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Exergy Analysis of Thermal Power Plant for Full Load and Part Load Condition

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Abstract— *Exergy is more specific and accurate parameter then energy by which the performance of any system can be evaluated. In this study, the exergy analysis of a Thermal Power plant is presented. The primary objective of this study is to analyze the system components separately and to identify and quantify the sites having largest exergy losses for the full load as well as for the part load condition of the thermal power plant. The performance of the plant was estimated by a component wise modeling and a detailed break-up of exergy losses for the considered plant. The boiler is the major source of irreversibility in the power plant amongst all other components but excluding the boiler, turbine is the highest exergy destruction component. So exergy destruction improvement techniques can be evaluated by analysing this study.*

Key Words — *Exergy Destruction, Irreversibility, Turbine, Thermal Power Plant.*

I. INTRODUCTION

Exergy analysis can help to detect where the Exergy losses occur. Exergy analysis provides mean to evaluate the degradation of energy during process, entropy generation, the lost of opportunity to do work and thus provides an alternative approach for improvement of power plant performance. The Exergy analysis of a thermal power station is taken up. The total generating capacity of this plant is 1470 MW. The plant consists of seven units each unit having capacity to produce 210 MW. The data for energy and exergy analysis is collected from plant. The results of exergy analysis show that maximum exergy losses occur in turbine and heater while the maximum amount of exergy loss is found in turbine. Possible causes of losses are identified and conclusion is made on state of each component and that by overall plant.

Second-law analysis is often used in contrast / complement to first-law analysis. First-law analysis is the typical analysis based on energy balance and energy efficiency.

The limit of first-law analysis is that it does not account for energy QUALITY. Electric, mechanical, chemical, thermal energy, are all valued the same. However, we know that this is not true. Converting from mechanical to thermal energy is rather easy, and is done even when we do not wish so.

The second law of thermodynamics comes into help introducing entropy. In thermodynamics, the exergy (in older usage, available work and/or availability) of a system is the maximum useful work possible during a process that brings the system into equilibrium with a heat reservoir. When the surroundings are the reservoir, exergy is the potential of a system to cause a change as it achieves equilibrium with its environment. Exergy is the energy that is available to be used. After the system and surroundings reach equilibrium, the exergy is zero. Determining exergy was also the first goal of thermodynamics.

Energy is never destroyed during a process; it changes from one form to another (First Law of Thermodynamics). In contrast, exergy accounts for the irreversibility of a process due to increase in entropy (Second Law of Thermodynamics). Exergy is always destroyed when a process involves a temperature change. This destruction is proportional to the entropy increase of the system together with its surroundings. The destroyed exergy has been called anergy. For an isothermal process, exergy and energy are interchangeable terms, and there is no anergy.

II. EXERGY ANALYSIS

A coal fired thermal power station which works on the Rankine Cycle. A continuous mass flow diagram for one unit of power plant modeled in this study includes the main components such as high, intermediate and low pressure turbines (HPT, IPT and LPT), a boiler, number of pumps (P), a deaerator (D), a condenser (C), low and high pressure feed water heaters (LPH and HPH). Thermodynamic properties at each node of the power plant cycle are found out. By these values the exergy at each node is evaluated considering the reference environmental condition.

a. Full load condition

The operating conditions of power plant are summarized in the following table.

Operating Conditions	Value	Unit
Power produced	210	MW
Power consumption	6.4	MW
Mass flow rate of coal	137	T/h
Main stream flow rate	654	T/h
Main stream pressure	159	kg/cm^2
Main stream temperature	535	°C

Table 1. Operating conditions of power plant for full load

Ambient Parameters	Value	Unit
Pressure	1.013	bar
Temperature	300	K
Enthalpy	113.277	kJ/kg
Entropy	0.3946	kJ/kg.K

Table 2. Reference environmental conditions

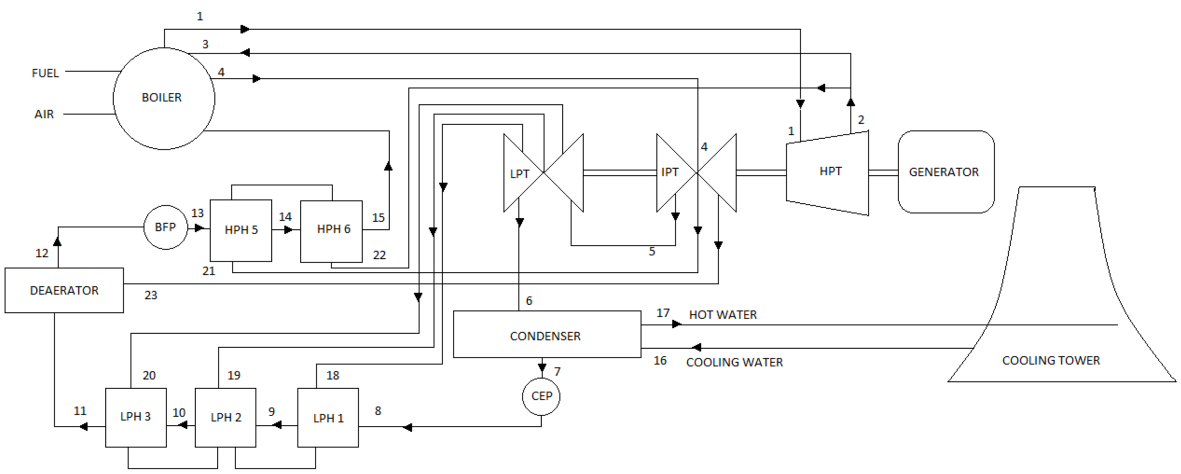

Figure 1. Schematic diagram of power plant

2.1.1 Exergy calculation for full load

POINT NO	PRESSURE (P)	TEMPERATURE(T)	MASS FLOW RATE (m)	ENTHALPY (h)	ENTROPY (s)	EXERGY (Ψ)	m*Ψ
	(bar)	(°C)	(kg/s)	(KJ/kg)	(KJ/kg.K)	(KJ/kg)	(MW)
1	155.82	535	181.6667	3402.9	6.4507	1472.793	267.5574
2	36.26	340	181.6667	3077	6.7036	1071.023	194.5692
3	36.26	340	165.5556	3077	6.7036	1071.023	177.3138
4	33.32	535	165.5556	3532.42	7.406	1315.723	217.8253
5	5.88	315	145	3093.49	7.4382	867.133	125.7343
6	0.098	58	115.6944	2607.36	8.2209	146.193	16.91372
7	0.98	45	115.6944	188.51	0.6381	2.183	0.252561
8	17.64	46	115.6944	194.15	0.6505	4.103	0.474694
9	17.444	48	128.1944	202.48	0.6768	4.543	0.582387
10	17.248	80	136.8056	336.25	1.0745	19.003	2.599716
11	17.101	112	145	471.01	1.4394	44.293	6.422485
12	6.86	161	155.5556	679.95	1.9525	99.303	15.44713
13	174.44	165.5	155.5556	709.185	1.9772	121.128	18.84213
14	171.01	199	165.5556	854.54	2.2975	170.393	28.20951
15	167.58	243	181.6667	1053.41	2.7011	248.183	45.08658
16	1.862	31	6637.222	130.09	0.4503	0.103	0.683634
17	1.372	40.5	6637.222	169.75	0.5789	1.183	7.851834
18	0.1519	65	12.5	2006.52	6.2521	135.993	1.699913

19	0.2842	142	8.611111	2766.26	8.1729	319.493	2.75119
20	0.6076	241	8.194444	2958	8.2322	493.443	4.043491
21	15.19	430.5	10	3322.1	7.4569	1090.133	10.90133
22	34.692	335.5	16.11111	3070.1	6.7189	1059.533	17.07025
23	6.86	314	10.55556	3088.8	7.3604	885.783	9.349932

Table 3. Thermodynamic property of points in cycle for full load

2.1.2 Analysis of exergy for full load

After deriving the exergy destruction value of the various power plant components, some of the analysis is shown in the following charts.

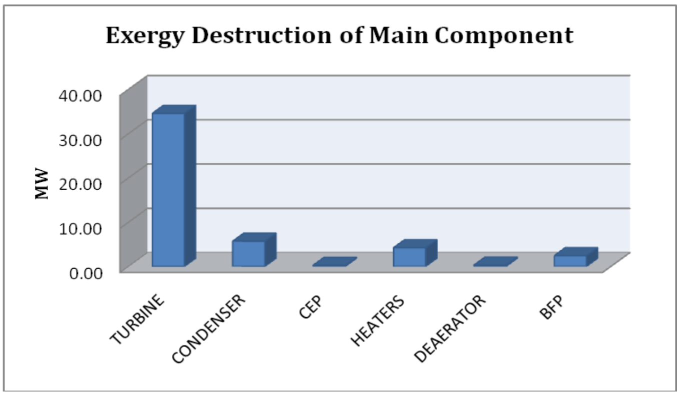

Figure 2. Exergy Destruction of Main Component for full load

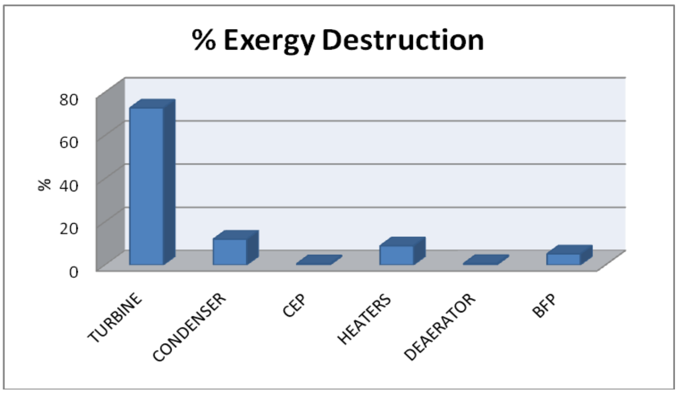

Figure 3. % Exergy Destruction for full load

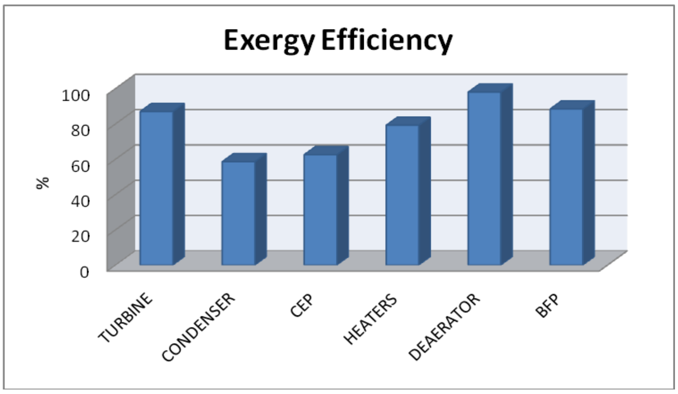

Figure 4. Exergy Efficiency for full load

These fig 2, fig 3 and fig 4 show the exergy destruction of main components, percentage exergy destruction and exergy efficiency respectively for the full load condition of the power plant that is 210 MW. From the figure it is shown that the maximum exergy destruction occurs in the turbines and hence maximum percentage of exergy destruction will be in turbine compare to other components of the power plant. Deaerator has the highest exergy efficiency. Turbine has lower exergy efficiency compare to deaerator while condenser has the lowest exergy efficiency of all.

b. Part load condition

The operating conditions of power plant are summarized in the following table.

Operating Conditions	Value	Unit
Power produced	160	MW
Power consumption	4.88	MW
Mass flow rate of coal	104	T/h
Main stream flow rate	500	T/h
Main stream pressure	154	kg/cm2
Main stream temperature	535	°C

Table 4. Operating conditions of power plant for part load

Ambient Parameters	Value	Unit
Pressure	1.013	bar
Temperature	300	K
Enthalpy	113.277	kJ/kg
Entropy	0.3946	kJ/kg.K

Table 5. Reference environmental conditions for part load

2.2.1 Exergy calculation for part load

POINT NO	PRESSURE (P)	TEMPERATURE (T)	MASS FLOW RATE (m)	ENTHALPY (h)	ENTROPY (s)	EXERGY (Ψ)	m*Ψ
	(bar)	(°C)	(kg/s)	(KJ/kg)	(KJ/kg.K)	(KJ/kg)	(MW)
1	150.9	535	138.89	3409.4	6.4727	1472.693	204.5407
2	27.44	330	138.89	3071.64	6.8537	1020.633	141.7546
3	27.44	330	126.67	3071.64	6.8537	1020.633	129.2802
4	25.48	530	126.67	3528.89	7.545	1270.493	160.9291
5	2.254	312	110.28	3095.82	7.8878	734.583	81.00818
6	0.098	44.4	88.19	1234.32	3.9215	62.973	5.553869
7	0.98	44	88.19	184.34	0.6249	1.973	0.174008
8	17.64	45	88.19	189.97	0.6374	3.853	0.339813
9	17.44	46	97.64	194.1264	0.6505	4.0794	0.398308
10	17.25	70	104.03	294.4527	0.9541	13.3257	1.386243
11	17.1	105	110.28	441.4505	1.362	37.9535	4.185428
12	5.88	150	119.17	632.2508	1.8416	84.8738	10.11413
13	165.6	156	119.17	667.8472	1.8844	107.6302	12.82593
14	163.7	182	126.67	779.7568	2.138	143.4598	18.17157
15	162.7	223	138.89	961.4635	2.5203	210.4765	29.23285
16	1.862	28	5074.44	117.5355	0.4087	0.0285	0.144622
17	1.372	36	5074.44	150.9312	0.5181	0.6042	3.065979
18	0.152	65	9.44	2006.62	6.2521	136.093	1.285323
19	0.284	142	6.39	2766.26	8.1729	319.493	2.041205
20	0.608	241	6.25	2957.976	8.2322	493.419	3.083869
21	11.76	422	7.50	3308.64	7.4999	1063.773	7.978298
22	27.44	335	12.22	3083.7	6.8737	1026.693	12.54847
23	5.292	151	8.89	2767.3056	6.8419	719.8386	6.398565

Table 6. Thermodynamic property of points in cycle for part load

2.2.2 Analysis of exergy for Part load

After deriving the exergy destruction value of the various power plant components, some of the analysis is shown in the following charts.

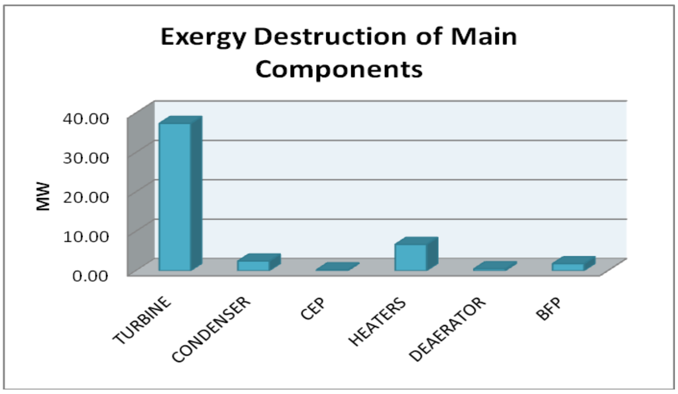

Figure 5. Exergy Destruction of Main Component for part load

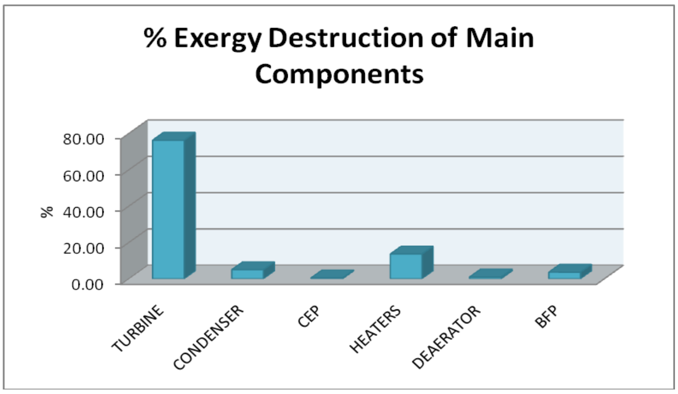

Figure 6. % Exergy Destruction for part load

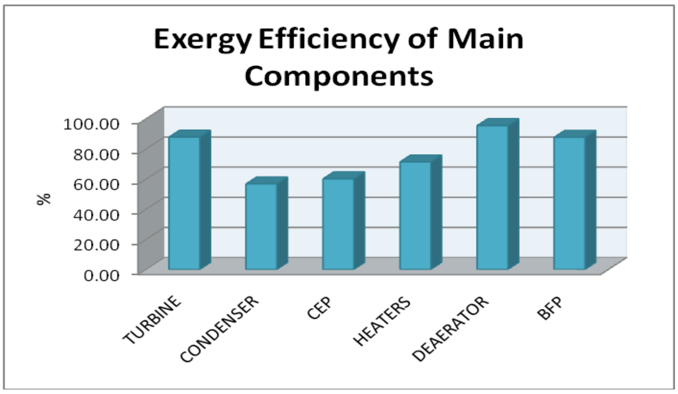

Figure 7. Exergy Efficiency for part load

These fig 5, fig 6 and fig 7 show the exergy destruction of main components, percentage exergy destruction and exergy efficiency respectively for the part load condition that is 160MW. From the figure it is shown that the maximum exergy destruction occurs in the turbines and hence maximum percentage of exergy destruction will be in turbine compare to other components of the power plant. Deaerator has the highest exergy efficiency. Turbine has lower exergy efficiency compare to deaerator while condenser has the lowest exergy efficiency of all.

III. COMPARISON

Exergy analysis has been carried out for full load and part load condition of the thermal power plant. Hence it needs to compare the results so that the difference can be analyzed. By comparison of these two results we can say which one of those two conditions is preferable for minimum exergy destruction.

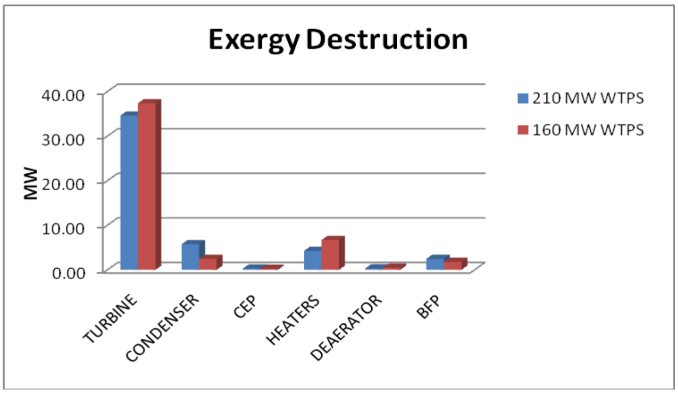

Figure 8. Comparison of Exergy Destruction

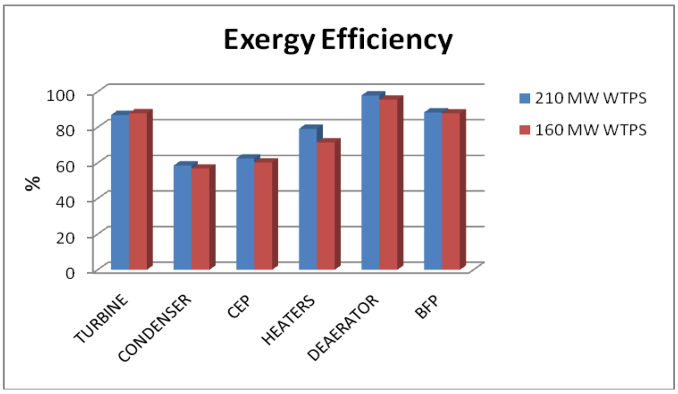

Figure 9. Comparison of Exergy Efficiency

The comparison of the exergy destruction and exergy efficiency of the main components of the themal power plant for the full load and part load condition are shown in the fig 8 and fig 9 respectively. Exergy destruction is slighly increased in turbine and heaters in part load condition compare to ful load condition while in other components exergy destruction is reduced. Exergy efficiency is almost the same for all the components of power plant in full load and part load condition. From this comparison it is noted that it is preferable to operate the power plant at full load so that the exergy destruction can be minimised.

IV. COMPARISON

So, from this study we can conclude that the maximum amount of exergy destruction occurs in turbine component compare to other components excluding the boiler. By comparison of full load and part load condition we can conclude that exergy destruction is minimum in full load condition. Here turbine has the highest exergy destruction value so that some improvement should be made such that exergy destruction value can be reduced. Hence we can improve the performance of the power plant.

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