BOILER PERFORMANCE ASSESSMENT AND HEAT BALANCE OF 70 MW LIGNITE BASED THERMAL POWER PLANT

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Abstract: *Thermal power plant converts the chemical energy of the coal into electricity. Coal fired boiler is one of the most important components for any thermal power plant. Boiler performance evaluation is necessary to find out variation of boiler efficiency related to its various operating parameters. Hence it is necessary to find out the current level of efficiency for performance evaluation of boiler, which is mandatory for energy conservation action in industry. The aim of boiler performance assessment is to conserve energy in boiler and reduce cost of electricity production by decreasing losses in boiler. Here the findings of 70 MW boiler unit efficiency improvement study carried out in a large boiler house unit of Lignite based Thermal Power Plant. The causes of poor boiler efficiency were various heat losses such as loss due to combustible in ash, loss due to dry flue gas, loss due to moisture and hydrogen in fuel, loss due to radiation, loss due to sensible heat in ash, etc. the various heat losses were analyzed from August 2018 to February 2019. The average loss due to moisture and hydrogen in fuel is 12.48%, loss due to dry flue gas 7.62% and loss due to combustible ash is 3.9%. And a set of recommendations were made to the plant management for implementation, so that efficiency of boiler could be increased. It is observed that the carefulness in the operation of the boiler can help a great deal in energy efficiency improvement in boiler.*

Keywords: *Boiler, Performance, Combustion, Losses*

1. INTRODUCTION

Thermal energy is one of the important requirements of any country. Realizing the fact that energy is the sinew of economic growth, energy management and energy conservation are of paramount importance. Energy efficiency improvement is the only cost effective and viable means of ensuring the proper use of finite natural resources, minimizing operating expenses and increasing the profitability [1]. Electrical power plants in India consumes more than 60 percent of thermal energy for raising steam for operating steam turbines and during every decade is expected to grow [2]. Electricity generate from coal currently accounts for about 40 percent of the electricity generated worldwide and about 53 percent in India. As coal is a comparatively more abundant fuel source in India, it is likely to remain a dominant fuel for electricity generation in future also [3]. The optimization of power generation systems is one of the most important subjects in the energy – engineering field. The performance evaluation and optimization of steam generating system is not only important to reduce the cost of steam generation but also helps in reducing the emissions of greenhouse gases in the environment. It is also reported that about 40-50 percent of the total energy used in dairy plants is heat energy for the processing and manufacture of dairy products [4,5]. The steam boiler in its original meaning is an object in which thermal energy, resulting from combustion of organic fuels, is transferred through heat surfaces to a working fluid which evaporates in the boiler with the steam further overheated to a certain temperature. The most common working fluid is water which evaporates in the boiler, and is being overheated so the final product is saturated or superheated steam. The boiler performance of Thermal Power Station is selected to evaluate its performance. The performance of boiler is expressed as efficiency of boiler which is the ratio of output energy to the input energy. It varies between 80 to 88 percent for a modern boiler. Equivalent evaporation is also used to compare the performance of boilers when the operating conditions are different for various boilers [6]. The performance of boilers is affected by various factors such as combustion efficiency, maintenance, quality of water, operating conditions of boilers etc. Steam is produced by combustion of various fuels and hence boiler performance may be expressed in term of quality of steam produced per kg of fuel used for comparing the steam output per unit quantity of fuel used [7]. The performance evaluation is one of the very essential requirements for the conservation of energy and optimization of operating parameters of boilers. There are two basic methods of assessing boiler efficiency (a) direct method and (b) Indirect method [8]. In case of boilers, cost of buying a new boiler is small compared to amount of money spent in operating the boiler year on year. It can be easily noticed that the fuel cost is the biggest contributor in the overall ownership cost for both oil and solid fuel fired boilers. Amount of money spent on fuel is closely related to the efficiency of boiler. A survey conducted by Confederation of Indian Industry shows that scope of savings in boiler house ranges from 28 to 46 percent for different industries. The objective of performance monitoring and assessment is to continuous evaluation of degradation ie, a decrease in performance of the steam boiler. These data enable additional information which is helpful in problem identification, improvement of plant performance and making economic decisions about maintenance schedule. All these actions are aimed towards optimization of boiler performance. The main analysis of the study is to find out those areas where heat losses are occurring maximum and modified them for efficient and effective improvement in thermal power station. The main points are (a) to evaluate operating efficiency of boiler with lignite coal as a fuel (b) determine various type of losses related to boiler operation (c) Identification the causes of performance degradation and its performance analysis (d) identifying heat rate gaps and then recommending corrective actions to eliminate that efficiency loss.

2. Literature Review

The purpose of literature survey is to understanding the methodology which had been implemented in research to carried out efficiency analysis of power plant or any thermal system. Some authors by using analysis of losses which occur in power plant had improve plant efficiency whereas some author used continuous monitoring system to improve plant and system efficiency. Virendra Nagar et al [9] has calculated operating efficiency of boiler and major losses for Vindhyachal Super thermal power plant of 210 MW. This plant used pulverized coal-fired with steam flow rate and coal flow rate with 615 tons per hour and 140 tons per hour. They identified major causes of heat losses by fault tree analysis (FTA). They concluded that major heat loss cause in dry heat gas loss 7.30 percent, loss due to hydrogen in fuel 4.55 percent, loss due to moisture in fuel 2.39 percent and partial combustion of C to CO 2.32 percent. Rajul Dev et al [4] carried out study for improvement of boiler efficiency which is unit of a pulp and paper mill. Author was performing calculation for finding current overall efficiency and analysis various losses which causes destruction of boiler efficiency. Some major recommendations by author to plant management are (a) maintain proper size of crushed coal before feeding into boiler (b) monitoring excess oxygen in flue gas every short time interval and based on it supply minimum excess air into the boiler (c) regularly in every 8 hours shift of the day operation of soot blower has to be done (d) blow down should give only when necessary based on chemistry of feed water (e) every boiler surface stem or condensate piping, valves and fittings whose temperature greater then 50 degree centigrade should be properly insulated. R Pachaiyappan et al. [10] have performed boiler efficiency calculation by using indirect method. They draw out result that efficiency loss occurs mainly due to large percentage of heat is wasted in flue gas (dry loss 5.14%) and moisture present in fuel (wet loss 4.2%). Results showed that for every 22-degree centigrade reduction in the flue gas temperature the boiler efficiency increases by 1% and correct optimization of combustion air can increase the boiler efficiency by 2-3%. K Sampath Kumar Reddy et al [11] in their study observed that boiler has 87.94% practical efficiency which could be improve by modification of economizer material. This was established using computational fluid dynamics and proposed mild steel as economizer material in place of carbon steel material. Umarao et al [12] determined boiler and plant overall performance for two operating condition of power plant such that part load condition and full load condition using indirect or heat loss method. It was observed that excess air requirement at full load is 31% whereas at part load condition it is only 22%. The unburnt carbon in bottom ash is 3% higher than the design value at full load whereas unburnt carbon fly ash is 1.2% as against design value of 0.4% for part load condition.

3. METHODS AND CALCULATION

The boiler performance helps us to evaluate overall assessment of the unit. Based on present performance data, we have to point out the factors and / or losses which will have effect on boiler performance. By minimizing such losses and improving those factors will improve boiler performance. The performance of boiler is expressed as efficiency of boiler which is the ratio of output energy (amount of heat used for the generation of steam) to the input energy (amount of heat supplied). It varies between 80 to 88 percent for a modern boiler.

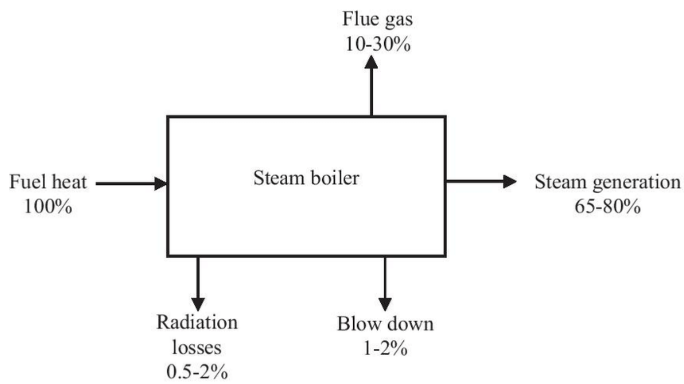

Figure 1. Typical Heat Balance of Boiler

As shown in figure 1 only part of the heat content of the fuel is converted into useful heat, while the rest is lost through exhaust gases, blow down and radiation losses. The efficiency of boilers is usually rated based on combustion efficiency, thermal efficiency and overall efficiency. There are two basic ways of determining the efficiency of boiler (a) direct method (input output method) and (b) indirect method (heat loss method).

3.1. Direct Method

This was standard for a long time, but is little used now. According to this method the boiler efficiency is defined as the ratio of the heat utilized by feed water in converting it to steam to the heat released by complete combustion of the fuel used in the same time. The output or the heat transferred to feed water is based on the mass of steam produced under the actual working conditions. The input to a boiler or heat released by complete combustion of fuel may be based on the higher calorific value of the fuel. The advantages of direct method are (a) quick evaluation (b) few parameters for computation (c) few monitoring instruments (d) easy to compare evaporation ratios with benchmark figures. The disadvantages of direct method are (a) no explanation of low efficiency and (b) various losses not calculated.

3.2. 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, this method is also known as heat loss method. The efficiency of a boiler equals 100% minus the losses. Thus, if the losses are known the efficiency can be derived easily. This method has an advantage such that errors are not significant for example, if the losses total 10% then an error of 1% will affect the result by only 0.1%. The advantage of indirect method is (a) complete mass and energy balance for each individual stream (b) makes it easier to identify options to improve boiler efficiency. The disadvantages of indirect method is (a) time consuming (b) requires lab facilities for analysis. Based on discussion, indirect method is best suitable for our study because it can identify option to improve boiler efficiency.

3.3. Heat losses in boiler plant

Heat losses in boiler plant is mainly divided into four parts (a) heat lost to chimney gases or flue gases ie. heat carried away by the products of combustion, (b) heat lost due to incomplete combustion, (c) heat lost due to sunburn fuel (d) heat lost to external radiation.

3.3.1. Heat lost to chimney gases or flue gases

The flue gases going out of chimney are made up of (a) dry flue gases (b) steam in flue gases formed from the combustion of hydrogen present in the fuel together with any moisture present in the fuel.

3.3.2. Heat lost due to incomplete combustion (burning of carbon to CO)

For complete combustion of any fuel, all the carbon should be converted to CO_2. Any CO present in flue gases is due to insufficient air supply. Incomplete combustion means burning of carbon C to CO. 1 kg of carbon burnt to CO_2 releases 33830 kJ while 1 kg of carbon burnt to CO releases only 10130 kJ. Thus 33830 – 10130 = 23700 kJ heat is lost due to incomplete combustion or in other words we can say that 23700 kJ heat is available in CO per kg of carbon.

3.3.3. Heat lost due to evaporation of water formed due to hydrogen 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.

3.3.4. Heat loss due to moisture present in fuel

Moisture is entering the boiler with the fuel leaves as superheated vapor. 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.

3.3.5. Heat lost due to moisture present in air

Vapor 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 the amount of air supplied per unit mass of coal burned must be known. The mass of vapor that air contains can be obtained from psychometric charts and typical values are included in Table 1.

Table 1. Humidity Factor

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

3.3.6. Heat lost due to external radiation

Effective lagging of the surface of boiler exposed to atmosphere is necessary to reduce such loss to minimum. These losses range for 110 / 210 MW units from 0.93% to 1% on higher side. They can be calculated by graphical methods and alignment charts.

3.4. Heat Measurement required for performance assessment testing

The following parameters need to be measured, as applicable for the computation of boiler efficiency and performance. (a) Flue gas analysis (percentage of CO_2 or O_2 in flue gas, percentage of CO in flue gas and temperature of flue gas), (b) Flow meter measurements for fuel, steam, feed water, condensate water and combustion air, (c) Temperature measurement for flue gas, steam, make up water, condensate return, combustion air, fuel and boiler feed water, (d) Pressure measurement for steam, fuel, combustion air (primary and secondary) and draft, (e) Water condition such that total dissolved solid, pH and blow down rate and quantity.

4. RESULT AND DISCUSSION

Data analysis is carried out on the recorded observation. The efficiency of boiler is calculated by indirect method. Indian coal (Lignite) is used as fuel. The quantity of carbon, hydrogen, nitrogen, oxygen, sulphur, and moisture present in coal in percentage are obtained from fuel analysis. Constituents of flue gases such as oxygen, carbon monoxide and temperature of flue gas, ambient temperature are obtained from flue gas analyzer. Constituents of fuel and flue gas are recorded for a period of seven months. The values of the various constituents of fuel such as carbon, hydrogen, nitrogen, and oxygen content for every month are given in Table 2.

Table 2. Month wise Ultimate Analysis of fuel

Constituents of Fuel (Ultimate Analysis)	Aug 2018	Sep 2018	Oct 2018	Nov 2018	Dec 2018	Jan 2019	Feb 2019
% Carbon	32.50	38.57	19.61	21.34	31.29	25.34	26.38
% Hydrogen	5.25	5.32	5.22	5.22	5.35	5.25	5.27
% Oxygen	9.74	3.30	7.73	8.63	9.15	10.19	10.23
% Sulphur	3.00	4.85	4.89	4.00	4.00	2.56	2.56
% Nitrogen	1.68	1.65	1.70	1.70	1.63	1.68	1.68
% Moisture	11.68	14.44	21.31	19.62	11.88	21.88	22.38
GCV (kCal/kg)	3449	3551	3082	3294	3368	3672	3792
% Ash	36.15	31.02	25.80	25.47	36.70	17.95	15.90

There is variation in the constituents of coal. The carbon content in coal in the month of September is maximum (38.57%). The percentage of hydrogen is maximum (5.35%) during December 2018 to February 2019. The percentage of nitrogen is maximum (1.7%) during October and November, and the percentage of oxygen is maximum (10.23%) during February. Table 3 shows the results of flue gas analysis and ash analysis for a period of seven months. The flue gas temperature is maintained between 191°C to 244°C. The ambient temperature range varies from 24°C to 35°C. Oxygen content in the flue gas for an entire seven month varies from 4% to 7%. Other parameters and constants that are measured during the period of 7 months are Load (MW), Steam pressure (bar), Steam temperature in degree C, Theoretical air required in kg/kg of fuel, Excess air, actual air supplied in kg/kg of fuel, Mass of dry flue gas in kg-mol/kg of fuel, Specific heat of dry gas in kJ/kg°C, Specific heat of fly ash in kCal/kg °C, Specific heat of bottom ash in kCal/kg°C, Specific heat of superheat steam in kJ/kg°C and fly ash to bottom ash ratio.

Table 3. Month wise Flue gas analysis and Ash analysis

Parameters	Aug 2018	Sep 2018	Oct 2018	Nov 2018	Dec 2018	Jan 2019	Feb 2019
Flue Gas Temp (Tf in °C)	214	206	205	202	244	198	191
Bottom Ash Temp (Tb in °C)	727	690	702	669	680	732	750
Ambient Temp (Ta in °C)	34	27.70	31.20	32.07	31.70	24.97	25.37
Humidity factor	0.01	0.01	0.01	0.02	0.01	0.01	0.01
%O_2	6.28	6.18	7.73	4.69	6.50	4.45	4.3
%CO_2	12.90	13.08	11.77	8.40	13.80	9.71	10.26
% Combustible in Bottom Ash	12.93	16.06	36.05	28	14.30	31.64	45.12
% Combustible in Fly ash	2.10	1.30	1.52	1.1	1.26	0.44	0.42
% ash appearing in bottom half	0.15	0.15	0.15	0.15	0.15	0.15	0.15
% ash appearing in dust collector & chimney	0.85	0.85	0.85	0.85	0.85	0.85	0.85
CV of Carbon (kCal/kg)	8049	8049	8049	8049	8049	8049	8049
CV of CO (kCal/kg)	2415	2415	2415	2415	2415	2415	2415

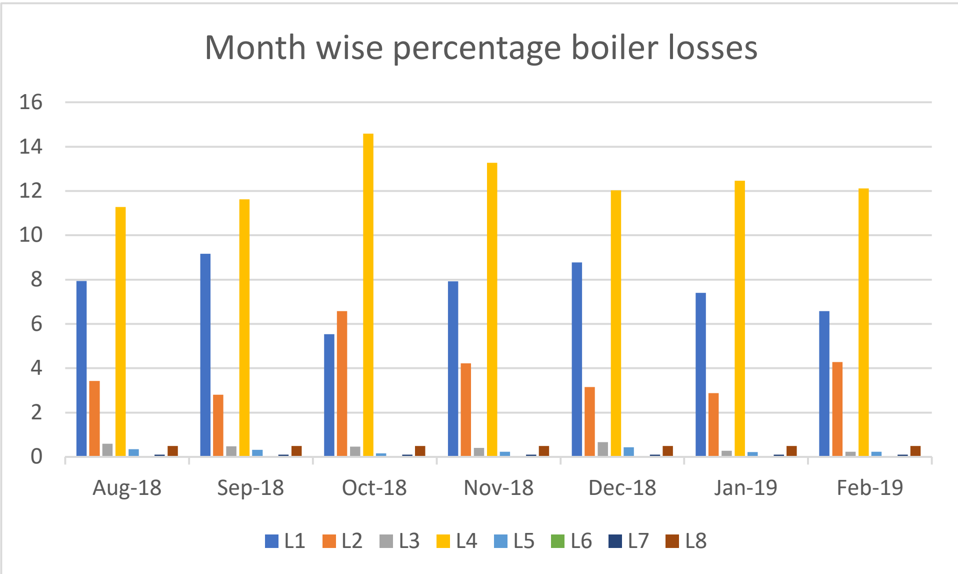

Figure 2. Month wise percentage boiler losses

Figure 2 shows the month wise percentage boiler losses where L1 is loss due to dry flue gas, L2 is loss due to combustible in ash, L3 is loss due to sensible heat loss in ash, L4 is loss due to moisture and hydrogen in fuel, L5 is loss due to moisture in air, L6 is loss due to coal mill reject, L7 is loss due to incomplete combustion and L8 is loss due to radiation and unaccounted losses in percentage. The values of boiler heat loss due to dry flue gas L1 is 5.54%, the heat loss due to combustible in ash L2 is 6.58%, the heat loss due to sensible heat in ash L3 is 0.46%, the heat loss due to formation of water because of presence of H_2 in fuel and due to moisture present in fuel L4 is 14.58%, heat loss due to moisture present in air L5 is 0.16%, heat loss due to incomplete combustion L7 is 0.1% and heat loss due to radiation and other un accounted losses L8 is 0.5%.

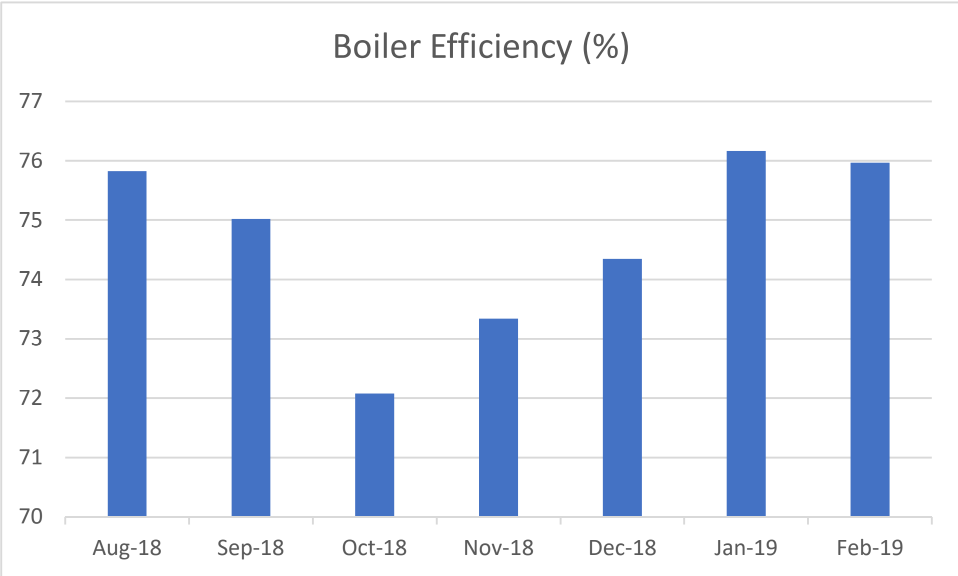

Figure 3. Month wise percentage boiler efficiency

Figure 3 shows the percentage of boiler efficiency for seven months, considering humidity range as 0.0100 to 0.0200 kg/kg of dry air. The value of radiation loss is assumed and the average value is 0.5%. As mentioned above all most all the heat losses are maximum in the month of October and hence the boiler efficiency is minimum 72.08% during that month when compared with the average value of boiler efficiency of 74.68%.

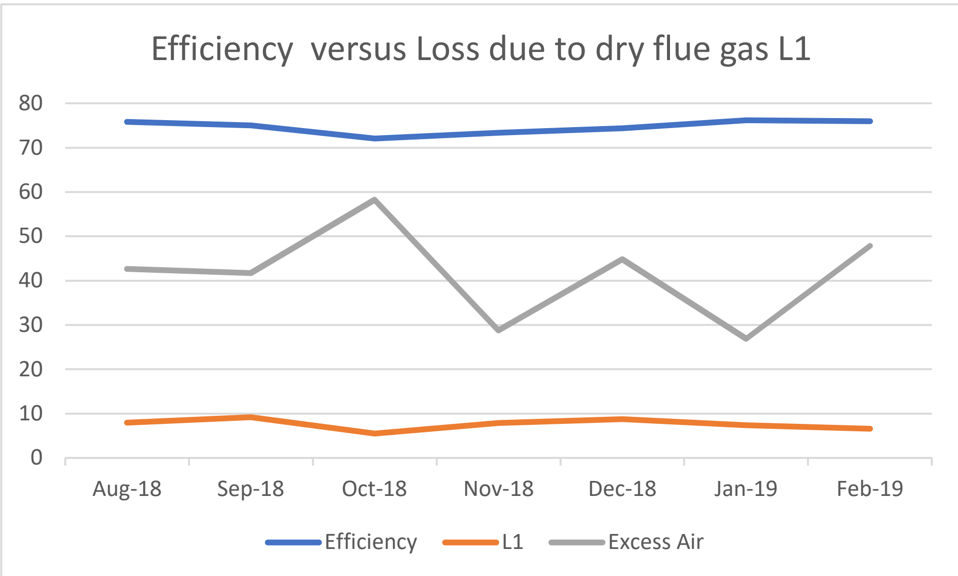

Figure 4. Efficiency vs Losses due to Dry Flue Gas

Figure 4 shows the effect of excess air supplied to the combustion chamber. As the excess supplied air to the boiler increases efficiency decreases and losses in dry flue gas also increases. The efficiency of boiler can be easily increased up to 1-2% if we can control the excess air supply from the graph. The excess air supply is directly proportional to the stach losses due to dry flue gases.

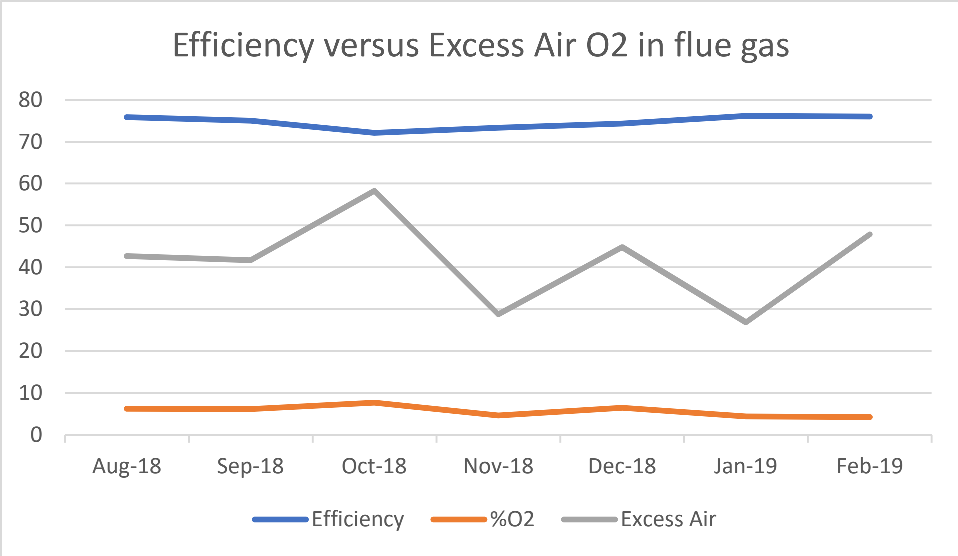

Figure 5. Efficiency vs Excess Air O2 in Flue Gas

As shown in Figure 5 an excess air supplied to combustion chamber increases the O_2 contain in flue gas along increase and dry flue gas loss increase due to which efficiency of boiler decrease. The reverse case when excess air supplied reduced below requirement due to improper combustion O_2 contain in flue gas decrease and boiler efficiency drastically decrease.

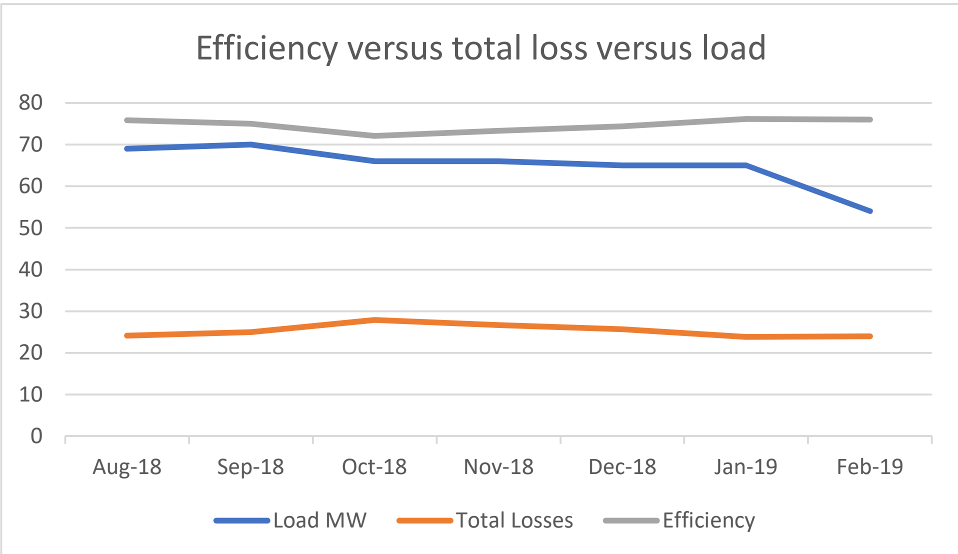

Figure 6. Efficiency vs Total Loss vs Load

As shown in figure 6 when boiler run at full load condition the total losses are decrease to minimum and corresponding boiler efficiency also higher compare to boiler run at part load condition. So, it is always desirable to boiler run at full load condition. As excess air supplied to boiler beyond optimum condition that additional excess air take combustion heat with it at boiler outlet as flue gas. So higher flue gas temperature clearly indicates that either boiler operating poorly or poor efficiency of air preheater.

4.1. Recommendation made to minimize boiler losses

The main factors affecting the boiler efficiency are incomplete combustion, excess air, thermal loss due to water vapor in flue gas, flue gas temperature, fuel type, burners, boiler load, thermal loss from boiler surface.

4.1.1. Reduction of Excess Air Leakage

After long duration of operation rotary preheater have more chances of air leakage inside structure. In practical life, it is impossible to completely avoid air leakage in rotary type air heaters. In this type of heaters air leakage increases as time passes because of the corrosion due to the combustion gases. Then the total boiler efficiency decreases as a result of increased air leakages. The amount of air leakage can be determined easily by the measurement of O_2 at the outlet of the boiler and the outlet of the flue gas. So, by preventive air leakage in air preheater dry gas losses can be minimized.

4.1.2. Reduction of Excess Air / Fuel Ratio

In the measurement of boiler performance, it was found out that the boiler operates over the optimum excess air to fuel ratio. Reducing excess air to that needed for complete combustion will improve boiler efficiency. The optimum excess air level for maximum boiler efficiency occurs when the sum of the losses due to incomplete combustion and loss due to heat in flue gases is minimum. Excess air levels will be different for different firing rates and for different boilers. This level varies with furnace design, type of burner, fuel and process variables. It can be determined by conducting tests with different air fuel ratios. Controlling excess air to an optimum level always results in reduction in flue gas losses. For operation at only 25% output, every 1% reduction in excess air there is approximately 0.6% rise in efficiency. Various methods are available to control the excess air. Potable oxygen analyzers and draft gauges can be used to make periodic readings to guide the operator manually to adjust the flow of air for optimum operation. Excess air reduction up to 20% is feasible.

4.1.3. Boiler Load Fluctuations

The load on the boiler is fluctuating in nature. The efficiency of boiler varies according to load. As load is suddenly increased steam demand is also increased and pressure will drop. Burner is start to fire at its full rate to meet this demand. But pressure continues to drop because boiler is taking some time to respond. Similar, if load is suddenly decreased steam demand is reduced and steam pressure is increased, burner immediately lower the firing rate but again it will take some time so that stem pressure over shoots the relief valve setting. The maximum efficiency of boiler will be occurred at nearly 70-85% of full load. Beyond or under this load limits, the efficiency will be decreased. As the load falls, the fuel air supply is reducing; hence mass of flue gas will be reduced. The reduction in flow rate of flue gas for some heat transfer area will also reduce the exit flue gas temperature. These all raise the efficiency of boiler.

4.1.4. Insulation

It is observed that some boiler surfaces and valves are not properly insulated. One rule of thumb is that any surface above 120 F should be insulated, including boiler surfaces, steam or condensation pipes, valves and fittings. All the damaged or worn out insulation should be changed on priority basis. Boiler casing should be checked for hot spots. Hot spots are an indication of excessive heat losses from the boiler enclosure. The temperature of surface of outer skin should not be more than 50°C.

4.1.5. Coal Preparation and Handling

Due to moisture contain in fuel boiler losses increases which significantly effect on boiler efficiency. This loss could be reduced by reducing moisture content in the coal as follows: (a) Coal must be dried before reaching the combustion chamber so that moisture does not enter the combustion chamber, (b) Proper amount of secondary air should be supplied for proper combustion, (c) Consistent quality coal by blending the proper mixing to achieve a minimum range of variation in calorific value, volatile matter and moisture.

5. CONCLUSION

The boiler performance assessment has been done for period of seven months to investigate reason behind deteriorate boiler efficiency day by day. By investigation we came to conclusion that main reason for deteriorate boiler efficiency is three major boiler losses. The average loss due to moisture and hydrogen in fuel is 12.48% which is maximum loss occur due to frequent poor coal quality and another factors which is mentioned. While other two major losses are loss due to dry flue gas 7.62% and loss due to combustible in ash 3.9% respectively. Other remaining losses are less than 1%. By analysis of recorded data of seven months, find out reasons behind above major losses and various recommendation suggested to management to reduce losses as described. Management will take appropriate action based on this recommendation made by considering payback period and economical condition of company. There is a great scope of application of energy efficiency improvement techniques in boilers. It is hoped that energy efficiency improvement techniques as embedded in this work would go a long way in improving efficiency of boilers. The boiler efficiency improvement can be predicted by using simulation model of boiler unit without implementation of recommendation made during this study.

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