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Study onEfficiency of a30MW Coal Fueled Thermal Power Plant Attached with a Paper Mill

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ABSTRACT

Electricity almost affects every part of our lives. It is a milestone that we have seen in the progress of science. Coal-fired power plants rank first in the world for producing maximum amount of electricity that is consumed every year. The rate at which the non- renewable resources are depleting, the conservation of energy is the need of the hour. Therefore, energy security is the major concern of today's world. And one of the methods to secure energy is by increasing efficiency of all the power plants. Present study gives the efficiency calculations on a 30 MW thermal power plant attached to a paper mill in Pune district. Factors affecting the efficiency of the power plant can be studied by two methods (1) the direct method (2) indirect method where efficiency is the difference between the losses and energy input. The aim of this study is to calculate the overall thermal efficiency of the thermal power plant and analyze the thermodynamic performance of the components in the plant by using direct and indirect method.

KEY WORDS : Thermal power plant, efficiency

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INTRODUCTION

Electricity is the most amazing discovery of mankind and almost affects every part of our lives. It is a milestone that we have seen in the progress of science. To meet the ever increasing use of electricity, the need to generate electricity has reached its peak, and these demands are achieved with the help of suitable power producing units, which are known as power generating stations. Coal-fired power plants rank first in the world for producing maximum amount of electricity that is consumed every year. The rate at which the non- renewable resources are depleting, the conservation of energy is the need of the hour. Therefore, energy security is the major concern of today’s world. And one of the methods to secure energy is by increasing efficiency of all the power plants.

Everything in the universe ages with time, so does the performance and efficiency. Efficiency deterioration of power plant can be reduced by maximizing heat transfer and minimizing heat losses. In a power plant initially internal energy or chemical energy is converted into mechanical work and later on into electric energy that is used for domestic purposes, industrial work, etc.

Muchof the electricity that we use is still from sources such as fossil fuels which are not renewable sources. The more electricity we consume, the faster these resources will be depleted. So it is necessary to increase the efficiency of the thermal power plants to get more yields. With the ever increasing need of the coal, which is a non renewable source of energy and depleting with a very fast pace, it is need of the hour to have optimal techniques which can reduce the energy losses in the coal fired boiler and improves its performance.

The objective of the present work is to study the efficiency of the thermal power plant. Generally, it is predicted that even a small improvement in any part of the plant can improve the efficiency significantly. Factors affecting the efficiency of the power plant can be studied by two methods. The first one is the direct method or the first law of thermodynamics; it cannot properly determine the quantity and quality of energy that is generated. And the second is indirect method where efficiency is the difference between the losses and energy input. The aim of this study is to calculate the overall thermal efficiency of the thermal power plant and analyze the thermodynamic performance of the components in the plant by using direct and indirect method.

DESCRIPTION AND WORKING OF A THERMAL POWER PLANT

The paper company under present study has two boilers which are of the Circulating Fluidized Bed Combustion (CFBC) type. Here two types of coal are used as fuel Indian coal and imported coal. De-Mineralized (DM) water is used to generate steams to run the turbine. Boiler has a steam evaporation capacity of 175 tons per hour each at a pressure of 105 kg/cm^2 and a temperature of about 525 $\pm$ 5°C. The feed water temperature at economizer inlet is 185°C.

Two types of fuels are burnt in these boilers, light diesel oil (LDO) and coal. Light diesel oil is burnt in the startup burner for initial warming of the boiler and then later on coal is fed in the boiler. Average bed temperature above 400 - 450°C Coal is the main fuel that is fed in the boiler that sustains combustion in the furnace to continue the generation of steam. Constituent of bed material by weight should be as: Silica =70%-85%; Alúmina=5%-15% ; Fe_2O_3 = 1%-5%; CaO=0.5%-2%; Na_2=1%-2%; K_2=2%-3%; others=0-1%.

Before starting the boiler, it is necessary to check that power supply for all equipments connected to boiler is available. Check that all the electrostatic precipitator(ESP) auxiliaries are put in operation from 4 hours before start up of the boiler. Then it is essential to analyze that the instrument air pressure is normal, boiler interlocks are healthy, cooling water pressure is normal and that drum water level is normal (between 35% to 45%). If not filled then drained the water as required.

Water quality of boiler drum water, de-aerator water, feed tank water, and condensate& DM Water is tested in laboratory. The steam is generated in the drum where feed water is heated and steam is formed. The steam generated in the evaporation zone is superheated in three stages. The steam from the drum passes over to the primary superheater located in the connective second pass of the boiler just above the economizer. In boiler, economizers are heat exchange devices that heat fluids, usually water, up to but not normally beyond the boiling point of that fluid. The enthalpy in fluid streams that are hot, but below the level to be used in a boiler, improve the boiler’s efficiency.

The steam coming out of the primary superheater is then heated in the secondary superheater mounted on the primary superheater. From the secondary superheater, the steam passes into the final superheater for further superheating. Final superheater is also located in the convection zone in back pass of the Boiler. between the primary and the secondary superheaters and Secondary and final superheaters there are two stages of water spray for desuperheating. The Final superheater outlet steam temperature is maintained at 515 $\pm$ 5°C with the help ofthese de-superheaters[5].

Heat is also extracted out of the hot flue gas to heat up the incoming air for aiding combustion in the furnace. This flue gas to air heat exchanger is called air heater. There are two air heaters - one for secondary air and the other for the primary air. Both the primary and secondary air are heated up to200°C beforeentering the furnace.

This superheated steam from the boiler impinges on the turbine, resulting in the rotation of mechanical shaft and generation of electricity in the alternator. The exhaust steams from the turbine is further condensed and pumped back to the boiler to repeat the cycle.

Turbine Generator is 30 megawatt capacities each with double extraction, condensing type. High pressure steam from boiler at 101 Kg/cm^{2}pressure and 515^{0}C temperature is supplied to turbine for generation of power. After doing the work in turbine the steam is exhausted in to condenser where the latent heat of the steam is extracted by the cooling water & steam gets condensed.The condensate is collected in the hotwell and supplied to the boiler as feed water.

METHODS OF TESTING THE PERFORMANCE OF A BOILER

The Direct Method:

The other name for this method is input-output method, where useful output (steam) and the heat input (fuel i.e. coal)is evaluatedto calculate the efficiency of the boiler.

Table 1 Data collected for coal used in thermal power plant

Parameter	Unit	Quantity
Steam Flow(F)	Ton/hr	2529
Steam Enthalpy(H)	Kcal/kg	812
Feed water Enthalpy	Kcal/kg	185
Gross calorific value of coal	Kcal/kg	3880.21
Coal flow	Ton/hr	500
M.P extraction steam flow (f1)		430
M.P enthalpy (h1)	Kcal/kg	752.31
L.P extraction steam flow (f2)		1201
L.P extraction enthalpy (h2)	Kcal/kg	689.86
Bleed flow(f3)		24
Bleed enthalpy (h3)	Kcal/kg	608.27
Condenser flow (f4)		788
Condenser enthalpy (h4)	Kcal/kg	39.74
Power generation in MWH	MWH	377.20

Efficiency of boiler can be given by:

Boiler Efficiency = <u>[Steam flow rate x (steam enthalpy – feed water enthalpy)] x 100</u>

Fuel firing rate x gross calorific value

$$\mathbf{BoilerEfficiencybydirectmethod(\eta b)} = \frac{2529(812 - 185)}{500 * 3880.21} * 100$$

=**81.7318%**

$$\mathbf{Turbine\ Efficiency(\eta t)} = \frac{860}{eatrate} x\, 100$$

$$\textbf{Heat Rate}^{6} = \frac{(FxH) - (f1\,x\ \ 1) - (f2\,x\ \ 2) - (f3\,x\ \ 3) - (f4\,x\ \ 4)}{power\ generation\ in\ MWH}$$

$\mathbf{Heat\ rate} = 2469.92\ Kcal/KWH$ $\mathbf{Turbine\ Efficiency(\eta t)} = \frac{860}{2469.92} * 100$

=**34.819%**

$\mathbf{Generator\ Efficiency(\eta g) = 99.5\%}$

Overall efficiency of the power plant[7]= ηb x ηt x ηg

= (81.7318/100) x (34.819/100) x (99.5/100)

=**28.3048%**

A. Some other factors affecting performance:

$$\textbf{Evaporation ratio} = \frac{total\ steam\ from\ coal\ boiler}{total\ coal\ consumption}$$

=2529/500

=5.06

$$\textbf{Overallplantheatrate} = \frac{total\ coal\ consumption\ x\ GCV(coal)}{power generated\ in\ MWH}$$

= (500 x 3880.21)/377.20

=**5143.4Kcal/KWH**

Speciic coal consumption[8] = Coal consumption / Power consumption in MWH

= 500/377.20

= **1.3255 MT/MWH**

The Indirect Method:

Basically, the efficiency of a given machine can be calculated by calculating all the losses that arise due to different conditions. Indirect method is one of the methods where we can calculate the efficiency by measuring all the losses and subtracting them from 100.

Efficiency is given by:

$$\textbf{Efficiency(boiler)} = \mathbf{100 - (L1 + L2 + L3 + L4 + L5 + L6 + L7 + L8)}$$

The following losses are as follows:

L1:Heat loss due to dry flue gas

L2:Heat loss due to presence of hydrogen in coal

L3:heat loss due to presence moisture in coal

L4: heat loss due to presence moisture in air

L5:Heat loss due to unburnt carbon in combustible

L6: Heat loss due to surface radiation, convection, conduction and other unaccounted

L7:Unburnt losses in fly ash (Carbon)

L8:Unburnt losses in bottom ash (Carbon)

B. Coal Analysis Report of Feeding Sample

Table 2Proximate and GCV result

PARAMETER	UNIT	RESULTS (Air Dried Basis)	RESULT (Air Received Basis)
Total Moisture(TM)	%	---	18.80
Inherent Moisture(IM)	%	10.87	---
Volatile Matter(VM)	%	30.57	27.85
Ash	%	24.22	22.07
Gross Calorific Value	Kcal/kg	4575.00	4167.96

Table 3 Ultimate analysis of coal

	Basis	
	ADB (Air Dried Basis)	ARB (Air Received Basis)
Carbon (%)	42.40	37.60
Hydrogen (%)	3.54	4.41
Nitrogen (%)	1.13	1.00
Sulphur (%)	0.87	0.80
Oxygen (%)	27.71	16.75
Ash Content (%)	24.35	22.26
Total Moisture (%)	---	18.24

Remark: Values used in the formulae are from Air Received Basis (ARB)

Theoretical air require for complete combustion = [(11.6 x C) + {34.8 x (H_2-O_2/8)}+(4.35 x S)]/100

=[(11.6 x 37.60)+{34.8 x (4.41-16.75/8)}+{4.35 x 0.8}]/100

= **5.2024 Kg/Kg of coal**

$$\% \ \mathbf{CO2\ at\ theoretical\ condition(CO2t)} = \frac{\text{moles of C}}{\text{moles of N2} + \text{moles of C}}$$

Moles of N_2 $=\{\frac{wt.of N2\ in\ t\ \ eoretical\ air}{mol.\ Wt.\ of\ N2}+\frac{wt.\ of\ N2\ in\ fuel}{mol.\ Wt.\ of\ N2}\}$

= {(5.2024 x (77/100))/28} +{0.010/28}

Moles of N_2 = **0.1434**

Moles of C = 0.3760/12 =**0.03133**

$(CO_2)_t$ = {0.03133/(0.1434+0.03133)}*100

= 17.93 %

Actual CO_2 measured in a flue gas $(CO_2)_a$ = 15.92 %

% Excess air supplied (EA)$=\frac{7900*((CO2)t-(CO2)a)}{(CO2)a*(100-(CO2)t)}$

$=\frac{7900*(17.93-15.92)}{15.92*(100-17.93)}$

$=\frac{15879}{1306.5544}$

$=\mathbf{12.15\%}$

Actual mass of air supplied$=1+\frac{EA}{100}*theoretical\ air$

=(1+(12.15/100))*5.2024

=**5.834 kg/kg of coal**

Mass of dry flue gas = Mass of CO_2 + mass of N_2 content in fuel +Mass of N_2 in the combustion air supplied + mass of O_2 in flue gas

=6.0448 kg/kg of coal

Table 4 Data collected on various parameters of the boiler

Parameters	unit	Quantity
Specific heat of superheated steam (Cp)	kCal/kg°C	0.262
Flue gas temperature (Tf)	°C	142.59
Ambient temperature (Ta)	°C	41.33
Mass of dry flue gas (m)	kg/kg of coal	6.0448
Latent heat corresponding to partial pressure of water vapor		584
kg moisture in fuel on 1 kg basis (M)	/kg of coal	0.1824
Actual mass of air supplied (AAS)	/kg of coal	5.834
Humidity factor	kg of water/kg of dry air	0.008
Fly Ash	%	1.21
Bottom Ash	%	0.65
CO_2In Flue Gas	%	15.92

a) Heat loss in dry flue gas (L1):

$$L1 = \frac{m\ x\ Cp\ x\ (Tf - Ta)}{GCV\ of\ coal}\ x\ 100$$

$$L1 = \frac{6.0448\ x\ 0.262(142.59 - 41.33)}{3880.21}\ x\ 100$$

$$\mathbf{L1 = 4.4086\%}$$

b) Heat loss due to presence of H_2 in coal (L2):

$$L2 = \frac{9\ x\ H2\ x\ \{584 + Cp(Tf - Ta)\}}{GCV\ of\ coal}\ x\ 100$$

$$L2 = \frac{9\ x\ 0.0441\ x\ (584 + 0.262(142.59 - 41.33)}{3880.21}\ x\ 100$$

$\mathbf{L2 = 6.245\%}$

H2 = kg of hydrogen present in fuel on 1 kg basis

c) Heat loss due to moisture in coal (L3):

$$L3 = \frac{M * \{584 + Cp(Tf - Ta)\}}{GCV\ of\ coal} * 100$$

$$L3 = \frac{0.1824\ x\ \{584 + 0.262(142.59 - 41.33)\}}{3880.21}\ x\ 100$$

$\boldsymbol{L3 = 2.87\%}$

d) Heat loss due to moisture present in air (L4):

$$L4 = \frac{AAS\ x\ Humidity\ factor\ x\ Cp\ x\ (Tf - Ta)}{GCVofcoal}\ x\ 100$$

$$L4 = \frac{5.834\ x\ 0.008\ x\ 0.262\ x\ (142.59 - 41.33)}{3880.21}\ x\ 100$$

$$\boldsymbol{L4 = 0.0319\%}$$

e)Heat loss due to unburnt carbon in combustible (L5):

$$L5 = \left\{ \begin{matrix} \left(0.2\ x\ \frac{bottomas}{100}\right)\left(1 - \frac{bottomas}{100}\right) + \\ \left(0.8\ x\ \frac{flyas}{100}\right)(1 - \frac{flyas}{100}) \end{matrix} \right\}\ x\ (22.26/100)$$

$$L5 = \left\{\left(0.2\ x\ \frac{0.65}{100}\right)\left(1 - \frac{0.65}{100}\right) + \left(0.8\ x\ \frac{1.21}{100}\right)\left(1 - \frac{1.21}{100}\right)\right\}\ x\ 0.2226$$

$$\boldsymbol{L5 = 0.00245\%}$$

f) Heat loss due to radiation, convention and unaccounted losses (L6):

For industrial fire tube / packaged boiler = 1.5 to 2.5%

For industrial water tube boiler = 2 to 3%

For power station boiler = 0.4 to 1%

Here, $\boldsymbol{L6 \approx 1\%}$

g) Sensible heat losses:

g.1) Heat loss due to unburnt in flyash (L7):

$$\text{L7} = \left(0.8\ \text{x}\ \frac{\text{ash\%}}{100}\right)\ x\ \text{Cp x}\ \frac{(\text{Tf} - \text{Ta})}{\text{Gcv of coal}}\ x\ 100$$

$$\text{L7} = \left(0.8\ \text{x}\frac{22.26}{100}\right)\ x\ 0.262\ \text{x}\ \frac{(142.59 - 41.33)}{3880.21} x\ 100$$

$$\boldsymbol{L7 = 0.12272\%}$$

g.2) Heat loss due to unburnt in bottom ash(L8):

$$\text{L8} = \left(0.2\ \text{x}\ \frac{\text{ash\%}}{100}\right) x\ \text{Cp x}\ \frac{(\text{Tf} - \text{Ta})}{\text{Gcv of coal}}\ x\ 100$$

$$L8 = \left(0.2 \text{ x } \frac{22.26}{100}\right) x\ 0.262 \text{ x } \frac{(142.59 - 41.33)}{3880.21}\ x\ 100$$

$$\boldsymbol{L8 = 0.03044\%}$$

C) Overall Efficiency Of The Boiler By Indirect Method

$$\boldsymbol{Efficiency = 100 - (L1 + L2 + L3 + L4 + L5 + L6 + L7 + L8)}$$

=100-(4.4068+6.245+2.87+0.0319+0.00245+0.12272+0.03044)

$$\boldsymbol{= 85.29069\%}$$

Table 5Comparison of data obtained by direct and indirect method

Efficiency	Direct method	Indirect method
Boiler	81.7318%	85.29%
Turbine	34.819%	34.819%
Generator	99.5%	99.5%
Overall efficiency	28.3048%	29.5494%

CONCLUSION

The efficiency of boiler in the power plant was found out by using direct and indirect calculations. We can conclude that efficiency calculated by indirect method is more accurate and also more than the efficiency calculated by direct method. Heat loss due to formation of water from H_2 in coal is the maximum out of all the losses. The presence of H_2 in the fuel here is accountable for a loss but when seen GCV of hydrogen, it is more than that of carbon, and can be used as fuel for combustion. Proper maintenance of the units of the power plant can help increase the efficiency by some percent by minimizing various losses.

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