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DETERMINATION OF EFFICIENCY OF A WATER-TUBE BOILER

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ABSTRACT

In our current era, each and every field are running and upgrading to automation. Without electricity, automation is not possible. In India, electricity production is mainly of coal based thermal power plants. Efficiency of a conventional coal based power plant varies from 34-38%. Efficiency of the plant should be maintained and improved in order to use the fossil fuels effectively. Efficiency of a thermal power plant mainly depends upon the boiler efficiency and turbine efficiency. This paper is about determination of boiler efficiency of a 510MW thermal power plant. This paper presents the efficiency calculation of boiler. The study focuses on proximate analysis and ultimate analysis and various parameters like theoretical air supply, excess air, actual air supply, dry flue gas loss, loss due to H_2, loss due to moisture, loss due to un-burnt carbon in fly and bottom ash, loss due to radiation and convection, etc. comparison of the design and operational values are included. Justification and various parameters are mentioned for further improvement of plant performance.

KEYWORDS: automation, electricity, thermal power plants, turbine efficiency, proximate analysis, ultimate analysis, auditing, boiler efficiency, various losses, performance.

I. INTRODUCTION :

Efficiency of a power plant directly depends on the boiler fficiency. The boiler must be maintained well and to be checked periodically whether the maintenance is working or not. There is no use if we maintain the boiler properly and didn't verify the efficiency periodically [1] because we might not know the error spot where the problem available which is to be noted and rectified. This paper deals about the efficiency of a 510MW water-tube boiler which is used in NTPL power plant, Tuticorin, Tamilnadu, India. Now let's see the calculation of a boiler efficiency of a water tube boiler of a 510MW power plant.

II. OVERVIEW OF NTPL :

NLC Tamilnadu Power Limited, the 2 x500 MW thermal power project was a dream of NLC India Ltd. to diversify from lignite to coal based power plant and use exemplary knowledge gained over the years in power generation. Unlike NLC, NTPL uses coal, the latter form of lignite for power generation. It also fulfilled the mission of NLC India Ltd. to spread its wing outside Neyveli in Tamilnadu. The search for the project location based power plant located in the harbour estate of Tuticorin port trust and adjacent to TTPS. The power generated from NTPL is transmitted to SRLDC Bangalore from where it is shared to Tamilnadu, Kerala, Karnataka and Pondicherry. On the whole, NTPL is a joint venture project of NLC India and TNEB for an extended power generation in Southern India which started its operation in 2014. [2]

Fig.1 NTPL

III. LITERATURE REVIEW :

RenJianxing et.al [6] from China studied a 300 MW Coal fired unit using three kinds of mixed coal A, B and C. Under designed load conditions the characteristics of coal and burning characteristics in boilers were studied. Their aim was to increase boiler efficiency by experiments based on parameters such as flame transparency, burning status, and unburned combustible in flue gas temperature. Slag of mixed coal C was high than the other two. The results of the experiment showed that mixed coal A showed better results than B and C on above mentioned parameters and hence it helps to optimize combustion and boiler efficiency.

Tharayil James Joseph et.al [7] came up with some ideas to improve the efficiency of pulverized coal fired boiler. Operation of non-optimized boiler can lead to reduced boiler efficiency, increased excess air requirements, delayed combustion, increased heat loss, high CO and NOx emission and many other. Their aim was to optimize combustion using secondary air damper which leads to better boiler efficiency and reduces heat losses. If the coal is burned only with theoretical amount of excess air it leads to incomplete combustion, increase in un-burnt carbon and soot formation. If more amount of excess air is supplied it causes high amount of dry flue gas loss. They corrected the damper postion of secondary air and calculated the heat loss in boiler before and after it. Their results showed that the efficiency of boiler was increased by decreasing the excess air to optimum value.

Brundaban Patro [8] studied the combination tube boilers, as applicable to commercial use, along with the significant features, limitations and applicability in his article "Efficiency studies of combination tube boilers". A heat balanced sheet is prepared to know the various heat losses in two different two-pass combination tube boilers, using low grade coal and rice husk as fuel. Also, the efficiency of combination tube boilers is studied by the direct and heat loss method. It is observed that the dry flue gas loss is a major loss in the combination tube boilers. The loss due to the un-burnt in the fly ash is very less in the combination tube boilers, due to the surrounded membrane wall. It is also observed that the loss due to the un-burnt in the bottom ash has considerable amount for the heat loss and cannot be ignored.

Sangeeth G.S and Praveen Marathur [9] on their journal titled "Efficiency Improvement of Boilers" proposed the necessity of boiler efficiency in smooth running of a power plant. The performance evaluation of boiler such as evaporation ratio and efficiency reduces with time. Proper maintenance is the only way to have efficient usage of boilers. Their results showed that overall efficiency of any boiler depends upon the technical difficulties under unpredictable conditions.

Moni Kuntal Bora et.al [10] published their journal named "Performance Analysis from the Efficiency Estimation of Coal Fired Boiler", studied the various losses of heat during combustion inside a coal fired boiler. Various factors that affects the boiler efficiency was analysed elaborately. Both direct and indirect methods of calculation of boiler efficiency was given and compared with design values. Types of control in boilers were mentioned and various maintenance methods for good running of a boiler were suggested. They concluded their journal by implementation of advance technology and management skills in all spheres that result in effective turnover of the company.

DETERMINATION OF BOILER EFFICIENCY

There are two methods of assessing boiler efficiency: [2][3][4][5]

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.

2) The Indirect Method: Where the efficiency is the difference between the losses and the energy input.

4.1. DIRECT METHOD:

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. This efficiency can be evaluated using the formula

$$\eta = \frac{Q \times (hg - hf)}{q \times GCV} \times 100$$

Where,

h_g – Enthalpy of saturated steam in KCal/kg of steam.

h_f – Enthalpy of feed water in KCal/kg of water .

Q – Quantity of steam generated per hour (Q) in kg/hr.

q – Quantity of fuel used per hour (q) in Kg/hr.

GCV – gross calorific value of the fuel in KCal/kg of fuel

IV. INDIRECT METHOD:

Indirect method is also called as heat loss method. The efficiency can be arrived at, by subtracting the heat loss fractions from 100. The standards do not include blow down loss in the efficiency determination process. A detailed procedure for calculating boiler efficiency by indirect method is given below. However, it may be noted that the practicing energy mangers in industries prefer simpler calculation procedures.

The principle losses that occur in a boiler are:

- Loss of heat due to dry flue-gas
- Loss of heat due to moisture in fuel and combustion air
- Loss of heat due to combustion of hydrogen
- Loss of heat due to radiation
- Loss of heat due to unburnt
- In the above, loss due to moisture in fuel and the loss due to combustion of hydrogen are dependent on the fuel, and cannot be controlled by design.

The data required for calculation of boiler efficiency using indirect method are:

- Ultimate analysis of fuel (H2, O2, S, C, moisture content, ash content)
- Percentage of Oxygen or CO2 in the flue gas
- Flue gas temperature in °C (Tf)
- Ambient temperature in °C (Ta) & humidity of air in kg/kg of dry air

- GCV of fuel in kCal/kg
- Percentage combustible in ash (in case of solid fuels)
- GCV of ash in kCal/kg (in case of solid fuels)

In order to calculate the boiler efficiency by indirect method, all the losses that occur in the boiler must be established. These losses are conveniently related to the amount of fuel burnt. In this way it is easy to compare the performance of various boilers with different ratings.

Conversion formula for proximate analysis to ultimate analysis

%C = 0.97C + 0.7 (VM + 0.1A)-M (0.6 - 0.01M)
%H2 = 0.036C + 0.086 (VM-0.1A)-{0.0035M*2*(1-0.02M)}
%N2 = 2.10-(0.020V.M)
$\%O_2$ = 100-($M+A+C+H_2+N_2+S$)

Where
C = % of fixed carbon
A = % of ash
VM = % of volatile matter
M = % of moisture

Theoretical (stoichiometric) air fuel ratio and excess air supplied are to be determined first for computing the boiler losses. The formula is given below for the same.

Theoretical air requirement,

$$TA = \frac{(11.6\times C)+[(34.8)\times(H_2-(O_2/8))]+(4.35\times S)}{100}$$ kg/kg of fuel

$$\text{Excess Air supplied, } EA = 1+\frac{EA}{100}\times TA$$

$$\text{Actual air supplied, } AAS = 1+\frac{EA}{100}\times TA$$ kg/kg of fuel

The various losses associated with the operation of a boiler are discussed below with required formula.

CALCULATION OF MASS

$$\%\text{ of } Co_2 \text{ in flue gas} = \frac{c}{100}\times\frac{44}{12}$$

$$\%\text{ of } So_2 \text{ in the flue gas} = \frac{s}{100}\times\frac{64}{32}$$

% of N_2 in air = AAS × 0.77
% of O_2 in flue gas = (AAS - TA) × 0.25
% of N_2 in flue gas = 0.02%
Mass, m = % of [Co_2 in flue gas + So_2 in flue gas $_+$ N_2 in air + O_2 in flue gas + N_2 in flue gas]

4.5. Calculation of losses

4.5.1. Heat loss due to dry flue gas

This is the greatest boiler loss and can be calculated with the following formula:

$$L1 = = \frac{m\times c_p(T_f - T_a)}{GCV}$$

Where,
L1 = % Heat loss due to dry flue gas
m = Mass of dry flue gas in kg/kg of fuel
= Combustion products from fuel: CO2 + SO2 + Nitrogen in fuel +Nitrogen in the actual mass of air supplied + O2 in flue gas.(H2O/Water vapour in the flue gas should not be considered)
Cp = Specific heat of flue gas in kCal/kg°C
Tf = Flue gas temperature in °C
Ta = Ambient temperature in °C

4.5.2. Heat loss due to evaporation of water formed due to H2 in fuel (%)

The combustion of hydrogen causes a heat loss because the product of combustion is water. This water is converted to steam and this carries away heat in the form of its latent heat.

$$L2 = \frac{9\times\frac{H_2}{100}584+0.45\ (T_f - T_a)}{GCV}$$

Where
H_2 = kg of hydrogen present in fuel on 1 kg basis
C_p = Specific heat of superheated steam in kCal/kg°C
T_f = Flue gas temperature in °C
T_a = Ambient temperature in °C
584 = Latent heat corresponding to partial pressure of water vapour

4.5.3. Heat loss due to moisture present in fuel

Moisture entering the boiler with the fuel leaves as a superheated vapour. This moisture loss is made up of the sensible heat to bring the moisture to boiling point, the latent heat of evaporation of the moisture, and the superheat required bringing this steam to the temperature of the exhaust gas.

This loss can be calculated with the following formula:

$$L3 = M \times \frac{584 + C_P(T_f - T_a)}{GCV} \times 100$$

Where

M = kg moisture in fuel on 1 kg basis

C_p = Specific heat of flue gas in kCal/kg°C

T_f = Flue gas temperature in °C

T_a = Ambient temperature in °C

584 = Latent heat corresponding to partial pressure of water vapour

4.5.4. Heat loss due to moisture present in air

Vapour in the form of humidity in the incoming air, is superheated as it passes through the boiler. Since this heat passes up the stack, it must be included as a boiler loss. To relate this loss to the mass of coal burned, the moisture content of the combustion air and the amount of air supplied per unit mass of coal burned must be known.

The mass of vapour that air contains can be obtained from psychometric charts and typical values are included below:

Table.1. humidity factor

Dry-Bulb	Wet Bulb	Relative Humidity	Kilogram water per Kilogram dry Temp °C Temp °C (%) air (Humidity Factor)
Temp °C	Temp °C	(%)	
20	20	100	0.016
20	14	50	0.008
30	22	50	0.014
40	30	50	0.024

$$L4 = \frac{ASS \times h_f \times C_p(T_f - T_a)}{GCV}$$

Where

AAS = Actual mass of air supplied per kg of fuel

Humidity factor = kg of water/kg of dry air

C_p = Specific heat of superheated steam in kCal/kg°C

T_f = Flue gas temperature in °C

T_a = Ambient temperature in °C (dry bulb)

4.5.5. Heat loss due to radiation and convection:

The other heat losses from a boiler consist of the loss of heat by radiation and convection from the boiler casting into the surrounding boiler house.

Normally surface loss and other unaccounted losses is assumed based on the type and size of the boiler as given below:

For industrial fire tube / packaged boiler = 1.5 to 2.5%
For industrial water-tube boiler = 2 to 3%
For power station boiler = 0.4 to 1%

Heat loss due to unburned carbon in fly ash and bottom ash:

Small amounts of carbon will be left in the ash and this constitutes a loss of potential heat in the fuel. To assess these heat losses, samples of ash must be analysed for carbon content. The quantity of ash produced per unit of fuel must also be known.

4.5.6. Heat loss due to un-burnt carbon in fly ash (%).

Heat loss due to fly ash

L6 = ------------------------------------ x 100

GCV of fuel

Heat loss due to fly ash = fly ash generation × GCV of fly ash

Fly ash generation = Ash contain coal * Boiler designed fly ash ratio

4.5.7. Heat loss due to un-burnt carbon in bottom ash (%)

Heat loss due to fly bottom ash

L7 = --------------------------------------- x 100

GCV of fuel

Heat loss due to bottom ash = bottom ash generation * GCV of bottom ash

Bottom ash generation = Ash contain coal * Boiler designed bottom ash ratio

V. CALCULATIONS:

(The readings are obtained from the NTPL control room from the coal used at NTPL on 07/02/2019 at steady load condition of unit-1)

Table.5.2. lab readings

Contents	Design value	Test value Unit-1
Moisture %	14	15.57
Ash %	36	29.61
Volatile matter %	23	24.93
Fixed carbon %	27	29.9

Sulphur %	0.5	0.3
Gross calorific value of coal Kcal/Kg	3700	3872
Bottom ash ratio	20/100	20/100
Fly ash ratio	80/100	80/100
G.C.V of bottom ash Kcal/Kg	10	10.479
G.C.V of fly ash Kcal/Kg	40	41.916
Flue gas temp, T_f °C	135	139
Ambient gas temp, T_a °C	31	31
% N_2	0.02	0.02
C_p of flue gas	0.24	0.24
C_p of super-heated steam	0.43	0.43

5.1. Ultimate analysis:

%C = 0.97(29.9) + 0.7 [24.93 + 0.1(29.61)]-15.57[0.6.-0.01(15.57)]
= 41.61%
%H2 = 0.036(41.61) + 0.086 [24.93-0.1(29.61)]-{0.0035(15.57)*2*[1-0.02(15.57)}
=3.312%
%N2 = 2.10-[0.020(24.93)]
=1.6014%
%O_2 = 100-(M+A+C+H_2+N_2+S)
=100-(15.57+29.61+41.61+3.312+1.6014+0.3)
=7.99%
Air supply calculation
Theoretical air, T.A=
(11.6*41.61)+[34.8*{3.312-(7.99/8)}+(4.35*0.3

100
=5.6448 kg/kg of coal
% of excess air, E.A = {7.99/ (21-7.99)}*100
= 61.414%
Actual air supply, A.A.S = 1+(61.414/100)}*5.6448
= 9.1115 kg/kg of coal
Calculation of mass
mass of CO_2 in flue gas = {41.61*44}/{100*12}
= 1.5257kg
mass of SO_2 in flue gas = {0.3*64}/ {100*32}
= 0.006 kg
mass of N_2 in air = 9.115*0.77
= 7.015855 kg
mass of O_2 in flue gas = (9.1115-5.6448)*0.25
= 0.866675 kg
mass of N_2 in flue gas= 0.02 = 0.02 kg
Total mass of flue gas,
m = 1.5257+0.006+7.015855+0.866675+0.02
= 9.43423 kg

5.4. Calculation of losses

5.4.1. Heat loss due to dry flue gas

9.43 x 0.24 x (139 – 31)
L1= -------------------------------------x 100
3872
=6.31%

5.4.2. Heat loss due to evaporation of water formed due to H2 in fuel (%)

9 x (3.312/100) x {584 + 0.43 (139 -31)}
L2=---x 100
3872
=4.85%

5.4.3. Heat loss due to moisture present in fuel

(15.57/100) x {584 + 0.43 (139 -31)}
L3 = --X 100
3872
= 2.535%

5.4.4. Heat loss due to moisture present in air

9.115 x 0.0254 x 0.43 (139 -31)
L4 = --x 100
3872
= 0.2623%

5.4.5. Heat loss due to radiation and convection:

For industrial water-tube boiler = 2 to 3%
L_5 = 2.5%

5.4.6. Heat loss due to un-burnt carbon in fly ash

Fly ash generation * GCV of fly ash
L6 = ---x 100
GCV of fuel
Fly ash generation = (29.61/100)*(80/100) = 0.23688
0.23688*41.916
L6 = ----------------------------------- x 100
%3872
= 0.2564

5.4.7. Heat loss due to un-burnt carbon in bottom ash (%)

Bottom ash generation * GCV of bottom ash
L_7 = -- x 100
GCV of fuel
Bottom ash generation = (29.61/100)*(20/100) = 0.05922
0.05922*10.479
L_7 = ----------------------------------- x 100

3872
= 0.016%

Efficiency = 100-($L_1+L_2+L_3+L_4+L_5+L_6+L_7$)
= 100-17.58%
= 82.42%

VI. RESULT

The efficiency of the boiler is 82.42%
The available losses % is 17.58%
The highest loss is due to dry flue gas and due to hydrogen
The percentage of various losses is shown below:

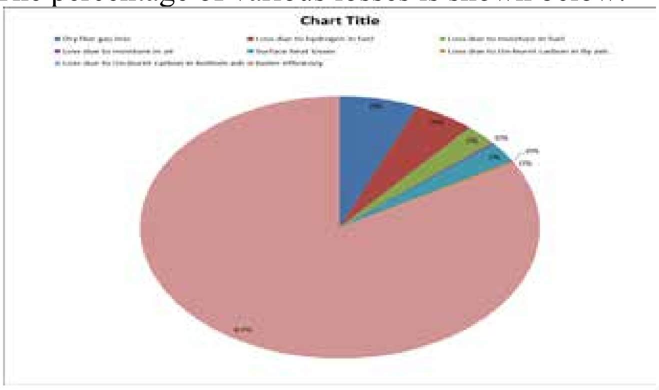

Fig.2.graph of various losses

RECOMMENDATION:

It is suggested to buy coal with less dry flue gas
It is suggested to buy coal with less hydrogen
It is suggested to buy coal with less moisture

VII. CONCLUSION:

The efficiency of the boiler is determined as per the ASME PTC-4.1 Standards

VIII. FUTURE SCOPE:

Heat rate of a thermal power plant depends on boiler efficiency and turbine heat rate. My future work is on determination of turbine heat rate and plant heat rate.

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