Boiler Efficiency Improvement through Analysis of Losses

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Abstract— Thermal is the main source for power generation in India. The percentage of thermal power generation as compare to other sources is 65 %. The main objective of thermal power plant is to fulfill the energy demands of the market and to achieve these demands; plant requires technical availability with the parts reliability and maintenance strategy. This paper deals with the determination of current operating efficiency of Boiler and calculates major losses for Vindhyachal Super thermal power plant (India) of 210 MW units. Then identify the causes of performance degradation. Also find the major causes of heat losses by Fault Tree Analysis (FTA) and recommends its appropriate strategy to reduce major losses. The aim of performance monitoring is continuous evaluation of degradation i.e. decrease in performance of the steam boiler. These data enable additional information which is helpful in problem identification, improvement of boiler performance and making economic decisions about maintenance schedule.

Keywords: Boiler Efficiency, Fault Tree Analysis (FTA), Maintenance

I. INTRODUCTION

Today, most of the electricity produced throughout the world is from steam power plants. Looking to the statically data, rate which power demand increases is extremely very high compared to the rate at which generation capacity increase. Efficient operation of power plants has always been important to utilities. The heat rate of a conventional coal fired power plant is a measure of how efficiently it converts the chemical energy contained in the fuel into electrical energy. This conversion is accomplished in four major steps. First, the chemical energy in the fuel is converted into thermal energy, then the thermal energy is converted into kinetic energy, then the kinetic energy is converted in mechanical energy, and last the mechanical energy is converted to electrical energy. In each of these sub-processes, some energy is lost to the environment. Some of the fuel is not burned completely, some of the thermal energy is lost out through the stack and also rejected to the cooling water, some of the kinetic and mechanical energy produces heat instead of electricity, and last, some of the electricity that is produced is used by these sub-processes.

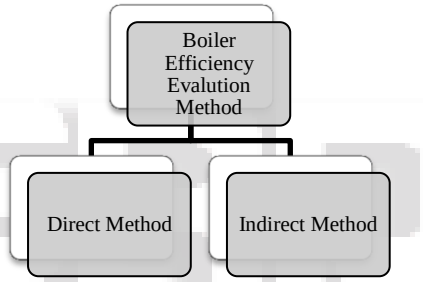
A boiler is an enclosed vessel that provides a means for combustion heat to be transferred into water until it becomes heated water or steam [2]. The hot water or steam under pressure is then usable for transferring the heat to a process. So Boiler is the main equipment to produce power but every equipment does not runs with full efficiency regularly/continuously, it requires regular maintenance and condition monitoring to it reliable in future. Therefore to calculate boiler heat loss and their causes makes easy to apply appropriate maintenance strategy for increasing efficiency of power plant [1].

Objective

- To evaluate operating efficiency of Boiler
- Determine various types of losses related to boiler operation
- Identification the causes of performance degradation and its performance analysis
- Identifying heat rate gaps and then implementing corrective actions to eliminate the efficiency loss.

II. METHODOLOGY

Thermal efficiency of boiler is defined as the percentage of heat input that is effectively utilized to generate steam. There are two methods of assessing boiler efficiency.



A. The Direct Method:

Where the energy gain of the working fluid (water and steam) is compared with the energy content of the boiler fuel [4].

B. The Indirect Method:

Where the efficiency is the difference between the losses and the energy input.

In indirect method the efficiency can be measured easily by measuring all the losses occurring in the boilers using the principles to be described.

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.An important advantage of this method is that the errors in measurement do not make significant change in efficiency.

- *Boiler Efficiency by Indirect Method: Calculation Procedure and Formula*

The data required for calculation of boiler efficiency using indirect method are [2]:

1) Ultimate analysis of fuel (H_2, O_2, S, C, moisture content, ash content)
2) Percentage of Oxygen or CO_2 in the flue gas
3) Flue gas temperature in ^0C (T_f)

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4) Ambient temperature in ^0C (T_a) & humidity of air in kg/kg of dry air.
5) GCV of fuel in kcal/kg
6) Percentage combustible in ash (in case of solid fuels)
7) GCV of ash in kcal/kg (in case of solid fuels)

Unit Load	=	210MW
Steam Flow	=	615 T/hr
Total Coal Flow	=	140 T/hr
Wet Bulb Temp	=	24 ^oC
Dry bulb Temp	=	30 ^oC
$\%CO_2$ in Flue gas	=	14.3
%CO in flue gas	=	0.5
Average flue gas temperature	=	180 ^oC
Ambient temperature	=	30 ^oC
Humidity in ambient air	=	0.014 kg/ kg dry air
Carbon in Ash / kg of coal	=	0.002 kg/kg coal
Ratio of bottom ash to fly ash	=	90:10
Fuel Analysis (in %)		
Ash content in fuel	=	40
Moisture in coal	=	12.2
Carbon content	=	39.71
Hydrogen content	=	2.58
Nitrogen content	=	0.76
Oxygen content	=	4.15
Sulphur	=	0.6
GCV of Coal	=	3501 kCal/kg
CV of Carbon	=	8077.8 kCal/kg

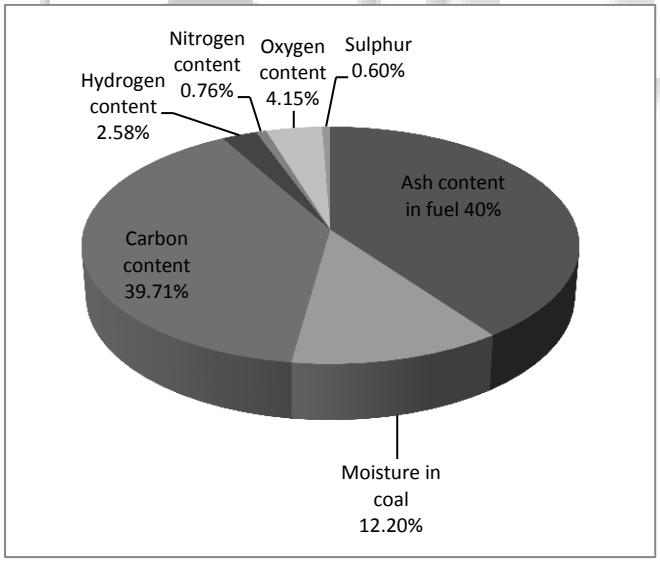

Fig. 1 : Fuel content

Step – 1 Find theoretical air requirement

Theoretical air required for complete combustion =
= [(11.6 x C) + {34.8 x ($H_2 – O_2/8$)} + (4.35 x S)]/100 kg/kg of fuel
= [(11.6 x 39.71) + {34.8 x (2.58 -4.15/8)} + (4.35 x 0.6)]/100 kg/kg of fuel
= [460.636 +71.73 +2.61]/100 kg/kg of fuel
= 5.34 kg/kg of fuel

Step – 2 Find theoretical CO_2 %

% CO_2 at theoretical condition $(CO_2)_t$ = Moles of C/ (Moles of C + Moles of N_2)

Where,

Moles of N_2 = (Wt of N_2 in theoretical air/Mol. wt of N_2) + (Wt of N_2 in fuel/ Mol. wt of N_2)

Moles of N_2 = [(5.34 x 77/100)/28] + .0076/28
= 0.1471

Where moles of C = 0.3971/12 = 0.033

$(CO_2)_t$= 0.033/ (0.1471+0.033) = 18.33%

Step – 3 to find Excess air supplied

Actual CO2 measured in flue gas = 14.3%

Excess Air supplied (EA) %=7900x $[(CO_2\%)_t-(CO_2\%)_a]/(CO_2\%)_a x[100-[(CO_2\%)_t]$

Excess Air supplied (EA) % = 7900 x [18.33-14.3]/14.3 x [100-18.33]

Excess Air supplied (EA) % = 27.26%

Step – 4 to find actual mass of air supplied

Actual mass of air supplied = {1 + EA/100} x theoretical air

Actual mass of air supplied = {1 +27.26/100} x 5.34
= 6.795 kg/kg coal

Step –5 to find actual mass of dry flue gas

Mass of dry flue gas = (Mass of CO_2 +Mass of N_2 content in the fuel+ Mass of N_2 in the combustion air supplied + Mass of oxygen in flue gas)

Mass of dry flue gas = [(0.3971 x 44)/12] + 0.0076 + [(6.795 x77)/100] + [(6.795-5.34) x 23]/100
= 1.463 + 5.23 + 0.334
= 7.027 kg/kg coal

Step – 6 to find all losses

% Heat loss due to dry flue gas = [m x Cp x (Tf – Ta) x 100] / GCV of fuel

m = mass of dry flue gas in kg/kg

Cp = Specific heat of flue gas (0.23 kcal/kg)

% Heat loss due to dry flue gas = 7.027x0.23x (180-30) x100/3320

% Heat loss due to dry flue gas (L_1) = 7.302%

% Heat loss due to formation of water from H2 in fuel (L_2)

$$\frac{9 \times H_2 \{584 + C_p (T_f - T_a)\} \times 100}{\text{GCV of fuel}}$$

Where,

H2 percentage of H2 in 1 kg of fuel

Cp – Specific heat of superheated steam (0.45 kcal/kg)

L_2 = 9 x 0.0258x {584+0.45(180-30)} x 100/3320

L_2 = 0.2322 x 651.5 x 100/3320

L_2 = 4.55%

% heat loss due to evaporation of moisture present in fuel (L_3)

L_3= M x {584 + Cp (Tf-Ta)} x 100/GCV of fuel

Where,

M – % moisture in 1kg of fuel

Cp – Specific heat of superheated steam (0.45 kcal/kg)

L_3= 0.122 x {584 + 0.45(180-30)} x 100/3320

L_3= 2.39%

% heat loss due to moisture present in air (L_4)

= AAS x humidity x Cp x (Tf-Ta) x100/GCV

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L_4 = 6.795 x0.014x 0.45x (180-30) x 100/3320
L_4 = 0.193%

% Heat loss due to partial conversion of C to CO (L5) =
L5=
$$=\frac{\%CO\times C}{\%CO+CO_2}\times\frac{5744\times100}{GCV\ of\ Fuel}$$
$$=\frac{0.5\times0.3971}{0.5+14.3}\times\frac{5744\times100}{3320}$$
L_5 = 2.32%

%heat loss due to radiation and other unaccounted loss (L_6) are 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%

% Loss due to Unburnt Carbon (L_7) = UxCVcx100/Gcv
Where,
U = Carbon in Ash / kg of coal
CVc = CV of Carbon
L7 = 0.002 x 8077.8 x 100/3320
L_7 = 0.48%
Boiler efficiency by indirect method
= 100 – (L_1+ L_2+ L_3+ L_4+ L_5+ L_6+ L_7)
=100-(7.302+4.55+2.39+0.193+2.32+0.3+0.48)
= 82.465%

Input/output Parameter		**kCal / kg of coal**	**% loss**
Heat Input	=	3320	100
Losses in boiler			
1. Dry flue gas, L_1	=	242.42	7.302
2. Loss due to hydrogen in fuel, L_2	=	151.06	4.55
3. Loss due to moisture in fuel, L_3	=	79.34	2.39
4. Loss due to moisture in air, L_4	=	6.407	0.193
5. Partial combustion of C to CO, L_5	=	77.02	2.32
6. Surface heat losses, L_6	=	9.96	0.3
7. Loss due to Unburnt carbon, L_7	=	15.93	0.48
Boiler Efficiency = 100 – (L_1 + L_2 + L_3 + L_4 + L_5 + L_6 + L_7) = 82.447%			

III. ANALYSIS

The above mathematical calculation to determining the actual heat losses in boiler by using indirect method, So the major heat losses in boiler occurs due to Dry heat gas loss (7.302%),Loss due to hydrogen in fuel (4.55%),Loss due to moisture in fuel (2.39%) and Partial combustion of C to CO (2.32%). To find causes behind above losses in detail by using Fault Tree Analysis (FTA). And also recommend appropriate maintenance strategy to reduce the causes of degradation boiler performance. Analysis shows different types of heat losses, Energy waste in Kcal/Kg of coal, Contents of fuel etc.

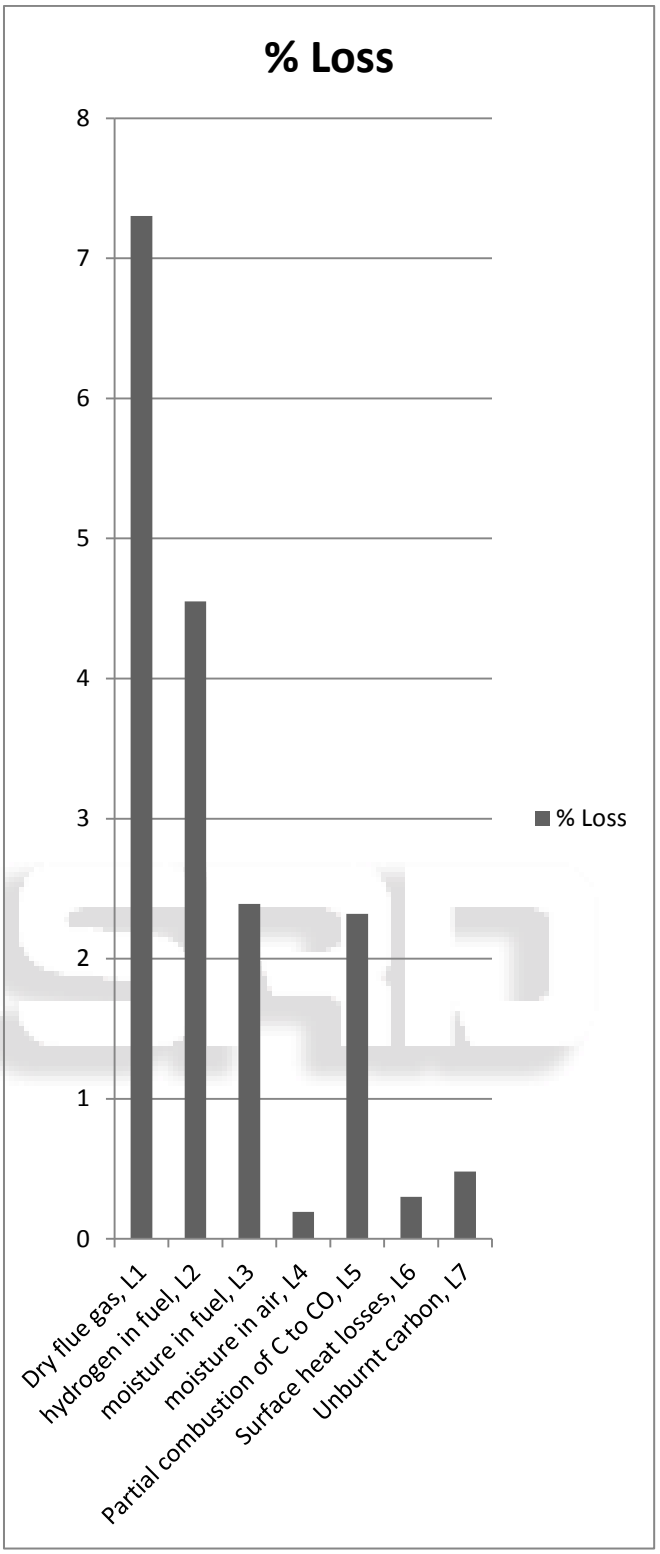

Fig. 3: Percentage losses in boiler

Fault Tree Analysis (FTA) The heat rate fault tree is used to identify areas in the plant where heat rate degradation may be occurring without conducting expensive tests. The fault tree is structured to provide a process by which decisions can be determined that narrow down the cause of the problem based on available information [3].

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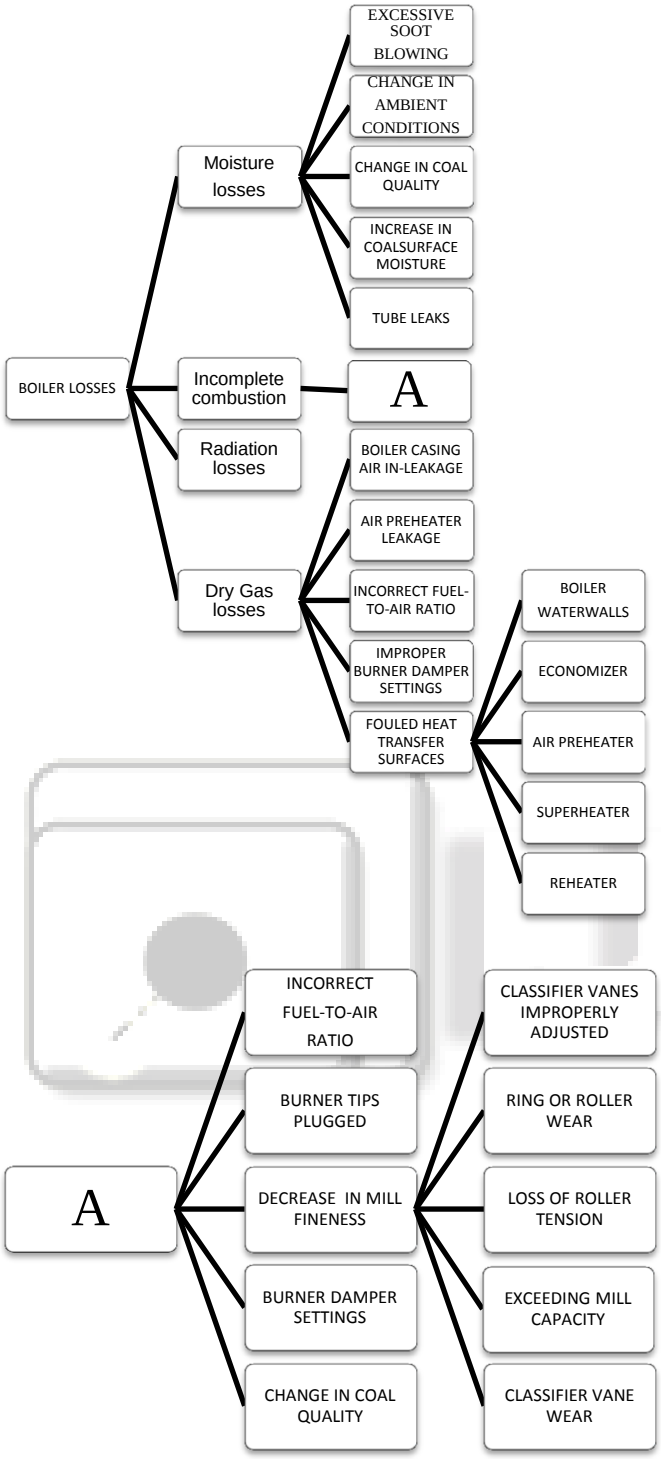

– *Maintenance Recommendation*

On the basis of FTA & computing the heat losses there are three major losses and their sub losses that affect the boiler efficiency. The corrective actions should be taken for minimizing the heat losses are shown below:

Type of losses	**Corrective Actions**
Dry gas losses	
Boiler casing air in-leakage	O_2 reading should be taken at several stages
Air preheater leakage	Condition monitoring of inlet and outlet temperature of gases.
Incorrect fuel-to-air ratio	Proper O_2 monitoring system
Improper burner damper settings	• Adjust burner tilts • Continuous check burners setting.
Fouled heat transfer surfaces	Periodic cleaning of Fouled heat transfer surfaces
Moisture losses	
Excessive soot blowing	Optimize blow shoot selectively
Change in ambient conditions	Adjust the primary air temperature at air Preheater
Change in coal quality	Periodically check the coal quality
Increase in coal surface moisture	• Check coal surface moisture before entering in mill • Supply the proper amount of primary air
Tube leaks	• Acoustic condition monitoring for leakage • Take corrective when boiler shutdown
Incomplete combustion	
Incorrect fuel-to-air ratio	Proper O_2 monitoring system
Burner tips plugged	Use bypass burner
Decrease in mill fineness	• Adjust and control the fineness of pulverized coal • Collect coal sample from pulverize mills and analyze for fineness • Set proper classifier settings • Set proper mill journal and spring tension.
Burner damper settings	Adjust damper setting properly
Change in coal quality	Collect coal sample from pulverize mills and analyze the coal quality periodically.

IV. CONCLUSION

In this paper we focused on the heat losses of boiler and find that the actual major heat losses are:-

Dry heat gas loss (7.302%), Loss due to hydrogen in fuel (4.55%), Loss due to moisture in fuel (2.39%) and Partial combustion of C to CO (2.32%) And also find the reason behind the heat losses. On the basis of causes of heat losses, we suggest the corrective actions to increase the boiler performance.

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