Appendix D

Heat Pipe Performance Evaluation Test Procedure

McCoy, D. C., “Heat Pipe Performance Evaluation And Acceptance Testing,” Equipment test procedure prepared by CONSOL R&D for NYSEG, New York State Electric & Gas Corporation, Binghamton, New York, April 1996.

HEAT PIPE PERFORMANCE EVALUATION AND ACCEPTANCE TESTING—TEST PROCEDURE

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HEAT PIPE PERFORMANCE EVALUATION AND ACCEPTANCE TESTING

1.0 Introduction

A heat pipe air preheater was installed on the Milliken Station Unit 2 boiler. Tests will be conducted to determine if performance guarantees are met and to establish performance in both unfouled and fouled conditions. Unfouled condition tests will be tests conducted when ABB/API engineers approve the heat pipe operating condition. Fouled condition tests will normally be conducted about six months or later after a clean condition start-up, but may be conducted earlier in anticipation of a unit shutdown if day-to-day monitoring indicates significant thermal performance decline. All tests will be conducted only after stable operation of the boiler is achieved.

2.0 System Description

The Milliken Station Unit 2 is a tangentially-fired bituminous coal boiler with a full load operating point of normally 150 MW_{net}. Unit 2 was retrofitted with low-NO_x burners and with two flue gas-to-air heat pipe heat exchangers for air preheat. The heat pipe air preheaters are expected to improve the Unit 2 thermal performance by operating at lower flue gas outlet temperatures and by eliminating the air leakage associated with the operation of the original Ljungstrom air preheaters. Additionally, since metal temperatures in heat pipes are uniform across a tube, air preheater corrosion is expected to be low for a 250°F flue gas outlet temperature.

3.0 Performance Guarantee Requirements

There are three heat pipe performance guarantees to be met:

(1) A heat pipe flue gas zero air leak outlet temperature of 253°F or lower when:

Flue Gas Input Rate	1,500,000 lb/hr
Flue Gas Inlet Temperature	680°F
Primary Air Rate To Heat Pipe	125,000 lb/hr
Secondary Air Rate	1,125,000 lb/hr
Air Inlet Temperature	80°F

(2) Full Load Pressure Drops not exceeding:

Air Side	5.35" W.C.
Flue Gas Side	3.65" W.C.

(3) Zero air leakage.

To establish if the unit meets the thermal performance guarantees at design conditions, the heat pipe tests will be conducted in accordance with ASME Performance Test Code 4.3 (PTC 4.3). The code provides a standard procedure for calculating and applying flow and temperature corrections for deviations from design conditions. Corrections are made for deviation from design for: inlet flue gas temperature, inlet air temperature, X-ratio, and inlet flue gas flow. After applying the corrections, if the totally corrected outlet flue gas temperature is less than or equal to the design outlet temperature, the exchanger meets design. If the corrected outlet temperature is greater than design (plus any NYSEG-ABB/API agreed-upon tolerance) the performance does not meet design.

For the initial performance test, it will be assumed that the heat pipe meets the zero air leak guarantee. This assumption is made because the individual heat pipe tubes are welded at the flue gas/air partition wall, and the tube modules are all seal welded together. There will be some air leak at the sootblower wall penetrations. Plans are to quantify the total air leakage based on overall inlet and outlet flue gas compositions as described in test code PTC 4.3. The leakage will be ascribed to as sootblower leaks. If, however, the overall leakage appears to be excessive, (i.e., >2.5 wt % of entering flue gas flow), NYSEG reserves the right to revisit with ABB/API the guarantee issue of zero air leak.

4.0 Test Objectives

Heat pipe performance tests will be conducted to establish if performance guarantees are achieved. Additional tests will be conducted to quantify any performance decline due to fouling and performance recovery following water washing cleanup. For performance tests, the main objectives are to:

(1) Measure thermal performance at full load (145-150 MW net) and optionally, low load (90-100 MW net) conditions.

(2) Measure primary air side, secondary air side, and flue gas side pressure drops at full load.

CONSOL R&D will be responsible for conducting the heat pipe performance tests and will coordinate efforts to establish test block periods and operating conditions with NYSEG and ABB/API. Low load tests are optional and will be conducted depending upon load availability. When acceptance tests are conducted, an ABB/API designated representative will determine and certify if the overall condition of the unit is acceptable for testing. Before a test is conducted the boiler load, excess air levels, and air flow rates through the heat pipe will be stabilized at target levels and then held constant during the test. It is anticipated that boiler load will be held within ±3% (15 minute average) and excess oxygen at the economizer outlet at ±0.3% absolute (15 minute average) of target levels. Tests will not be rejected due to load variation if variation is less than ±5% of target load.

5.0 Test Methods, Assumptions and Instrumentation

5.1 Coal Samples. Tests will be conducted only after boiler operations are stable and without oil support. The test code requires calculation of the flue gas rate to the heat pipe. For this the coal rate and ultimate analysis are needed. When the heat pipes are tested, a CONSOL employee(s) will be assigned to collect coal samples every 20-30 minutes until at least 15 increments have been collected (ASTM D-2234). The samples will be composited and riffled down to proper size for analysis. The samples will be retained in airtight containers to prevent moisture loss. CONSOL will determine moisture, C, H, N, S, ash, O (by difference) and higher heating value, (HHV), using standard or modified ASTM methods (i.e., ASTM D-5142 for moisture and ash; ASTM D-5373 for C, H, and N; ASTM D-4239 Method C for S and ASTM D-2014 for HHV).

5.2 Coal Feed Rate. Four calibrated gravimetric coal feeders supply coal to the Unit 2 boiler with the feed rate monitored by the WE-DPC system. NYSEG will be responsible for coal feeder calibrations. During testing, coal feed rates will be obtained from computer logs.

5.3 Refuse Rate and Composition. The test code requires calculation of the carbon burned per pound of "as-fired" coal. Unburned carbon remains with various refuse streams (i.e., bottom ash, dust collector ash, boiler back pass hopper solids, mill rejects). The amount of unburned carbon is calculated from the refuse rate and the refuse heating value converted to carbon equivalent (i.e., refuse rate, lb/lb "as-fire" coal x HHV, BTU/lb ÷ 14500 BTU/lb C). For the purpose of the air heater performance tests, refuse rates will be estimated from the coal feed rate and ash percent with the following assumed partitioning:

Fly Ash	90%
Bottom Ash	10%
Mill Rejects	0%

The partitioning recommendation is based on data from the Chemical Emission Inventory Testing program conducted during May 1994 and conversations with NYSEG personnel. The test program results indicate high fly ash carry over (i.e., >85% of total ash). Carbon contents of the overhead ashes averaged 3.63 wt % which was slightly more than three times the carbon content of the bottom ash. Since new mills installed at Milliken are operated to produce a finer grind for the new low-NO_x burners, higher fly ash carry over from the boiler is expected; so the 90% carry over should be a reasonable approximation.

Zero mill rejects will be assumed since plant personnel report little or no mill rejects (i.e., ≤"25 gallons/week").

Approximately every 1.5 to 2 hours, the boiler back pass and ESP ash hoppers are pneumatically emptied with the fly ash conveyed to the dry ash silo. During each heat pipe performance test, samples of fly ash will be obtained using the continuous ash sampler located above the ash silo. The sampler uses an eductor to extract ash solids from the ash conveying line into a cyclone/bagfilter collector. The continuous sampler will be put into operation before an ash hopper unloading cycle begins and shut off after the cycle is completed. The sample will be used to determine the carbon in ash content.

The heating value of the overhead fly ash will not be measured in a bomb calorimeter because of low combustible content. The fly ash sample will be analyzed for moisture, C, H, and CO_2 using ASTM methods D-5142 for moisture; D-5373 for C (NIST low carbon standard) and H; and coulombmetric titration for CO_2. The carbon content will then be adjusted for the CO_2 and the H for moisture H if necessary. The heating value for the overhead refuse will be estimated by:

$$HV_O = 145C_O + 610H_O \qquad \textbf{(1)}$$

Where:

HV_O = *Higher Heating Value of Overhead Flyash, BTU/lb*

C_O = *Overhead Flyash Carbon Content, wt %*

H_O = *Overhead Flyash Hydrogen Content, wt %*

The bottom ash percent carbon and heating value will be assumed to be one-third that of the overhead fly ash. The total carbon free refuse rate will be calculated from the measured coal rate and the "as-fired" coal ash percent.

5.4 Ashpit Steam Production. This term will be neglected in the calculation of the flue gas rate.

5.5 Heat Pipe Pressure Drop Air side and flue gas side pressure drops will be measured using liquid filled manometers. During a test, the pressure drops will be manually recorded ever 15 minutes. Special taps per ABB/API design have been installed on each heat pipe for manometer connections. At each sensing location (i.e., high side or low side for manometer hookup), two taps are employed. The taps will be configured as a "Y" using plastic or rubber tubing to form a single sensing line. The use of two taps helps reduce the chance of signal loss due to plugging. The pressure drops (DPs) which will be measured are: DP across the primary air section, DP across the secondary air section, and DP across the flue gas section.

5.6 Temperature Measurements. Flue gas and air temperatures around the heat pipes will be determined by temperature velocity traverses of the ductwork in accordance with PCT 4.3 (Section 5) recommendations. Velocity heads will be measured using type S pitot tubes. Operation of the pitot probes is described in Attachment 1. The pitot tubes will be constructed and calibrated as described in EPA Method 2. Shortridge Air Data Multimeters (high accuracy electronic manometers) will be used to measure the velocity head differential pressures. Each measurement will be an instrument averaged value of 10 readings.

Temperature/velocity probe thermocouples (TCs) will be made from 0.4% accuracy, 20 gage, Type K thermocouple wire. The junctions will be formed by twisting the ends of the TC wire together three times, fusing a bead using an oxy-acetylene torch, and then untwisting the wire ahead of the junction bead to prevent parallel junctions. Each TC will be calibrated against a National Institute of Standards and Technology (NIST) TC over the expected range of operation (Attachment 2). A TC will be considered acceptable if the readings are within ±2°F.[1]

Traverse plane temperatures will be calculated as weighted averages using the following equation:

$$\overline{T} = \frac{\sum_{i=1}^{n} A_i V_i \rho_i T_i}{\sum_{i=1}^{n} A_i V_i \rho_i} \qquad \textbf{(2)}$$

Where:

A_i = *Area Of Cross Section Element i, ft*^{2}

i = *Traverse Point Number*

n = *Total Number Of Traverse Elements*

T_i = *Temperature In Area Element i,* ° *R*

$\overline{T}$ = *Average Temperature Across Duct,* ° *R*

V_i = *Actual Gas Velocity In Area Element i, acf*/sec

ρ_i = *Wet Flue Gas Density, lbs/ft*^{3}

The velocity and density terms in equation 2 are:

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[1] Shigehara, R. T., and Stewart, E. W.: *"Simplified Thermocouple Calibration Procedure,"* Source Evaluation Society Newsletter, Vol. XVIII, No. 3, August 1994.

$$V_i = 85.49CP\left(\frac{DP_iT_i}{P_{sf}M_i}\right)^{1/2} \tag{3}$$

$$\rho_i = \frac{M_fP_{si}}{RT_i} \tag{4}$$

Where:

CP = *Pitot Tube Flow Coefficient, Dimensionless*

DP_i = *Velocity Head In Area Element i, in. WC*

M_i = *Wet Gas Mol Wt. In Area Element i, lbs/lb mol*

P_{si} = *Static Pressure In Area Element i, in. Hg*

R = *Gas Constant*, 0.04578 $(in.\ Hg)(ft^3)/(lb\ mol)(°\ R)$

By substituting Equations 3 and 4 into Equation 2 and collecting terms, the following final equation for average temperature is obtained:

$$\overline{T} = \frac{\sum_{i=1}^{n} A_i(DP_fM_fP_{si}T_i)^{1/2}}{\sum_{i=1}^{n} A_i\left(\frac{DP_fM_fP_{si}}{T_i}\right)^{1/2}} \tag{5}$$

<u>5.7 Flue Gas Rate and Analyses</u>. The flue gas rate per pound of "as-fired" coal will be calculated using the measured coal feed rate, coal and refuse compositions, combustion air moisture content and weighted flue gas composition. For each heat pipe, inlet/outlet measurements of velocity, temperature, and gas compositions will be made simultaneously using specially constructed gas sampling/pitot/TC probes. Multi-point traverses will be used to obtain weighted average duct velocities, temperatures, and gas compositions.

Gas samples will be withdrawn from the process streams using special Teflon™ lined diaphragm pumps. The sampling train will be similar to that shown in Figure 1. The procedure for taking gas samples from the flue gas ducts is provided in Attachment 3.

To insure that the gas samples are dry when analyzed, an ice bath impinger train will be used ahead of the analyzers. Final moisture removal occurs within the analyzers which are equipped with internal desiccant/sorbent beds. The desiccant/sorbent beds will be replaced when color indicators indicate depletion.

Before gases are sampled, the sampling train including probe will be leaked checked per EPA Method 3 procedure. For the leak check, the inlet to the stainless steel sampling probe will be plugged and a 10"-15" Hg vacuum will be pulled on the system. With the pump suction inlet valve closed and the pump off, the system will be considered acceptable if the vacuum does not change for 30 seconds. The gas sampling bags will also be checked for leaks prior to testing. This will be done per EPA Method 2 by letting air filled bags stand over night to determine if the bags deflate. Bags showing any sign of deflation will not be used.

Because of high accuracy, rapid response and ease of use, an electronic Teledyne Max 5 combustion gas analyzer will be used for measurement of dry flue gas oxygen (O_2), carbon monoxide (CO) and % combustibles. The unit will be calibrated using air and a low O_2 standard gas (nominally 3.5 vol % O_2, 100 ppm CO, 0.5 vol % CH_4, bal N_2). The flue gas percent combustibles will be ignored in the performance calculations since the levels are expected to be less than 0.1%. If the average level is higher, NYSEG will be asked to adjust boiler operations to reduce the combustibles below 0.1% before the heat pipe is tested.

Orsat analysis using a 100 ml burette will verify the performance of the gas analyzers on site. The Orsat analysis will be conducted as described in EPA Method 3. The O_2 analyzer will be considered correct if it agrees within 0.1 vol% of the Orsat value. Because of the large number of traverse points required for weighted average gas compositions (20 for each flue gas inlet duct, 24 for each outlet duct) and the time required per analysis (approximately 10 minutes), Orsat measurements will only be used to spot check the electronic analyzer readings. The Orsat CO_2 readings along with the corresponding O_2 and CO readings will be used to construct a fuel line on three component dry flue gas volumetric combustion chart paper (see Figure 2). In constructing the fuel line, an effort will be made to obtain Orsat measurements at two widely different O_2 levels. For traverse points where Orsat measurements are not made, CO_2 values will be taken from the plotted fuel line.[2]

Average gas compositions will be calculated by:

$$\overline{X} = \frac{\sum_{i=1}^{n} A_i V_i (1 - M_{FGi}) X_i}{\sum_{i=1}^{n} A_i V_i (1 - M_{FGi})} \qquad (6)$$

[2] Proposed procedure agreed to between ABB Air Preheater and CONSOL R&D. Telephone conversation between C. L. Bledsoe, D. E. Gorski and D. C. McCoy, 12/5/94.

Where:

A_i = *Area Of Cross Section Element i, ft^2*

M_{FGi} = *Flue Gas Moisture In Area Element i, Mol Fraction*

X_i = *Individual Component Concentration (i.e. O_2, CO_2, or CO) In Area Element i, Vol % (Dry)*

V_i = *Duct Velocity In Area Element i Corrected To* *<u>Standard</u> Conditions, scf*/sec

$\overline{X}$ = *Average Inlet Or Outlet Component Concentration, Vol % (Dry)*

The velocity terms in Equation 6 are defined by:

$$V_i = 85.49CP\left(\frac{DP_iT_i}{P_{si}M_i}\right)^{1/2}\left(\frac{P_{si}}{29.92}\right)\left(\frac{520}{T_i}\right)$$

$$= 1485.8CP(P_{si})^{1/2}\left(\frac{DP_i}{M_iT_i}\right)^{1/2} \quad \textbf{(7)}$$

Substituting Equation 7 into Equation 6 gives:

$$\overline{X} = \frac{\sum_{i=1}^{n} A_i\left(\frac{DP_iP_{si}}{M_iT_i}\right)^{1/2}(1 - M_{FGi})X_i}{\sum_{i=1}^{n} A_i\left(\frac{DP_iP_{si}}{M_iT_i}\right)^{1/2}(1 - M_{FGi})} \quad \textbf{(8)}$$

The flue gas moisture in each traverse point area will not be measured directly; rather it will be calculated using the coal feed composition, ambient air moisture content, dry gas composition in traverse area, and carbon in ash content. If:

m_f = *Coal Moisture, lbs/lb As Fired (A.F.) Coal*

C = *Coal Carbon, lbs/lb A.F. Coal*

H = *Coal Hydrogen, lbs/lb A.F. Coal*

N = *Coal Nitrogen, lbs/lb A.F. Coal*

S = *Coal Sulfur, lbs/lb A.F. Coal*

O = *Coal Oxygen, lbs/lb A.F. Coal*

A = *Coal Ash, lbs/lb A.F. Coal*

C_b = *Carbon In Ash (Refuse), lbs/lb A.F. Coal*

CO = *Flue Gas Carbon Monoxide Level, Vol % (dry)*

CO_2 = *Flue Gas Carbon Dioxide Level, Vol % (dry)*

O_2 = *Flue Gas Oxygen Level, Vol % (dry)*

Wma = *Air Moisture, lbs/lb Bone Dry Air*

and

$$K_3 = \frac{C_b + \frac{12.01S}{32.07}}{12.01(CO_2 + CO)} \quad (9)$$

$$K_4 = 8.936H + Wma\left[\frac{28.02(100 - CO - CO_2 - O_2)K_3 - N}{0.7685}\right] + m_f \quad (10)$$

Then the moisture in the flue gas is:

$$M_{FGi} = \frac{0.055506K_4}{0.055506K_4 + 100K_3} \quad (11)$$

Additionally, the flue gas mol weight in each traverse area is:

$$M_i = \frac{18.016K_4 + K_3(288.08CO_2 + 71.70O_2 + 50480.8)}{K_4 + 1801.6K_3} \quad \textbf{(12)}$$

Ambient air moisture will be measured during each test using a sling psychrometer and a psychrometer chart.

6.0 Test Protocol

6.1 Pre-Test System Setup If plant operations allow, testing will be scheduled to normally begin around 9:00 a.m. each day. NYSEG operations will be requested to bring the Unit 2 boiler to the desired load (normally 148-150 MW_{net}) by 7:00 a.m. and stabilize the operation. Both heat pipes will then be sootblown and the sootblowers shut out of service for the test duration. Between 8:00 and 9:00 a.m. NYSEG, ABB/API, and CONSOL will review the operation of the boiler to determine if the operation is stable prior to testing. Stable operation will be established for at least one hour before a test begins. Suggested criteria for stability are:

(1) Boiler load swing less than ±3% of target load.

(2) Economizer outlet oxygen level variation less than ±0.3% (absolute) of the target level (target likely to be typically 3.5 to 4.0% O_2).

(3) Coal feed rate stable with variation less than ±5%.

(4) Main steam flow stable with variation less than ±5%.

(5) Individual heat pipe average inlet flue gas temperature stable with variation less than ±10°F. (Average temperature determined by simple mean of TE-5207A-J for 'A' heat pipe, and TE-5208A-J for 'B' heat pipe.)

The boiler will be operated in a fashion consistent with maintaining NO_x emission requirements and sufficient carbon burnout to maintain marketable fly ash. Primary air rates will be adjusted to assure proper coal grinding and drying. No effort will be made to fine tune the boiler to achieve design air and flue gas rates and inlet temperatures. Instead, the heat pipe performance evaluation will take into account differences between actual operating conditions and design conditions by applying appropriate correction factors which are described by the PTC 4.3 Test Code. As part of the test code requirements, ABB/API has provided performance correction charts. These charts will be used to determine corrected flue gas outlet temperatures for deviations from design flue gas flow and design X-ratio. As mentioned in Section 4.0, before the performance test is conducted, the authorized ABB/API representative will determine and certify overall unit operation is acceptable for testing.

Boiler load will be held constant over the test period. The secondary air by-pass damper will be completely closed so that all the air flow passes through the heat pipe (see Figure 3). ABB/API will supply a hot wire anemometer and confirm zero air flow through the bypass. Guarantee performance tests will not be conducted if there is measurable secondary air bypass flow. Should damper adjustment not eliminate air leakage across the secondary air damper, ABB/API and NYSEG will be responsible for correcting the situation.

For any non-guarantee performance tests in which secondary air bypass is purposefully used, the outlet secondary air temperature must be corrected. Correction is required since the bypassed air combines with the heated air prior to where outlet temperature measurements can be made. The following equation will be used to estimate the actual temperature of the secondary air exiting the heat pipe:

$$T'_{SAO} = T_{SAO} + \frac{W_{BP} C_{P_{BP}} (T_{SAO} - T_{BPI})}{(W_{SAO} - W_{BP}) C_{P_{SA}}} \quad \textbf{(13)}$$

Where:

$C_{P_{BP}}$ = *Average By-passed Air Specific Heat From* T_{BPI} *to* T_{SAO}, *Btu/lb-°F*

$C_{P_{SA}}$ = *Average Secondary Air Specific Heat From* T_{SAO} *to* T_{SAO}, *Btu/lb-°F*

W_{SAO} = *Secondary Air Flow At Outlet, lb/lb A.F. Coal*

W_{BP} = *Bypass Air Flow, lb/lb A.F. Coal*

T'_{SAO} = *Corrected Secondary Air Outlet Temperature, °F*

T_{SAO} = *Secondary Air Outlet Temperature, °F*

T_{BPI} = *Bypass Air Inlet Temperature (Same As Secondary Air Inlet Temperature To Heat Pipe), °F*

When the secondary air bypass is zero, Equation 13 reduces to T'_{SAO} equals T_{SAO}.

As a general practice, the ideal gas specific heats presented in: Smith, J. M., and Van Ness, H. C., *Introduction To Chemical Engineering Thermodynamics*, p. 120, McGraw-Hill Inc., New York, 1959, will be used for calculations throughout the test program. The reference provides equations for specific heats at specified temperatures. These equations will be integrated over the temperature ranges of interest to obtain average specific heats for the performance calculations.

6.2 Air leakage Measurement As mentioned in Section 3.0, unless the air leakage is excessive (i.e., greater than 2.5 wt % of entering flue gas flow) the air leakage will be ascribed to leaks at the sootblower wall penetrations. The Test Code procedure is to determine the air leakage from calculated flue gas inlet and outlet rates based on the coal analysis, carbon in the ash, and inlet/outlet gas compositions. The air leakage is reported as a weight percent of the inlet flue gas rate. Before a performance test begins, the air supply to the sootblowers will be blocked out of service and tape will be placed over the small air purge valves on each sootblower. The only air leaks into the heat pipes should then be at the sootblower wall penetrations.

6.3 Flue Gas Flow Split Between Heat Pipes. Figure 4 schematically shows the boiler/heat pipe configuration with flue gas split between the two heat pipes. Since Code calculations are generally on a per lb of as fired coal basis, the coal burned on each side of the boiler needs to be estimated. This will allow proper calculation of the primary air rate per lb of as fired coal from the measured primary air flow. The flow split between the two heat pipes and the coal burn split in the boiler will be based on CO_2 flow rates to each heat pipe. The CO_2 flow rates will be determined based on inlet duct traverses. The flow of CO_2 to each heat pipe will be calculated from the following equations:

$$FA_{CO_2} = 3600\sum_{i=1}^{n} 85.49 A_i CP\left(\frac{DP_i T_i}{P_{sf} M_i}\right)^{1/2}\left(\frac{P_{si}}{29.92}\right)\left(\frac{520}{T_i}\right)(1 - M_{FGi})\frac{CO_{2i}}{100} \qquad \textbf{(14)}$$

Which reduces to:

$$FA_{CO_2} = 53{,}488\sum_{i=1}^{n} A_i CP\left(\frac{DP_f P_{si}}{T_f M_i}\right)^{1/2}(1 - M_{FGi})CO_{2i} \qquad \textbf{(15)}$$

and

$$FB_{CO_2} = 53{,}488\sum_{j=1}^{n} A_j CP\left(\frac{DP_f P_{sj}}{T_f M_j}\right)^{1/2}(1 - M_{FGj})CO_{2j} \qquad \textbf{(16)}$$

Where:

FA_{CO_2} = *Flow of CO_2 To "A" Side Air Heater, SCFH*

FB_{CO_2} = *Flow of CO_2 To "B" Side Air Heater, SCFH*

i, j = *Denote Traverse Points On "A" And "B" Sides Respectively*

The flow split is then determined by:

$$SA = \frac{FA_{CO_2} \; x \; 100}{(FA_{CO_2} + FB_{CO_2})} \tag{17}$$

$$SB = 100 - SA$$

Where:

SA = *Flow Split To "A" Side Air Heater ,%*

SB = *Flow Split To "B" Side Air Heater ,%*

The flue gas flow to each heat pipe will be calculated using the flow splits and the calculated gas rates which are based on the total coal feed rate, coal composition, the inlet air moisture and the weighted average inlet gas compositions to each heat pipe.

6.4 Test and Sample Sequencing. The gas flows to and from a heat pipe are shown in Figure 3. To characterize the operation of each heat pipe, weighted average temperatures for seven streams, and gas compositions for two streams are needed. Because there are two heat pipes and the number of streams to be sampled on each heat pipe is large, simultaneous testing of both heat pipes and measurement of all streams at once will not be attempted. Each heat pipe will be tested separately in quick succession with boiler operations held constant. Three test crews will be used to take as much simultaneous data as possible. Data collection will be grouped as follows:

Stream Grouping	Data Collected	Duct Size	Ports	No. of Points
Flue Gas In	Temp, Velocity, Composition	5.5' x 14.5'	5	20
Flue Gas Out	Temp, Velocity, Composition	2.5' x 34.0'	12	24
Secondary Air Out	Temp, Velocity	6.33' x 9.0'	4	24
Primary Air In	Temp, Velocity	3.28' x 17.5'	6	12
Primary Air Out	Temp, Velocity	48" OD	2	20
Primary Flue Gas Out	Temp, Velocity	3.28' x 17.5'	7	14
Secondary Air In	Temp (Recorded Continuously)	5.85' x 5.65'	4	4

Because of site limitations, it is impractical to obtain temperature/velocity traverses of the secondary air inlet near the heat pipe tube bank. For the purpose of performance testing, ABB/API, agreed that installing four point temperature grids at the discharge of each secondary air fan would be adequate for determining the average air inlet temperatures.[3] The TCs will be installed such that the duct is divided into four equal areas with a TC in the center of each area. The inlet temperature will be the arithmetic average. TC values will be continuously recorded on a strip chart.

__6.5 Thermal Performance Evaluation__. To follow the ASME PTC 4.3 procedure and to properly apply the use of the ABB/API performance corrections, each heat pipe must be considered as two separate heat exchangers, one heating primary air and the other heating secondary air. The PTC 4.3 uses velocity traverses only for estimating weighted stream temperatures and flue gas compositions. Flue gas flows are calculated from fuel analysis and gas compositions. To estimate the thermal performance of each heat pipe the primary air flows will need to be measured directly. Because of seal welded construction, the primary air inlet and outlet flows will be assumed to be equal. The outlet flow, rather than inlet will be directly measured since the outlet duct layout is more suitable for accurate flow measurement. Additionally, the outlet primary air velocity heads are expected to be about 40 times the inlet levels which further reduces measurement error.

The thermal performance of each heat pipe will be determined in the following fashion:

1. Measure the primary air (PA), secondary air (SA) and flue gas (FG) inlet and outlet temperatures via standard pitot/temperature traverses as described in PTC 4.3 Section 5. Calculate weighted average temperatures and flue gas compositions from the velocity head/temperature data.

2. Measure the PA outlet flow rate by a 20 point standard pitot traverse.

3. Per PCT 4.3 Section 7, calculate inlet and outlet flue gas flow rates and the overall air leak.

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[3] Agreed to during 11/17/94 meeting at the Milliken site between ABB Air Preheater representatives C. L. Bledsoe, D. E. Gorski, M. M. Chen, NYSEG representative B. Marker, and CONSOL representative D. C. McCoy.

4. By overall heat balance, calculate the secondary air flow rate.

5. From the PA flow and inlet/outlet temperatures, calculate the PA heat duty.

6. Assume that all of the air leak occurs at the sootblower wall penetrations into the heat pipe. The leak flow then reports only to the primary flue gas (PFG) flow through the heat pipe (see Figure 3).

7. Using the FG inlet temperature, the PFG outlet temperature, the air leak and the PA heating duty, calculate the PFG flow.

8. Calculate the secondary flue gas (SFG) flow rate by subtracting the PFG from the total inlet FG flow.

9. By heat balance calculate the SFG outlet temperature using SFG, PFG, and air leak flows, the PFG outlet temperature and the overall FG outlet temperature. As a check, also calculate the SFG outlet temperature from a heat balance between the SA and SFG sides using the measured air inlet and outlet temperatures, the measured FG inlet temperature, and the calculated SFG and SA flow rates. If a discrepancy occurs, then an evaluation of the validity of the test data will be considered.

10. Calculate the Totally Corrected Flue Gas Outlet Temperature by procedures outlined in PCT 4.3 Section 7 and detailed in the CONSOL uncertainty analysis.[4]

With respect to Item 7 above, ABB/API agrees to assume that the measured weighted average FG inlet temperature to a heat pipe is the inlet temperature for both the PFG and SFG sections. However, if the tests show inlet FG temperature stratification from the top of the inlet ducts to the bottom of the ducts, ABB/API reserves the right to assess the effect of the stratification on the inlet temperature to the two sections and to negotiate with all parties involved the overall effect on the test results.

The heat pipe is designed with sootblower penetration ports through the baffle separating the PFG from the SFG sides. Some flue gas communication through these ports will occur. This is unavoidable, accepted, and assumed to be negligible in the heat pipe performance analysis. To minimize flue gas communication, metal plates have been placed over the PFG/SFG baffle manways.

The heat balance used to calculate the SA flow (Item 4 above) will be calculated in the following fashion:

---

[4] Maskew, J. T.: *Milliken Station Heat Pipe Air Heater Performance Uncertainty Analysis Of "Totally Corrected Gas Temperature Leaving The Air Heater,"* Report Prepared for New York State Electric & Gas Corporation, April 1996.

$$W_{SA} = \frac{W_{FGI}[C_{P_{FG}}(T_{FGI}-T_{FGO})-(AL)C_{P_{AL}}(T_{FGO}-T_{amb})]-W_{PAO}C_{P_{PA}}(T_{PAO}-T_{PAI})}{C_{P_{SA}}(T_{SAO}-T_{SAI})} \quad \textbf{(19)}$$

Where:

AL = *Fraction Air Leakage, Pounds Air Leak Per Pound Entering Flue Gas*

$C_{P_{AL}}$ = *Leaked Air Specific Heat From* T_{amb} *To* T_{FGO}, *Btu/Lb-°F*

$C_{P_{FG}}$ = *Flue Gas Specific Heat From* T_{FGI} *To* T_{FGO}, *Btu/lb-°F*

$C_{P_{PA}}$ = *Primary Air Specific Heat From* T_{PAI} *To* T_{PAO}, *Btu/lb-°F*

$C_{P_{SA}}$ = *Secondary Air Specific Heat From* T_{SAI} *To* T_{SAO}, *Btu/lb-°F*

W_{FGI} = *Flue Gas Flow In, lb/lb A.F. Coal*

W_{PAO} = *Primary Air Flow In, lb/lb A.F. Coal*

W_{SA} = *Secondary Air Flow In, lb/lb A.F. Coal*

$T_{FGI,FGO}$ = *Flue Gas In, Out Temperature Respectively, °F*

$T_{PAI,PAO}$ = *Primary Air In, Out Temperature Respetively, °F*

$T_{SAI,SAO}$ = *Secondary Air In, Out Temperature Respectively, °F*

T_{amb} = *Air Leak Inlet Temperature (Same As* T_{SAI}*), °F*

Equation 19 represents the total secondary air flow through the heat pipe including any bypass flow (see Figure 3). If there is a measurable bypass flow for non-guarantee performance tests, the secondary air temperature out of the heat pipe (T'_{SAO}) will be calculated by Equation 13. For performance tests the secondary air bypass will be closed to eliminate this flow.

The PA heating duty (Item 5 above) will be calculated by:

$$Q_{PA} = W_{PAO}C_{P_{PA}}(T_{PAO} - T_{PAI}) \quad \textbf{(20)}$$

Where:

$C_{P_{PA}}$ = *Primary Air Specific Heat From* T_{PAI} *To* T_{PAO}, *Btu/Lb-°F*

Q_{PA} = *Primary Air Heating Duty, Btu/lb A.F. Coal*

W_{PAO} = *Primary Air Flow At Outlet, lb/lb A.F. Coal*

T_{PAI} = *Measured Primary Air Inlet Temperature, °F*

T_{PAO} = *Measured Primary Air Outlet Temperature, °F*

The primary air duty plus the air leak duty (Q_{LEAK}) represents the heat transferred from the PFG (Q_{PFG}) or:

$$Q_{PFG} = Q_{PA} + Q_{LEAK} \tag{21}$$

Then:

$$Q_{PA} = W_{PFG}\, C_{P_{PFG}}(T_{FGI} - T_{PFGO}) - W_{FGI}\, AL\; C_{P_{AL}}(T_{PFGO} - T_{amb}) \tag{22}$$

Where:

$C_{P_{AL}}$ = *Air Leak Specific Heat From* T_{amb} *To* T_{PFGO}, *Btu/Lb-°F*

$C_{P_{PFG}}$ = *Primary Flue Gas Specific Heat From* T_{FGI} *To* T_{PFGO}, *Btu/lb-°F*

W_{PFG} = *Primary Flue Gas Flow, lb/lb A.F. Coal*

T_{PFGO} = *Measured Primary Flue Gas Outlet Temperature, °F*

Rearranging Equation 22 gives:

$$W_{PFG} = \frac{Q_{PA} + W_{FGI}\, AL\; C_{P_{AL}}(T_{PFGO} - T_{amb})}{C_{P_{PFG}}(T_{FGI} - T_{PFGO})} \tag{23}$$

The primary flue gas outlet temperature corrected for no leak is required for calculation of the ABB/API zero leak corrections. This temperature can now be calculated by:

$$T_{PFGO}^{NL} = \frac{W_{FGI}\ AL\ C_{P_{AL}}(T_{PFGO} - T_{amb})}{W_{PFG}C'_{P_{PFG}}} + T_{PFGO} \tag{24}$$

Where:

$C'_{P_{PFG}}$ = *Primary Flue Gas Specific Heat From* T_{PFGO} *To* T_{PFGO}^{NL}, *Btu/Lb-°F*

T_{PFGO}^{NL} = *No Leak Primary Flue Gas Outlet Temperature, °F*

The secondary flue gas flow, W_{SFG}, is by Item 8:

$$W_{SFG} = W_{FGI} - W_{PFG} \tag{25}$$

The SFG outlet temperature can now be determined (above Item 9):

$$W_{SFG}C'_{P_{SFG}}(T_{FGO} - T_{SFGO}) = W_{PFG}C''_{P_{PFG}}(T_{PFGO} - T_{FGO}) + W_{FGI}AL\ C'_{P_{AL}}(T_{PFGO} - T_{FGO}) \tag{26}$$

Where:

$C'_{P_{AL}}$ = *Leak Air Specific Heat From* T_{FGO} *To* T_{PFGO}, *Btu/lb-°F*

$C''_{P_{PFG}}$ = *Primary Flue Gas Specific Heat From* T_{PFGO} *To* T_{FGO}, *Btu/Lb-°F*

$C'_{P_{SFG}}$ = *Secondary Flue Gas Specific Heat From* T_{SFGO} *To* T_{FGO}, *Btu/lb-°F*

T_{SFGO} = *Secondary Flue Gas Outlet Temperature, °F*

Solving Equation 26 for T_{SFGO} gives:

$$T_{SFGO} = T_{FGO} - \frac{W_{PFG} C^{*}_{P_{PFG}} (T_{PFGO} - T_{FGO}) + W_{FGI}\, AL\, C'_{P_{AL}} (T_{PFGO} - T_{FGO})}{W_{SFG} C_{P_{SFG}}} \tag{27}$$

Alternately, T_{SFGO} is:

$$T_{SFGO} = T_{FGI} - \frac{W_{SA}\, C_{P_{SA}} (T_{SAO} - T_{SAI})}{W_{SFG} C^{*}_{P_{SFG}}} \tag{28}$$

Where:

$C^{*}_{P_{SFG}}$ = *Secondary Flue Gas Specific Heat From* T_{SFGO} *To* T_{FGI}, *Btu/lb-°F*

All temperature corrections specified by Power Test Code can now be determined. The reader is referred to the previously mentioned CONSOL uncertainty analysis for specific calculations (i.e., Equations 20, 44, and 50).

<u>6.5 Test Schedule</u>. The heat pipe tests are expected to require four to five days for setup and testing. The expected test schedule is shown in Table 1.

Table 1
Heat Pipe Performance Test Activities

Activity	Boiler load	Location Unit	Measurements	Samples	Sampling Time, hrs	Replicate	Test Time Hrs
Day 1							
Equipment Setup and Checkout							
Setup Test Trailer, Assemble Crews							3
Orientation, Test Equipment Setup							3
Check Out Platforms and Scaffolding							
Check Secondary Air Bypass For Leak							
Check Out Operation Of Ash Sampler							
Coordinate Testing With Plant Personnel							
Establish Fuel Line Plot	Any Constant	2A & 2B	Orsat	Coal, Ash			2
Total							8
Day 2							
Performance Test -- High Load							
Line System Out At Full Load For At Least 1 Hour Before Test					0		
Confirm System Stability	Full/Hold O2	2A & 2B			1	NA	1
Check 2nd Air Bypass For Leak	Full/Hold O2	2A & 2B	V, T			No	
Flue Gas In Traverse	Full/Hold O2	2A & 2B	V, T, O2, & Orsat Checks	Coal, Ash		Yes	
Flue Gas Out Traverse	Full/Hold O2	2A & 2B		"	1.45	Yes	2.9
Secondary Air Out	Full/Hold O2	2A & 2B	V, T	"		Yes	
Primary Air In	Full/Hold O2	2A & 2B	V, T	"		Yes	
Primary Air Out	Full/Hold O2	2A & 2B	V, T	"	1.25	Yes	2.5
Primary Flue Gas Out	Full/Hold O2	2A & 2B	V, T, O2, & Orsat Checks	"		Yes	
Move Equipment to Other Heat Pipe					1	NA	1
Total							7.4
Day 3							
Performance Test -- High Load							
Line System Out At Full Load For At Least 1 Hour Before Test					0		
Confirm System Stability	Full/Hold O2	2A & 2B			1	NA	1
Check 2nd Air Bypass For Leak	Full/Hold O2	2A & 2B	V, T			No	
Flue Gas In Traverse	Full/Hold O2	2A & 2B	V, T, O2, & Orsat Checks	Coal, Ash		Yes	
Flue Gas Out Traverse	Full/Hold O2	2A & 2B		"	1.45	Yes	2.9
Secondary Air Out	Full/Hold O2	2A & 2B	V, T	"		Yes	
Primary Air In	Full/Hold O2	2A & 2B	V, T	"		Yes	
Primary Air Out	Full/Hold O2	2A & 2B	V, T	"	1.25	Yes	2.5
Primary Flue Gas Out	Full/Hold O2	2A & 2B	V, T, O2, & Orsat Checks	"		Yes	
Move Equipment to Other Heat Pipe					1	NA	1
Total							7.4
Day 4							
Performance Test -- Low Load							
Line System Out At Low Load For At Least 1 Hour Before Test					0		
Confirm System Stability	Low/Hold O2	2A & 2B			1	NA	1
Check 2nd Air Bypass For Leak	Low/Hold O2	2A & 2B	V, T			No	
Flue Gas In Traverse	Low/Hold O2	2A & 2B	V, T, O2, & Orsat Checks	Coal, Ash		Yes	
Flue Gas Out Traverse	Low/Hold O2	2A & 2B		"	1.45	Yes	2.9
Secondary Air Out	Low/Hold O2	2A & 2B	V, T	"		Yes	
Primary Air In	Low/Hold O2	2A & 2B	V, T	"		Yes	
Primary Air Out	Low/Hold O2	2A & 2B	V, T	"	1.25	Yes	2.5
Primary Flue Gas Out	Low/Hold O2	2A & 2B	V, T, O2, & Orsat Checks	"		Yes	
Move Equipment to Other Heat Pipe					1	NA	1
Total							7.4
Day 5							
Contingency							

FIGURE 1
Velocity, Temperature, And Gas Sampling System For Milliken

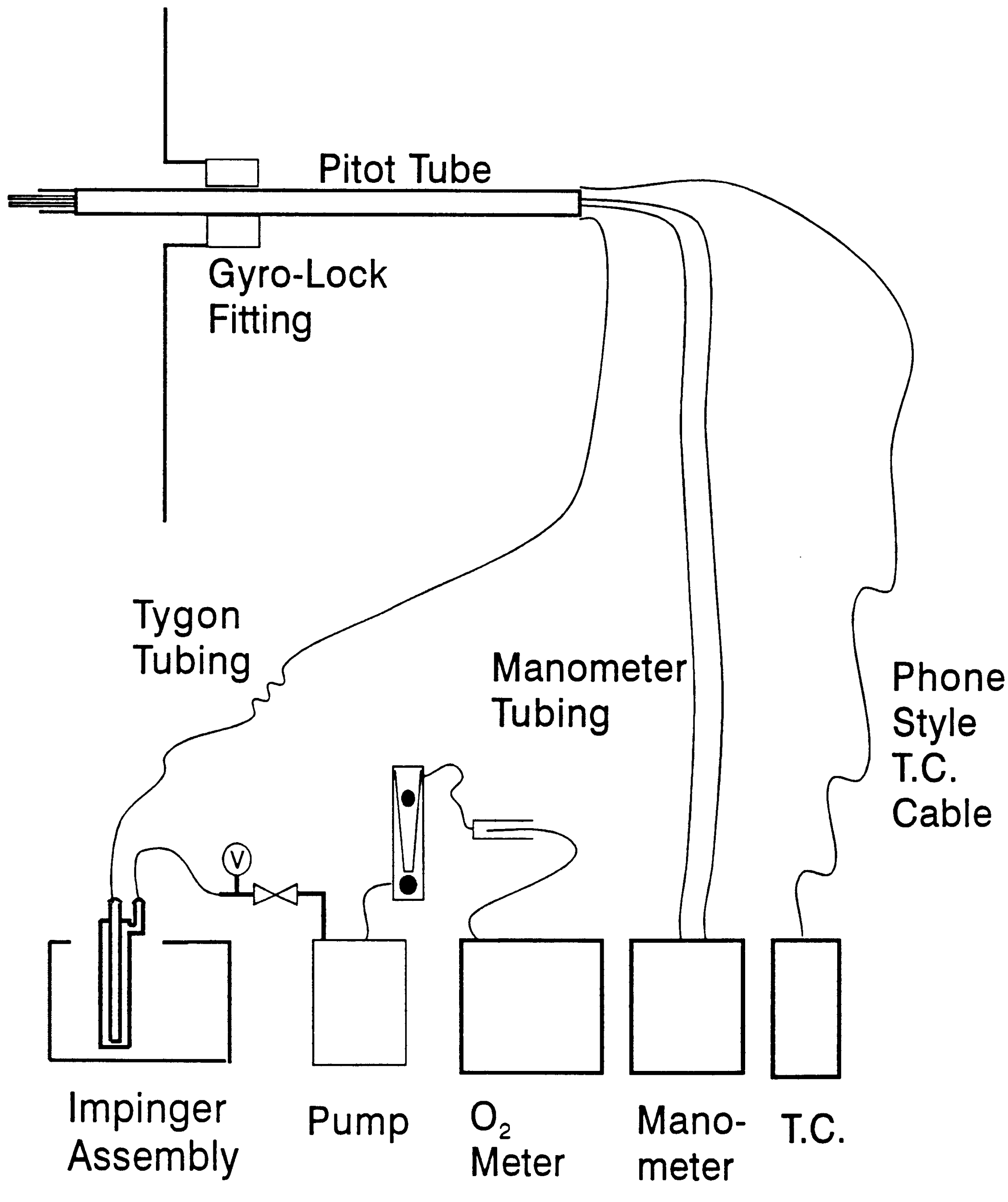
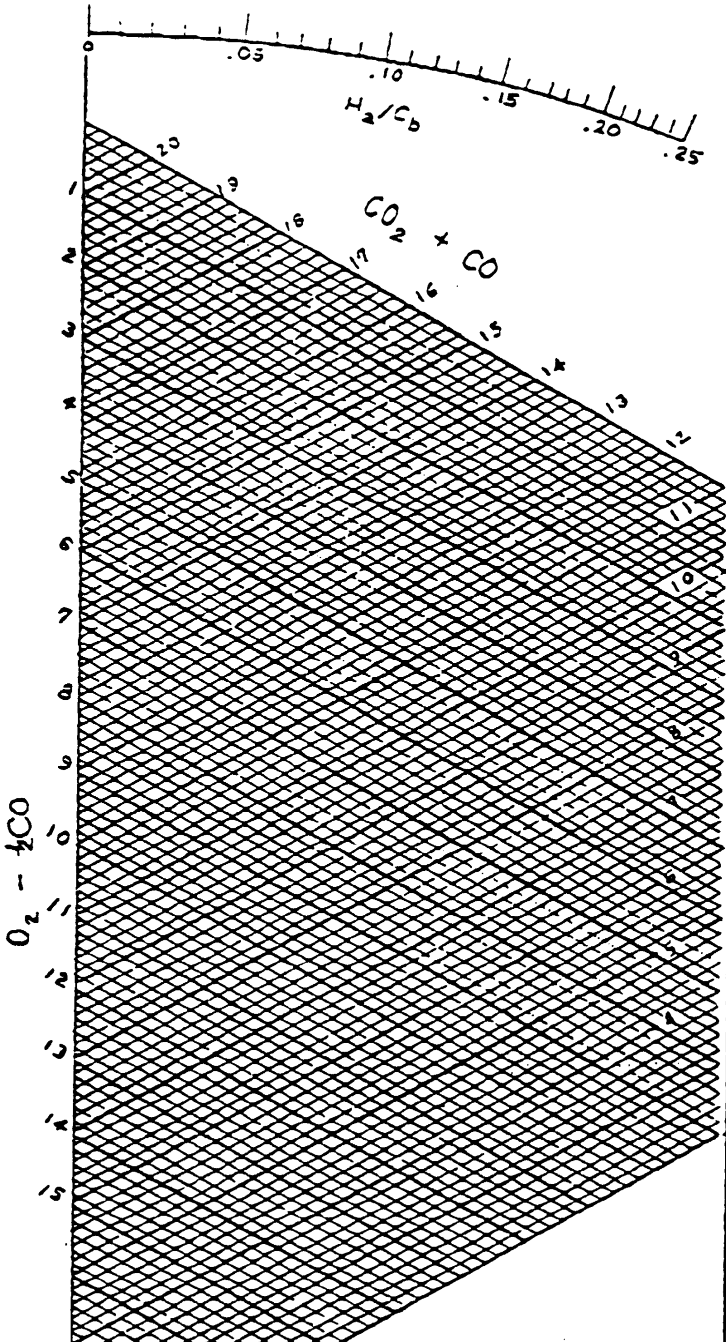


FIGURE 2
DRY FLUE GAS VOLUMETRIC COMBUSTION CHAR



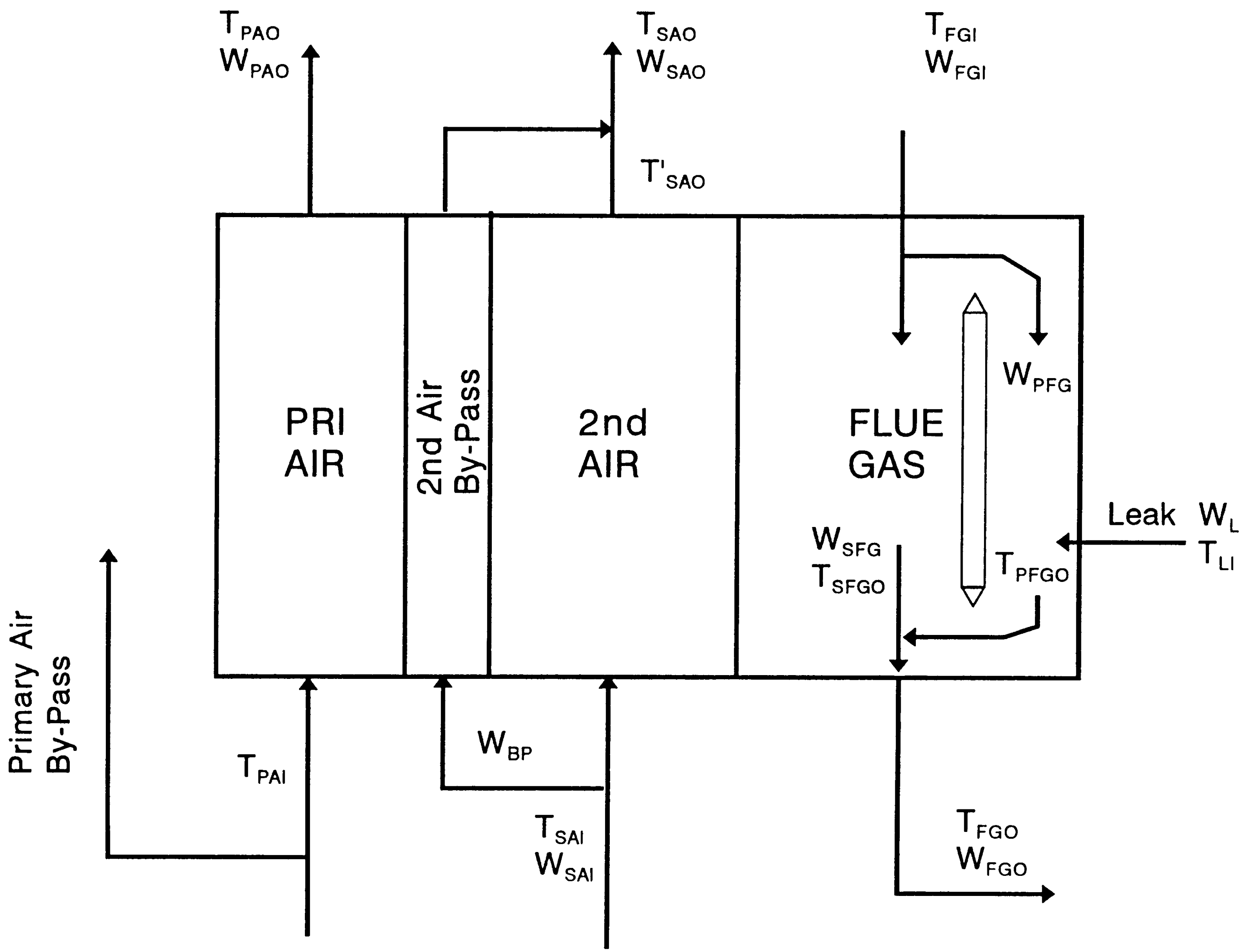
$\Sigma \sqrt{VP}$ = ______
$\Sigma \sqrt{VP} \times CO_2$ = ______
WTD. CO_2 = ______
ST. CO_2 = ______

PIVOT POINT

LOC	√VP	CO_2	$+O_2$	O_2	LOC	√VP	CO_2	$+O_2$	O

SUBJECT	FILE NO.
	BY
	DATE
	TEST NO.

FIGURE 3
HEAT PIPE PROCESS FLOWS



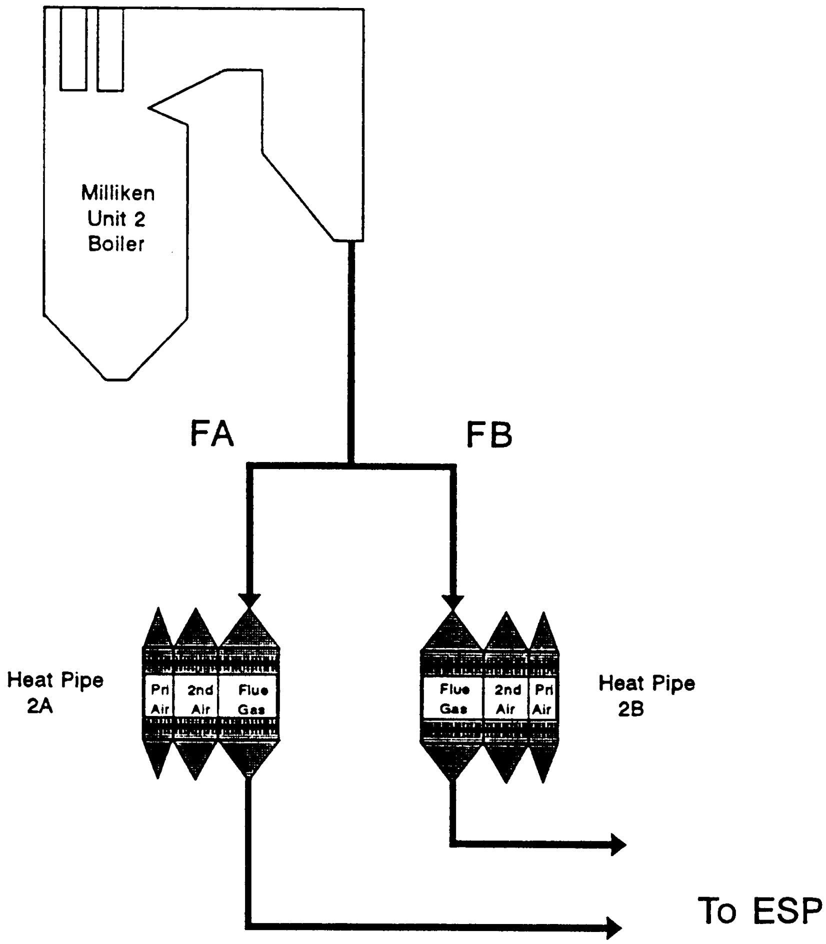


Figure 4
Flue Gas Flow Path

U.S. EPA Method 2 Procedure for Determination of Stack Gas Velocity and Volumetric Flowrate (Type S Pitot Tube)

The procedure for this method is described in the Code of Federal Regulation 40 - Protection of the Environment - Part 60 - Appendix A - Method 2 and briefly outlined below.

The average stack gas velocity in a stack is determined from the gas density and from measurement of the average velocity head with a Type S (Stausscheibe) pitot tube. Field instructions for the CONSOL test team are outlined in this discussion. Please refer to the CFR reference for a complete description of this procedure.

Check to see that the duct is properly identified and the proper sampling points have been designated. Assemble the pitot equipment as follows:

1. Connect manometer tubing to probe and manometer.

2. Connect TC cable and readout.

3. Connect gas sampling line to knock-out impinger and pump.

4. Calibrate portable gas analyzer.

5. Leak check pitot lines from probe tip to end of manometer tubing by connecting to a 12" water manometer or by using the existing electronic manometer. Blow through the pitot opening on the positive pressure line to achieve a water displacement between 7-10 inches. Tightly seal off the pitot opening and observe the liquid level in the manometer. If no leaks are present, the liquid level will remain constant. A drop in the liquid level signifies a leak. If a leak is detected, identify the cause, correct, then recheck. Complete similar procedure on vacuum side.

6. Leak check the gas sampling system from the pump inlet to the gas inlet by pulling a gas flow through the system and then tightly sealing off the gas inlet opening. This will cause the in-line vacuum gauge to raise. When the vacuum gauge indicates a vacuum of between 10-15"Hg, close valve located downstream of gauge and shutoff pump. Observe the gauge vacuum. If no leaks are present, the gauge level will remain constant for at least 0.5 minutes. A drop in vacuum indicates a leak. If a leak is detected, identify the cause, correct, then recheck.

7. Check "0" level of Dp cell by loosely placing a glove over the pitot opening. Dp sensor should read 0.000X. If not, replace Dp unit.

8. Check to see that TC is reading correct ambient temperature. If a fault is indicated, remedy and continue.

9. Complete information on pitot field data sheet. Complete QC check list.

10. Insert pitot tube into duct through air-tight bushing. Positions at the first point and mark the probe accordingly to designate a reference distance.

11. Orient tube into the gas flow. Start pulling a gas sample. Observe to see temperature and $\%O_2$ line out. Take differential pressure reading. Record Average Dp for ten readings, temperature, and gas composition on data sheet. Move to next point and repeat step 11.

12. After completing all points in a line traverse, remove tube from duct.

13. Inspect tips for disfigurement.

14. Move to next point and repeat steps 10 through 13.

15. Take static pressure near midpoint of duct. Do this by turning pitot tube perpendicular to gas flow. Disconnect negative manometer tube from meter and take Dp (duct vs. ambient) reading. This is the duct's static pressure.

16. At completion of sampling inspect pitot tips for disfigurement, leak check both the pitot and gas sampling lines, check calibration on portable gas analyzer, and verify that all data has been properly recorded. Check pitot field sampling sheet for completeness.

Method 2 QA/QC Checklist

Plant: ________________________
Date: ________________________
Start Time: ____________________ Stop Time: ____________________
Unit ID: ______________________ Duct ID: ______________________
Testers: ____

Pitot ID___________ Cp________ Calibration Date______________

Pitot Opening Checked?_____ By Whom?_________ Condition?________

Leak Check of System?______ By Whom?_________ Condition?________

Dp Gauge ID________ Static Pressure Gauge ID _______________

TC ID_____________ Handheld TC Readout ID __________________

Barometer ID _________

Leak Check of Gas Sampling System?_____ By Whom?____ Condition?_____

Gas Meter ID______ ORSAT Bag ID ___________________________

QA/QC Check List:

Proper sampling points identified? ______________

Pitot orientation properly marked? ______________

Reference point for pitot depth marked? ______________

Pitot leak check? ______________

Gas sampling system leak check? ______________

Gas Meter Calibrated? ______________

Safety equipment utilized? ______________

(Hot Gloves, Ear Protection, Eye Protection, Safety Harness, Radio)

Tight seal around probe entry port? ______________

Proper probe orientation while traversing? ______________

Process at steady state prior to testing? ______________

ATTACHMENT 2

Thermocouple Calibration Procedure

Objective:

To verify the integrity of the thermocouple junctions and the accuracy of the handheld thermometers by comparing their performances to NIST traceable temperature references. In addition, this procedure will determine the impact (if any) that extension grade cable extensions have on overall measured accuracy.

Background:

Test Thermocouples- Eighteen type K T/C's were assembled from special tolerance, thermocouple grade wire with fiberglass insulation. The T/C's are comprised of three different lengths (12'-8",6'-5", and 5'-0"), corresponding to the three different pitot tube lengths. The test T/C's have been labeled #2A through #7C (see attached tables).

Reference Thermocouple- A 1/8" diameter X 36" long type K T/C with special limits wire and a 316 stainless steel sheath was purchased from Watlow/Gordon. This T/C underwent a four point NIST certification at the factory. The four calibration points were 100°F, 300°F, 500°F, and 700°F.

Handheld Thermometer- Five Watlow/Gordon model 5401 digital thermometers were purchased to read the thermocouples during the field testing. Each unit was factory-calibrated against NIST curves for type K thermocouples to confirm its claimed accuracy of 0.1% of reading/0.8F. The thermometers have been identified as handheld #1 through handheld #5.

Extension Cable- Four retractable type K extension cables were purchased to provide added flexibility during the field testing.

Sand Bath- A fluidized bed sand bath equipped with analog temperature controls was prepared to facilitate the thermocouple calibrations.

Procedure:

1. Securely fasten all eighteen test thermocouples along the sheath of the reference thermocouple, making certain that all nineteen junctions are in very close proximity (within 1/2").

2. Prepare an ice bath of crushed ice in distilled water.

3. Position the bundle of test thermocouples and reference thermocouples in the ice bath and allow the temperature to reach a steady state condition.

4. Record the indicated temperatures in the Thermocouple Calibration Data Tables as follows:

a. Using the ANALOGIC device without the extension cable attached, record the temperature of the reference thermocouple and the eighteen test thermocouples.

b. Using handheld #1 without the extension cable attached, record the temperature of the reference thermocouple. Repeat with handheld #2, #3, #4, and #5.

c. Using the ANALOGIC device with the extension cable attached, record the temperature of the reference thermocouple and the eighteen test thermocouples.

5. Remove the bundle of thermocouples from the ice bath and suspend it securely in the fluidized bed of the sand bath.

6. Set the temperature controls for 100°F and allow the sand bath temperature to stabilize for at least 10 minutes. Repeat step 4).

7. Set the temperature controls for 300°F and allow the sand bath temperature to stabilize for at least 10 minutes. Repeat step 4).

8. Set the temperature controls for 500°F and allow the sand bath temperature to stabilize for at least 10 minutes. Repeat step 4).

9. Set the temperature controls for 700°F and allow the sand bath temperature to stabilize for at least 10 minutes. Repeat step 4).

Thermocouple Calibration Data Tables

CALIBRATION @ 32F

	NIST Certified	T/C Length = 12' – 8"						T/C Length = 6' – 5"						T/C Length = 5' – 0"					
Readout Device	Reference T/C	#2A	#2B	#2C	#3A	#3B	#3C	#4A	#4B	#4C	#5A	#5B	#5C	#6A	#6B	#6C	#7A	#7B	#7C
Analogic w/o ext																			
Handheld #1 w/o																			
Handheld #2 w/o																			
Handheld #3 w/o																			
Handheld #4 w/o																			
Handheld #5 w/o																			
Analogic w/ ext																			

CALIBRATION @ 100F

	NIST Certified	T/C Length = 12' – 8"						T/C Length = 6' – 5"						T/C Length = 5' – 0"					
Readout Device	Reference T/C	#2A	#2B	#2C	#3A	#3B	#3C	#4A	#4B	#4C	#5A	#5B	#5C	#6A	#6B	#6C	#7A	#7B	#7C
Analogic w/o ext																			
Handheld #1 w/o																			
Handheld #2 w/o																			
Handheld #3 w/o																			
Handheld #4 w/o																			
Handheld #5 w/o																			
Analogic w/ ext																			

CALIBRATION @ 300F

	NIST Certified	T/C Length = 12' – 8"						T/C Length = 6' – 5"						T/C Length = 5' – 0"					
Readout Device	Reference T/C	#2A	#2B	#2C	#3A	#3B	#3C	#4A	#4B	#4C	#5A	#5B	#5C	#6A	#6B	#6C	#7A	#7B	#7C
Analogic w/o ext																			
Handheld #1 w/o																			
Handheld #2 w/o																			
Handheld #3 w/o																			
Handheld #4 w/o																			
Handheld #5 w/o																			
Analogic w/ ext																			

Analogic =

Handeld #1 = Watlow/Gordon M/#5401, S/#D96002614

Handeld #2 = Watlow/Gordon M/#5401, S/#M95001829

Handeld #3 = Watlow/Gordon M/#5401, S/#K94002792

Handeld #4 = Watlow/Gordon M/#5401, S/#L94003776

Handeld #5 = Watlow/Gordon M/#5401, S/#L94003789

Thermocouple Calibration Data Tables

CALIBRATION @ 500F

Readout Device	NIST Certified Reference T/C	T/C Length = 12' – 8"						T/C Length = 6' – 5"						T/C Length = 5' – 0"					
		#2A	#2B	#2C	#3A	#3B	#3C	#4A	#4B	#4C	#5A	#5B	#5C	#6A	#6B	#6C	#7A	#7B	#7C
Analogic w/o ext																			
Handheld #1 w/o																			
Handheld #2 w/o																			
Handheld #3 w/o																			
Handheld #4 w/o																			
Handheld #5 w/o																			
Analogic w/ ext																			

CALIBRATION @ 700F

Readout Device	NIST Certified Reference T/C	T/C Length = 12' – 8"						T/C Length = 6' – 5"						T/C Length = 5' – 0"					
		#2A	#2B	#2C	#3A	#3B	#3C	#4A	#4B	#4C	#5A	#5B	#5C	#6A	#6B	#6C	#7A	#7B	#7C
Analogic w/o ext																			
Handheld #1 w/o																			
Handheld #2 w/o																			
Handheld #3 w/o																			
Handheld #4 w/o																			
Handheld #5 w/o																			
Analogic w/ ext																			

Analogic =

Handeld #1 = Watlow/Gordon M/#5401, S/#D96002614

Handeld #2 = Watlow/Gordon M/#5401, S/#M95001829

Handeld #3 = Watlow/Gordon M/#5401, S/#K94002792

Handeld #4 = Watlow/Gordon M/#5401, S/#L94003776

Handeld #5 = Watlow/Gordon M/#5401, S/#L94003789

ATTACHMENT 3

U.S. EPA Method 3 Procedure for Flue Gas Analysis for the Determination of Dry Molecular

Weight (ORSAT)

The procedure for this method is described in the Code of Federal Regulation 40 - Protection of the Environment - Part 60 - Appendix A - Method 3 and briefly outlined below.

In this method, a flue gas sample is extracted from the duct through a stainless steel probe using a leak-proof, teflon-coated pump. Moisture is removed by passing the gas through a condenser system. The dry gas sample is collected in a Tedlar bag and analyzed by ORSAT or alternative electrochemical sensors for %O_2, %CO_2, %CO, and %N_2 (by difference). Field instructions for the CONSOL sampling team are as follows.

1. Leak-check Tedlar bags prior to test program by inflating to near capacity and observing the overnight leak rate. If any bag is deflated, it is indicative of a leak and will be taken out of service.

2. Connect gas sampling line to knock-out impinger and pump. Insert a glass wool plug in the end of the sampling probe to knock out particulate matter.

3. Calibrate portable gas analyzer.

4. Leak check the gas sampling system from the pump inlet to the gas inlet by pulling a gas flow through the system and then tightly sealing off the gas inlet opening. This will cause the in-line vacuum gauge to raise. When the vacuum gauge indicates a vacuum of between 10-15"Hg, close valve located downstream of gauge. Observe the gauge vacuum. If no leaks are present, the gauge level will remain constant for at least 0.5 minutes. A drop in vacuum indicates a leak. If a leak is detected, identify the cause, correct, then recheck.

5. Insert pitot tube into duct through air-tight bushing. Position probe at the first point and mark the probe accordingly to designate a reference distance.

6. Orient pitot tube into the gas flow. Start pulling a gas sample. Observe to see temperature and %O_2 line out. Take differential pressure reading. Record Dp, temperature, and gas composition on data sheet. Move to next point and repeat. 11.

7. Collect a gas sample in a Tedlar bag at a point near the duct mid-point. Analyze this sample by ORSAT to verify the accuracy and/or bias of the electrochemical sensors. Refer to EPA Method 3 and the ORSAT instructions for this determination.

Method Specific QA/QC

The O_2 electrochemical sensors will be calibrated on ambient air. The accuracy of the electrochemical sensors will be determined daily by comparison with a certified gas blend containing ~3.5% O_2. Past experience has shown that the sensors used by CONSOL are accurate to within 0.1% at this level. The CO sensors will be calibrated with a certified gas blend containing ~100 ppm CO. All of the electrochemical sensors used by CONSOL have undergone a recent factory rebuild and calibration and have all new gas sensors.

Specific QA\QC procedures for the ORSAT are contained in the reference method.