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Operational Optimization of Boilers in Coal-Fired Base Load Thermal Power Plants

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This paper describes the performance analysis of steam generators. Various energy conservation measures such as operating excess air level control and insulation condition and its impact on overall heat rate of a thermal power station are discussed. Study results show that the change in operating oxygen level in flue gas can give benefit in unit heat rate to the tune of 10–40 kcal/kWh in 210 MW units and 10–50 kcal/kWh in 500 MW units. Reduction in the boiler skin temperature from 30°C to 10°C above the ambient dry bulb temperature will result in improvement in unit heat rate by 60 kcal/kWh in 210 MW units and 80 kcal/kWh in 500 MW units.

1.0 INTRODUCTION

The present installed capacity of power generation in India is 200 GW (31-03-2012), out of which 65.44 % is through thermal generation [1]. The national average plant load factor is 77.68 % [2]. National weighted average operating overall station heat rate (SHR) is 2618.2 kcal/kWh against the design SHR 2347.9 kcal/kWh [3].

The observed deviation in the operating SHR from design SHR is mainly due to deviation in the operating performance of

- Turbine
- Boiler
- Auxiliary system
- Steam consumption
- Other external parameters such as deteriorating coal quality, ambient conditions, etc.

Researchers Andrew Kusiak and Zhe Song [4,5] used a data-mining approach to improve the combustion efficiency. Clustering-based performance optimization of the boiler–turbine system using two approaches, viz. Unit Heat Rate (UHR) and Fuel Electricity Rate (FER), is discussed in [6] which has the potential to improve the performance of the boiler-turbine system. Vladimir I Kuprianov *et al.* [7–9] proposed a cost-based method to reduce the fuel consumption and emission reduction simultaneously. M.S. Bhatt *et al*. [10,11] identified the various operational optimization opportunities in a coal-fired thermal power plant.

Although various research works have progressed in different optimization techniques, this research work was aimed at suitable optimization parameters which influences, the various power boiler of capacity ranging from 30 MW to 500 MW installed in India. Extensive field trials were carried out in these different capacity range power boilers to identify the various operational performance influencing parameters. The vital performance influencing parameters are

- Heating surface
- Air and flue gas parameters

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- Combustion parameters
- Insulation and refractory
- Fuel quality

2.0 BOILER AND ASSOCIATED SYSTEM

Study was carried out on boilers of capacity ranging from unit size of 30 MW to 500 MW. The performance analysis of various system is given in the following sections.

2.1 Heating Surface

In most of the boilers, it was observed that the heating surfaces such as effective projected radiant surface (EPRS), re-heater (RH) were undersized and the super heater (SH) was oversized. This results in high main steam and reheat steam spray attemperation for temperature control. The other heating surfaces such as economizer and air preheater are adequately sized.

Sub-optimal performance of water wall and economizer was observed in many of the older units. It is recommended to carryout chemical cleaning of boiler water pressure parts circuits to improve the performance. During shut down, clean air velocity test must be carried out before cleaning and clearing of the debris, clean air velocity test must be carried out to confirm the velocity profile in the ECO in the running condition. After clearing of all debris and fouling, the same must be repeated and the velocity profile must be restored to the design value.

2.2 Air and Flue Gas Circuit

Table 1 gives the operating values (maximum and minimum) of oxygen in flue gas at various zones of typical 210 MW and 500 MW units.

Variation of oxygen level indicates level of air ingress occuring in a boiler at different zones. It was observed that the maximum level of ingress occurs in the air preheaters. In rotary air preheaters, air ingress to the tune of 43 % was observed in some of the plants. Figures 1 and 2 shows the effect of change in operating oxygen level in flue gas and its impact on overall unit heat rate (UHR) of 210 MW and 500 MW units, respectively.

TABLE 1

OXYGEN LEVEL IN UTILITY COAL-FIRED BOILERS

Location	Max in 210 MW	Min in 210 MW	Max in 500 MW	Min in 500 MW
Before APH (L)	6.35	2.1	6.8	3.8
Before APH (R)	5.3	2	5.2	3.15
After APH (L)	9.9	3	10.9	5.3
After APH (R)	9.4	3.3	9.8	5.1
IDF discharge (L)	9.95	4.75	9.65	6.5
IDF discharge (R)	10.09	5.15	9.65	7.57

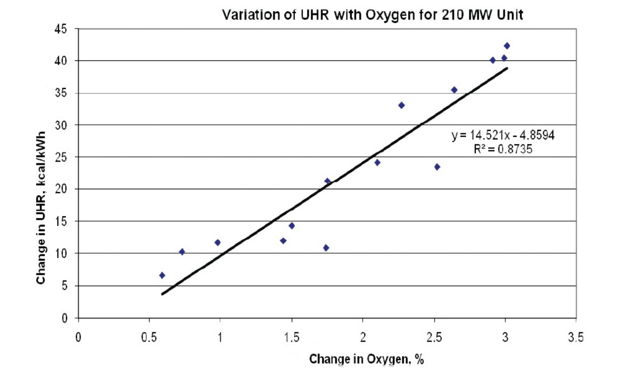

FIG. 1 EFFECT OF REDUCTION IN OXYGEN IN FLUE GAS ON OVERALL UNIT HEAT RATE (UHR) OF 210 MW UNITS

From Figure 1, it can be observed that a change in operating oxygen level by 3 % will lead to reduction of 40 kcal/kWh UHR in a 210 MW unit. From Figure 2, it can be observed that, a change in operating oxygen level by 2 % will lead to reduction of 45 kcal/kWh UHR in a 500 MW unit.

Various recommended measures to improve the operating level of oxygen in flue gas one through

(a) arresting ingress of air through various peep holes, manholes and bottom ash hopper sealing trough in boiler.

(b) providing more number of oxygen measuring probes to measure the oxygen in a grid pattern.

(c) stringent air ingress visual survey programme.

(d) strengthening the weak joints, bellows.

(e) feedback control to the control desk engineer/operator to operate the primary air and secondary air fans as per the load and the quality of the coal being fired.

(f) renewal of radial and axial seals in rotary air preheaters.

(g) providing regenerative dynamic sealing where the captured leaked air is diverted back into the hot air stream.

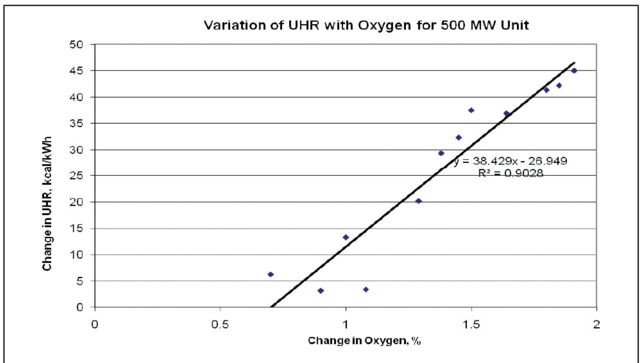

FIG. 2 EFFECT OF REDUCTION IN OXYGEN IN FLUE GAS ON OVERALL UNIT HEAT RATE (UHR) OF 500 MW UNITS

2.3 Combustion

Combustion and insulation play a vital role in boiler efficiency. Combustion efficiency is affected to large extent due to particle size distribution and percentage of volatiles. Common problem associated with combustion efficiency was uneven fireball maintenance which will lead to uneven heat flux distribution that gives rise to reduced heat transfer and tube failures.

Recommended measures to improve the combustion efficiency are.

(a) TGA analysis of coal fired into the boiler will help to optimize combustion control.

(b) providing furnace exit gas temperature monitoring system (FEGT).

(c) upgrading to smart soot blower system.

(d) oxygen and carbon mono-oxide (CO) measurement at furnace exit for excess air and combustion control.

2.4 Insulation and Refractory

For every 1°C rise in furnace skin temperature in excess of 10°C above the ambient dry bulb temperature will lead to a rise in overall unit heat rate by 2.5 kcal/kWh [3].

Figures 3 and 4 show the effect of change in boiler skin temperature on overall unit heat rate of 210 MW units and 500 MW units, respectively. The observed boiler skin temperature varies

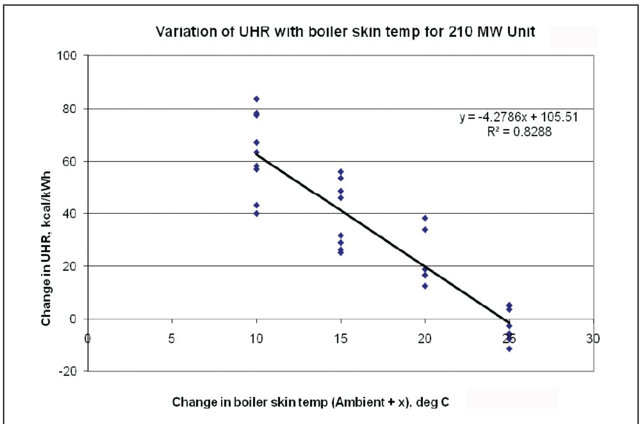

FIG. 3 EFFECT OF CHANGE IN BOILER SKIN TEMPERATURE ON OVERALL UNIT HEAT RATE (UHR) OF 210 MW UNITS

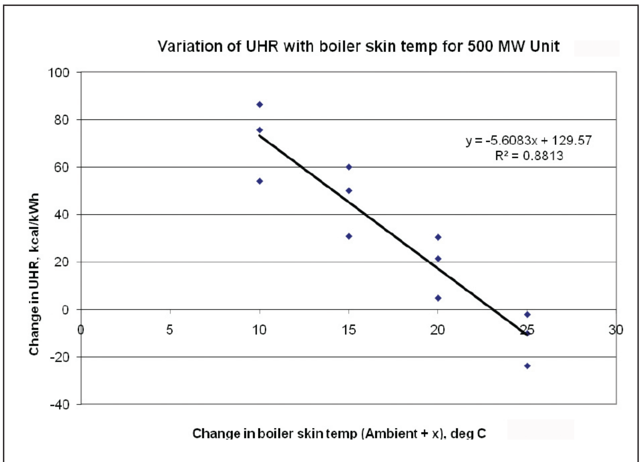

FIG. 4 EFFECT OF CHANGE IN BOILER SKIN TEMPERATURE ON OVERALL UNIT HEAT RATE (UHR) OF 500 MW UNITS

from 20°C to 26°C above ambient temperature. Reduction in boiler skin insulation temperature from 30°C to 10°C above the ambient temperature can bring in benefits of 60 kcal/kWh in unit heat rate for 210 MW units and the same for 500 MW units, it is 80 kcal/kWh.

Causes for insulation damage are mainly in boiler repair areas of water walls or other portions where the insulation is cut open and damage in tubes are attended. Recommended measures are .

(a) periodic thermal insulation survey.

(b) strategy for overall insulation change.

(c) deployment of new insulation material for better boiler skin temperature.

Annex-1 shows Photographs of inservice boiler under performance test.

2.5 Coal Quality

Coal quality plays a major role in governing boiler efficiency. Units served a life of more than 20–25 years are designed for a higher GCV (typically 5000 kcal/kg) of design coal. Coal quality has deteriorated and the average GCV of coal being fired to boiler presently ranges from 2800 kcal/kg to 3500 kcal/kg. The impact of coal quality on UHR has been worked out as –0.1247 kcal/kWh per +1 kcal/kg of increase in coal GCV [4]. Variation of GCV with boiler efficiency of large number of units ranging from 30 MW to 500 MW was studied and the curve fits were made. Those A_0 and A_1 values are plotted to see its effect on unit size. The variation of these A_0 and A_1 values with unit size is given in Figures 5 and 6, respectively.

It was observed that these A_0 and A_1 values do not have a bearing on unit size. The summarized equation obtained from this curve fit for the effect of coal quality on boiler efficiency is as follows

$$\eta_{Boiler} = 71.2+0.0032\ x$$

where x is the coal GCV in kcal/kg.

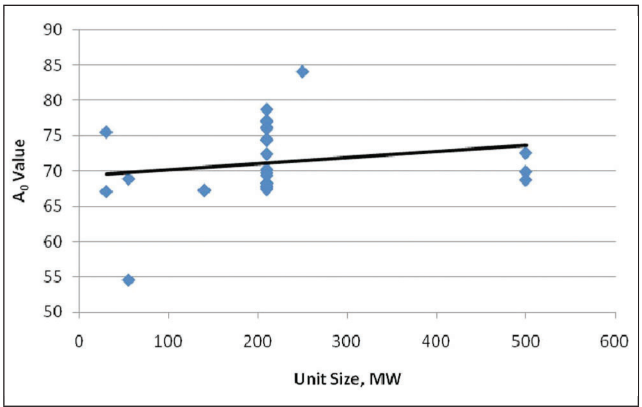

FIG. 5 VARIATION OF A_0 VALUE WITH UNIT SIZE

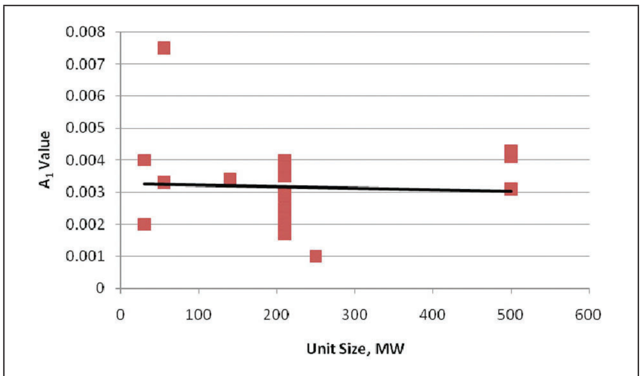

FIG. 6 VARIATION OF A_1 VALUE WITH UNIT SIZE

2.6 Other Performance Improvement Options

Other energy efficiency improvement options are:

(a) valves such as SH and RH spray control valves, safety valves, etc. need to be critically examined during overhaul/shutdown for any internal damages, etc.

(b) Providing temperature sensors with indicators at downstream side of high–energy drains is an option to control any valve passing in such lines.

(c) routine condition assessment of steam generator components such as furnace and water walls, ring header, economizer, super heaters, soot blowers, coal burners, insulation, lagging and cladding, valves and dampers, steam generator integral piping, air/gas ducts, dampers, valves, windbox, etc.

3.0 CONCLUSION

Boiler efficiency plays a vital role in the unit heat rate. The study result shows that

- Change in operating oxygen level in flue gas can give benefit in UHR to the tune of 10–40 kcal/kWh in 210 MW units and 10–50 kcal/kWh in 500 MW units.
- Reduction in the boiler skin temperature from 30°C to 10°C above the ambient dry bulb temperature will result in improvement in UHR by 60 kcal/kWh in 210 MW units and 80 kcal/kWh in 500 MW units.
- Various performance improvement options such as combustion control, excess air control to reduce the oxygen level in flue gas and improvement of thermal insulation of boiler surface will lead to an overall heat rate improvement ranging from 20 kcal/kWh to 120 kcal/kWh.

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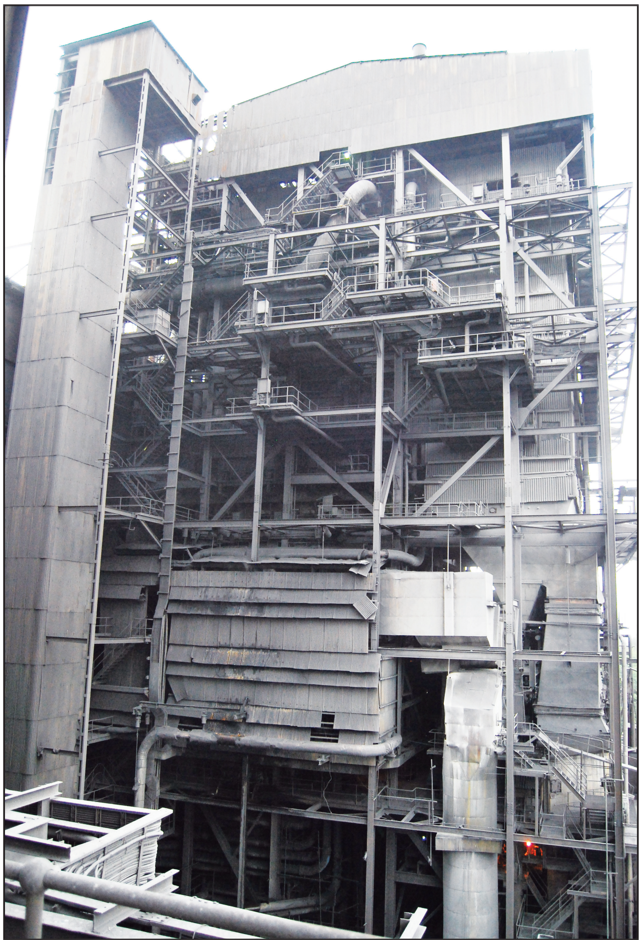
ANNEX-1

VIEW OF BOILER-1


VIEW OF BOILER-3


VIEW OF BOILER-2


DAMAGED INSULATION AND HEAT LEAK FROM FURNACE-1


DAMAGED INSULATION AND HEAT LEAK FROM FURNACE-2