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Investigation of Influencing Process Parameters to Energy and Exergy Efficiencies of a Coal Fired Thermal Power Plant using Cycle Tempo

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Abstract— This work is carried out to study the effect of various process parameters upon plant efficiencies in order to prioritise them for posssible improvement in utilisation of input energy. In the process a flow sheet computer program "Cycle Tempo 5" has been used for modeling and simulation of a 250MW coal fired thermal power plant. Effects of individual parameters upon plant energy and exergy efficiency are investigated and the energy and exergy balance diagram is also drawn. The condenser pressure is found to be the most influencing factor which on changing from 0.1bar to 0.12bar both the energy and exergy efficiency reduces by 0.4%. Main steam pressure, reheat steam temperature and pressure are also affecting the performance considerably while main steam temperature is found to be the least affecting parameter among the studied one. Energy balance diagram clearly shows that the major portion of energy loss takes place at condenser while boiler is the component causing major exergy loss as seen from the exergy balance diagram.

Keywords— Process parameters, Efficiencies, Simulation, Cycle Tempo, Energy and exergy balance.

I. INTRODUCTION

Coal has been the major conventional source for power generation in India. Even with the steadily growing share of renewable sources in total power generation, more than two-third of it is still coming from thermal power plants in which the share of coal is more than 88% [1]. This fact alone is sufficient enough to understand the importance of maximization of efficiency of coal based thermal power plants. In last few decades, the concept of exergy has increasingly been used in the design of thermal systems. The exergy concept emphasizes the minimization of exergy destruction, so that both the quanitative and qualitative use of energy can be ensured. In the series of attempts made by several author to analyse the energetic and exergetic performance of thermal power plants Suresh et al. [2] analyzed a 62.5MW coal based thermal power plant on a case study basis by using a flow-sheet program 'Cycle Tempo' and found that the energy efficiency was reduced to 28.5% at 40% load factor in comparison to 31.5% at designed rating. They also presented the variation of overall energy and exergy efficiency with parameters such as temperature gain of cooling water across the condenser, excess air and condenser pressure.

Jamel et al. [3] simulated a 200MW gas fuelled steam power plant and estimated the thermodynamic performance of the considered power plant by using Cycle Tempo flow-sheet program. Badi and Fathoni [4] carried out a thermodynamic study of a combined cycle power plant by Cycle Tempo software. As a result the heat rate found at 50% load was 2217.3kCal/kWh and that at 100% load was 1861.75kCal/kWh. Ravindra Kumar et al. [5] optimize the extraction pressures for three different cycles of a coal fired thermal power plant by keeping the main steam temperature, reheat temperature and condenser pressure as constant.

Mukesh Gupta and Raj Kumar [6] analyze the effect of hot air temperature on the thermoeconomic performance of a boiler used in a coal fired thermal power plant by developing a thermoeconomic model of the boiler. They studied the effect of air preheater temperature on exergetic efficiency of the boiler, unit product cost of boiler and air preheater. Ahmadi et al. [7] investigated a steam cycle and determined the effect of changes in turbine inlet temperature and pressure, mass of steam extraction and condenser pressure and calculated the energy and exergy efficiency, energy and exergy losses and exergy destruction in main equipments of the plant by using energy equation solver software. Rashidi et al. [8] in a research work carried out the exergy and irreversibility analysis of each component of steam cycle. They investigated the effects of turbine inlet pressure, boiler exit steam temperature and condenser pressure on the first and second law efficiencies and also they obtain the best turbine extraction pressure on the first law efficiency.

Mehdi and Vosough [9] in an energy and exergy concept based analysis of a thermal power plant found the highest irreversibility at boiler followed by the turbines. Effect of ambient temperature on energy and exergy efficiency at constant and variable condenser pressure were also analyzed by them. Abtin Ataei and Chang Kyoo Yoo [10] simulated a 325MW steam power plant in a Cycle Tempo 5.0 simulator and optimize the operational parameters of Rankine cycle using exergy concept combined with a pinch-based approach and concluded that the fuel consumption could be reduced by 5.3% and cycle thermal efficiency could be increased by 2.5% and cooling load reduction of 18.77MW could be achieved. They estimated the yearly reduction of green house gas emission as 63226 tons, equivalent to not using 11580 cars and light trucks.

Akolekar et al. [11] in a research work, attempted to optimize reheat and regenerative cycle process parameters such as reheat pressure, tapping pressure of bled steam and mass fraction of bled steam by using a Microsot Visual Studio simulation program. Yunus et al. [12] in an analysis for energy efficiency improvement of a thermal power plant estimated the performance first by component wise modeling followed by a system simulation. They conducted the parametric study under various operating conditons including change in condenser pressure, temperature and flow rate of cooling water across the condenser, ambient air temperature, steam pressure and temperature and load factor.

Geete and Khandwawala ([13] in an exergy analysis for different components of 120MW thermal power plant analyzed the performance by varying inlet steam temperature from 507.78^{o}C to 567.78^{o}C. Rosen and Tang [14] in second part of their study using energy and exergy analysis investigated the effect of increasing reheat pressure and concluded that though irreversibility rate decreased with increase in reheat pressure, the overall plant exergy efficiency decreases. Aljundi I. H. [15] in an energy and exergy analyses of steam power plant studied the effect of reference environment temperature on the exergy efficiency of major plant components. Vosough Amir et al. [16] determined the performance of the considered plant by a component wise modeling and presented the detailed break-up of energy and exergy losses for the plant. He also studied the effect of varying the condenser pressure on the subcritical boiler. Vosough Amir [17] studied the improvement of steam power plant efficiency through exergy analysis with varying ambient temperature. Paper studied the effect of decreasing the excess combustion air fraction and/or the stack gas temperature and result was increase in overall-plant energy and exergy efficiencies by 0.19% and 0.37% respectively when the fraction of excess combustion air decreases from 0.4 to 0.15, and by 0.84% and 2.3% when the stack gas temperature decreases form 137°C to 90°C. Vosough Amir and Vosough Sadegh [18] in an energy and exergy analysis of a power plant studied the effect of varying the reference environment and found that for a moderate change in the reference environment state temperature, no drastic change occurs in the performance of major components. Soundhar J. et al.[19] in an analyses concluded that the condenser pressure is an important parameter that affects the output power and thermal and exergy efficiency of the cycle and suggested that considering the inherent limitation of this parameter as well as the turbine limitation, the minimum allowable condenser pressure should be chosen to produce maximum efficiency. Adeyinka et al. [20] calculated the overall efficiency of the plant as well as effect of varying the condenser pressure and environment temperature. They found that an increase in the reference environment temperature increases the Rankine efficiency and exergy efficiency of the plant. Also as the condenser pressure increases, the efficiency of the plant decreases. Rosen and Tang [21] examined the effect of decreasing the fraction of excess combustion air, and/or the stack-gas temperature. They found that overall-plant energy and exergy efficiencies both increases by 1.4% when the fraction of excess combustion air decreases from 0.4 to 0.15 and by 3.5% when the exhaust gas temperature decreases from 149°C to 87°C. With the decrease in both, plant energy and exergy efficiencies both increases by 4.1%. They observed that the plant energy and exergy efficiencies both increase by 4.7% when the stack-gas temperature is 87°C and theoretical combustion air is used. Regulagadda et al. [22] in a parametric study of 32MW coal fired thermal power plant determined the parameters that maximize plant performance. Literature survey clearly shows that most of the earlier works in the field were focussed to determine the performance of existing plants and influence of parameters like ambient temperature, air-fuel ratio, flue gas exhaust temperature etc. Therefore, this research work has been taken to investigate the influence of some process parameters which seems to have considerable affect over plant energy and exergy efficiency by using the advanced simulation tool like Cycle Tempo.

This paper is arranged in seven sections. Background behind choosing the currrent topic for research and brief account of work carried out so far by various authors in the related field are given under section I. A brief description of the plant is given in section II. Methodology adapted for the current research is explained in Section III while the method of calculating energy and exergy efficiency is given in section IV. Results of the study and their interpretation are provided in secftion V. Outcome of the research is summarized in section VI and scope for further research in the field is suggested in the final section.

II. PLANT DESCRIPTION

Plant details are already described in author's earlier research paper [23]. The plant has two units of 250MW capacity each. Unit no. 1 has been considered for the study which consists of a high pressure turbine, an intermediate pressure turbine, a low pressure turbine, three low-pressure heaters, gland steam condenser, drain cooler, deaerator and two high pressure heaters. The heat exchanger section in boiler comprises evaporator, reheater and superheaters.

III. METHODOLOGY

Methodology for this research work involves the following major steps:

A. Simulation

In the present study, a flow-sheet program Cycle Tempo 5 [24] has been used. Cycle Tempo is a computer program for thermodynamic modeling and optimization of energy conversion systems. It can be used for a variety of purposes for example to calculate and optimise the process variables, to determine the consequences of a change in operation, and to evaluate and test the results.

At first, the simulation model of 250MW coal fired thermal power plant at Korba, India for its operation at designed load is prepared by drawing all appratuses and pipes. The simulation process was considered to be successful when run time message indicates **zero warning and zero error.** Schemetic layout of Cycle Tempo model of the considered power plant is shown in Figure 1.

Assumptions: Flow-sheet program requires some assumptions to be made before starting the process of simulation. These assumptions are:

1. Ambient pressure and temperature of the reference environment is taken as 1.013bar and 27^{o}C respectively.
   Reference Environment Composition: Element Mole fraction (%) [24]:
   N_2 = 75.65
   O_2 = 20.30
   H_2O = 3.12
   CO_2 = 0.03
   Ar = 0.90
2. Kinetic and potential energies are negligible.
3 All the components are operating at study state conditions..

B. Validation of Simulated Model

After the successful simulation, next step is to compare the process data of simulated model with that of plant records. The thermodynamic properties of the cycle as obtained from the modeling and the power plant data as given by Patel and Agrawal [23] are illustrated in Table 1. Simulation process is considered successful as the two values of the plant parameters are in close agreement except small deviations in few ones which are due to some assumptions and default values inherently applied in the Cycle Tempo software.

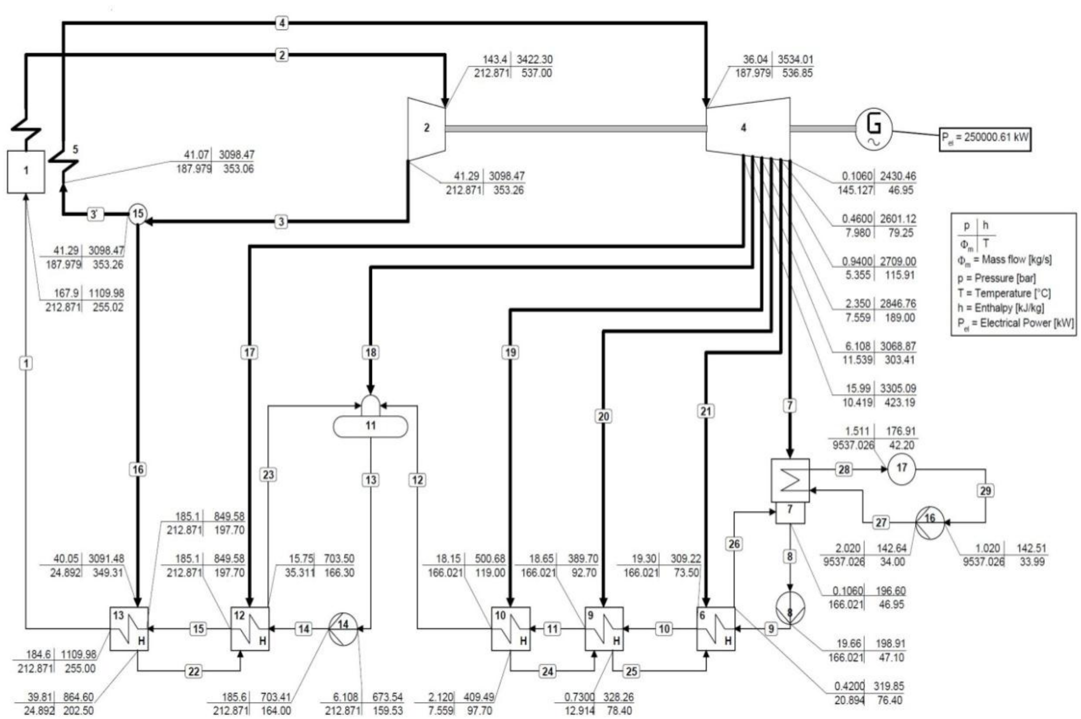

Figure1. Schematic layout of Cycle Tempo model of the power plant

Table 1. Validation of stream data of 250MW thermal power plant with the software 'Cycle Tempo'

Point	t (°C) Operation	t (°C) Simulation	% Variation	p (bar) Operation	p (bar) Simulation	% Variation	m (kg/s) Operation	m (kg/s) Simulation	% Variation
1	255.00	255.02	0.0	167.78	167.9	0.07	204.79	212.87	3.94
2	537.00	537.00	0.0	143.75	143.4	– 0.24	204.79	212.87	3.94
3	347.20	353.26	1.74	40.05	41.29	3.09	204.79	212.87	3.94
3'	347.20	353.06	1.74	40.05	41.07	2.54	183.24	187.98	2.59
4	537.00	536.85	– 0.03	36.04	36.04	0.0	183.24	187.98	2.59
7	46.30	46.95	1.4	0.106	0.106	0.0	141.33	145.12	2.69
8	46.30	46.95	1.4	0.106	0.106	0.0	162.78	166.02	1.99
9	46.50	47.10	1.3	19.66	19.66	0.0	162.78	166.02	1.99
10	73.50	73.50	0.0	19.66	19.15	– 2.6	162.78	166.02	1.99
11	92.70	92.70	0.0	19.66	18.65	–5.1	162.78	166.02	1.99
12	119.80	119.20	– 0.5	19.18	18.15	–5.3	162.78	166.02	1.99
13	158.30	159.53	0.77	6.108	6.108	0.0	204.79	212.87	3.94
14	161.40	164.00	1.61	185.56	185.6	0.21	204.79	212.87	3.94
15	197.70	197.70	0.0	185.56	185.1	0.28	204.79	212.87	3.94
16	347.20	349.31	0.6	40.05	40.05	0.0	24.10	24.89	3.28
17	417.10	423.19	1.46	15.99	15.99	0.0	10.20	10.41	– 2.14
18	302.50	303.41	0.3	6.80	6.60	– 2.82	11.72	11.53	–1.6
19	188.10	189.00	0.48	2.35	2.35	0.0	7.66	7.55	–1.31
20	114.70	115.91	1.05	0.94	0.94	0.0	5.31	5.35	0.84
21	78.40	79.25	1.08	0.44	0.46	4.5	7.97	7.98	0.13
22	202.50	201.35	– 0.57	39.81	39.81	0.0	24.10	24.89	3.28
23	166.30	159.53	– 4.07	15.78	15.75	0.19	34.31	35.31	2.95
24	97.70	97.70	0.0	2.12	2.12	0.0	7.66	7.55	–1.31
25	78.40	78.40	0.0	0.73	0.73	0.0	12.97	12.91	– 0.43
26	76.4	76.40	0.0	0.42	0.42	0.0	19.93	20.89	4.83
27	34.00	34.00	0.0	2.02	2.02	0.0	9750	9537.02	– 2.18
28	42.20	42.20	0.0	1.49	1.511	1.41	9750	9537.02	– 2.18

IV. ENERGY AND EXERGY EFFICIENCY

Energy and exergy analysis enables to determine the thermodynamics first law efficiency and second law efficiency respectively. The energy efficiency or first law efficiency of a system is given by:

η_I = Desired output energy/ Input energy supplied

i.e. $\eta_I = E_{out} / E_{in}$

For the whole plant, $\eta_I = W_{net} / Q_{fuel}$

Exergy or maximum obtainable work of a system is given by:

$\psi = m [(h - h_0) - T_0 (s - s_0)]$

Where m, h, s denotes the mass flow, specific enthalpy and specific entropy respectively and refers to system while h_0, T_0, s_0 refers to the surrounding or datum.

The exergy or second law efficiency is given by:

η_{II} = Exergy output /Exergy input or Product exergy/ Input exergy = ψ_{out} / ψ_{in}

For the whole plant, $\eta_{II} = W_{net} / \psi_{fuel} = W_{net} / (m_f \times \gamma \times LHV)$

Where m_f is the mass rate of fuel consumption, LHV is the lower heating value of coal and γ is the exergy factor based on the LHV. Value of γ is generally taken as 1.06.

V. RESULTS AND DISCUSSION

With the help of simulation model effect of the five important process parameters have been studied. Results are presented in graphical form in Figure 2 to 6.

A.The effect of change in condenser pressure

The effect of change in condenser pressure is shown in Figure 2. It is clear that as the condenser pressure increases from 0.1bar to 0.12bar both energy and exergy efficiencies decreases by around 0.4% and this trend is continue with further increase in condenser pressure. The decrease in energy efficiciency can be attributed to the fact that increase in condenser pressure also increases condenser saturation temperature which means the increase in mean temperature of heat rejection while the decrease in exergy efficiency is due to the increase in mass flow rate of the steam for the fixed turbine power or due to the increased steam rate.

B.The effect of main steam pressure

Another important influencing parameter to both the energy and exergy eficiency is main steam pressure which upon variation from 150bar to 140bar decreases the efficiencies to the tune of 0.25% as shown in Figure 3. With further reduction in main steam pressure decrease in efficiecies are proportionately more. The decrease in energy and exergy efficiency is due to the increase in boiler heat load and increased irreversibility in the boiler respectively.

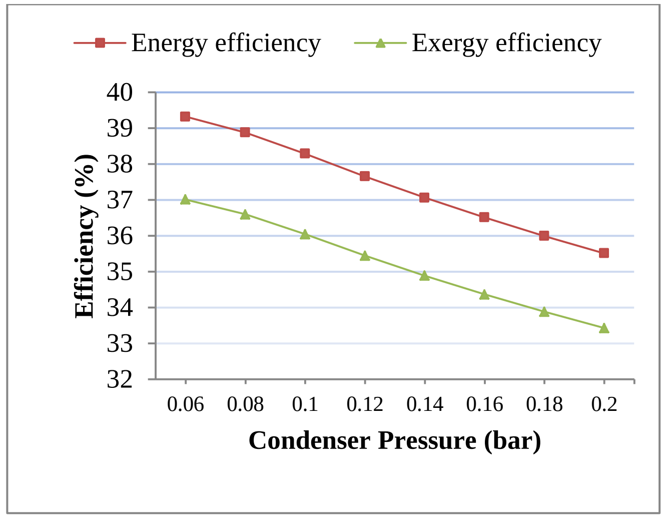

Figure 2. Effect of condenser pressure on energy and exergy efficiency

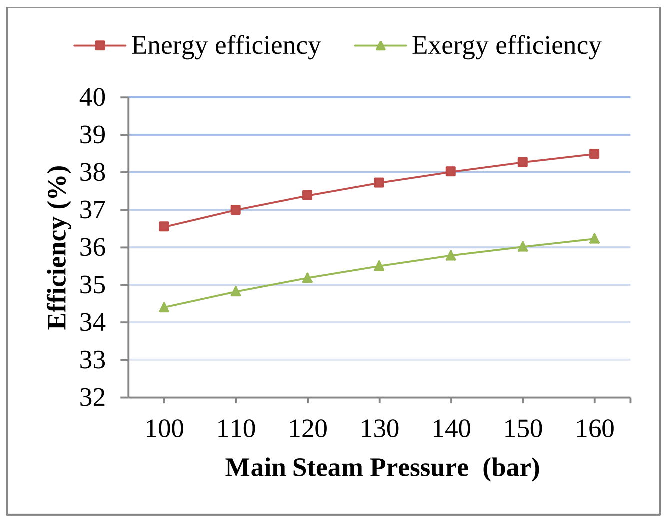

Figure 3. Effect of main steam pressure on energy and exergy efficiency

C. Effect of variation in reheat steam temperature and main steam temperature

Effect of variation in reheat steam temperature is also considerable but same cannot be said about the main steam temperature. Effect of main steam temperature and reheat steam temperature are shown respectively in Figure 4 and 5.

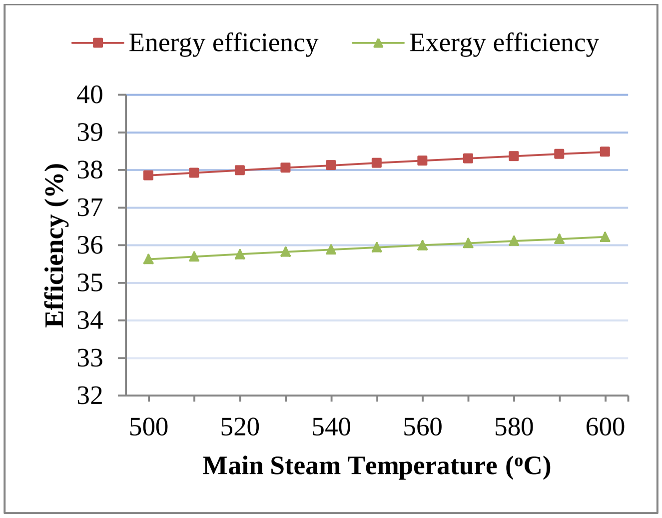

Figure 4. Effect of main steam temperature on energy and exergy efficiency

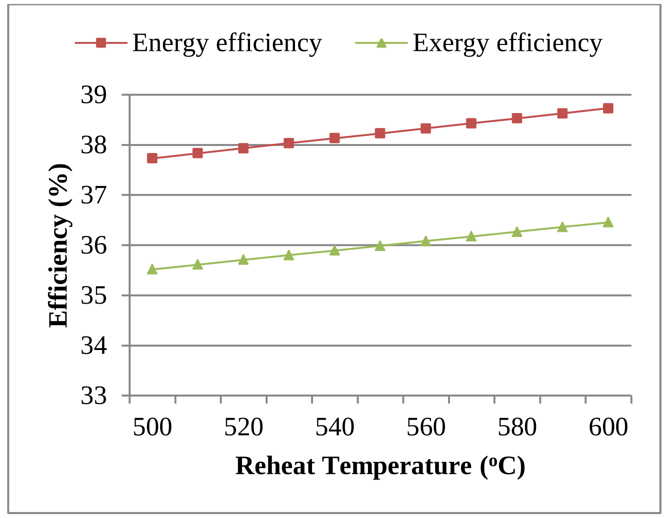

Figure 5. Effect of reheat temperature on energy exergy efficiency

D. Effect of variation in reheat pressure

Effect of variation in reheat pressure is depicted in Figure 6. The decrease in reheat pressure affects the plant efficiencies comparatively more than the corresponding increase in its value.

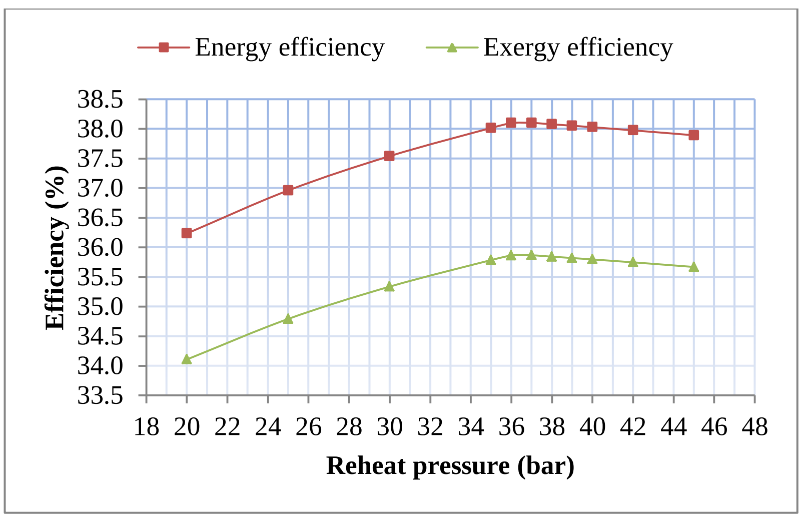

Figure 6. Effect of reheat pressure on energy and exergy efficiency

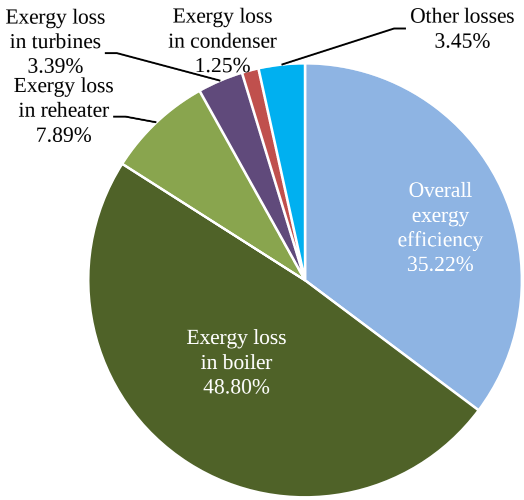

Figure 7. Energy balance of 250MW thermal power plant

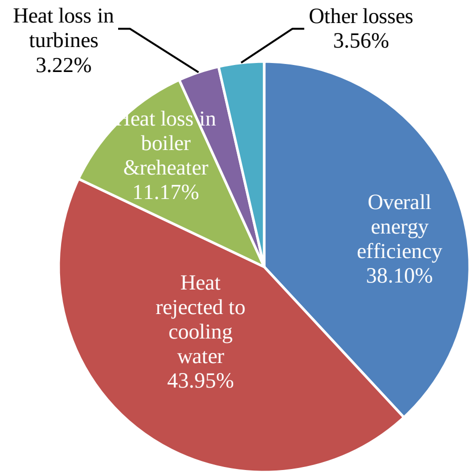

Figure 8. Exergy balance of 250MW thermal power plant

E. Energy and exergy balance

Plant energy and exergy balances at rated load are shown respectively in Figure 7 and 8. It is clear from the energy balance diagram that a major amount of heat loss is through cooling water in condenser while almost half of the total exergy is lost in the boiler alone. The possible causes of boiler being major component of exergy destructions are the heat exchange with fininte temperature difference, irreversibility in combustion process, and mixing of two streams in the drum. Thus, the energy analysis alone may lead to the conclusion that maximum amount of heat loss is taking place at the condenser which is true only regarding quantity of energy loss, but the exergy analysis of the plant has enabled to locate the place of real quality degradation of energy.

VI. CONCLUSION

In this study, a simulation model of the power plant system is prepared and the effects of process parameters upon plant efficiencies are investigated. Based on the results of analysis following conclusions can be drawn:

1. The condenser pressure is the most influencing parameter as its variation has highest impact over both the energy and exergy efficiency of the plant.
2. The main steam pressure is another parameter influencing significantly to the plant efficiencies. It is noticed that the drop in main steam pressure below 130bar has more negative impact over the efficiencies.
3. For the variation to same extent the reheat temperature has more impact in comparison to the main steam temperature.
4. The optimum value of reheat pressure is found to be around 36.5bar.
5. Heat rejection through cooling water is the biggest source of energy loss while maximum exergy loss takess place in the boiler.

VII. FUTURE SCOPE OF WORK

Effect of variation in individual values of some important parameters over energy and exergy efficiencies have been studied in this paper, but the effect of change in set of parameters together can be investigated to have more accurate idea about the plant performance. Further, to determine the optimized set of important process parameters for optimal performance (specifically exegy efficiency) the optimzation study using some advanced design method can be carried out. Also, the influence of factor like variation in load and effect of addition of more number of feed water heaters in considered plant should be investigated.

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