8.8 BOILER EFFICIENCY TEST

8.8.1 Introduction

This procedure provides a systematic approach for conducting routine boiler efficiency tests on pulverized coal fired units.

The result of this testing shall enable computation of Gross Boiler Efficiency. This procedure is based on the abbreviated efficiency test, offered in the ASME PTC 4-1998 and BS 2885 (1974). All the major boiler efficiency losses are quantified and corrections to design coal and design ambient temperature are applied.

The test method employed by this procedure is based on the abbreviated efficiency by the loss method. The abbreviated version neglects the minor losses and heat credits. Boiler efficiency, Beff, can be expressed by the following equation.

Beff = 100 % - L

Where L = the summation of the major heat losses

L = Ldg + Luc + Lmf + Lhf + Lco + Lma + Lun

- Ldg - heat loss due to dry gas
- Luc - heat loss due to combustibles in refuse
- Lmf - heat loss due to moisture in the fuel
- Lhf - heat loss due to moisture of burning hydrogen
- Lco - heat loss due to carbon monoxide
- Lma - heat loss due to moisture in air
- Lun - heat loss due to radiation and Unaccounted losses

Unaccounted losses typically include sensible heat loss with flyash and bottomash, radiation loss through bottom ash hopper, coal mill reject loss etc. The individual heat losses calculations are appended as Annexure 1.

8.8.2 Objectives

The Objectives of the routine boiler efficiency test are as follows.

1. To compute boiler efficiency and provide information to assist in identifying the cause of the changes, if any

2. To provide information to allow accounting for the contribution of boiler performance deficiencies on unit heat rate and capacity

8.8.3 Parameters required for Efficiency Computation

Proximate Coal Analysis – 'As Fired'	**Units**
Moisture	%
Ash	%
Volatile Matter	%
Fixed Carbon	%
Gross Calorific Value	kcal/kg
Parameters	
Avg. Flue Gas O2 - AH Out	%
Avg. Flue Gas CO2 - AH Out	%
Avg. Flue Gas CO - AH Out	ppm
Avg. Flue Gas Temp - AH In	C
Avg. Flue Gas Temp - AH Out	C
Avg. Primary Air to AH Temp In	C
Avg. Primary Air from AH Temp Out	C
Avg. Secondary Air to AH Temp In	C
Avg. Secondary Air from AH Temp Out	C
Total Secondary Air Flow	T/hr
Total Primary Air Flow	T/hr
Design Ambient / Ref Air Temp	C
Wet Bulb Temp	C
Dry bulb Temp	C
Barometric Pressure	mmHgC
Unburnt C in Bottom Ash	%
Unburnt C in Flyash	%
% of Flyash to Total Ash	%
% of Bottom ash to Total Ash	%

8.8.4 Test Procedure

8.8.4.1 Unit Operation- Operating Conditions of Test Runs

Test runs are conducted at defined optimum baseline settings for each unit based on station experience. All tests are to be conducted at full load at the optimum set of operating parameters to the extent possible. The operating conditions for each test run are as follows.

- i. Furnace wall blowers and the air heater soot blowers are operated prior to the efficiency test.
- ii. The soot blowing cycle is completed at least an hour before testing to ensure roughly the same level of furnace cleanliness in all the tests.
- iii. No furnace or air heater soot blowing is done during the test.
- iv. Unit operation is kept steady for at least 60 minutes prior to the test.
- v. Main Steam pressure and temperature and Reheat Steam temperature are set as close to design values as possible.
- vi. Steam coil Air heaters' (SCAPH) steam supply is kept isolated and gas recirculation dampers if any, are tightly shut.
- vii. Auxiliary PRDS steam flow from the unit being tested is kept isolated.
- viii. Continuous Blow down, Intermittent Blow down is not operated during the test.
- ix. No mill change over is done during the test.
- x. The test is abandoned in case of any oil support during the test period.
- xi. Bottom ash hopper deashing is done prior to the test stabilization period.
- xii. Eco hopper deashing or Bottom hopper deashing is not done during the test.
- xiii. Regenerative system should be in service with normal mode.

8.8.4.2 Test Duration

Each test would be of **two-hour** duration, subject to the completion of measurement and sampling at various locations.

8.8.4.3 Data Collection and Measurement Locations

8.8.4.3.1 Control Room Data - A separate test log for control room data shall be created in unit DAS for data collection at an interval of five minutes or less and averaged over the test period.

The online measurements of flue gas and air temperatures at air heater inlet and outlet are used for efficiency computations.

It’s important to ensure that the online measurements of air and flue gas temperatures are representative of average temperatures in the duct. The on line feedback of flue gas exit temperature after air heaters can be affected by gas stratification and may require more number of thermocouples than presently installed.

In some layouts, the online thermocouples for flue gas temperature measurement are mounted too close to air heaters in a cluster and need to be relocated for representative measurement. Similarly the location and number of temperature sensors on airside at air heater inlet and outlet should be reviewed to obtain a representative average.

The new locations can be decided only by doing multiple point temperature measurements in a plane perpendicular to the flow in the respective ducts. The number of measurement points is determined as per ASME PTC 19.10, ‘Flue and Exhaust Gas Analysis’ and would vary with duct configuration and size.

8.8.4.3.2 Field Measurements / Sampling - The following field measurements / sampling are done simultaneously during the test period.

1) Air Heater Outlet - Flue Gas Composition (O_2 / CO_2 /CO)
2) Ambient air-conditions using psychrometer
3) Feeder inlet chutes of all running feeders - ‘As fired’ coal sample
4) ESP hoppers – Fly ash Sample for unburnt carbon
5) Bottom ash hoppers / scrappers - Bottomash Sample for unburnt Carbon

8.8.4.3.3 Air Heater Outlet - Flue Gas Sampling (Fig 8.8.1)

A representative value of flue gas composition (O_2 / CO_2 /CO) is obtained by grid sampling of the flue gas at multiple points in a plane perpendicular to the flow at air heater outlet.

The test ports in flue gas duct at AH outlet are made as per ASME PTC 19.10 for a grid measurement. The number of measurement points would vary with duct configuration and size.

The gas outlet traverse plane is located as far downstream from the air heater as possible, to allow mixing of the flow to reduce temperature and 0_2 stratification.

However, it should not be located downstream of other equipment or access ways that might contribute to air ingress (e.g. Mechanical collectors, ESPs, manholes, or ID fans).

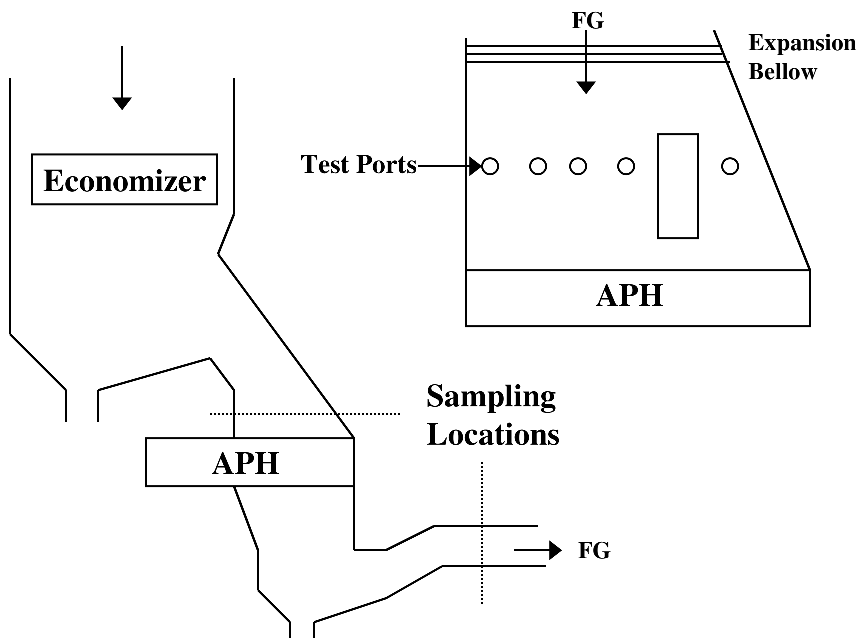

Fig-8.8.1

If a single point sampling is to be done, the representativeness of the point and its repeatability should be ensured by a grid survey. A portable O_2 / CO_2 / CO gas analyzer is used to draw a sample from the flue gas ducts. Orsat apparatus can be used if a portable analyzer is not available.

In 500 MW units, the flue gas sampling and temperature measurement should be done in the common flue gas duct of Primary and Secondary air heater outlet on each side.

8.8.4.3.4 Ambient air-conditions using psychrometer

Dry Bulb and Wet Bulb temperature measurement is done using a calibrated psychrometer near FD fan inlet at the start of the test and at the end of the test and an average is computed for the test period.

8.8.4.3.5 'As fired' Coal Sampling

Coal sampling is done manually from feeder inlet chutes of all running feeders during the test and a representative sample prepared from the gross sample collected by quartering and coning.

A minimum of two samples from each feeder should be collected during the test.

A separate coal sample is collected for determination of total moisture and kept in a sealed container. For conversion of Proximate and Ultimate analysis of coal on 'Air dried basis' to 'As fired basis' multiply each component by X, which shall remain as it is.

$$X = \frac{(100 - \text{Total moisture})}{(100 - \text{Air dried moisture})}$$

The 'as fired' proximate analysis of coal and GCV shall be reported on 'Total Moisture' basis.

8.8.4.3.6 Flyash Sampling

Flyash samples for determination of 'unburnt carbon in flyash' are collected from hoppers of the ESP fields. Two incremental samples, one from the hoppers on left side and one from the hoppers on right side of ESP are collected separately and sent to labs for analysis.

A convenient method for representative flyash sampling during the test involves removing fly ash from the gas stream using a High Volume sampling probe at economiser outlet on both sides of the boiler. The flue gas is sucked using an air aspirator and passed through a cylinder containing filter paper that catches the fly ash in collection canister. One probe is traversed on either side simultaneously during the test and flyash sample is collected separately from left and right side.

8.8.4.3.7 Bottom Ash Sampling

In case of scrappers incremental bottom ash sample from scrapper system is collected during the test.

In case of impounded hoppers, ash sample is collected after completion of the test from the Ash Slurry discharge end using a cup type probe. Incremental samples are collected from each of the disposal line till the flushing is complete to form a gross sample.

8.8.4.3.8 Results

A typical calculation of the losses is enclosed as Annexure I. All the losses and the boiler efficiency have been corrected using the design values of coal and design ambient conditions. A formal report including the test conditions, test results, any unusual findings and recommendations is prepared for every test. A typical format is enclosed as Annexure II.

8.8.5 References

BS 2885 – September 1974

ASME PTC 19.10, Flue and Exhaust Gas Analysis

ASME PTC 4 – 1998, Fired Steam Generators

Annexure 1 - Typical Boiler Efficiency Computation

1 Conversion from Proximate Analysis to Ultimate Analysis

PROXIMATE ANALYSIS : Reporting of Proximate Analysis of as fired coal should be on 'Total Moisture' basis

		TEST
TOTAL MOISTURE	---------	M - %
ASH	---------	A - %
VOLATILE MATTER	---------	VM - %
FIXED CARBON	---------	FC - %
		TOTAL - 100 %

FcDc(T)=FREE CARBON ON DRY ASH FREE BASIS $= \dfrac{FC}{\left[1 - 1.1 * \dfrac{A}{100} - \dfrac{M}{100}\right]}$

VmDf(T) = VOLATILE MATTER ON DRY ASH FREE BASIS = [100 - FcDc(T)]

Cdf(T)=FIXED CARBON ON DRY ASH FREE BASIS =[FcDc(T)+ 0.9*[VmDf(T) – 14]

Hdf(T)= HYDROGEN ON DRY ASH FREE BASIS $= VmDf(T) * \left[\dfrac{7.35}{VmDf(T) + 10} - 0.013\right]$

Ndf(T) = NITROGEN ON DRY ASH FREE BASIS = [2.1 - (0.012 * VmDf(T)]

Ca % = CARBON PERCENTAGE (ULTIMATE VALUE) $= \dfrac{Cdf(T) * [VM + FC(T)]}{[VmDf(T) + FcDc(T)]}$

H % = HYDROGEN PERCENTAGE (ULTIMATE VALUE) $= \dfrac{Hdf(T) * [VM(T) + FC]}{[VmDf(T) + FcDc(T)]}$

N % =NITROGEN PERCENTAGE (ULTIMATE VALUE) $= \dfrac{Ndf(T) * M(T) + C(T)]}{[VmDf(T) + FcDc(T)]}$

S % = SULPHER PERCENTAGE (ULTIMATE VALUE)
= ASSUMED AS PER SITE REFERENCE VALUE.

0 % =OXYGEN PERCENTAGE (ULTIMATE VALUE)= 100 – M - A – Ca – H – N - S

2	Summary		
		As Run	**Corrected**
	Efficiency	**86.47**	**87.26**
	Total Losses	13.53	12.74
1	Dry Gas Loss	4.62	4.71
2	Loss due to Unburnt Carbon	0.55	0.55
3	Loss due to moisture in fuel	2.28	2.26
4	Loss due to Hydrogen in Fuel	4.72	3.90
5	Loss due to Carbon monoxide	0.02	0.02
6	Loss due to moisture in air	0.14	0.11
7	Radiation & unaccounted Loss	1.20	1.20

Inputs	**Units**	**Symbol**	**Value**
Unit Load	MW	L	210
FW Flow at Eco Inlet	T/hr	Ffw	615
Wet Bulb Temp	C	Wb	24
Dry bulb Temp	C	Db	30
Barometric Pressure	mmHgC	BP	760
Total Coal Flow	T/hr	Fin	140
Unburnt C in Bottom Ash	%	Cba	1.2
Unburnt C in Flysash	%	Cfa	0.4
Radiation & Unaccounted Loss	%	Lrad	1.2
% of Flyash to Total Ash	%	Pfa	80
% of Bottom ash to Total Ash	%	Pba	20
Ultimate Analysis - As Fired			
Carbon	%	Ca	36.4
Sulfur	%	S	0.6
Hydrogen	%	H	2.8
Moisture	%	M	12.2
Nitrogen	%	N	1
Oxygen	%	O	7
Ash	%	A	40
Gross Calorific Value	kcal/kg	Gcv	3320
Avg. Flue Gas O2 - APH In (optional)	%	O2in	3.5
Avg. Flue Gas CO2 - APH In (optional)	%	CO2in	15.8
Avg. Flue Gas CO - APH In (optional)	ppm	COin	39

Avg. Flue Gas O2 - APH Out	%	O2out	5.0
Avg. Flue Gas CO2 - APH Out	%	CO2out	14.3
Avg. Flue Gas CO - APH Out	ppm	COout	50
Avg. Flue Gas Temp - APH In	C	Tgi	350
Avg. Flue Gas Temp - APH Out	C	Tgo	135
Primary Air to APH Temp In	C	Tpai	40
Primary Air from APH Temp Out	C	Tpao	325
Secondary Air to APH Temp In	C	Tsai	34
Secondary Air from APH Temp Out	C	Tsao	325
Total Secondary Air Flow	T/hr	Fsa	450
Total Primary Air Flow	T/hr	Fpa	250
Design Ambient / Ref Air Temp	C	Tref	30

Computations

	Losses - Test Conditions	**Unit**	**Symbol**	**Value**
1	Dry Gas Loss			
	= Sh*100/(Gcv*4.186)	%	Ldg	4.617
	Carbon in fuel	%	Ca	36.4
	Sulfur in fuel	%	S	0.6
	Carbon in ash / kg of fuel	kg/kg coal	U	0.002253
	Specific heat of gas	kg/kg/C	Cp	30.6
	Avg. Flue Gas Temp - APH Out	C	Tgo	135
	Unburnt C in ash = Pfa/100*Cfa + Pba/100*Cba	%	Cash	0.56
	C in ash / kg of coal = A/100*Cash/(100-Cash)	kg	U	0.00225
	Total air flow = SA + PA flow	T/hr	Fta	700
	Ratio SA flow to Total Air flow = Fsa/Fta	%	Rsa	0.64
	Ratio PA flow to Total Air flow = Fpa/Fta	%	Rpa	0.36
	Weighted Temp Air In = Tsai*Rsa + Tpai*Rpa	C	Trai	36.1
	Weighted Temp Air Out = Tsao*Rsa + Tpao*Rpa	C	Tao	325
	Avg. Flue Gas CO2 - APH Out	%	CO2out	14.3

	Gross CV	kcal/kg	Gcv	3315.19
	Weight of dry gas = (Ca+S/2.67-100*U)/(12*CO2out)	kg/kg coal	Wd	0.2121
	Sensible Heat dry gas = Wd*30.6(Tgo-Trai)	kJ/kg	Sh	641.66
2	**Loss due to Unburnt Carbon**			
	= U*CVc*100/Gcv	%	Luc	0.55
	Carbon in Ash / kg of coal	kg/kg coal	U	0.00225
	CV of Carbon	kcal/kg	CVc	8077.8
	Gross CV	kcal/kg	Gcv	3320
3	**Loss due to moisture in fuel**			
	= Sw*M/(Gcv*4.186)	%	Lmf	2.284
	Moisture in Fuel	%	M	12.2
	Avg. Flue Gas Temp - APH Out	C	Tgo	135
	Weighted Temp Air - APH In	C	Tai	36.1
	Gross CV	kcal/kg	Gcv	3320.0
	Sensible heat of water vapour Sw = 1.88*(Tgo -25)+2442+4.2*(25-Trai)	kJ/kg	Sw	2602
4	**Loss due to Hydrogen in Fuel**			
	=9*H*Sw/ (Gcv*4.186)	%	Lhf	4.72
	Hydrogen in fuel	%	H	2.8
5	**Loss due to Carbon monoxide**			
	= COoutp*7*Cvco*(Ca-100*U) /3 / (CO2out+Cooutp) / Gcv	%	Lco	0.021
	Avg. Flue Gas CO2 - APH Out	%	CO2out	14.3
	Avg. Flue Gas CO - APH Out	%	Cooutp	0.005
	Carbon in fuel	%	Ca	36.4
	CV of Carbon Monoxide	kcal/kg	CVco	2415
	Gross CV	kcal/kg	Gcv	3320
	Carbon in Ash / kg of coal	kg/kg coal	U	0.002253

6	**Loss due to moisture in air**			
	= Ma*1.88*(Tgo-Trai)*100/(Gcv*4.186)	%	Lma	0.139
	Carbon in fuel	%	Ca	36.4
	Hydrogen in fuel	%	H	2.8
	Sulfur in fuel	%	S	0.6
	Oxygen in fuel	%	O	7
	Carbon in ash / kg of fuel	kg/kg coal	U	0.002253
	Gross CV	kcal/kg	Gcv	3320
	Moisture in Air (from Psychrometric Chart)	kg/kg	Mwv	0.0165
	Ref.air temp	C	Trai	36.14
	Avg. Flue Gas Temp - APH Out	C	Tgo	135
	Avg. Flue Gas O2 - APH Out	%	O2out	5
	Avg. Flue Gas N2 - APH Out = 100 - (O2out-CO2out-Cooutp)	%	N2out	80.7
	Stoichiometric air = (2.66*(C-U*100)+7.937*H+0.996*S-O)/23.2	kg/kg coal	Sa	4.83
	Excess Air = 1+[(O2out-Cooutp/2)]/ [0.2682*N-(O2out-Cooutp)]		Ea	1.30
	Total Moisture in air = Sa*Ea*Mwv	%	Ma	0.1036

Corrections to Design

Design Conditions	**Unit**	**Symbol**	**Value**
Proximate - As Fired			
Moisture	%	Md	13
Ash	%	Ad	40
Volatile Matter	%	VMd	24
Fixed Carbon	%	FCd	23
Ultimate Analysis - As Fired			
Carbon	%	Cd	37
Sulfur	%	Sd	0.3
Hydrogen	%	Hd	2.3
Moisture	%	Md	12
Nitrogen	%	Nd	0.8
Oxygen	%	Od	7.6
Ash	%	Ad	40

Gross Calorific Value	kcal/kg	Gcvd	3300
Ambient Temperature	C	Tadd	30
Relative Humidity		RH	60
Gas Temp Leaving AH – Corr to design ambient			
Ambient Temp - test	C	Tad	30
Ambient Temp - design	C	Tadd	30
Ref. Air Temp - test	C	Trai	36.14
Ref. Air Temp - design	C	Trad	36.14
=Tadd+(Trai-Tad)			
Gas Temp entering AH - test	C	Tgi	350
Gas Temp leaving AH - test	C	Tgo	135
Gas Temp leaving AH (Corr) = (Trad*(Tgi-Tgo)+Tgi*(Tgo-Trai)) / (Tgi-Trai)	C	Tgc	135.00

Losses - Corrected to Design

1. Dry Gas Loss			
=Shc*100/Gcvd/4.186	%	Ldgc	4.707
Carbon in fuel	%	Cd	37
Sulfur in fuel	%	Sd	0.3
Carbon in ash / kg of fuel	kg/kg coal	U	0.00225
Specific heat of gas	kg/kg/C	Cp	30.6
Avg. Flue Gas Temp - APH Out	C	Tgc	135.00
Ref Air Temp - design	C	Trad	36.14
Avg. Flue Gas CO2 - APH Out	%	CO2out	14.3
Gross CV	kcal/kg	Gcvd	3300
Weight of dry gas = (Cd+Sd/2.67-100*U)/(12*CO2out)	kg/kg coal	Wdc	0.2150
Sensible Heat dry gas = Wdc*30.6(Tgc-Trad)	kJ/kg	Shc	650.26

3. Loss due to Unburnt Carbon - Corrected			
= Luc* [(Ad * Gcv) / (A * Gcvd)] +V	%	Lucc	0.553
V = 0 (where volatile matter of fuel < 17 %)			
If the volatile matter > 17 % then			
V = .013 * [(Ad * Gcv) / (A * Gcvd)] * K			
K = Exp [0.225 * Cd/Hd] – Exp [0.225 Ct/Ht]			
Ash -test	%	A	40
Ash -design	%	Ad	40
Volatile Matter - test	%	VM	22.93
Volatile Matter - design	%	VMd	24
Test Unburnt Carbon Loss		Luc	0.55
3. Loss due to moisture in fuel (Corrected)			
= Sw*Md/(Gcvd*4.186)	%	Lmfc	2.260
Moisture in Fuel - design	%	Md	12
Avg. Flue Gas Temp - APH Out (corr)	C	Tgc	135.00
Ref Air temp - design	C	Trad	36.14
Gross CV - design	kcal/kg	Gcvd	3300
Sensible heat of water vapour Sw = 1.88*(Tgc-25)+2442+4.2*(25-Trad)	kJ/kg	Swd	2602
4. Loss due to Hydrogen in Fuel			
=9*Hd*Swd/(Gcvd*4.186)	%	Lhfc	3.899
Hydrogen in fuel - design	%	Hd	2.3
5. Loss due to Carbon monoxide			
= Cooutp*7*Cvco*(Cd-100*U) /3 / (CO2out+Cooutp) / Gcvd	%	Lcoc	0.022
Avg. Flue Gas CO2 - APH Out	%	CO2out	14.3
Avg. Flue Gas CO - APH Out	%	Cooutp	0.005
Carbon in fuel - design	%	Cd	37
CV of Carbon Monoxide	kcal/kg	CVco	2415
Gross CV - design	kcal/kg	Gcv	3300
Carbon in Ash / kg of coal	kg/kg coal	U	0.00225

6. Loss due to moisture in air			
= Mad*1.88*(Tgc-Trad)*100/(Gcvd*4.186)	%	Lmac	0.107
Carbon in fuel - design	%	Cd	37
Hydrogen in fuel - design	%	Hd	2.3
Sulfur in fuel - design	%	Sd	0.3
Oxygen in fuel - design	%	Od	7.6
Carbon in ash / kg of fuel	kg/kg coal	U	0.00225
Gross CV - design	kcal/kg	cvd	3300
Moisture in Air (from Psychrometric Chart)	kg/kg	Mwvd	0.013
Ref. air temp - design	C	Trad	36.1429
Avg. Flue Gas Temp - APH Out (Corr.)	C	Tgc	135.00
Avg. Flue Gas O2 - APH Out	%	O2out	5
Avg. Flue Gas N2 - APH Out = 100 - (O2out-CO2out-Cooutp)	%	N2out	80.7
Stoichiometric air = (2.66*(Cd-U*100)+7.937*Hd+0.996*Sd-Od)/23.2	kg/kg coal	Sad	4.69
Excess Air = 1+[(O2out-Cooutp/2)]/[0.2682*N2out-(O2out-Cooutp)]		Ead	1.30
Total Moisture in air = Sad*Ead*Mwvd	%	Mad	0.0792

Boiler Efficiency Test Report

Station: **Unit:**			**Report date:** **Test Date:**		
Test Condition					
Unit Load	MW		Coal Flow	T/hr	
Steam Flow	T/hr		Mills in service	Nos.	
Air flow	T/hr		FW inlet temperature	C	
Flue Gas analysis			**Avg. Air Temperatures**		
AH Inlet O_2 L/R (UCB)	%		Design air inlet temp	C	
AH Inlet O_2 L/R (Local)	%		Dry Bulb Temperature	C	
AH outlet Avg. O_2	%		Wet Bulb Temperature	C	
AH outlet Avg. CO_2	%		PAPH Air inlet Temp	C	
AH outlet Avg. CO	ppm		SAPH Air inlet Temp	C	
PAPH-A/B Gas O/L Temp	C		PAPH Air outlet Temp	C	
SAPH-A/B Gas O/L Temp	C		SAPH Air Outlet Temp	C	
Coal - Proximate Analysis			**Unburned C in ashes**		
Moisture	%		Unburnt C in bottom ash	%	
Ash	%		Unburnt C in fly ash	%	
Volatile Matter	%				
Fixed Carbon	%				
GCV	kcal/kg				

Heat Losses	Unit	PG Test Value	Uncorrected Test Value	Corrected Test Value
Dry Gas Loss	%			
Loss due to Unburnt Carbon	%			
Loss due to moisture in fuel	%			
Loss due to Hydrogen in Fuel	%			
Loss due to Carbon monoxide	%			
Loss due to moisture in air	%			
Radiation & unaccounted Loss	%			
BOILER EFFICIENCY	**%**			

Remarks

Format No-8.8.1