ENERGY AND EXERGY ANALYSIS OF A 250MW COAL FIRED THERMAL POWER PLANT AT DIFFERENT LOADS

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Abstract

In this present investigation exergy and energy efficiencies of a coal fired 250 MW thermal power plant operating in eastern part of India are determined both for 100% and 90% load based on actual operating data. The efficiencies are evaluated for the overall plant as well as for different equipments like boiler, turbine, all feed water heaters and condenser. Similarly effectiveness of the feed water heaters is evaluated for both the loads. Exergy destruction % for each of the equipment are also given for clear understandingof the loss of available energy due to irreversibilities involved in the processes for each equipment and the whole plant.

It is observed that a major irreversibility or, exergy destruction takes place at boiler though 1st law energy efficiency is quite high. This signifies that there might have further scope of improvement in this equipment. Similar analyses are carried out for other equipments. The results obtained in present analysis are compared with those of other investigators.

Keywords: *Energy, Exergy, Efficiency, Effectiveness, Exergy destruction, Power plant*

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1. INTRODUCTION

Exergy or, availability of a system signifies the part of the system energy that can be converted into maximum useful or desired work with respect to immediate surrounding condition, referred to as 'dead state'. The term Exergy was used for the first time by Rant, Z. in 1956. According to 1st law of thermodynamics energy is conserved, but energy is conserved only quantitatively and not qualitatively. But exergy is a manifestation of quality of energy and unlike energy, exergy is not conserved and in fact, get destroyed due to irreversibility during a process. The energy efficiency or, 1st law efficiency merely implies the ratio of desired or, useful work output against total energy input for a system. But this does not consider the true capability of the system by considering the thermodynamic limitations for which the system is not responsible. Efficiency based on exergy for any system like whole thermal power plant or, say, a turbine reflect the true capability of the concerned system i.e., their actual working capability against their maximum possible capability due to irreversibility present in the system process. Thus unlike, energy efficiency, exergy efficiency gives more insight into the problem and help design, analyse and performance improvement of the energy conversion systems more effectively by identifying the locations and associated irreversibilities. A relationship between energy and exergy is pictorially shown in Fig-1.Of late, many researchers are using exergy methodology for analysing different types of energy conversion systems [1– 6] and in fact, some good books are now available in this arena [8 – 10].

In the present investigation, for a 250 MW thermal power plant energy, exergy efficiency and effectiveness of different equipments as well as for the whole plant are determined based on plant operating data at 100% and 90% load. The results for the loads are compared, analysed and discussed. The present results obtained are compared with those of other investigators. It is believed that present investigation will help understanding the possible improvement locations for a power plant as well as will indicate the priority areas of action for better performance and operation of the plant.

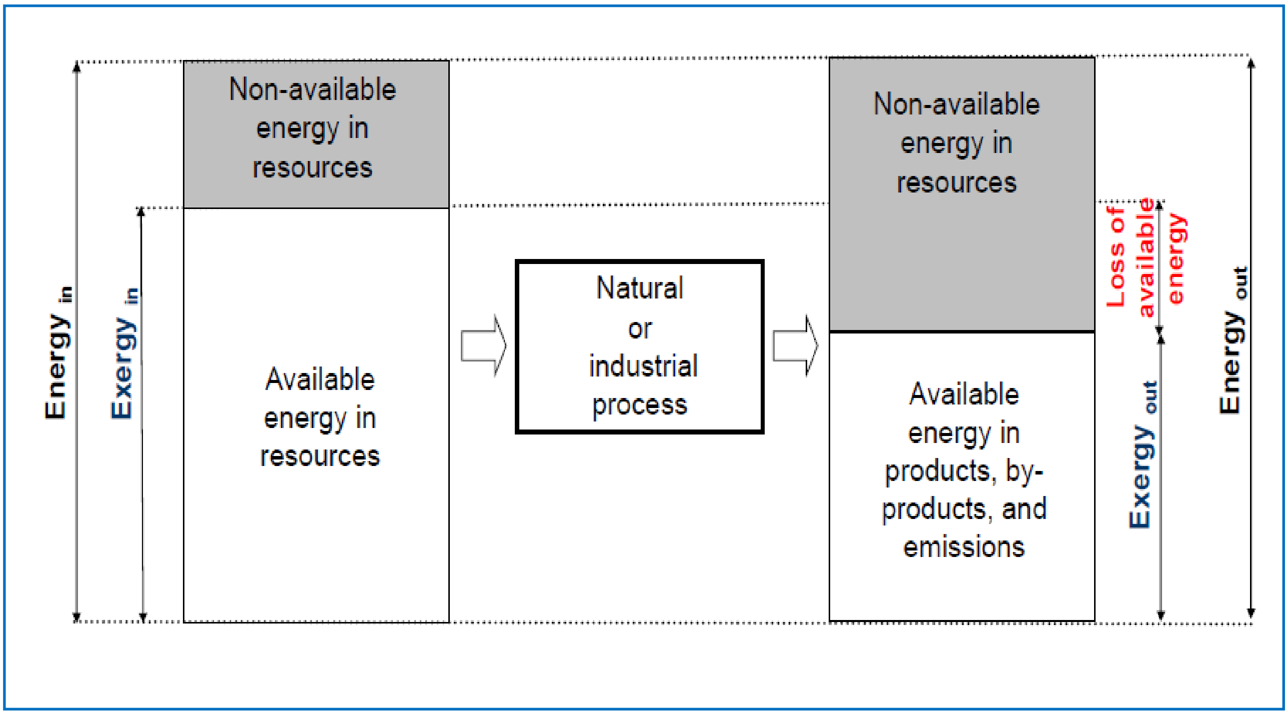

Fig-1: Relationship between Energy and Exergy

2. A BRIEF NOTE ABOUT THE POWER PLANT SELECTED FOR PRESENT ANALYSIS

For the present analysis operating data of a 250 MW thermal power plant located in India are collected. The plant was commissioned about six years back and running smoothly. The plant is based on cornered fired firing technology. The prevailing ambient temperature varies from 0 to 45^{0}C, normal being about 30^{0}C. At the time of collecting data temperature was 30^{0}C. It's a condensing steam plant and like other steam power plant it runs on Rankine cycle. Water from river is chemically treated and demineralised at D.M (Demineralised) plant. Water enters into boiler through economiser and ultimately converted into superheated steam. The superheated steam passes through HP, IP, LP turbines and turbine shafts are coupled with generator to produce electric power. Exhaust two-phase steam from LP turbine then enters into condenser and get condensed by circulating cooling water. The condensate then passes through low pressure (LP) heaters and deaerator. After deaerator by feed pump pressure of the water is raised considering the pressure required for boiler and then water passes through high pressure (HP) feed water heaters and enters into boiler through economiser and the cycle repeats. The LP, HP and deaerator are continuously supplied with bled or, extracted steam from CRH (Cold ReHeat) line, IP and LP turbines at selective points. The details of the plant layout including extraction of steams, heater drips etc. are shown in Fig-2.

The plant normally runs on E-grade coal. The ultimate analysis of operating coal is given by C = 34.20%, H = 5.00%, N = 1.80%, O = 10.70%, M (moisture) = 8.00%, S= 0.30 %. Ash = 40.00% . Coal GCV is 3700 KCal/kg i.e.15490 KJ/kg.

3. REFERENCE OR DEAD STATE

In any exergy analysis proper selection of reference or Dead state is of extreme importance. The exergy value of any system, flow or equipment depends on the reference or Dead state. In our exergy analysis the dead state pressure(p_o)and temperature(T_o)are considered as 1 bar and 303 K i.e., 30^{0}C respectively.In fact, this corresponds to plant operating ambient condition. Dead state enthalpy (h_o) and entropy (s_o) are given by 125.83 KJ/kg and 0.437 KJ/kg-K respectively.

4. FLOW LAYOUT DIAGRAM OF THE POWER PLANT

Total flow layout of the power plant is shown in **Fig.-2**

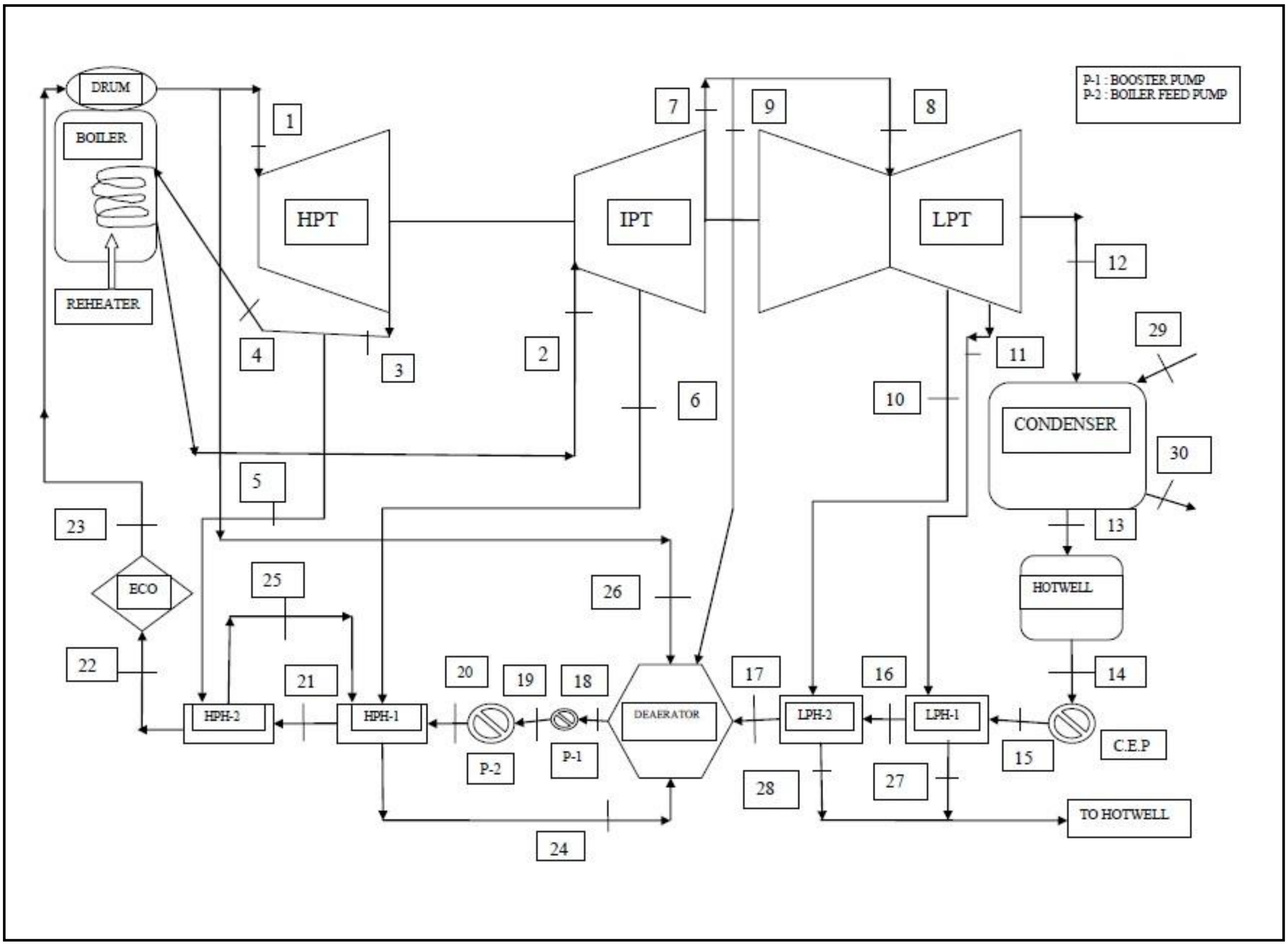

Fig-2: Plant flow layout diagram

5. METHODOLOGY OF ANALYSIS :

In this present investigation following methodology and equations are used to determine energy, exergy efficiencies, and effectiveness of different equipments like boiler, turbine, heaters, and condenser of the plant. We note that all the flow processes through different equipments of the thermal power plant individually and also through the whole power plant are steady and hence no energy or exergy is stored within any system or equipment.

- Mass balance equation :

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \quad (1)$$

- Energy balance equation :

$$\sum_{in} \dot{E}_{in} + \dot{Q} = \sum_{out} \dot{E}_{out} + \dot{W} \quad (2)$$

- General Exergy balance equation :

$$\sum_{in} \dot{m_{in}}\, x_{in} + \sum \dot{X}_Q + \sum \dot{X}_{CH} = \sum_{out} \dot{m_{out}}\, x_{out} + \dot{W} + \dot{X}_{des} \quad (3)$$

- Energy efficiency equation or, 1st Law efficiency :

$$\eta_1 = \frac{\text{Useful i.e.desired energy output}}{\text{Total energy input}} \quad (4)$$

But, for condenser,

$$\eta_1 = \frac{\text{Actual temperature rise of the cold fluid}}{\text{Maximum possible temperature rise of the cold fluid}}$$

For example, overall power plant,

$$\eta_1 = \frac{\text{Total Power output}}{\text{Total Energy supplied by fuel}}$$

❖ Exergy efficiency equation or, 2nd Law efficiency :

$$\eta_2 = \frac{\text{Exergy recovered}}{\text{Total exergy input or,supplied}}$$

or, may be given by,

$$= \frac{\text{Actual thermal efficiency}}{\text{Maximum possible (reversible) thermal efficiency}} \quad (5)$$

❖ Effectiveness (for heaters) :

$$\epsilon = \frac{\text{Actual temperature rise of the cold fluid}}{\text{Maximum possible temperature rise of the cold fluid}} \quad (6)$$

❖ Total exergy flow rate into a control volume or, an equipment is given by :

$$\dot{X}_{in} = \dot{m}_{in} x_{in} \quad (7)$$

Similarly, exergy outlet flow rate can be determined.

❖ Specific exergyis given by :

$$x = (h - h_o) - T_o (s - s_o) \quad (8)$$

6. ENERGY AND EXERGY FLOW RATES THROUGHOUT THE POWER PLANT

In Table-1, at 100% load operating pressure, temperature and flow of the working fluid are given in each node of the plant corresponding to Fig-2. Based on this in the same Table-1, at 100% load corresponding specific enthalpy, specific entropy, total energy flow rate and total exergy flow rate are given. For 90% load corresponding operating parameters are not tabulated here, but all relevant calculations are carried out and results are shown.

Table-1: Operational Data For 100% Load at Each Node Shown in Fig.-2

Node	[Pr, bar]	[Temp, ^{0}C]	[Flow, TPH]	[h, kJ/kg]	[s, kJ/kg-K]	[$\dot{E}$, MW]	[$\dot{X}$, MW]
1	147.00	549.00	785.00	3450.940	6.532	752.497	322.357
2	40.50	549.00	715.00	3557.460	7.226	706.551	273.003
3	41.53	360.00	785.00	3114.730	6.602	679.184	244.420
4	41.53	360.00	715.00	3114.730	6.602	618.620	222.624
5	41.53	360.00	70.00	3114.730	6.602	60.564	21.795
6	20.00	437.00	68.00	3329.510	7.247	62.891	21.538
7	10.00	348.00	647.00	3153.920	7.296	566.830	170.703
8	10.00	348.00	627.20	3153.920	7.296	549.483	165.479
9	10.00	348.00	19.80	3153.920	7.296	17.347	5.224
10	1.82	216.00	30.00	2903.710	7.620	24.198	5.012
11	1.64	120.00	38.00	2709.810	7.226	28.604	5.562
12	0.10	45.800	559.20	2414.000	7.575	374.975	19.472
13	0.10	45.800	559.20	199.660	0.649	31.014	1.490
14	0.10	45.80	635.20	199.660	0.649	35.229	1.693
15	12.00	51.000	635.20	214.540	0.716	37.854	0.736
16	10.00	76.00	635.20	318.940	1.027	56.275	2.530
17	8.00	98.00	635.20	411.200	1.284	72.554	5.069
18	6.00	158.80	795.00	670.500	1.931	148.069	20.314
19	20.00	167.00	795.00	706.790	2.011	156.083	22.975
20	190.00	171.00	795.00	733.740	2.029	162.034	27.722
21	189.00	207.00	795.00	890.810	2.369	196.721	39.658
22	185.00	242.00	795.00	1049.070	2.688	231.670	53.262

23	175.00	253.00	795.00	1100.440	2.789	243.014	57.848
24	8.00	170.40	138.00	721.020	2.046	27.639	4.127
25	26.00	215.00	70.000	920.760	2.471	17.904	3.473
26	10.00	210.00	2.000	2852.200	6.746	1.585	0.453
27	0.80	93.40	38.000	391.640	1.232	4.134	0.263
28	1.00	99.60	30.000	417.440	1.302	3.479	0.246
29	6.00	30.00	33000.00	126.29	0.437	1157.650	4.216
30	5.00	38.90	33000.00	163.380	0.558	1497.650	8.131

7. SOME SAMPLE CALCULATIONS

Some sample calculations are carried out hereunder to illustrate the use of the above equations.

(1) Energy efficiency (η_1) of overall plant at 100 % load :
Total gross power output from the power plant at 100% load = 250 MW.

Energy supplied by coal to the plant at 100% load = Coal GCV (15490kJ/kg) × Coal firing rate (158 TPH i.e.43.88 kg/s) = 679.7012 MW.

η_1= (250/679.7012) × 100 % = 36.78 %

Similarly,at 90% load with coal firing rate 151 TPH, η_1 = (225 MW /651.90 MW)× 100% = 34.51 %

(2)Efficiency (η_1) of Condenser at 100% load

$$\eta_1 = \frac{\text{Actual temperature rise of the cooling water}}{\text{saturated steam inlet temp .to condenser} - \text{Cooling water inlet temp}}$$

= [(38.90 – 30) /(45.8 – 30)] × 100% = 56.32 %

(3) Exergy efficiency (η_2)of L.P. Heater (LPH) No.-2 at 100% load
Total Exergysuppliedto the heater = $\dot{X}_{16} + \dot{X}_{10}$ = 2.53 + 5.012 = 7.542 MW

Total Exergyrecovered from the heater = $\dot{X}_{17} + \dot{X}_{27}$= 5.069 + 0.246 = 5.315 MW

Therefore, η_2 = (5.315/ 7.542) × 100% = 70.47 %

(4) Exergy efficiency (η_2) of Boiler at 100% load :
Exergy supply by coal= Coal GCV(15490 kJ/kg) × Coal firing rate (158 TPH i.e., 43.8888 kg/s) × 1.06= 720.4832 MW

where 1.06 is the Exergy Grade Function(f)for coal [7 , 8].
Exergy flow into boiler = $\dot{X}_{23} + \dot{X}_4 + \text{Coal exergy}$= 1000.95 MW

Exergy flow out from the boiler = $\dot{X}_1 + \dot{X}_2$= 595.36 MW.
η_2= (595.36 /1000.95) × 100% = 59.47 %

(5) Effectiveness (ϵ) of HPH No.-1 at 100% load :
Actual temperature rise of cold fluid = (207 – 171) ^{0}C = 36 ^{0}C

Maximum possible temperature rise = (hotfluid inlet temperature, 437 ^{0}C)– (171^{0}C) = 266 ^{0}C
Effectiveness (ϵ)= 36 ^{0}C/266 ^{0}C = 0.135

8. RESULTS AND DISCUSSION

All relevant calculations are done based on above stated methodology for both 100% and 90% load at different equipment level as well as considering the whole power plant. The results obtained are given in both tabular and graphical forms for ease of comparison and understanding. In Table-2,η_1 and $\eta_2$for 90% and 100% load are given side by side.

Table-2: Energy and Exergy efficiencies for 100% and 90% load

Equipment	**100% Load**		**90% Load**	
	η_1 (%)	η_2 (%)	η_1 (%)	η_2 (%)
Boiler	**94.52**	**59.47**	**94.38**	**58.05**
Turbine	**91.96**	**84.99**	**87.05**	**79.55**
Condenser	**56.32**	**40.61**	**69.04**	**43.93**
Overall Plant	**36.78**	**32.15**	**34.51**	**30.34**

Table-3: Exergy efficiency and effectiveness for 100% and 90% load

Equipment	100% Load		90% Load	
	$\eta_{2\,(\%)}$	ϵ	$\eta_{2\,(\%)}$	ϵ
LPH-1	44.35	0.36	43.82	0.33
LPH-2	70.47	0.15	71.56	0.14
HPH-1	83.03	0.13	81.42	0.12
HPH-2	92.32	0.22	93.78	0.25

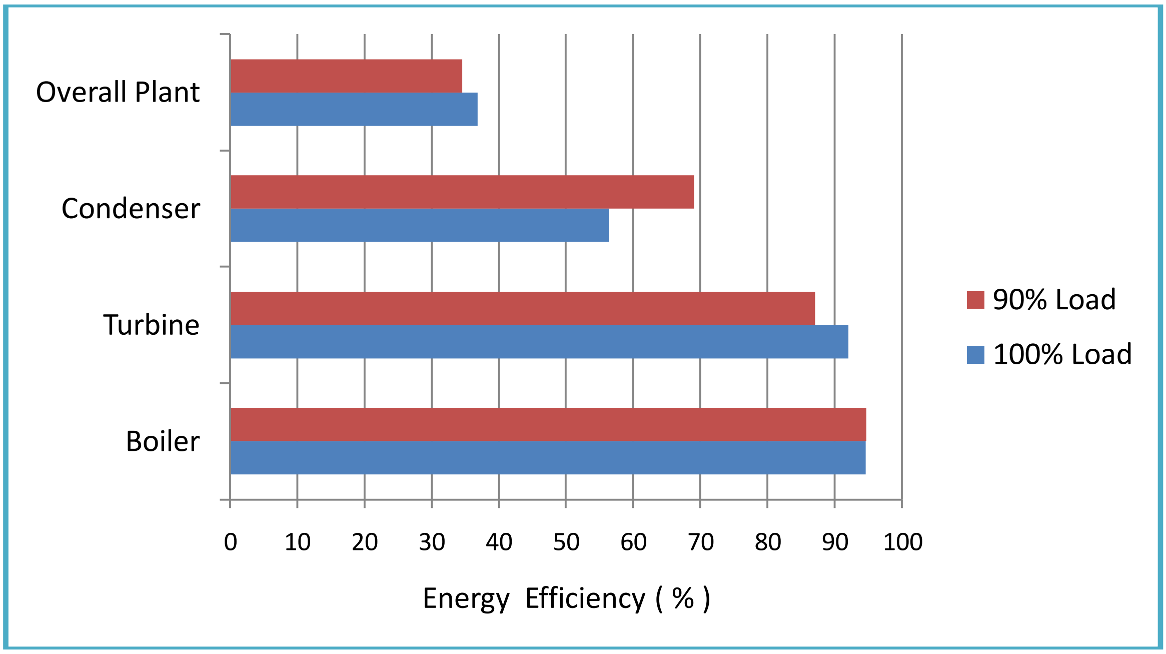

Fig.-3: Energy Efficiency($\eta_{1,\%}$)

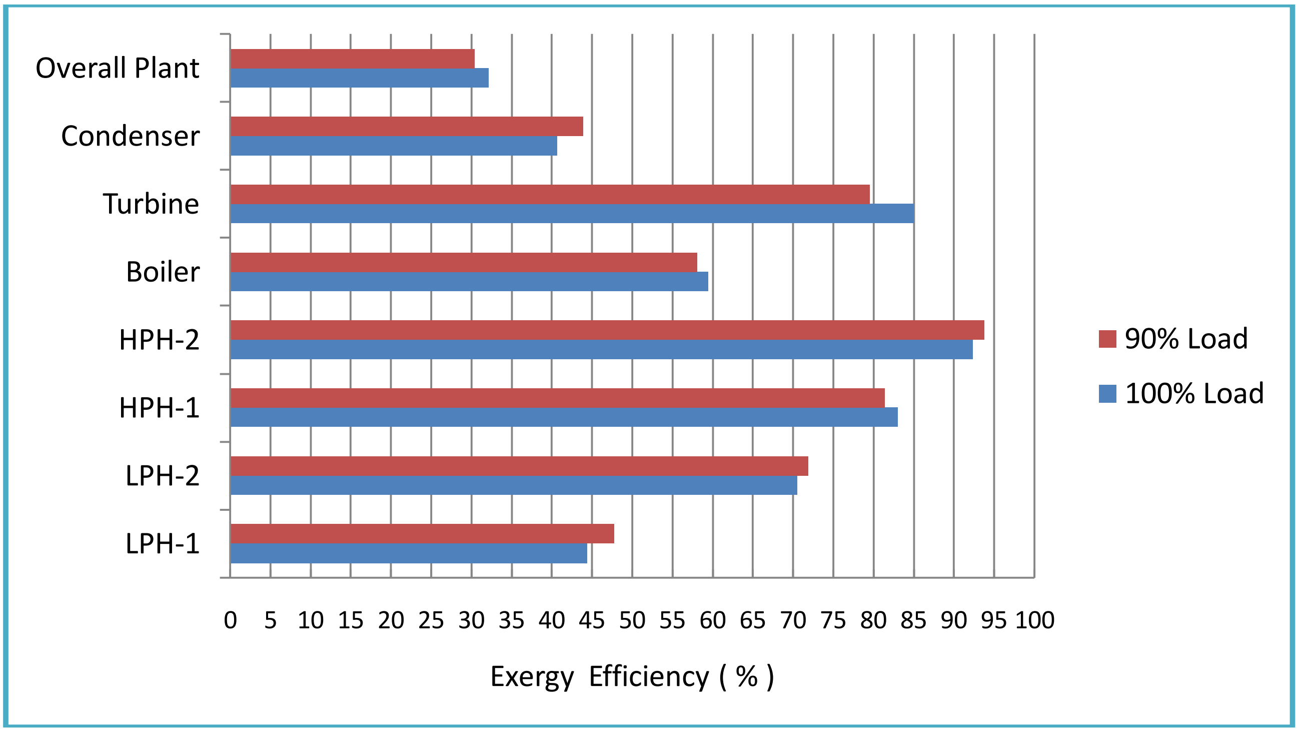

Fig.-4: Exergy Efficiency ($\eta_{2,}$ %)

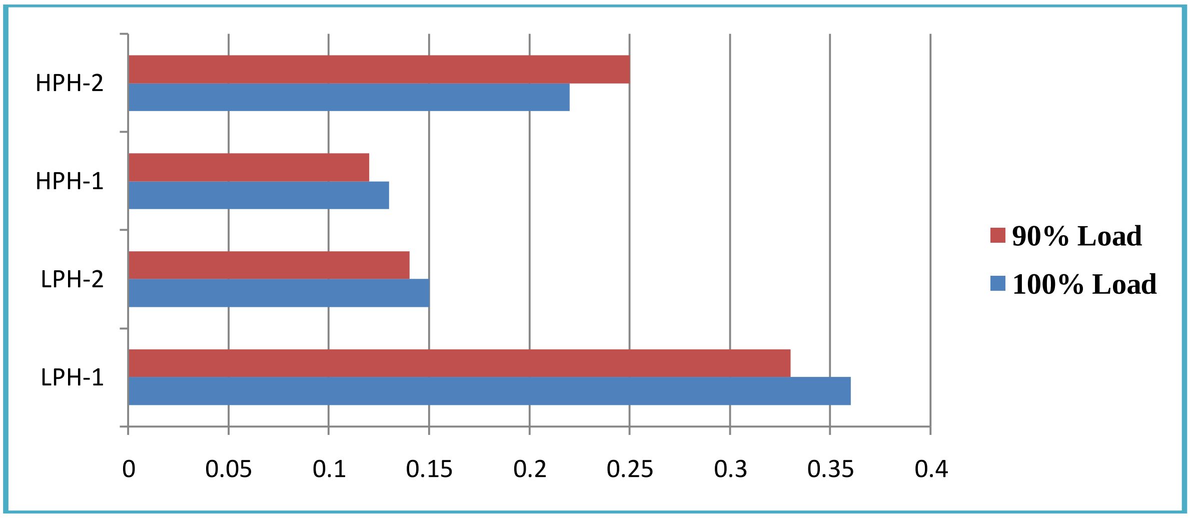

Fig.-5: Effectiveness of Heaters (ϵ)

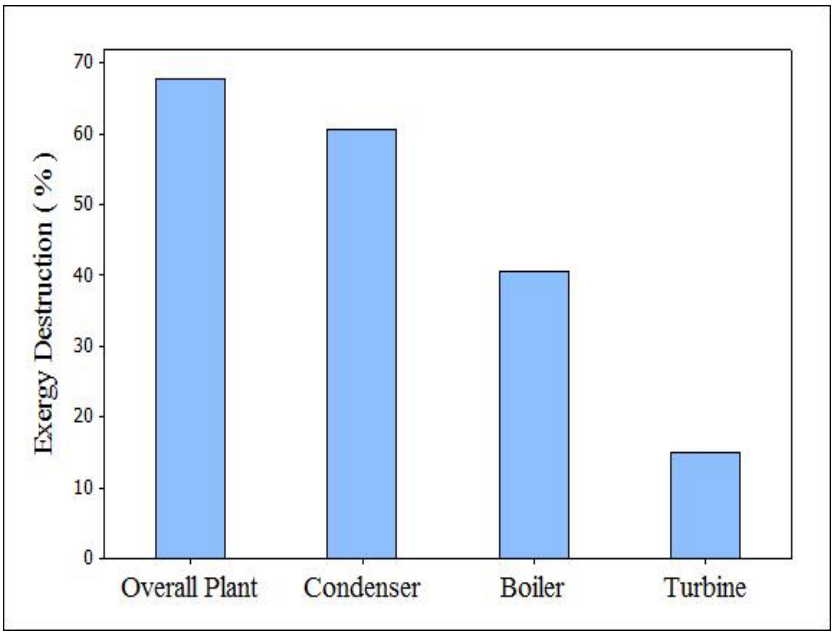

Fig.-6: Exergy destruction (%) for equipment & overall plant at 100% load

We searched literatures to compare our results to those obtained by other investigators. But not much data are available for energy and exergy efficiency and for effectiveness of individual component and for the overall power plant of 250 MW capacity under more or less similar conditions to ours. In some cases only some scattered data are available. Based on the available data, we have compared our results which are given in Table-4 and Table-5.

Table – 4: Comparison of Energy efficiency (η_1 in %)and effectiveness (ϵ)at 100% load

Sl No.	Parameter	Present Investigation	Ref [3]
1.	Boiler η_1	94.52	85.23
2.	Condenser η_1	56.32	53.33
3.	Overall Plantη_1	36.78	36.74
4.	LPH-1 ϵ	0.36	0.46
5.	LPH-2 ϵ	0.15	0.14
6.	HPH-1 ϵ	0.13	0.13
7.	HPH-2 ϵ	0.22	0.29

Table-5: Comparison of Exergy efficiency (η_2 in %) at 100% load

Sl No.	Parameter	Present Investigation	Ref [4]	Ref[5]	Ref [6]
1.	Boiler η_2	59.47	46.24	53.00	48.55
2.	Turbine η_2	84.99	87.78	92.25	92.71
3.	Overall Plant η_2	32.15	NA	36.80	44.07
4.	LPH-1 η_2	44.35	89.71	NA	NA
5.	LPH-2 η_2	70.47	96.46	NA	NA
6.	HPH-1 η_2	83.03	97.64	NA	NA
7.	HPH-2 η_2	92.32	93.52	NA	NA

From the above results and comparison, it is clear that our obtained results compare reasonably well with other available results of similar category power plant. Of course, the energy and exergy efficiency and effectiveness of heaters in a plant depend on many other factors apart from size of the plant. For example, ultimate composition of coal, coal GCV, coal burning mechanism and associated irresversibilities in the combustion process and irreversibility for large temperature gradient heat transfer from flue gas to water & steam, individual equipment irreversibility, prevailing ambient condition are some of the factors to name which effect the performance of the plant and the plant equipments. Finally, our results along with other available results can generate a data pool and by analysing this type of data pool more insights about the performance of the power plant and its equipments can be obtained. This definitely will boil down to more effective design and operation of the power plant and thereby will save our precious energy resources and help reduce pollution effects.

9. CONCLUSION

In this present study energy, exergy efficiencies and effectiveness of different relevant equipments as well as for the overall plant are carried out both at 100 % and 90% load for a 250 MW coal fired power plant based on plant operating data. The energy and exergy flow rates at each of the nodal points of the whole plant are calculated and tabulated. All relevant equations for performance calculations are illustrated by carrying out some sample calculations for each of the different situation. From the analysis it is found that major energy loss in the plant occurs at the condenser due to phase conversion of working fluid. Similarly major exergy loss occurs at the boiler and the condenser. Our results are compared reasonably well with other available investigators results for similar type of power plants; of course there are certain deviations. It is expected that all these data will form a pool of plant performance data which may ultimately results in better understanding of the plantand thereby possibly help improvement in plant design and operation.

NOMENCLATURE

E : Energy [MW]
h : Specific enthalpy [kJ/kg]
m : Mass [Ton]
s : Specific entropy [kJ/kg-K]
X : Total exergy [MW]
x : Specific Exergy [kW]
ECO : Economizer
GCV : Gross Calorific Value [kJ/kg]
HPH : High Pressure Heater
HPT : High Pressure Turbine
IPT : Intermediate Pressure Turbine
LPH : Low Pressure Heater
LPT : Low Pressure Turbine
NA : Not available
Q : Heat input [MW]
TPH : Ton per hour
W : Work output [MW]
ϵ : Effectiveness [unit less]
η_1 : Energy efficiency or, 1st law efficiency [%]
η_2 : Exergyefficiency or, 2nd law efficiency [%]

Subscripts

des : destruction
in : at inlet condition
out : at outlet condition
0 : reference or, dead state
.(dot) : 'dot' over any parameter implies corresponding flow rate

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