Enhancement of Boiler Efficiency for Industrial Boiler by Energy Audit

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Abstract— Boiler efficiency and energy losses from boiler are important parameter for any industry using boiler. In this paper a detailed analysis is carried out for combined water and fire tube boiler using biomass coal as fuel. Boiler efficiency calculated by direct method is in range of (78.5% to 81.6%). Major losses from boiler are heat loss due to radiation and convection from non-insulated surfaces (4.8% to 6.3%), heat loss due to flue gas (6.3% to 6.4%), heat loss due to blow down (0.263 to 0.398%), heat loss due to incomplete combustion (1.87% to 2.21%), heat loss due to unburnt coal in bottom ash (1.74 % to 1.86) and heat loss due to moisture present in fuel (1.3% to 1.6%).

Key words: Industrial Boiler, Boiler Efficiency

I. INTRODUCTION

Generally, in an industry packaged type boilers are used because it comes with a complete package. Once delivered to site, it requires only the steam piping, water pipe work, fuel supply system and electrical connections to be made for it to become operational. Packaged boilers are generally of shell type with fire tube design so as to achieve high heat transfer rates by both radiation and convection.

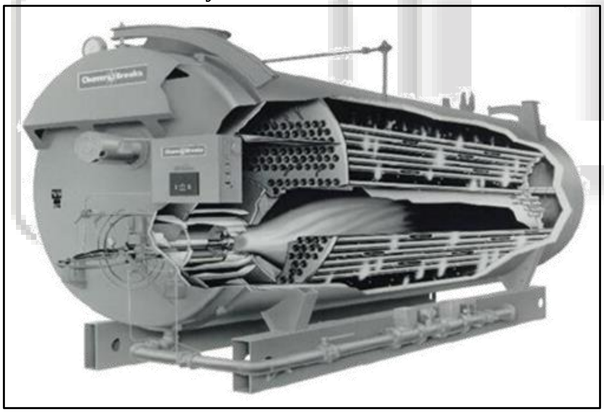

Fig. 1: Packaged type boiler [10]

A. Types of Package Boilers

The D type boiler, The D-type boiler has a water drum, steam drum, and generating tubes. Water flows into the steam drum, flows down the down comers and into the water drum. Water is then sent from the water drum through the generating tubes, where the fire is located around causing water molecules to boil off into steam. Steam rises up more generating tubes and finally back into the steam drum where the dry pipe is located then into the plant. This configuration shaped the package boiler into a D-shape, hence the name D-type Package Boiler. These boilers are mostly used for plants that allow greater clearances.2) the A type boiler, A-type package boiler has two water drums and one steam drum compared to the D-type package boiler. Water boils off in the water drums shared by a common header, and then sent up the generating tubes, into the steam drum and up the dry pipe. Just like the D-type package boiler, fire heats the tubes surroundings causing the tubes to increase the in temperature thus boiling off water molecules to steam. A-type package boilers were designed to improve package boiler reliability and reduce tube replacements. A-type package boilers are smaller than D-type therefore will fit smaller plants, but does not have the same power output as D-type package boilers. 3) the O type boiler, The O-type boilers are a little simpler compared to D-type and A-type. They consist of one water drum and one steam drum. Generating tubes are lined up from either side of the steam and water drums. When water boils due to convection heating, steam rises up through the tubes and into the steam drum. This is a symmetrical design for restrictive plant layouts. O-type boilers are mainly used for their fast steam production and reduced maintenance cost.

B. Performance Evaluation of Boilers

Boiler efficiency, equivalent evaporation and factor of evaporation are performance parameter for boiler. Performance of the boiler, like efficiency reduces with time, due to poor combustion, heat transfer fouling and poor operation and maintenance. Deterioration of fuel quality and water quality also leads to poor performance of boiler. Efficiency testing helps us to find out how far the boiler efficiency drifts away from the best efficiency.

C. Methods for Testing Boiler Efficiency

Boiler efficiency can be tested by the following two methods:

1) The 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. Efficiency can be evaluated using the formula.

$$\text{Boiler Efficiency } (\eta) = \frac{\textbf{heat output}}{\textbf{heat input}}$$

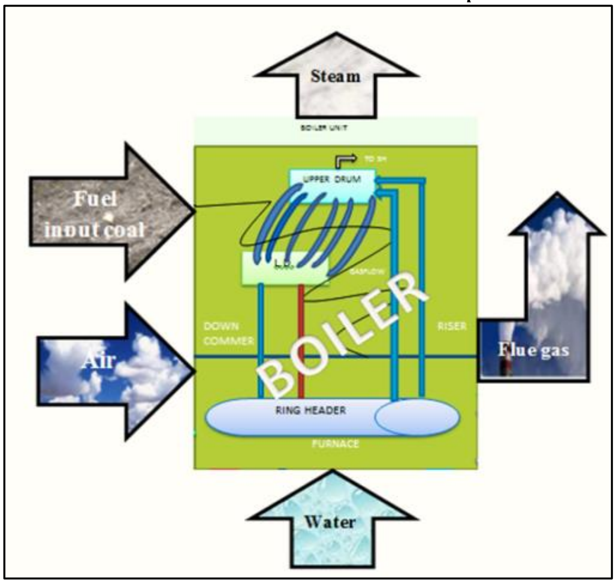

Fig. 2: Boiler system [10]

$$\text{Boiler Efficiency } (\eta) = \frac{Q \times (h_g - h_f)}{q \times GCV} \times 100$$

Parameters to be monitored for the calculation of boiler efficiency by direct method are: quantity of steam generated per hour (q) in kg/hr. quantity of fuel used per hour (q) in kg/hr. enthalpy of steam at (h_g) at working pressure (kg/cm^2) and superheat temperature, if any enthalpy of feed water (h_f)at the temperature of feed water type of fuel and gross calorific value of the fuel (gcv) in kcal/kg of fuel.

2) Indirect Method or Heat Loss Method

In the heat loss method 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 weaknesses of the direct method can be overwhelmed by this method, which calculates the various heat losses associated with boiler. The efficiency can be arrived at, by subtracting the heat loss percentages from 100. An important advantage of this method is that the errors in measurement do not make significant change in efficiency. The indirect method does not account for Standby losses; Blow down loss, energy loss in Soot blowing, and energy loss running the auxiliary equipment such as burners, fans, and pumps.

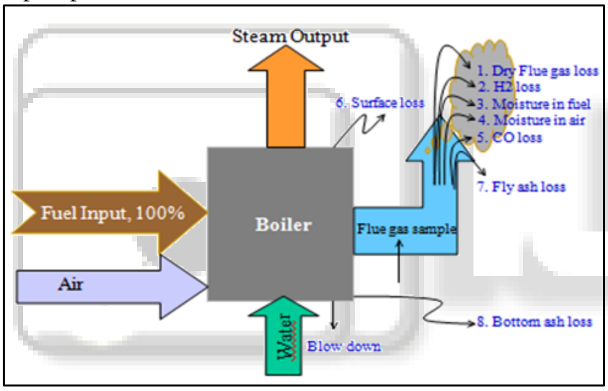

Fig. 3: Energy Loss In Boiler **[10]**

The Following Losses Are Applicable To Liquid, Gas And Solid Fired Boiler

- L1- Loss Due To Dry Flue Gas (Sensible Heat)
- L2- Loss Due To Hydrogen In Fuel (H_2)
- L3- Loss Due To Moisture In Fuel (H_2o)
- L4- Loss Due To Moisture In Air (H_2o)
- L5- Loss Due To Carbon Monoxide (Co)
- L6- Loss Due To Surface Radiation, Convection and Other Unaccounted*
- Losses Which Are Insignificant and Are Difficult To Measure
- L7- Unburnt Losses In Fly Ash (Carbon)
- L8- Unburnt Losses In Bottom Ash (Carbon)

Boiler Efficiency By Indirect Method =

100 – (L1+L2+L3+L4+L5+L6+L7+L8)

Boiler Efficiency, Ŋ = 100- (Total Loss In %)

3) Procedure for Indirect Method

Heat loss method is better to use in practice. The main reasons for that are following. It is easier to calculate the losses as compared to measure the flow rate of coal. Easy to check the controllable & uncontrollable losses & can do try to reduce the controllable losses. Complementary ideas for efficient boiler operation can be generated. Efficiency can be improved by combined effect of these entire things. It is more accurate as compared to direct method.

D. Boiler Efficiency Calculation by Indirect Method

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

1) Heat Loss Due To Dry Flue Gas: ([10] Page 9)

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

$$L_1 = \frac{m \times cp \times (Tf - Ta)}{GCV \ of \ fuel} \times 100$$

2) Heat Loss Due To Evaporation Of Water Formed Due To H2 In Fuel: ([10] Page 10)

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.

$$L_2 = \frac{9 \times H_2 \times \{584 + C_p(T_f - T_a)\}}{GCV \ of \ fuel} \times 100$$

3) Heat Loss Due To Moisture Present In Fuel: ([10] Page 10)

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.

$$L_3 = \frac{M \times \{584 + C_p(T_f - T_a)\}}{GCV \ of \ fuel} \times 100$$

4) Heat Loss Due To Moisture Present In Air: ([10] Page 11)

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.

$$L_4 = \frac{AAS \times humidity \ \ factor \times C_p \times (T_f - T_a)}{GCV \ of \ fuel} \times 100$$

5) Heat Loss Due To Incomplete Combustion: ([10] Page11)

Products formed by incomplete combustion could be mixed with oxygen and burned again with a further release of energy. Such products include CO, H_2, and various hydrocarbons and are generally found in the flue gas of the boilers. Carbon monoxide is the only gas whose concentration can be determined conveniently in a boiler plant test.

$$L_5 = \frac{\%CO \times C}{\%CO + \%CO_2} \times \frac{5744}{GCV \ of \ fuel} \times 100$$

6) Heat Loss Due to Radiation and Convection: ([10] Page 12)

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. However it can be calculated if the surface area of boiler and its surface temperature are known as given below:

$$L_6 = 0.548 \times \left[\left(\frac{T_s}{55.55}\right)^4 - \left(\frac{T_a}{55.55}\right)^4\right] + 1.957 \times (T_s - T_a)^{1.25} \times \sqrt{\frac{196.85\, V_m + 68.9}{68.9}}$$

7) Heat Loss Due To Unburnt In Fly Ash: ([10] Page 13)

Small Amounts Of Carbon Will Be Left In The Ash and This Constitutes A Loss of Potential Heating The Fuel. To Assess These Heat Losses, Samples of Ash Must Be Analyzed for Carbon Content. The Quantity of Ash Produced Per Unit of Fuel Must Also Be Known.

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

8) Heat Loss Due To Unburnt In Bottom Ash: ([10] Page 13)

$$L_8 = \frac{\text{Total ash collected / kg of fuel burnt} \times \text{GCV of bottom ash}}{\text{GCV of fuel}} \times 100$$

II. COMBINED WATER TUBE AND FIRE TUBE BOILER AT ANISH CHEMICALS

A. Specification of Combined Fire and Water Tube Boiler

Model	CTM 25
Capacity	2.5 tons/hr
Design temperature	205^0C
Type of fuel used	Coal, wood
Working pressure	17.5 kg/cm^2
Hydraulic test pressure	26.25 kg/cm^2

Table 1: Specification of Combined Fire and Water Tube Boiler

B. Working Principle of Combined Water Tube and Fire Tube Boiler at Anish Chemicals

1) Water Circuit

Feed water pump feeds water to boiler drum. The drum is a heat exchanger with hot gases at tube side and water at shell side. Hot water from bottom of drum is circulated to tube circuit inside the combustion zone of furnace. Thus within furnace water is at tube side and hot gases are at furnace wall side. Steam water mixture is transferred to drum. Steam is collect at top in the drum and it is drawn to main steam line by main steam valve.

2) Gas Circuit

Atmosphere air is drawn by F.D fan, air is heated by energy of flue gases in air pre heater. Heated air enters the combustion chamber, combustion of coal take place in combustion chamber. Hot gases transfers heat to water inside the tube circuit. A gas passes through tubes of drum and transfers sensible heat to water which is at shell side. Flue gases coming out of drum passes through air preheater, I.D fan and chimney.

C. Flow Diagram of Boiler

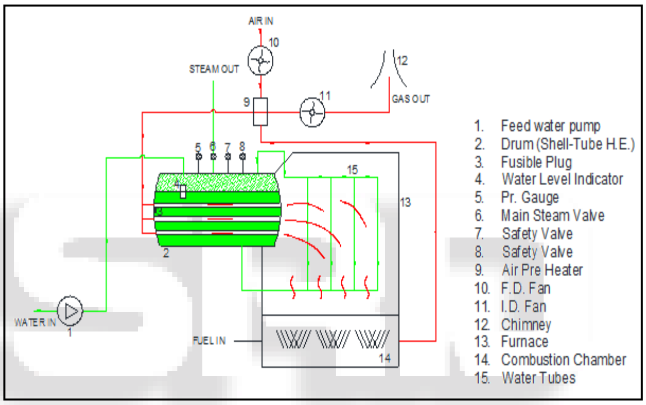

Fig. 4: Arrangement of boiler CTM

D. Boiler Analysis

Sr. No.	Parameters	Week 1	Week 2	Week 3	Week 4
1	Fuel firing rate(kg/hr)	60.55	61.74	65.32	64.20
2	Steam generation rate(kg/hr)	290	280	306	305.3
3	Steam pressure (kg/cm^2 (g))	4	4	4	4
4	Steam temperature(^{0}C)	156	160	161	158
5	Feed water temperature(^{0}C)	65	64.34	65.66	66
6	Surface temperature of boiler Furnace wall(^{0}C)	44	45	44	43
7	Wind velocity around the boiler(m/s)	3.09	3.06	3.01	3.09
8	Total surface area of boiler furnace (m^2)	24.25	24.25	24.25	24.25
9	Surface area of flue gas duct(m^2)	9.1	9.1	9.1	9.1
10	water loss during blow down(kg/hr)	61.83	64.46	69.3	70
11	Temperature of water leaving boiler(^{0}C)	74	76	77.8	79
12	Surface temperature of flue gas duct wall (^{0}C)	73	74	72	73

Table 2: Boiler Analysis

E. Flue Gas Analysis

Sr. No.	Parameters	Week 1	Week 2	Week 3	Week 4
1	%C% CO_2 in Flue gas (%)	11	10.2	11.05	12
2	CO in flue gas (%)	0.41	0.44	0.43	0.48
3	Average flue gas temperature (^{0}C)	155	154	153.9	155.8
4	Ambient temperature (^{0}C)	31	32	32	33
5	Mass flow rate of flue gas (kg/hr)	470	490	500	510

Table 3: Flue Gas Analysis

F. Fuel Analysis

Sr no	Parameters	Week 1	Week 2	Week 3	Week 4
1	GCV of coal (kcal/kg)	3492	3467	3500	3560
2	Amount of bottom ash in 1 kg of coal (kg)	0.07767	0.07902	0.07424	0.08001
3	Moisture in coal (%)	7.1	8.5	7.2	9
4	GCV of bottom ash (kcal/kg)	822	819	825	821

Table 4: Fuel Analysis

III. CALCULATION FOR BOILER EFFICIENCY AND ENERGY LOSSES

A. Boiler Efficiency (η)

Efficiency is calculated by Direct Method

$$\eta = \frac{\text{heat output}}{\text{heat input}}$$

$$= \frac{Q(h_g - h_f)}{q \times G.C.V.} \times 100$$

$$\eta = 81.6\ \%$$

B. Energy Losses from Boiler

1) Heat Loss Due To Radiation and Convection from Uninsulated Surfaces ([10] Page 12)

a) Heat Loss From Furnace Wall

$$L_{1a} = 0.548 \times [(\frac{T_s}{55.55})^4 (\frac{T_a}{55.55})^4] + 1.957(T_s - T_a)^{1.25} \times \frac{\sqrt{196.85 V_m + 68.9}}{68.9}$$

Here $T_s = 317$ K
$T_a = 304$ K
$V_m = 3.09$ m/ sec
Surface area = 24.25 m^2
$L_{1a} = 6362.47$ Watts

b) Heat Loss from Flue Gas Duct (L_{1b}):

$$L_{1b} = 0.548 \times [(\frac{T_s}{55.55})^4 (\frac{T_a}{55.55})^4] + 1.957(T_s - T_a)^{1.25} \times \frac{\sqrt{196.85 V_m + 68.9}}{68.9}$$

Here $T_s = 346$K
$T_a = 304$ K
$V_m = 3.09$ m/ sec
Surface area = 9.1 m^2
$L_{1b} = 8991.97$ Watts

$$L_1 = L_{1a} + L_{1b} = \text{watts}$$

$$\% L_1 = \frac{L1}{G.C.V \times \text{Fuel consumption/sec}} \times 100$$

Putting values

$$\% L_1 = 6.3\ \%$$

c) Heat Loss Due To Flue Gas (L2) ([10] Page 9)

$$L_2 = m_f \times C_{pg}\ (T_f - T_a)$$

Here, $m_f = 470$ Kg/hr = 0.131 Kg / Sec.
$C_{pg} = 0.963$ KJ/Kg K
$T_f = 155°$ C = 428 K
$T_a = 31°$ C = 304 K
Putting values

$$L_2 = 15.64 \text{ KJ / Sec.}$$

$$\% L_2 = \frac{L_2}{G.C.V. \times \text{Fuel consumption /sec}} \times 100$$

$$\% L_2 = 6.33\ \%$$

d) Heat Loss Due To Blow down (L3)

$L_3 = m_{Bw} C_{pw} (T_{wo} - T_{wi})$
$m_{Bw} = 61.83$ Kg /hr = 0.0172 Kg / sec
$C_{pw} = 4.2$ KJ / Kg K
$T_{wo} = 74°$ C = 347 K
$T_{wi} = 65°$C = 338 K
$\% L_3 = 0.650$ KJ / Sec.

$$\% L_3 = \frac{L_3}{G.C.V. \times \text{Fuel consumption /sec}} \times 100$$

$$\% L_3 = 0.263\ \%$$

e) Heat Loss Due To Incomplete Combustion (L4) ([10] Page 11)

It is represented by amount of Co. in flue gas

$$\% L4 = \frac{\% CO \times C}{\%CO + \%CO_2} \times \frac{5744}{G.C.V} \times 100$$

Here
% CO = 0.41
% CO_2 = 11
C = 0.3174
Putting values

$$\therefore \% L_4 = 1.87\ \%$$

f) Heat Loss Due To Unburnt Coal In Bottom Ash (L5) ([10] Page 13)

$$\% L5 = \frac{\text{Kg of ash/ Kg of fuel} \times \text{G.C.V. of bottom ash} \times 100}{\text{G.C.V.}}$$

$$= \frac{0.07767 \times 822 \times 100}{3492}$$

$$\% L5 = 1.8\%$$

g) Heat Loss Due To Moisture Present In Fuel (L6) ([10] Page 9)

$$\% L6 = \frac{M \times [584 + C_p\ (T_f - T_a)]}{\text{G.C.V. of fuel}} \times 100$$

Here
M = 0.071
Cp = 0.45 Kcal / Kg°c
Tf = 155° C = 428 K
Ta = 31° C = 304 K
Putting values

$$\% L6 = 1.3\ \%$$

C. Result Table

Sr. No	Parameters (%)	Week 1	Week 2	Week 3	Week 4
1	L1	6.3	5.9	5.19	4.8
2	L2	6.33	6.4	6.13	6.3
3	L3	0.263	0.351	0.367	0.398
4	L4	1.87	2.21	2.02	2.20
5	L5	1.8	1.86	1.74	1.84
6	L6	1.3	1.56	1.3	1.6
7	Boiler efficiency	81.6	78.5	80.2	79.6

Table 5: Result table

IV. CONCLUSIONS

A. Following Conclusions are made after Detailed Analysis and Calculations

1) Boiler efficiency is calculated by direct method

In direct method efficiency is calculated as ratio of boiler output to boiler input, without calculating individual loss Boiler output is equal to enthalpy rise of feed water when it is converted to superheated steam. Boiler input is amount of energy supplied in the form of energy of fuel. Boiler efficiency calculated by this method is 78.5 to 81.6%.

2) *Major energy losses in boiler are*

- Heat loss due to radiation and convection: Heat loss due to radiation and convection from insulated surface is 4.8% to 6.3% as a large area of flue gas duct and furnace is not insulated radiation and convective losses are high.
- Heat loss due to flue gas: Higher flue gas Discharge temperature is (153.9 ^{o} C to 155.8^{o}C) results in higher heat loss due to flue gas (6.3% to 6.4%).
- Heat loss due to moisture present in fuel: Heat loss due to moisture in fuel is (1.3% to 1.6%) .Fuel energy utilized to evaporate moisture present in fuel results in loss.
- Heat loss due to incomplete combustion: Heat loss due to incomplete combustion (1.87% to 2.21%). For effective conversion of chemical energy of fuel in to heat energy the combustion should be complete combustion. Combustion quality depends upon amount of air supplied, air velocity, air temperature, fuel size and fuel distribution etc. Higher CO% in flue gases indicated incomplete combustion.
- Heat loss due to unburnt coal in bottom ash: Heat loss due to unburnt coal in bottom ash (1.74% to 1.86%). Some coal is left unburnt and discharged with ash, results in energy loss.
- Heat loss due to blow down: Heat loss due to blow down (0.263% to 0.398%). blow down of hot boiler water is carried out to control concentration of dissolved solids and to remove sludge from water. Hot water discharged during blow down results in heat losses.

V. Scope of Future Work

Economizer design should be verified using suitable software. Boiler efficiency and losses should be calculated after installing economizer and flue gas duct insulation. Number of bends in steam line should be reducing to save energy.

Energy loss due to moisture content in coal is 1.3% to 1.6%. So suitable type of coal dryer should be used to reduce energy loss due to moisture. Proper maintenance: A detailed maintenance plan should be prepared and implemented. It should include preventive and predictive maintenance activities. Boiler, air-preheater and economizer tubes are critical parts. Tube cleaning, leak test and wall thickness analysis should be carried out according to maintenance plan. Wall thickness measurement and corrosion check must be carried out for components of flue gas path. Vibration analysis would lead to better boiler performance.

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