Energy, Exergy, and Losses in Components of a Coal Thermal Power Plant

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***Abstract*: In this work, energy and exergy are investigated of a 600 MW coal thermal power plant on working load condition. The research is done on a load of nearly 94.3% of the design load with constant pressures and temperatures corresponding to various components and does not change with variation in load. This research aims to explore various components of plant thermodynamically and to know how efficiently they are working on a load lower than design load and also on the varying quality of coal used. After calculations, I found that the main energy losses happen in the condenser, boiler, and deaerator but condenser has the highest loss with 71.98 % to 74% of total energy loss. The variation in energy loss ratio in the condenser is because of the quality of fuel used. The Boiler feed pump and condensate extraction pump show minimum energy loss. Boiler, condenser, turbines, and deaerator show high exergy losses, but boiler having the maximum exergy loss with 61.98 % to 60.12 % of the total exergy loss. The Condenser is also having a high amount of exergy loss but the exergy available in the condenser is low grade because of low temperature, so we focus on minimizing high-quality exergy losses which are in boiler and turbines and hence increase in exergetic efficiency of corresponding and the whole plant. Boiler feed pump and condensate extraction pump show minimum exergy loss. This study helps in finding the components which are responsible for lowering the efficiency of the plant.**

***Keywords*: Energy, Energy loss, Energetic efficiency, Enthalpy, exergy, Exergy loss, Exergetic efficiency, Power plant.**

1. Introduction

In this modern world when human is surrounded by machines, it becomes necessities that electricity must be available for continuous functioning of machines.

Due to an increase in industrialization, urbanization, and technology with an increasing population, energy consumption is increasing day by day in every country. To fulfill this demand, one needs to install electricity generation plants. At present, total install capacity (as on 30/05/2020) of India is 370348 MW out of which coal-based plants have 198525 MW [1]. Currently, India is producing 53.6 % of its electricity by coal-based thermal power plants [1]. This shows that coal thermal power plants are the backbone of India’s power generation industry.

Electricity is one form of energy that we get from another form of energy by conversion through a mechanism. This energy conversion follows some principles, and the very basic one is the first law of thermodynamics [2] which deals with energy and the first law efficiency of any physical system. The next law we have is the second law of thermodynamics, in which quality of energy (exergy) and entropy is the main concern [2]. For the thermodynamic development of any machine, energy and exergy both are important and should be considered for the improvement of a thermal system.

The coal-based power station under our observation is the Rajiv Gandhi thermal power plant, khedar located near Hisar city of Haryana (India). This plant has two units of each 600 MW. The project approved on 31st December 2005 and commissioned Unit-I on 24th august 2010 and Unit-II on 1st march 2011[3]. This is the best economical plant whose electricity production cost Rs. 3.19 crore per megawatt which is lowest in coal thermal power plants in India [3].

2. Abbreviations

HPT – High pressure turbine
IPT – Intermediate pressure turbine
LPT – Low pressure turbine
Con. - Condenser
CEP – Condensate extraction pump
Dea. – Deaerator
HPH – High pressure heater
BFP – Boiler feed pump
LPH – Low pressure heater
Eco. – Economizer
BD – Boiler drum
SH – Superheater
RH – Reheater
WC - worst coal
PC – Performance coal
L1 – Low pressure heater 1
L2 – Low pressure heater 2
L3 – Low pressure heater 3
H5 – High pressure heater 5

H6 – High pressure heater 6
H7 – High pressure heater 7
$Ö_a$ - Heat added
$Ö_r$ - Heat removed
T – Temperature
P – Pressure
$\dot{E}_{loss}$ - Energy loss
h – Specific enthalpy
s – Specific entropy
$\dot{m}_f$ - mass flow rate of water/steam
h_0 - ambient specific enthalpy
s_0 – ambient Specific entropy
Ψ – specific exergy
Ψ_0 - ambient specific exergy
η_1 - first law efficiency or energetic efficiency
η_2 - second law efficiency or exergetic efficiency
$\dot{m}_a$ - mass flow rate of air
$\dot{m}_w$ - mass of cooling water flow through condenser and cooling tower only
$\dot{m}_n$ - mass flow rate of water/steam through point n
$\eta_{1,x}$ - first law efficiency or energetic efficiency of component X
$\eta_{2,y}$ - second law efficiency or exergetic efficiency of component Y
h_{1s} – isentropic specific enthalpy at point 1.

3. Mathematical Formulae

A flowing fluid have four types of energy associated with that i.e. Kinetic energy, Potential energy, Internal energy & boundary work [4].

specific energy = u + Pv + $v^2/2$ + gz

As, specific enthalpy (h) = u + pv

Hence, specific energy = h + $v^2/2$ + gz if kinetic and potential energies are very less as compare to specific enthalpy then it can be neglected and specific energy can be represented only by specific enthalpy.

specific energy = h

If in a system the fluid is flowing then the energy difference will be -

Energy Difference = m $(h_f - h_i)$

Where,

h_f = specific energy at outlet

h_i = specific energy at inlet

If the above system is a turbine then the energy difference is the actual work produced. i.e.

$$W_{turbine} = m\,(h_f - h_i)$$

The energetic efficiency of a heat exchanger is proportion of energy used for heating to the total energy available. The energetic efficiency of a power consuming system is the the proportion of enthalpy differences across the system to the work provided to operate the system.

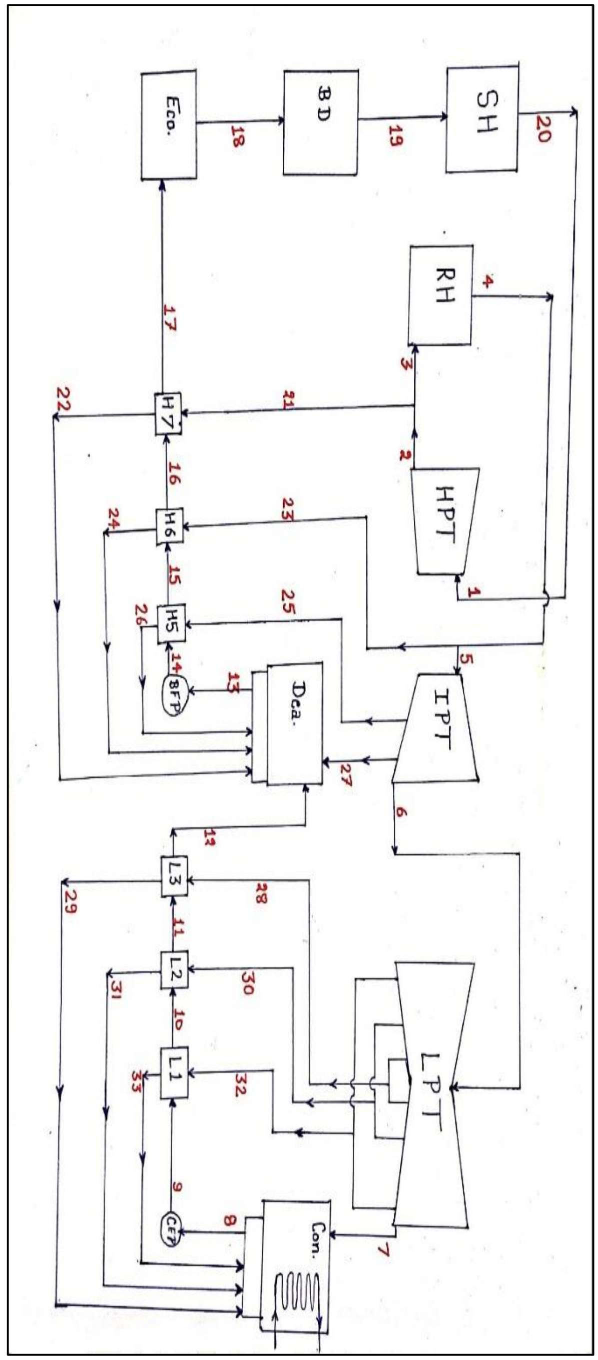

Fig. 1. Diagram of components of power plants under consideration

Exergy: It is the highest amount of useful work obtainable until the system attains the dead situation with the environment. It is represented by (Ψ). Total exergy of a system has four main exergies i.e.

Physical exergy (Ψ_{PH}), Chemical exergy (Ψ_{CH}), Potential exergy (Ψ_{PT}) and Kinetic exergy (Ψ_{KN}),

$$\Psi_{TOTAL} = \Psi_{PH} + \Psi_{CH} + \Psi_{PT} + \Psi_{KN}$$

If chemical, potential & kinetic exergies are negligible as

Table 1
Characteristics table at various point of power plant

Serial no.	$\dot{m}_f$		P (bar)	T (^{0}c)	h (kJ/kg)	S (kJ/kg-K)	Ψ (kJ/kg)
	TPH	kg/sec					
1	1948	541.11	166.71	537	3396.1137	6.4127	1441.6949
2	1948	541.11	37.5	322	3028.6315	6.5054	1045.8465
2s	1948	541.11	37.5	309.1477	2994.8711	6.4127	1029.6
3	1808.316	502.31	36.48	320	3026.3345	6.5132	1041.1627
4	1808.316	502.31	34.617	540	3542.5742	7.2787	1323.1594
5	1676.556	465.71	32.4	537	3537.9369	7.3031	1311.0557
6	1535.148	426.43	8.39	354	3169.8054	7.4011	912.9362
6s	1535.148	426.43	8.39	333.1689	3125.9111	7.3031	890.7985
7	1240.2	344.5	0.47	85	2653.0957	7.6434	322.0827
7s Wet Steam	1240.2	344.5	0.47	79.78	2567.512	7.4011	310.6428
8	1535.148	426.43	0.4	60	251.17	0.8312	4.6902
9	1535.148	426.43	31.4	60.2	254.6	0.8321	7.8448
10	1535.148	426.43	30.6	99.48	419.1336	1.2988	29.5682
11	1535.148	426.43	29.8	134.49	567.3594	1.6792	61.3916
12	1535.148	426.43	29.0	168.79	715.0858	2.0273	102.5994
13	1948	541.11	12.0	178.9	758.4446	2.1286	114.9604
14	1948	541.11	201.54	179.2	769.7779	2.1067	132.9951
15	1948	541.11	200.74	207.5	893.5242	2.3723	175.4678
16	1948	541.11	199.94	243.1	1054.4572	2.6954	237.5322
17	1948	541.11	199.2	275	1206.5133	2.9813	302.1029
18	1948	541.11	195.57	314	1411.3370	3.3428	396.3076
19	1948	541.11	188.48	365	2560.0366	5.1750	984.354
20	1948	541.11	173.28	540	3397.1817	6.3983	1447.1693
21	139.68	38.8	36.6	316	3015.6334	6.4937	1036.4286
22	139.68	38.8	36.0	170.7	723.8	2.0452	105.8362
23	131.76	36.6	28.4	524	3512.6386	7.3312	1277.1588
24	131.76	36.6	27.8	216.6	928.14	2.4852	175.5362
25	97.92	27.2	22.2	485	3432.4659	7.3396	1194.4157
25s	97.92	27.2	22.2	473.8931	3407.9061	7.3069	1179.8621
26	97.92	27.2	21.6	195.2	831.14	2.2842	140.0422
27	43.488	12.08	12.24	396	3252.2328	7.3568	1008.9194
27s	43.488	12.08	12.24	384.3296	3227.2261	7.3191	995.4489
28	91.944	25.54	5.58	305	3073.4968	7.4269	808.7328
28s	91.944	25.54	5.58	298.4232	3059.8572	7.4032	802.3454
29	91.944	25.54	5.28	112	470.105	1.44	37.3324
30	100.872	28.02	1.27	170.70	2816	7.5962	499.4302
30s	100.872	28.02	1.27	135.00	2744.387	7.4279	479.3170
31	100.872	28.02	0.97	62.8	262.9326	0.8662	5.7428
32	102.132	28.37	0.732	112	2703.4304	7.5762	392.9806
32s wet steam	102.132	28.37	0.732	91.11	2638.4988	7.4011	381.6296
33	102.132	28.37	0.53	47.5	198.92	0.6713	1.3696

compare to physical exergy then,

$$\Psi_{TOTAL} = \Psi_{PH}$$

exergy can be transferred through three modes i.e. mass, heat, and work.

1. exergy transfer by mass –

$$\Psi = m\,[(h - h_0) + T_0(s - s_o)]$$

2. exergy shifting by heat –

$$\Psi = Q\,[1 - T_0/T]$$

3. Exergy transfer by work –

$$\Psi = W_{total} - W_{loss}$$

The exergetic efficiency of a heat exchanger is the ratio of exergy used to the total exergy difference across the system.

The energetic efficiency of a power-consuming system is the ratio of exergy differences across the system to the work provided to operate the system.

4. Results and Discussion

The energetic and exergetic efficiencies of various components are calculated below,

A. High pressure turbine

$$\eta_{adiabatic,\,HPT} = \frac{Actual\ work\ output}{isentropic\ or\ ideal\ work\ output} = \frac{\dot{m}_1(h_1-h_2)}{\dot{m}_1(h_1-h_{2s})} = \frac{367.4822}{401.2426} = 91.59\ \%$$

$$\eta_{2,\,HPT} = \frac{Actual\ exergy\ output}{isentropic\ or\ ideal\ exergy\ output} = \frac{\dot{m}_1(\Psi_1-\Psi_2)}{\dot{m}_1(\Psi_1-\Psi_{2s})} = \frac{395.8484}{412.0949} = 96.06\ \%$$

B. Intermediate pressure turbine

$$\eta_{adiabatic,\ IPT} = \frac{Actual\ work\ output}{isentropic\ or\ ideal\ work\ output}$$

$$\eta_{adiabatic,\ IPT} = \frac{\dot{m}_5(h_5-h_{25})+(\dot{m}_5-\dot{m}_{25})(h_{25}-h_{27})+(\dot{m}_5-\dot{m}_{25}-\dot{m}_{27})(h_{27}-h_6)}{\dot{m}_5(h_5-h_{25s})+(\dot{m}_5-\dot{m}_{25})(h_{25s}-h_{27s})+(\dot{m}_5-\dot{m}_{25}-\dot{m}_{27})(h_{27s}-h_{6s})}$$

$$\eta_{adiabatic,\ IPT} = \frac{163302.43}{182990.39} = 89.24\ \%$$

$$\eta_{2,\ IPT} = \frac{Actual\ exergy\ output}{isentropic\ or\ ideal\ exergy\ output}$$

$$\eta_{2,\ IPT} = \frac{\dot{m}_5(\Psi_5-\Psi_{25})+(\dot{m}_5-\dot{m}_{25})(\Psi_{25}-\Psi_{27})+(\dot{m}_5-\dot{m}_{25}-\dot{m}_{27})(\Psi_{27}-\Psi_6)}{\dot{m}_5(\Psi_5-\Psi_{25s})+(\dot{m}_5-\dot{m}_{25})(\Psi_{25s}-\Psi_{27s})+(\dot{m}_5-\dot{m}_{25}-\dot{m}_{27})(\Psi_{27s}-\Psi_{6s})}$$

$$\eta_{2,\ IPT} = \frac{176592.5}{186591.3} = 94.64\ \%$$

C. Low pressure turbine

$$\eta_{adiabatic,\ LPT} = \frac{Actual\ work\ output}{isentropic\ or\ ideal\ work\ output}$$

$$\eta_{adiabatic,\ LPT} = \frac{\dot{m}_6(h_6-h_{28})+(\dot{m}_6-\dot{m}_{28})(h_{28}-h_{30})+(\dot{m}_6-\dot{m}_{28}-\dot{m}_{30})(h_{30}-h_{32})+\dot{m}_7(h_{32}-h_7)}{\dot{m}_6(h_6-h_{28s})+(\dot{m}_6-\dot{m}_{28})(h_{28s}-h_{30s})+(\dot{m}_6-\dot{m}_{28}-\dot{m}_{30})(h_{30s}-h_{32s})+\dot{m}_7(h_{32s}-h_{7s})}$$

$$\eta_{adiabatic,\ LPT} = \frac{203610.9}{237291.54} = 85.81\ \%$$

$$\eta_{2,\ LPT} = \frac{Actual\ exergy\ output}{isentropic\ or\ ideal\ exergy\ output}$$

$$\eta_{2,\ LPT} = \frac{\dot{m}_6(\Psi_6-\Psi_{28})+(\dot{m}_6-\dot{m}_{28})(\Psi_{28}-\Psi_{30})+(\dot{m}_6-\dot{m}_{28}-\dot{m}_{30})(\Psi_{30}-\Psi_{32})+\dot{m}_7(\Psi_{32}-\Psi_7)}{\dot{m}_6(\Psi_6-\Psi_{28s})+(\dot{m}_6-\dot{m}_{28})(\Psi_{28s}-\Psi_{30s})+(\dot{m}_6-\dot{m}_{28}-\dot{m}_{30})(\Psi_{30s}-\Psi_{32s})+\dot{m}_7(\Psi_{32s}-\Psi_{7s})}$$

$$\eta_{2,\ LPT} = \frac{232547.96}{237537.74} = 97.9\ \%$$

D. Deaerator

$$\eta_{1,\ Dea.} = \frac{\dot{m}_{13}h_{13}}{\dot{m}_{12}h_{12} + \dot{m}_{22}h_{22} + \dot{m}_{24}h_{24} + \dot{m}_{26}h_{26} + \dot{m}_{27}h_{27}} = \frac{410401.9575}{510058.74} = 80.46\ \%$$

$$\eta_{2,\ Dea.} = \frac{\dot{m}_{13}\Psi_{13}}{\dot{m}_{12}\Psi_{12} + \dot{m}_{22}\Psi_{22} + \dot{m}_{24}\Psi_{24} + \dot{m}_{26}\Psi_{26} + \dot{m}_{27}\Psi_{27}}$$

$$= \frac{62206.222}{85550.87} = 72.71\ \%$$

E. Boiler

$$\eta_{1,\ B,\ PC} = \frac{\dot{m}_{20}(h_{20}-h_{17}) + \dot{m}_3(h_4-h_3)}{(Q_a)_{PC}} = \frac{1444704.94163}{1583162{,}5778}$$

$= 91.25\ \%$

$$\eta_{1,\ B,\ WC} = \frac{\dot{m}_{20}(h_{20}-h_{17}) + \dot{m}_3(h_4-h_3)}{(Q_a)_{WC}} = \frac{1444704.94163}{1612631.77}$$

$= 89.59\ \%$

$$\eta_{2,\ B,\ PC} = \frac{\dot{m}_{20}(\Psi_{20}-\Psi_{17}) + \dot{m}_3(\Psi_4-\Psi_3)}{\left[Q_a\left\{1-\frac{T_0}{T_B}\right\}\right]_{PC}} = \frac{761256.642081}{987285.888}$$

$= 77.11\ \%$

$$\eta_{2,\ B,\ WC} = \frac{\dot{m}_{20}(\Psi_{20}-\Psi_{17}) + \dot{m}_3(\Psi_4-\Psi_3)}{[Q_a\left\{1-\frac{T_0}{T_B}\right\}]_{WC}} = \frac{761256.642081}{1005663.35628}$$

$= 75.7\ \%$

If Air preheater is considered inside Rankine cycle then energetic and exergetic efficiencies of boiler becomes,

$$\eta_{1,B,PC} = \frac{\dot{m}_4(h_4 - h_3) + [\{\dot{m}_a C_p (T_f - T_i)\}_{Air}]_{P+S} + \dot{m}_{20}(h_{20} - h_{17})}{[\text{Ö}_a]_{PC} + [\{\dot{m}_a C_p (T_f - T_i)\}_{Air}]_{P+S}}$$

{Because, $[\{\dot{m}_a C_p (T_f - T_i)\}_{Air}]_{P+S}$
= 53927.20555 + 130213.33 = 184140.5389}

$$\eta_{1,B,PC} = \frac{502.31(516.2397)+541.11(2190.6684)+184140.54}{1583162.5778+184140.54}$$

$= 92.1656\ \%$

$$\eta_{1,B,WC} = \frac{\dot{m}_4(h_4 - h_3) + [\{\dot{m}_a C_p (T_f - T_i)\}_{Air}]_{P+S} + \dot{m}_{20}(h_{20} - h_{17})}{[\text{Ö}_a]_{WC} + [\{\dot{m}_a C_p (T_f - T_i)\}_{Air}]_{P+S}}$$

$$\eta_{1,B,WC} = \frac{502.31(516.2397)+541.11(2190.6684)+184140.54}{1796772.3089} = 90.65\ \%$$

$$\eta_{2,\ B,\ PC} = \frac{\dot{m}_{20}(\Psi_{20}-\Psi_{17}) + \dot{m}_3(\Psi_4-\Psi_3)+[\{\dot{m}_a C_p (T_f-T_i)\}_{Air}]_{P+S}\left[T_0\left\{\frac{1}{T_i}-\frac{1}{T_f}\right\}\right]}{[Q_a\left\{1-\frac{T_0}{T_B}\right\}]_{PC}+[\{\dot{m}_a C_p (T_f-T_i)\}_{Air}]_{P+S}\left[T_0\left\{\frac{1}{T_i}-\frac{1}{T_f}\right\}\right]}$$

$$\eta_{2,\ B,\ PC} = \frac{541.11(1145.0664) + 502.31(281.9967) + 87405.807}{987285.888 + 87405.807}$$

$= 78.97\ \%$

$$\eta_{2,\ B,\ WC} = \frac{\dot{m}_{20}(\Psi_{20}-\Psi_{17})+\dot{m}_3(\Psi_4-\Psi_3)+[\{\dot{m}_a C_p (T_f-T_i)\}_{Air}]_{P+S}\left[T_0\left\{\frac{1}{T_i}-\frac{1}{T_f}\right\}\right]}{[Q_a\left\{1-\frac{T_0}{T_B}\right\}]_{WC}+[\{\dot{m}_a C_p (T_f-T_i)\}_{Air}]_{P+S}\left[T_0\left\{\frac{1}{T_i}-\frac{1}{T_f}\right\}\right]}$$

$$\eta_{2,\ B,\ WC} = \frac{541.11(1145.0664) + 502.31(281.9967) + 87405.807}{1005663.35628 + 87405.807}$$

$= 77.64\ \%$

By comparing the first law and second law efficiencies of the boiler without air-preheater and with air-preheater, it can be seen that efficiencies have increased by using air- preheater. The energetic efficiency is increased by 0.91% and 1.06% when using performance coal and the worst coal respectively. The exergetic efficiency is increased by 1.86% and 1.94% when using performance coal and worst coal respectively.

F. Condenser

$$\eta_{1,\ Con.} = \frac{\text{Ö}r}{\dot{m}_7h_7 + \dot{m}_{29}h_{29} + \dot{m}_{31}h_{31} + \dot{m}_{33}h_{33} - \dot{m}_8h_8}$$

$$= \frac{776721.52}{831902.26} = 93.37\ \%$$

$$\eta_{2,\ Con.} = \frac{\text{Ö}r\left\{1-\frac{T_0}{T_B}\right\}}{\dot{m}_7\Psi_7+\dot{m}_{29}\Psi_{29}+\dot{m}_{31}\Psi_{31}+\dot{m}_{33}\Psi_{33}-\dot{m}_8\Psi_8} = \frac{24103.454}{110110.68}$$

$= 21.89\ \%$

G. Condensate extraction pump

$$\eta_{1,\ CEP} = \frac{\dot{m}_9h_9-\dot{m}_8h_8}{\dot{W}_{CEP}} = \frac{1462.65}{1600} = 91.42\ \%$$

$$\eta_{2,\ CEP} = \frac{\dot{m}_9\Psi_9-\dot{m}_8\Psi_8}{\dot{W}_{CEP}} = \frac{1345.216}{1600} = 84.08\ \%$$

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H. Boiler feed pump

$$\eta_{1,\,BFP} = \frac{\dot{m}_{14}h_{14} - \dot{m}_{13}h_{13}}{\dot{W}_{BFP}} = \frac{6132.561963}{10100} = 61.42\ \%$$

$$\eta_{2,\,BFP} = \frac{\dot{m}_{14}\Psi_{14} - \dot{m}_{13}\Psi_{13}}{\dot{W}_{BFP}} = \frac{9758.756517}{10100} = 96.62\ \%$$

I. Low pressure heater and High pressure heater

$$\eta_{1,\,L1} = \frac{\dot{m}_{10}(h_{10} - h_9)}{\dot{m}_{32}(h_{32} - h_{33})} = \frac{70162.063}{71052.96} = 98.75\ \%$$

$$\eta_{1,\,L2} = \frac{\dot{m}_{11}(h_{11} - h_{10})}{\dot{m}_{30}(h_{30} - h_{31})} = \frac{63207.93}{71536.95} = 88.36\ \%$$

$$\eta_{1,\,L3} = \frac{\dot{m}_{12}(h_{12} - h_{11})}{\dot{m}_{28}(h_{28} - h_{29})} = \frac{62994.97}{66490.63} = 94.74\ \%$$

$$\eta_{1,\,H5} = \frac{\dot{m}_{15}(h_{15} - h_{14})}{\dot{m}_{25}(h_{25} - h_{26})} = \frac{66960.36}{70756.06} = 94.63\ \%$$

$$\eta_{1,\,H6} = \frac{\dot{m}_{16}(h_{16} - h_{15})}{\dot{m}_{23}(h_{23} - h_{24})} = \frac{87082.45}{94592.65} = 92.06\ \%$$

$$\eta_{1,\,H7} = \frac{\dot{m}_{17}(h_{17} - h_{16})}{\dot{m}_{21}(h_{21} - h_{22})} = \frac{82279.076}{88923.136} = 92.53\ \%$$

$$\eta_{2,\,L1} = \frac{\dot{m}_{10}(\Psi_{10} - \Psi_9)}{\dot{m}_{32}(\Psi_{32} - \Psi_{33})} = \frac{9263.51}{11110.00407} = 83.38\ \%$$

$$\eta_{2,\,L2} = \frac{\dot{m}_{11}(\Psi_{11} - \Psi_{10})}{\dot{m}_{30}(\Psi_{30} - \Psi_{31})} = \frac{13570.45}{13833.121} = 98.10\ \%$$

$$\eta_{2,\,L3} = \frac{\dot{m}_{12}(\Psi_{12} - \Psi_{11})}{\dot{m}_{28}(\Psi_{28} - \Psi_{29})} = \frac{17572.24}{19701.57} = 89.19\ \%$$

$$\eta_{2,\,H5} = \frac{\dot{m}_{15}(\Psi_{15} - \Psi_{14})}{\dot{m}_{25}(\Psi_{25} - \Psi_{26})} = \frac{22981.98}{28678.96} = 80.13\ \%$$

$$\eta_{2,\,H6} = \frac{\dot{m}_{16}(\Psi_{16} - \Psi_{15})}{\dot{m}_{23}(\Psi_{23} - \Psi_{24})} = \frac{33583.67}{40319.30} = 83.29\ \%$$

$$\eta_{2,\,H7} = \frac{\dot{m}_{17}(\Psi_{17} - \Psi_{16})}{\dot{m}_{21}(\Psi_{21} - \Psi_{22})} = \frac{34939.85}{36106.98} = 96.77\ \%$$

J. Overall plant

$$\eta_{1,\,OVERALL,\,PC} = \frac{\dot{W}_{Turbines} - \dot{W}_{Pumps}}{(Q_a)_{PC}} = \frac{554061.62}{1583162.5778} = 35\%$$

$$\eta_{1,\,OVERALL,\,WC} = \frac{\dot{W}_{Turbines} - \dot{W}_{Pumps}}{(Q_a)_{WC}} = \frac{554061.62}{1612631.7725} = 34.36\ \%$$

The overall plant energetic efficiency increases by nearly 0.64% as we shift to performance coal than the worst coal.

Table 2
Energy and exergy loss table of the components

Components	Energy loss (in kW)	Exergy loss (in kW)
Boiler (worst coal)	167926.83	244406.71
Boiler (performance coal)	138457.64	226029.25
HPT	-	8791.14
IPT	-	9998.76
LPT	-	4489.75
Condenser	776721.52	84854.036
CEP	137.35	254.78
L1	890.897	1846.49
L2	8329.02	262.67
L3	3495.66	2129.33
Deaerator	99656.7825	23344.65
BFP	3967.44	341.24
H5	3795.70	5696.98
H6	7510.2	6735.72
H7	6644.06	1167.13
Overall plant (worst coal)	1079075.4595	394319.41
Overall plant (performance coal)	1049606.2695	375941.95

The main energy loss components include condenser, boiler, and deaerator with at least 96 % of total energy loss but condenser has the highest loss with 71.98 % to 74% of total energy loss. The variation in energy loss ratio in the condenser is due to the quality of fuel feed to the boiler furnace. Afterward low and high pressure heaters and lastly BFP and CEP comes in contribution to energy loss. The energy which is drawn out in condenser is our necessities but the energy which is lost in all other components is not recommended. Boiler, condenser, turbines, and deaerator are the major source of exergy loss with nearly 95 % of total exergy loss. Boiler is responsible for 60.12 % to 61.98 % of exergy loss, which is highest among all. The variation in exergy loss ratio in boiler is due to quality of fuel used. For higher efficiency of plant we must focus on boiler as it destroy largest amount of useful energy. In the exergy loss table, Water heater and pumps count in last. From the above table, it is clear that pumps have minimum energy and exergy loss among all components. The adiabatic and the exergetic efficiencies of all turbines are shown in figure 2.

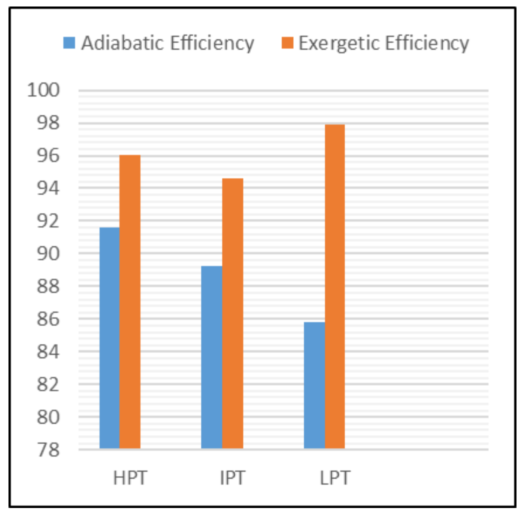

Fig. 2. Comparison of efficiencies of turbines

The above figure indicates that every turbine shows high exergetic efficiency than adiabatic efficiency.

5. Conclusion

- The main exergy losses take place in the boiler, condenser, turbines, and deaerator but in the boiler is the most.
- The main energy losses take place in the condenser, boiler, and deaerator but in the condenser is the most.
- The energy loss in condenser is highest but the quality of energy is very poor on the other hand boiler and turbines have high a quality of energy because of very high temperature and pressure, Hence, these losses must be minimized.
- By using the accessories of the boiler like super-heater, economizer, and air preheater, the efficiency of the boiler as well as the whole plant increases.
- The energy and exergy losses increase when we use the

worst coal. Also, the performance coal gives higher plant efficiency than that of the worst coal.

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