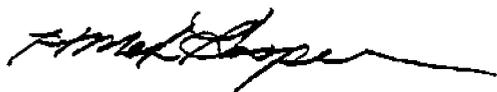
with measured sulfur dioxide in stack.

The JCDH proposed emission factors were:

	<u>(ARIS)</u>	<u>AP-42</u>
Particulate Matter (PM)	0.58	0.47
Sulfur Dioxide (SO ₂)	4.00	4.00
Nitrogen Oxides (NO _x)	0.04	--
Hydrocarbons (VOC)	2.0	--

The stack data collected at the KII facility in Dolomite is, with analysis, similar to the proposed emission factors for the #3 battery rebuilding. As soon as the JCDH has responded to the current permitting issues, Struthers believes that we are in a position to advance the permitting for the #3 battery.

If you have any questions regarding the above comments, please call.



H. Maxwell Hooper, P.E.

TABLE OF CONTENTS

1. INTRODUCTION 1

2. SUMMARY AND DISCUSSION OF RESULTS 2

3. PROCESS DESCRIPTION 6

4. SAMPLING AND ANALYTICAL PROCEDURES 8

5. PARTICULATE SAMPLING PROCEDURES (METHOD 5) 10

 5.1 Particulate Sample Recovery 11

 5.2 Particulate Analytical Procedures 12

6. NITROGEN OXIDES SAMPLING PROCEDURE 14

 6.1. Sample Recovery & Analysis 16

7. SULFUR DIOXIDE SAMPLING PROCEDURE 18

 7.1. Sample Recovery & Analysis 20

LIST OF TABLES

- TABLE I: PARTICULATE TEST RESULTS
- TABLE II: NITROGEN OXIDES TEST RESULTS
- TABLE III: SULFUR DIOXIDE TEST RESULTS

LIST OF ILLUSTRATIONS

- FIGURE 1: SAMPLE POINT LOCATION
- FIGURE 2: PARTICULATE SAMPLING TRAIN
- FIGURE 3: NITROGEN OXIDES SAMPLING TRAIN
- FIGURE 4: SULFUR DIOXIDE SAMPLING TRAIN

APPENDICES

**APPENDIX A: FIELD DATA SHEETS, EQUATIONS AND
 RECORDER CHARTS**

APPENDIX B: CALIBRATIONS

13 December 1991

BY FAX:

To: Mr. Donald Hall
Koppers Industries, Inc.
Woodward Plant

Mr. William Swearingen
Koppers Industries, Inc.
Pittsburgh Office

From: H. Maxwell Hooper, P.E.

Reference: Koppers Industries, Inc.
No. 3 Battery Rebuild - Struthers No. P636-16

Subject: Stack Testing Battery #1

Struthers has reviewed the results of the Stack Testing at Koppers Industries, Inc. (KII) Dolomite, Alabama Facility on August 21, 1991 and September 26, 1991 and offers the following comments:

- . Battery #1 operates under Jefferson County Department of Health (JCDH) Permit No. 4-07-0430-9002. The permit requires, among other things, that "Particulate matter emissions rate from the source permitted herein shall not exceed 0.03 grains of filterable particulate matter per cubic foot of dry flue gas to be determined by EPA's Reference Method #5" (See attached Air Permit Item #17).
- . The analytical results of the testing program indicates that the particulate concentration was on average:
 - August 21, 1991 - 0.044 grs/acf
 - September 26, 1991 - 0.017 grs/acf
- . The average moisture concentration in the gas stream was reported to be 10.8% and 11.3%. Adjusting the particulate concentration to a dry flue gas basis results in the following:
 - August 21, 1991 - 0.049 grs/acf
 - September 26, 1991 - 0.019 grs/acf
- . The August 21, 1991 particulate matter flue gas concentration exceeded the permit value of 0.03 grs/acf dry. The September 26, 1991 particulate matter flue gas concentration was below the permit value of 0.03 grs/acf dry.

The August stack sampling results were reported by the plant to be unusual as a result of operating upsets in the plant gas treatment equipment, most notable, ammonia removal. The system stack sampling is believed to be more representative of typical plant performance.

As the stack sampling data has been submitted to JCDE, it would be appropriate to provide JCDH with an evaluation/explanation of the stack sampling data. The plant should indicate that the September data is considered more accurate and that the stack sampling data demonstrates that the battery is operating in accordance with permit conditions.

The stack data was collected while the battery charged 39.33 tons of coal per hour or 944 tons/day of coal, based on 80 pushes per day and 11.8 tons of coal charged per oven. The data indicates the following emission factor in lb/ton of coal charged:

<u>August 21, 1991</u>	<u>Emission Factor (Lb/Ton)</u>
Particulate Matter (PM)	0.503
Sulfur Oxides (SO ₂)	3.577
Nitrogen Oxides (NO _x)	1.203
<u>September 26, 1991</u>	<u>Emission Factor (Lb/Ton)</u>
Particulate Matter (PM)	0.234
Hydrocarbons (VOC)	0.094

The particulate matter collected by KII was reported to contain 50.4% SO₄. This indicates that some condensation due to the presence of SO₂ in the flue gas was taking place, most likely in the gas sampling train and not in the battery stack. An argument can be made that the actual particulate matter to be found in a dry flue gas sample would have been

$$\text{PM} = \frac{0.234 \text{ lb}}{\text{ton}} \times (1 - 50.4\%) = 0.116 \frac{\text{lb}}{\text{ton}}$$

By comparison, the information provided JCDH by KII regarding proposed emission factors for use in evaluating the #3 Battery are:

Particulate Matter (PM)	0.13
Sulfur Dioxides* (SO ₂)	07.43
Nitrogen Oxides (NO _x)	1.97
Hydrocarbons (VOC)	---

*Value represents total sulfur dioxide emitted - assuming 50% of the coke oven gas used for battery heating. The comparable emission factor is 3.715 lb/ton of coal charged. This is in close agreement.

1. INTRODUCTION

Sanders Engineering & Analytical Services, Inc., (SEAS) performed sulfur dioxide, nitrogen oxides, and particulate emissions tests on the coke battery at Koppers Industry facility located in Dolomite, Alabama. The tests were performed on August 21, 1991. The testing was performed in accordance with the applicable U.S. EPA procedures specified at 40 CFR, Part 60, Appendix A.

The purpose of the tests was to gain additional information concerning the emission rate of the process.

The tests were conducted by Mr. Bob Richmann, Mr. Chris Leitsch, Mr. John Wilson, and Mr. Tim Kray of Sanders Engineering & Analytical Services, Inc., and were coordinated with Mr. Don Hall of Koppers Industry. Representatives of the Jefferson County Bureau of Environmental Health were also present to observe the testing.

The tests were conducted in accordance with the rules and regulations of the Jefferson County Bureau of Environmental Health. Further discussion of the test methods are included in the report.

2. SUMMARY AND DISCUSSION OF RESULTS

The summary of the particulate, nitrogen oxides and sulfur dioxides emissions test results are presented in Tables I through III, respectively. The completed field data sheets, a copy of the recorder charts, and the equations used in the calculations are included in Appendix A. The initial and final calibrations and the bias drift data of the equipment used in the sampling program are included in Appendix B.

The results of the testing for each pollutant, as required by the Jefferson County Bureau of Environmental Health, are as follows:

<u>Pollutant</u>	<u>Emission Rate</u> <u>LB/HR</u>
Particulate	19.8
Sulfur Dioxide	140.7
Nitrogen Oxides	47.3

No unusual sampling problems were experienced during the performance of the test. At the completion of each run, the filters, nozzles, and all sample exposed surfaces were removed to a relatively clean, draft-free area for cleanup.

**TABLE I
PARTICULATE TEST RESULTS
KOPPERS INDUSTRY
DOLOMITE PLANT
08-21-91**

Title of Run		Run 1	Run 2	Run 3
F Factor	SDCF/MMBTU	9820.00	9820.00	9820.00
Static Pressure	IN. H2O	-1.10	-1.10	-1.22
Barometric Pressure	In. Hg.	29.71	29.71	29.79
Average ΔH	In. H2O	0.896	1.151	2.440
Meter Correction		1.009	1.009	1.012
Avg Meter Temp.	DEG F	104.9	111.6	90.5
% O2	%	10.0	9.5	9.3
% CO2	%	10.8	11.3	11.5
Volume Metered	ACF	31.826	36.345	50.185
Volume Water	ML	84.7	86.0	112.1
Sampling Time	MINUTES	60	60	60
Nozzle Diameter	INCHES	0.382	0.482	0.494
Avg. Stack Temp.	DEG F	568.7	492.6	483.3
Area Of Stack	SQ. FEET	50.266	50.266	50.266
Wt. Of Part.	MG	210.1	262.7	145.5
Number Of Points		12	12	12
Avg. Sqrt. ΔP	In. H2O	0.269	0.183	0.256

9.16 1000

RESULTS OF COMPUTATIONS

		RUN 1	RUN 2	RUN 3	AVERAGE
Volume of Gas Sampled	SDCF	29.860	33.721	48.776	37.452
Molecular Wt. Of St. Gas	LB/LB-MOLE	28.70	28.88	29.02	28.87
H2O Vapor in Gas Stream	PERCENT	11.8	10.7	9.8	10.8
Avg Stack Gas Velocity	FT/SEC	21.3	13.9	19.2	18.1
Volumetric Flow Rate	SDCFM	28800	20500	29100	26100
Volumetric Flow Rate	ACFM	64200	41800	58000	54700
Particulate Conc.	GRS/SDCF	0.108	0.120	0.046	0.091
Particulate Conc.	GRS/ACF	0.049	0.059	0.023	0.044
Particulate Mass Rate	LB/HR	26.7	21.1	11.5	19.8
Emission Rate	LBS/MM Btu	0.291	0.309	0.116	0.239
Percent of Isokinetic		109.20	108.80	105.60	

SEAS, INC.

$$\frac{0.091 \text{ gr}}{\text{FT}^3} \times \frac{26100 \text{ CFM}^3}{\text{MIN}} \times \frac{60 \text{ MIN}}{\text{HR}} \times \frac{\#}{7000 \text{ gr}} = 50.36$$

KOPPERS INDUSTRY

DOLOMITE, ALABAMA

TABLE II: NITROGEN OXIDES TEST RESULTS
 KOPPERS INDUSTRY
 COKE BATTERY-DOLOMITE, ALABAMA
 SUMMARY OF RUNS

Run	\bar{C}	C_o	C_{ma}	C_m	C_{gas}^*	lb/hr**
1	266.52	4	450	456.00	261.35	54.9
2	266.28	2	450	459.50	259.95	39.1
3	<u>232.59</u>	<u>-2</u>	<u>450</u>	<u>457.50</u>	<u>229.74</u>	<u>48.5</u>
AVG	255.13	1.33	450	457.67	250.30	47.3

WHERE:

\bar{C} = Average Analyses response, dry basis, ppm

C_o = Average Initial and Final zero bias check, ppm

C_m = Average Initial and Final upscale bias check, ppm

C_{ma} = Actual Concentration of the upscale calibration gas, ppm

* $C_{gas} = (\bar{C} - C_o) C_{ma} / C_m - C_o$

** lb/hr = ppm NO_x x (SDCFM) x (60 min/hr) x (1.194 x 10⁻⁷)

KOPPERS INDUSTRY

DOLOMITE, ALABAMA

TABLE III: SULFUR DIOXIDE TEST RESULTS
 KOPPERS INDUSTRY
 COKE BATTERY-DOLOMITE, ALABAMA
 SUMMARY OF RUNS

Run	\bar{C}	C_o	C_{ma}	C_m	C_{gas}^*	lb/hr**
1	555.30	4	452	452	556.22	159
2	616.43	9	452	465	602.10	126
3	<u>473.52</u>	<u>5</u>	<u>452</u>	<u>449</u>	<u>476.96</u>	<u>137</u>
AVG	548.417	6	452	452	549.71	140.7

WHERE:

\bar{C} = Average Analyses response, dry basis, ppm

C_o = Average Initial and Final zero bias check, ppm

C_m = Average Initial and Final upscale bias check, ppm

C_{ma} = Actual Concentration of the upscale calibration gas, ppm

* $C_{gas} = (\bar{C} - C_o) C_{ma} / (C_m - C_o)$

** lb/hr = ppm SO₂ x (SDCFM) x (60 min/hr) x (1.66 x 10⁻⁷)

$$\frac{64.06}{325.8 \times 10^3} = 1.66 \times 10^{-7}$$

3. PROCESS DESCRIPTION

Coke is produced in narrow, slot type ovens constructed of silica brick. A coke oven battery may have a series of 10 to 100 individual ovens, with a heating flue between each oven pair. Ovens are charged with pulverized coal, through ports in the oven top, by a larry car traveling on tracks along the top of each battery. After charging, the ports are sealed, and the coking process begins. Combustion of gases in burners in the flues between the ovens provides heat for the process. Coke oven gas from the by-product recovery plant is the common fuel for underfiring the ovens at most plants, but blast furnace gas and, infrequently, natural gas may also be used.

After a coking time typically between 12 and 20 hours, almost all volatile matter is driven from the coal mass, and the coke is formed. Maximum temperature at the center of the coke mass is usually 1100 to 1150°C (2000 to 2100°F).

After coking, machinery located on tracks on each side of the battery removes the vertical door on each end of an oven, and a long ram pushes the coke from the oven into a rail quench car, whence it goes to a quench tower, where several thousand gallons of water are sprayed onto the coke mass to cool it. The car then discharges the coke onto a wharf along the battery for further cooling and drainage of water. From here, coke is screened and sent to the blast furnace or to storage in outdoor piles.

4. SAMPLING AND ANALYTICAL PROCEDURES

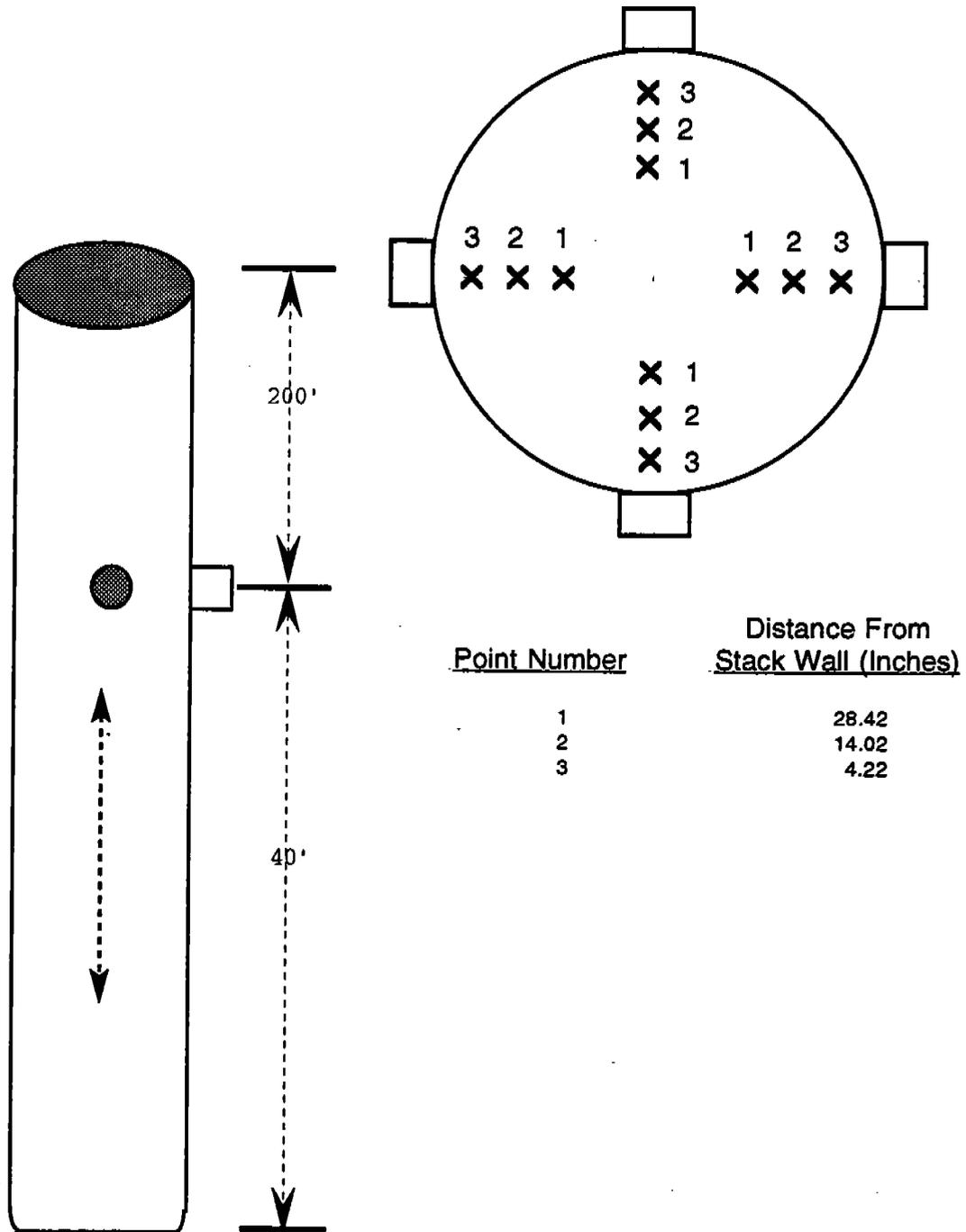
The sample point location and outlet duct schematic for Koppers Industry, Coke Battery, is presented in Figure 1.

KOPPERS INDUSTRY

DOLOMITE, ALABAMA

During the coking cycle, volatile matter driven from the coal mass is collected by off-takes located at one or both ends of the oven. A common collector main transports the gases from each oven to the by-product recovery plant. Here, coke oven gas is separated, cleaned and returned to heat the ovens. Only 40 percent of recovered coke oven gas is required for underfiring, and the remainder is used throughout the ~~steel~~ ^{COKE} plant. Other coal byproducts also are recovered in the byproduct plant for reuse, sale or disposal.

FIGURE 1
Sample Point Location
KOPPERS INDUSTRY
DOLOMITE PLANT



5. PARTICULATE SAMPLING PROCEDURES (METHOD 5)

A brief description of the sampling procedure is as follows:

The sample train was prepared in the following manner: 100 milliliters of distilled water were added to the first and second impingers. The third impinger was left empty to act as a moisture trap, and preweighed silica gel was added to the fourth impinger. The train with the probe, as shown in the following schematic, Figure 2, was leak checked by plugging the inlet to the nozzle and pulling a 15 inch mercury vacuum. A leakage rate not in excess of 0.02 cubic feet per minute was considered acceptable.

The inside dimensions of the stack liner were measured and recorded. The number of sampling points, and the location of these points on a traverse, were determined by the guidelines set forth in the Federal Register, Vol. 36, No. 247, Sec. 60.85, Method 1. These points were then marked on the probe for easy visibility.

A preliminary traverse was conducted to determine the range of velocity head and the pressure of the stack. From this data, the correct nozzle size and the nomograph multiplication factor were determined.

The probe was attached and the heater was adjusted to provide a temperature of 248 degrees fahrenheit (± 25). Crushed ice was then placed around the impingers. The nozzle was placed on the first traverse point with the tip pointing directly into the gas stream. The pump was started immediately and the flow was adjusted to

isokinetic sampling conditions. After the required time interval had elapsed, the probe was repositioned to the next traverse point and isokinetic sampling was re-established. This was done for each point on the traverse until the run was completed. Readings were taken at each point. When changes in stack conditions occurred, adjustments in sampling flow rate were performed. At the conclusion of each run, the pump was turned off and the final readings were recorded.

5.1 Particulate Sample Recovery

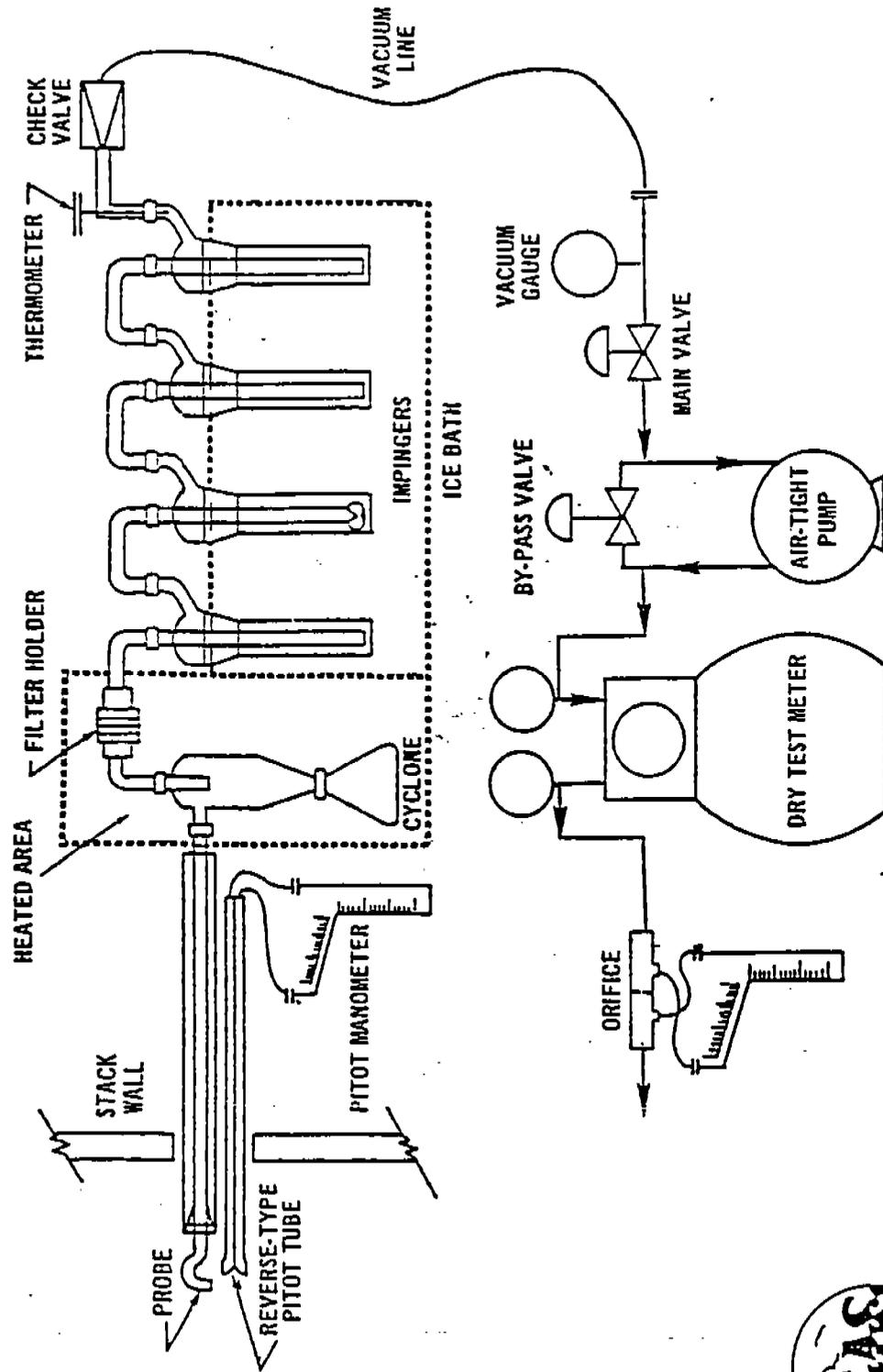
Care was exercised in moving the collection train to the sample recovery area to minimize the loss of collected sample, or the gain of extraneous particulate matter. The volume of water in the first three impingers was measured, the silica gel impinger was weighed and recorded on the field data sheet. The probe, nozzle, and all sample-exposed surfaces were washed with reagent grade acetone and the wash solution was put into a clean sample bottle. A brush was used to loosen any adhering particulate matter and subsequent washings were put into the container. The filter was carefully removed from the fritted glass support and placed in a clean dish. A sample of the acetone used in the washing was saved for a blank laboratory analysis.

5.2 Particulate Analytical Procedures

The filter and any loose particulate matter were transferred from the dish to a clean, tared weighing dish. The filter was placed in a desiccator for a least 24 hours and then weighed to the nearest 0.1 milligram until a constant weight was obtained. The original weight of the filter was deducted, and the weight gain was recorded to the nearest 0.1 milligram.

The wash solution was transferred to a clean, tared beaker. The solution was evaporated to dryness, desiccated to a constant weight, and the weight gain was recorded to the nearest 0.1 milligram.

Figure 2. Particulate Sampling Train.



6. NITROGEN OXIDES SAMPLING PROCEDURE

The NO_x sampling procedure utilized was an EPA Method 7E, which was approved by the Mississippi Department of Environmental Quality. A brief description of the sampling procedure is as follows.

The analyzing instrument used in this test was a Thermo Electron Model 10A chemiluminescent NO-NO_x gas analyzer, Serial No. 10AR-11795-126. The chart recorder used was a Soltec Model 1241.

The sampling train consisted of stainless steel and teflon tubing which ran from the Stack to a three way valve connected to a teflon impinger in an ice bath. Teflon tubing was connected between the impinger box and the NO_x analyzer. Teflon tubing was also connected between the calibration gas cylinders and the three way valve.

The sample train is presented in Figure 3.

The instrument was allowed to warm up for at least 30 minutes before it was initially calibrated. Then a high range calibration gas between 80-90% of the span value was introduced to the instrument. The instrument was allowed to fully respond to the calibration gas and the analyzer was adjusted to the correct value. Next, a mid range calibration gas between 50 to 60 percent of the span was introduced to the instrument. Ambient air was then used as zero air to check the zero reading of the instrument.

KOPPERS INDUSTRY

DOLOMITE, ALABAMA

If any of the readings indicated a difference of more than $\pm 2\%$ of the span, the analyzer was recalibrated. Next, the high, middle and zero zones was introduced to the system at the three way valve. The response value for each of these gases was recorded,. The system response time was recorded during the bias check and found to be approximately 4 minutes.

To begin sampling, the three way valve was switched to allow the instrument to sample the exhaust gas. Twice, the system response time was allowed to elapse before the chart was marked for the beginning of the run. After sixty minutes of sampling, the chart was marked for the end of the run. At the end of each run, the three way valve was switched to allow introduction of the calibration gas which was closest in value to the exhaust gas NO_x concentration. Zero air was then introduced to the system. The zero and calibration drift were recorded. If the drift values were greater than $\pm 5\%$ of the span, then the run was invalidated. The three way switch was set to allow sampling of the exhaust gas, and the next run was begun after the elapse of the response time. This procedure was repeated until three runs were completed.

6.1. Sample Recovery & Analysis

After the tests were completed on each unit, the chart recorder data was reduced to give an average NO_x concentration in ppm for each run. This average concentration was then corrected for the analyzer zero and span drift using the equation:

$$C_{\text{gas}} = \frac{(C - CO) \cdot CMA}{C_m - CO}$$

Where:

C gas = Effluent gas Concentration, dry basis, ppm.

C = Average gas concentration indicated by the gas analyzer, dry basis, ppm.

CO = Average of initial and final system calibration responses for the zero gas, ppm.

C_m = Average of initial and final calibration responses for the upscale calibration gas, ppm.

CMA = Actual concentration of the scale calibration gas, ppm.

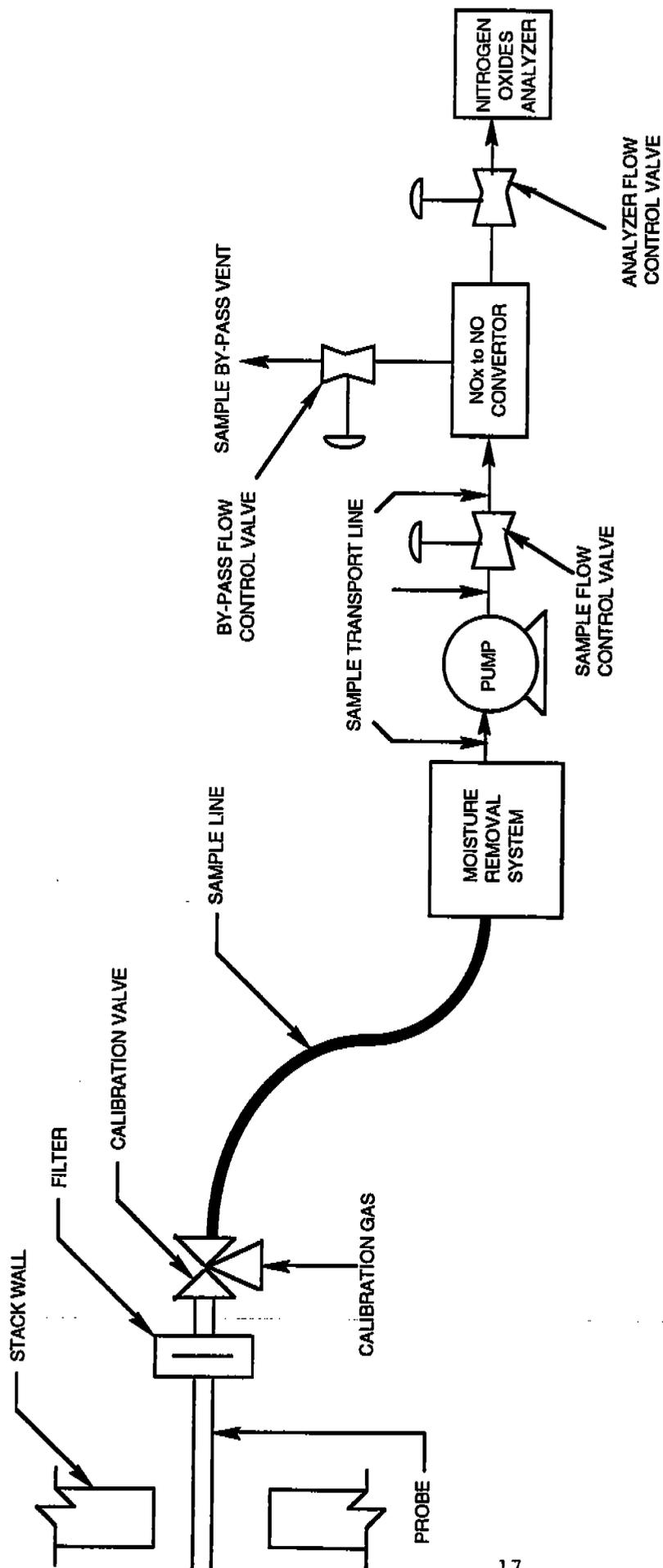


FIGURE 3: OXIDES OF NITROGEN SAMPLING TRAIN

7. SULFUR DIOXIDE SAMPLING PROCEDURE

The SO₂ sampling procedure utilized was an EPA Method 6C, which was approved by the Alabama Department of Environmental Management. A brief description of the sampling procedure is as follows:

The analyzing instrument used in this test was a Western Research Model 721AT2 UV Absorbtion gas analyzer, Serial No. 91-721 AT2-7810-1. The chart recorder used was a Soltec Model 1241.

The sampling train consisted of stainless steel and teflon tubing which ran from the stack to a three was valve connected to a teflon impinger in an ice bath. Teflon tubing was connected between the impinger box and the SO₂ analyzer. Teflon tubing was also connected between the calibration gas cylinders and the three was valve. The sample train is presented in Figure 3.

The instrument was allowed to warm up for at least one (1) hour before it was initially calibrated. Then a high range calibration gas between 80 to 90 percent of the span value was introduced to the instrument. The instrument was allowed to fully respond to the calibration gas and the analyzer was adjusted to the correct value. Next, a mid range calibration gas between 50 to 60 percent of the span was introduced to the instrument. Ambient air was then used as zero air to check the zero reading of the instrument.

KOPPERS INDUSTRY

DOLOMITE, ALABAMA

If any of the readings indicated a difference of more than ± 2 percent of the span, the analyzer was recalibrated. Next, the high, middle and zero zones was introduced to the system at the three way valve. The response value for each of these gases was recorded. The system response time recorded during the bias check and found to be approximately four (4) minutes.

To begin sampling, the three way valve was switched to allow the instrument to sample the exhaust gas. Twice, the system response time was allowed to elapse before the chart was marked to the beginning of the run. After sixty minutes of sampling, the chart was marked for the end of the run. At the end of each run, the three way valve was switched to allow introduction of the calibration gas which was closest in value to the exhaust gas SO_2 concentration. Zero air was then introduced to the system. The zero and calibration drift were recorded. If the drift values were greater than ± 5 percent of the span, then the run was invalidated. The three way switch was set to allow sampling of the exhaust gas, and the next run was begun after the elapse of the response time. This procedure was repeated until three runs were completed.

7.1. Sample Recovery & Analysis

After the tests were completed on each unit, the chart recorder data was reduced to give an average SO₂ concentration in ppm for each run. This average concentration was then corrected for the analyzer zero and span drift using the equation:

$$C_{\text{gas}} = \frac{(C - CO) \cdot CMA}{C_m - CO}$$

Where:

C gas = Effluent gas Concentration, dry basis, ppm.

C = Average gas concentration indicated by the gas analyzer, dry basis, ppm.

CO = Average of Initial and final system calibration responses for the zero gas, ppm.

C_m = Average of initial and final calibration responses for the upscale calibration gas, ppm.

CMA = Actual concentration of the scale calibration gas, ppm.

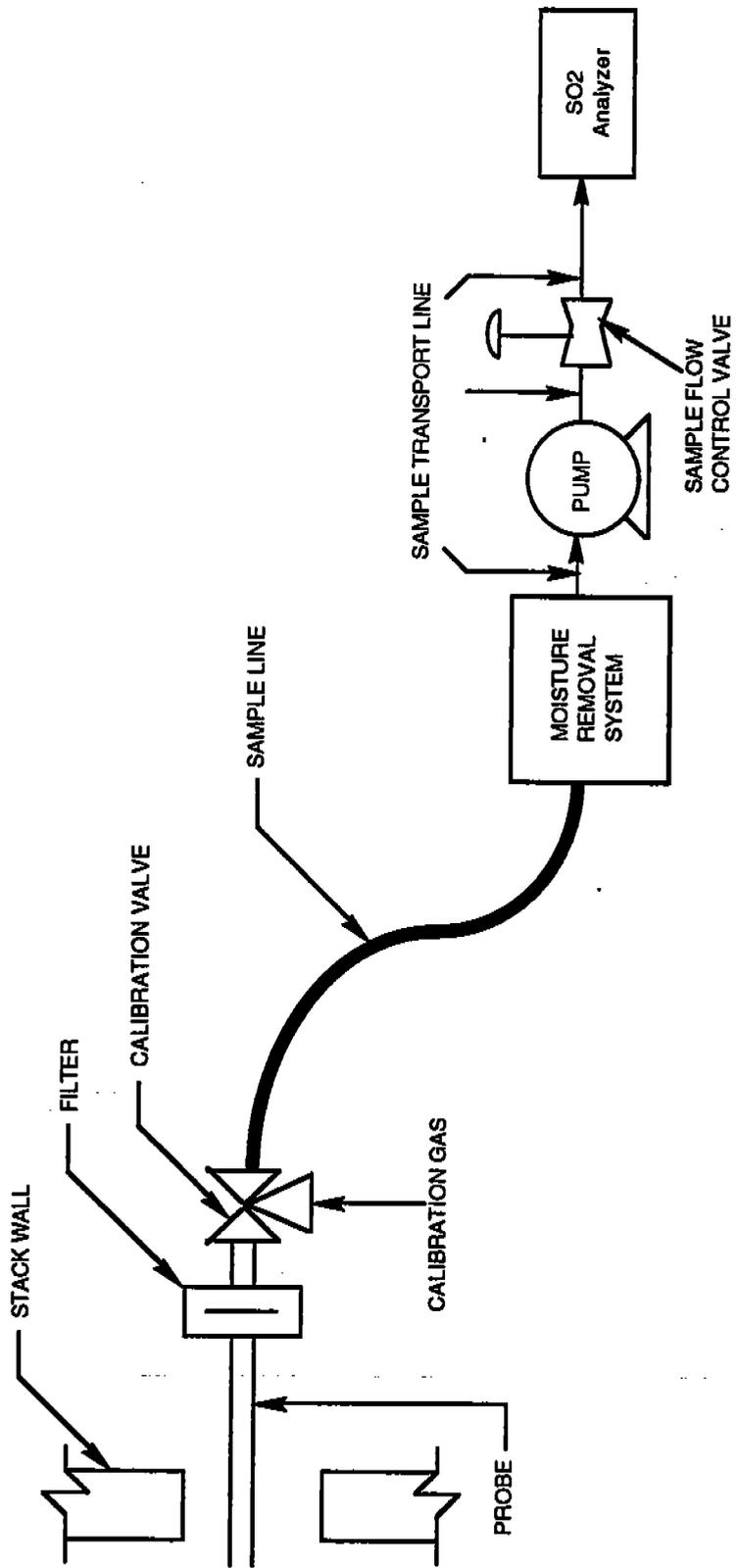


FIGURE 4: SULFUR DIOXIDE SAMPLING TRAIN

KOPPERS INDUSTRY

DOLOMITE, ALABAMA

COM
PLANT
LOCAL

N
CALIBR
PRE
382
382
382
382
AVERAGE

APPENDIX A: FIELD DATA SHEETS, EQUATIONS AND RECORDER CHARTS

524.31
FI AL
492
INI
318

SYST
Pre
24
in. Hg
010
clm

LIQU
IMP. 1 IN
168
FINAL
100
INITIAL INI
68
NET NI

GAS A
O₂ 10
CO₂ 10
CO

18-21-91



SANDERS ENGINEERING & ANALYTICAL SERVICES, Inc.

1568 Leroy Stevens Rd.
Mobile, AL 36695

Office: (205) 633-4120
FAX#: (205) 633-2285

WS
8-22-91

D-460

PORT #	DINT #	TIME	GAS METER VOLUME (cu.ft.)	VEL. HEAD ΔP in. H ₂ O	ORIFICE HEAD ΔH in. H ₂ O	TEMPERATURE °F					VAC. in. Hg	
						STACK	PROBE	HOT BOX	IMP.	GAS METER		
										IN		OUT
1-1		10:18	536.488	.088	3.05	497	/	/	✓	80	76	12
2		23	541.1	.072	2.76	482	/	/	/	81	78	13
3		28	545.8	.058	2.10	453	-	/	/	86	80	13
2-1		43	549.950	.078	3.09	480	✓	/	/	87	83	13
2		48	554.6	.075	2.88	480	✓	-	-	93	86	13
3		57	539.5	.060	2.30	494	✓	-	/	95	87	10
3-1		11:01	563.037	.074	2.89	563	/	/	/	98	90	12
2		06	567.7	.067	2.32	576	✓	-	-	97	92	10
3		11	572.1	.058	2.06	527	/	/	-	98	93	9
4-1		11:22	576.2	.066	2.32	454	/	/	/	99	96	9
2		27	579.9	.060	2.38	480	✓	-	-	101	97	9
3		32	584.2	.043	1.78	424	/	-	✓	103	99	8
		37	588.673									
					2.44							
						483.33				90.488		

✓ INDICATES TEMPERATURES MEET REQUIRED LIMITS

± or - 2σ 248° ± or - 2σ 248° less than 6.8°

COMPANY Kopper

OPERATOR BR

PLANT Birmingham

DATE 8-22-91

UNIT Underboiling #1

RUN# 3

PAGE 4 OF 4



SANDERS ENGINEERING & ANALYTICAL SERVICES, Inc.

1568 Leroy Stevens Rd.
Mobile, AL 36695

Office: (205) 633-4120
FAX#: (205) 633-2285

CHAIN of CUSTODY & LABORATORY ANALYSIS

COMPANY Kopper Industries
PLANT Woodward
UNIT Unit 1 - Underfiring

DATE of TEST 8-21-91 to 8-22-91
TEST: M-5 M-17
 OTHER _____

SAMPLE NO.	WASH	RETURNED BY	RECEIVED BY	TIME	DATE	REASON FOR CHANGE
6575	W6575	CAV	HW	9:40 AM	8-23-91	Analysis
6576	W6576	CAV	HW	9:40 AM	8-23-91	Analysis
6578	W6578	CAV	HW	9:40 AM	8-23-91	Analysis

UNIT: #1 Underfiring

UNIT: _____

RUN #	FILTER #	BEAKER. #
	6575	33
	F 673.5	F 6372.2
	I 592.6	I 63817.2
	D 80.9	D 129.2
TOTAL		210.1
	6576	36
	F 742.5	F 69202.2
	I 595.0	I 69687.0
	D 147.5	D 1152
TOTAL		262.7
	6578	45
	F 683.4	F 65555.7
	I 593.9	I 64479.9
	D 89.3	D 56.0
TOTAL		145.5
	F	F
	I	I
	D	D
TOTAL		

RUN #	FILTER #	BEAKER. #
	F	F
	I	I
	D	D
TOTAL		
	F	F
	I	I
	D	D
TOTAL		



SANDERS ENGINEERING & ANALYTICAL SERVICES, Inc.

1568 Leroy Stevens Rd.
Mobile, AL 36695

Office: (205) 633-4120
FAX#: (205) 633-2285

C-175

PORT #	TIME	GAS METER VOLUME (cu.ft.)	VEL. HEAD ΔP In. H ₂ O	ORIFICE HEAD ΔH In. H ₂ O	TEMPERATURE °F					VAC. In. Hg	
					STACK	PROBE	HOT BOX	IMP.	GAS METER		
									IN		OUT
-1	10:54	492.543	.078	.96	537	✓	✓	✓	97	96	6
2	56	495.7	.081	.99	574	✓	✓	✓	103	99	6
3	11:01	498.0	.085	1.03	593	✓	✓	✓	111	101	7
4	11:06	500.6	.083	.99	609	✓	✓	✓	105	105	7
5	11:11	503.3	.089	1.06	611	✓	✓	✓	107	108	8
6	11:16	506.00	.073	.87	549	✓	✓	✓	110	101	6
-1	11:43	508.76	.085	.85	536	✓	✓	✓	110	103	7
2	46	511.3	.075	.84	535	✓	✓	✓	108	108	8
3	57	513.9	.070	.88	560	✓	✓	✓	116	100	7
4	57	516.4	.078	.97	570	✓	✓	✓	110	103	7
5	12:05	519.1	.050	.62	580	✓	✓	✓	112	104	6
6	68	521.7	.058	.68	573	✓	✓	✓	112	105	6
	12	524.369									
				.896							
					568.667				104.875		

✓ INDICATES TEMPERATURES MEET REQUIRED LIMITS

+ or - 25 248° + or - 25 248° less than 68°

COMPANY Koppers

OPERATOR BR

PLANT Dolomite

DATE 8-21-91

UNIT Underfiring Battery #1

RUN# 1

PAGE 2 OF 41



SANDERS ENGINEERING & ANALYTICAL SERVICES, Inc.

1560 Leroy Stevens Rd.
Mobile, AL 36695

Office: (205) 633-4120
FAX#: (205) 633-2285

C-175

PORT #	POINT #	TIME	GAS METER VOLUME (cu.ft.)	VEL. HEAD ΔP In. H ₂ O	ORIFICE HEAD ΔH In. H ₂ O	TEMPERATURE °F				VAC. In. Hg		
						1 STACK	2 PROBE	3 HOT BOX	4 IMP.		5 6 GAS METER	
											IN	OUT
1-1	3:07	525.347	0.03	1.93	594	✓	✓	✓	104	109	6	
2	12	528.9	.032	.96	602	✓	✓	✓	112	105	3	
3	17	532.2	.032	1.38	571	✓	✓	✓	114	107	4	
2-1	3:19	535.507	.028	1.35	481	✓	✓	✓	106	105	3	
2	32	538.206	.028	.95	485	✓	✓	✓	116	108	3	
3	37	541.004	0.015	.75	180	—	—	—	118	108	3	
3-1	3:47	543.701	0.038	1.29	485	—	—	—	113	108	4	
2	52	546.709	0.023	0.74	543	—	—	—	108	111	3	
3	51	549.302	0.030	0.95	560	—	—	—	118	112	4	
4-1	4:12	552.008	0.050	1.56	570	—	—	—	118	112	4	
2	4:17	554.803	0.040	1.25	570	—	—	—	120	112	4	
3	4:22	558.110	0.035	1.10	560	—	—	—	118	112	4	
		560.692										
				1.151					111.58			
					492.58							

✓ INDICATES TEMPERATURES MEET REQUIRED LIMITS

+ or - 20 240° + or - 20 240° less than 68°

COMPANY Koppers

OPERATOR B.R

PLANT Birmingham

DATE 8-21-91

UNIT Underfiring Bat 1

RUN# 2

PAGE 3 OF 4

SANDERS ENGINEERING & ANALYTICAL SERVICES, INC.

EQUATIONS

$$1. P_s = P_{\text{bar}} + \frac{P_g}{13.6}$$

$$2. P_m = P_{\text{bar}} + \frac{\overline{\Delta H}}{13.6}$$

$$3. v_s = K_p C_p \sqrt{\Delta p} \sqrt{\frac{\overline{T_s}}{M_s P_s}}$$

$$4. V_{m(\text{std})} = 17.64 V_m Y \left[\frac{P_{\text{bar}} + \frac{\overline{\Delta H}}{13.6}}{\overline{T_m}} \right]$$

$$5. V_{mc} = V_m - (L_p - L_a)\theta$$

$$6. V_{w(\text{std})} = 0.04707 V_{lc}$$

$$7. B_{ws} = \frac{V_{w(\text{std})}}{V_{m(\text{std})} + V_{w(\text{std})}}$$

$$8. M_d = 0.44(\%CO_2) + 0.32(\%O_2) + 0.28(\%N_2 + \%CO)$$

$$9. M_s = M_d(1 - B_{ws}) + 18(B_{ws})$$

$$10. EA = \left[\frac{\%O_2 - 0.5(\%CO)}{0.264(\%N_2) - (\%O_2) + 0.5(\%CO)} \right] 100$$

$$11. Q_a = (v_s)(A_s)(60)$$

$$12. Q_s = Q_a(1 - B_{ws}) \left(\frac{528}{\overline{T_s}} \right) \left(\frac{P_s}{29.92} \right)$$

$$13. W_a = \frac{m_a V_{aw}}{V_a}$$





$$21. \quad C_{H_2SO_4} = 1.081 \times 10^{-4} (V_t - V_{tb}) N \frac{V_{soln}}{V_a} \frac{V_m(\text{std})}{V}$$

$$20. \quad C_{SO_2} = 7.061 \times 10^{-5} (V_t - V_{tb}) N \frac{V_{soln}}{V_a} \frac{60.0 V_A n}{100 V_n} \frac{V_m(\text{std})}{V}$$

$$60.0 V_A n$$

$$19. \quad I = 100 \frac{P_s}{P} \left[(0.002669) V_{lc} + \frac{V_m}{V_n} \left(P_{bar} + \frac{H}{13.6} \right) \right]$$

$$18. \quad V_n = \frac{P_s}{P} \left[(0.002669) (V_{lc}) + \frac{V_m}{V_n} \left(P_{bar} + \frac{H}{13.6} \right) \right]$$

$$17. \quad PMR = (c_s) \left(\frac{Q_B}{7000} \right)$$

$$16. \quad c_{12} = c_B \left(\frac{12}{\% CO_2} \right)$$

$$15. \quad c_{50} = \frac{1 - \left[(1.3) (\%O_2) - 0.133 (\%N_2) - 0.75 (\%CO) \right]}{c_B}$$

$$14. \quad c_s = 0.0154 \left(\frac{V_m(\text{std})}{V_n} \right)$$

SANDERS ENGINEERING & ANALYTICAL SERVICES, INC.

$$22. V_{m(\text{std})} = K_1 Y \frac{V_m P_{\text{bar}}}{T_m}$$

$$23. V_{\text{sc}} = \frac{T_{\text{std}}}{P_{\text{std}}} (V_f - V_a) \left[\frac{P_f}{T_f} - \frac{P_i}{T_i} \right] = K_1 (V_f - 25\text{ml}) \left[\frac{P_f}{T_f} - \frac{P_i}{T_i} \right]$$

$$24. F = \sum_{i=1}^n X_i F_i \text{ or } F_c = \sum_{i=1}^n X_i (F_c)_i$$

$$25. C_{\text{TRS as H}_2\text{S (ppm)}} = K_2 \frac{(V_t - V_{\text{tb}}) N (V_{\text{soln}}/V_a)}{V_m}$$

$$26. C_{\text{TRS as H}_2\text{S (lbs/sdcf)}} = C_{\text{SO}_2} \frac{34.02}{64.06}$$



SANDERS ENGINEERING & ANALYTICAL SERVICES, INC.

NOMENCLATURE

- A_n = Cross-sectional area of nozzle, ft²
- A_s = Area of stack, ft²
- B_{ws} = Water vapor in the gas stream, proportion by volume (dimensionless)
- C_p = Pitot tube coefficient (dimensionless)
- C_s = Particulate concentration, grains/SDCF
- I = Percent of isokinetic sampling
- K_m = Orifice correction factor (dimensionless)
- K_p = Pitot tube constant,
 $85.49 \text{ ft/sec} \left[\frac{(\text{lb/lb-mole}) (\text{in. Hg})}{(^{\circ}\text{R}) (\text{inc. H}_2\text{O})} \right]^{1/2}$
- M_n = Total amount of particulate matter collected, mg
- M_d = Molecular weight of stack gas; dry basis, lb/lb-mole
- M_s = Molecular weight of stack gas; wet basis, lb/lb-mole
- P_{bar} = Barometric pressure at the sampling site, in. Hg
- P_m = Meter pressure, in. Hg
- P_s = Absolute stack pressure, in. Hg
- P_g = Stack static pressure, in H₂O
- P_{std} = Standard absolute pressure, 29.92 in. Hg
- PMR = Particulate mass rate, lb/hr
- Q_a = Volumetric flow rate, ACFM
- Q_s = Volumetric flow rate, SDCFM

SANDERS ENGINEERING & ANALYTICAL SERVICES, INC.

\bar{t}_m = Average temperature of meter, °F

\bar{t}_s = Average temperature of stack, °F

t_{std} = Standard temperature, 68 °F

NOTE: Capital T denotes degrees Rankin

V_s = Average stack gas velocity, ft/sec

V_{lc} = Total volume of liquid collected in impingers and silica gel, ml

V_m = Volume of gas sample as measured by dry gas meter, ACF

$V_{m(std)}$ = Volume of gas sample measured by the dry gas meter,
corrected to standard conditions, SDCF

$V_{w(std)}$ = Volume of water vapor in the gas sample, corrected to standard
conditions, SCF

V_n = Volume collected at stack conditions through nozzle, ACF

Y = Dry gas meter calibration factor (dimensionless)

E = Emission in lbs/mmBTU

$\bar{\Delta H}$ = Average pressure difference of orifice, in. H₂O

Δp = Velocity head of stack gas, in. H₂O

$\sqrt{\Delta p}$ = Average of the square roots of the velocity pressure, in. H₂O^{1/2}

Θ = Total sampling time, minutes

%CO₂, %O₂, %N₂, %CO - Number % by volume, dry basis, from gas analysis.

K_1 = 17.64 °R/in. Hg

F = Oxygen based F factor (9820 SDCF/mmBTU for bituminous coal)

Koppers/Birmingham

08.21.91

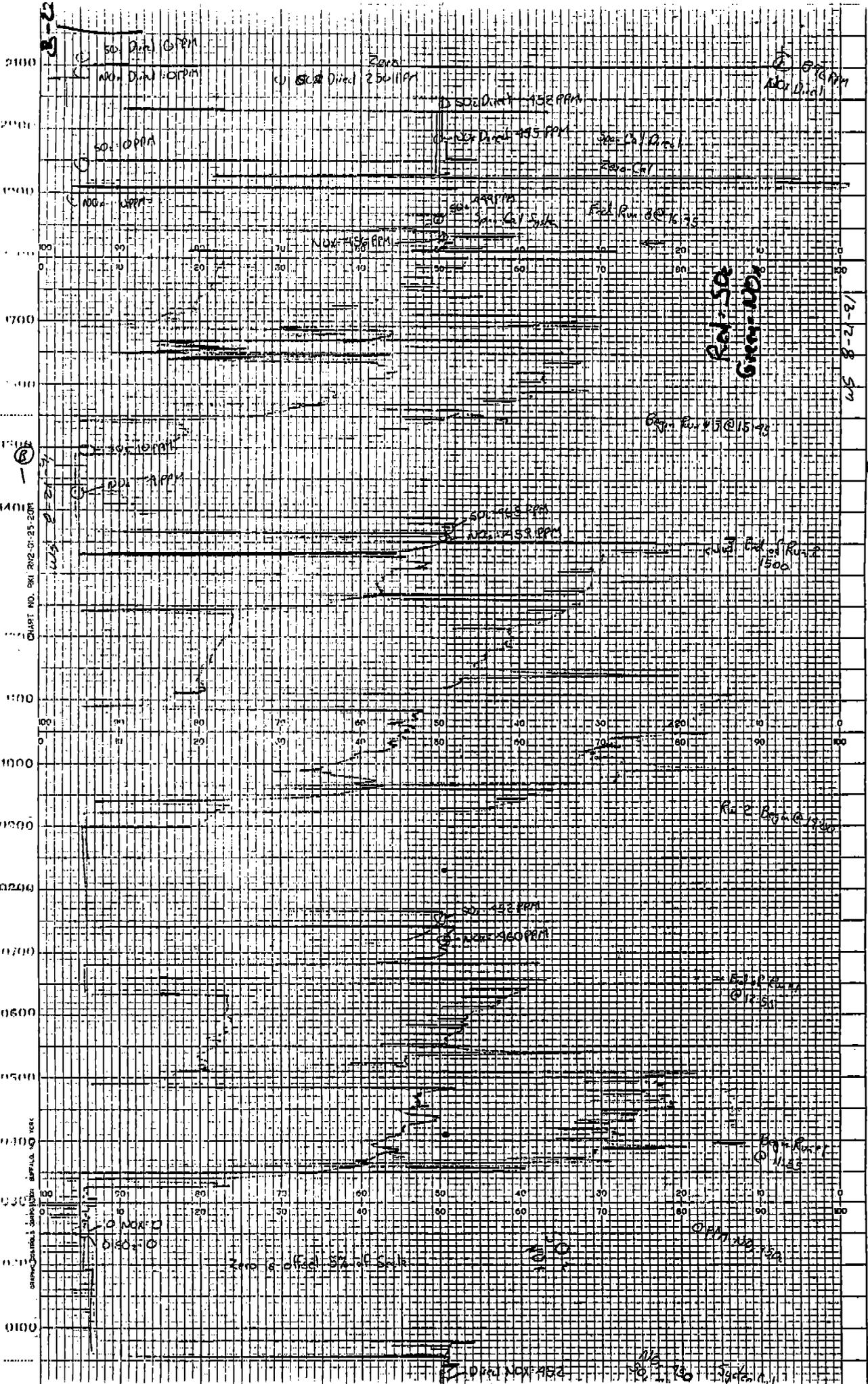
Stack Test O₂ SO₂ NO_x

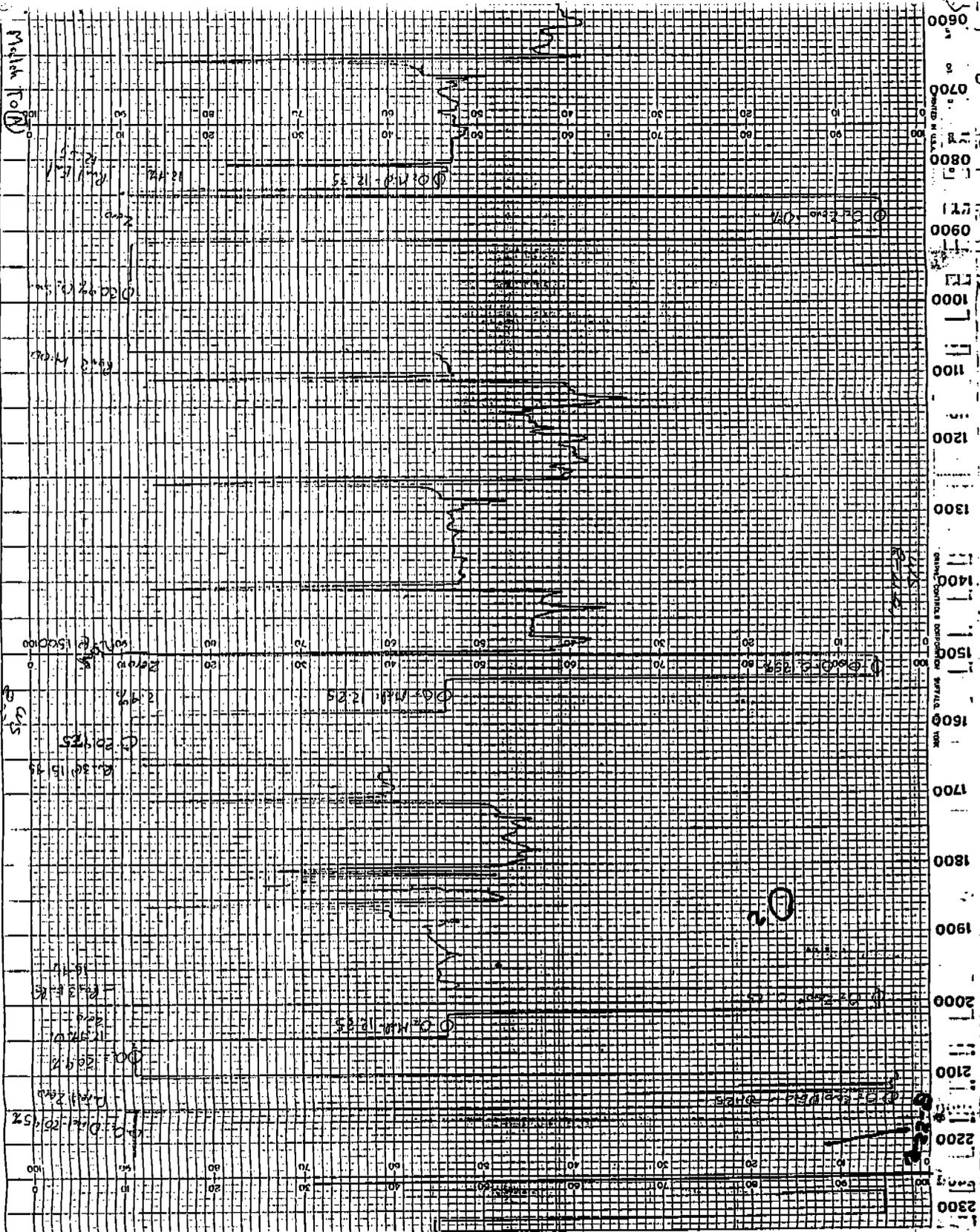
O ₂	<u>0%</u>	<u>12.4%</u>	<u>20.9%</u>
Direct Calibration	0.0	12.425%	20.8%
System Calibration	0.0	12.425%	20.95%
End Run 1	0.0	12.35%	20.975%
End Run 2	0.125	12.25%	20.975%
End Run 3	0.125	12.25%	20.95%
Direct Calibration	-0.125		20.95%

SO ₂ (Red)	<u>0</u>	<u>250</u>	<u>452</u>
Direct Calibration	7	250	452
System Calibration	0		449
End Run 1	8		452
End Run 2	10		465
End Run 3	0		449
Direct Calibration	0	250	452

NO _x (Green)	<u>0</u>	<u>450</u>	<u>876</u>
Direct Calibration	8	452	876
System Calibration	0	452	
End Run 1	8	460	
End Run 2	-4	459	
End Run 3	0	456	
Direct Calibration	0	452	876

Run Averages	<u>O₂ %</u>	<u>SO₂ PPM</u>	<u>NO_x PPM</u>
Run 1	10.423%	555.3 PPM	266.52 PPM
Run 2	10.705%	616.43 PPM	266.28 PPM
Run 3	13.156%	473.52 PPM	232.59 PPM
Average	11.428%	548.4167	255.13





Koppers Birmingham
 08.21.1991
 O₂ Range 0 to 25%
 5% of Scale Zero Offset

KOPPERS INDUSTRY

DOLOMITE, ALABAMA

APPENDIX B: CALIBRATIONS

**INITIAL
METER CALIBRATION FORM - DGM**

DATE: 06-16-91 Box No. C-175

Ref. DGM Ser. #	1044453	Calibrated By		JOSEPH SANDERS		
RUN #		1	2	3	4	5
DELTA H (DGM)	0.50	1.00	1.50	2.00	3.00	
Y (Ref. DGM)	1.00	1.00	1.00	1.00	1.00	
Reference DGM						
Gas Vol. Initial	117.658	130.919	142.064	158.765	169.561	
Gas Vol. Final	130.909	142.064	158.765	169.561	181.230	
Meter Box DGM						
Gas Vol. Initial	723.753	737.414	748.956	766.298	777.540	
Gas Vol. Final	737.414	748.956	766.298	777.540	789.688	
Reference DGM						
Temp.		Avg.	Avg.	Avg.	Avg.	Avg.
Deg F Initial		84	86	88	88	88
Deg F Final		85	86	88	87	89
Meter Box DGM						
Temp. Initial In		97	113	118	124	126
Temp. Initial Out		89	104	110	115	117
Temp. Final In		112	119	126	128	131
Temp. Final Out		104	111	116	119	120
P Bar IN. Hg	30.00	30.00	30.00	30.00	30.00	30.00
Time (sec.)	2207	1258	1530	849	764	
Meter Calibration						
Factor (Y)	0.997	1.009	1.011	1.015	1.014	
Qm (C.F.M.)	0.350	0.515	0.633	0.738	0.885	
Km (Std Pressure)	0.618	0.637	0.635	0.640	0.626	
DELTA Ha	2.17	1.97	1.94	1.89	1.96	
Average Y (Meter Calibration Factor)				1.009		
Average Km (Standard Pressure)				0.631		
Average DELTA Ha of Orifice				1.98		

**FINAL
METER CALIBRATION FORM - DGM**

DATE: 08-23-91 Box No. C-175
 Ref. DGM Ser. # 1044456 Calibrated By CHRIS LEITSCH

RUN #	1	2	3
DELTA H (DGM)	1.0	1.0	1.0
Y (Ref. DGM)	1.000	1.000	1.000
Reference DGM			
Gas Vol. Initial	820.200	826.800	833.300
Gas Vol. Final	826.000	832.700	839.500
Meter Box DGM			
Gas Vol. Initial	567.500	574.200	580.800
Gas Vol. Final	573.400	580.200	587.100
Reference DGM			
Temp.	Avg.	Avg.	Avg.
Deg F Initial	75	83	91
Deg F Final	81	90	98
Meter Box DGM			
Temp. Initial In	74	86	99
Temp. Initial Out	71	83	93
Temp. Final In	85	98	108
Temp. Final Out	81	92	103
P Bar IN. Hg	30.14	30.14	30.14
Time (sec.)	660	650	680
Meter Calibration			
Factor (Y)	0.980	0.987	0.993
Qm (C.F.M.)	0.521	0.530	0.525
Km (Std Pressure)	0.666	0.669	0.656
DELTA Ha	2.04	1.93	1.94

Average Y (Meter Calibration Factor)	0.987
Initial Y (Meter Calibration Factor)	1.009
Percent Error	2.18%
Average Km (Standard Pressure)	0.664
Average DELTA Ha of Orifice	1.97

**INITIAL
METER CALIBRATION FORM - DGM**

DATE: 08-12-91 Box No. D-460

Ref. DGM Ser. #	1044453	Calibrated By			JACK COVINGTON	
RUN #		1	2	3	4	5
DELTA H (DGM)		0.50	1.00	1.50	2.00	3.00
Y (Ref. DGM)		1.00	1.00	1.00	1.00	1.00
Reference DGM						
Gas Vol. Initial		130.000	139.200	166.200	173.900	180.300
Gas Vol. Final		138.300	165.500	173.000	179.400	186.000
Meter Box DGM						
Gas Vol. Initial		345.275	354.595	382.075	389.900	396.375
Gas Vol. Final		353.675	381.360	388.995	395.465	402.082
Reference DGM						
Temp. Deg F Initial		Avg. 86	Avg. 87	Avg. 88	Avg. 88	Avg. 90
Temp. Deg F Final		87	88	88	89	90
Meter Box DGM						
Temp. Initial In		94	100	107	110	111
Temp. Initial Out		92	97	104	104	105
Temp. Final In		100	107	108	110	111
Temp. Final Out		97	104	104	105	105
P Bar IN. Hg		30.17	30.17	30.17	30.17	30.17
Time (sec.)		1221	2783	594	416	354
Meter Calibration Factor (Y)		1.004	1.006	1.011	1.017	1.024
Qm (C.F.M.)		0.397	0.551	0.667	0.770	0.935
Km (Std Pressure)		0.706	0.689	0.679	0.678	0.673
DELTA Ha		1.70	1.75	1.78	1.78	1.81
Average Y (Meter Calibration Factor)					1.012	
Average Km (Standard Pressure)					0.685	
Average DELTA Ha of Orifice					1.76	

**FINAL
METER CALIBRATION FORM - DGM**

DATE: 08-23-91 Box No. D-460

Ref. DGM Ser. # 1044453 Calibrated By JACK COVINGTON

RUN # 1 2 3

DELTA H (DGM) 1.0 1.0 1.0

Y (Ref. DGM) 1.000 1.000 1.000

Reference DGM

Gas Vol. Initial 211.500 226.100 233.600

Gas Vol. Final 226.100 233.600 238.700

Meter Box DGM

Gas Vol. Initial 594.200 608.730 616.265

Gas Vol. Final 608.730 616.265 621.431

Reference DGM

Temp. Avg. Avg. Avg.

Deg F Initial 77 79 80

Deg F Final 79 80 81

Meter Box DGM

Temp. Initial In 77 86 90

Temp. Initial Out 75 84 89

Temp. Final In 86 90 92

Temp. Final Out 84 89 91

P Bar IN. Hg 30.14 30.14 30.14

Time (sec.) 1515 788 536

Meter Calibration

Factor (Y) 1.007 1.007 1.003

Qm (C.F.M.) 0.572 0.563 0.562

Km (Std Pressure) 0.728 0.713 0.709

DELTA Ha 1.69 1.72 1.71

Average Y (Meter Calibration Factor) 1.006

Initial Y (Meter Calibration Factor) 1.012

Percent Error 0.59%

Average Km (Standard Pressure) 0.716

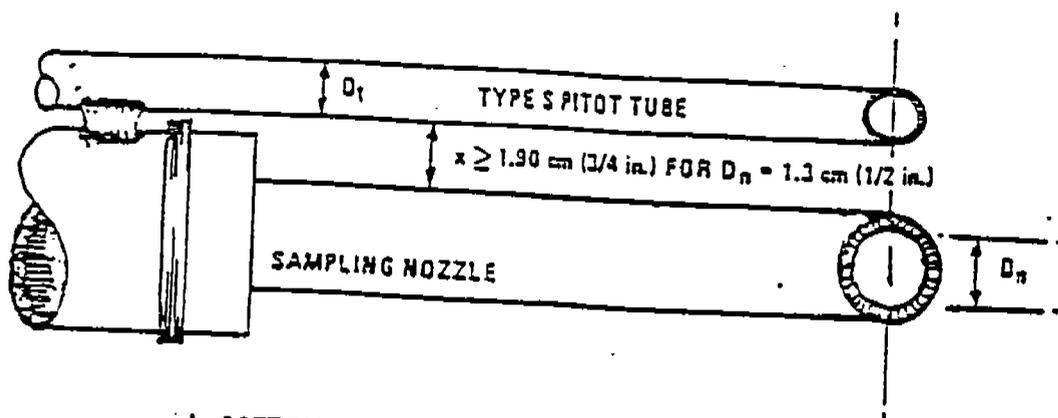
Average DELTA Ha of Orifice 1.71

MAGEHELIC CALIBRATION

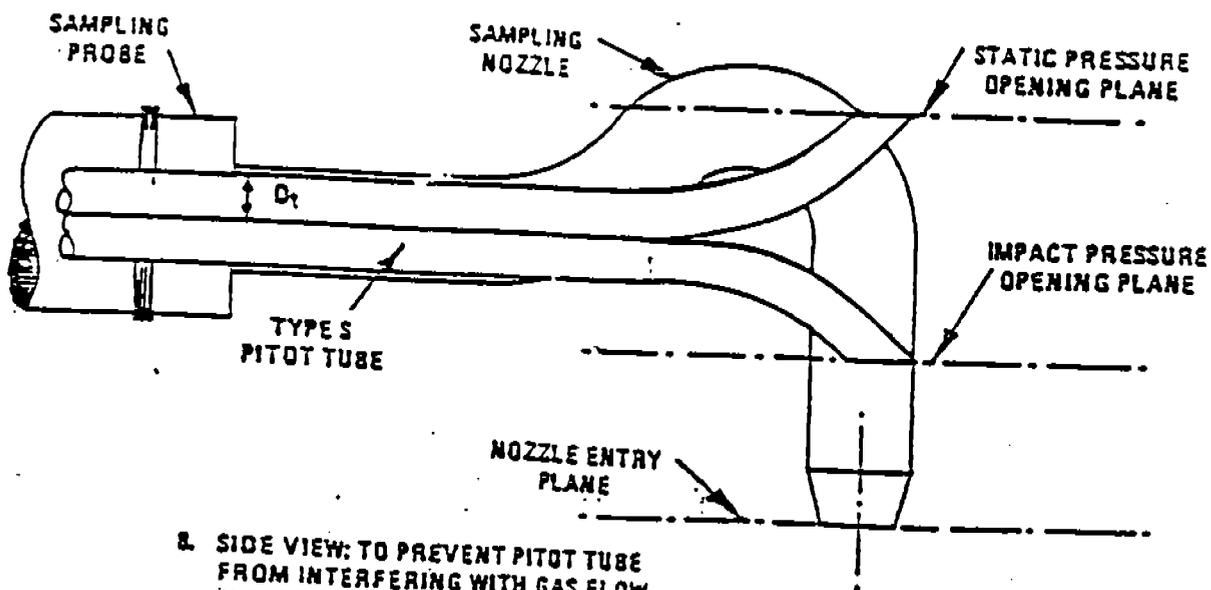
SER. NO.	10720- AB68	R1061- 6AG48	R5031- SEB76	R1062- 9JA82	R1051- 3MR42	R1071- JA8
RANGE	0-.25	0-.50	0-2	0-5	0-10	0-25
REFERENCE READING	FIELD DEVICE READING					
BOX #1						
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.05	0.05					
0.10	0.110	0.11				
0.200	0.210	0.210				
0.400		0.400				
0.500			0.500			
1.000			0.990	1.000		
1.500			1.490			
2.000				2.000	2.000	
3.500				3.490		
5.000					4.800	5.000
8.00					7.80	
10.00						10.00
20.00						19.95

DATE: 07-08-91

SIGNATURE: *Robert Richman*



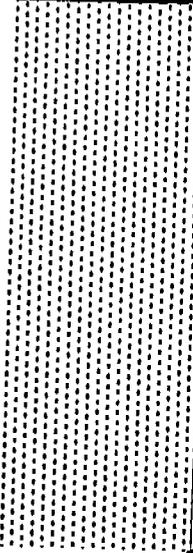
A. BOTTOM VIEW; SHOWING MINIMUM PITOT-NOZZLE SEPARATION.



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

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

**MAGNEHELIC CALIBRATION
BOX #5**

SERIAL NO.	R900723MRR1	R901003CD87	R901119RR106			
RANGE	0 - 0.5	0 - 5	0 - 25			
* REFERENE READING TAKEN FROM OIL GAGE MANOMETER						
	*REF.	ACTUAL	*REF.	ACTUAL	*REF.	ACTUAL
	0.50	0.49	5.00	5.00	20.0	20.0
	0.30	0.30	3.00	2.95	15.0	15.0
	0.20	0.20	2.00	1.95	10.0	10.0
	0.10	0.09	1.00	1.00	5.00	5.00
	0.00	0.00	0.00	0.00	0.00	0.00

DATE: 7-8-91

SIGNATURE: Robert Richman

29

MAGNEHELIC CALIBRATION

BOX #	D-460		C-133		C-173		C-175	
	R01123TC2				R10608CF14		R10831CF80	
SER. NO.	91127WW137		91126AM91		R20208A617		R01126YC2	
RANGE	0-2	0-5	0-2	0-5	0-2	0-4	0-2	0-4
REFERENCE READING	FIELD DEVICE READING							
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.50	0.50	0.00	0.50	0.00	0.51	0.00	0.00	0.00
1.00	0.99	0.00	0.99	0.00	1.01	0.00	0.00	0.00
1.75	1.74	0.00	1.77	0.00	1.73	0.00	0.00	0.00
3.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

DATE: 07-08-91

SIGNATURE: Robert Richman

TEMPERATURE CALIBRATIONS - DEGREES FAHRENHEIT

REFERENCE DEVICE READING*	Date Calibrated	0 DEG. F	210 DEG.	420 DEG.	630 DEG.	840 DEG.	1050 DEG.	1260 DEG.	1470 DEG.	1680 DEG.	1900 DEG.
METER BOX C-133 11580	07-09-91	0	209	412	626	836	1048	1260	1467	1680	1905
METER BOX C-175 15962	06-16-91	0	208	415	622	831	1041	1251	1457	1674	1901
METER BOX C-173 S11-24	06-15-91	2	211	419	627	836	1047	1258	1465	1680	1906
METER BOX D-460 15751	06-16-91	0	208	418	624	834	1046	1256	1463	1675	1901
METER BOX 2879	06-21-91	0	211	421	631	840	1050	1260	1471	1681	1901
PORTABLE THERMOCOUPLE # 1 249662	07-08-91	-2	209	418	631	839	1049	1258	1469	1680	1900
PORTABLE THERMOCOUPLE # 2 T-05792	07-08-91	2	211	419	630	847	1060	1284	1489	1707	1918
PORTABLE THERMOCOUPLE #3 T-61422	07-08-91	1	208	415	625	840	1057	1272	1482	1685	1894

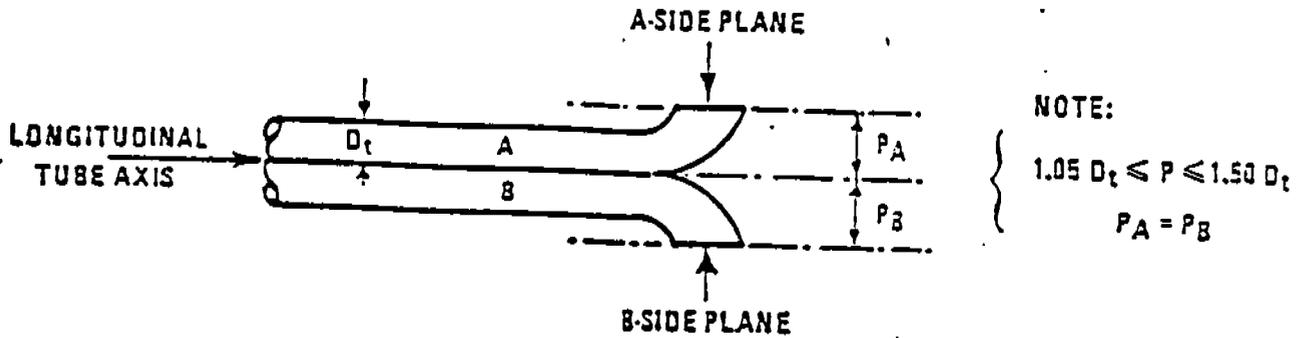
SIGNATURE: *Robert Richman*

* Reference Device is an Omega Engineering CL505-A calibrated reference thermocouple-potentiometer system.

PITOT CALIBRATIONS

The Pitot used was within the following geometric specifications:

$$C_p = 0.84$$



NOTE:

$$1.05 D_t \leq P \leq 1.50 D_t$$

$$P_A = P_B$$

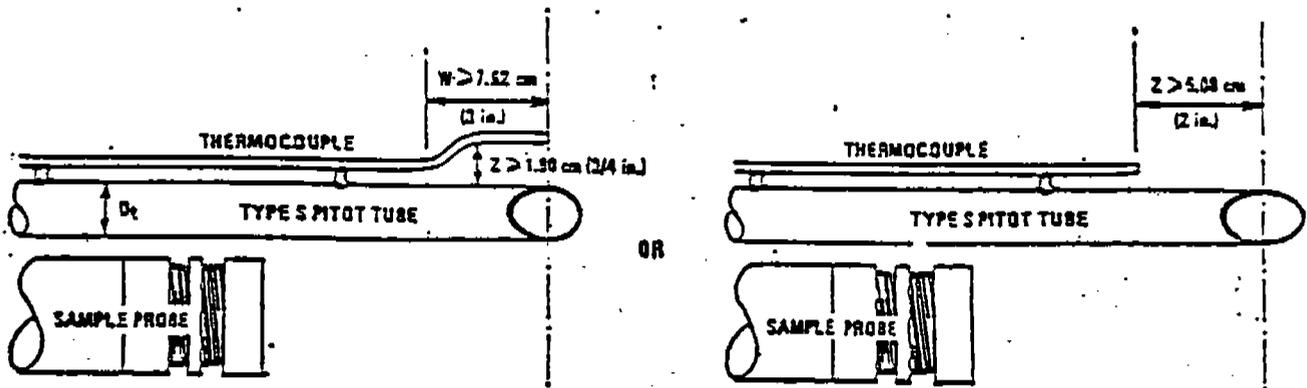


Figure 2-7. Proper thermocouple placement to prevent interference; D_t between 0.48 and 0.95 cm (3/16 and 3/8 in.).

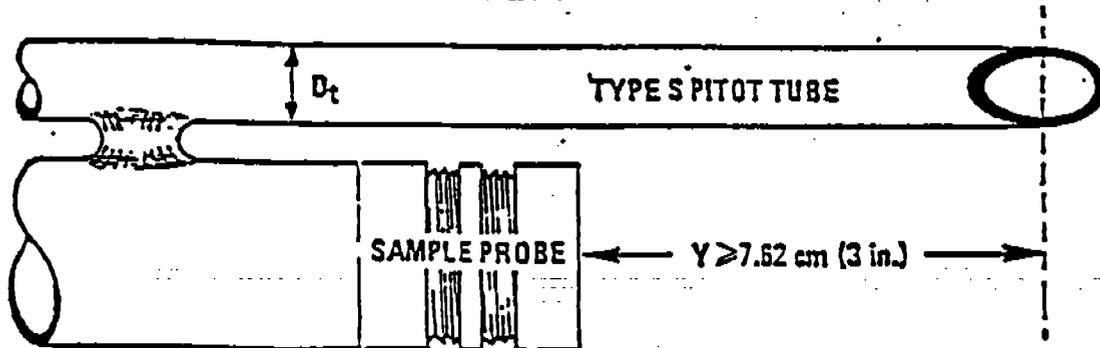
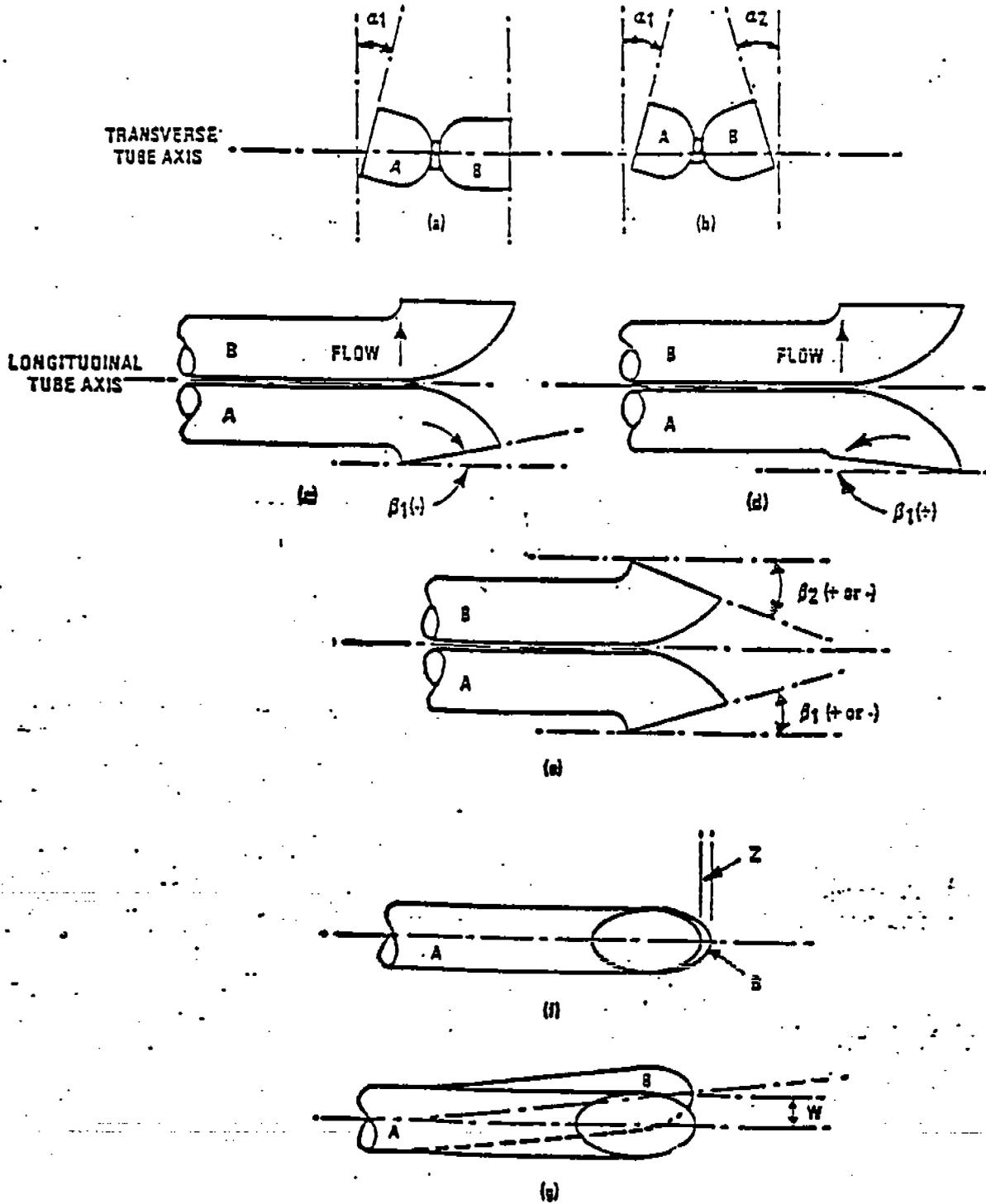
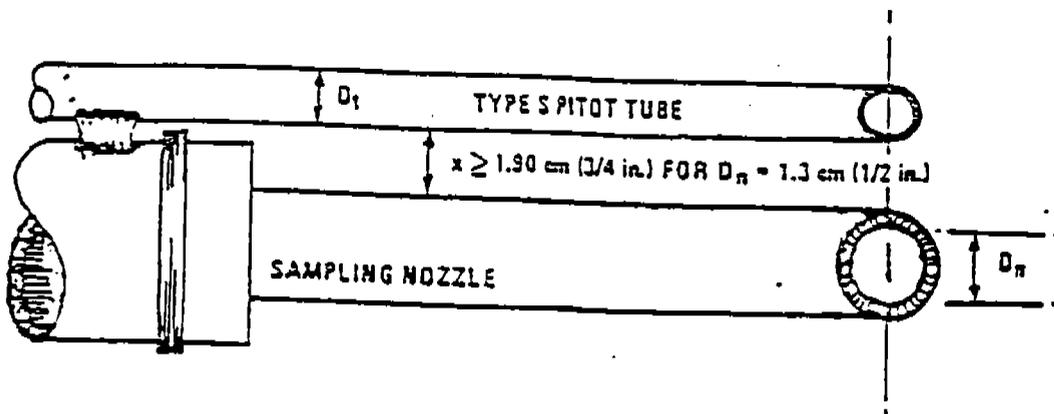


Figure 2-8. Minimum pitot-sample probe separation needed to prevent interference; D_t between 0.48 and 0.95 cm (3/16 and 3/8 in.).

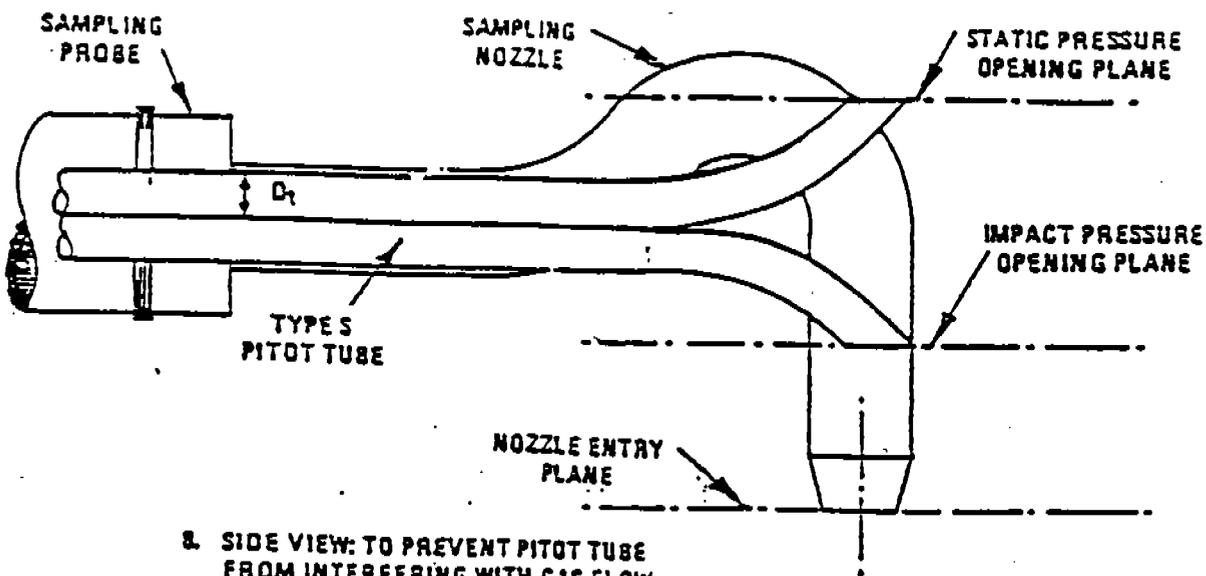
PITOT CALIBRATIONS



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



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



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

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

MAGNEHELIC CALIBRATION

Ser. No.	10819-DR2	R1090-2AG18	R50315-EB93	R1062-9TA87	30830-AM79	R1072-2MC5	
Range	0-.25	0-.5	0-2	0-5	0-10	0-25	

Reference Reading	Box #2	Field Device Reading					
0.00	0.00	0.00	0.00	0.00	0.00	0.00	
0.05	0.05						
0.10	0.10	0.10					
0.20	0.20	0.20					
0.40		0.40					
0.50			0.50				
1.00			1.00	0.92			
1.50			1.49				
2.00				1.90	2.00		
3.50				3.40			
5.00					4.95	4.80	
8.00					8.05		
10.00						10.20	
20.00						20.20	

Date: 7-8-91

Signature: *Robert Richman*

**MAGNEHELIC CALIBRATION
BOX #3**

SERIAL NO.	R10831CF80	R01126TC2	R10608CF14			
RANGE	0 - 0.5	0 - 2	0 - 10			
* REFERENE READING TAKEN FROM OIL GAGE MANOMETER						
REFERENCE READING FROM OIL GAGE MANOMETER	* REF.	ACTUAL	* REF.	ACTUAL	* REF.	ACTUAL
	0.50	0.50	2.00	1.99	10.0	10.0
	0.30	0.29	1.50	1.49	8.00	8.00
	0.20	0.20	1.00	0.99	5.00	5.00
	0.10	0.09	0.50	0.49	2.00	2.00
	0.00	0.00	0.00	0.00	0.00	0.00

DATE: 7-8-91

SIGNATURE: Robert Richman