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Improved Efficiency of Boiler Plant with Different GCV and Carbon Percentage

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Abstract: Energy sector is one of the important areas in the economic development of any country. Meeting the growing energy demands at acceptable costs in various sectors like industries, commercial, transport, etc., is the challenge to the energy planner. Energy analysis helps to designer to find out to improve the performance of a system. The energy losses from individual components in the plant are calculated based on these losses. In this first law of thermodynamics analysis was performed to evaluate efficiency and various energy losses. In addition, variation in the percentage of carbon in coal content increases the overall efficiency of plant that shows the economic Optimization of plant.

Keywords: Energy, Boiler, First law of Thermodynamic, Efficiency, Energy losses, Optimization.

1. INTRODUCTION

The power sector in India faces peculiar problems. With highly subsidized agricultural rates, most electricity boards are making heavy losses. The electricity boards have no money to invest in new power plants, while foreign investors as well as institutions like the World Bank are reluctant to lend to loss making electricity boards. To a certain extent, energy efficiency improvement can help this matter. From 151 to 400 units, the tariff is Rs 4.20 per kWh and for above 400 units the tariff is Rs 4.40 per kWh in nearest future it may touch Rs 5 per kWh. In most countries numerous steam power plant driven by fossil fuels are in service today. During the past decade, many power generation companies have paid attention to process improvement in steam power plants by taking measures to improve the plant efficiencies and to minimize the environment impact. Today, many electrical generating utilities are striving to improve the efficiency at their exiting thermal electric generating station, many of which are over 25 years old and mature. Often, a heat rate improvement of only a few percent appears to be desired as it is thought that the costs and complexity of such measures may be more manageable than more expensive options.

Boiler is an energy conversion device is usually, a closed vessel made of steel and it is a place where the heat produced due to burning of coal in the furnace is used to convert the feed water into steam. The steam produced may be supplied to an external combustion engine of steam engines and turbines, at lower pressure for industrial process work in cotton mills, sugar factories, breweries etc. and for producing hot water, which can be used for heating installations at much lower pressure.

Boiler is commonly used in industries to generate utility steam used for various purpose like heating or drying chemical compounds in a reactor. The primary function of boiler is to maintain the steam energy in balance with the load demand while maintaining the internal variables such as pressure level in a desired range. Steam pressure is one of the most important parameters for power plant efficiency.

2. LITERATURE REVIEW

One of earliest procedure in the evaluation of power cycle using energy analysis was due to J. K. Salibury. Significant features of this method, generally known as heat deviation method, were to use the analytic description of the boiler cycle in order to reduce the required input data and computational time.

Marc A. Rosen in paper presented energy and exergy based comparison of coal fired and nuclear electrical generating stations. In comparison he concluded that energy losses are emissions(heat rejected by condensers) and exergy losses primarily with consumption(reactors). Effort to increase the efficiencies of coal fired and nuclear electrical generating stations should focus on the combustion and nuclear reactor respectively.[3]

R. Saidur in paper presented the useful concept of energy and exergy utilization is analyzed and applied to the boiler system. Energy and exergy flows in a boiler have been shown in this paper. In a boiler, the energy and exergy efficiencies are found to be 72.46% and 24.89% respectively. A boiler energy and exergy efficiencies are compared with others work as well.[4]

V. S. Reddy, S.C. Kaushik in paper a thermodynamic analysis of a coal based thermal power plant and gas based cogeneration power plant has been carried out. The energy and exergy analysis has been studies for the different components of both power plants. The paper analyses the information available in the open literature regarding energy and exergy analysis on high temperature power plant has been included. Finally, explaining the procedure of analysis of thermal power plant systems by exergetic approach.[5]

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3. METHODOLOGY OF FIRST LAW ANALYSIS

The first law of thermodynamic states that a system executes a cyclic process, the net work is proportional to the net heat, mathematically.

$$\int dw = \int dq$$

Heat and work are different forms of same entity called energy which is conserved, energy which enters the system as heat may leave the system as work, or energy which enters the system as work may leave the system as heat.

For non cyclic process, the increase of energy of system, during the change of state is numerically equal.

$$Q - W = \Delta E$$

The concept of first law efficiency for heat engines or in general for thermodynamic

Cycle representing the fractional part of the heat supplied to a cycle, which is converted into work.

$$\eta_{1\text{ st law}} = W / Q$$

Therefore, first law efficiency is the ratio of quantitative of desired output to the quantitative value of inputs used to produce that results. The efficiencies of different energy system involving different types of energy inputs and outputs cannot be compared directly. Identification of particular energy quantities as output and input give rise to different definitions of efficiency. Such definitions some times (as in case of electricity driven pumps and refrigerators) give rise to efficiency greater than one. [1]

Energy analysis of boiler plant

Basically boiler efficiency can be tested by the following methods:

1) Direct method: Where the energy gain of the working fluid(water and steam) is compared with the energy content of the boiler fuel[6, 7].

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

Indirect method

There are reference standards for Boiler Testing at Site using indirect method namely British Standard, BS 845: 1987 and USA standard is 'ASME PTC 4-1 Power Test Code Steam Generating Units'.

Indirect method is also called as heat loss method. 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 simple calculation procedures.

The principle losses that occur in a boiler are:

L_1 - Loss of heat due to dry flue gas (Sensible heat)

L_2- Loss due to hydrogen in fuel(H2)

L_3 - Loss of heat due to moisture in fuel(H2O)

L_4 – Loss of heat due to moisture in air(H2O)

L_5 – Loss of heat due to radiation and Convection

L_6 – Un-burnt losses in fly ash(Carbon)

L_7 – Un-burnt losses in bottom ash(Carbon)

Boiler Efficiency by indirect method= 100 – (L_1 + L_2 + L_3 + L_4 + L_5+ L_6 + L_7)

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.

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

a) Theoretical air required for combustion

$$[(11.6 \times C) + \{H_2 - O_2 / 8)\} + (4.35 \times S)] / 100$$

b) % Excess air supplied

$$\frac{O_2\,\%}{21 - O_2\,\%} \times 100$$

Normally O_2 measured is recommended. If O_2 measurement is not available, use CO_2 measurement

$$\frac{7900 \times [(CO_2\%)_t - (CO_2\%)_a]}{(CO_2)_a\% \times [100 - (CO_2\%)_t]}$$ (From flue gas analysis)

Where, $(CO_2\%)_t = \dfrac{\text{Moles of C}}{\text{Moles of } N_2 + \text{Moles of C}}$

$$\text{Moles of } N_2 = \frac{\text{wt.of } N_2 \text{ in theoretical air}}{\text{Mol wt of } N_2} + \frac{\text{wt.of } N_2 \text{ in fuel}}{\text{Mol.wt of } N_2}$$

$$\text{Moles of C} = \frac{\text{wt.of C in fuel}}{\text{Molecular Wt of C}}$$

c) Actual mass of air supplied / kg of fuel (AAS)

$\{1 + EA/100\} \times$ theoretical air

1. Heat loss due to dry flue gas

$$L_1 = \frac{m \times c_p \times (T_f - T_a)}{GCV} \times 100$$

2. Heat loss due to formation of water from hydrogen in fuel(%):- The combustion of hydrogen causes a heat loss because the product of combustion is water. This water is converted into steam and this carries away heat in the form of its latent heat.

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

3. Heat loss due to moisture in fuel:- 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 to bring this steam to the temperature of the exhaust Gas. This loss can be calculated with the following equation

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

4. Heat loss due to moisture in air:-

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

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

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surrounding boiler house.

$$L_5 = 0.548 \times [(T_s/55.55)^4 - (T_a/55.55)^4] + 1.957 \times (T_s - T_a)^{1.25} \times \sqrt{[(196.85V_m + \sqrt{68.9})/\sqrt{68.9}]}$$

Normally surface loss and other unaccounted losses is assumed based on the type and size of the boiler is 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 %

6. Heat loss due to un-burnt in fly ash (%):-

$$L_6 = \frac{\text{Total ash collected / kg of fuel burnt} \times \text{GCV of fly ash}}{\text{GCV of fuel}} \times 100$$

7. Heat loss due to un-burnt in bottom ash (%):-

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

4. DATA COLLECTION OF BOILER PLANT

Table 1 Ultimate Analysis of Coal

Description	Unit	Coal sample
C	%	49.3
H	%	3.9
N	%	1
O	%	4.56
S	%	0.58
Ash	%	31.26
Moisture	%	12.52

Table 2 Proximate Analysis of Coal

Description	Unit	Coal sample
Fixed Carbon	%	38.69
Volatile mater	%	25.24
FC/VM ratio	-	1.53
Calorific Value	Kcal/kg	5481

Table 3 Variations in Coal Composition

Description	Unit	Variations in Coal sample composition
C	%	45.0 - 72.0
H	%	3.00 – 0.3
N	%	2.75 - 0.5
O	%	3.00 - 10
S	%	2.00 – 0.20
Ash	%	7.25 – 5.25
Moisture	%	21.0 – 12.0

Table 4 Summary of Boiler Losses

Losses	%
Dry Flue gas loss(L_1)	8.86
Heat loss due to formation of water from hydrogen in fuel(L_2)	5.54
Losses due to the moisture in fuel(L_3)	3.91
Losses due to the moisture in air(L_4)	0.341
Radiation and Convection losses(L_5)	1.37
Losses due to un- burnt in fly ash(L_6)	0.241
Losses due to un-burnt in bottom ash(L_7)	3.42
Total Losses	23.682

Boiler Efficiency by indirect Method

= 100-Total losses
= 100-23.682
= 76.31

5. RESULTS AND DISCUSSION

The calculated values as results are plotted as is following graphs. Fig. Shows that the graph is plotted between losses in (%) Vs GCV of coal (kcal/kg) with constant wind velocity at 4.1 m/s. It was found from the graph that as GCV of coal increases there is a decrease in percentage of losses. However the percentage of losses such as heat loss due to moisture present in air and radiation and convection loss signifies a contribute amount to losses.

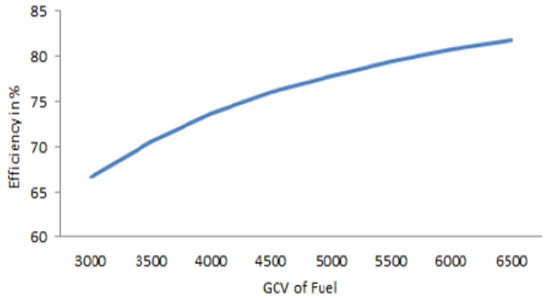

Fig Efficiency Vs GCV of fuel

Fig. Shows that as the carbon percentage increase the value of efficiency is also increase. So the increase in carbon percentage is directly proportional to efficiency.

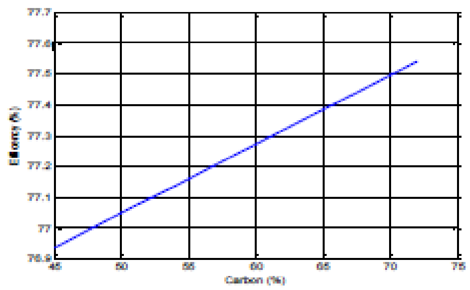

Fig Efficiency Vs Carbon

Fig. Shows that the variation is carbon percentage is increase in higher heating value through the consumption of fuel. Therefore, it decrease mass flow rate of fuel. That shows the increase in carbon percentage is inversely proportional to mass flow rate of fuel.

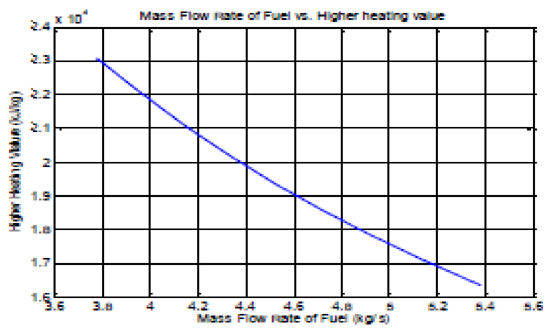

Fig Mass Flow Rate of Fuel vs. Higher heating value

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Fig. Shows that Increase in efficiency as the oxygen percentage is decrease.

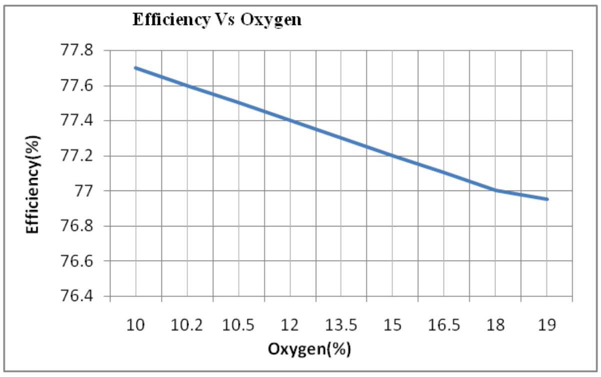

Fig Efficiency Vs Oxygen

Fig. Shows that Increase in efficiency as the moisture percentage is decrease.

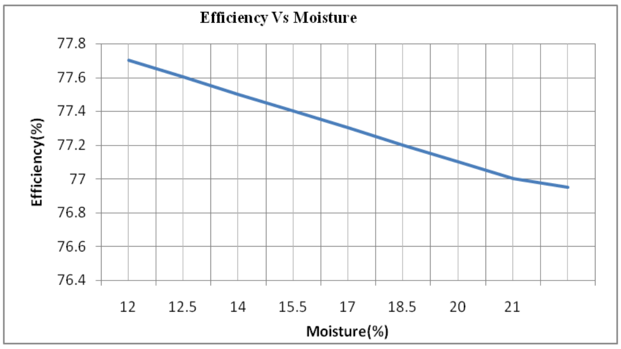

Fig Efficiency Vs Moisture

6. CONCLUSION

Energy Analysis of a thermal power plant is reported in this paper. It provides the basis to understand the performance of a Pulverised bed coal fired boiler. The energy balance sheet shows that theoretical losses in various component of boiler. It provides information for selection of the components which has maximum losses. So, that optimization technique could be used to make it more efficient.

Following conclusion can be drawn from this study:

- The coal type affects the first law efficiency of the system considerably.
- It has been also analysed that a part of energy loss occurs through flue gas.
- The carbon content in the coal has to be proper.
- The presence of moisture has a determined effect on overall efficiency.

With the growing need of the coal, which is an non renewable sources of energy and depleting with a very fast pace, it is desirable to have such optimal techniques(better quality of coal) which can reduce the energy losses in the coal fired boiler and improve its performance these create impact on production and optimizations use of energy sources. In addition this study shows the better quality of coal giving the high performance of plant and even through the consumption of coal is been reduced that creates economic condition for overall plant.

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