

Exergy Analysis of a Thermal Power Plant in RASTRIYA ISPAT Nigam Limited

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ABSTRACT: The work on Exergy Analysis was undertaken on RINL Thermal Power Plant situated in Visakhapatnam (steel plant) Andhra Pradesh. The capacity of the plant is 315 MW. Energy analysis presents only quantitative results while Exergy analysis presents qualitative results about actual energy consumption. The performance of plant was estimated by component-wise modelling and a detailed exergy losses for the considered plant has been presented at max load. Exergy destruction mainly occurred in boiler (97.4 MW) followed by condenser (19.22 MW). It also presents Exergy losses at boiler, turbine section, condenser, pump, heaters. Exergy destruction, Percentage of exergy destruction & exergetic efficiency comparison charts with power plant components are plotted. Optimization of power plant is carried out in MINITAB software to know the optimal values for best efficiency. The results are tabulated and graphs are plotted to show correlation between various parameters. This project would also throw light on the scope for further research and recommendations for improvement in the further existing plant.

KEYWORDS: Exergy, Exergy destruction, Exergetic efficiency, MINITAB

I. INTRODUCTION

[1]The twenty-first century is forming into a perfect energy storm. This is evidence from rising energy prices, diminishing energy availability & growing environmental concern. All these factors are quickly changing the global energy panorama. Energy and water are key to modern life and they provide the basic necessities for sustained economic development. Industrialized Nations have become increasingly dependent on fossil fuels for myriad uses. Modern appliances & machines are sustained through exploration of expensive fossil fuels. Securing sustainable & future energy supplies will be the greatest challenge faced by all nations in this century.

[2]Power is one of the basic needs along with food clothing and shelter now-a-days irrespective of the life style of the people. It has occupied such a place in our daily routine. India's energy basket is a mixture of all available resources i.e., both renewable and non-renewable energy resources. Coal is the major source for the power production when compared with other sources. A thermal power plant is a plant in which steam is used to drive the prime mover. Around 58.75% of the power generation is from coal based power plants of the total installed capacity. Natural gas contribute around 8.91%, Nuclear and oil contribute around 2.11% and 0.52%. The share of coal and petroleum is expected to be around 66.8% in the total commercial energy produced. The share of crude oil in production and consumption is expected to be around 6.7% and 23% by 2021-22.

[2]The fact that thermal energy is the major source of power generation itself shows Thermal power plants importance in India. More than 60% of electrical power is produced by Thermal powered steam plants in India. The steep rise in the demand for power demands a larger unit setup which requires the use of more fuel. These plants are trying to keep the overall cost of power generation low using modern technique and devices. Studies of energy and exergy analyses for power generation systems are of scientific interest and jointly essential for the economical utilization of energy resources. For this reason, the exergy analysis has drawn a lot of attention by scientists and system designers in recent years. Some devoted their studies to part exergy analyses and efficiency improvement.

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[3]Efficiency is one of the most frequently used terms in thermodynamics & it indicates how well an energy process is accomplished. Efficiency is also one of the most frequently misused terms in thermodynamics & is often a source of misunderstanding. This is because efficiency is often used without being properly defined first.[4]Efficiency traditionally has been primarily defined based on the first law (i.e, energy). In recent decades, exergy analysis has found increasingly widespread acceptance as a useful tool in the design, assessment, optimization & improvement of energy systems.[5]Determining exergy efficiency for individual components making up the system constitutes a major part of exergy analysis. A comprehensive analysis of a thermodynamic system includes both energy & exergy analyses in order to obtain a more complete picture of system behaviour.

II. PLANT DESCRIPTION

The captive Thermal Power Plant (TPP) of Visakhapatnam Steel Plant has got an in plant capacity to generate 315 MW of power at its main TPP and about 39 MW of power from its auxiliary power generation situated at Back Pressure Turbine Station and Gas expansion Turbine station.

The power produced is used for the steel plant loads and the excess power around 30 to 40 MW is sold to the APTRANSCO. The plant has 5 Boilers of 690 T/Hr each. The boilers are operated within the norms and water chemistry is maintained well. Thermal power plant always get synchronised with AP Transco grid. Power generation is maintained always at optimum level and whatever excess generation is there that will be export to AP Transco grid. In case of any problem in our plant we import the power from AP Transco grid. And there is a provision to de-synchronise automatically from grid whenever frequency fluctuations are high in AP Transco grid which will save our plant from total power failure. During that period our plant will run on isolation mode. After frequency getting stabilised, once again we have to synchronise our plant with AP Transco grid.

Thermal Power Plant has 5 Boilers each generating of 690 T/hr. The boilers are of BHL make, capable of firing combination of fuels namely Coal, Coke Oven Gas, Blast Furnace Gas and Oil. Crushed coal is conveyed from Raw Material Handling Plant to TPP through conveyors. The coal is pulverized in Bowl Mills and fired in the furnace. Boilers are kept in full load operation to produce 315 MW of power, supply steam to Turbines and process needs boilers outlet flue gas it passes through Electro Static Precipitators to control air pollution. The Fly ash and bottom ash generated are pumped in slurry form to ash pond through on ground pipelines. The clarified water is re-circulated back to ash system.

Generally Thermal power plants are categorized as:

- Utility Power Plant: Power is produced solely for purpose of generation and supplied to the various kinds of customers through grid.
- Captive Power Plant: Power is produced for supplying quality power for the effective functioning of the actual plant (say a case of a Thermal power plant present in a steel plant). Import and export of power takes place in accordance with the load.

The Thermal power plant seen in Visakhapatnam Steel Plant is a captive power plant. The power requirement of VSP is met through captive generation as well as supply from APSEB grid.

Captive capacity of TPP in VSP : 315 MW

- 3 units of 60 MW generation capacity.
- 2 unit of 67.5 MW generation capacity.
- 2 units of 7.5 MW capacity at Back Pressure Turbine Station (BPTS).
- 2 units of 12 MW capacity at Gas Expansion Turbine Station (GETS).

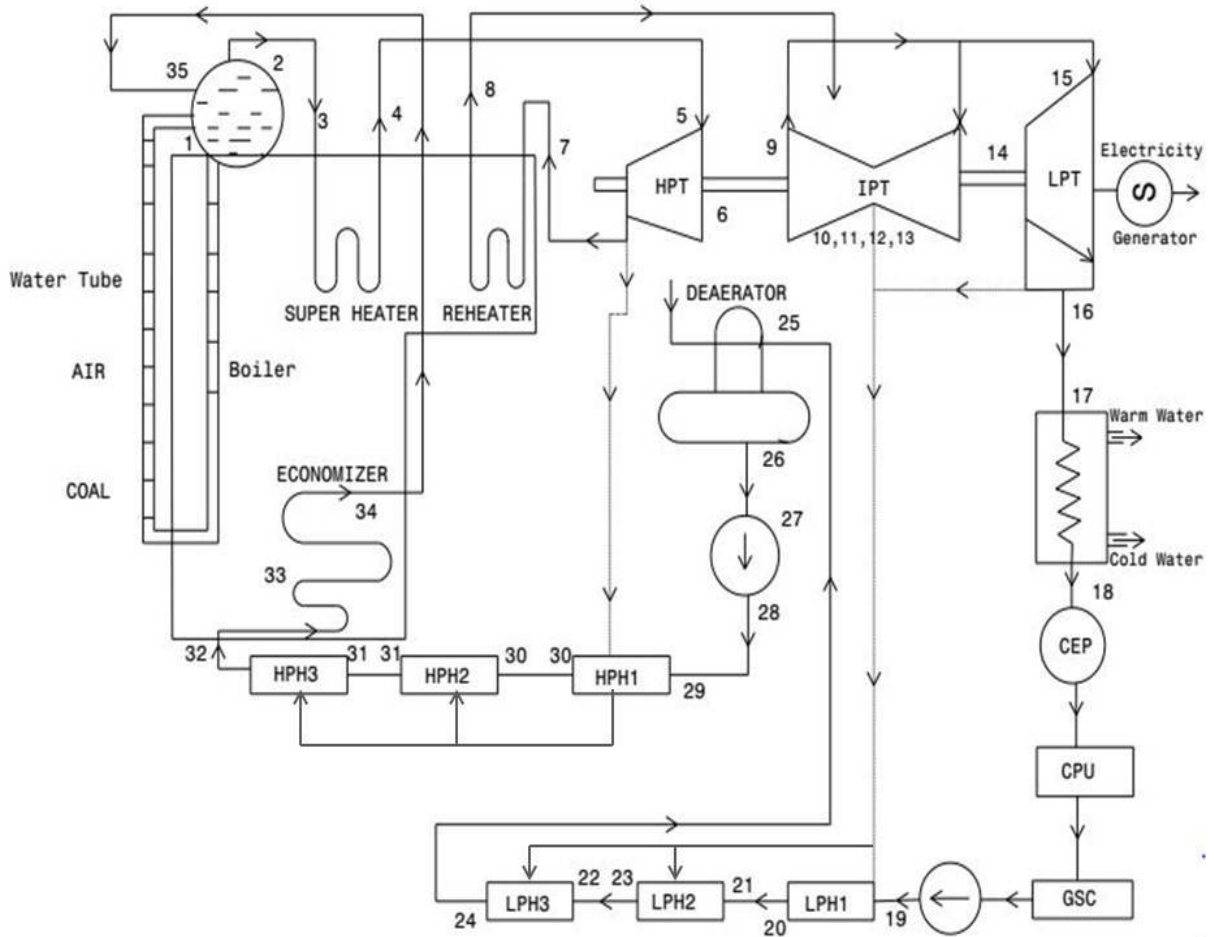
The specialty of this power plant is that the energy from the flue gas is not wasted .It is used in BPTS and GETS power is generated.

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LAYOUT OF THERMAL POWER PLANT

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II (i).OPERATING CONDITIONS OF THE RINL POWER PLANT

Table 1 :Overview Of Operating Conditions For Various Components For RINL Thermal Power Plant

Components	State points	T (° C)	P (bar)	m(kg/s)
Boiler Inlet	1	301	155	173.05
Outlet	2	355	145	173.05
S.H Inlet	3	355	145	173.05
Outlet	4	535	124	173.05
HPT Inlet	5	535	124	173.05
Outlet	6	320	30	165
R.H Inlet	7	320	30	165
Outlet	8	535	26	154.2
IPT Inlet	9	535	26	154.2
Tapping 1	10 (a)	440	12	154.2
Tapping 1	10 (b)	440	12	150.3
Tapping 2	11(a)	380	6.5	150.3
Tapping 2	11(b)	380	6.5	143
Tapping 3	12(a)	300	3	143
Tapping 3	12(b)	300	3	137.5
Tapping 4	13(a)	210	2	137.5
Tapping 4	13(b)	210	2	130.8
Outlet	14	180	1.3	130.8
LPT Inlet	15	180	1.3	130.8
Outlet	16	50	1	130.8
Condenser Inlet	17	50	1	130.8
Outlet	18	45	1	130.8
Deaerator Inlet	25	160	8.5	173.05
Outlet	26	170	7.9	173.05
BFP Inlet	27	170	7.9	173.05
Outlet	28	170	7.9	173.05
Eco Inlet	35	240	145	173.05
Outlet	36	275	137	173.05
LPH-1 Inlet(s)	19(a)	210	2	8.89
Inlet(w)	19(b)	88	16.68	130.08
Outlet	20	102	13.7	130.08
LPH-2 Inlet(s)	21(a)	380	6.5	10.49
Inlet(w)	22(b)	102	13.7	130.08
Outlet	22	130	12	143.3
LPH-3 Inlet(s)	23(a)	440	7.23	8.83
Inlet(w)	23(b)	130	12	143.3
Outlet	24	160	8.5	173.05
HPH-1 Inlet(s)	29(a)	320	30	10.49
Inlet(w)	29(b)	170	155	173.05
Outlet	30	197	150	173.05
HPH-2 Inlet(s)	31(a)	380	39.5	8.35
Inlet(w)	31(b)	197	150	173.05
Outlet	32	220	147	173.05
HPH-3 Inlet(s)	33(a)	440	12	7.23
Inlet(w)	33(b)	220	147	173.05
Outlet	34	240	145	173.05

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III. THERMODYNAMIC ANALYSIS

[6]Exergy is a measure of the maximum capacity of a system to perform useful work as it proceeds to a specified final state in equilibrium with its surroundings. Exergy is generally not conserved as energy but destroyed in the system. Exergy destruction is the measure of irreversibility that is the source of performance loss. Therefore, an exergy analysis assessing the magnitude of exergy destruction identifies the location, the magnitude and the source of thermodynamic inefficiencies in a thermal system.

Mass, energy, and exergy balances for any control volume at steady state with negligible potential and kinetic energy changes can be expressed, respectively, by

- $Q - W = \sum m_e h_e - \sum m_i h_i$
- $X^o - W = \sum m_e \Psi_e - \sum m_i \Psi_i$
- Specific exergy is given by $\Psi = (h-h_o)-T_o(s-s_o)$
- Total Exergy is given by $X^o = m^o [(h-h_o)-T_o(s-s_o)]$
- Exergy Destruction $I = Ex_{in} - Ex_{out} - W$
- Percentage Exergy Destruction = (Exergy destruction/Total exergy destruction of the power cycle) * 100

[7]Table 2 : Definitions of the exergy destruction rate and the exergy efficiency

Components	Exergy Destruction Rate	Exergy efficiency
Pumps	$I_{pump} = X^o_{in} - X^o_{out} + W_{pump}$	$\eta_{II pump} = 1 - (I_{pump} / W_{pump})$
Turbine	$I_{turbine} = X^o_{in} - X^o_{out} - W_{turbine}$	$\eta_{II} = 1 - (I_{turbine} / (X^o_{in} - X^o_{out}))$
Heaters	$I_{heater} = X^o_{in} - X^o_{out}$	$\eta_{II heater} = 1 - (I_{heater} / X^o_{in})$
Condenser	$I_{condenser} = X^o_{in} - X^o_{out} + W_{condenser}$	$\eta_{III con} = X^o_{out} / (X^o_{in} + W_c)$

IV. OPTIMIZATION

Optimization of power plant is carried out in MINITAB software by using **Response Surface Methodology**. Response surface methodology (RSM) is a collection of mathematical and statistical techniques for empirical model building. By careful design of experiments, the objective is to optimize a response (output variable) which is influenced by several independent variables (input variables). An experiment is a series of tests, called runs, in which changes are made in the input variables in order to identify the reasons for changes in the output response. The application of RSM to design optimization is aimed at reducing the cost of expensive analysis methods (e.g. finite element method or CFD analysis) and their associated numerical noise. The problem can be approximated as described with smooth functions that improve the convergence of the optimization process because they reduce the effects of noise and they allow for the use of derivative-based algorithms. Venter et al. (1996) have discussed the advantages of using RSM for design optimization applications.

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IV. RESULTS AND DISCUSSIONS

The power plant was analyzed using the above relations noting that the environment reference temperature and pressure are 301 K and 0.037 bar, respectively.

Table 3 :Overview Of Exergy Values For Various Components For RINL Thermal Power Plant

Components	State points	Enthalpy (kJ/kg)	Entropy (kJ/kg-K)	Exergy (ψ) (kJ/kg)	Total exergy (χ^0) (kW)
Boiler Inlet	1	1345.4	3.27	366.63	63460
Outlet	2	2530.4	5.14	987.86	170900
S.H Inlet	3	2530.4	5.14	987.86	170900
Outlet	4	3472.3	6.56	1503.2	260100
HPT Inlet	5	3472.3	6.56	1503.2	260100
Outlet	6	3044.0	6.62	1056.0	174200
R.H Inlet	7	3044.0	6.62	1056.0	174200
Outlet	8	3534.8	7.33	1334.3	205700
IPT Inlet	9	3534.8	7.33	1334.3	205700
Tapping 1	10 (a)	3302.3	7.45	1065.7	164300
Tapping 1	10 (b)	3302.3	7.45	1065.7	160200
Tapping 2	11(a)	3227.9	7.60	943.78	141900
Tapping 2	11(b)	3227.9	7.60	943.78	134960
Tapping 3	12(a)	3069.7	7.78	731.02	104500
Tapping 3	12(b)	3069.7	7.78	731.02	100500
Tapping 4	13(a)	2890.5	7.54	624.66	85800
Tapping 4	13(b)	2890.5	7.54	624.66	81700
Outlet	14	2830.3	7.56	558.14	73000
LPT Inlet	15	2830.3	7.56	558.14	73000
Outlet	16	2675.4	7.36	465.84	60930
Condenser Inlet	17	2675.4	7.36	465.84	60930
Outlet	18	419.1	1.3	31.502	4120
Deaerator Inlet	25	675.5	1.94	96.46	16693
Outlet	26	719.1	2.04	110.26	19080
BFP Inlet	27	719.1	2.04	110.26	19080
Outlet	28	705.8	1.97	117.52	20330
Eco Inlet	35	1037.6	2.70	230.10	39820
Outlet	36	1210.9	3.02	307.08	53140
LPH-1 Inlet(s)	19(a)	2890.5	7.54	626.76	5500
Inlet(w)	19(b)	368.5	1.16	22.4	2920
Outlet	20	427.5	1.32	33.28	4350
LPH-2 Inlet(s)	21(a)	3227.9	7.60	943.78	9900
Inlet(w)	22(b)	427.5	1.32	33.28	4350
Outlet	22	546.3	1.63	60.27	8630
LPH-3 Inlet(s)	23(a)	3302.3	7.45	1065.7	9400
Inlet(w)	23(b)	546.3	1.63	60.27	8630
Outlet	24	675.5	1.94	96.46	16693
HPH-1 Inlet(s)	29(a)	3044	6.62	1056	11070
Inlet(w)	29(b)	719.1	2.04	110.26	19080
Outlet	30	829.9	2.28	148.52	25700
HPH-2 Inlet(s)	31(a)	3227.9	7.60	943.78	7800
Inlet(w)	31(b)	829.9	2.28	148.52	25700
Outlet	32	943.7	2.51	191.59	33150
HPH-3 Inlet(s)	33(a)	3302.3	7.45	1065	7690
Inlet(w)	33(b)	943.7	2.51	191.59	33150
Outlet	34	1037.6	2.70	230.10	39820

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Table 4: Showing Exergy Destruction , Percentage Of Exergy Destruction & Exergy Efficiency

Components		Exergy destruction (MW)	Percentage exergy destruction (%)	Exergy Efficiency (%)
High pressure turbine	Stage 1	12.91	14.4	88.4
Intermediate pressure turbine	Stage 1	5.5	6.13	86.5
	Stage 2	6.7	7.47	62.2
	Stage 3	7.7	8.59	74.4
	Stage 4	9.9	11.04	71.2
	Stage 5	0.78	0.87	90.9
Low pressure turbine	Stage 1	7.87	8.78	72
Condenser		19.22	21.4	16.1
Pumps		1.05	1.17	54.3
LP Heaters	LPH 1	3.63	4.04	52
	LPH 2	5.25	5.85	60.5
	LPH 3	3.2	3.57	92.6
HP Heater	HPH 1	4.45	4.96	85.2
	HPH 2	0.45	0.5	98
	HPH 3	1.02	1.13	97.5
	Total cycle	89.63		

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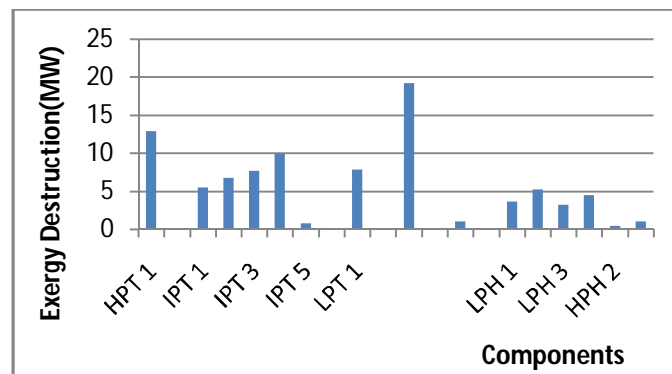
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V(i). GRAPHS

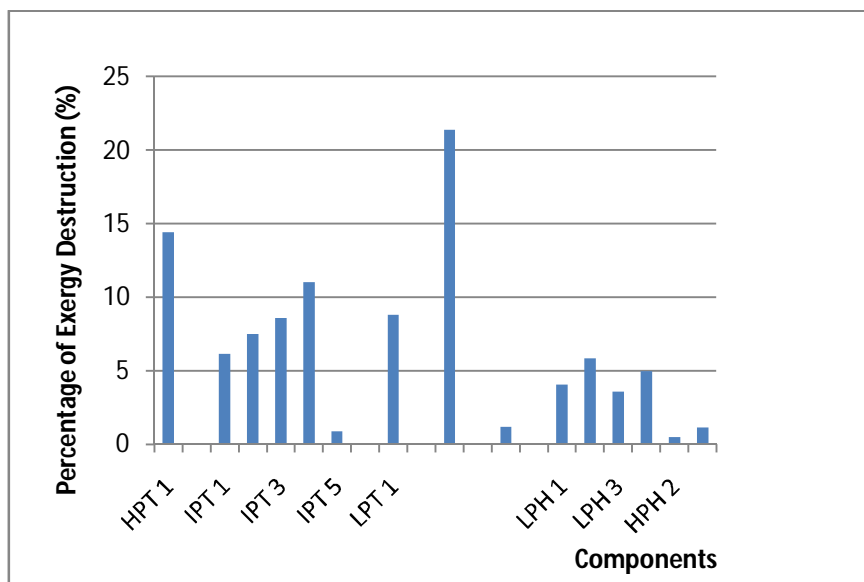
By using Table 3 the graphs a, b & c shows exergy destruction(MW) , exergy destruction percentage and exergy efficiency varies with the component

Graph (a) : Variation of exergy destruction(MW) with components



Graph (a) shows the variation of exergy destruction with power plant components. Components are located on X-axis & Exergy destruction is located on Y-axis as shown in graph (a). Exergy destruction is high in condenser as shown in graph (a).

Graph (b) : Variation of percentage of exergy destruction(%) with components



Graph (b) shows the variation of percentage of exergy destruction with power plant components. Components are located on X-axis & Percentage of exergy destruction is located on Y-axis as shown in graph (b). Percentage of exergy destruction is high in condenser as shown in graph (b).

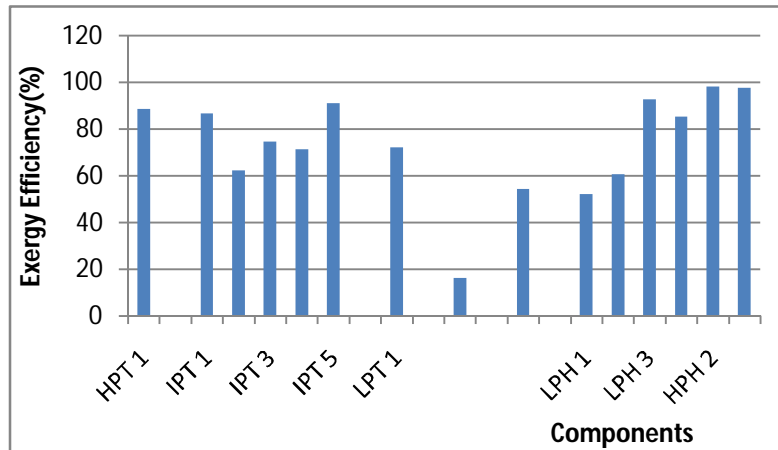
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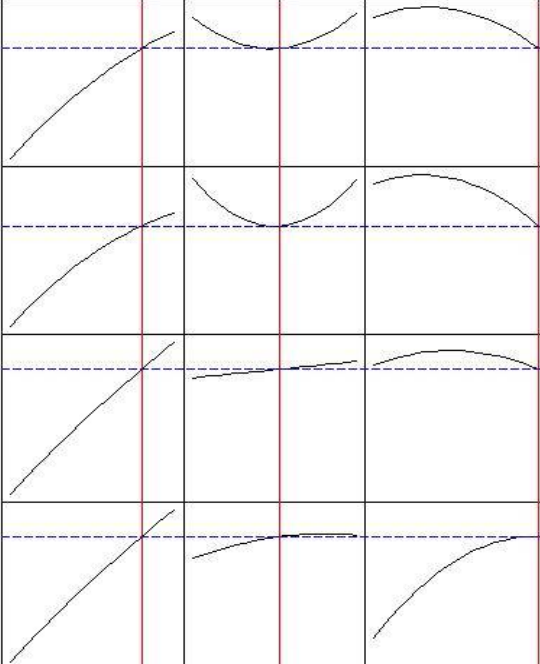
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Graph (c) : Variation of exergy efficiency(%) with components



Graph (c) shows the variation of exergy efficiency with power plant components. Components are located on X-axis & exergy efficiency is located on Y-axis as shown in graph (c). Exergy efficiency is high for High pressure heaters as shown in graph (c)

V(ii). OPTIMIZATION RESULTS

	Optimal D	Hi Cur	T (o C)	P (bar)	m(kg/s)
	0.66647	Lo	535.0 [436.4451] 45.0	155.0 [82.9580] 1.0	173.050 [173.050] 7.230
h(kJ/kg) Maximum y = 2178.6840 d = 0.57170					
s(kJ/kg- Minimum y = 3.6052 d = 0.62779					
ψ (kJ/kg) Maximum y = 1099.6372 d = 0.72747					
χo(kW) Maximum y = 1.973E+05 d = 0.75567					

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Optimization of power plant is carried out in MINITAB software to know the optimal values for better efficiency. We have two methods in MINITAB software. They are Taguchi method & Response surface methodology. By Response surface methodology, we got the optimal values which are shown in above figure. The optimal values are $T=436.5\text{ }^{\circ}\text{C}$, $P=82.9\text{ bar}$ & $m=173.05\text{ kg/s}$. These are the best values for better efficiency of power plant.

VI. CONCLUSION

This project has presented the results of an exergy analysis performed on 315 MW RINL Thermal power plant. The total exergy, exergy destruction, percentage of exergy destruction, exergy efficiency are calculated for various components with operating parameters. The values are tabulated in the Table no. 4.7 & 4.8. The operating parameters are taken when thermal power plant is working at max load of rated capacity. Table no 4.6 shows the overview of operating parameters for various components. The exergy destruction on plant components are presented.

- The results of the exergy indicate that boiler produces highest exergy destruction rate of 97.4 MW. The exergy analysis of the plant showed that lost energy in the boiler thermodynamically significant due to its squality. So some improvements should be recommended.
- Comparing the 3 turbine stages, the results of analysis indicate that High pressure turbine produces highest exergy destruction rate of 12.91 MW than Intermediate pressure turbine and Low pressure turbine. It was found that exergy destruction rate of the turbine is dominant over all other irreversibilities in the power plant.
- In case of power producing equipments, the High pressure turbine & Intermediate pressure turbine has high efficiency and Low pressure turbine has lowest efficiency. This indicates that entropy generation is high in Low pressure turbine.
- In condenser the efficiency is low and exergy destruction is high. The condenser operates at low temperature and work potential is low. Though the quantity of exergy losses is high but it can be neglected due to low quality of heat energy. Exergy analysis of plant showed that lost energy in the condenser is thermodynamically insignificant due to its low quality.
- In pump workdone is less compared to turbine work. Exergy destruction at pumps is too small compared to that at other components. Exergy analysis of plant showed that lost energy in pump is thermodynamically insignificant due its less energy.
- The exergy efficiency is high for High pressure heaters when compared to Low pressure heaters as shown in table no 4.8. High pressure heater – 2 has maximum efficiency of 98% as shown in table no 4.8.
- Exergy Destruction is less in Low pressure heaters & High pressure heaters. In Low pressure heater -2 & High pressure heater - 1 maximum exergy destruction causes which are 5.25 MW and 4.45 MW respectively as shown in table no 4.8.
- The highest exergy destruction occurs because the low pressure steam has high entropy value.
- The calculated exergy efficiency of each component in power plant at max load should compare with modern power plants for better efficiency. This indicates that tremendous opportunities are available for improvement. However, part of this irreversibility cannot be avoided due to physical, technological and economic constraints.

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Nomenclature

h Specific enthalpy (kJ/kg)

s specific entropy (kJ/kg-K)

I Exergy destruction rate (kW)

\dot{m} Mass flow rate (kg/s)

W Work done rate or power
 X^o Total exergy rate (kW)
done by the system (kW)

Q Heat transfer rate to the system (kW)

Greek symbols

η_{II} efficiency ψ Specific exergy (J/kg)

Subscripts

e exit i inlet