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Thermal Analysis of Steam Power Plant of High Capacity

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***Abstract:** Steam power plants are widely utilized throughout the world for electricity generation, and coal is often used to fuel these plants. To utilize coal more effectively and competently in electricity generation processes the energy optimization is required. Thus the thermal analyses of different components are performed to improve efficiency and performance. Present work deals with the thermal analysis of 600 MW steam power plant. The energy efficiency of boiler, turbine and condenser are found to be 63.05, 48.25 and 92.67 respectively. Similarly the respective exergy efficiencies are 52.69, 88.25 and 18.5 for boiler, turbine and condenser. The results indicate the exergy reduction of steam is high in condenser showing low efficiency. The energy loss of steam in the condenser can be compensated by adopting binary power generation cycles.*

***Keywords :**Energy efficiency , Exergy efficiency, Exergy destruction, Energy loss.*

I. INTRODUCTION

Most of the energy produced in the world is from stream power plants in the present-day situation. It is very important to see that these plants work efficiently to produced power continuously. Power production using thermal power has been topic of interest from the decades. Coal fired plants are most common in Indian circumstances even though the coal available in India is of mediocre quality. However, the existing plants are working at good efficiency following the standard norms. However, it is possible to enhance further the efficiency of the plant by effective management of the waste heat. It is observed that majority of heat goes in the form of waste from the power plant. In this paper the efforts are made to estimate the some of the parameters of the steam power plant. The data is collected from a plant which is in good working condition with a power output capacity of 600 MW.

II. PLANT DESCRIPTION

The selected thermal power plant consists oftwofluidized bed combustion boilers are loaded with a coal rate of 400 tons/hour. The power plant selected is fully equipped with several mountings and accessories, the process is automated for efficient production of power. The system uses single turbine with power output as specified and supported by the refining techniques like regeneration, air preheater and feed water heating to enhance the performance.The layout of power plant is shown as line diagram in figure 1. Power plant economics is generally studied to bring down the operational costs of the plant to facilitate the better usage of the equipment. The processes can be further optimized to enhance the performance of the plant. The first law and second law analysis can provide better insight into the problems of heat loss from the different components of the plant. So, in the present work the energy and exergy analysis of the boiler, turbine and condenser have been performed for the purpose of comparison.

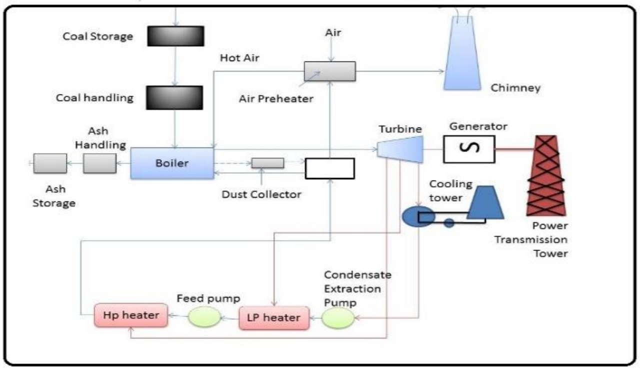

Figure.1 Layout of Steam Power Plant

III. MATERIALS AND CALCULATIONS

3.1. OVERALL THERMAL EFFICIENCY

Boiler, Turbine and Condenser are the three main components of the thermal power plant. Therefore, the overall thermal power plant efficiency depends on the efficiencies of these three components. The thermal efficiencyshows how well the plant operates in relation to th e design features. The detailed operating values are given in following table 1.

Table.1. Plant flow parameters

PARAMETERS	UNIT	QUANTITY
Enthalpy of Feed Water	KJ/Kg	280.6
Enthalpy of Steam	KJ/Kg	2898
Mass Flow Rate of Fuel(Coal)	Kg/hr	385.45×10^3
Calorific Value of Fuel(Coal)	KJ/Kg	17793.9
Mass Flow Rate of Fuel (To Ignite Coal)	Kg/hr	5000
Calorific Value of Fuel (To Ignite Coal)	KJ/Kg	19677.96
Boiler Steam Flow	Kg/hr	1676000
Work done on the turbine	MW	587.9
Enthalpy of Steam at inlet to the Condenser	KJ/Kg	2762.8
Enthalpy of Steam at outlet to the Condenser	KJ/Kg	188.4

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Mass Flowrate of Cooling Water in Condenser	Kg/hr	110000×10^3
Calorific Value of Cooling Water	KJ/Kg	4.178
Inlet Temperature of Cooling Water	K	306.82
Outlet Temperature of Cooling Water	K	315.52

3.2. BOILER EFFICIENCY CALCULATIONS

Input heat content through coal = CV × Coal consumption
= $17793.9\times(385.45\times 10^3)$
= 6858658.75×10^3 kJ/hr
= 1905.18×10^3 kW
= 1905.18 MW

Input heat content through black liquor = CV ×black liquor consumption
= 19677.96 × 5000
= 98389.8×10^3 kJ/hr
= 27.33×10^3 kW
= 27.33 MW

Total input heat content = 1905.18 + 27.33
=1932.51 MW

Output heat content of steam generated = Q × (h_1-h_0)
= $1676\times 10^3\times(2898\text{-}280.6)$
= 4386762.4×10^3 kJ/hr
= 1218.55×10^3 kW
= 1218.55 MW

$$\eta_{Boiler} = \frac{output\ heat\ content}{input\ heat\ content}$$

$$= \frac{1218.55}{1932.51}$$

The efficiency of boiler = 63.05%
Energy loss in Boiler = Heat input – Heat output
= 1932.51-1218.55
= 713.96 MW

3.3. TURBINE EFFICIENCY CALCULATIONS

The heat energy supplied by the steam is converted into a mechanical energy by expanding at high pressure and temperature. After passing through the turbine, pressure and temperature are lowered.

Work done on the turbine = 587.9 MW
Work input to the Turbine = 1218.55 MW

$$\text{Efficiency of the turbine} = \frac{Work\ output\ of\ Turbine}{Work\ input\ to\ the\ Turbine}$$

$$\eta_T = \frac{587.9}{1218.55}$$

η_T = 48.25%

Energy loss in Turbine = Work input to the Turbine – Turbine work output
= 1218.55 – 587.9
= 630.65 MW

3.4. CONDENSER CALCULATIONS

$$\text{Energy efficiency of condenser} = \frac{Mw\ Cpw\ (Two-Twi)}{Mst\ (h2-h3)}$$

Energy efficiency of condenser

$$= \frac{110000\times1000\times4.178\ (315.52-306.82)}{1676\times1000\times(2762.8-188.4)}$$

$$= \frac{110000\times1000\times36.35}{1676\times1000\times2574.4}$$

$$= \frac{3998500\times1000}{4314694.4\times1000}$$

Energy efficiency of condenser = $\eta_{Condensor}$= 92.67 %
Energy loss = $Mst\ (h2-h3)$ - $Mw\ Cpw\ (Two-Twi)$
`= (4314694.4 × 1000) – (3998500 × 1000)
= 316194.4×10^3 kJ/hr
= 87.83×10^3 kW
= 87.83 MW

3.5. OVERALL EFFICIENCY

Overall efficiency is calculated as follows

η_{over} = $\eta_{Boiler}\times\ \eta_T\times\ \eta_{Condensor}$
= 0.6305× 0.4825×0.9267
= 28.19 %

The general heat effectiveness of a power plant in general is much lower. An exergy estimation of each element is required to understand the true concern in the plant.

Table:2 Efficiency of Components

S.No	Component	Efficiency (%)
1	Boiler	63.05
2	Turbine	48.25
3	Condenser	92.67
4	Overall	28.19

IV. EXERGY ANALYSIS

In order to quantify the reductions in effectiveness in a system the researchers have traditionally used the First thermodynamics law to calculation of energetic balance.Since the first law analysis from an energy performance point of view is nascent, the exergy components have gained considerable attention in the thermodynamic analysis of thermal processes and plant systems. There are three kinds of energy transmission across the control surface which include work transfer, heat transfer and energy connection with mass transfer or fluid.The temperature of the heat source and the system's function are also used to evaluate open flow systems and to examine plant efficiency when kinetic and potential energy changes are neglected.It can be decidedwhich processes should be taken into account.The basic energy balance isn't enough to spot the system deficiency. In such cases, the exergy evaluation is considered important throughout order to determine the imperfections of the process. The details of the different components used for exergy analysis are shown in figures 2 to 4.

$$\eta_{ii} = \frac{Desired\ output\ energy}{Maximum\ possible\ output}$$

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4.1. BOILER CALCULATIONS

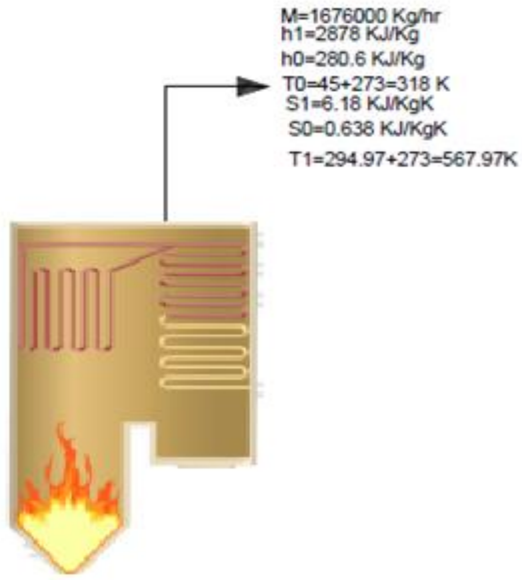

Figure.2 Boiler

<u>Energy analysis</u>

Energy efficiency of boiler

$$\eta_{Boiler} = \frac{output\ heat\ content}{input\ heat\ content}$$

$$= \frac{1218.55}{1932.51}$$

The efficiency of boiler = 63.05%

Energy loss in Boiler = Heat input – Heat output

= 1932.51-1218.55

= 713.96 MW

<u>Exergy Analysis</u>

$$\psi_{boiler} = \frac{Exergy\ increase\ of\ steam}{Exergy\ of\ heat\ input}$$

$$\psi_{boiler} = \frac{M[(h1-h0)-T0(S1-S0)]}{Qin\left[1-\frac{T0}{T1}\right]}$$

Exergy increase of steam = $M(h_1 - h_0) - T_0(S_1 - S_0)]$

$= 1676 \times 10^3 \times [(2898-280.6)-318(6.18-0.638)]$

$= 1433.05 \times 10^6$

Exergy of heat input $= Q_{in}\ [1-\frac{T0}{T1}]$

Where,

$Q_{in} = m\ (h_1 - h_0)$

Exergy of heat input = $1676 \times 10^3 \times (2898-280.6)(1-\frac{318}{840.97})$

$= 1676 \times 10^3 \times 2617.4 \times 0.62$

$= 2719.79 \times 10^6$

$$\psi_{boiler} = \frac{1433.05}{2719.79} = 52.69\%$$

Exergy destruction in boiler

$= Q_{in}\ [1-\frac{T0}{T1}] - m\ [(h_1 - h_0) - T_0(S_1 - S_0)]$

$= (2719.79 \times 10^6)-(1433.05 \times 10^6)$

$= 1286.74 \times 10^6$ kJ/hr

$= 357.43 \times 10^3$ kW

= 357.43 MW

Exergy destruction in boiler = 357.43 M W

4.2. TURBINE CALCULATIONS

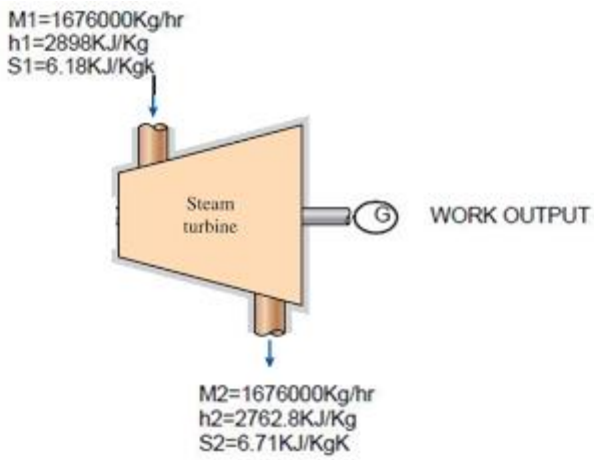

Figure.3 Turbine

<u>Energy analysis</u>

Work done on the turbine (W_T) = 587.9 M Watt

Work input to the Turbine from the boiler = 1218.55 M Watt

Efficiency of the turbine

$$= \frac{Turbine\ Work\ output}{Work\ input\ to\ the\ Turbine}$$

$$\eta_T = \frac{587.9}{1218.55}$$

η_T = 48.25%

Energy efficiency of turbine = 48.25%

Energy loss in Turbine

= Work to Turbine – Turbine work output

= 1218.55 – 587.9

= 630.65 M Watt

<u>Exergy Analysis</u>

W_T = 587.9 M Watt

Exergy destruction can find out from exergy balance,

Exergy destruction in Turbine $= T_0\sigma$

$\sigma = m\ (s_2 - s_1)$

$\sigma = 1676 \times 10^3\ (6.71-6.18)$

$= 888.28 \times 10^3$ kJ/hr.K

= 246.74 kW/K

Exergy destruction $= T_0\sigma = 318 \times 246.74$

= 78463.32 K Watt

=78.46 MW

Exergetic Efficiency $= \frac{Wt}{Wt+Ed}$

Exergetic efficiency $= \frac{587.9}{587.9+78.46}$

$\psi_{Turbine}$= 88.23 %

4.3. CONDENSER CALCULATIONS

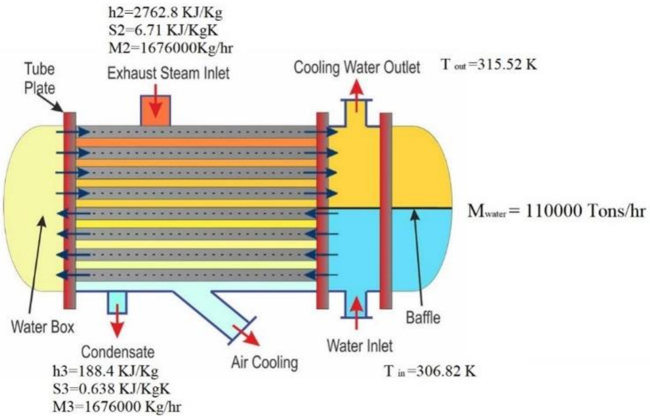

Figure.4 Condenser

<u>Energy Analysis</u>

Energy efficiency of condenser $= \frac{Mw\ Cpw\ (Two-Twi)}{Mst\ (h2-h3)}$

Energy efficiency of condenser

$$= \frac{110000 \times 1000 \times 4.178\ (315.52-306.82)}{1676 \times 1000 \times (2762.8-188.4)}$$

$$= \frac{110000 \times 1000 \times 36.35}{1676 \times 1000 \times 2574.4}$$

$$= \frac{3998500 \times 1000}{4314694.4 \times 1000}$$

Energy efficiency of condenser = 92.67 %

Energy loss $= Mst\ (h2-h3)$ - $Mw\ Cpw\ (Two-Twi)$

= (4314694.4 × 1000) – (3998500 × 1000)

= 316194.4× 10^3 kJ/hr

= 87.83× 10^3 kW

= 87.83 MW

<u>Exergy analysis</u>

Exergy reduction of water

$$\varepsilon_{wo} - \varepsilon_{wi} = (h_{wo} - h_{wi}) - T_0\,(s_{wo} - s_{wi})$$

$$= C_{pw}\,(T_{wo} - T_{wi}) - T_0 C_{pw} \ln\frac{Two}{twi}$$

$$= 4.178(315.52-306.82) - (318 \times 4.178 \times \ln\frac{315}{306.82})$$

= 36.35- (318× 4.178×0.026)

= 36.35 - 34.54

= 1.81 kJ/Kg

Exergy reduction of steam due to condensation

$$\varepsilon_2 - \varepsilon_3 = (h_2 - h_3) - T_0(s_2 - s_3)$$

=(2762.8-188.43)-318(6.71-0.638)

= 2574.37 – 1930.89

= 643.48 kJ/Kg

$$\psi_{condenser} = \frac{Mw(\varepsilon wo - \varepsilon wi)}{Mst\ (\varepsilon 2 - \varepsilon 3)}$$

$$\psi_{condenser} = \frac{110000 \times 1000 \times 1.81}{1676 \times 1000 \times 643.48}$$

$\psi_{condenser}$=18.5 %

Destruction in condenser $= M_{steam}(\varepsilon_3 - \varepsilon_4) - M_{water}(\varepsilon_{wo} - \varepsilon_{wi})$

=(1676×10^3×643.48) – (110000×10^3×1.81)

= 1078472.48 ×10^3–199100 ×10^3

= 879372.48 ×10^3 kJ/hr

= 244.27 ×10^3 kW

= 244.27 MW

V. CONCLUSIONS

- The performance analysis of the 600 MW steam power plant is considered.
- The boiler, turbine and condenser efficiencies are calculated as mentioned above. The values are given in table.
- The exergy efficiency of turbine indicates better utilization of heat, where as the boiler exergy efficiency indicates losses.
- The condenser exergy losses are high, system can be supported with some bottoming cycle (binary power cycle) arrangement to capture the heat available.
- The details of the calculated first and second law efficiencies and estimated losses are shown in Figures 5 and 6.

The exergy and energy analysis are thus the tools to monitor the performance of the plant.

Table: 3 Comparison of Energy & Exergy Analysis

Component	η_I (%)	η_{II} (%)	Energy loss MW	Exergy loss MW
BOILER	63.05	52.69	713.96	357.43
TURBINE	48.25	88.23	630.65	78.46
CONDESER	92..67	18.5	87.83	244.27

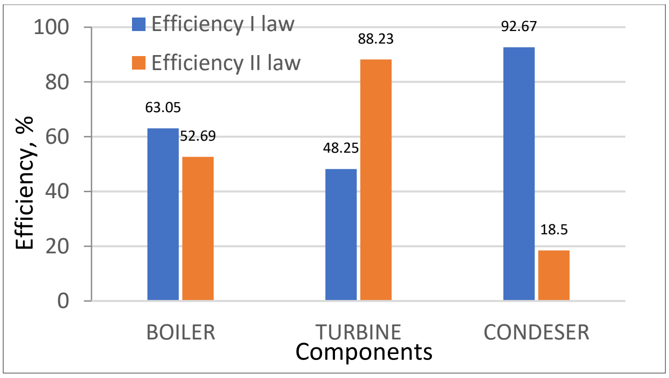

Figure.5 Efficiency comparison of different components

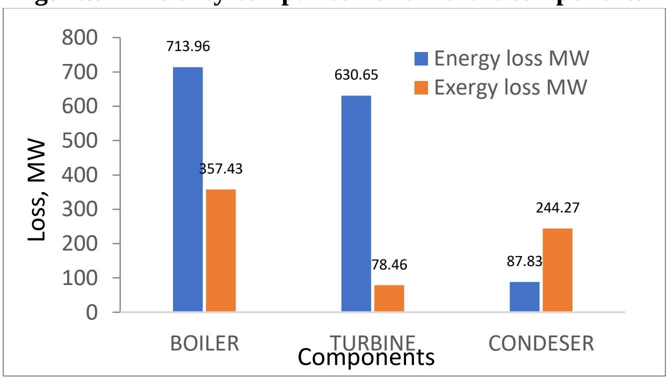

Figure.6 Power loss comparison of different components

NOMENCLATURE

TERM		FULL FORM	UNIT
CV	=	CALORIFIC VALUE	KJ/Kg
Q	=	DISCHARGE (OR) MASS FLOWRATE OF STEAM	Kg/hr
h_1	=	ENTHALPY OF STEAM FROM BOILER	KJ/Kg
$H=h_0$	=	ENTHALPY OF FEED WATER	KJ/Kg
AFBC	=	ATMOSPHERIC FLUIDISED BED COMBUSTION BOILER	
η_{Boiler}	=	ENERGY EFFICIENCY OF BOILER	%
M	=	MASS FLOWRATE OF STEAM TO THE TURBINE	Kg/hr
h_1	=	ENTHALPY OF STEAM BEFORE GO TO THE TURBINE	KJ/Kg
M	=	MASS FLOWRATE OF STEAM AT THE TURBINE EXIT	Kg/hr
h_2	=	ENTHALPY OF STEAM AT THE TURBINE EXIT	KJ/Kg
$\eta_{Turbine}$	=	ENERGY EFFICIENCY OF TURBINE	%
$\eta_{Cond.}$	=	ENERGY EFFICIENCY OF CONDESER	%
$\eta_{Overall}$	=	OVERALL PLANT ENERGY EFFICIENCY	%
η_{I}	=	EFFICIENCY BY USING FIRST LAW OF THERMODYNAMICS	%
η_{II}	=	EFFICIENCY BY USING SECOND LAW OF THERMODYNAMICS	%
T_0	=	TEMPERATURE OF FEED WATER	K
S_0	=	ENTROPY OF FEED WATER	KJ/KgK
S_1	=	ENTROPY OF STEAM BEFORE GO TO THE TURBINE	KJ/KgK
ψ_{boiler}	=	EXERGY ANALYSIS OF BOILER	%
W_T	=	WORKDONE BY THE TURBINE	Watt
S_2	=	ENTROPY OF STEAM AT THE TURBINE EXIT	KJ/KgK
E_d	=	EXERGY DESTRUCTION	Watt
$\psi_{Turbine}$	=	EXERGY ANALYSIS OF TURBINE	%
h_3	=	ENTHALPY OF FEED WATER AT CONDENSOR EXIT	KJ/Kg
S_3	=	ENTROPY OF FEED WATER AT CONDENSOR EXIT	KJ/Kg
M_{St}	=	MASS FLOWRATE OF FEED WAYER AT CONDENSOR EXIT	Kg/hr
M_{Water}	=	MASS FLOWRATE OF COOLING WATER IN CONDENSOR	Kg/hr
T_{IN}	=	INLET TEMPERATURE OF COOLING WATER AT CONDENSOR	K
T_{OUT}	=	OUTLET TEMPERATURE OF COOLING WATER AT CONDENSOR	K
C_{PW}	=	SPECIFIC HEAT OF COOLING WATER AT CONSTENT PRESSURE	KJ/KgK
$\psi_{Cond.}$	=	EXERGY ANALYSIS OF CONDENSOR	%

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