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EXERGY ANALYSIS FOR 120MW THERMAL POWER PLANT WITH DIFFERENT INLET TEMPERATURE CONDITIONS

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ABSTRACT

In this research paper, exergy analysis for different components of 120MW thermal power plant has been done. For analysis different inlet temperature conditions have been taken as a parameter, different inlet temperature conditions are – (1) 507.78°C, (2) 517.78°C, (3) 527.78°C, (4) 537.78°C, (5) 547.78°C, (6) 557.78°C and (7) 567.78°C. Exergy analysis has been done for boiler, for steam turbines (high pressure turbine, intermediate pressure turbine and low pressure turbine), for condenser and for feed water heaters with different inlet temperature conditions. And exergy curves have also been generated for different component of the plant.

KEYWORDS: Exergy or Available Energy, Power Output, Heat Rate, Inlet Temperature and Exergy Curves

LIST OF SYMBOLS, ABBREVIATION AND NOMENCLATURE

Ex_i = Extraction Quantity from HP, IP and LP Turbines at different stages (kg/sec).

FF = Flow Function

h_i = Enthalpy of steam at different stages (kJ/kg).

L_1 = Steam Used for Reducing Pressure Difference b/w 1st and Last Stage of HP Turbine (kg/sec)

L_2, L_3 and L_4 = Leakage before Entering Steam in HP Turbine (kg/sec).

L_5 and L_6 = Leakage after Steam Expand in HP Turbine (kg/sec).

L_7 and L_8 = Leakage before Entering Steam in IP Turbine (kg/sec).

L_9 = Leakage before Entering Steam in LP Turbine (kg/sec).

P = Pressure of Steam for 120MW Power Plant (design condition) (bar).

Q_1 = Heat addition in Boiler (kJ/kg).

Q_2 = Heat addition in Superheater (kJ/kg).

V = Specific Volume of Steam for 120MW Power Plant (design condition) (m^3/kg).

W = Mass Flow Rate of Steam for 120MW Power Plant (design condition) (kg/sec).

W' = Mass Flow Rate Generated in Boiler at Different Conditions (kg/sec).

W_i = Mass Flow Rate of Steam at different stages (kg/sec).

W_{max} or P_{net} = Available Energy (A.E.) or Exergy outlet (MW).

Q = Total Heat Supplied (MJ/sec or kJ/sec).

T_0 *= Atmospheric Temperature (310 K).*

dS_1, dS_2, dS_3, dS_4, dS_5, dS_6, *= Change in Entropy for Feed Water Heater 1,2,3,4,5,6 respectively (kJ/kg-K).*

h_{fg} *= Latent Heat Transfer for Condenser (kJ/kg).*

h_{fg1}, h_{fg2}, h_{fg3}, h_{fg4}, h_{fg5}, h_{fg6} *= Latent Heat Transfer for Feed Water Heater 1,2,3,4,5,6 respectively (kJ/kg).*

m_s *and* m_w *= Mass Flow Rate of Steam and Mass Flow Rate of Water (kg/sec).*

C_{ps} *and* C_{pw} *= Specific Heat at Constant Pressure for Steam and Water (kJ/kg K).*

T_1, T_2 *and* T_3 *= Temperature of Water at Boiler's Entrance, Saturated Temperature in Boiler and Superheated Steam Temperature in the Boiler (K).*

T_{in} *and* T_{out} *= Inlet and Outlet Temperature of Circulating Water in Condenser (K).*

INTRODUCTION

This paper is based on 120 MW thermal power plant and a thermal power plant consists of five major components – (1) Boiler, (2) Steam Turbines – High pressure turbine, Intermediate pressure turbine and Low pressure turbine, (3) Condenser, (4) Feed Water Pump – Pump after condenser and Pump after deaerator and (5) Feed Water Heater – one feed water heater for high pressure turbine, two feed water heater for intermediate pressure turbine and three feed water heater for low pressure turbine. In the boiler, water converts into high pressure and temperature steam by the constant pressure heating process.

Then high pressure and temperature steam enters into a high pressure steam turbine, in which steam expands and some amount of steam extract for feed water heating process. Then steam enters into an intermediate pressure turbine, in which steam expands and some amount of steam again extract for feed water heating process. And finally steam enters into a low pressure turbine, in which steam expands and some amount of steam again extract for feed water heating process. After passing through the low pressure turbine steam is converted into saturated water. Then water enters into the boiler with the help of a pump [1].

Simply exergy outlet can be defined as energy which is available or exergy outlet can also be defined as the maximum useful work output from a system. And exergy destruction is the summation of exergy destruction of each component of the power plant. So exergy destruction of a cycle can be determined by tracing the individual component of the plant. During the operation some amount of energy is rejected into the surrounding and this energy cannot be converted into work, this is called unavailable energy [1]. Geete A. et al [2] have analyzed thermal power plant with the combined effect of constant inlet pressure (124.61 bar) and different inlet temperatures. They have also generated correction curves for power and heat rate. Corrado A. et al [3] have assessed and analyzed high-efficiency steam power plant on the basis of exergy. They have suggested two different life cycle approach methodologies – (1) the life cycle assessment and (2) the extended exergy analysis. They have concluded that the real exergy efficiency of the system can be decreased from 41.8% to 17% by adopting extended exergy analysis (EEA) methodology. Amir Vosough et al [4] have improved the efficiency of thermal power plant. They have analyzed Rankine cycle with reheat on the basis of energy and exergy analysis. They have found that the combined energy loss in the condenser and other components is 13.22%. And they have also found that the thermal and exergy efficiencies of the power plant are 38.39% and 45.85% respectively.

Wang Y. Hong et al [5] have built a relationship between the efficiency of the thermal power plant and the total process of irreversibility in the rotary air preheater by using exergy analysis. And they have suggested some optimal parameters to improve performance of rotary air preheater as well as a power plant. Eskin Nurdil et al [6] have developed a model for the analysis of FBCC (fluidized bed coal combustor) steam power plant. They have concluded that the exergy efficiency of the system can be increased to 19.9% by increasing steam pressure from 4 to 12 bars.

Aljundi H. Isam [7] has identified and quantified the sites which are having largest energy and exergy losses in a steam power plant. He has found that the boiler is the major source of irreversibility and suggested that irreversibility in the boiler can be reduced by preheating the combustion air and reducing the air–fuel ratio. Vosough Amir [8] has calculated energy and exergy of the boiler. After different calculations he has found that energy efficiency of the boiler is 89.21% and exergy efficiency of the boiler is 45.48%.

Rosen A. Marc et al [9] have analyzed steam power plant on the basis of exergy to improve the efficiency of the plant. And they have observed that the efficiency of the steam power plant can be increased by – (1) reduction in irreversibility in the steam generator, (2) reduction in the fraction of excess combustion air and (3) reduction in stack gas temperature. Mali D. Sanjay et al [10] have done energy and exergy analysis for thermal power plants.

They have analyzed efficiencies at every point and they have also found the major losses occur at combustion chamber, superheater, economizer and air preheater. Egware H.O. et al [13] have investigated different methods to improve the performance of the power plant. They have evaluated the performance of Omotosho Phase 1 Thermal Power Plant.

Gulhane J Sarang et al [14] have found amount and source of irreversibility in the boiler of 6 MW thermal power plant. They have also identified the component which is having largest energy losses and it helps to improve the design of that component. Reddy V. Siva et al [15] have analysed thermal power plants on the basis of energy and exergy. They have conducted comparative analysis for coal fired thermal power plant and natural gas fired thermal power plant. Suryvanshee Sahil et al [16] have presented a case study on thermal power plant. They have analysed plant components separately and then identified which component is having largest exergy losses.

They have calculated percentage ratio of exergy destruction to the total exergy destruction for boiler, for steam turbine and for condenser. And they have found that the ratio is 57%, 33.3% and 5.34% respectively. Pandey M. et al [17] have performed energy and exergy analysis of reheat regenerative power plant. Energy and exergy balance sheet have been made for each component of the plant. Rocco Matteo et al [18] have presented exergy and thermo-economic analysis of a 320 MW power plant. The main aim of these analyses was to identify the optimal design configuration of the plant.

Ayoola O. Phillip et al [19] have carried out energy and exergy analysis of a thermal power plant to investigate effects on thermodynamic efficiencies. Acir Adem [20] has predicted exergy efficiency of thermal power plant by using artificial neural network. He has developed an artificial neural network model which is based on back propagation learning algorithm. Khanmohammadi Shoaib et al [21] have performed exergy analysis and exergo-economic analysis on Isfahan thermal power plant, Iran.

A simulation program has been used for modelling the plant. Pal K. M. et at [22] have recommended that the actual irreversibility of different components of the power plant can be estimated by energy/exergy analysis. They have observed that real assessment of the power plant can be done by exergy analysis. This work deals with the exergy analysis of different components of 120 MW thermal power plant and generation of different curves. Layout of 120MW thermal power plant is as shown in figure 1. [12]

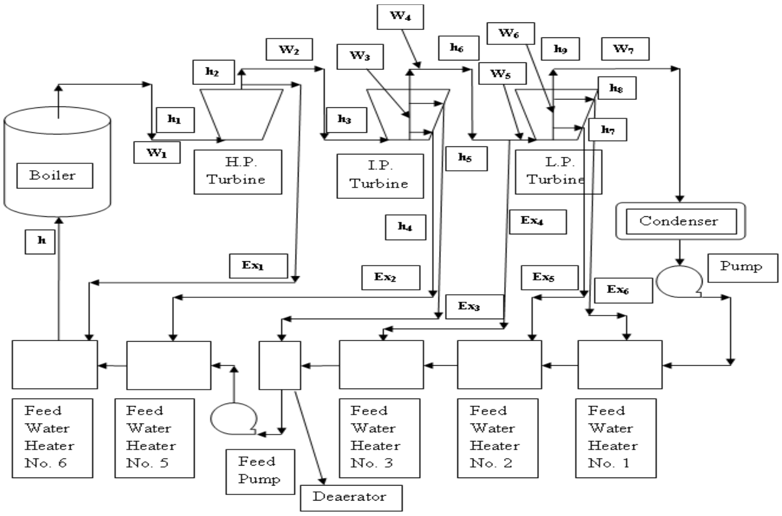


Figure 1: Layout of 120 MW Thermal Power Plant

METHODOLOGY

Exergy Analysis for Boiler

First of all change in entropy for boiler has been calculated with the relationship between sensible heat, latent heat and temperature. Then unavailable energy has been calculated with the relationship between change in entropy and ambient temperature. And after finding heat addition in boiler, exergy has been calculated with the relationship between exergy, heat addition and unavailable energy. [1]

- $dS = \{(C_{pw}) \ln[T_2/T_1] + \text{Latent Heat}/ T_2 + (C_{ps}) \ln[T_3/T_2]\}$, kJ/kg K (1)
- $T_0 dS$, kJ/kg (2)
- $A.E. = Q - T_0 ds$ (3)

Exergy Analysis for Steam Turbines

Flow Function Calculation

First of all flow function has been calculated with the relationship between mass flow rate, pressure and specific volume. [11]

$FF = W/\sqrt{(P/V)}$ kg²/bar m³ hr (4)

$FF = 363313.0/ \sqrt{(125.1/0.0186)} = 4430.051$ kg²/bar m³ hr

W = 363313.0 kg/hr, P = 125.1 bar and V = 0.0186 m³/kg for 120MW power plant. (Ideal condition)

Mass Flow Rate Calculation

Then mass flow rate (W) has been calculated for given condition. [11]

$FF = W/\sqrt{(P/V)}$ kg²/bar m³ hr

$4430.051 = W / \sqrt{(P/V)}$, here P and V given as per given condition.

Mass Flow Rate Calculation for Different Stages of HP, IP and LP Turbines

Then different mass flow rates have been calculated at different stages for HP, IP and LP Turbines for given condition. Different leakage rates and different extraction rates have been taken for the BHEL thermal power plant. [12]

- $W_1 = (W' - L_1 - L_2 - L_3 - L_4)$ kg/sec (5)
- $W_2 = (W_1 + L_1 - L_5 - L_6 - Ex_1)$ kg/sec (6)
- $W_3 = (W_2 - Ex_2 - L_7 - L_8)$ kg/sec (7)
- $W_4 = (W_3 - Ex_3)$ kg/sec (8)
- $W_5 = (W_4 - Ex_4)$ kg/sec (9)
- $W_6 = (W_5 - Ex_5 - L_9)$ kg/sec (10)
- $W_7 = (W_6 - Ex_6)$ kg/sec (11)

Total Power Calculation

Then power has been calculated with the relationship between mass flow rate and enthalpy drop in the turbine for given condition. [12]

Power = Mass flow rate (Enthalpy drop in the turbine), MW (12)

P = HP Turbine $\{W_1 (h_1 - h_2)\}$ + IP Turbine $\{[W_2 (h_3 - h_4)] + [W_3 (h_4 - h_5)] + [W_4 (h_5 - h_6)]\}$ + LP Turbine $\{[W_5 (h_6 - h_7)] + [W_6 (h_7 - h_8)] + [W_7 (h_8 - h_9)]\}$ MW (13)

Exergy or Net Power Calculation

Then net power has been calculated for given condition. [12]

Exergy or P_{net} = Generator Efficiency (Power – Mechanical Losses), MW (14)

Exergy Analysis for Condenser

Mass flow rate of water has been calculated by energy balancing equation. Then change in entropy has been calculated with the relationship between heat transfer and temperature. Then unavailable energy has been calculated with the relationship between change in entropy and ambient temperature. Then amount of heat transfer has been calculated with the relationship between mass flow rate of steam and enthalpy drop for steam. Finally exergy has been calculated with the relationship between exergy, heat addition and unavailable energy. [1]

(m_s) (h_{fg}, Enthalpy drop in condenser) = $(m_w) (C_{pw}) (T_{out} – T_{in})$ (15)

Change in entropy for Condenser (dS) = (Enthalpy drop in condenser / Saturated temperature) (16)

Unavailable energy = T_0(dS), Change in entropy (17)

Heat transfer (Q) = $(m_s) (h_{fg})$ (18)

A.E. = Q – T_0ds, (19)

Exergy Analysis for Feed Water Heaters

Change in entropy has been calculated with the relationship between latent heat transfer and saturated temperature of feed water heater. Then unavailable energy has been calculated with the relationship between extraction quantity for heater, change in entropy and ambient temperature. Then amount of heat transfer has been calculated with the relationship between extraction quantity for heater and enthalpy drop for steam. Finally exergy has been calculated with the relationship between exergy, heat addition and unavailable energy. [1]

$dS = h_{fg}/T_{sat}$ = (Latent heat transfer in heater)/(Saturated temperature) (20)

For heater 1, Unavailable Energy (U.E.) = (Ex_6) (T_0dS_1) (21)

And Q = (Ex_6) (h_{fg1}, for heater 1) (22)

For heater 2, Unavailable Energy (U.E.) = (Ex_5) (T_0dS_2) (23)

And Q = (Ex_5) (h_{fg2}, for heater 2) (24)

For heater 3, Unavailable Energy (U.E.) = (Ex_4) (T_0dS_3) (25)

And Q = (Ex_4) (h_{fg3}, for heater 3) (26)

For heater 4, Unavailable Energy (U.E.) = (Ex_3) (T_0dS_4) (27)

And Q = (Ex_3) (h_{fg4}, for heater 4) (28)

For heater 5, Unavailable Energy (U.E.) = (Ex_2 x T_0dS_5) (29)

And Q = (Ex_2) (h_{fg5}, for heater 5) (30)

For heater 6, Unavailable Energy (U.E.) = (Ex_1) (T_0dS_6) (31)

And Q = (Ex_1) (h_{fg6}, for heater 6) (32)

Available Energy (A.E.) or Exergy outlet = Q - Unavailable Energy (U.E.) (33)

Now total exergy has been calculated by summation of each exergy which has been found after calculations.

Total Available Energy or Exergy = (Exergy for Heater 1) + (Exergy for Heater 2) + (Exergy for Heater 3) + (Exergy for Heater 4) + (Exergy for Heater 5) + (Exergy for Heater 6) (34)

Heat Rate Calculation

And then heat rate has been calculated with the relationship between total heat addition in boiler and net power output from the power plant for given condition. [12]

Heat rate = (Total heat addition in boiler) / (Net power) (35)

HR = $(Q_1 + Q_2)/ P_{net}$ kJ/MW-sec (36)

Q_1 = W' (h_1 - h), (Heat addition in Boiler) kJ/sec (37)

$Q_2 = W_2$ (h_3 - h') (Heat addition in Super heater) kJ/sec (38)

RESULTS

Seven different case studies have been done for different inlet temperature conditions. After analysis, some important results have been found. And all results are given in tabular form (in table 1 and table 2). And different curves have also been generated (in figures 2 - 5).

Table 1: Exergy for Different Components of the Power Plant at Different Inlet Temperature Conditions

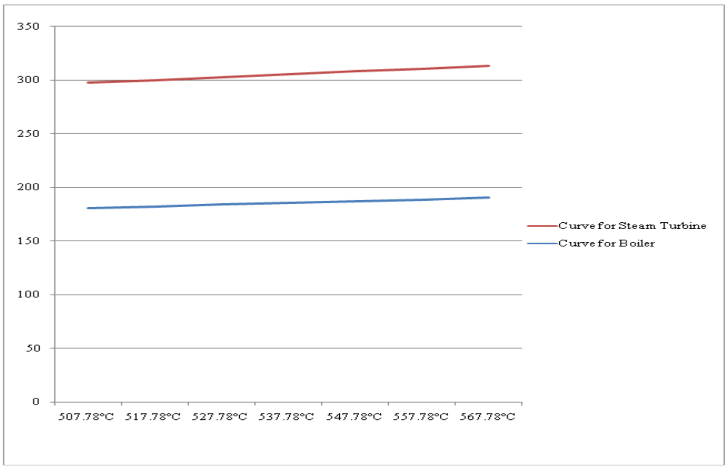
Inlet Temperature (in ◦C)		507.78	517.78	527.78	537.78	547.78	557.78	567.78
Inlet Pressure (in Bar)		**125.10**	**125.10**	**125.10**	**125.10**	**125.10**	**125.10**	**125.10**
1	Boiler (MW)	183.513	184.348	185.189	185.526	186.378	187.235	188.094
2	Steam Turbines (MW)	120.822	120.580	120.355	120.0	119.505	119.276	119.042
3	Condenser (MW)	5.015	5.003	4.992	4.961	4.948	4.936	4.922

Table 1: Contd.,

4	Feed Water Heater 1 (MW)	1.001	0.986	0.969	0.953	0.941	0.927	0.915
5	Feed Water Heater 2 (MW)	1.660	1.643	1.628	1.621	1.598	1.584	1.570
6	Feed Water Heater 3 (MW)	1.048	1.038	1.026	1.009	1.008	1.001	0.989
7	Feed Water Heater 4 (MW)	3.613	3.569	3.524	3.483	3.441	3.402	3.364
8	Feed Water Heater 5 (MW)	2.921	2.890	2.856	2.826	2.797	2.766	2.739
9	Feed Water Heater 6 (MW)	4.931	4.825	4.721	4.619	4.527	4.434	4.347

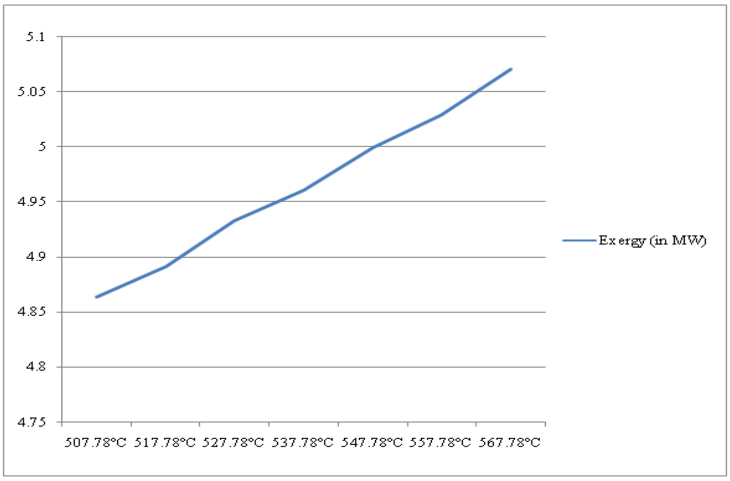
Table 2: Decrease in Exergy with Different Numbers of Feed Water Heaters at Different Inlet Temperature Conditions

Inlet Temperature (in ◦C)		507.78	517.78	527.78	537.78	547.78	557.78	567.78
Inlet Pressure (in Bar)		**125.10**	**125.10**	**125.10**	**125.10**	**125.10**	**125.10**	**125.10**
1	Decrease in Exergy with One Feed Water Heater (in MW)	56.675	57.779	58.873	59.612	60.984	62.096	63.215
2	Decrease in Exergy with Two Feed Water Heater (in MW)	55.015	56.136	57.245	57.991	59.386	60.512	61.645
3	Decrease in Exergy with Three Feed Water Heater (in MW)	53.967	56.136	56.219	56.982	58.378	59.511	60.656
4	Decrease in Exergy with Four Feed Water Heater (in MW)	50.354	52.567	52.695	53.499	54.937	56.109	57.292
5	Decrease in Exergy with Five Feed Water Heater (in MW)	47.433	49.677	49.839	50.673	52.140	53.343	54.553
6	Decrease in Exergy with Six Feed Water Heater (in MW)	42.502	44.852	45.118	46.054	47.613	48.909	50.206
7	2^{nd} Law Efficiency (in %)	42.07	41.83	41.59	41.42	41.09	40.86	40.63



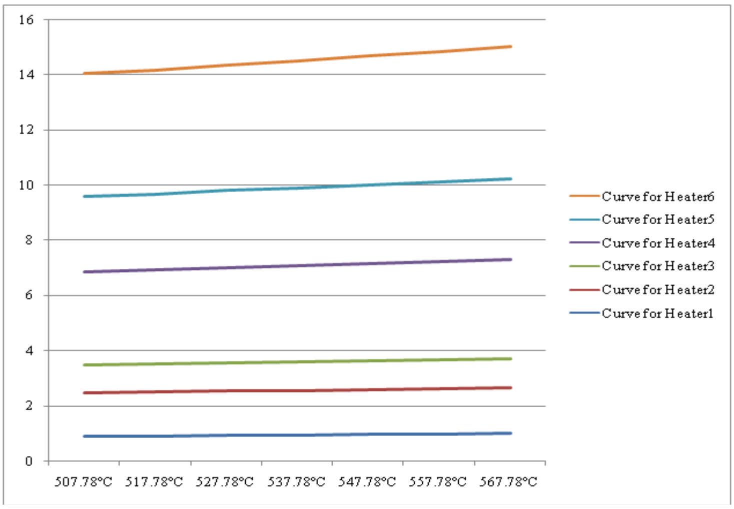
X axis – Different Inlet Temperature Conditions, Y axis – Exergy (in MW)

Figure 2: Exergy Curves for Boiler and Steam Turbine



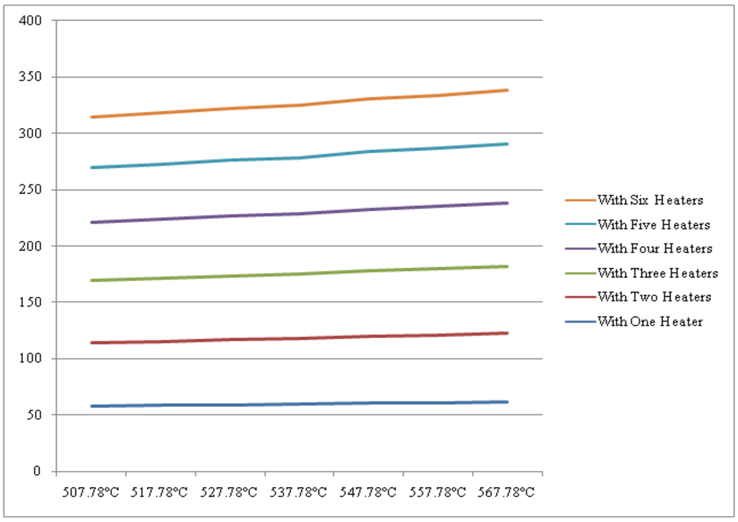
X axis – Different Inlet Temperature Conditions, Y axis – Exergy (in MW)

Figure 3: Exergy Curve for Condenser



X axis – Different Inlet Temperature Conditions, Y axis – Exergy (in MW)

Figure 4: Exergy Curves for Feed Water Heater 1, Heater 2, Heater 3, Heater 4, Heater 5 and Heater 6



X axis – Different Inlet Temperature Conditions, Y axis – Exergy (in MW)

Figure 5: Curves for Decrease in Exergy with Different Numbers of Feed Water Heaters

CONCLUSIONS

Different seven case studies have been done on 120MW thermal power plant to analyze exergy outlet from different components. After analysis, decrease in exergy outlet with different numbers of heaters and second law efficiencies have also been found. Work has been concluded as – (1) When inlet temperature increases then exergy for boiler increases, (2) When inlet temperature increases then exergy for steam turbine and condenser decrease, (3) and exergy for all feed water heaters decrease when inlet temperature increases, (4) When inlet temperature increases then decrease in exergy with different numbers of feed water heaters (one heater, two heaters, three heaters, four heaters, five heaters and six heaters) also increase and (3) Maximum second law efficiency can be achieved at 507.78°C inlet temperature.

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