International Journal of Emerging Technologies in Engineering Research (IJETER)
Volume 6, Issue 4, April (2018) www.ijeter.everscience.org

An Analysis on Various Coal Samples for Improving Steam Generator Efficiency of a 210 MW Coal Fired Thermal Power Plant

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Abstract – A major portion of electricity is generated across the world based on coal. However, use of coal leads to high level of unwanted emission of greenhouse gases. Due to the limitation of other energy sources, it becomes necessary to rely on coal based power plants. Hence, it is imperative to maximize the steam generator efficiency of the power plants and to minimize the use of coal as basic fuel. Therefore, in the present work, efficiency determination of steam generator of a 210MW power plant in India is considered using relevant data. The steam generator efficiency is determined adopting indirect method for five coal samples. Different heat losses of the steam generator have been calculated for the five coal samples to identify the most prominent losses. It is seen that coal sample-1 provides the maximum efficiency.

Index Terms – Steam generator, indirect method, efficiency, losses.

1. INTRODUCTION

Power consumption per capital indicates the industrial and economic growth of the country and thereby represents the living standard of the people. The whole world is in grip of electrical energy crisis and pollution due to the power plants. The overall power scenario shows shortfall almost in every states of India. The significant role of coal fired thermal power station in India's power generation scenario can be assessed from the truth that they supply about 66% of the total installed capacity. It is also seen that the total reserve of fossil fuels is getting reduced as the day progresses. Hence, strategies are to be implemented to minimise the consumption of coal and maximise the steam generator efficiency. Some of the available options are to evaluate efficiency by indirect method or loss method and to identify the different heat losses, thereby improving the steam generator efficiency. The conventional energy analysis, based on the first law of thermodynamics, evaluates energy mainly on the quantity. Very carefully analysis of the problem and proper planning and execution is necessary to solve the power crisis in India.

Therefore, in the present work, efficiency determination by indirect method of the steam generator of a 210MW power plant in India is considered. Five different coal samples are used to determine the efficiency and heat losses. Finally, the coal sample with better efficiency and less effect on the environment is to be identified. In this connection few literature are studied. Vosough and Mostafagoodarzi [1] considered the effect of excess air to boiler pollution and solved the incomplete combustion process. They concluded that there is an optimum for excess air to reduce boiler pollution and increase boiler efficiency. The conclusion also shows to reduce mole fraction of NO, CO_2 and CO in a gas fired boiler, the excess must be about 10 percent. Mehta et el. [2] considered a detailed energy study of a 210MW coal fired thermal power plant to evaluate the plant and subsystem efficiencies. They used energy analysis to evaluate the overall thermal efficiency of the plant by determining the individual efficiency of the boiler (86.84%), steam turbine (43.5%), and generator (98%). Bakhshesh and Vosough [3] presented energy and exergy flows in a boiler. The energy and exergy efficiencies have been determined as well. In a boiler, the energy and exergy efficiencies are found to be 89.21% and 45.48%, respectively. Rozpondek and Siudek [4] reported in their paper that new and improved technologies can greatly reduce the emissions produced per ton of burning coal. They stated that the wet methods of desulfurization at present are the widest applied technology in professional energetics. From the above literature, it is observed that the environmental damage can certainly be minimized by reducing coal consumption through improved efficiency of the steam generators.

2. PROBLEM DESCRIPTION

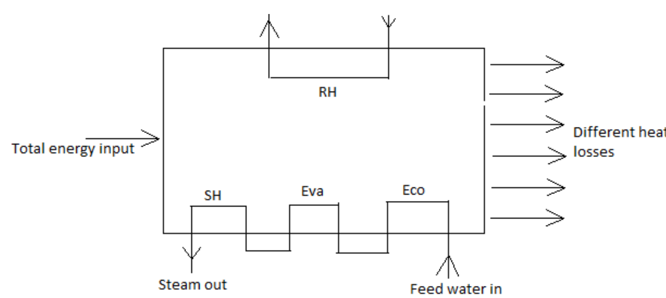

Figure 1 Schematic of the steam generator

In the present study, efficiency determination of the steam generator of a 210MW coal based steam power plant in India is considered. The schematic of the steam generator associated with different heat losses is shown in Fig.1. The indirect or loss method is adopted to determine the different heat losses and the efficiency. The analysis is carried out for five different coal samples.

Table 1 The system data of the steam generator

Coal sample	Proximate Analysis				Ultimate Analysis					Net Heating Value (MJ/kg)
	Fixed Carbon	Volatile Matter	Moisture	Ash	C	H	O	N	S	
Sample 1	81.8	7.7	4.5	6.0	91.8	3.6	2.5	1.4	0.7	36.2
Sample 2	54.9	35.6	5.3	4.2	82.8	5.1	10.1	1.4	0.6	36.1
Sample 3	43.6	34.7	10.5	11.2	76.4	5.6	14.9	1.7	1.4	31.8
Sample 4	27.8	24.9	36.9	10.4	71.0	4.3	23.2	1.1	0.4	26.7
Sample 5	41.48	10.51	10.0	38.0	89.82	2.8	6.41	0.69	0.28	40.5

Particulars	Values
Ambient temperature	29 °C
Moisture content from psychrometric chart	0.02%
Furnace Temperature	1050 °C
Fly Ash ration to total ash	85%
Bottom Ash ratio to total ash	15%
% loss due to radiation	0.3

3. MATHEMATICAL ANALYSIS

In the present study, efficiency determination of steam generator of a 210 MW steam power plant is considered. The indirect method or loss method is adopted for determining the steam generator efficiency which is based on measuring all the heat losses incurred with the system. An important advantage of this method is that, the error in measurement does not make significant effect in efficiency. The following losses are measured as [7]

3.1 Loss due to sensible heat in dry flue gases (L_1)

Flue gases produced during combustion of coal in the boiler leave the boiler at a temperature higher than that of the surrounding air. This loss calculates the sensible heat loss due to only the dry flue gases. The sensible heat loss is calculated as

$$L_1 = m \times C_p \times (T_f - T_a) \times \frac{100}{GCV} \quad (1)$$

Where, m is the mass of dry flue gas in kg/kg of fuel, c_p is specific heat of flue gas in kCal/kg ℃ (= 0.23), T_f is the corrected air pre heater exit flue gas temperature and T_a is the ambient air temperature in ℃

3.2 Loss due to combustion of hydrogen in fuel (L_2)

The Hydrogen contained in the fuel burns in the boiler to form water vapour and is finally converted to steam which leaves the boiler along with the flue gases. Energy of the fuel is consumed in the process and this is a loss for the boiler. The loss is calculated as

$$L_2 = 9 \times H_2 \times \{584 + C_p(T_f - T_a)\} \times \frac{100}{GCV} \quad (2)$$

where, H_2 = Hydrogen % in fuel, C_p = Specific heat of superheated steam in kCal/kg ℃ (= 0.45) and 584 = factor for Latent heat of vaporization of water in Kcal/kg.

3.3 Loss due to moisture present in fuel (L_3)

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 vaporization of the moisture, and the heat required to bring this steam to the temperature of the exhaust gas. This loss can be calculated as

$$L_3 = M \times \{584 + C_p(T_f - T_a)\} \times \frac{100}{GCV} \quad (3)$$

where, M = Moisture in fuel, C_p = Specific heat of superheated steam in kCal/kg ℃ (=0.45), and 584 = factor for Latent heat of vaporization of water in Kcal/kg

3.4 Loss due to moisture in air (L_4)

Water vapour is present in the incoming air to the boiler. This water vapour gets superheated as it passes through the boiler and leaves with the flue gases. Energy of the fuel is consumed in the process and can be measured as

$$L_4 = AAS \times HF \times C_p \times (T_f - T_a) \times \frac{100}{GCV} \quad (4)$$

3.5 Loss due to incomplete combustion of fuel (L_5)

Incomplete combustion of fuel mainly leads to formation of Carbon Monoxide. This loss is calculated as shown below by measuring the Carbon Monoxide (CO) at the economizer outlet. (1)

$$L_5 = \frac{\%CO \times C}{\%CO + \%CO_2} \times \frac{5744}{GCV} \times 100 \quad (5)$$

3.6 Loss due to unburnt carbon in fly ash (L_6)

In spite of all efforts at complete combustion of the fuel, some amount of carbon which is not burned is found in the fly ash. This may be due to improper coal mill performance also. This constitutes a loss of potential heat in the fuel. To access this heat loss, samples of fly ash are analysed for unburnt carbon content. It is also required to know the fraction of fly ash and bottom ash of the total ash produced in the boiler. Generally, the amount of fly ash is 80% to 90% of the total ash and bottom ash is 10% to 20% and the figure is also given by the boiler manufacturers. The quantity of fly ash produced per kg. of fuel is then calculated.

$$L_6 = \frac{UC_1\% \times A\% \times n_1}{\{100 \times 100 \times (100 - UC_1\%)\}} \times \frac{8097}{GCV} \times 100$$

(6)

% fly ash in total ash= n_1 (= 85%), 8097 = heat value of burning 1 kg of carbon in Kcal/kg

3.7 Loss due to unburnt carbon in bottom ash (L_7)

In spite of all efforts at complete combustion of the fuel, some amount of carbon which is not burned is also found in the bottom ash which again may be due to improper coal mill performance. This constitutes a loss of potential heat in the fuel. To access this heat loss, samples of bottom ash are analysed for unburnt carbon content.

$$L_7 = \frac{UC_2\% \times A\% \times n_2}{\{100 \times 100 \times (100 - UC_2\%)\}} \times \frac{8097}{GCV} \times 100 \qquad (7)$$

where, A% = Ash % in fuel, UC_2% = Unburnt Carbon % in Bottom Ash sample , n_2 Bottom ash in total Ash = 85%, 8097 = Heat value of burning 1 kg of Carbon in Kcal/kg.

3.8 Loss due to surface radiation, convection and other unaccounted losses (L_8)

Radiation and convection losses inevitably occur from the external surface of the boiler. These losses depend on the boiler surface temperature as well as the wind velocity of the surrounding air. The figures for pulverized fuel fired boilers range from 0.2% to 1.5% with lower figures for higher sized units.

3.9 Loss due to sensible heat in fly ash (L_9)

The fly ash which is generated in the boiler is deposited and ultimately removed from the ESP hoppers at a higher temperature compared to the surrounding air and this is a heat loss for the boiler. For fly ash, the Air Heater outlet gas temperature is considered for calculating the loss as

$$L_9 = \frac{\alpha \times 0.2 \times (T_r - T_a)}{GCV} \times 100 \qquad (9)$$

Where, T_r =air heater outlet flue gas temperature, mass of fly ash/kg of fuel = ash% in fuel * %fly ash in total ash (say 85%), 0.2 = Specific heat capacity of ash in Kcal / kg˚C

3.10 Loss due to sensible heat in bottom ash (L_{10})

The fly ash which is generated in the furnace falls into the water filled bottom ash hopper at a temperature of around 750 to 800 which is approximate furnace bottom zone temperature. This is a heat loss for the boiler and is calculated as

$$L_{10} = \frac{\alpha \times 0.2 \times (T_b - T_a)}{GCV} \times 100 \qquad (10)$$

4. RESULTS AND DISCUSSION

(6) where, A% = Ash % in fuel, U

In the present study, the efficiency determination of the steam generator of a 210 MW power plant in India is considered. The efficiency is determined based on indirect method where the different heat losses are calculated individually. Five coal samples are considered for the efficiency determination for identifying the coal sample with better efficiency and less efficient on the environment.

From the analysis, it is observed that there are four main reasons which accounted for the bulk of the heat loss in the boiler. If these four areas are improved that would result in a significant increase in the efficiency. The four main losses are loss due to dry flue gas, hydrogen in fuel, moisture in fuel and unburnt carbon in fly ash. Thereafter, the same calculations were done with four different coal samples which were all different from the one used in the literature.

(7)

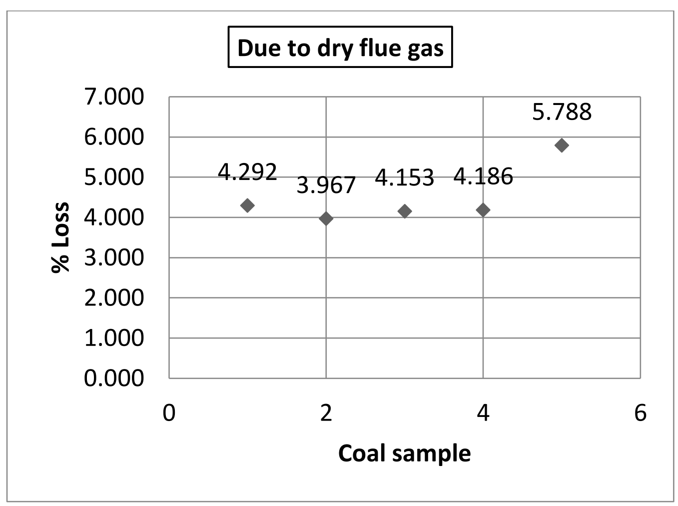

Figure 2 Heat loss due to exhaust dry flue gas for different coal samples.

In the fig. 2, it is seen that the loss due to dry flue gas is reduced when the other samples are used. Thus using these samples will result in higher efficiency. This reduction in heat loss can be attributed to their high gross calorific value which bears an inverse relation to the loss due to dry flue gas, thus higher the GCV lesser will be the loss due to dry flue gas.

In fig.3, the comparison between the losses due to hydrogen in fuel is shown for the different coal samples. It was observed that the loss reduces when the new samples were used due to their lower hydrogen content. The hydrogen present in the fuel reacts with oxygen in the boiler at high temperature and forms steam which escapes as flue gas. This reaction however absorbs some energy which reduces the energy available and hence is considered to be a loss.

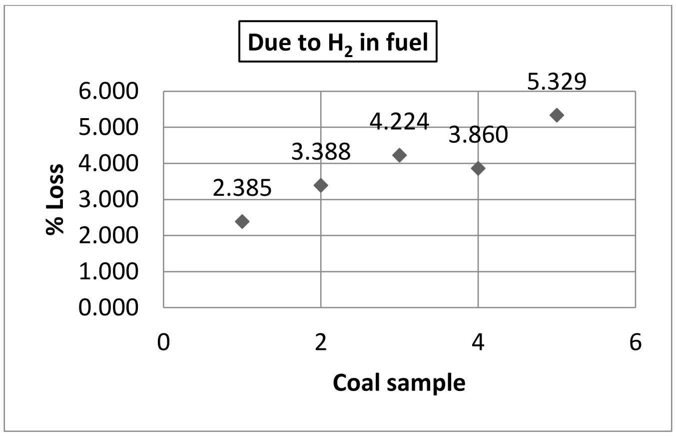

Figure 3 Heat loss due to hydrogen present in coal for different coal samples.

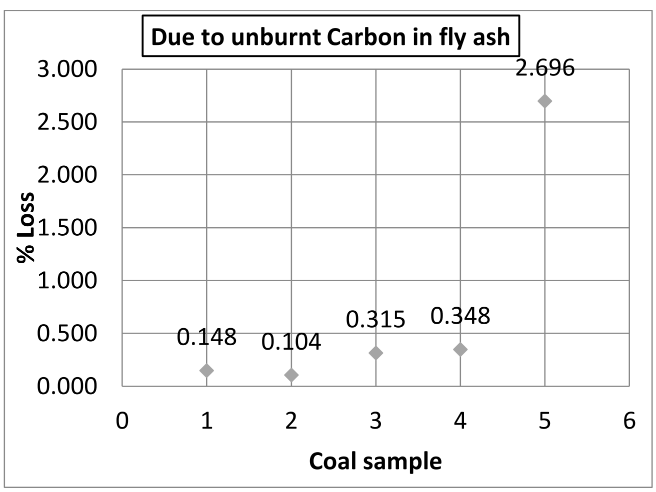

Figure 4 Heat loss due unburned carbon in fly ash for different coal samples.

Fig.4 shows, that the heat loss due to unburnt carbon is lesser for the new samples as the ash content is also considerably lower. It is the fly ash which holds the maximum amount of unburnt carbon so reduction in the amount fly ash means a larger proportion of carbon has undergone complete combustion. This causes considerable reduction in the loss.

In the fig. 5, it is seen that the moisture content in the fuel accounts for quite a substantial amount of heat loss. This is because the moisture in the fuel leaves as superheated vapour, hence absorbs the available energy in the boiler, to first get sensibly heated to its boiling temperature, then absorb latent heat to get converted to steam and then again get heated to the temperature of exhaust gasses. Thus with decrease in moisture content in the fuel, the energy available is more and loss is less. So for the samples with high moisture content the loss due to moisture in fuel is high.

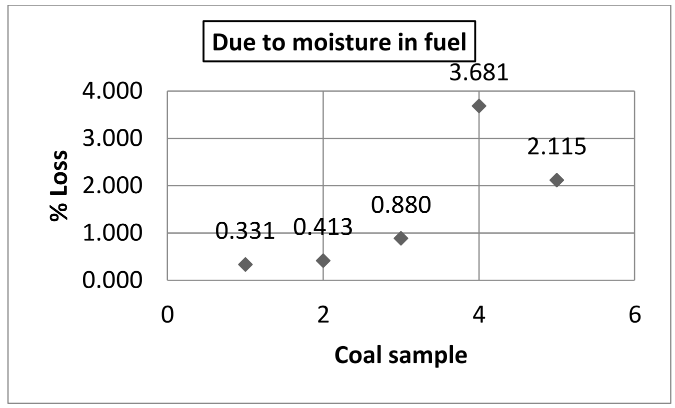

Figure 5 Heat loss due to moisture in coal for different coal samples.

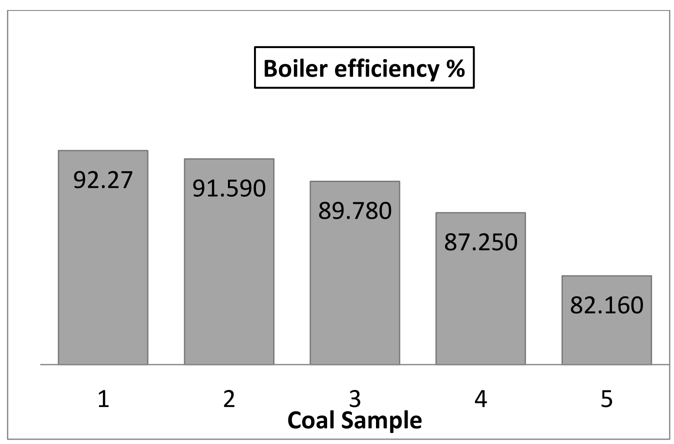

Figure 6 Variation of steam generator efficiency for different coal samples

5. CONCLUSION

In the present study, the efficiency determination of the steam generator of a 210 MW power plant in India is considered. The efficiency is determined based on indirect method where the different heat losses are calculated individually. Five coal samples are considered for the efficiency determination for identifying the coal sample with better efficiency and less effect on the environment. From the present analysis, it is seen that the efficiency can be greatly increased by using the coal sample which provides better efficiency. This results show better utilisation of resources and increase in productivity which can vastly improve the power scene in India.

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