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Energy and Exergy Analysis of a 250 mw Coal Thermal Power Plant at Design Load Conditions

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Abstract: In this research work thermodynamic analysis of 250 MW Panipat coal thermal power plants has been carried out by using an energy and exergy analysis method at design load conditions. The exergy analysis of a power plant deals with the analysis of energy on the basis of quantity only however the energy analysis deals with the analysis of energy on the basis of quantity as well as quality. The aim of present research work is to conduct an energy and exergy analysis of the major components of a coal thermal power plant like boiler, turbine, and condenser and pump in order to identify the magnitude and location of real energy efficiency. The temperature and pressure of main stream and the condenser pressure are considered as operating parameters. From the study it is observed that the major contribution of energy efficiency is found in pump of 94.56% followed boiler of about 87.11% and condenser of 59.67%. The major exergy efficiency is found in the pump of 91.19% followed by turbine of 52.33% and condenser of 32.40% of the total exergy supplied.
Keywords: Exergy; Energy; Thermal power plant; Energy efficiency; Exergy efficiency.

I. INTRODUCTION

The panipat thermal power station (PTPS) is fully operated by Haryana power generation corporation limited (HPGCL) as it is wholly owned by the state government of Haryana under the Ministry of power (Government of India). Panipat Thermal Power Station was a designated consumer in the state of Haryana, under management of HPGCL. HPGCL was incorporated as company on 17 March 1997 but it came existence on 14 August, 1998 and given the responsibility of operating and maintenance of state own power generating plant and projects. Currently, it had six power station and project situated at panipat, Yamuna Nagar, Hisar and Jhajjar districts [1].

Fig 1.Photographic view of panipat thermal power plant

PTPS is the major coal based and first power station installed in the Haryana by the HPGCL. The plant is located at village Assan which is 12KM away from the city. Total present installed capacity of the power plant 1360MW in six stages as given in the table 1.

Table1.Year wise installed capacity of PTPS.

Stage	Unit	Capacity	Date of installation
Stage-1	Unit-1	110MW	01.11.1979
	Unit-2	110MW	27.03.1980

Stage-2	Unit-3	110MW	01.11.1985
	Unit-4	110MW	11.01.1987
Stage-3	Unit-5	210MW	28.03.1989
Stage-4	Unit-6	210MW	31.03.2001
Stage-5	Unit-7	250MW	28.092004
Stage-6	Unit-8	250MW	28.01.2005

Transportation of coal is done by wagons. PTPS draws water from right main canal through an intake channel to meet its water requirement. The primary fuel input to the plant is coal which is taken from Jhariya and Raniganj Mines. PTPS disposes bottom ash to the nearest ash pond in slurry form and the dry fly ash to the nearby cement industries and fly ash traders [2]. The project detail of PTPS is given in table 2.

Table 2.Project detail of PTPS

Sponsor	HPGCL
Name	Panipat thermal power station(PTPS)
Location	Assan village, panipat district, Haryana
Source of financing	Government of India
Plant capacity	1360MW (4x110+2x210+2x250 MW)
Total unit	8
Type	Coal based thermal power plant
Coal source	Jhariya and Raniganj mines
Water source	Canal through
Plant area	660 acres
Colony	400 acres
Ash storage & Raw water	940 acres

The schematic view of important major components of a thermal power plant, namely, boiler, turbine, condenser and pump are shown in figure 2,3,4 and 5 respectively.

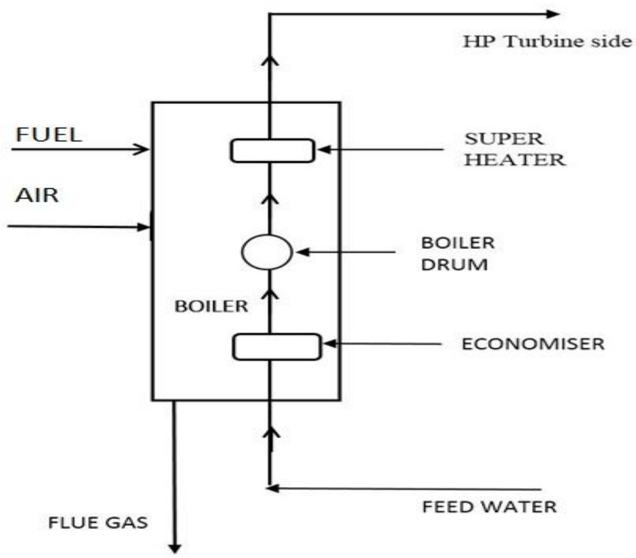

Fig.2 Schematic view of boiler.

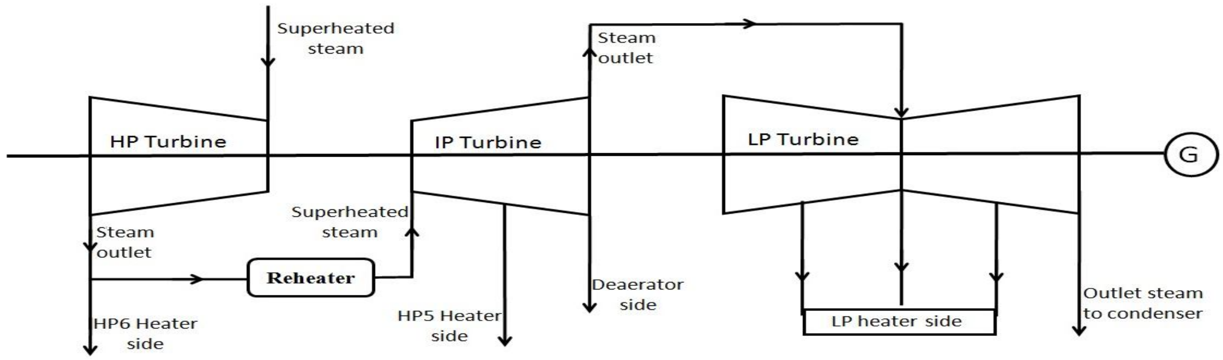

Fig.3. Schematic view of turbine

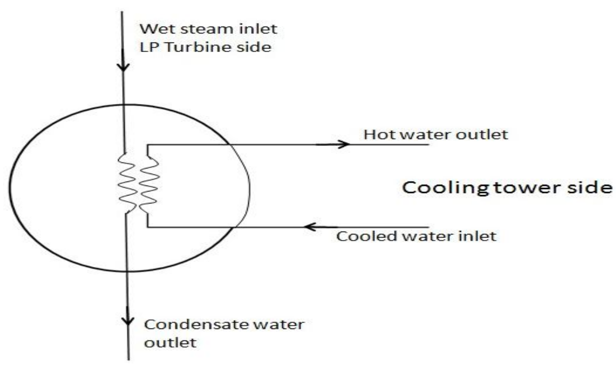

Fig. 4. Schematic view of condenser

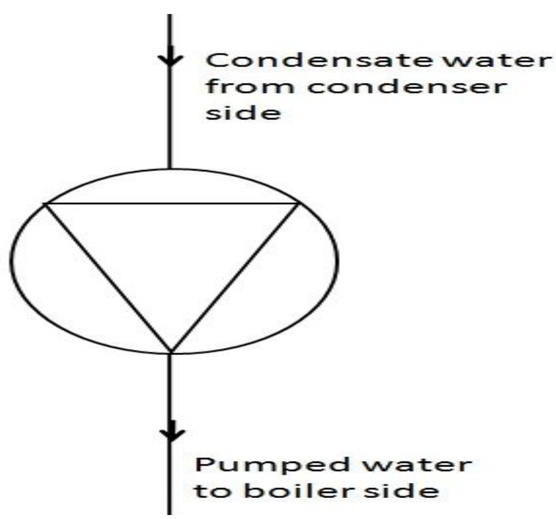

Fig. 5. Schematic view of CEP pump

II. THERMAL MODELING AND FORMULAE USED

The energy and exergy analysis of a thermal power plant is studied by using the basic thermodynamics laws. The energy analysis of the thermal power plant has been evaluated by the 1stlaw and the exergy analysis of thermal power plant studied by the 2nd law of thermodynamic [3]. The energy and exergy analysis of a thermal power plant mainly depend upon the major working components like boiler, turbine, condenser and pump.

A. Energy and exergy analysis boiler

The specifications and the operating parameters of boiler are given in table 3 and 4.

Table 3.Specification of boiler

Type	Water-tube
Running Authority	BHEL
Mode of heat transfer	Natural circulation and sub-critical

Table 4.Operating parameter of the boiler

Parameter	Unit	Input	Output
Mass flow	TPH	740.88	740.88
Temperature	Celsius	246	537
Pressure	Bar	176.52	150
Enthalpy	kj/kg	1067.6764	3416.57
Entropy	kj/kg-k	2.7263	6.4906

The proximate and ultimate analysis of lignite coal is given in table5 and 6.

Table5.Proximate analysis of coal.

Coal contents	Units	Value
Fixed carbon	%	21
Volatile matter	%	30
Moisture	%	15
Ash contents	%	34
Calorific value of coal	Kcal/kg	4000
Calorific value of carbon	Kcal/kg	8077.8

Table 6.Ultimate analysis of coal

Coal constituents	Units	Value
Carbon	%	40.58
Hydrogen	%	2.84
Nitrogen	%	0.76
Oxygen	%	7.11
Sulphur	%	0.35
CO_2	%	14.5
Ambient temperature	^0C	32
Surface temperature of boiler	^0C	352

1) *Energy analysis of boiler;* The energy analysis of the boiler can be carried out by using the equation 1, 2, 3, 4, 5, 6 and 7 respectively [4-8].

Unburnt carbon loss (L_1)

$$L_1 = \frac{U_C \times CV_C \times 100}{GCV} \qquad (1)$$

Where: U_c= Total unburnt carbon in ash
CV_c= Calorific value of carbon
GCV= Gross calorific value of carbon

Dry flue gas loss (L_2)

$$L_2 = \frac{M_f \times C_p \times (T_g - T_a) \times 100}{GCV} \quad (2)$$

Where:M_f= Mass of flue gases
C_p= Specific heat capacity
T_g= Temperature of flue gas
T_a= Ambient Temperature

Loss due to moisture in fuel (L_3)

$$L_3 = \frac{M \times [584 + C_p (T_g - T_a)]}{GCV} \times 100 \quad (3)$$

Where:M= Total mositure in fuel

Loss due to hydrogen in fuel (L_4)

$$L_4 = \frac{9 \times H \times 584 + C_p (T_g - T_a)}{GCV} \times 100 \quad (4)$$

Where: H= Hydrogen percentage

Loss due to moisture in air (L_5)

$$L_5 = \frac{AAS \times humidity\ factor \times C_{p\,steam} (T_g - T_a) \times 100}{GCV} \quad (5)$$

Where: AAS= Actual mass of air supplied
$C_{p\ steam}$ = Specific heat capacity steam

Loss due to radiation (L_6)

$$L_6 = 0.548 \times \left[\left(\frac{T_s}{55.55} \right)^4 - \left(\frac{T_a}{55.55} \right)^4 \right] + 1.957 \times (T_s - T_a) \sqrt{\frac{196.85 \times V_m + 68.9}{68.9}} \quad (6)$$

Where: T_s= Temperature of boiler surface
V_m= Wind velocity

Heat loss due to unmeasured loss in boiler (L_7)
Total losses =L_1+L_2+L_3+L_4+L_5+L_6+ L_7 (7)
Boiler efficiency = 100-Total losses

2) *Exergy analysis of boiler:* The exergy of boiler in the form of the superheated steam, which is produced with the help of hot flues gasses to convert the water into the steam. The parameters used for exergy efficiency of boiler are given in table 7.

Table 7.Working parameters of boiler

Substance	Mass flow rate(TPH)	Temperature (^{o}C)
Fuel (coal)	140	1100
Water	740.833	246
Air supplied	850	140
Steam	740.833	537
Flue Gasses	1100	140

The exergy analysis of boiler can be carried out by using the equation 8, 9, 10, 11, 12, 13 and 14 respectively [9].

Exergy of fuel (ε_f)

$$\varepsilon_f = 34183.16\,(C) + 21.95\,(N) + 11659.9\,(H) + 18242.90\,(S) + 13265.9\,(O) \qquad (8)$$

Where:

C= Carbon
N= Nitrogen
H= hydrogen
S= Sulpher
O=Oxygen

Exergy of feed water (ε_ω)

$$\varepsilon_\omega = (C_p)_w\left[(T_w - T_o) - T_o l_n\left(T_w / T_o\right)\right] \qquad (9)$$

Where

$(C_p)_w$ = Specific heat of water
T_w= Temperature of feed water
T_w= Referance temperature

Exergy of air supply (ε_a)

$$\varepsilon_a = C_{pa}\left[(T_a - T_o) - T_o l_n\left(T_a / T_o\right)\right] \qquad (10)$$

Where

C_{pa}= Specific heat of air
T_a= Temperature of air supplied

Exergy of steam formed (ε_s)

$$\varepsilon_s = (h - h_o) - T_o(S - S_o) \qquad (11)$$

Where

h= Enthalpy of outlet steam
h_0= Enthalpy referance temperature

Exergy of flue gasses(ε_g)

$$\varepsilon_g = C_{pg}\left[(T_g - T_o) - T_o l_n\left(T_g / T_o\right)\right] \qquad (12)$$

Where

C_{pg}=specific heat of flue gas

The total irreversibility in the steam boiler is given by

I_b = Total exergy entering the boiler – Total exergy leaving the boiler

$$I_b = (\varepsilon_\alpha + \varepsilon_\omega + \varepsilon_f) - (\varepsilon_s + \varepsilon_g) \qquad (13)$$

Exergy efficiency (2nd law efficiency) of boiler

$$\eta_{II} = \frac{\text{total exergy leaving the boiler}}{\text{total exergy entering the boiler}}$$

$$\eta_{II} = \frac{\varepsilon_s + \varepsilon_g}{\varepsilon_\alpha + \varepsilon_\omega + \varepsilon_f} \qquad (14)$$

B. Energy and exergy analysis turbine

The specifications of turbine and operating parameters are given in table 8, 9, 10, 11, 12, 13 and 14 respectively.

Table 8. Specification of turbine

Type	3-Cylinder mixed flow Tanden
Capacity	250MW
Speed	3000 rpm
Overall length	16.975m
Width	10m
Stage	3

1) Energy analysis of turvine

Energy enters in the turbine in the form of the thermal energy of superheated steam coming from the boiler.

Thermal power plant turbine consists of three sections of turbine which are

HP Turbine (High pressure turbine)

IP Turbine (Intermediate pressure turbine)

LP Turbine (low pressure turbine)

a) HP Turbine

Table9. Parameter used for efficiency calculation HP turbine

Parameter	Units	Input	Output
Steam flow	TPH	740.88	655.533
Pressure	Bar	147.1	38.80
Temperature	celsius	537	343.2
Enthalpy	kj/kg	3416.57	3080.8621
Entropy	kj/kg-K	6.4906	6.5770

The energy analysis of turbine can be calculated by using equation 15, 16, 17 and 18 respectively [10].

Isentropic energy efficiency

$$\text{Isentropicefficiency} = \frac{\text{Actual Work}}{\text{Iesentropic efficiency}(\text{Ideal work})}$$

$$\eta_1 = \frac{h_1 - h_{2a}}{h_1 - h_{2s}} \qquad (15)$$

h_1 = Enthalpy at inlet of HP turbine

h_{2a} = Enthalpy at outlet of HP turbine

h_{2s} = Isentropic enthalpy of HP turbine

b) IP Turbine

Table 10.Parameter used for efficiency calculation HP turbine

Parameter	Units	Input	Output
Steam flow	TPH	665.533	586.446
Pressure	kg/cm^2	38.85	6.796
Temperature	Celsius	537	296
Enthalpy	kj/kg	3530.17	3051.92
Entropy	kj/kg-K	7.2116	7.2993

Isentropic energy efficiency

$$\text{Iesentropi c efficiency} = \frac{\text{Actual Work}}{\text{Iesentropi c efficiency (Ideal work)}}$$

$$\eta_1 = \frac{h_1 - h_{2a}}{h_1 - h_{2s}} \quad (16)$$

h_1 =Enthalpy at inlet of IP turbine
h_{2a} =Enthalpy at outlet of IP turbine
h_{2s} = Isentropic enthalpy of IP turbine

c) LP Turbine

Table 11Parameter used for efficiency calculation HP turbine

Parameter	Units	Input	Output
Steam flow	TPH	586.446	513.243
Pressure	Bar	6.796	0.1013
Temperature	Celsius	296	46.08
Enthalpy	kj/kg	3051.92	2585.23
Entropy	kj/kg-K	7.2993	8.1466

Isentropic energy efficiency

$$\text{Iesentropic efficiency} = \frac{\text{Actual Work}}{\text{Iesentropic efficiency (Ideal work)}}$$

$$\eta_1 = \frac{h_1 - h_{2a}}{h_1 - h_{2s}} \quad (17)$$

h_1 =Enthalpy at inlet of LP turbine
h_{2a} =Enthalpy at outlet of LP turbine
h_{2s} = Isentropic enthalpy of LP turbine
The energy efficiency of whole turbine is given by the

$$\eta_T = \eta_H \times \eta_I \times \eta_L \quad (18)$$

2) *Exergy analysis of turbine:*Theexergy of the turbine in the form of work done (electric generator), which is being converted from the thermal energy of steam.

Thermal power plant turbine consists of three sections of turbine which are
HP Turbine (High pressure turbine)
IP Turbine (Intermediate pressure turbine)
LP Turbine(low pressure turbine)

a) HP Turbine

Table 12Parameter used for exergy efficiency of HP turbine

Parameter	Units	Input	Output
Steam flow	TPH	740.88	655.533
Pressure	Bar	147.1	38.8049
Temperature	Celsius	537	343.2
Enthalpy	kj/kg	3416.57	3080.8621
Entropy	kj/kg-K	6.4906	6.5770
Exergy	kj/kg	1474.598	1132.206

The exergy analysis of turbine can be calculated by using equation 19, 20, 21, 22, 23, 25, 26, 27 and 28 respectively [11].

$$\text{Exergatic efficiency} = \frac{\text{Exergy Recovered}}{\text{Exergy Supplied}}$$

$$\eta_{II} = 1 - \frac{T_{\circ} S_{gen.}}{\Psi_1 - \Psi_2} \quad (19)$$

$$\text{Entropy Generation}(S_{gen.}) = S_2 - S_1 \quad (20)$$

$$\Psi = (h_1 - h_0) - T_0 (S_1 - S_0) \quad (21)$$

Ψ_1=exergy at inlet

Ψ_1=exergy at outlet

b) IP Turbine

Table 13Parameter used for exergy efficiency of IP turbine

Parameter	Units	Input	Output
Steam flow	TPH	665.533	586.446
Pressure	Bar	38.85	6.796
Temperature	Celsius	537	296
Enthalpy	kj/kg	3530.17	3051.92
Entropy	kj/kg-K	7.2116	7.2993
Exergy	kj/kg	1371.898	867.343

The exergy analysis of turbine can be calculated by using equation 18, 19, 20, 21, 22, 23 and 24 respectively [11-12].

$$\text{Exergatic efficiency} = \frac{\text{Exergy Recovered}}{\text{Exergy Supplied}}$$

$$\eta_{II} = 1 - \frac{T_{\circ} S_{gen.}}{\Psi_1 - \Psi_2} \quad (22)$$

$$\text{Entropy Generation}(S_{gen.}) = S_2 - S_1 \quad (23)$$

$$\Psi = (h_1 - h_0) - T_0 (S_1 - S_0) \quad (24)$$

Ψ_1=exergy at inlet

Ψ_1=exergy at outlet

c) LP Turbine

Table 14.Parameter used for exergy efficiency of LP turbine

Parameter	Units	Input	Output
Steam flow	TPH	586.446	513.243
Pressure	Bar	6.796	0.1013
Temperature	Celsius	296	46.08
Enthalpy	kj/kg	3051.92	2585.23
Entropy	kj/kg-K	7.2993	8.1466
Exergy	kj/kg	867.343	146.458

$$\text{Exergatic efficiency} = \frac{\text{Exergy Recovered}}{\text{Exergy Supplied}}$$

$$\eta_{II} = 1 - \frac{T_{\circ} S_{gen.}}{\Psi_1 - \Psi_2} \quad (25)$$

$$\text{Entropy Generation}(S_{gen.}) = S_2 - S_1 \quad (26)$$

$$\Psi = (h_1 - h_0) - T_0 (S_1 - S_0) \quad (27)$$

Ψ_1=exergy at inlet
Ψ_1=exergy at outlet

Exergy efficiency of complete turbine is given by the

$$\eta_T = \eta_H \times \eta_I \times \eta_L \quad (28)$$

C. Energy and exergy analysis condenser

The specifications and operating parameters of condenser are given in table 15 and 16.

Table 15.Specification of condenser

Type	Surface type made of fabricated single head
Area	96.55cm^2
Cooling water flow rate	24250 TPH

1) *Energy analysis of condenser:* Energy entered in the condenser in the form wet steam.

Table 16.Parameter used for the efficiency calculation of condenser

Parameters	Unit	Inlet	Outlet
Mass flow	TPH	513.243	589.60
Pressure	Bar	0.1013	0.1013
Temperature	Celsius	46.7	46.01
Enthalpy	kj/kg	2586.4016	192.57
Entropy	kj/kg-K	8.1502	0.6516
Exergy	kj/kg	95.23	7.03
Cooling tower			
Temperature	Celsius	36	42.2
Water flow	TPH	32000	32000

The energy analysis of condenser can be calculated by using equation 29, 30 and 31 respectively [12].
Mass balance of condenser is

$$\text{Energy loss} = m_{in}(h_{in} - h_{out}) - Q_K \quad (29)$$

First law efficiency of condenser is given by the formula

$$\eta_1 = \frac{Q_K}{m_{in}(h_{in} - h_{out})} \quad (30)$$

$$Q_k = mC_p dt \quad (31)$$

m= water flow in the cooling water
m_{in}= water inlet in condenser
Q_k=heat loss in condenser
h_{in}= enthalpy of inlet saturated steam

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h_{out}= enthalpy of out let condensate water

dt= terminal temperature difference of cooling tower

*2) Exergy analysis of condenser :*Exergy out from the condenser is the form of condensate water.
The exergy analysis of condenser can be calculated by using equation 32, 33 and 34 respectively [12].
Mass balance of condenser is given by

$$T_o S_{gen} = m_{in}\left(\Psi_{in} - \Psi_{out}\right) - \Sigma Q_{in}\left(1 - \frac{T_0}{T_{out}}\right) \quad (32)$$

2nd law efficiency of condenser is given by the formula

$$\eta_{II} = 1 - \frac{I_{destroyed}}{m_{in}\left(\Psi_{in} - \Psi_{out}\right)} \quad (33)$$

$$\eta_{II} = \frac{Q_{in}\left(1 - \frac{T_0}{T_{out}}\right)}{m_{in}\left(\Psi_{in} - \Psi_{out}\right)} \quad (34)$$

T_{out}=temperature at the outlet of condenser

Ψ_{in}= exergy inlet in the condenser

Ψ_{out}= exergy inlet in the condenser

D. Energy and exergy analysis pump

The specifications and operating parameters of condenser are given in table 17 and 18.

Table 17Specification of CEP pump

Type of motor	Induction type
Speed	1483rpm
Power	325 kw
Quantity	3

Table 18Parameter used for the calculation of CEP efficiency

Parameters	Unit	Inlet	Outlet
Mass flow	TPH	589.60	589.60
Temperature	Celsius	46.01	46.11
Pressure	KPa	10.1302	1919.16
Enthalpy	kj/kg	192.5741	194.6527
Entropy	kj/kg-K	0.6516	0.6522

E. Energy analysis of pump

Energy entered by the pump in the form of power of electric motor. The energy analysis of pump can be calculated by using equation 31and 32 respectively [12].

$$\text{Iesentropic efficiency} = \frac{\text{Iesentropic efficiency}\left(\text{Ideal work}\right)}{\text{Actual Work}}$$

$$\eta_p = \frac{h_{2s} - h_1}{h_{2a} - h_1} \quad (35)$$

*Exergy analysis of pump*Exergy out from the pump in the form pressurized water.

1)

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$$\text{Exergetic efficiency} = \frac{\text{Exergy Recovered}}{\text{Exergy Supplied}}$$

$$\eta_{II} = 1 - \frac{T_{\circ} S_{gen.}}{h_2 - h_1} \qquad (36)$$

III. RESULT AND DISCUSSION

A. *Results for the energy and exergy analysis of boiler*

The energy analysis of the boiler can be carried out by using the equation 1, 2, 3, 4, 5, 6 and 7 are as follows:

Unburnt carbon loss

$$L_1 = \frac{0.006192 \times 8077.8 kj/kg \times 100}{4000 \, kj/kg}$$

$$\text{heat loss due to Unburnt Carbon} = 1.2504\%$$

Dry flue gas loss

$$L_2 = \frac{6.81 \times 0.23 \times (140 - 32) \times 100}{4000}$$

$$\text{heat loss due to dry flue gases} = 4.2298\%$$

Loss due to moisture in fuel

$$L_3 = \frac{0.15 \times [584 + 0.23(140 - 32)]}{4000} \times 100$$

$$\text{Heat loss due to the Mositure in fuel} = 2.2831\%$$

Loss due to hydrogen in fuel

$$L_4 = \frac{9 \times 2.84 \times 584 + 0.23(140 - 32)}{4000} \times 100$$

$$\text{Heat loss due to hydrogen in fuel} = 3.8905\%$$

Loss due to moisture in air

$$L_5 = \frac{6.8521 \times 0.0204 \times 0.43(140 - 32) \times 100}{4000}$$

$$\text{Heat loss due to moisture in air} = 0.1698\%$$

Loss due to radiation

$$L_6 = 0.548 \times \left[\left(\frac{352}{55.55} \right)^4 - \left(\frac{305}{55.55} \right)^4 \right] + 1.957 \times (352 - 305)^{1.25} \sqrt{\frac{196.85 \times 3.5 + 68.9}{68.9}}$$

$$\text{heat loss due to Radition} = 0.1909\%$$

Heat loss due to unmeasured loss in boiler

$L_7 = 0.8700$

Total losses= 1.2504+4.2298+2.2831+3.8905+0.1698+0.1909+0.8700

= 12.8845%

Boiler efficiency = 100 -12.8845%

= 87.1155%

The results for the exergy analysis of boiler carried out by using equation 8, 9, 10, 11, 12, 13 and 14 are as follows:

Exergy of fuel

$$\varepsilon_f = 34183.16 \times 0.4058 + 21.95 \times 0.0076 + 11659.9 \times 0.0284 + 18242.90 \times 0.0035 + 13265.9 \times 0.0711$$

$$\varepsilon_f = 15209.89 kj/kg$$

$$\text{Total Exergy of fuel} = 591.36\text{MW}$$

Exergy of feed water

$$\varepsilon_\omega = 4.178\left[(519-305) - 305 \times l_n \left(519/305\right)\right]$$

$$\varepsilon_\omega = 216.68 kj/kg$$

$$\text{Total exergy of feed water} = 44.588\text{MW}$$

Exergy of air supply

$$\varepsilon_a = 1.005\left[(413-305) - 305 l_n \left(413/305\right)\right]$$

$$\varepsilon_a = 15.6169 kj/kg$$

$$\text{Total exergy of air supplieded} = 3.6851\text{MW}$$

$$\varepsilon_s = (3416.57 - 113.295) - 305\,(6.4906 - 0.395)$$

$$\varepsilon_s = 1444.117 kj/kg$$

$$\text{Total exergy of steam} = 297.156 MW$$

Exergy of flue gas

$$\varepsilon_g = 1.321\left[(413-305) - 305 l_n \left(413/305\right)\right]$$

$$\varepsilon_g = 20.533 kj/kg$$

$$\text{Total exergy of flue gas} = 6.2739\text{MW}$$

Exergy efficiency (2^{nd} law efficiency) of boiler

$$\eta_{II} = \frac{\text{total exergy leaving the boiler}}{\text{total exergy entering the boiler}}$$

$$\eta_{II} = \frac{303.4299}{639.6339} = 0.4743$$

Exergy efficiency of boiler= 47.43%

Table 19 comparesion of energy and exergy analysis of boiler

Result		
1	Energy	87.11%
2	Exergy	47.43%

B. Results for the energy and exergy analysis of turbine

The results for the energy analysis of turbine by using equation 15, 16, 17 and 18 are as follows:

1) Energy efficiency of HP Turbine

$$\eta_1 = \frac{3416.57 - 3080.8621}{3416.57 - 3028.5129}$$

$$\text{EnergyefficiencyHPT}(\eta_1) = 86.50\%$$

2) Energy efficiency of IP Turbine

$$\eta_1 = \frac{3530.17 - 3051.92}{3530.17 - 3003.01}$$

$$\text{Energy efficiency of IPT}(\eta_1) = 90.72\%$$

3) *Energy efficiency of LP Turbine*

$$\eta_1 = \frac{3051.92 - 2585.23}{3051.92 - 2314.7571}$$

$$\text{Energy efficiency of LPT}(\eta_1) = 63.30\%$$

Table 20 Comparison of Energy analysis of different components of turbine

Sr. No.	Components	Value
1.	High Pressure Turbine(HPT)	86.50%
2.	Intermediate Pressure Turbine(IPT)	90.72%
3.	Low Pressure Turbine (LPT)	63.30%

The energy efficiency of total turbine is given by the

$$\eta_T = 0.8650 \times 0.9072 \times 0.6330$$

$$\text{Total energy efficency of turbine}(\eta_T) = 49.63\%$$

The results for the exergy analysis of turbine by using equation 19, 20, 21, 22, 23, 25, 26, 27 and 28 are as follows:

a) *Exergy efficiency of HP Turbine*

$$\eta_{II} = 1 - \frac{300 \times (6.2397 - 6.0956)}{(1474.598 - 1132.206)}$$

$$\text{Exergy efficiency of HPT}(\eta_{II}) = 87.16\%$$

b) *Exergy efficiency IP Turbine*

$$\eta_{II} = 1 - \frac{300 \times (6.9043 - 6.8166)}{(1371.898 - 867.343)}$$

$$\text{Exergy efficiency of IPT}(\eta_{II}) = 94.69\%$$

c) *Exergy efficiency of LP Turbine*

Formula used for

$$\eta_{II} = 1 - \frac{300 \times (6.9043 - 7.7516)}{(867.343 - 146.458)}$$

$$\text{Exergy efficiency of LPT}(\eta_{II}) = 64.15\%$$

Table 21.Exergy efficiency of different components of turbine

Sr. No.	Components	Value
1.	High Pressure Turbine(HPT)	87.16%
2.	Intermediate Pressure Turbine(IPT)	94.69%
3.	Low Pressure Turbine (LPT)	64.15%

$$\eta_T = 0.8716 \times 0.9469 \times 0.6415$$

$$\text{Total energy efficency of turbine}(\eta_T) = 52.33\%$$

Table 22. Comparison energy and exergy analysis of turbine

RESULTS		
1	Energy	49.63%
2	Exergy	52.33%

C. Results for the energy and exergy analysis of condenser

The results for the energy analysis of condenser can be calculated by using equation 29, 30 and 31 are as follows:

$$\eta_1 = \frac{32000 \times 4.178 \times (315.2 - 309)}{589.60(2586.4016 - 192.57)}$$

$$\text{Energy efficiency of condenser } (\eta_1) = 59.67\%$$

The results for the exergy analysis of condenser calculated by using equation 32, 33 and 34 are as follows:

$$\eta_{II} = \frac{32000 \times 4.178 \times (315.2 - 30)\left(1 - \frac{30}{315.2}\right)}{589.60\,(95.23 - 7.03)}$$

Exergy efficiency of condenser =32.40%

Table 23. Comparison of Energy and exergy analysis of condenser

Result		
1.	Energy	58.89%
2.	Exergy	34.69%

D. Results for the energy and exergy analysis of pump

The results for the energy analysis of pump by using equation 35 are as follows:

$$\eta_p = \frac{194.5306 - 192.5741}{194.6527 - 192.5305}$$

$$\eta_p = 94.56\%$$

The results for the exergy analysis of pump by using equation 36 are as follows:

$$\eta_{II} = 1 - \frac{305(0.6522 - 0.6516)}{194.6522 - 192.5741}$$

$$\eta_{II} = 91.19\%$$

Table 24. Comparison of energy and exergy analysis of CEP pump

Result		
1.	Energy	94.56 %
2.	Exergy	91.19%

IV. CONCLUSION

This study presents the energy and exergy analysis of 250 MW Panipat coal thermal power plant. The temperature and pressure of main stream and the condenser pressure are considered as operating parameters. From the study it is observed that the major contribution of energy efficiency is found in pump of 94.56% followed boiler of about 87.11% and condenser of 59.67%. The major exergy efficiency is found in the pump of 91.19% followed by turbine of 52.33% and condenser of 32.40% of the total exergy supplied.

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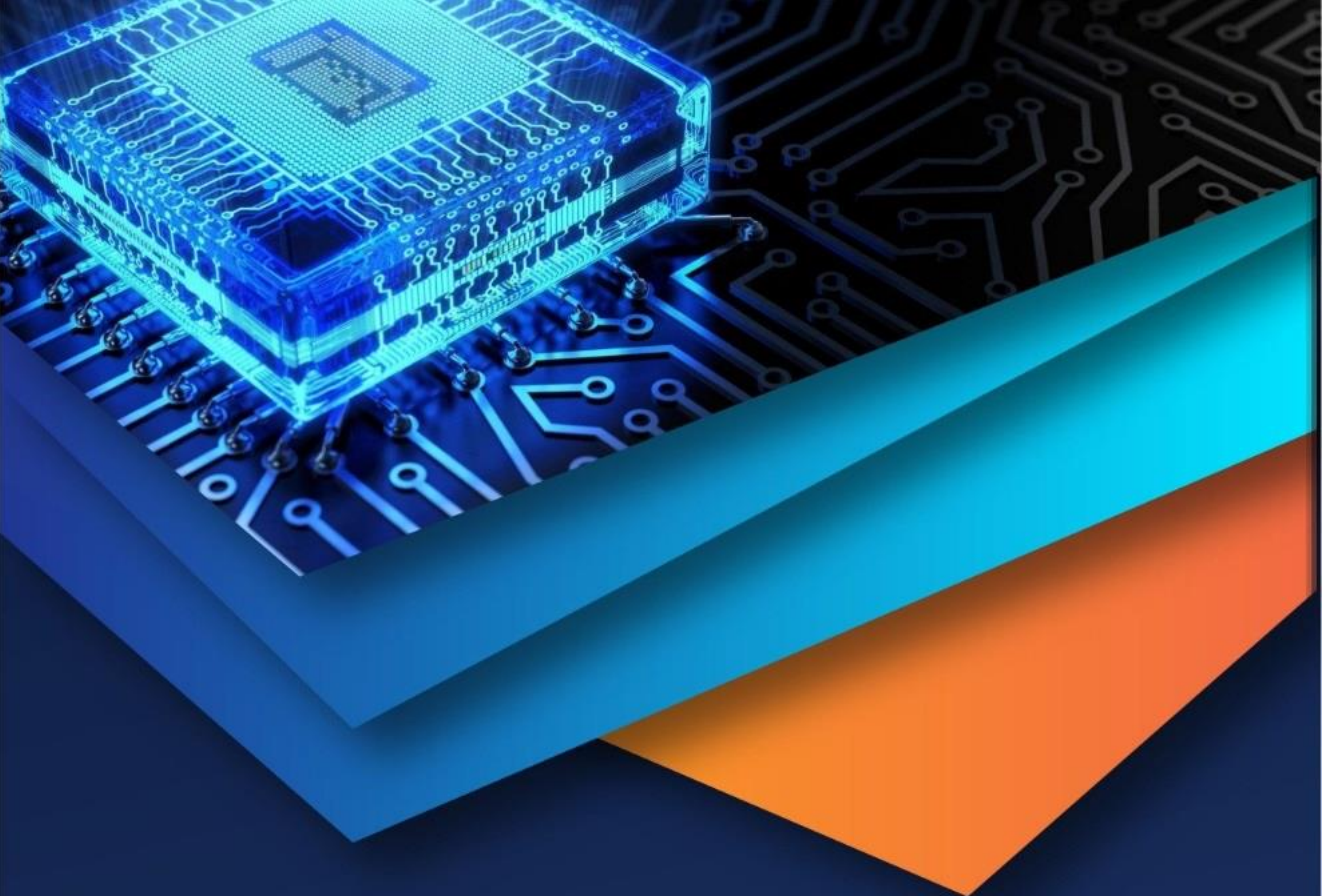

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