Energy Performance Assessment of CFBC Boiler

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***Abstract*— Steam power plant generates electricity by using fuel as input. In steam power plant boiler is a crucial part. Boiler is a most useful device for any developing industries to process & production. It also had some losses through some part of the boiler. Due to this, day by day fuel consumption increases and to maintain it at a constant level is required to evaluate the performance of the boiler. Performance assessment of the boiler is nothing but the calculating the efficiency of the boiler. The performance parameters of boiler, like efficiency and evaporation ratio reduces with time due to poor combustion, heat transfer surface fouling and poor operation and maintenance. Even for a new boiler, reasons such as deteriorating fuel quality, water quality etc. can result in poor boiler performance. Boiler efficiency tests help us to find out the deviation of boiler efficiency from the best efficiency and target problem area for corrective action. Different methods are adopted for calculating efficiency of the boiler such as direct method and indirect method. Direct method does not include any losses for calculating boiler efficiency, while indirect method includes all the heat losses from a system to find boiler efficiency. This project will give the information about the efficiency of the CFBC boiler from 150 MW power plant by the indirect method. Any observed abnormal deviations could therefore be investigated.**

Keywords- Eefficiency of CFBC boiler, Heat balance sheet of CFBC boiler

I. INTRODUCTION

Economic growth of India being dependent on the power sector has necessitated an enormous growth in electricity demand over the last two decades. The establishment of a sustainable energy is one of the most pressing tasks of humanity. The initial developed reciprocating steam engine has been produce mechanical power since the 18th century. Now in the present scenario, steam power plants continuously convert the fuel heating energy to the electricity.

Now coming to the main part of the power plant which is Boiler. Boiler or steam generator is a device used to creat steam by applying heat energy to water. A boiler or steam generator is used wherever a source of steam is required. Boiler is a very crucial part of the power plant. So for this it is desired that to maintain it to a desired level. Here a CFBC (circulating fluidized bed combustion boiler) is taken for the study of some losses through some part of the boiler from a 150MW steam power plant. .

The CFBC boiler is said to be the second generation fluidized bed boiler. It is divided into two parts first is fluidized and the second one is the gas solid separator or say a cyclone. CFBC boiler is generally made of water tubes as in pulverized coal fired boilers. The primary combustion air enters the furnace through an air distributor or grate at the furnace floor. The secondary air is injected at some height above the grate to complete the combustion. Bed solids are well mixed throughout the height of the furnace. Thus, the bed temperature is nearly uniform in the range, though heat is extracted along its height. Relatively coarse particles are captured in the cyclone and unburned coal, larger than the cyclone cut-off size, are captured in the cyclone and are recycled back near the base of the furnace.

II. LITERATURE SURVEY

A) Coal analysis

P.K. Nag [5] explained the analysis of coal. According to this book the coal analysis are of two types, such as.

1) Ultimate Analysis
2) Proximate Analysis

Proximate analysis and ultimate analysis; both done on a mass percent basis.

Both these types may be based on

1) As-received basis useful for combustion calculation,
2) Dry or moisture free basis
3) Dry mineral-matter-free basis.

According to this proximate analysis of coal gives the information of FC, VM, M, ash, etc. And the other side the ultimate analysis gives the information about the chemical elements that comprise the coal substance together with ash and moisture.

B) CFBC boiler

P.K. Nag [5] through which we understand the functioning of the CFBC boiler. It gives an overview of the functioning of the boiler.

According to this, the CFBC boler is divided into two sections.

1) It consists of furnace or fluidized bed, cyclone, loop seal, and external heat exchanger.
2) The second section is the back-pass, where the remaining heat from the flue gas is absorbed by the economizer, superheater and air preheater.

C) Methods

Bureau of Energy Efficiency [6], it is a guide book. According to this book there are two methods to find out the efficiency of the boiler, and the two methods are given by as follows :-

1) Direct method
2) Indirect method

1) The Direct Method: Where the energy gain of the working fluid (water and steam) is compared with the energy content of the boiler fuel. This is also known as 'input-output method' due to the fact that it needs only the useful output (steam) and the heat input (i.e. fuel) for evaluating the efficiency
2) The Indirect Method: This method is based upon accurate and complete information which will make possible the calculations to determine all accountable losses and heat credits. The efficiency then is equal to 100 percent minus accountable losses expressed in percentage.

Rahul S.Patel, Prof. Bhavesh K.Patel [5] also explained the above two methods in their paper.

D) Losses

For the indirect method we must need all the losses occurs in the boiler. Mukesh Gupta, Raj Kumar, Manmohan Kakkar [4] The major heat losses from boiler are due to

1) High temperature flue gases leaving the stack (Dry flue gas)
2) Moisture in fuel and combustion air
3) Combustion of hydrogen
4) Heat in un- burnt combustibles in refuse
5) Radiation from boiler surfaces
6) Un- accounted losses.

But the above paper does not taking account of the combustible losses. Bureau of Indian Standards [10] proposed the consideration of the combustible losses. According to Bureau of Indian Standards [10], it plays an important role for the calculation of the boiler efficiency. As per the Bureau of Indian Standards [10] the combustible losses are found to be fewer boilers, if it is occurred we have to consider this.

E) Assumptions

Every method is underperformed by taking in account of some assumptions. In indirect method some assumptions are taken for the calculation of the efficiency of the boiler. Bureau of Energy Efficiency [6] has explained the assumptions which should be consider in the indierct method.

The assumptions are given by as follows :

1) Standby losses,
2) Blow down loss,
3) Soot blower steam,
4) Auxiliary equipment energy consumption.

F) Heat balance sheet

Heat balance shows the computed mass and energy flows between the major equipment of power plant. In this we are focusing on the boiler only. A heat stream is often the best way to present a heat balance since it is easy and everybody can understand the relative magnitude of energy involved in different section of heat power equipment.

Prabir Basu [9] explained the purpose of the heat balance sheet of the boiler. He proposed that The distribution of the heat supplied to the boiler as useful heat and lost heat is the basis for compiling the heat balance of a steam boiler.

Chetan T. Patel, Dr. Bhavesh K. patel, Vijay K. Patel, they had calculating efficiency of FBC boiler. The mathematical model in the Microsoft excel is prepared for the indirect method for finding boiler efficiency, because these method has a lots of calculation which make us a bore if the same calculation is required for the different value of GCV of coal. By using Microsoft excel the repeated calculations are being quite easy and time saving. Just change the various values and at the last you got the result immediately without any hand written time consuming paperwork.

III. Methodology

Indirect method:-

The efficiency can be measured easily by measuring all the losses occurring in the boiler. The disadvantages of the direct method can be overcome by this method, which calculates the various heat losses associated with boiler. The efficiency can be arrived at, by subtracting the heat loss fractions from 100. Indirect method is also called as method of losses.

The following losses which are given by as follows:-

1) L_1 - Loss due to dry flue gas (sensible heat)
2) L_2 - Loss due to hydrogen in fuel (H_2)
3) L_3 - Loss due to moisture in fuel (H_2O)
4) L_4 - Loss due to moisture in air (H_2O)
5) L_5 - Loss due to carbon monoxide (CO)

*Losses which are difficult to measure and mostly taken from the manuals.

6) L_6 - Loss due to surface radiation, convection and other unaccounted.
7) L_7 - Unburnt losses in fly ash (Carbon)
8) L_8 - Unburnt losses in bottom ash (Carbon)
9) L_9 - Losses due to combustibles

Boiler Efficiency by indirect method = 100 - ($L_1 + L_2 + L_3 + L_4 + L_5 + L_6 + L_7 + L_8 + L_9$)

Equations

Step 1: Calculate the theoretical air requirement:-This is the theoretical air required for the complete combustion. Fuel contains following elements such as:

1) Carbon
2) Hydrogen
3) Sulphur

And oxygen is already present in the fuel. So in burning process

$$C + O_2 \longrightarrow CO_2$$

12 32 44

1 32/12 44/12

So for 1kg of carbon required oxygen is = 32/12 = 8/3

For C kg of carbon required oxygen is = 8/3 × C

Now for hydrogen

$$2H_2 + O_2 \longrightarrow 2H_2O$$

4 32 20

1 8 5

So for 1kg of hydrogen required oxygen is = 8

For H_2 kg of hydrogen required oxygen is = 8 × H_2

Now for sulphur

$$S + O_2 \longrightarrow SO_2$$

32 32 64

1 1 2

So for 1kg of sulpher required oxygen is = 8 kg of O_2

For S kg of sulpher required oxygen is = 1 × S

So the total amount of oxygen required for the complete combustion of 1 kg of fuel it also called as theoretical air.

$$T_a = 8/3 \text{ kg of } O_2 \times C + 8 \text{ kg of } O_2 \times H_2 + S - O_2$$

$$T_a = 8/3 \text{ kg of } O_2 \times C + 8 \text{ kg of } O_2 (H_2 - O_2/8) + S$$

We know that atmospheric air contains 23 % of oxygen by mass so the equation is written as

$$T_a = 100/23 \times [8/3 \times C + 8\{ H_2 - O_2/8 \} + S]$$

$$T_a = [(11.6 \text{ x } C) + \{34.8 \text{ x } (H_2 – O_2/8)\} + (4.35 \text{ x } S)]/100$$
(kg/kg of fuel)

Step 2: Calculate the % excess air supplied (EA) :- The excess air, which is the quantity of air, required to be fed to the boiler over the theoretically correct quantity of air needed for complete combustion of fuel.

$$EA = \frac{O_2\% \text{ x } 100}{(21 – O_2\%)}$$

Step 3: Calculate actual mass of air supplied/ kg of fuel (AAS):- This is the actual air supplied, if too little air is supplied, the fuel is not completely burnt and if too great quantity of air is supplied the heat being carried up in the stack in greater quantity than normal.

AAS = {1 + EA/100} x theoretical air

Step 4: Estimate all heat losses

i. Percentage heat loss due to dry flue gas(L_1):- This is the heat loss from the boiler in the dry component of gases to the stack. The flue gas exit temperature and flue gas mass stack determines the order of this loss.

$$L_1 = \frac{m \text{ x } C p_g \text{ x } (T_f - T_a) \text{ x } 100}{\text{GCV of fuel}}$$

Where, m = mass of dry flue gas in kg/kg of fuel

m = (mass of dry products of combustion / kg of fuel) + (mass of N2 in fuel on 1 kg basis) + (mass of N2 in actual mass of air we are supplying) .

Cp_g = Specific heat of flue gas (0.378 kcal/kg)

ii. Percentage heat loss due to evaporation of water formed due to H2 in fuel(L_2): - During combustion of the fuel some heat losses occurs due to the presence of the hydrogen in the fuel.

$$L_2 = \frac{9 \text{ x } H_2 \{ 584 + C p (T_f - T_a) \} \text{ x } 100}{\text{GCV of fuel}}$$

Where, H_2 = percentage of H_2 in 1 kg of fuel
Cp_s = specific heat of superheated steam (0.45 kcal/kg)

iii. Percentage heat loss due to evaporation of moisture present in fuel (L_3):-This is the loss of heat from the boiler in the flue gases due to water vapour which was present initially as moisture in the coal burnt. This heat loss is the latent heat supplied to evaporate the moisture.

$$L_3 = \frac{M \{ 584 + Cp_s (T_f - T_a) \} \text{ x } 100}{\text{GCV of fuel}}$$

Where, M – % moisture in 1kg of fuel
Cp_s – Specific heat of superheated steam (0.45 kcal/kg)

iv. Percentage heat loss due to moisture present in the air (L_4):-This is the heat loss due to moisture present in the air. Humidity factor plays a small role in this calculation.

$$L_4 = \frac{\text{AAS x humidity factor x } Cp_s (T_f - T_a) \} \text{ x } 100}{\text{GCV of fuel}}$$

Where, M – % moisture in 1kg of air
Cp_s – Specific heat of superheated steam (0.45 kcal/kg)

v. percentage heat loss due to partial conversion of C to CO (L_5):- This is the heat loss due to the partial combustion of the fuel during combustion process.

$$L_5 = \frac{\%CO \text{ x } C}{\%CO + CO_2} \text{ x } \frac{5744}{\text{GCV of fuel}}$$

vi. Percentage heat loss due to radiation and other unaccounted loss(L_6):- No measurement of this loss of heat from boiler is possible except that by some empirical formulae.

The actual radiation and convection losses are difficult to assess because of particular emissivity of various surfaces, its inclination, airflow patterns etc.

vii. Percentage heat loss due to unburnt fuel in fly ash

Constituents	Unit %	Quantity
CO2	%	15.40
CO	%	0.55
O2	%	4.00
Temperature after A/H (T_f)	(^{0}C)	165
Ambient air temperature (ta)	(^{0}C)	30
Absolute humidity	-------	0.01
Specific heat of flue gas	Kcal/kg	0.378

(L_7): This loss is due to small amount of carbon, which remains as a residue in the ash from boiler. The losses in function of % ash in fuel and % carbon in ash from boiler.

$$L_7 = \frac{\text{Total ash collected/kg of fuel burnt x GCV of fly ash x 100}}{\text{GCV of fuel}}$$

viii. Percentage heat loss due to unburnt fuel in bottom ash (L_8):- This is the heat loss due to unburnt fuel in the ash.

$$L_8 = \frac{\text{Total ash collected per Kg of fuel burnt x G.C.V of bottom ash x 100}}{\text{GCV of fuel}}$$

ix. Percentage heat loss due to combustibles (L_9):- This is the unaccounted losses.

5.4 The following data is taken for calculating efficiency: -

Here the data is taken from a 150 MW thermal power plant. The proximate and ultimate analysis was carried out with the help of chemistry division of industry and the results have been tabulated in the table given below.

Ultimate analysis: - Ultimate analysis gives chemical elements that comprise the coal substance, together with ash and moisture. The coal substance consists of organic compounds of carbon, hydrogen, and oxygen derived from the original matter. The analysis shows the following components on the mass basis.

TABLE. I ULTIMATE ANALYSIS OF COAL

COAL CONSTITUENTS	UNIT %	QUANTITY
Carbon (C)	%	51.32
Hydrogen (H)	%	3.00
Nitrogen (N)	%	0.94
Sulpher (S)	%	0.54
Oxygen (O)	%	4.70
Water (H_2O)	%	7.50
Ash	%	32.00
GCV of coal	Kcal/kg	8078

Proximate analysis: The proximate analysis indicates the behavior of the coal when it is heated. When 1 g sample of coal is subjected to a temperature of about 105^{0}C for a period of 1 hour, the loss in weight of the sample gives the moisture content of the coal.

TABLE.II PROXIMATE ANALYSIS

Constituents	Unit %	qunatity
Fixed carbon	%	40
Moisture	%	7.5
Volatile matter	%	20.5
Ash	%	32
Fixed carbon / volatile matter	%	1.95

Other parameter required for the calculation:-

Table.III OTHER PARAMETERS

IV. RESULT

TABLE.IV HEAT BALANCE SHEET

S.No.	parameters		%
1.	L_1	=	5.52 %
2.	L_2	=	2.15%
3.	L_3	=	0.59%
4.	L_4	=	0.06%
5.	L_5	=	1.38%
6.	L_6	=	0.41%
7.	L_7	=	0.13%
8.	L_8	=	0.06%
9.	L_9	=	3.65%
10.	Total losses	=	13.95%
11.	Boiler efficiency	=	86.05%

V. CONCLUSION

Conclusion derived from the data related to the boiler, if higher GCV coal is used, then the efficiency should be increased and the other one is the excess air. The quantity of excess air adversely affects boiler efficiency The quantity of excess air needs to be optimized for achieving maximum efficiency of boiler If the excess air is provided at maximum rate then it causes to reduce the temperature inside the boiler. The result is comes out to be 86.06 %. Ash and Moisture content inside the fuel will affect the efficiency. From this Indirect Method mathematical model, the efficiency should be easily calculated.

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