Exergetic and energetic analysis of a 210 MW Thermal Power Plant in Pakistan

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Abstract-Exergetic analysis is a modern tool to assess the optimum thermal performance of a power plant during design as well as during its operational period. This approach can identify the components of low efficiency in the running plant and therefore suitable corrective action can be applied to enhance the performance of a plant. In this study exergetic and energetic analysis of Thermal Power Station Muzaffargarh in Pakistan is carried out with an objective to explore the sites having highest exergetic and energetic losses in the system. Component wise modelling is used to estimate the performance of the plant by incorporating the effects of varying environmental conditions. It has been found that highest energetic losses happened in the condenser system where 295 MW was lost in the atmosphere. The percent ratio of irreversibility to the total irreversibility of the boiler system was 84 % and 9 % of the condenser system. The system energetic efficiency calculated on the basis of the fuel lower heating value was 34%, and exergetic efficiency of power cycle was 32%. In addition, a parametric analysis of the plant performance by varying parameters at the inlet of turbine section has also been presented.

Keywords-Energetic Analysis, Exergetic Analysis, Efficiency, Dead State, Thermal Power Plant

I. INTRODUCTION

The development in the countries and living standard of the communities are indicated by energy consumption within it. Rise in energy consumption is resulted due to multiple factors like: tremendous increase in population, shifts towards urbanization, technological progress and industrial revolution. Pakistan is a developing country and is facing an unprecedented energy crisis since last few years, which has resulted a supply demand gap of up to 4,500-5,500 MW [i]. The energy mix of Pakistan comprises about 88% fossil fuels, 10.6 % hydropower and 0.7 % nuclear according to water and power ministry [ii]. These fossil fuel fired thermal power plants are playing a key role in the scenario of Pakistan electricity generation. Therefore, it is essential that these power generation units work at optimum conditions for fuel efficiency.

First law of thermodynamics was the initial criteria of a power plant's performance evaluation, however the first law has some inherent limitations and it is more appropriate to use the thermodynamics second law as the basis of investigation. Based upon the second law exergetic analysis has become a modern tool used to analyze, design, evaluate and to optimize the power plant efficiency. Hasan et al. [iv] presented work on coal fired thermal power plants and gave detail of thermodynamic inefficiencies and comparison of one plant to the other. Aljundi [v] presented work on steam power plant in Jordan by analyzing all the power plant sites separately. Datta et al. [vi] has divided the entire cycle of thermal power station into three zones and presented the exergetic analysis of the power plant. Zubair and Habib [vii] presented an exergetic analysis based study on a Rankine cycle with regeneration and reheating. Naterer et al. [viii] measured losses in turbine and boiler of a coal fueled thermal power plant. Ganapathy et al. [ix] presented available and actual energy losses in a lignite fueled thermal power plant.

Rosen and Dincer [x] determined the effects of changing the dead state conditions for exergetic and energetic study of a thermal power plant. Khaliq and Kaushik [xi] analyzed the reheat Baryton and Rankine combined power cycle and present analysis on the basis of the thermodynamics second law. Kurkiya and Chaudhary [xii] presented an energetic investigation of a steam power plant by calculating energy losses in each component separately and also gave the economic optimization of a plant by varying the percentage of carbon in coal content. Vosough [xiii] analyzed a thermal power plant with its exergy based analysis. In this analysis the irreversibility in the boiler and also the exergetic and energetic based efficiencies of the power plant components were determined. Reddy et al. [xiv]

presented a review of exergetic and energetic based investigation of gas fueled and coal fueled CCP plant.

II. PLANT DESCRIPTION

A 1350 MW power station located in Multan division's district Muzaffargarh of Pakistan was used for analysis in this study. The power plant comprises of six steam turbine units (3×210) MW, (2×200) MW, (1×320) MW at 100% load. Characteristics of heavy fuel being used in the thermal power plant are given in I. Working parameters of the power plant are listed in II. The schematic diagram of 210 MW unit is shown in Fig.1.

This section of 210 MW has a feed water heating (FWH) system. This FWH system is executed in two steps. First one is low pressure heating which have four heaters and the second one is high pressure heating which have three heaters and a deaerator heat exchanger.

TABLE I
TPS MUZAFFARGARH FUEL CHARACTRICTICS [iii]

Property	Unit	Quantity
Density at 15 °C	Kg/m^3	991.0
Flash point	°C	66-164
Viscosity at 50 °C	centistokes	400
Pour point	°C	+ 30
Moisture	% V/V	0.5
Sulphur	% m/m	3.5
Ash content	% m/m	0.1
Calorific value	K Cal/Kg	9570/1000

TABLE II
TPS MUZAFFARGARH WORKING PARAMETERS

Parameters	Unit	Quantity
Steam flow rate of mass	Kg/s	15.3
Hot products to the boiler flow rate of mass	Kg/s	475
Flue gases temperature	°C	160
Feed water entering temperature to boiler	°C	234.5
Flow rate of steam	Kg/s	180
Temperature of steam	°C	540
Pressure of steam	MPa	12.7
Output power	MW	210
Cooling water flow rate of mass	Kg/s	7039
Cooling water temperature	°C	32

Steam turbine with steam reheating is used which comprises of single shaft and three cylinders. Steam is superheated to 540 ^{0}C with a pressure of 12.7 MPa, which is pushed to the turbine section. The steam coming out from the turbine is then sent to water cooled condenser where the phase change occurs for reuse and the cyclic process starts. Parametric values of the thermal power plant are given in III.

III. ANALYSIS

The aim of this study is to identify the power plant components which have a critical contribution towards plant efficiency. The thermal power plant is analyzed on the basis of both exergetic and energetic analysis together to get the complete interpretation of system features.

Mass, energetic and exergetic balances are considered in the following thermodynamical analysis of the power plant. Steady state flow is assumed and changes in both potential and kinetic energies are neglected.

The general mass balance for any control volume of a steady state process is written as:

$$\sum \dot{m}_i = \sum \dot{m}_e \quad (1)$$

For any control volume, the general energy balance can be written as:

$$\dot{Q} - \dot{W} = \sum \dot{m}_e h_e - \sum \dot{m}_i h_i \quad (2)$$

For any control volume, the general exergy balance can be written as:

$$\dot{X}_{heat} - \dot{W} = \sum \dot{m}_e \psi_e - \sum \dot{m}_i \psi_i + \dot{I} \quad (3)$$

Where X_{heat} represents the net energy transfer by heat at temperature T, can be calculated as:

$$\dot{X}_{heat} = \sum (1 - \frac{T_o}{T}) \dot{Q} \quad (4)$$

Total exergy rate is written as:

$$\dot{X} = \dot{m}\psi = \dot{m}[h - h_o - T_o(s - s_o)] \quad (5)$$

The energetic efficiency of the power plant is:

$$\eta_{th,pp} = \frac{W_{net}}{Q_{in}} \quad (6)$$

The Exergetic efficiency of the power plant is:

$$\eta_{ex,pp} = \frac{W_{Net}}{\dot{X}_{fuel}} \quad (7)$$

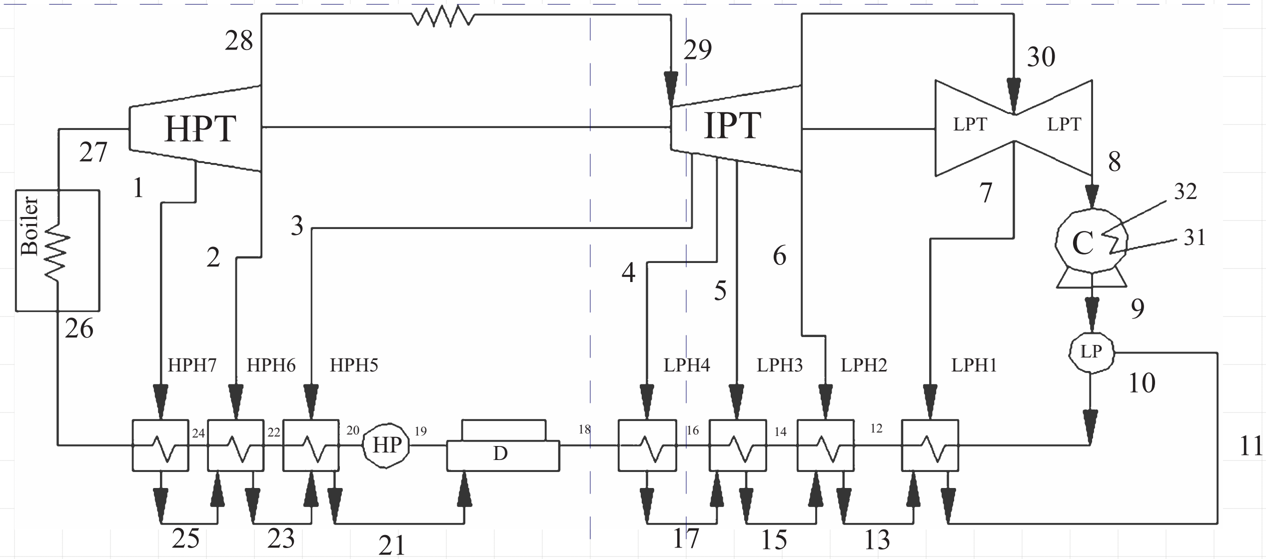

Fig. 1. TPS Muzaffargarh 210MW unit layout.

IV. Result and Discussion

Engineering Equation Solver (EES) software was used to calculate the water thermodynamic properties at designated points in Fig. 1. The thermal power plant was analyzed by above relations with dead state pressure and temperature 101.35 kPa and 25 ^{0}C respectively.

The energetic balance and percent ratio of input energy of fuel in the thermal power plant components are presented in IV. It shows that 50.2 % of the total fuel energy is lost in the condenser and discharge in the atmosphere. The percent ratio of energy lost in the boiler is 28 % of all the losses [v]. However, energy based analysis can be misleading.

TABLE IV
Energetic Balance and Percent Ratio of Fuel Energy Input in Power Plant Components

Section	Heat Loss (MW)	Percent ratio
Condenser	295.215	50.2
Boiler	162.903	27.6
Turbine	126.295	21.4
Heaters	2.912	0.5
Deaerator	1.704	0.3
Total	589.029	100

The values of irreversibility and percent ratio of irreversibility in the components are given in V. It shows that boiler alone destroyed 84 % of available energy in the power plant. Energetic analysis shows condenser to be highest energy destruction site, yet in exergetic analysis the percent ratio of irreversibility to the total irreversibility in the condenser is only 9 %. Based on LHV of fuel exergetic and energetic efficiencies of the Thermal Power Station Muzaffargarh comes out 32 % and 34 % respectively [v].

TABLE V
Irreversibility and Its Percent Ratio of Irreversibility in TPS Muzaffargarh Components At T_0=25 ^{0}C, P_0=101.35 kPa.

Section	Irreversibility (MW)	Percent ratio
Boiler	72.87	84.5
Condenser	7.35	8.52
Turbine	2.48	2.87
LP pump	0.212	0.26
LPH 1	0.439	0.52
LPH 2	0.507	0.58
LPH 3	0.394	0.46
LPH 4	0.398	0.47
HP pump	0.048	0.06
HPH 5	0.522	0.60
HPH 6	0.493	0.57
HPH 7	0.513	0.59
Power cycle	86.23	100.00

TABLE III
PARAMETERIC VALUES OF POWER PLANT

Points	Mass flow rate (Kg/s)	Temperature (°C)	Pressure (KPa)	Enthalpy (KJ/Kg)	Entropy (KJ/KgK)
1	9.28	398	3638	3215	6.813
2	12.7	331	2481	3082	6.772
3	5.5	448	1128	3365	7.555
4	7.14	364	598.2	3195	7.594
5	5.81	255	205.2	2980	7.715
6	7.14	168	113.6	2811	7.635
7	3.47	69	29.5	2624	7.774
8	126.4	49	9.73	2590	8.18
9	131.5	45	9.73	188.4	0.6385
10	131.5	50	1588	210.7	0.703
11	3.47	67	27.5	280.4	0.9182
12	131.5	64	1490	269.1	0.8803
13	21.8	103	113	431.7	1.341
14	153.7	94	1442	394.8	1.238
15	14.7	110	254.9	461.4	1.418
16	153.5	116	1402	487.7	1.483
17	8.9	139	598.1	585.1	1.729
18	153.6	144	1343	607	1.78
19	180.6	151	804	636.8	1.852
20	180.6	154	18632	660.8	1.863
21	26.75	177	1128	750.1	2.11
22	180.6	172	18388	737.8	2.04
23	22.1	192	2481	817	2.253
24	180.6	208	18152	894.9	2.38
25	9.28	198	3638	844.3	2.309
26	180.6	234	17848	1014	2.622
27	180.6	540	12749	3446	6.586
28	155.8	299	2756	2999	6.586
29	155.7	540	2422	3552	7.451
30	129.5	168	120.6	2810	7.607
31	7035	32	196	134.1	0.464
32	7039	42	96	176.2	0.5988

Fig. 2 shows significant differences between energetic losses and irreversibility in the main sites of the thermal power plant which are boiler, condenser and three compounds of the turbine. It can be seen that available energy losses in the condenser are quite less than actual energy losses, indicating the energy destroyed in the condenser system was thermodynamically unimportant due to its low quality. The boiler section shows the highest irreversibility in the thermal power plant components.

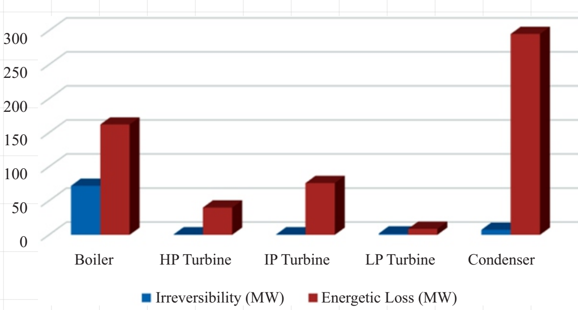

Fig. 2. Energetic losses and irreversibilities in the main sites.

Fig. 3 shows generated power output variation with respect to steam mass flow rate inlet to the turbine. It shows a rise in power output values with the rise in mass flow rate value [viii]. This can be helpful in determining the requirement of steam mass flow rate, according to the required power production when the generation unit has to operate on part load conditions.

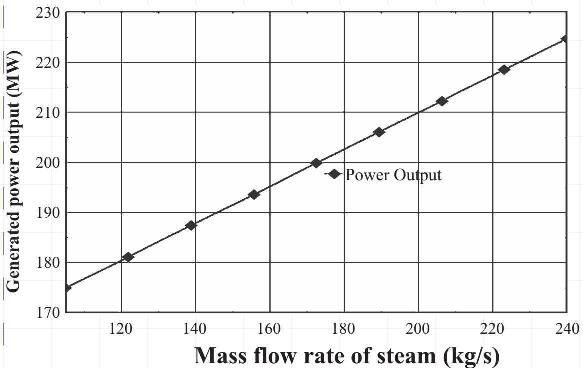

Fig. 3. Effect of mass flow rate on the generated power output.

Fig. 4 and 5 show the influence of the steam pressure and temperature on the cyclic performance respectively. It is clear that by increasing the superheated steam parameters efficiency of the system rises [viii]. While keeping same, the steam mass flow rate and fuel input to the boiler, we can obtain higher power outputs by increasing the cycle steam temperature and pressure.

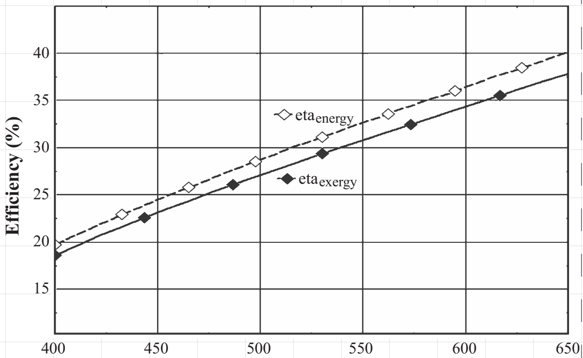

Fig. 4. Effect of steam temperatures on efficiencies.

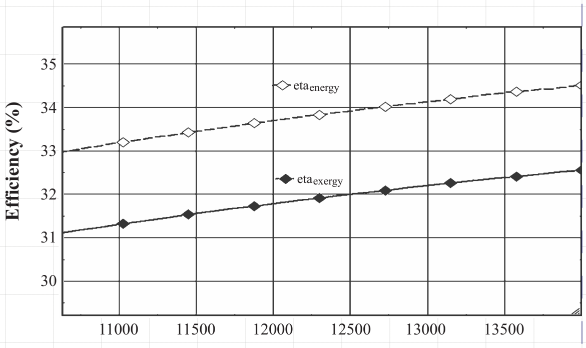

Fig. 5. Effect of steam pressure on efficiencies.

We can quantify exergy of any system by specifying the system and its surroundings. According to energy analysis the thermodynamic property is not effected by changing the dead state, however, change in the dead state can affect the exergetic analysis results. To observe the effectiveness of dead state in the system performance the dead state temperature is varied from 10 ^{0}C to 50 ^{0}C while maintaining the pressure at 101.35 kPa. The total irreversibility rates of all the thermal power plant components at different dead state temperatures are summarized in VI, whereas irreversibility with respect to varying dead state temperature in three main sites of the thermal power plant are shown in Fig. 6, which shows that the irreversibility rate in the boiler and turbine increases and decreases in the condenser with the increase in a dead state temperature [v]. The result still remains the same that whatever the dead state will be, the boiler remains the largest irreversibility site in the power plant.

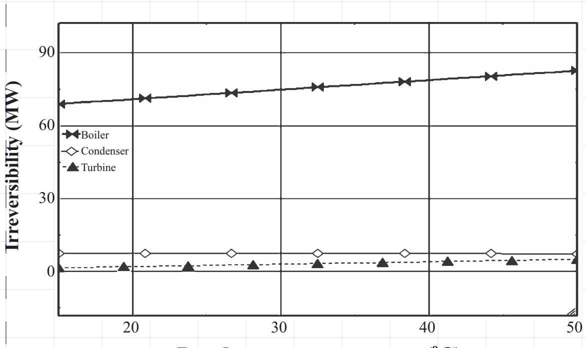

Fig. 6. Effect of dead state temperature in main components of the thermal power plant.

TABLE VI

IRREVERSIBILITY IN ALL COMPONENTS OF POWER PLANT AT DIFFERENT DEAD STATE TEMPERATURE, (MW).

Section	10 (°C)	15 (°C)	20 (°C)	25 (°C)	30 (°C)	35 (°C)	40 (°C)	45 (°C)	50 (°C)
Boiler	66.98	68.95	70.91	72.87	74.83	76.80	78.64	80.73	82.68
Condenser	7.431	7.405	7.378	7.352	7.325	7.299	7.272	7.246	7.220
Turbine	0.993	1.491	1.988	2.485	2.982	3.479	3.976	4.472	4.969
LP pump	0.084	0.127	0.169	0.212	0.254	0.296	0.339	0.381	0.423
LPH 1	0.446	0.443	0.441	0.439	0.436	0.434	0.431	0.429	0.427
LPH 2	0.477	0.487	0.497	0.507	0.518	0.528	0.538	0.538	0.559
LPH 3	0.376	0.382	0.388	0.394	0.400	0.406	0.412	0.418	0.424
LPH 4	0.343	0.362	0.380	0.398	0.417	0.435	0.454	0.472	0.490
HP pump	0.019	0.028	0.038	0.048	0.057	0.067	0.077	0.087	0.096
HPH 5	0.491	0.501	0.511	0.522	0.532	0.542	0.553	0.564	0.573
HPH 6	0.433	0.453	0.473	0.493	0.513	0.533	0.554	0.573	0.593
HPH 7	0.484	0.494	0.503	0.513	0.522	0.532	0.541	0.552	0.560

V. CONCLUSION

In this paper exergetic and energetic analysis of Thermal Power Station at Muzaffargarh in Pakistan has been presented. In this power plant condenser showed the highest energetic losses where almost half of the fuel energy input to system was lost in the environment. Whereas in exergetic analysis the percent ratio of irreversibility to the total irreversibility in the condenser was only 9% indicating the energetic loss in the condenser was thermodynamically unimportant due to its low quality.

Exergetic analysis showed boiler to be the highest irreversibility site where the percent ratio of irreversibility to the total irreversibility was 84%. The energteic efficiency of the system calculated on the basis of the fuel LHV was 34 % and exergetic efficiency of the thermal power cycle was found to be 32 %.

A parametric analysis of the thermal power plant, on the basis of varying the parameters like mass flow rate, pressure and temperature of steam at the inlet of turbine has been presented. It is observed that by increasing superheated steam parameters system efficiency increases.

Despite the effectiveness of the dead state temperature on irreversibility in each site of the power plant yet the boiler remains the key site of irreversibility in the system, which demand directed efforts to enhance the boiler section performance.

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NOMENCLATURE

h - Specific enthalpy (KJ/Kg)
s - Specific entropy (J/KgK)
m - Mass flow rate (Kg/s)
P - Pressure (Pa)
I - Exergy destruction rate (W)
Q - Heat transfer to steam (W)
T - Temperature (K)
W - Work rate or power done by the system (W)
X - Total exergy rate (W)
LHV- Lower heating value

Greek symbols

$\eta_{ex,pp}$ - Exergy efficiency
ψ - Specific exergy
γ - Exergy factor Subscripts
e - Exit
i - Inlet
s - Isentropic
o - Dead state condition
f - Fuel
p Heat products
g - Flue gas