Performance Analysis from the Energy Audit Of A Thermal Power Plant

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ABSTRACT- The results from the Energy audit of KOTHAGUDEM Thermal power station, Andhra Pradesh has been presented in this paper. The scope of any energy audit in a thermal power plant should include the study of the coal flow, air and flue gas flow, excess air factors and oxygen in the flue gas; study of the heat transfer, effectiveness, proportioning of heat and pressure drop in the heat-exchangers of the water-steam circuit; study of the auxiliary power consumption; the overall performance evaluation such as the gross and the net overall efficiencies, boiler efficiency, boiler feed pump efficiency, air compressor efficiency, evaporation losses and blow down losses of cooling tower etc. Results from such a study at a 500 MW power plant are presented in this report.

A detailed analysis of the effect of the fuel on the boiler efficiency, the dry and the wet flue gas loss, combustion characteristics, the start-up and the shut-down losses, the radiation losses and the heat losses due to hydrogen in fuel, moisture in fuel, carbon monoxide in fuel are explained. Factors leading to the deterioration of the boiler efficiency by direct method and indirect method and evaporation losses and blow down losses of cooling tower are also presented.

Keywords: Energy audit, Thermal power station, efficiency, losses, combustion

INTRODUCTION

Energy auditing of a thermal power plant involves the study of boiler system, electrical system, pumping system, air compressor system, cooling towers, auxiliaries power consumption etc. This project analyses the performance assessment of Boiler system, cooling tower of a 500MW KOTHAGUDEM thermal power plant.

PROFILE OF KTPS

KOTHAGUDEM thermal power station is a coal, fired thermal power generating station with a total installed capacity of 1180 MW out of which KTPS-A station has two stages. Stage – I consists of two units 1 & 2 and stage-II consists of two units 3 & 4 each of 60MW capacity. The KTPS-B, station stage-III consists of two units 5 & 6 of each 110MW capacity and KTPS-C, station stage-IV consists of two units 7 & 8 each of 110MW. Recently during 1996, one more stage KTPS-V stage was constructed which consists of two units 9 & 10 each of 250MW.

The KTPS-V stage is highly technical and has more advantages. Units 9 & 10 of KTPS-V stage were successfully completed and commissioned in a record time of 31 & 28 months respectively after commencement of work [1] .

Thus the total installed capacity of the plant is: KTPS-A Station: 4 * 60 = 240 MW (commissioned in the year 1996)

KTPS-B Station: 2 * 110 = 220 MW (commissioned in the year 1973)

KTPS-C Station: 2 * 110 = 220 MW (commissioned in the year 1976)

KTPS-V Station: 2 * 250 = 500 MW (commissioned in the year 1996)

TOTAL : 1180 MW

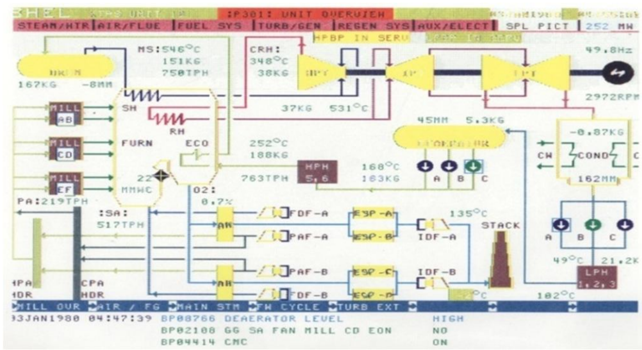

Figure 1 plant overall energy generation and consumption

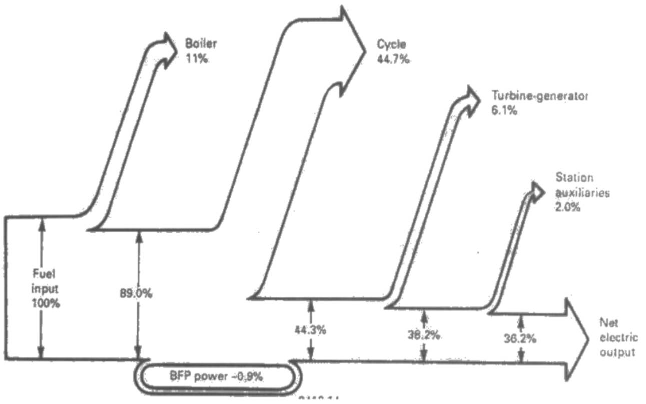

Figure2 various losses of thermal power plant

ENERGY AUDIT

The objective of energy auditing is to find out the different ways to reduce the energy consumption in different fields by elucidating the losses at various stages.
An Energy Audit can be classified into the following two types.
i) Preliminary Audit
ii) Detailed Audit
Preliminary Audit finds out all information about plant and identify the major energy consumption areas in the plant by using energy meters. In Detailed Audit different energy auditing techniques are used and methods to reduce energy consumption are suggested.

BOILER SYSTEM

Boiler is a closed vessel that gives combustion heat to be transferred into water until it becomes steam. The Water is a useful and cheap medium for transferring heat. When water is boiled into steam its volume increases about 1,600 times. This heat is transferred from one body to another by means of radiation, convection, conduction. The main losses that occur in a boiler are:
1. Loss of heat due to dry flue gas
2. Loss of heat due to moisture in fuel and combustion air
3. Loss of heat due to combustion of hydrogen
4. Loss of heat due to radiation
5. Loss of heat due to un burnt fuel
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. Figure 3 shows various boiler losses [2].

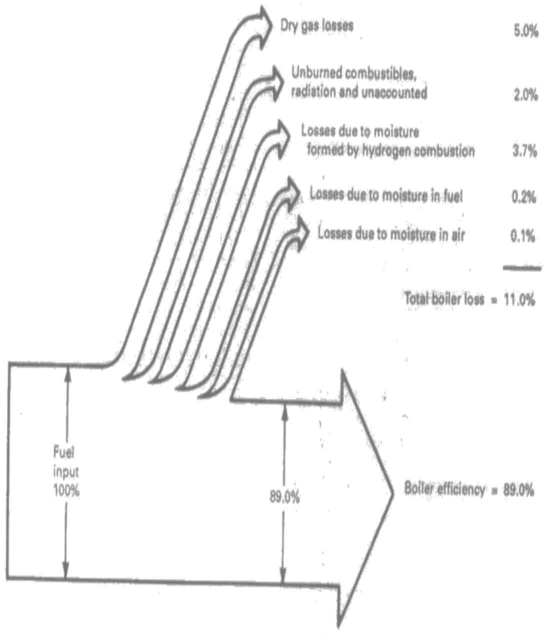

Figure 3 various boiler losses

BOILER EFFICIENCY

Thermal efficiency of boiler is defined as the percentage of heat input that is effectively utilized to generate steam. There are two methods of assessing boiler efficiency.
1) **The direct method:** Where the energy gain of the working fluid (water and steam) is compared with the energy content of the boiler fuel.
2) **The Indirect Method:** Where the efficiency is the difference between the losses and the energy input.

1. Direct method

This is also known as 'input-output method' due to the fact that it needs only the useful output (steam) and the heat input (i.e. fuel) for evaluating the efficiency. This efficiency can be evaluated using the formula

Efficiency

$\eta = Q*(h_g - h_f)*100/ q* GCV$

Where, hg – Enthalpy of saturated steam in kCal/kg of steam
h_f – Enthalpy of feed water in kCal/kg of water

Parameters to be monitored for the calculation of boiler efficiency by direct method are:
• Quantity of steam generated per hour (Q) in kg/hr.
• Quantity of fuel used per hour (q) in kg/hr.
• The working pressure (in kg/cm^2(g)) and superheat temperature (°C), if any
• The temperature of feed water (°C).
• Type of fuel and gross calorific value of the fuel (GCV) in kCal/kg of fuel.

It should be noted that boiler may not generate 100% saturated dry steam, and there may be some amount of wetness in the steam.

Advantages of direct method:

1. Plant people can evaluate quickly the efficiency of boilers
2. Requires few parameters for computation
3. Needs few instruments for monitoring

Disadvantages of direct method:

1. Does not give clues to the operator as to why efficiency of system is lower
2. Does not calculate various losses accountable for various efficiency levels

2. Indirect method

Indirect method is also called as heat loss method. The efficiency can be arrived at, by subtracting the heat loss fractions from 100. The standards do not include blow down loss in the efficiency determination process. 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 simpler calculation procedures.

The data required for calculation of boiler efficiency using indirect method are:

1. Ultimate analysis of fuel (H_2, O_2, S, C, moisture content, ash content)
2. Percentage of Oxygen or CO_2 in the flue gas
3. Flue gas temperature in °C (T_f)
4. Ambient temperature in °C (T_a) & humidity of air in kg/kg of dry air
5. GCV of fuel in kCal/kg
6. Percentage combustible in ash (in case of solid fuels)
7. GCV of ash in kCal/kg (in case of solid fuels)

1. Theoretical air requirement= $[(11.6 \times C) + \{34.8 \times (H_2 - O2/8)\} + (4.35 \times S)]/100$ kg/kg of fuel

2. Excess Air supplied (EA)= $O_2\%*100/(21-O_2\%)$

3. Actual mass of air supplied/ kg of fuel (AAS) = $\{1 + EA/100\} \times$ theoretical air

4. Percentage heat loss due to dry flue gas =

$$\frac{m_{flue} \times cp_{flue} \times (Tf - Ta) \times 100}{GCV\ of\ fuel} ------1$$

where m_{flue}= sum of masses of Combustion products from fuel i.e. CO_2 + SO_2 + Nitrogen in fuel + Nitrogen in the actual mass of air supplied + O_2 in flue gas.

5. Percentage heat loss due to evaporation of water formed due to H2 in fuel =

$$\frac{9 \times H2 \times \{584 \times Cp_{steam} \times (Tf - Ta)\} \times 100}{GCV\ of\ fuel} ---2$$

6. Percentage heat loss due to evaporation of moisture present in fuel =

$$\frac{M \times \{584 \times Cp_{steam} \times (Tf - Ta)\} \times 100}{GCV\ of\ fuel} ------3$$

Where 584 is the latent heat corresponding to the partial pressure of water vapour.

7. Percentage heat loss due to moisture present in air =

$$\frac{AAS \times humidity\ factor \times Cp_{steam} \times (T_f - T_a) \times 100}{GCV\ of\ fuel} ----4$$

8. Percentage heat loss due to un burnt in fly ash=

$$\frac{total\ ash\ collected\ per\ kg\ of\ fuel\ burnt \times G.C.V\ fly\ ash \times 100}{GCV\ of\ fuel} ----5$$

9. Percentage heat loss due to un burnt in bottom ash =

$$\frac{total\ ash\ collected\ per\ kg\ of\ fuel\ burnt \times G.C.V\ bottom\ ash \times 100}{GCV\ of\ fuel} ----6$$

10. Percentage heat loss due to radiation and other unaccounted loss ------------------------- 7

The actual radiation and convection losses are difficult to assess because of particular emissivity of various surfaces, its inclination, air flow pattern etc. In a relatively small boiler, with a capacity of 10 MW, the radiation and unaccounted losses could amount to between 1% and 2% of the gross calorific value of the fuel, while in a 500 MW boiler, values between 0.2% to 1% are typical [3].

Efficiency of boiler = 100 - (1 + 2+ 3 + 4+ 5 + 6+7).

Table1 two months average readings

INPUTS ON 15:50	**Unit# 10**		
Parameter	**Units**	**Symbol**	**Value**
Unit Load	MW	L	252
FW Flow at Economizer inlet	T/Hr	Ffw	772
Wet bulb temp.	Deg C	Wb	24
Dry bulb temp.	Deg C	Db	30
Barometric Pressure	mm Hg	BP	760
Total Coal flow	T/Hr	Fin	189
Unburned C in Bottom Ash	%	Cba	6.36
Unburned C in fly ash	%	Cfa	0.57
Radiation & Unaccounted loss	%	Lrad	1.2
% of Flyash to toal ash	%	Pfa	70
% of Botom ash to Total ash	%	Pba	30

Ultimate analysis - As fired			
Carbon	%	C	27.77
Sulphur	%	S	0.5
Hydrogen	%	H	2.12
Moisture	%	M	9.29
Nitrogen	%	N	1.7
Oxygen	%	O	6.21
Ash	%	A	46.48
Gross Calorific value	kcal/kg	GCV	3072
Avg.Flue Gas O2 - APH in (Optional)	%	O2in	1.4
Avg.Flue Gas CO2 - APH in (Optional)	%	CO2in	1
Avg.Flue Gas CO - APH in (Optional)	ppm	COin	39
Avg.Flue Gas O2 - APH out	%	O2out	1.1
Avg.Flue Gas CO2 - APH out	%	CO2out	14.3
Avg.Flue Gas CO - APH out	ppm	Coout	50
Avg.Flue Gas Temp - APH in	deg C	Tgf	344
Avg.Flue Gas Temp - APH Out	deg C	Tgo	154
Primary Air to APH Temp in.	deg C	Tpai	51
Primary Air from APH Temp Out.	deg C	Tpao	289
Secondary Air to APH Temp in.	deg C	Tsai	44
Secondary Air from APH Temp. Out.	deg C	Tsao	285

Total Secondary Air Flow	T/Hr	Fsa	560
Total Primary Air flow	T/Hr	Fpa	271
Design Ambient/ Ref. Air Temp.	Deg C	Tref	30
CV of Carbon	Kcal/kg	CVC	8078
CV of Carbon monixide	Kcal/kg	CVCO	2415

Moisture in Air(from Psychometric chart)	kg/kg	Mwv	0.017
COMPUTED VALUES			
BOILER EFFICIENCY	%		**86.48%**
Dry Gas Loss	%	Log	3.6396
Loss due to unburned Carbon	%	Luc	2.8862
Loss due to Moisture in Fuel	%	Lmf	1.8612
Loss due to Hydrogen in fuel	%	Lhf	3.8226
Loss due to Carbon monoxide	%	Lco	0.0171
Loss due to moisture in air	%	Lma	0.0902
Un account loss 1.2%			
TOTAL LOSSES	%		13.5170

COOLING TOWER

The primary task of a cooling tower is to reject heat into the atmosphere. The make-up water source is used to replenish water lost to evaporation. Hot water from heat exchangers is sent to the cooling tower. The water exits the cooling tower and is sent back to the exchangers or to other units for further cooling. Typical closed loop cooling tower system is shown in Figure4 [3].

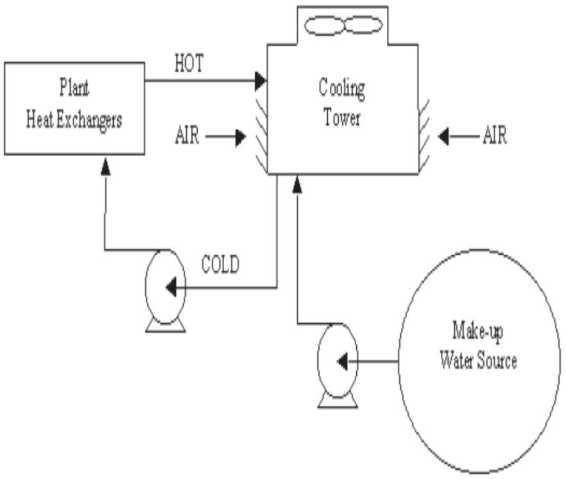

Figure 4 closed loop cooling tower

Cooling tower types

Cooling towers are two types

1. Natural draft and 2.Mechanical draft.

Natural draft towers use very large concrete chimneys to introduce air through the media. Due to the large size of these towers, they are generally used for water flow rates above 45,000 m^3/hr. These types of towers are used only by utility power stations. Mechanical draft towers utilize large fans to force or suck air through circulated water. Cooling rates of Mechanical draft towers depend upon their fan diameter and speed of operation. The mechanical draft cooling towers are much more widely used.

Cooling Water Treatment

Cooling water treatment is mandatory for any cooling tower whether with splash fill or with film type fill for controlling suspended solids, algae growth, etc.

With increasing costs of water, efforts to increase Cycles of Concentration (COC), by

Cooling Water Treatment would help to reduce make up water requirements significantly. In large industries, power plants,

Table 2 Calculation of cooling tower losses

COC improvement is often considered as a key area for water conservation.

Range" is the difference between the cooling tower water inlet and outlet temperature. "Approach" is the difference between the cooling tower outlet cold water temperatures and ambient wet bulb temperature.

Formulae for calculating Cooling Tower losses

Cooling tower effectiveness (in percentage) is the ratio of range, to the ideal range, i.e., difference between cooling water inlet temperature and ambient wet bulb temperature, or in other words it is = Range / (Range + Approach).

Evaporation Loss (m3/hr) = 0.00085 x 1.8 x circulation rate (m3/hr) x (T1-T2)

T1-T2 = Temperature difference between inlet and outlet water.

Cycles of concentration (C.O.C) is the ratio of dissolved solids in circulating water to the dissolved solids in makeup water.

Blow down losses depend upon cycles of concentration and the evaporation losses and is given by relation [3]

Blow Down = Evaporation Loss / (C.O.C. – 1)

CONCLUSONS AND RECOMMENDATIONS

By comparing the actual values of the Boiler losses with the reference or design values it is clearly concluded that all the boiler losses are within the limit except the heat loss due to hydrogen present in the fuel as shown below.

The reference values are taken from BHEL manuals [4].

Boiler Losses	reference	Actual
1. Dry flue gas loss	4.65	4.28
2 Due to moisture present in fuel	4.23	2.12
3. Due to hydrogen present in fuel	1.67	4.29
4Due to moisture present in air	0.26	0.12
5. Un burnt carbon loss	1.5	1.25
6. Total Un account loss	2.0	1.20

For controlling heat loss due to hydrogen present in fuel, the supply of fuel should have less content of hydrogen and the surface moisture of the coal can be reduced by proper maintenance of coal shed. The boiler losses will be reduced if gross caloric value of coal is high. Further improvement of boiler efficiency the flue gas outlet temperature should maintain in between 140 to 150 degree C. Excess air can be controlled by keeping combustion system in auto to maintain 3.5% of Oxygen and excess air below 20%.For achieving energy savings use variable frequency drives for speed control of boiler feed pumps instead of Hydraulic coupling control. By calculating evaporation and blow down losses it is clearly concluded that evaporation losses is directly proportional to water flow rate and approach. So it is recommended to maintain them as low as pos-

Date	Inlet Temp T1	Outlet Temp T2	Wet Bulb Temp T	Range T1-T2	Approach T2-T	Water Flow Rate m^3/hr	Evaporation Loss m^3/hr	Blow down loss m^3/hr	Make up Water m^3/hr
13.11.11	36	27	24	9	3	28012	385.56	419.08	804.64
14.11.11	45	35	27	10	8	32040	489.62	532.17	1021.79
15.11.11	47	35	27	12	8	32540	605.88	658.56	1264.44
16.11.11	47	36	26	11	10	34023	572.22	621.97	1194.19
17.11.11	43	33	26	10	7	30515	466.51	507.11	973.66
18.11.11	45	33	26	12	7	31034	569.16	618.65	1187.81
19.11.11	46	35	28	11	7	30512	513.31	557.94	1071.25
20.11.11	40	29	24	11	5	30048	504.9	548.82	1053.72

sible. The blow down losses depends on cycles of concentration (C.O.C).

So the C.O.C value must be increase from present value1.92 to >2.0 by decreasing dissolved solids in make up water.

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NOMENCLATURE

m_{flue} = mass of dry flue gas in kg/kg of fuel Cp_{flue} = Specific heat of flue gas (0.23 kCal/kg °C)
H_2 - kg of H_2 in 1 kg of fuel
Cp_{steam} - Specific heat of superheated steam (0.45 kCal/kg °C)
M – kg of moisture in 1kg of fuel

BIOGRAPHIES

Chilakala Kiran Kumar was born in India in 1992. He is pursuing B. Tech final year in KL University in Electrical and Electronics Engineering. His field of interest is Renewable Energy Systems and Power Electronics.

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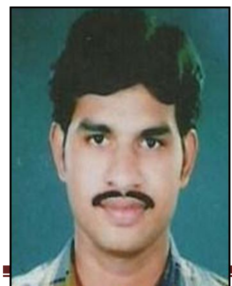

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