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1. INTRODUCTION

Air preheaters on Eskom thermal power stations play a significant role in maximising the overall efficiency of electricity generation. It is therefore important for Eskom Generation to assess the performance and leakage rate of the tubular and rotary regenerative air preheaters at power stations. The aim of this document is to provide a methodology to conduct accurate tests on this plant and to define the performance of the air preheaters.

It is to be noted that using on-line plant process data to derive air heater performance and leakage rate is highly sensitive to process changes, credibility of instrumentation and open to interpretation. Any indications so-determined are to be regarded as qualitative and for guidance only.

2. SUPPORTING CLAUSES

2.1 SCOPE

2.1.1 Purpose

The purpose of this document is to outline the procedures for conducting accurate site tests on air preheaters at Eskom Power stations, under defined conditions, and eliminate any subjectivity that may be associated with interpretation of on-line process data.

Site tests can be conducted on air preheaters to determine the following operating characteristics

- Air to Gas side leakage
- Gas and air temperatures
- Air and Gas side effectiveness
- Gas and air pressure drops
- Air Preheater Energy Balance
- Air Preheater Thermal Performance

Evaluation of any or all of the performance items specified above may be necessary for;

- Checking the actual performance against the specifications.
- Comparing these items with standards of operation
- Comparing performance when firing different fuels
- Determining the effect of changes to equipment

It is not necessary to apply this standard in its entirety to every test. Components of this standard can be applied for specific purposes as required (such as determining air preheater leakage only).

2.1.2 Applicability

This document shall apply throughout Eskom Holdings Limited Divisions when performing air preheater performance tests.

2.2 NORMATIVE/INFORMATIVE REFERENCES

Parties using this document shall apply the most recent edition of the documents listed in the following paragraphs:

2.2.1 Normative

[1] ISO 9001 Quality Management Systems.

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2.2.2 Informative

[2] ES 1023 Rev 3, “Performance Testing of Air Preheaters”, Howden UK

[3] ASME PTC 4.3 Reaffirmed 1991

[4] BS EN ISO 5802:2008 / BS 848-3:2001

[5] Keir J, “Survey of Oxygen and Carbon Monoxide Analysers and their application in Power Stations – Volume 1” (Eskom Report number TRR/P95/025)

2.3 DEFINITIONS

Air leakage:	Amount of air passing from the air side to the gas side, assumed to pass directly from the air inlet to the gas outlet of an air heater. May also be applied to describe leakage from the primary air side to secondary air side on dual air heaters.
Exit gas temperature:	The measured gas temperature
Gas side effectiveness:	Ratio of the gas temperature drop, to the difference between the air inlet and gas inlet temperatures
Gas	Generally refers to boiler flue gas
Undiluted exit gas temperature:	The temperature at which the gas would have left the heater if there were no leakage.

2.3.1 Disclosure Classification

Controlled disclosure: controlled disclosure to external parties (either enforced by law, or discretionary).

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2.4 ABBREVIATIONS

Abbreviation	Description	Units
A	Duct area	m^2
Bp	Barometric pressure	kPa
Cp	Specific heat	J/kg°C
k	% mass moisture in flue gas entering heater	decimal
L	Leakage (% of gas inlet mass flow)	%
M	Mass flow rate	kg/s
N_2	Nitrogen Gas	%
O_2	Oxygen Gas	%
Ps	Static pressure	kPa
Pv	Velocity pressure	kPa
T	Temperature	°C
ΔP	Pressure difference	kPa
η	Effectiveness	%
ρ_a	Density of air at NTP	kg/m^3
ρ_g	Density of flue gas at NTP	kg/m^3
ρ_w	Density of water vapour at NTP	kg/m^3

Table 1: Subscript Definitions

Subscript	Description
a	air side parameter
g	gas side parameter
1	entering condition
2	leaving condition
NL	no leakage (undiluted)

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2.5 ROLES AND RESPONSIBILITIES

The Process Engineering/Performance and Test Manager of each Power Station shall be responsible for ensuring that:

- Applicable responsibilities to carry out the processes described in this standard are defined, communicated and implemented within their Departments.
- All personnel participating in the test are fully qualified and trained to perform their particular function.
- Records of all tests are documented and maintained.
- Measuring instrumentation used in tests is calibrated and appropriately maintained as per Original Equipment Manufacturer (OEM) requirements.

2.6 PROCESS FOR MONITORING

The monitoring of this process shall take place through the continual assessments and “spot checks” by a qualified person other than the test team leader. Reports detailing results of tests shall be reviewed and approved by the Process Engineering/Performance and Test Manager.

Application of this standard shall be audited at least once every 3 years at each site.

2.7 RELATED/SUPPORTING DOCUMENTS

[6] 36-1263 Air Heater Test Procedure

3. REQUIREMENTS

3.1 PREPARATION FOR TESTING

3.1.1 Selection of Personnel

To ensure obtaining reliable results, all personnel participating in the test shall be fully qualified to perform their particular function. Parties to the test may designate a person to direct the test and to serve as arbiter in the event of disputes as to the accuracy of observations, conditions or methods of operation. Responsibility should be appointed to a single person for all performance and operating conditions which affect the test

3.1.2 Heater Inspection and Operation

It is recommended that if possible, the air preheater be inspected prior to the test to note the condition of all parts which can affect the performance. In particular, the condition and cleanliness of tubes or elements should be examined and the air preheater placed in proper operating condition. Any external air bypasses or recirculating dampers must be checked for sealing effectiveness, and any expansion joints between the test points should be checked for integrity.

All heating elements or tubes should be commercially clean (normal operating cleanliness) before starting the test. All on-load soot blowing (both boiler and air heater) must be carried out prior to commencement of the test, and no cleaning shall be permitted during the test. On coal fired boilers, all de-ashing must be carried out prior to the test period (except for boilers that do continuous ashing) because such an operation can produce large amounts of water vapour and can lead to air ingress.

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3.2 TESTING

3.2.1 Test Conditions

It is important that air and gas flow through the air preheater remains essentially constant, and the O_2 levels are steady throughout the test. The steam generator output shall be set as close as possible to the design value and shall be held stable for at least 30 minutes prior to the start of each test and maintained throughout the test.

Testing shall commence only when the parties to the test certify that the unit is operating to their satisfaction and is, therefore, ready for test.

3.2.2 Duration

Test runs shall be of at least two hours duration but sufficiently long to permit the taking of at least two complete sets of consistent readings for a single air preheater. (Often the test will last much longer than 2 hours).

3.2.3 Check of Inlet Oxygen

Prior to the test a preliminary check of inlet O_2 should be made using the installed station instrumentation to ensure that the unit is operating at the specified excess air conditions. Similarly, if the station has installed O_2 measurement downstream of the air heater, then this operating measurement should be recorded. If both inlet and outlet values are known then a preliminary estimate of leakage can be calculated (see section 3.8.1).

The recommended maximum permissible deviation in inlet O_2 from design is ±1.5% O_2 (Table 4).

3.2.4 Gas Side Effectiveness

If the test results exceed the previously agreed upon deviation in gas side effectiveness between runs, a third run shall be required. The test effectiveness will be the average of the two runs which fall within the permissible deviation.

The recommended maximum deviation in Gas Side Effectiveness between runs is ±7.5% (Table 4).

3.2.5 Rejection of Runs

Should inconsistencies in the observed data be detected during a run or during the computations that would cause obviously untrue results, the run shall be rejected completely. A run that has been rejected shall be repeated to attain the objectives of the test.

3.3 RECORDS AND TEST REPORTS

All observations, measurements and instrument readings necessary for the objective of the test shall be recorded as observed. Corrections and corrected values shall be entered separately in the test record.

3.4 MEASUREMENTS

The variables listed in Table 3 are required in order to determine the performance of the air preheater:

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Table 2: Air preheater performance measurements

Temperature of air entering heater	#	Ta_1
Temperature of air leaving heater	#	Ta_2
Gas inlet temperature		Tg_1
Measured gas exit temperature		Tg_2
Certain air and gas mass flow rates		Ma_1, Ma_2, Mg_1 or Mg_2
Air side inlet and outlet static pressure	#	Psa_1, Psa_2
Gas side inlet and outlet static pressure		Psg_1, Psg_2
% O_2 content of dry gas entering and leaving heater		O_2in, O_2out

#: Primary Air and Secondary Air if applicable

In order to determine all aspects of the air heater performance as documented in this standard, it is essential that a sample of the fuel consumed during the test period should be sent for laboratory analysis to determine the fuel constituents. From this, the products of combustion can be calculated including the moisture content of the flue gas. These can then be used to determine the density of the flue gas. Moisture content may also be calculated using the station specific Mass and Energy Balance spreadsheets where available. An alternative method for determining air heater leakage using the laboratory analyses is documented in “36-1263 Air Heater Test Procedure”.

In the event that only limited components of this standard will be applied (for example to determine air heater leakage only), then the laboratory analysis is not a necessity.

To allow complete analysis of the test data, records of control panel recordings at regular intervals should be supplied by the Power Station detailing the following:

- Ambient barometric Pressure
- Boiler load
- Fuel flow
- All recorded temperatures, mass flows and pressures for both air and gas side of the air heater and fans where applicable.
- Fan amps
- Any other factors which may affect heater performance i.e. Control Damper Positions

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3.5 APPARATUS

The apparatus required for the test is as follows:

3.5.1 Thermocouples

Calibrated temperature sensors shall be used with a calibrated Digital Thermometer or with an Analogue to Digital converter connected to a data logger.
The temperature sensors shall comply with the following specifications: (Table 4)

Operating Temperature Range (minimum): 0-500^{0}C
Total Accuracy: ± 1.5^{0}C

3.5.2 Manometers

Calibrated Electronic Micro-manometers or calibrated 4-20 mA pressure transmitters connected to a data logger would normally be used. U-Tube/inclined manometers filled with water or a light liquid of known specific gravity may also be used.

The recommended maximum pressure tolerance of the measurement instrument should be ±4% (Table 4).

3.5.3 Analysers

Gas analysers shall be used to determine the % concentration of Oxygen in the gas streams.

These can be of any type e.g.

- Paramagnetic Attraction
- Catalytic Combustion
- Electro-chemical Membrane Diffusion
- Zirconia Cell Diffusion

and may be connected to a data logger.

The analysers which are most commonly used on the Eskom Fleet are:
- Electro-chemical Membrane Diffusion (Portable analysers)
- Zirconia Cell Diffusion (Fixed Station analysers)

Note that for purposes of this standard, it is assumed that the analysers measure:
- % concentration by volume
- on a dry basis (for analysers that measure on a wet basis – results must be converted to dry basis, either through calculation or by drying the gas to ensure that all moisture is removed prior to measurement)

More detailed information regarding application of analysers in power stations is documented in TRR/P95/025 “Survey of Oxygen and Carbon Monoxide Analysers and their application in Power Stations – Volume 1”

The calibration of this equipment shall be checked on site prior to and after each test to ensure consistency of readings and freedom from any significant deviations. A 100% (99.9%) N_2 gas bottle is used for the zero calibration setting and a 95% N_2 + 5% 0_2 gas mix is used for the span calibration

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setting. This gas mix cylinder is prepared in the lab by a recognized supplier and should be changed as recommended on the expiry date card.

The recommended maximum tolerance of the Oxygen Analyser measurement should be ±0.15% O_2 (Table 4).

3.5.4 Sampling Probe

Figure 1 shows the recommended equipment and probe set-up for combined gas analysis, temperature and static pressure measurement.

Care should be taken to ensure that the probe is grounded to the duct at all times to prevent damage to electronic equipment from static charges. This can be done by either ensuring direct contact at the sampling port or by using a separate earth strap from the probe to the duct.

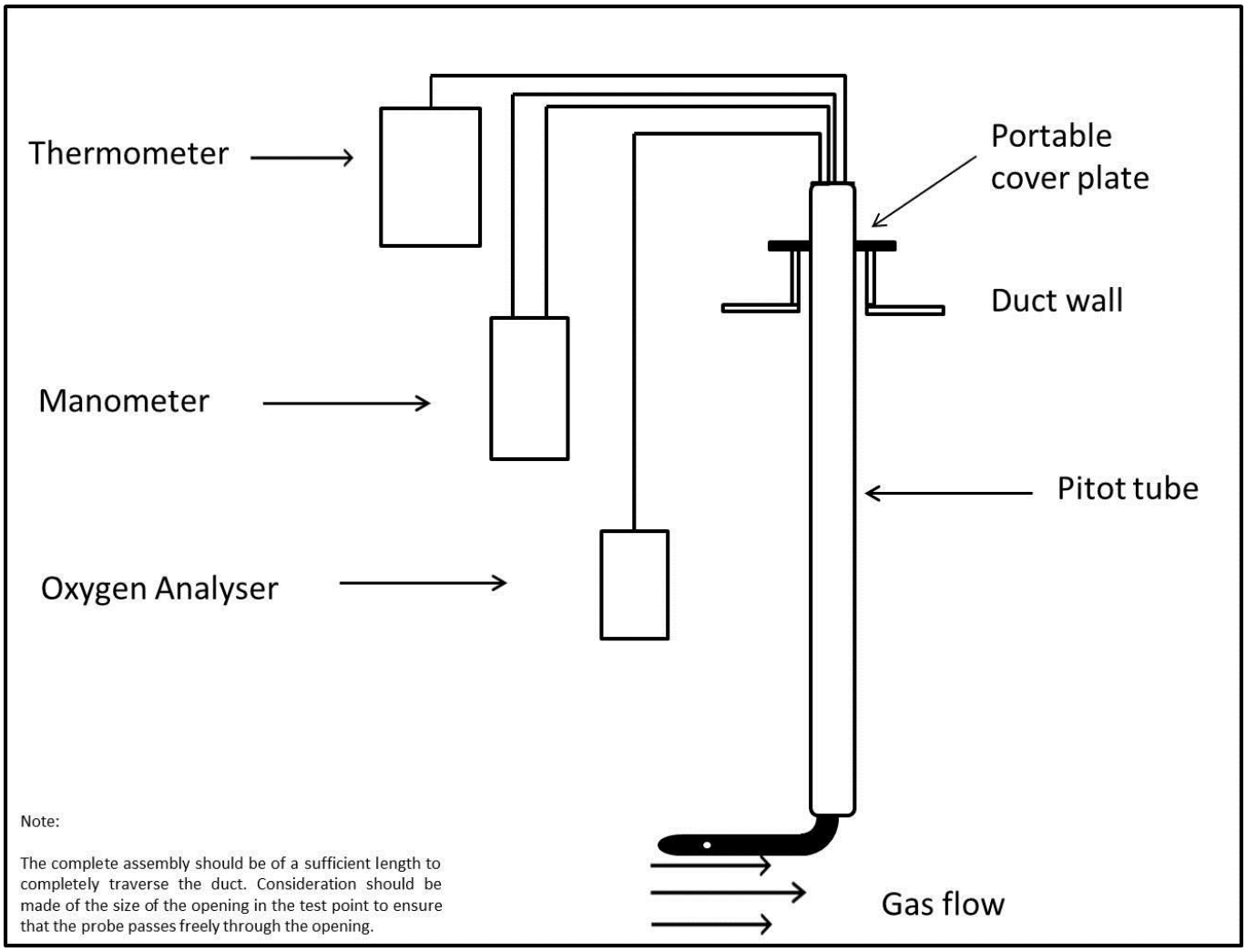

Figure 1: Pitot tube set up with measuring equipment as required.

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3.6 TEST PROCEDURE

3.6.1 Location of Test Points

Sampling points in the gas inlet and outlet ducts shall be located as close to the air preheater as practical, and as consistent as possible with good velocity measurement practice. Due to the probable stratification at the gas outlet for both tubular and rotary heaters the traverse section should be located as far from the heat exchange media as possible but prior to any expansion joints which may allow air ingress to influence the measurements.

Alternative positioning of test points to those suggested in 3.6.1.1 and 3.6.1.2 below may be used, provided that the method used is an accepted international standard method for measurement of gaseous fluid flow in closed conduits. The method used should be consistently used in subsequent tests and must be documented in the test report.

In general measuring points should not be more than 1m apart.

3.6.1.1 Circular Ducts

Figures 2 and 3 detail the suggested number of test points required and their positioning for circular ducts across either four or three diameters using the log-linear method. Where judgement indicates possible severe stratification, consideration should be given to a system of closer spacing.

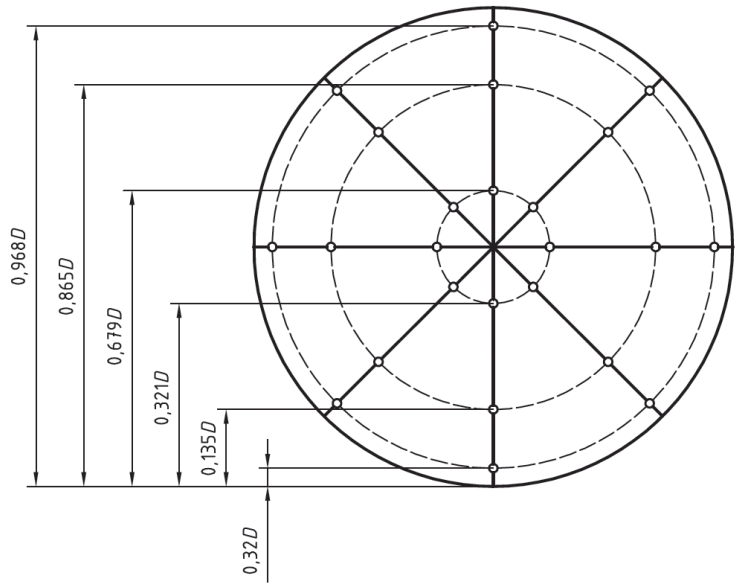

Figure 2: Measuring locations of circular ducts as per BS EN ISO 5802:2008 / BS 848-3:2001 for six points on four diameters.

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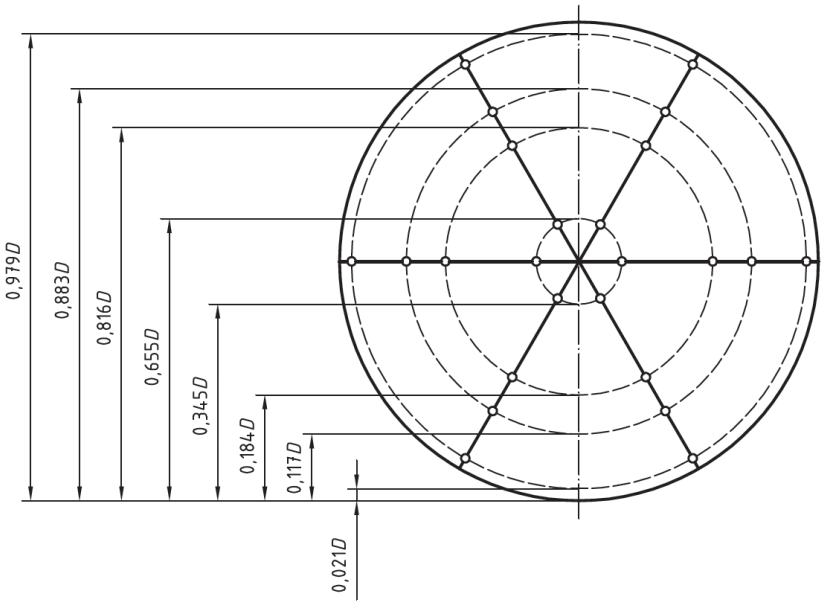

Figure 3: Measuring locations of circular ducts as per BS EN ISO 5802:2008 / BS 848-3:2001 for eight points on three diameters.

3.6.1.2 Rectangular Ducts

Figure 4 indicates the suggested locations of measuring points for rectangular ducts. If however the aspect ratio (ratio of the duct's length to its height) deviates much from one, the number of cross lines should be increased to achieve an approximate aspect ratio of one. (See Table 3).

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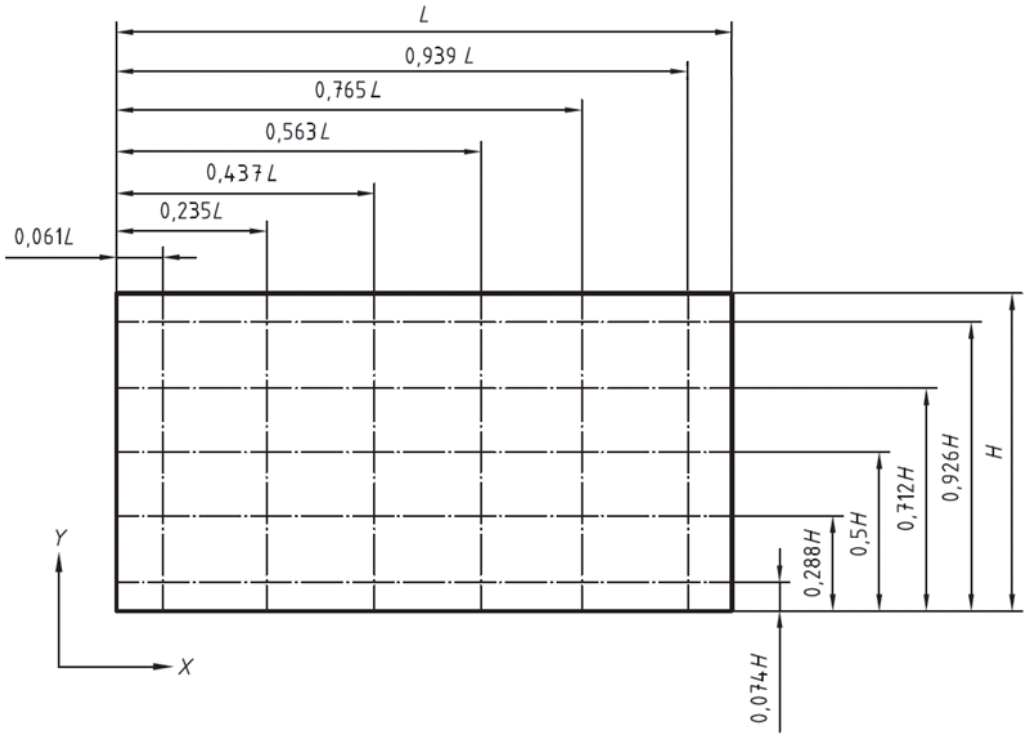

Figure 4: Measuring locations for rectangular ducts as per BS EN ISO 5802:2008 / BS 848-3:2001 with six cross-lines and five measuring points per cross-line.

Table 3: Point and line distribution in rectangular duct as per BS EN ISO 5802:2008 / BS 848-3:2001

Number of cross-lines or number of measuring points per cross-line	Point	Values of x/L or y/H
5	1	0.074
	2	0.288
	3	0.500
	4	0.712
	5	0.926
6	1	0.061
	2	0.235
	3	0.437
	4	0.563
	5	0.765
	6	0.939
7	1	0.053
	2	0.203
	3	0.366
	4	0.500
	5	0.634
	6	0.797
	7	0.947

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3.6.2 Temperatures

Flue gas temperatures must be recorded at the same locations and instants as those used for flue gas sampling, therefore a thermocouple shall be fitted to the sampling probe as shown in Figure 1.

3.6.3 Flue Gas O_2 Readings

Flue gas O_2 measurements are required to calculate air preheater leakage. Air preheater leakage shall be measured coincident with the flow measurement. For very steady boiler load conditions with minimal time variations in the boiler outlet/air preheater inlet O_2 levels, Oxygen measurement is carried out by comprehensive traverses over the duct, using a single sampling probe (Figure 1).

Before taking measurements at each duct traverse point a minimum waiting period must be observed in order to ensure that the gas sample in the sampling tubes to the analyser is representative of the gas at the new sampling point. The waiting period should be sufficient for all gas in the sample extraction tubes from the previous sampling point to completely replaced by a gas sample from the new sampling point. The waiting period will be determined by the analyser volume flow extraction rate and length of sampling tubes. Generally a waiting period of 2-5 minutes or more should be sufficient. This process eliminates the possibility of residual gas in the pipe being mistakenly taken as a new location reading

Especially when using Electro-chemical Analysers, the analyser should be purged with clean air after a maximum of 2 traverse points before continuing the traverse. To purge the analyser the probe sampling tube should be disconnected from the analyser for a short period to allow ambient O_2 to flow through the instrument to prevent drift of the analyser. The purge should continue until the analyser reading is close to the ambient reading for O_2 (ie above 20% O_2) before reconnecting the sampling tube and commencing with the next sampling point measurement.

It is highly recommended that traverses be conducted with two portable analysers so that analysers can be purged after every traverse point. (Ie. when one analyser is measuring the one analyser is on purge.)

After the waiting period, measurements at a new traverse point can commence.

- **For Tubular air heaters** the gas sample measurements should be recorded when the reading stabilises. If the readings are not stable then the average value over approximately 2 to 3 minutes should be recorded.
- **For air heaters with rotating packs (Ljungstrom type)** the gas sample measurements should be recorded when the reading stabilises. If the readings are not stable then the average value over approximately 3 to 4 minutes should be recorded.
- **For air heaters with rotating hoods (Rothemuhle type)**
  - **On the gas Inlet** the gas sample measurements should be recorded when the reading stabilises. If the readings are not stable then the average value over approximately 3 to 4 minutes should be recorded.,
  - **On the gas outlet** from the air heater the gas sample measurements should be over a period of two or more full rotations of the hood (ie. 2, 3, 4, … etc). This is necessary because O_2, temperature and velocity readings will not be constant, but will vary with time according to the rotation of the hoods. For example, if the air heater rotational speed is 0.6 rpm, then a single rotation will take place every 1.67 minutes. The minimum period of sampling for this air heater should be 3.33 minutes (2 rotations), or 5 minutes (3 rotations), or 6.67 minutes (4 rotations), etc.

If possible the flue gas analyser should be set to automatic data logging at a minimum of 3 second intervals. This will not only improve the accuracy of measurements at each point but (especially for Rothemuhle type air heaters) this will help the operator to identify the exact rotational period in order to compute accurate results after the test.

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Where it is not possible to have automatic data logging of measurements, then the operators must take special care at the gas outlet where Rothemuhle type air heaters (rotating hoods) are concerned. All parameters (velocity, temperature and O_2) must be manually recorded at the same time as the maximum and minimum peak readings of O_2. For each traverse point the averaged values for each of the peaks (maximum and minimum of O_2) should be calculated, and the final measurement result for each traverse point will be the average of the maximum and minimum readings.

Proper steps shall be taken to prevent air ingress in gas analysing apparatus and sampling lines. Apparatus should be kept clean to maintain calibration accuracy.

On some stations (especially those with high ash content), additional purging of the sampling probe pitot tube will be necessary to prevent ash blockages in the sampling tube. It is recommended that station compressed air be used to blow through the probe in the reverse direction, after rotating the probe to point the pitot downstream of the flow. In extreme cases this may need to be repeated between each reading.

Human errors can be minimised by employing careful operators who are given adequate information on common sources of error.

The recommended maximum permissible deviation in inlet O_2 between test runs is ±1.5% O_2 (Table 4).

3.6.4 Flue Gas And Air Flow

Flue gas and air quantity shall be determined by calculation from either pitot tube traverse or heat balance. If air inlet flow is measured, a check should be made for any air drawn off after the forced draft fan (such as mill primary or tempering air) before the air preheater. If leakage through bypass or recirculating dampers is significant it must be taken into account and any possible influence of hot and cold crossover ducts will have to be considered.

For determination air heater performance, air and gas flows should be measured at points where there are the least disturbances and variations in the flow conditions. This is generally on the upstream side of the air heater. Once air leakage has been determined using O_2 measurements (section 3.6.3), the leakage flow can be applied as a correction to determine the air and gas outlet flows from the air heater. These calculated flows can also be used as a check on air and gas outlet flows measured during the O_2 measurement process.

3.6.5 Static Pressure

Static pressures shall be measured by one of the following methods:

- Connect the manometer to pressure tappings on the faces of the preheater transition ducts. Experience has shown that side-wall static tappings give sufficiently accurate values of average static pressures compared to those obtained with traverses.
- If no side-wall tappings are available, traverses should be employed using a probe as detailed in Figure 1.

3.6.6 Velocity Weighting

O_2 measurements often vary significantly across the flue gas duct. It is therefore recommended that the measurements at individual locations in the duct cross section be weighted in proportion to the gas flow at the corresponding locations, and an average of the weighted values be used as representing the measurement at the cross section. Velocity pressures should be measured using a pitot-tube at the same positions and time as the gas sampling/temperature measurements. (See Figure 1).

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3.7 SPECIAL CONSIDERATIONS AFFECTING AIR PREHEATER PERFORMANCE

Conditions which affect the air preheater performance and which should be given special consideration are:

- Quantity of air and gas passing through the air preheater
- Temperature of air and gas entering the air preheater
- Air preheater leakage (condition of seals)
- Recirculating or bypassing of air to control cold-end temperature
- Tempering air and furnace in leakage which did not pass through the heater
- Fouled, worn or corroded elements

3.8 CALCULATIONS AND FORMULAE

For clarification of the symbols in the following equations, please refer to the Abbreviations and Definitions section of this document.

Where applicable, many of the following equations can be used for primary and secondary air flows, and for primary and secondary air heaters.

3.8.1 Leakage

The leakage expressed as a percentage of the gas inlet mass flow (*L*) is calculated by:

$$L = \left(\frac{O_2 out - O_2 in}{20.9 - O_2 out}\right) x\ Factor\ x\ 100\%$$

For Eskom reporting purposes the value of *Factor* may be determined by the formula given in Howden procedure ES 1023:

$$Factor = \left[\frac{1.28701}{\rho_g} - 1.6011 \times k\right] \times 99$$

The factor converts from a dry basis to a wet basis. For accurate determination of the factor it is necessary to do an Ultimate Coal analysis or a Flue gas constituents analysis. In practice the value of the factor changes little.

For purposes of this standard the value of *Factor* may be approximated as equal to 0.89.

3.8.2 Undiluted Gas Exit Temperature

$$T_{g_{2NL}} = L \times \left(T_{g_2} - T_{a_1}\right) + T_{g_2}$$

Where L is the leakage expressed as a decimal

3.8.3 Temperature Differentials

Gas side $\Delta T_g = T_{g_1} - T_{g_{2NL}}$

Air side $\Delta T_a = T_{a_2} - T_{a_1}$

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3.8.4 Effectiveness

Gas side $\eta_g = \frac{T_{g_1} - T_{g_{2NL}}}{T_{g_1} - T_{a_1}} \times 100$

Air side $\eta_a = \frac{T_{a_2} - T_{a_1}}{T_{g_1} - T_{a_1}} \times 100$

3.8.5 Pressure Drops

Gas side pressure drop: $Ps_{g_1} - Ps_{g_2} = \Delta P_g$
Air side pressure drop: $Ps_{a_1} - Ps_{a_2} = \Delta P_a$

3.8.6 Pressure Differentials

Hot End Pressure Differential: HEPD= $Ps_{a_2} - Ps_{g_1}$
Cold End Pressure Differential: CEPD= $Ps_{a_1} - Ps_{g_2}$

3.8.7 Mean Specific Heats

$Cp_g = \frac{(T_{g_1} \times Cp) - (T_{g_{2NL}} \times Cp)}{T_{g_1} - T_{g_{2NL}}}$; $Cp_a = \frac{(T_{a_1} \times Cp) - (T_{a_2} \times Cp)}{T_{a_1} - T_{a_2}}$

Cp is the specific heat of the gas or air at the temperature to the left of it in the parenthesis.

3.8.8 Air and Gas Density

In order to apply the remaining calculations in this standard, air and flue gas density is required.

A standard methodology for determining flue gas density in Eskom is currently being developed and will be included in future revisions of this standard.

3.8.9 Gas and Air Velocity and Mass Flow from Velocity Pressure

Velocity Pressure; Pv=$\frac{1}{2x1000}\rho . v^2$ so velocity $v = \sqrt{\frac{2 \times 1000 \times Pv}{\rho}}$

Mass flow rate; $\dot{M} = \rho \times A \times v$ $= \rho \times A \times \sqrt{\frac{2 \times 1000 \times Pv}{\rho}}$ $= \sqrt{\rho} \times A \times \sqrt{2000} \times \sqrt{Pv}$

Where $\sqrt{Pv}$ is the average of the sum of the individual square roots of *Pv* obtained from the pitot traverse across a duct of area A m^2, and *p* is the density of the flow being measured. If a non-standard pitot tube is used (e.g. an S-type pitot) a correction factor may be required for the measured velocity pressure.

3.8.10 Air Preheater Energy Balance

When performing the energy balance, we assume that the radiation losses are insignificant.

Tubular preheater or Bi-sector Rotary Regenerative heater

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$$\dot{M}_{g1} \times \Delta T_g \times Cp_g = \dot{M}_{a_2} \times \Delta T_a \times Cp_a$$

Tri-sector and Quad-sector Rotary Regenerative heater:

$$\dot{M}_{g_1} \times \Delta T_g \times Cp_g = \left[\dot{M}_{a_2} \times \Delta T_a \times Cp_a\right]Primary + \left[\dot{M}_{a_2} \times \Delta T_a \times Cp_a\right]Secondary$$

3.9 MEASUREMENT OF MASS FLOWS AND CALCULATION OF UNKNOWN FLOWS

3.9.1 Tubular preheater

It is often convenient to measure the air inlet flow to the heater at tubular heater inlet. It is then possible to calculate the other flows from the heat balance equation:

$$\dot{M}_{g_1} = \frac{\dot{M}_{a_1} \times \Delta T_a \times Cp_a}{(\Delta T_g \times Cp_g) + (\Delta T_a \times Cp_a \times L)}$$

$$\dot{M}_{a_2} = \frac{M_{g_1} \times \Delta T_g \times Cp_g}{\Delta T_a \times Cp_a}$$

$$\dot{M}_{g_2} = \dot{M}_{g_1} \times (1 + L)$$

3.9.2 Bi-sector Rotary regenerative preheater

It is often convenient to measure the air inlet flow to the heater from test points of the FD fan outlet. It is then possible to calculate the other flows from the heat balance equation:

$$\dot{M}_{g_1} = \frac{\dot{M}_{a_1} \times \Delta T_a \times Cp_a}{(\Delta T_g \times Cp_g) + (\Delta T_a \times Cp_a \times L)}$$

$$\dot{M}_{a_2} = \frac{M_{g_1} \times \Delta T_g \times Cp_g}{\Delta T_a \times Cp_a}$$

$$\dot{M}_{g_2} = \dot{M}_{g_1} \times (1 + L)$$

3.9.3 Tri-sector and Quad-sector Rotary regenerative preheater

These air preheaters have two/three separate flows of air through the rotor. The leakage measured by the Oxygen concentrations gives the total air to gas leakage from both the Primary and Secondary flows, and it is not possible to determine how much of this total comes from each air flow, or how much air passes from the high pressure Primary to the lower pressure Secondary air side. With these unknowns, the measurement of the two air inlet flows and manipulation of the heat balance equation will not work. For an accurate analysis, the air outlet mass flows require to be measured and the following equations used to calculate the gas flows:

$$\dot{M}_{g_1} = \frac{\left[\dot{M}_{a_2} \times \Delta T_a \times Cp_a\right]Primary + \left[\dot{M}_{a_2} \times \Delta T_a \times Cp_a\right]Secondary}{\Delta T_g \times Cp_g}$$

$$\dot{M}_{g_2} = \dot{M}_{g_1} \times (1 + L)$$

Note: It is very difficult to measure the hot primary air flow, as it has a very high positive pressure. Protective equipment may be required for the test personnel, and the space around the sampling tube

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into the duct should be sealed to ensure effective readings.

Where an ultimate analysis of the fuel and the quantity burned per unit time is known, a check can be made against the calculated gas mass. The gross or net calorific value of the fuel and the boiler excess air percentage are also required for this procedure. (See 36-1263 Air Heater Performance Procedure)

3.10 THERMAL PERFORMANCE

Air preheater thermal performance is measured by means of X-ratio or LMTD (Log Mean Temperature Difference).

X-ratio is defined as the ratio of the heat capacity of the air passing through the air heater to the heat capacity of the gas passing through the air heater and is given as follows.

$$X_R = \frac{\dot{M}_{a_2}.Cp_a}{\dot{M}_{g_1}.Cp_g} = \frac{T_{g_1} - T_{g_{2NL}}}{T_{a_2} - T_{a_1}}$$

The value of the X-ratio will always be less than 1. Values should typically be greater than 0.9, with higher values indicating better thermal performance.

Thermal performance may also be analysed by determining the air heater Log Mean Temperature Difference (LMTD).

$$LMTD = \frac{(T_{g_2} - T_{a_1}) - (T_{g_1} - T_{a_2})}{Log_e((T_{g_2} - T_{a_1})/(T_{g_1} - T_{a_2}))}$$

3.11 SCHEDULE OF ITEMS TO AGREE PRIOR TO TESTING

Table 4: Accuracy tolerances of test parameters

ITEM	Standard Value
Total Temperature measurement instrument tolerance	± 1.5 °C
Oxygen analyser instrument tolerance	± 0.15% O_2
Pressure measurement instrument tolerance	± 4%
Permissible deviation in gas side effectiveness test runs	± 7.5%
Permissible deviation in inlet oxygen level from design conditions	±1.5%
Permissible deviation in inlet oxygen level between test runs	±1.5%
Zero calibration gas	0.0% O_2, 100.0% N_2
Span calibration gas	5.0% O_2, 95.0% N_2

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Date	Rev.	Compiler	Remarks
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6. DEVELOPMENT TEAM

The following people were involved in the development of this document:

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