

Assessment of Losses and Investigation of Influencing Parameters for Performance Improvement of a Boiler of 250MW Coal Fired Thermal Power Plant

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ABSTRACT: Boiler is one of the major components in a coal fired thermal power plant and its efficient operation, not only improves the plant performance but also helps to reduce emission level. In this paper, various losses in the boiler of a coal fired thermal power plant at four different loading conditions have been determined to identify the major sources of heat losses, so that improvement measures could be suggested. The indirect method of boiler performance assessment has been used in the study. The results of study shows that the total losses in the boiler are 13.44%, 13.40%, 13.10% and 13.35% respectively at 100%BMCR, 100%TMCR, 80%TMCR, and 50%TMCR. Loss through dry flue gases found to be the biggest source following losses due to hydrogen in fuel. Controlling these losses along with the supply of proper quantity of excess air to ensure complete combustion are the essential steps suggested for performance improvement of the boiler and plant.

It is also observed that variation in H₂ content of fuel is among one of the most influencing parameters to the boiler efficiency. Similar analyses are carried out to investigate the effect of other parameters such as flue gas exhaust temperature, CO content of the flue gas, moisture in air and ambient air temperature.

KEYWORDS: Boiler losses, Indirect method, Performance improvement, Coal fired boiler, Boiler efficiency, Influencing parameters.

I. INTRODUCTION

In India, coal based power plants are the single largest source of power generation. Power sector is the biggest consumer of coal with the demand of 527.1MT during 2014-15. As on 31st of January 2016 share of coal based power plants in India's total installed capacity was 60.84% to the tune of 175237.88MW and in power generation by thermal plants, share was 69.7% [1].

First stage of energy conversion/transfer in coal fired thermal power plant takes place at boiler when coal is burnt to release heat energy. Effective utilization of heat energy released in furnace, not only improves the boiler performance but also affects the efficiency of the whole plant. Therefore, a careful correct assessment of losses in the boiler is essential for initiating effective measures to improve the boiler efficiency and its performance in terms of heat rate and evaporation ratio.

Energy analyses of boilers at different plants have been carried out by several authors. Kumar A. et al. [2] studied the variation of boiler efficiency with respect to excess air percentage at different loads. Wu J. T. et al. [3] uses artificial bee colony (ABC) algorithm to optimize boiler efficiency. They set up an optimization model by taking efficiency as objective and used ABC to solve optimal value of boiler efficiency.

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In a performance analysis for heat recovery components in coal/biomass fired boilers, Ghorpade A. et al. [4] uses the Computational Fluid Dynamics (CFD) technique for the analysis of boiler heat recovery components such as economizer and air preheater. Gupta R. D. et al. [5] conducted a case study in the boiler house of a pulp and paper mill and found the boiler efficiency as 80.98%. They proposed few recommendations like installation of sieve analyzer for regular monitoring of coal size after crusher, control excess air quantity to the tune of 40–50% by regularly analyzing oxygen percentage in flue gas, ensure proper functioning of soot blowers and avoid continuous blow down etc. After implementation of some of the recommendations, efficiency was increased to 82.98% and estimated annual coal saving was 444.6 tons.

Mohammed et al. [6] evaluated the performance of 62MW coal based thermal power plant through energy and exergy analysis, first by component wise modeling followed by a system simulation. Also they conducted the study under varying operating conditions. Patel D. T. and Modi K. V. [7] evaluated the performance of an industrial boiler of Mahuva Sahkari Khand Udyog Mandali through indirect method. Chirag A. et al. [8] determined the efficiency of a coal fired boiler of 210MW and found the flue gas losses as a major component of total heat loss.

Gulhane S. J. and Thakur A. K. [9] determined the boiler losses in 6MW captive power plant and depicted the various losses against four different loads. Meena V. S. and Singh M. P. [10] calculated the boiler efficiency of a super thermal power station with designed and actual data at 250MW rated load. Kurkiya R. and Chaudhary S. [11] in an energy analysis of a thermal power plant, studied the boiler losses by indirect method and variation of energy efficiency against the varying percentage of carbon, oxygen, moisture and ash using MATLAB 2008a computer program. They concluded that the presence of moisture has a detrimental effect on overall efficiency while the coal type affects considerably. Kumar C. K. and Rao G. S. [12] analyze the losses in the boiler and cooling tower of a thermal power plant. They compared the actual value of boiler losses with the reference and found that except heat loss due to hydrogen, all other losses were within the limit. Shende M. B. et al. [13] analyzes the performance of a thermal power plant on system basis by dividing whole plant into eight circuits. Vinchurkar A. G. et al. [14] studied the energy performance improvement of many thermal power plants with a case study approach. They discuss the various energy management practices followed in thermal power plants.

II. BOILER DESCRIPTION

Boiler of a 250MW coal fired thermal power plant located in Chhattisgarh, India is considered for the analysis. Boiler in addition to an economizer and air preheater, is also equipped with three superheaters and one reheater. Some important operating parameters of the boiler are given in Table 1.

Table 1. Operating parameters of boiler at different load

Description	Unit	Load			
	W	100%BMCR	100%TMCR	80%TMCR	50%TMCR
Main steam pressure	bar	152.44	151.45	149.80	147.92
Main steam temperature	°C	540	540	540	540
Main steam flow	kg/s	225	183.55	165.11	108.39
Reheat steam pressure	bar	36.68	35.20	28.52	17.80
Reheat steam temperature	°C	540	540	540	540
Superheater spray flow	kg/s	0.0	4.88	9.02	10.38
Reheater spray flow	kg/s	0.0	0.0	0.0	0.0
Feed water temperature at economizer inlet	°C	247	246	236	214
Feed water temperature at economizer outlet	°C	289	290	282	269
Flue gas temperature at air heater inlet	°C	327	323	307	278

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Flue gas temperature at air heater outlet	°C	126	125	118	115
Oxygen in gas at air heater inlet	%	3.55	3.55	3.55	3.55
Un burnt carbon in fly ash	%	< 0.75	< 0.75	< 0.75	< 0.75
Un burnt carbon in bottom ash	%	< 4.0	< 4.0	< 4.0	< 4.0
Fuel (Sub-bituminous coal)					
Fixed carbon	%	24.0	Ash	%	43.0
Volatile matter	%	21.0	Sulphur	%	0.45
Moisture	%	12.0	GCV	kJ/kg	13800

III. METHODOLOGY

Performance of boilers are measured in several forms like boiler efficiency, thermal efficiency, combustion efficiency, fuel to steam efficiency, evaporation ratio etc. Boilers are tested as per the standard procedure described in one of the reference standards. Reference standards normally followed are British standard BS845:1987, ASME standard PTC4.1 and Indian standard IS: 8753. ASME standard consists of two parts: part one (direct method also called as input-output method) and part two (indirect method also called as heat loss method). Direct method requires only few calculations and measurements, hence gives quick results but does not provide any idea regarding quantity of different losses and answer to the question such as why the efficiency of boiler is lower. Also in direct method any small error in measurement affects the actual efficiency considerably. All the above disadvantages of direct method can be overcome by indirect method though it requires the measurement of several parameters like flow rate of fuel, water, steam etc., temperature of flue gas, steam, feed water, fuel, air etc., percent content of CO₂, CO, O₂ etc. In the present study, indirect method because of its several advantages, has been used to assess the boiler performance.

Indirect Method – Steps in the indirect method of calculation of boiler efficiency are:

1. Measurement/recording of required data—After a continuous and steady operation of boiler for at least one hour, various operational parameters are measured and a data sheet is prepared.

2. Calculation of stoichiometric air requirement, excess and actual air supplied and mass flow rate of flue gas –

These parameters are to be calculated by using following formulae [15–17]:

(i) **Stoichiometric air:** Theoretical air required for complete combustion,

$$\text{kg/kg of fuel} = [(11.6 \times C) + \{34.8 \times (H_2 - O_2/8)\} + 4.35 \times S]/100 \quad (1)$$

Where C, H₂, O₂ and S are the percentage of presence of carbon, hydrogen, oxygen and sulphur in the fuel.

(ii) **Excess air supplied:** % of excess air supplied,

$$EA\% = \frac{O_2\%}{(21 - O_2\%)} \times 100 \text{ [from flue gas analysis]} \quad (2)$$

(iii) **Actual air supplied (AAS):** Actual mass of air supplied,

$$\text{kg of air/kg of fuel} = [1 + (EA\%/100)] \times \text{stoichiometric air} \quad (3)$$

(iv) **Dry flue gas quantity (m_g):** Mass of dry flue gas,

$$\text{kg/kg of fuel} = \text{Actual mass of air supplied} + 1 \quad (4)$$

3. Calculation of input heat

$$\text{Input heat per kg of coal, } Q = \text{Gross Calorific Value (GCV) of coal} \quad (5)$$

4. Calculation of losses in kJ/kg of fuel

(i) **Losses due to dry flue gas (L₁)**

$$L_1 = m_g \times c_{pg} (t_g - t_o) \quad (6)$$

Where c_{pg} = specific heat of flue gas at t_g,

t_g = flue gas exhaust temperature, °C and

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t_o = ambient temperature, °C.

(ii) Losses due to hydrogen in fuel (L_2)

The combustion of hydrogen causes a heat loss because the product of combustion is water and this water is converted into steam which carries away heat in the form of its latent heat.

$$L_2 = 9H_2 [2441 + c_{ps}(t_g - t_o)] \quad (7)$$

Where H_2 = kg of hydrogen present in fuel on 1 kg basis,

c_{ps} = Specific heat of superheated steam in kJ/kg °C, and

2441 = Latent heat corresponding to partial pressure of water vapour.

(iii) Losses due to moisture in fuel (L_3)

$$L_3 = M [2441 + c_{ps}(t_g - t_o)] \quad (8)$$

Where M = kg moisture in fuel on 1 kg basis.

(iv) Losses due to moisture in air (L_4)

$$L_4 = AAS \times \text{Specific humidity} \times c_{ps}(t_g - t_o) \quad (9)$$

Where AAS = Actual mass of air supplied per kg of fuel, and

Specific humidity = kg of water/kg of dry air.

(v) Losses due to partial or incomplete combustion of fuel (L_5)

$$L_5 = \frac{(\%CO \times C)}{(\%CO + \%CO_2)} \times 24010 \quad (10)$$

Where %CO = % Volume of CO in flue gas leaving economizer (%),

%CO₂ = Actual volume of CO₂ in flue gas (%), and

C = Carbon content, kg/kg of fuel.

When CO is obtained in ppm during the flue gas analysis, then

$$L_5 = 24010 \times CO \text{ (ppm)} \times 10^{-6} \times 28 \quad (11)$$

(vi) Heat loss due to unburnt carbon in fly ash (L_6)

$$L_6 = \frac{M_{ubf}}{100} \times \frac{M_{ash}}{100} \times M_{ff} \times 33707 \quad (12)$$

Where M_{ubf} = % unburnt in fly ash,

M_{ash} = % ash in coal, and

M_{ff} = 0.9 (for pulverized coal firing)

(vii) Heat loss due to radiation and convection (L_7)

If the surface area of boiler and its surface temperature are known then, radiation and convection loss can be calculated as below:

$$L_7 = (548 \times 10^{-6} \times \text{boiler surface area} / m_f) \times [(T_s / 55.55)^4 - (T_o / 55.55)^4] + 1.957 \times (T_s - T_o)^{1.25} \times [(196.85V_m + 68.9) / 68.9]^{0.5} \quad (13)$$

Where m_f = fuel supplied per second, kg/s,

T_s = Boiler surface temperature (K),

T_o = Ambient temperature (K), and

V_m = Wind velocity, m/s.

(viii) Heat loss due to unburnt carbon in bottom ash (L_8)

$$L_8 = \frac{M_{ubbb}}{100} \times \frac{M_{ash}}{100} \times M_{fb} \times 33707 \quad (14)$$

Where M_{ubbb} = % unburnt in bottom ash, and

M_{fb} = 0.1 (for pulverized coal firing).

(ix) Heat loss due to sensible heat in bottom ash (L_9)

$$L_9 = \frac{M_{ash}}{100} \times M_{fb} \times c_{pash}(t_{ba} - t_o) \quad (15)$$

Where c_{pash} = Specific heat of ash, and

t_{ba} = bottom ash temperature.

$$\mathbf{5. Boiler efficiency, \% = [(Heat\ input - Total\ losses) / Heat\ input] \times 100} \quad (16)$$

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IV. RESULTS AND DISCUSSION

Boiler losses at different loads are determined by standard procedure as stated above. Results are summarized in Table 2 and major sources of heat losses are graphically shown in the Fig. 1 for ease of comparison.

Results clearly depicts that dry flue gas is the biggest source of loss and it amounts to over 4.5%. Another bigger source of loss is through hydrogen in fuel which is around 3.25%. Losses through moisture in fuel, partial combustion and unburnt carbon are also considerable, therefore needs to be controlled.

Effect of parameters related to flue gas, environment and fuel composition has also been studied in this paper and results are shown in Fig. 2–6.

From Table 2, when flue gas temperature reduces from 126°C at 100%BMCR to 125°C at 100% TMCR, dry flue gas loss reduces by 0.026%. Study shows that reduction in flue gas temperature by 10°C from 125°C at 100% TMCR to 115°C at 50% TMCR reduces flue gas loss by 0.145%. Further from Fig. 2, with the reduction in flue gas temperature, boiler efficiency increases which ranges from 86.33% at 130°C to 87.40% at 110°C for 100% TMCR load. Similar trends can be observed for other loads also.

Heat loss by evaporation of water formed due to H₂ content of the fuel is the second largest source. Result clearly shows that it is the most influencing factor with the effect of reducing boiler efficiency to 1.37% for increase in its content by 0.8% (from 0.018 to 0.026 kg/kg of fuel) at 100% TMCR.

Study also shows that the average improvement in boiler efficiency is about 0.27% for every 5°C increase in ambient temperature in all cases of loading. Effect of variation in moisture content is depicted in Fig. 5. With the increase in moisture content by 2%, boiler efficiency considerably reduces by more than 0.38%. Though this is the third largest component of losses, it is one of the most critical parameter to be controlled.

Table 2 : Boiler losses at different loads

Heat Component	Load				Loss in % =(Heat loss/Input heat)×100				
	100% BMCR	100% TMCR	80% TMCR	50% TMCR	100% BMCR	100% TMCR	80% TMCR	50% TMCR	
Input(kJ/kg of fuel)	13800.0	13800.0	13800.0	13800.0	-	-	-	-	
LOSSES (kJ/kg of fuel) DUE TO	1. Dry flue gas	662.162	658.560	618.209	638.484	4.798	4.772	4.480	4.627
	2. Hydrogen in fuel	453.966	453.641	451.367	450.393	3.290	3.287	3.271	3.264
	3. Moisture in fuel	315.254	315.029	313.450	312.773	2.284	2.283	2.271	2.266
	4. Moisture in air	15.792	15.545	14.434	14.507	0.114	0.113	0.105	0.105
	5. Partial combustion	168.070	168.070	168.070	168.070	1.218	1.218	1.218	1.218
	6. Unburnt C in fly ash	97.835	97.835	97.835	97.835	0.709	0.709	0.709	0.709
	7. Surface heat loss by radiation & convection	24.256	26.504	32.297	47.668	0.176	0.192	0.234	0.345
	8. Other unaccounted losses,%					0.850	0.830	0.820	0.820
Total losses (%)= (1+2+3+4+5+6+7+8)					13.439	13.404	13.107	13.354	
Boiler Efficiency, % = 100 – Total losses (%)					86.561	86.596	86.893	86.646	

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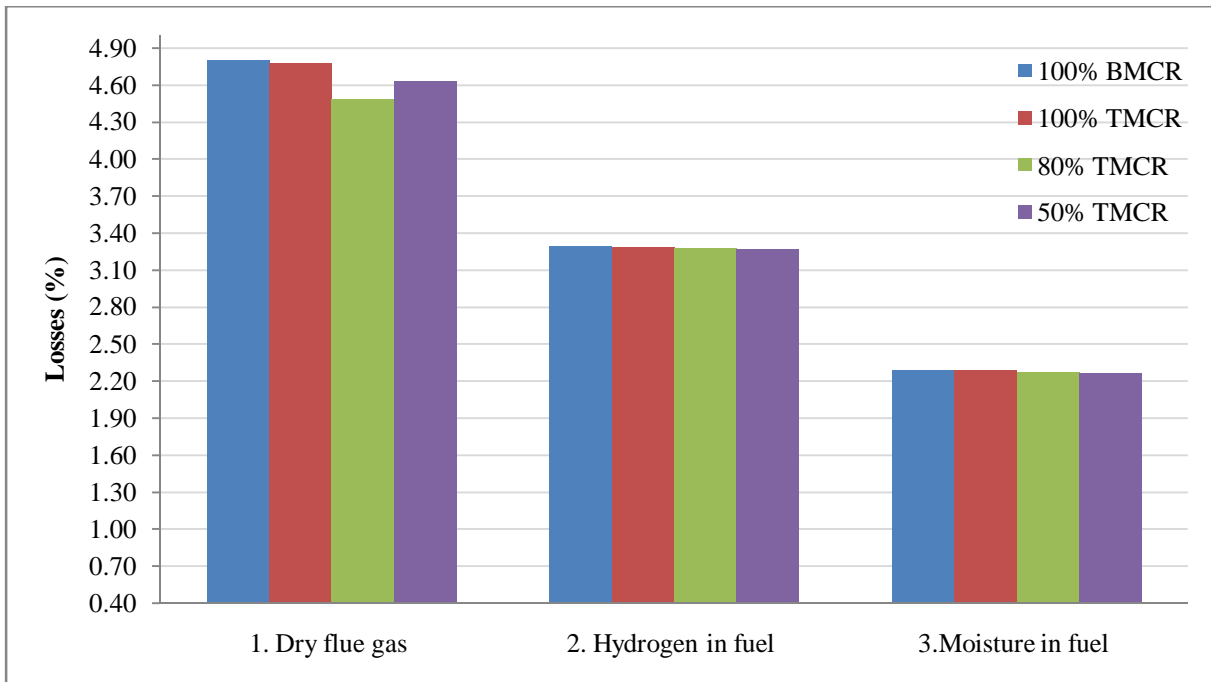


Fig. 1 Percentage of major losses at different loads

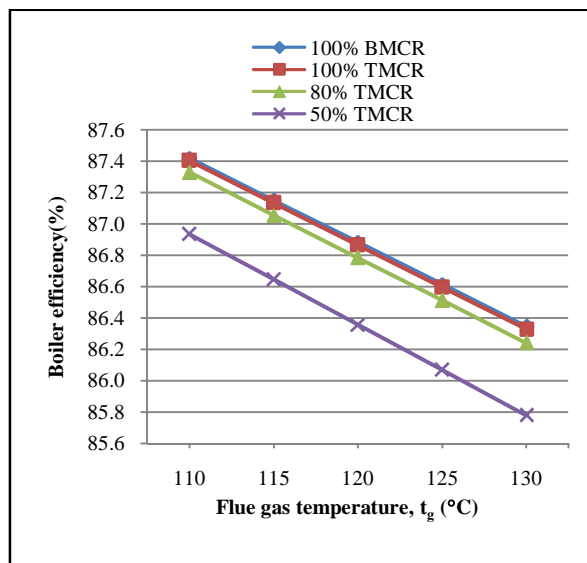


Fig. 2 Variation of boiler efficiency with flue gas temperature

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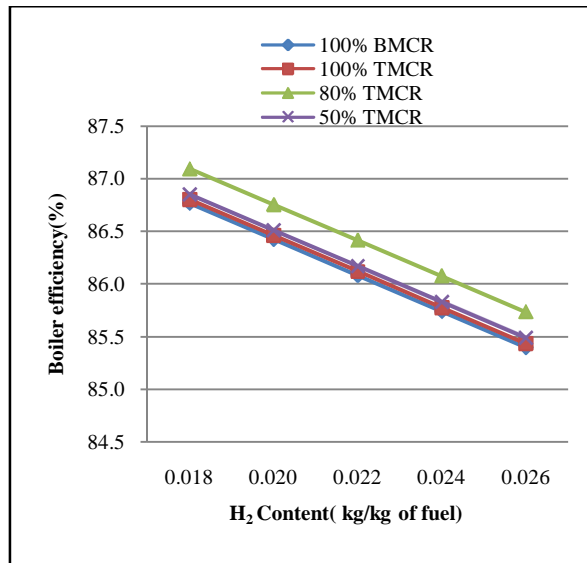


Fig. 3 Variation of boiler efficiency with H₂ content

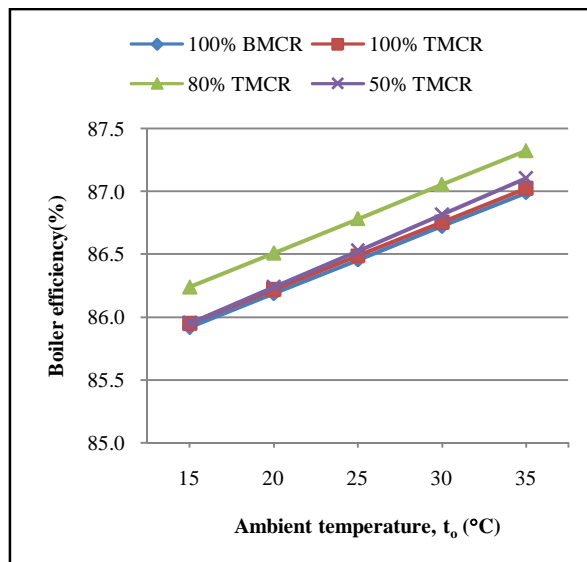


Fig. 4 Variation of boiler efficiency with ambient temperature

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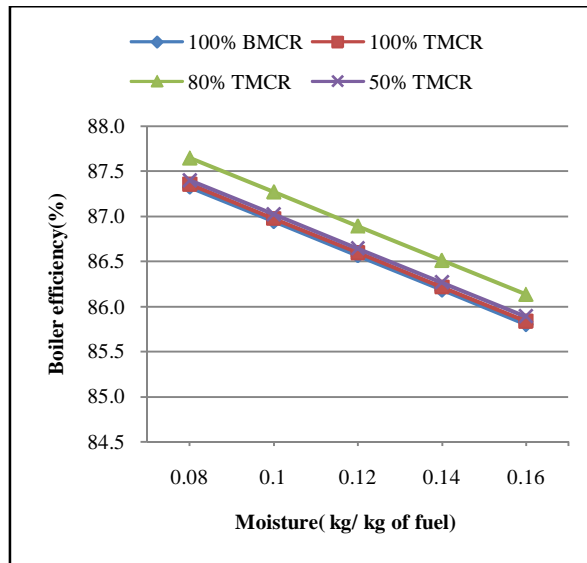


Fig. 5 Variation of boiler efficiency with moisture

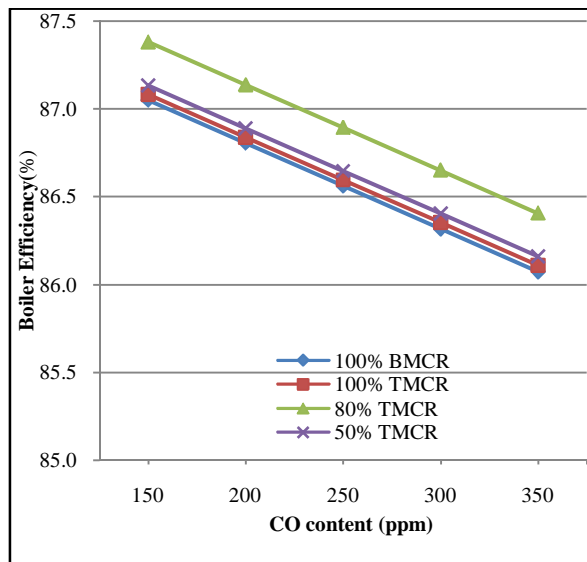


Fig. 6 Variation of boiler efficiency with CO content

V. CONCLUSION

From results of the analyses, following conclusions can be drawn:

1. More than one-third of total loss is through flue gas, therefore any efforts like an effective heat recovery system can help a lot to improve boiler efficiency.
2. Using better quality of coal (which contains less amount of hydrogen and moisture) will help to reduce boiler losses considerably.

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Advantage of above two efforts together can be understand as, when a good heat recovery system recovers heat from flue gas then its exhaust temperature will decrease and recovered heat in air preheater can be used for better drying of coal which will reduce the loss through moisture in the coal. Thus, both the efforts together will have an added advantage.

3. Complete or proper combustion with better technology can reduce CO content in the flue gas. Reduction in CO content is one of the most potential area for improving boiler efficiency.
4. Parameter ($t_g - t_o$) should be maintained to minimum possible value.
5. Another measure to control the boiler loss is to reduce the boiler surface temperature. Therefore, repairing of damaged insulation through periodic maintenance is of utmost importance.

VI. FUTURE SCOPE OF WORK

As the losses in boiler is the loss of high quality of energy means the direct loss of obtainable work, therefore a comprehensive performance analysis based on the thermodynamics first and second law together should be conducted. Further, a detailed component wise analysis should also be carried out to locate the area of major concerns and priorities them for necessary improvement measures to be adopted.

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