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Energy And Exergy Analysis Of Boiler And Turbine Of Coal Fired Thermal Power Plant.

M. K. Pal*, Anil Kumar and H. Chandra

Department of Mechanical Engineering, Bhilai Institute of technology Durg.(C.G.),India.

Abstract: This paper presents thermodynamic analysis of Boiler & Turbine of coal fired thermal power plant. Energy analysis gives energy loss and first law efficiency, while the exergy analysis gives entropy generation irreversibility, percentage exergy loss and second law efficiency of boiler and turbine. It is seen that energy loss in boiler is about 61% of total input. While the maximum exergy occurs in low pressure turbine. l occurs in low pressure turbine total input. While the maximum exergy loss occurs in low pressure turbine

exergy loss and second law efficiency of boiler and turbine. It is seen that energy loss in boiler is about 61% of total input. While the maximum exergy loss occurs in low pressure turbine.

Key words: Reheat Regeneration Rankine cycle, Energy analysis ,Exergy analysis, Second law efficiency.

1. Introduction:

The general energy supply and environmental situation requires an improved utilization of energy sources. Complexity of power generating units has been increased considerably. There is increasing demand of strictly guaranteed performance, which require thermodynamic calculation of high accuracy.[1] The most commonly used method for evaluating the efficiency of an energy conversion process is the first law analysis. However there is increasing interest in the combined utilization of the first and second laws of thermodynamics, using such concept as exergy analysis , entropy generation and irreversibility(exergy destruction) inorder to evaluate the efficiency with which the available energy is consumed.[2]

Exergetic analysis is a useful tool for more efficient use of energy because it enables the locations type and true magnitude of wastes and losses to be determined. An exergy analysis usually aimed to determine the maximum performance of the system and identify the sites of exergy destruction. Exergy analysis of a complex system can be performed by analyzing the main sites of exergy destruction shows the direction for potential improvements.[3-15]

Vosough Amir [16] presented thermodynamic inefficiencies as well as reasonable comparison of each plant to others are identified and discussed for the coal-fired thermal power plants in Turkey. S.C. Kaushik, V.SivaReddy, S.K.Tyagi[17] determined the performance of the plant was estimated by a component wise modeling and a detailed break-up of energy and exergy losses for the considered steam power plant. Mohammad Ahmadzadeh talatappeh and Mohsen Gazikhani[18] presented exergy analysis of a coal-based thermal power plant by splitting up the entire plant cycle into three zones for the analysis. Mehdi bakhshesh and Amir Vosough [19] analyzed the coal fired thermal power plant with measured boiler and turbine losses. Mali Sanjay D1, Dr. Mehta N S2 [20] presented energy and exergy-based comparison of coal-fired and nuclear steam power plants. They determined the energy losses and the exergy losses of the individual components of the lignite fired thermal power plant. They performed second law based thermodynamic analysis of the regenerative-reheat Rankine cycle power plants.

In this paper energy and exergy analysis of Boiler and Turbine of 210 MW Capacity of Rihand Super Thermal Power Station, Rihandnagar, district Sonebhadra (UP), is being carried out, to obtain first law, second law efficiency and irreversibility of different components.

2. System Description:

The schematic and T-s diagram of closed Reheat Regenerative Rankine cycle is shown in figure 1 and 2 respectively. The basic components of this cycle are Boiler(B), High pressure turbine(HPT), Intermediate Pressure Tubine(IPT),Low Pressure Tubine(LPT),Condenser(C), Feed Water Heater -1(FWH1),and Feed Water Heater-2(FWH-2).Steam generated in boiler at high pressure and temperature is passed in to high pressure turbine and then reheated at same initial temperature in reheater it is then allowed to expand in intermediate pressure turbine steam is partially bled and feed in to water heater 2, remaining steam is expanded to low pressure turbine to condenser pressure, condensate from condenser and water from water heaters is mixed in mixing chamber and then cycle is repeated. We have considered here theoretical Reheat Regenerative cycle with actual processes.

3. Thermodynamic Analysis:

The analysis of Reheat Regenerative Rankine Cycle is represented by a system of algebraic equations. The System of equations for thermodynamic analysis consists of the(¡) energy analysis (¡¡) exergy analysis.

3.1 Energy Analysis of Boiler:

The efficiency of Boiler can be measured easily by measuring all the losses occurring. The disadvantages of the direct method can be overcome by this method which calculates the various heat losses associated with the boiler. The efficiency can be arrived at by subtracting the heat loss from 100. An important advantage of this method is that the errors in measurement do not make significant change in efficiency.

The following losses are applicable to liquid ,gas and solid fired boiler.

L 1. Loss due to dry flue gas (sensible gas).

L 2. Loss due to hydrogen in fuel (H_2).

L 3. Loss due to moisture in fuel (H_2O)

L 4. Loss due to carbon monoxide in air(co)

L 5 Loss due to surface radiation, convection and other unaccounted.

Boiler efficiency by Indirect method :

$$100 - (L1+ L2+ L3+L4+L5) \quad \textbf{(1)}$$

3.2 Exergy Analysis of Boiler:

Exergy of fuel is given by the equation proposed by Shieh and Fan for calculating the exrgy of the fuel:

ε_f =34183.16(C) +21.95 (N) +11659.9 (H) +18242.90 (S) +13265.9 (O) **(2)**

Exergy of feed water can be calculated by the relation

$$\varepsilon_{wa} = C_{pw}\ (T_w - T_0)\ \text{--}T_0\ l_n\left(\frac{T_w}{T_0}\right) \quad \textbf{(3)}$$

Exergy of air supply can be calculated by the relation

$$\varepsilon_a = C_{pa}\ (T_a - T_0)\ \text{--}T_0\ l_n\left(\frac{T_a}{T_0}\right) \quad \textbf{(4)}$$

Table 1. for energy and exergy analysis of Boiler and Turbine

Fuel firing rate	5600 kg/hr
Steam generation	46592.52 kg/hr
Steam pressure	70 bar
Steam temp.	500 °C
Feed water temp.	96 °C
% CO_2 in flue gas	14
% CO in flue gas	0.55
Average flue gas temp.	190 °C
Ambient temp.	30 °C
Humidity in Ambient	.0204kg/kg of air
Surface temp. of boiler	70°C

Wind velocity around boiler	3.5 m/s
Total surface area of boiler	90 m^2
GCV of bottom Ash	800kgcal/kg
GCV of fly Ash	452.5kgcal/kg
Mass of feed water	30kg/sec
Mass of air supplied	60kg/sec
Mass of steam formed	12.94kg/sec
Mass of the flue gasses	65kg/sec
Temp. of flue gases	195^{0}C

Table 2.Fuel Analysis

Ash content in fuel	8.63
Moisture in coal	31.6
Carbon content	41.65
Hydrogen content	2.0415
Nitrogen content	1.6
Oxygen content	14.48
Sulphur content	0.6
GCV of coal	3500 kcal/kg

Table 3.Data of Turbine

Inlet temperature of HPT	500°C
Inlet pressure of HPT	70 bar
Reheat temperature	500 °C
Reheat pressure	25 bar
Inlet temperature of IPT	500°C
Inlet pressure of IPT	25 bar
Inlet pressure of LPT	5 bar
Condenser pressure	0.1bar
Inlet temperature to mixing chamber	250 °C
Enthalpy of steam at exhaust of HPT h_2'	3180.145 kJ/kg
Enthalpy of steam at exhaust of IPT h_2'	3081.375 kJ/kg
Enthalpy of steam at exhaust of HPT h_2'	2511 kJ/kg

Table-4. First law and second law analysis result.

Equipment	First law efficiency	Second law efficiency	Irreversibility
Boiler	77.42%	39.12%	31.93MW
High pressure turbine	78.5%	73.78%	0.64MW
Intermediate turbine	82.5%	80.79%	0.67MW
Low pressure turbine	82.0%	80.59%	0.84MW

Exergy of steam formed can be calculated by the relation

$$(h - h_0) - T_0 (S - S_0) \quad \textbf{(5)}$$

Exergy of flue gases can be determined by

$$\varepsilon_g = C_{pg} \left(T_g - T_0\right) \text{ --}T_0 \; l_n \left(\frac{T_g}{T_0}\right) \quad (6)$$

Total irreversibility in the steam boiler is given by

$$I_b = \left(\varepsilon_a + \varepsilon_w + \varepsilon_f\right) — \left(\varepsilon_S + \varepsilon_g\right) \quad \textbf{(7)}$$

3.3 Energy Analysis of Turbine :

Total work obtainable from turbine is given by

$$W_t = (h_1 - h_2) + (1 - m_1)(h_2 - h_3) + (1 - m_1 - m_2)(h_4 - h_5) \quad \textbf{(8)}$$

$$Total\ Heat\ supplied = (h_1 - h_{13}) \quad \textbf{(9)}$$

3.31 Efficiency of high pressure turbine :

$$\eta_{hpt} = \frac{(h_1 - h_{2'})}{(h_1 - h_2)} \quad \textbf{(10)}$$

3.32 Efficiency of intermediate pressure turbine:

$$\eta_{ipt} = \frac{(h_3 - h_{4'})}{(h_3 - h_4)} \quad \textbf{(11)}$$

3.33 Efficiency of low pressure turbine :

$$\eta_{lpt} = \frac{(h_{4'} - h_{5'})}{(h_{4'} - h_5)} \quad \textbf{(12)}$$

3.4 Exergy Analysis of Turbine :

Exergy analysis of turbine is given by

$$\dot{W}_{sh} = \dot{m}\left(h_i + \frac{V_i^2}{2} + gZ_i\right) - \dot{m}\left(h_e + \frac{V_e^2}{2} + gZ_e\right) - \dot{m}T_0\left(s_i - s_e\right)$$

(13)

3.41 Exergy of High Pressure Turbine :

$$\Psi_1 - \Psi_{2'} = (h_1 - h_{2'}) - T_0\,(S_{2'} - S_1) \quad \textbf{(14)}$$

Second law efficiency of High Pressure Turbine is

$$\eta_{IIhpt} = \frac{T_0(S_{gen})}{(\Psi_1 - \Psi_{2'})} \quad \textbf{(15)}$$

3.42 Exergy of Intermediate Pressure Turbine :

$$\Psi_3 - \Psi_{4'} = (h_3 - h_{4'}) - T_0\,(S_{4'} - S_3) \quad \textbf{(16)}$$

Second law efficiency of IPT is

$$\eta_{II\,ipt} = \frac{T_0\,S_{gen}}{(\Psi_3 - \Psi_{4'})} \quad \textbf{(17)}$$

3.43 Exergy of Low Pressure Turbine :

$$\Psi_{4'} - \Psi_{5'} = (h_{4'} - h_{5'}) - T_0\,(S_{5'} - S_{4'}) \quad \textbf{(18)}$$

Second law efficiency of Low Pressure Turbine is

$$\eta_{IIlpt} = \frac{T_0\,S_{gen}}{(\Psi_{4'} - \Psi_{5'})} \quad \textbf{(19)}$$

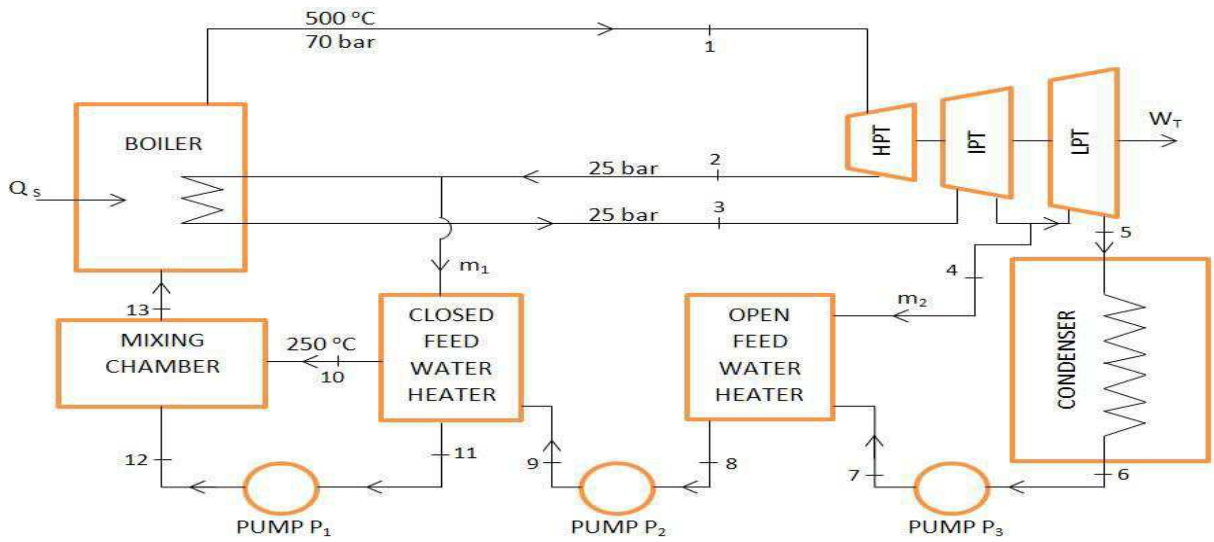

FIG. 1 Schematic Diagram of Reheat Regeneration Rankine Cycle.

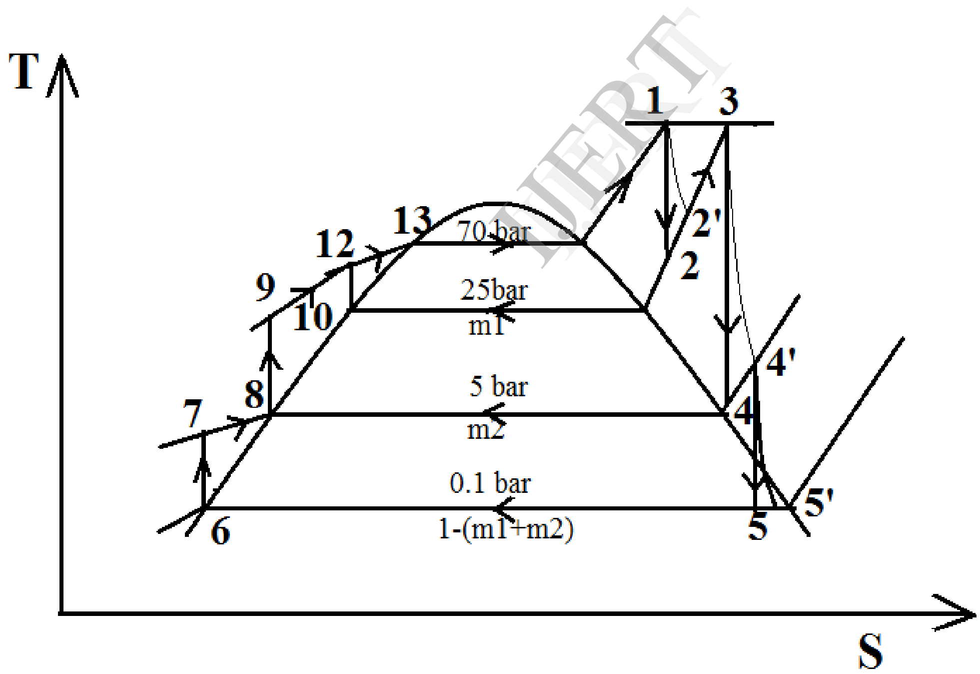

FIG.2 T-S Representation of Reheat Regeneration Rankine Cycle.

4. RESULT AND DISCUSSION

To have numerical appreciation of thermodynamic analysis ,calculations have been made using actual data from Rihand Super thermal power station for following operating conditions.

Steam inlet pressure =70 bar, Steam inlet temperature =500°c,

Feed water temperature 96°c,Steam generation rate =46592.52kg/hr,
Reheat temperature 500°c,Reheat pressure =25 bar.

The properties for energy and exergy analysis are given in Table 1. Table 2 gives percentage fuel aqnalysis and data for Turbine is given in Table 3.The
Irreversibility, First law efficiency and Second law efficiency is given in Table 4.

Fig. 3 shows first and second law efficiency of different components in reheat regeneration cycle, from this figure and from table 4 it can be found that maximum exergy loss takes place at Boiler. The result of exergy analysis indicates that boiler has the energy destruction of 31.93 MW, WHICH IS THE 61% of the total exergy input to the boiler. Exergy destruction of high pressure, intermediate and low pressure turbine is .64, 0.67&o.84MW respectively. From the figure 4 and table 4 it is clear that losses occur at all components due to entropy generation or irreversibilties.Thus exergy analysis is a necessary to have an accurate measure of the losses that takes place in different components.

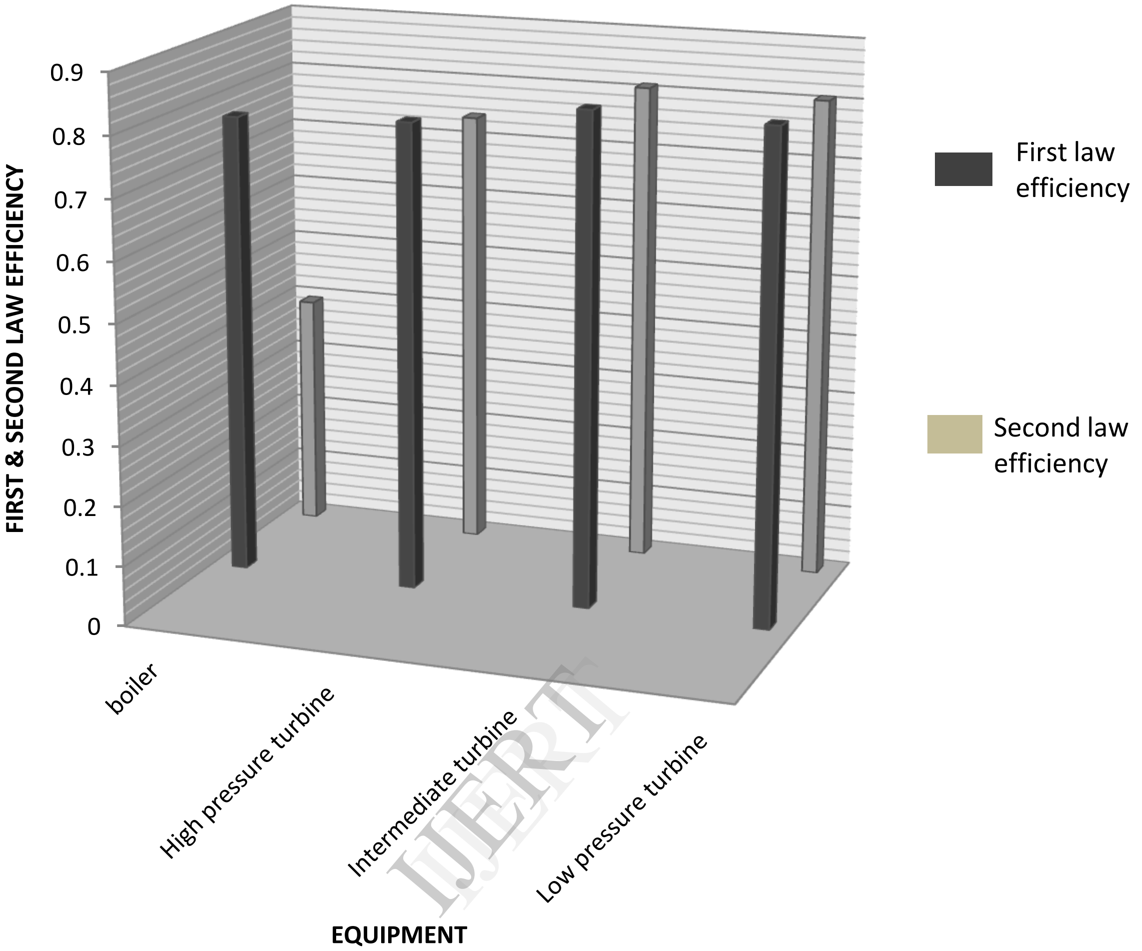

Fig. 3 First and Secnd Law Efficiency of Different Components.

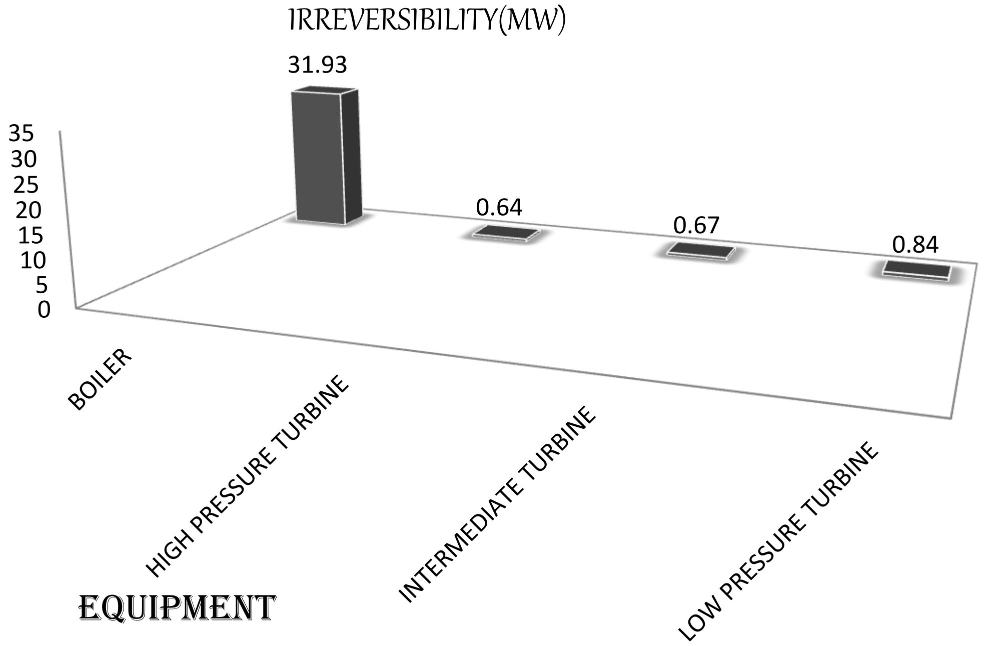

Fig. 4 Irreversibility in Different Components

5. CONCLUSIONS:

The exergy analysis is very important tool to find the actual irreversibilities in different components of any cycle/system and performance based on exergy analysis gives the real assessment of the system. In this present work energy and exergy analysis of Reheat Regeneration Rankin cycle is being carried out. The energy analysis gives the percentage energy loss and first law efficient and exergy analysis gives entropy generation, irreversibility percentage exergy loss and second law efficiency. The exergy loss or irreversibility is maximum at boiler. Thus to know about actual flow of exergy in the cycle thermodynamic analysis based on second law is desirable.

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NOMENCLATURE:

C_p Specific heat at constant pressure in Kj/Kg-K

C_{pg} Specific heat of gas in Kj/Kg-K

ε_f Exergy of fuel in KW.

ε_w Exergy of water in KW

ε_a Exergy of air in KW

ε_s Exergy of steam in KW

ε_g Exergy of flue gas. In KW

T_w Temperature of feed water

T_0 Reference temperature.

T_a Temperature of air

T_g Temperature of flue gas

h Enthalpy of steam

I_b Irreversibility in boiler.

1,2,3……State points.

I First law

II Second law