Exergy Analysis of 210 Mw of Vijayawada Thermal Power Station (V.T.P.S)

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Abstract: **Power generation has become a vital factor for the development of nation. As there are limited resources of fossil fuels it is necessary to utilize efficiently in thermal systems. Generally the power plants performance is analyzed using Energy Balance and first law of Thermodynamic efficiency. Exergy analysis is pertinent than energy analysis in the thermal systems as it also considers the quality of energy source. In this study exergy analysis for different components of a 210 MW thermal power plant has been performed and the results show that the exergy destruction is more in the Intermediate Pressure Turbine. Exergetic efficiency is compared with the thermal efficiency**

Key Words: Exergy, Exergetic efficiency, thermal efficiency.

I. INTRODUCTION

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% [1] 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. [1]

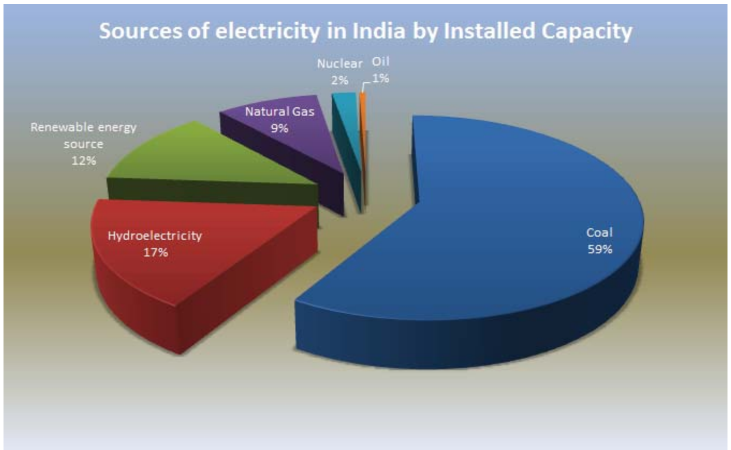


Fig 1 Sources of electricity in INDIA by installed capacity as of 2013[2]

One of the indicators which show the development and living standards a community is Energy Consumption. The performance of any power plant is evaluated through energetic performance criteria which are based on First law of thermodynamic. It is a simple energy balance without taking into account the quality of energy used. Exergetic analysis, based on second law of thermodynamics, takes in to account the energy quality. The energetic and exergetic analysis will provide a complete picture to improve the plant efficiency.

II. LAYOUT OF STEAM POWER PLANT

Fig. 2 gives the general layout the thermal power plant. The following section briefly describes the components across which energy transfer occurs.

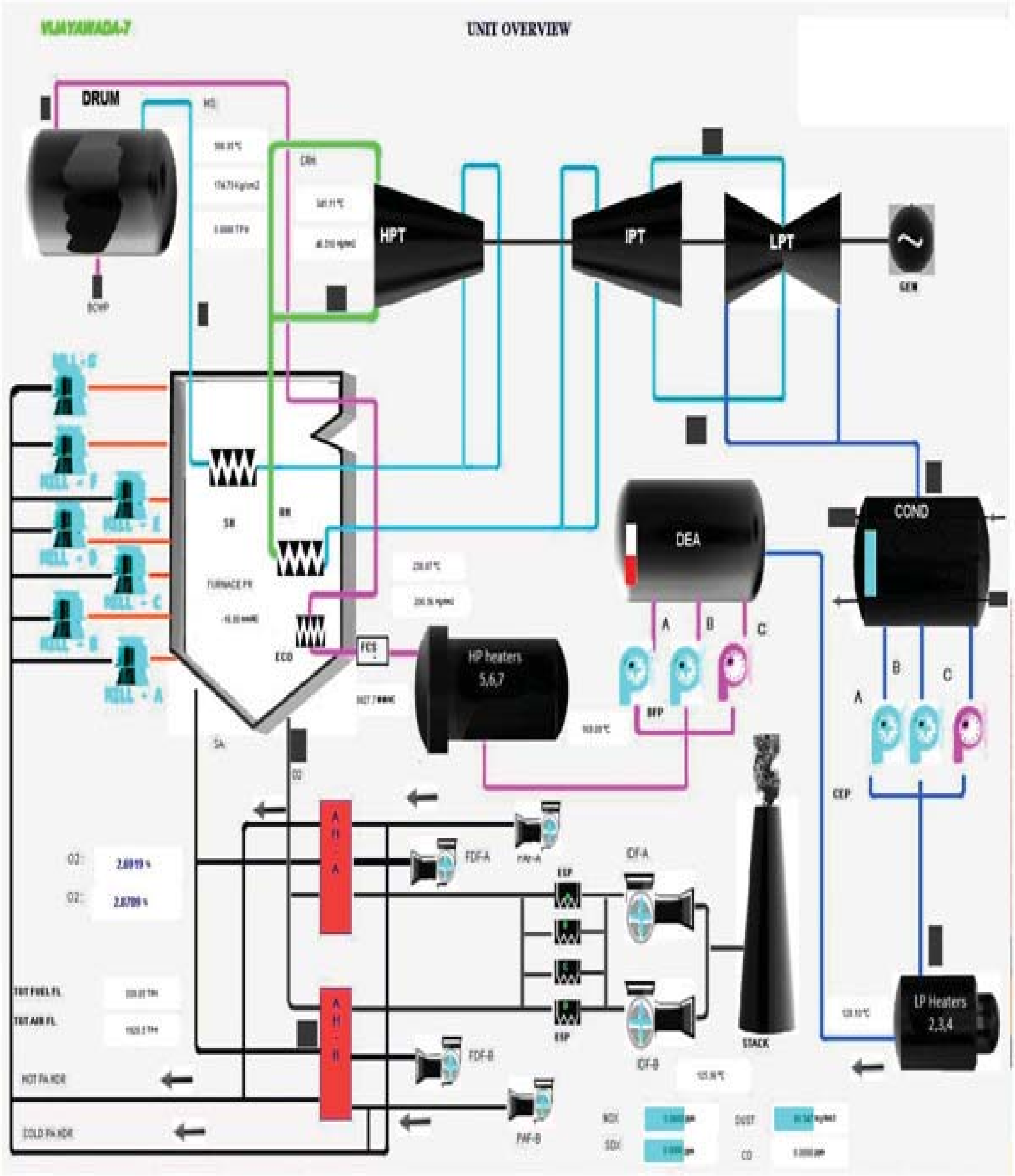


Fig 2 Layout of steam power plant

2.1 Individual Components:

2.1.1 Boiler: Boiler is an enclosed vessel in which water is heated and circulated until the water gets converted into steam at the required pressure. In V.T.P.S water tube boilers are being used.

2.1.1 Super-heater:

The purpose of super heater is to heat the steam which is coming from the boiler drum in order to reach the required super heated state before entering the turbine.

2.1.2 Re-heater:

Steam from high pressure turbine is re-heated before entering to intermittent and low pressure turbines.

2.1.3 Economiser:

Flue gases coming out of the boiler carry lot of heat. Function of economiser is to recover some of the heat from the heat carried away in the flue gases up the chimney and utilize for heating the feed water to the boiler. It is placed in the passage of flue gases in between the exit from the boiler and the entry to the chimney. The use of economiser results in saving in coal consumption, and high boiler efficiency. [3]

2.1.4 Turbines:

A turbine is a mechanical device which extracts energy from fluid flow and converts into useful work. In V.T.P.S Impulse-reaction turbine is used. There are 3 turbines namely High pressure turbine (HPT), Intermediate pressure turbine and Low pressure turbine. The inlet to the HPT is steam coming from Super-heater with a temperature of 535 ^{O}C and pressure 128 bar.

2.1.5 Deaerator:

The purpose of deaerator is to remove oxygen and other dissolved gases from the feed water. Because if at all if there are any traces of oxygen and other dissolved gases there is serious effect of corrosion which will damage the wall of the piping. Spray type deaerator is being used in V.T.P.S

2.1.6 Condenser:

Steam coming from the turbines enters the condenser. Shell and tube heat exchanger (or surface condenser) installed at the outlet of steam turbine in Thermal power stations in general. These condensers are heat exchangers which convert steam from its gaseous to its liquid state, also known as phase transition. In so doing, the latent heat of steam is given out inside the condenser. In V.T.P.S surface condenser is in use.

2.1.7 Feed water Heaters:

Feed water heaters are the heaters which are used in power plants to heat the feed water before entering into the boiler.

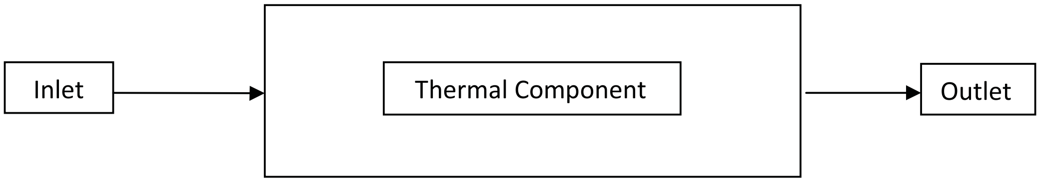
III. EXERGY MODELLING

3.1 Exergy Definition:

An energy source at a particular level (temperature) contains certain quantity of energy and cable to deliver definite work with respective to a reference state. The same quantity of energy at a higher level (temperature) will deliver more amount of work with respect to same reference state. Thus high quality (temperature) energy source has higher work potential. In order to determine the work potential of a energy source the concept of exergy is introduced. The term "exergy" was first coined by Zoran Rant in the year 1956 which is originated from Greek where ex and ergon meaning "from work" but the concept was developed by J. Willard Gibbs in 1873.

Exergy is defined as maximum possible work during a reversible process [4]. The most convenient way to obtain maximum work is from a given state of energy is by considering the environmental conditions so that we can keep them as reference [5]. In the dead state the temperature and pressure values are it environmental values. The notion is that to have a maximum work output it necessary that that a system must go to the dead state at the end of the process which can be explained as follows: If the temperature of the system temperature at the final state is higher or lesser than the temperature of the environment it is in, we can always produce additional work by running a heat engine between these two temperature levels. Likewise if the final pressure is higher or lower than the pressure of the environment, we can still obtain work by letting the system expand to the pressure o f the environment. The atmosphere around us contains a tremendous amount of energy. However, the atmosphere is in the dead state, and the energy it contains has no work potential Therefore, we conclude that a system delivers the maximum possible work as it undergoes a reversible process from the specified initial state to the state o f its environment, that is, the dead state. This represents the useful work potential of the system at the specified state and is called exergy. There will always be a difference, large or small, between exergy and the actual work delivered by a device. This difference represents the room engineers have for improvement. Exergy depends upon the environmental conditions as well as on the properties of the system. Therefore, exergy is a property of system and environment combination. [6]

3.2 Exergy Modelling for thermal Components:



Specific exergy for boiler is given by [7]:

$$- (h - h_0) - T_0 (s - s_0) \text{--------- >1}$$

Where h_o, s_o, T_o represents the reference state point (standard environment)

Total Exergy is given by

$$\dot{X} = \dot{m}$$

$$= \dot{m}[(h - h_0) - T_0(s - s_0)] \text{-------------} \rightarrow 2$$

Where $\dot{m}$ is the mass flow rate.

Exergy at the inlet =

$$\text{Ex}_{\text{in}} = \dot{m}[(h_1 - h_0) - T_0(s_1 - s_0)] \text{------------} \rightarrow 3$$

Exergy at the outlet =

$$\text{Ex}_{\text{out}}\ \dot{m}[(h_2 - h_0) - T_0(s_2 - s_0)] \text{------------} \rightarrow 4$$

Exergy Destruction (I) =

$$I = \text{Ex}_{\text{in}} - \text{Ex}_{\text{out}} - W \text{----------------} \rightarrow 5$$

Percentage Exergy Destruction = (Exergy destruction/Total exergy destruction of the power cycle) * 100------ →6

Second law efficiency or Exergy efficiency is defined as the

1. Actual work done to Maximum theoretical work [4]

$$\eta_{II} = \frac{\text{Actual Workdone}}{\text{Maximum theoritical work}} \text{--------------} \rightarrow 7$$

In other words it is defined as

2. Actual thermal efficiency to the maximum possible thermal efficiency [7]

$$\eta_{II} = \frac{\text{Exergy Output}}{\text{Exergy Input}} \text{----------------} \rightarrow 8$$

IV. LAYOUT OF TURBINE HOUSE

The layout of the turbine and other thermal components of VTPS is shown in fig.3. The inlet and outlet of each thermal component are numbered as shown. Also, the operating states (pressure, temperature and mass flow rate) of steam/water at each component inlet and outlet are mentioned.

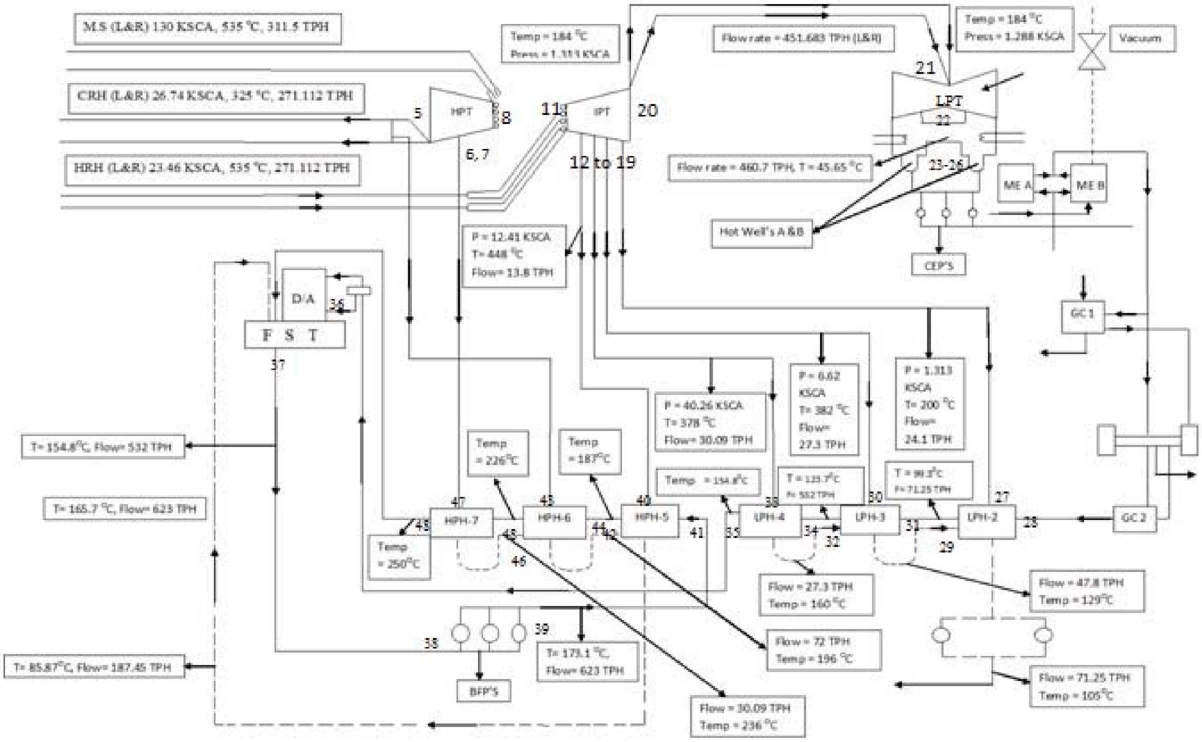


Fig 3 Layout of Turbine house of a 210 MW plant of VIjayawada Thermal Power Station

The exergy of the components at inlet and outlet points are calculated using equations 3 and 4. The results are tabulated in table no1. The exergy of heaters of HPT and LPT are tabulated in Table no 2 and 3.

TABLE 1: SHOWING EXERGY VALUES FOR VARIOUS COMPONENTS

COMPONENTS	Points	T (^{o}C)	P (bar)	$\dot{m}$ (kg/s)	H (kJ/kg)	Entropy (kJ/kg-K)	Ψ (kJ/kg)	$\dot{X}$ (MW)
Economizer inlet	1	247	145	173.05	1071.81	2.741	258.99	44.81
Economizer outlet	2	278	137	173.05	1205.16	3.026	306.84	53.09
S.H inlet	3	345	128	173.05	2930	5.9	1169.48	202.37
S.H Outlet	4	535	128	173.05	3430.12	6.561	1471.3	254.6
HPT inlet	5	535	128	173.05	3430.12	6.561	1471.3	254.6
Tapping	6	378	40	173.05	3113.23	6.6911	1115.38	193.01
Tapping	7	378	40	165	3113.23	6.6911	1115.38	184.03
HPT Outlet	8	330	26	165	3078.62	6.7444	1064.78	175.68
R.H Inlet	9	330	26	165	3078.62	6.7444	1064.78	175.67
R.H outlet	10	535	23	154.20	3539.87	7.459	1311.85	202.02
IPT Inlet	11	535	23	154.20	3539.87	7.459	1311.85	202.02
Tapping 1	12	448	12	154.20	3364.39	7.522	1117.23	172.05
tapping 1	13	448	12	150.36	3364.39	7.522	1117.23	167.986
Tapping 2	14	380	6.5	150.36	3227.98	7.6081	955.03	143.59

Tapping 2	15	380	6.5	143	3227.98	7.6081	955.03	136.56
Tapping 3	16	265	2.8	143	2999.18	7.616	723.86	103.511
Tapping 3	17	265	2.8	137.5	2999.18	7.616	723.86	99.530
Tapping 4	18	200	1.5	137.5	2872.9	7.644	589.18	81.012
Tapping 4	19	200	1.5	130.80	2872.9	7.644	589.18	77.064
IPT outlet	20	184	1.3	130.80	2842.3	7.668	551.31	72.11
LPT inlet	21	184	1.3	130.80	2842.3	7.668	551.31	72.11
LPT Outlet	22	50	0.1	130.80	2600	8.16	161.48	21.12
Condenser inlet1	23	50	0.1	130.80	2600	8.16	161.48	21.12
Condenser inlet 2	24	30	1.013	808	125.83	0.436	4.21	3.40
Condenser outlet 1	25	45	0.1	130.80	191.8	0.649	6.58	0.860
Condenser outlet 2	26	40	1.013	808	167.62	0.572	5.5	4.44
DEAERATOR INLET	36	154.5	8.5	147.7	651.9	1.887	95.28	14.07
DEAERATOR OUTLET	37	165	7.16	173.05	697.35	1.992	109.23	18.90
BFP INLET	38	165	7.16	173.05	697.35	1.992	109.23	18.90
BFP OUTLET	39	165	155	173.05	705.889	1.974	123.169	21.31

TABLE 2: SHOWING EXERGY VALUES FOR LP HEATERS

COMPONENTS	**Points**	**T (^oC)**	**P (bar)**	**o m (kg/s)**	**H (kJ/kg)**	**Entropy (kJ/kg-K)**	**Ψ (kJ/kg)**	**O X (MW)**
LPH 2 inlet 1(S)	27	200	1.5	6.69	2872.9	7.644	589.18	3.94
LPH 2 inlet 2(W)	28	87	16.68	130.80	365.60	1.156	28.28	3.69
LPH 2 Outlet	29	99.3	13.7	130.80	417.10	1.298	37.18	4.86
LPH 3 inlet 1(S)	30	265	2.78	5.5	2999.18	7.616	723.86	3.98
LPH 3 inlet 2(W)	31	106	13.7	130.80	417.10	1.298	37.18	5.60
LPH 3 Outlet	32	120	12	147.7	504.48	1.526	50.10	8.29
LPH 4 inlet 1(S)	33	381.5	6.49	7.23	3227.98	7.6081	955.03	7.23
LPH 4 inlet 2(W)	34	120	12	147.7	504.48	1.526	50.10	8.29
LPH 4 Outlet	35	154.5	8.5	147.7	651.90	1.887	95.28	14.07

TABLE 3: SHOWING EXERGY VALUES FOR HP HEATERS

COMPONENTS	**Points**	**T (^oC)**	**P (bar)**	**o m (kg/s)**	**H (kJ/kg)**	**Entropy (kJ/kg-K)**	**Ψ (kJ/kg)**	**. X (MW)**
HPH 5 inlet 1(S)	40	448	12.17	3.83	3364.39	7.522	1117.27	4.282
HPH 5 inlet 2(W)	41	173.1	155	173.05	740.81	2.053	134.39	23.25
HPH 5 Outlet	42	187	150	173.05	804.03	2.194	155.31	26.87
HPH 6 inlet 1(S)	43	325	26.24	10.49	3066.75	6.7249	1058.76	11.10
HPH 6 inlet 2(W)	44	187	150	173.05	804.03	2.194	155.31	26.87
HPH 6 Outlet	45	226	147.2	173.05	974.63	2.550	219.11	37.91
HPH 7 inlet 1(S)	46	378	39.5	8.35	3113.23	6.6911	1115.38	9.313
HPH 7 inlet 2(W)	47	226	147.2	173.05	974.63	2.550	219.11	37.91
HPH 7 Outlet	48	247	145	173.05	1071.81	2.741	258.99	44.81

4. DISCUSSIONS

In the present study exergetic analysis of a 210 MW plant of Vijayawada Thermal Power Plant is performed. Using the values in Table no's 1 to 3, the exergy destruction, percentage exergy destruction and second law efficiencies are calculated for various components as per equations 5, 6 and 7. The values are tabulated in Table no. 4. The values are the plant working 95% of rated capacity.

TABLE 4: SHOWING EXERGY, PERCENTAGE OF EXERGY DESTRUCTION AND SECOND LAW EFFICIENCY.

Loading		**@ 95% loading**		
Components		**Exergy destruction(MW)**	**Percentage exergy destruction (%)**	**2nd Law efficiency (%)**
High Pressure Turbine	Stage 1	6.76	9.99	89.03
	Stage 2	2.64	3.90	68.39
Intermediate Pressure Turbine	Stage 1	2.91	4.30	90.28
	Stage 2	3.886	5.74	84.07
	Stage 3	0.339	0.50	98.99
	Stage 4	1.158	1.71	93.76
	Stage 5	1.11652	1.65	80.79
Low Pressure Turbine	Stage 1	19.29	28.52	62.14
Total		**38.09**		77
Condenser		19.22	28.42	21.45
Pumps		2.41	3.56	60.25
LP Heaters	LPH 2	2.77	4.09	63.69
	LPH 3	0.74	1.09	91.62
	LPH 4	1.26	1.86	91.78
HP Heaters	HPH 5	0.662	0.97	97.59
	HPH 6	0.06	0.08	99.84
	HPH 7	2.413	3.56	94.89
Total		**7.905**		
Power Cycle		67.625		

Figures 4, 5 and 6 shows exergy efficiency, exergy destruction, and percentage exergy destruction varies with the components.

The exergy or second law efficiency are high for HPH as observed from fig.4. In case of power producing equipments, the IPT has high exergy efficiency and LPT has lowest efficiency. This indicates that in HPT and LPT the entropy generation is high and there is scope to improve the process. In condenser the efficiency is low and exergy destruction is high. The condenser operates at low temperatures 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.

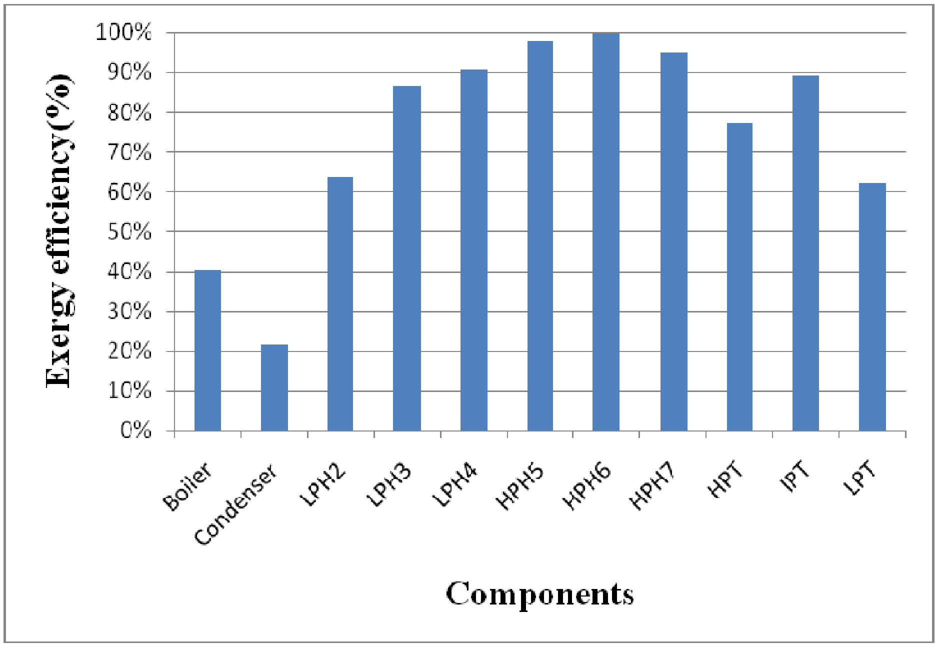


Fig 4: Variation of exergetic efficiency with the components

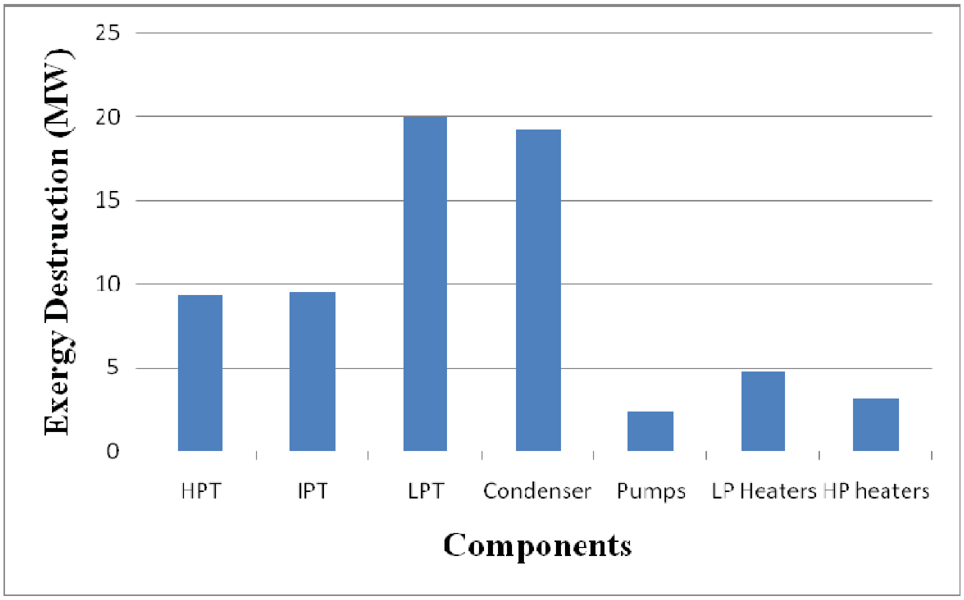


Fig 5: Variation of exergy destruction with the components [9]

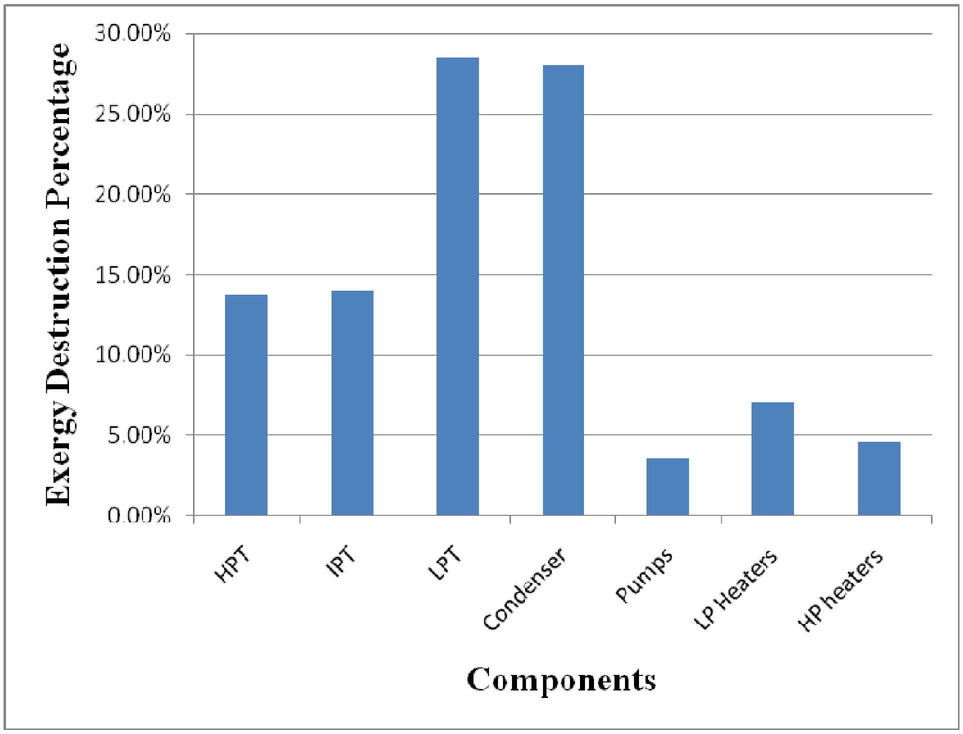


Fig 6: Variation of percentage of exergy destruction with the components

V. CONCLUSIONS

Exergy analysis of a 210 MW plant of Vijayawada Thermal power station was performed and it is found that that the maximum exergy destruction rate is observed in the Low pressure turbine which shows that there is a scope to develop the efficiency but practically it's not possible because of the physical and economical constraints.

VI. NOMENCLATURE

h =Specific enthalpy (kJ/kg)

s =Specific entropy (kJ/kg K)

h_o =Specific enthalpy at ambient condition (kJ/kg)

s_o =Specific entropy at ambient condition (kJ/kg-K)

$\dot{I}$ =Exergy destruction rate (MW)

T =Temperature (^oC)

m' = Mass flow rate (kg/s)

W= Work done rate or power done by the system (MW)

P= Pressure (bar)

=Specific exergy (kJ/kg)

$\dot{X}$ =Total energy rate (MW)

η_{II} = Second Law Efficiency

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