Energy and Exergy Analysis of Coal Fired Thermal Power Plant.

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***Abstract*- In this paper useful concept of energy and exergy analysis is analyzed and applied to the boiler of 250MW coal based thermal power plant. The energy analysis gives the percentage energy loss and the firsr law efficiency while the exergy analysis gives the entropy generation, irreversibility, percentage exergy loss and second law efficiency of each component Energy and Exergy flows are shown in this paper. The Energy and Exergy efficiency have been determined as well. In boiler energy and exergy efficiency are found to be 88.12% and 44.24% respectively. Energy and Exergy efficiency of boiler are compared with other work as well, it is found that maximum exergy destruction occurs in combustion chamber of boiler, followed by heat exchanger of boiler system.**

Keywords- Rankine thermal power cycle, energy analysis exergy analysis, first law and second law efficiency.

I. INTRODUCTION

The general energy supply environmental requirement situation requires an improved utilization of energy sources . Therefore complexity of power generating units has been increased considerably. Strictly guaranteed performance is required from thermal power plants. This requires thermodynamic calculation of high accuracy. As a result the expenditure for thermodynamic calculation during design and optimization has increased tremendously [1]. The most commonly used method for evaluating the efficiency of energy conversion process is the first law efficiency. However there is increasing interest in the combined utilization in the first and second law of thermodynamics using such concepts as exergy, entropy generation and irreversibility (exergy destruction) in order to evaluate efficiency with which available energy is consumed. Energetic analysis allows thermodynamic evaluation of energy conservation because it provide tool for a clear distinction between energy losses to environment and inter irreversibility's in the process. A thermal power plant is a good example of the utilization of exergy analysis. First law based energy analysis says energy losses associated with condenser are carried in to the environment by the cooling water and are significant because they represent about half of the energy input to the plant. Exergy based second law analysis however shows that virtually none of the exergy is lost in the water . The real loss primarily back in the boiler where entropy was produced. Therefore it is not reasonable to attempt to take advantage of energy lost in the condenser [2]. Recently, exergy analysis has become a key aspect in providing a better understanding of the process to quantify sources of inefficiency to distinguish quality of energy (or heat) used.[3-13]

Exergy is defined as the maximum theoretical useful work obtained as system interacts with an equilibrium state, Exergy is generally not conserved as energy but destructed 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 , and the magnitude and source of thermodynamic inefficiencies in a thermal system.[14].

Boiler efficiency has a great influence on heating related energy saving . It is therefore important to maximize the heat transfer to the water and minimize the heat losses in the boiler. Heat can be lost from boilers by a variety of methods, including hot flue gas losses, radiation losses etc.[15].To optimize the operation of boiler plant it is necessary to identify where energy losses likely to occure. A significant amount of energy is lost through the flue gases as all the heat produced by burning fuel is not transferred to water or steam in the boiler.

II. SYSTEM DESCRIPTION:

The schematic and T-s diagram of the basic Rankine cycle is shown in figure 1 and 2 respectively. The basic component of Rankine cycle are consist of Boiler(B), Steam Turbine(T),Condenser(C), and Feed Pump. The steam is generated in steam boiler and allowed to expand in steam Turbine represented by state 2, steam comes out from steam turbine at state 3. Condensation of steam takes place in condenser represented by state 4, condensate so formed is fed in to boiler represented by state 1_thus we have considered theoretical model of steam based Rankine cycle (cycle 1-2-3-4-1) with real processes.

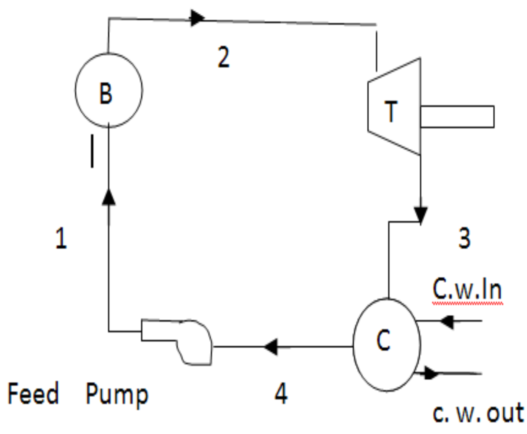

Figure 1: Schematic. Diagram. Rankine Cycle

The analysis of simple Rankine cycle is represented by a set of algebraic equations The set of equation for thermodynamic analysis consists of the (i) energy analysis (ii) exergy analysis.

3.1 Energy Analysis for Boiler Combustion Chamber:

$$E_{in} = m_f h_f + m_{pa} h_{pa} + m_s h_s \quad (1)$$

$$E_{out} = m_g h_g + m_s h_s \quad \text{in kJ/sec} \quad (2)$$

$$E_{loss} = E_{in} - E_{out} \quad \text{in kJ/sec} \quad (3)$$

$$\eta_i = \frac{E_{out}}{E_{in}} \quad (4)$$

3.2 Exergy Analysis for Boiler Combustion Chamber:

$$\psi_{in} = (\varepsilon_f + \varepsilon_{pa} + \varepsilon_{sa}) \quad \text{in kJ/sec} \quad (5)$$

$$\psi_{out} = (\varepsilon_g + \varepsilon_{sg}) \quad \text{in kJ/sec} \quad (6)$$

$$\psi_{destruction} = (\psi_{in} - \psi_{out}) \text{ kJ/sec} \quad (7)$$

$$\eta_{ii} = \frac{\psi_{out}}{\psi_{in}} \quad (8)$$

$$\varepsilon_f = m_f (h_f - T_0 s_f) \text{ in kJ /sec} \quad (9)$$

$$\varepsilon_{pa} = m_{pa}(h_{pa} - T_0\, s_{pa}) \text{ kJ/sec} \quad (10)$$

$$\varepsilon_{sa} = m_{sa}(h_{sa} - T_0 s_{sa}) \text{ kJ/sec} \quad (11)$$

$$\varepsilon_g = m_g (h_g - T_0\, s_g) \text{ kJ/sec} \quad (12)$$

$$\varepsilon_{sg} = m_{sg}(h_{sg} - T_0 s_g) \text{ kJ /sec} \quad (13)$$

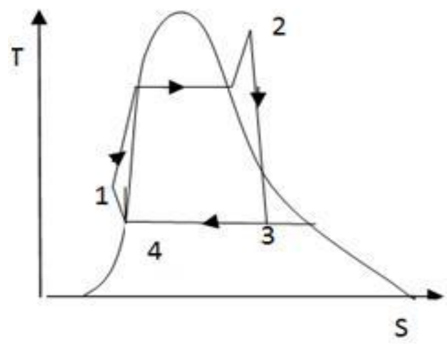

Figure 2: Fig.2: T-S Diagram Rankine Cycle

3.2 Energy Analysis for Individual Components :

3.2.1 Energy Analysis for Super heater :

$$E_{in} = m_g (h_{gi} - h_{gout}) \text{ kJ/sec} \quad (14)$$

$$E_{out} = m_{sup} (h_{supo} - h_{supi}) \text{ kJ/sec} \quad (15)$$

$$E_{loss} = E_{in} - E_{out} \text{ kJ/sec} \quad (16)$$

$$\eta_i = \frac{E_{out}}{E_{in}} \quad (17)$$

3.2.2 Energy Analysis for Economizer:

$$E_{in} = m_g (\Delta h_{gi} - \Delta h_{gout}) \text{ kJ/sec} \quad (18)$$

$$E_{out} = m_{eco}(\Delta h_{ecoo} - \Delta h_{ecoi}) \text{ kJ/sec} \quad (19)$$

$$E_{loss} = E_{in} - E_{out} \text{ kJ/sec} \quad (20)$$

$$\eta_i = \frac{E_{out}}{E_{in}} \quad (21)$$

3.2.3 Energy Analysis for Air pre heater:

$$E_{in} = m_g (\Delta h_{gi} - h_{gout}) \text{ kJ/sec} \quad (22)$$

$$E_{out} = m_{ap}(\Delta h_{apo} - \Delta h_{api}) \text{ kJ/sec} \quad (23)$$

$$E_{loss} = E_{in} - E_{out} \text{ kJ/sec} \quad (24)$$

$$\eta_i = \frac{E_{out}}{E_{in}} \quad (25)$$

IV. EXERGY PART:

4.1 Exergy Analysis:

$$\psi_{in} = \varepsilon_{gi} + \varepsilon_{go} \text{ kJ/sec} \quad (26)$$

$$\psi_{in} = (\varepsilon_{supo} + \varepsilon_{supi}) + (\varepsilon_{wo} + \varepsilon_{wi}) + (\varepsilon_{apo} + \varepsilon_{api}) + (\varepsilon_{sao} + \varepsilon_{sai}) \quad (27)$$

$$\varepsilon_g = m_g(h_g - T_0 s_g) \quad \text{kJ/sec} \qquad (28)$$

$$\varepsilon_{sup} = m_{sup}(h_{sup} - T_0 s_{sup}) \quad \text{kJ/sec} \qquad (29)$$

$$\varepsilon_w = m_w(h_w - T_0 s_w) \quad \text{kJ/sec} \qquad (30)$$

$$\varepsilon_{ap} = m_{ap}(h_{ap} - T_0 s_{ap}) \quad \text{kJ/sec} \qquad (31)$$

$$\varepsilon_{as} = m_{as}(h_{as} - T_0 s_{as}) \quad \text{kJ/sec} \qquad (32)$$

$$\psi_{in} = m_g(h_{gi} - T_0 s_{gi}) - m_g(h_{go} - T_0 s_{go}) \text{ kJ/sec} \qquad (33)$$

$$\psi_{out} = m_{sup}\{(h_{supo} - T_0 s_{supo}) - (h_{supi} - T_0 s_{supi})\} + m_w\{(h_{wo} - T_0 s_{wo}) - (h_{wi} - T_0 s_{wi})\} + m_{ap}\{(h_{apo} - T_0 s_{apo}) - (h_{api} - T_0 s_{api})\} + m_{as}\{(h_{aso} - T_0 s_{aso}) + (h_{asi} - T_0 s_{asi})\} \text{ kJ/sec} \qquad (34)$$

4.2 Exergy Calculation for Each Component:

4.2.1 Exergy Analysis for Super Heater:

$$\psi_{in} = m_g(h_{gi} - T_0 s_{gi}) - m_g(h_{go} - s_{go}) \quad \text{kJ/sec} \qquad (35)$$

$$\psi_{out} = m_{sup}(h_{supo} - T_0 s_{supo}) \quad \text{kJ/sec} \qquad (36)$$

$$\psi_{loss} = \psi_{in} - \psi_{out} \quad \text{kJ/sec} \qquad (37)$$

$$\eta_{ii} = \frac{\psi_{out}}{\psi_{in}} \qquad (38)$$

4.2.2 Exergy Analysis for Economizer:

$$\psi_{in} = m_g(h_{gi} - T_0 s_{gi}) - m_g(h_{go} - T_0 s_{go}) \quad \text{kJ/sec} \qquad (39)$$

$$\psi_{out} = m_w(h_{wo} - T_0 s_{wo}) - m_w(h_{wi} - T_0 s_{gi}) \text{ kJ/sec} \qquad (40)$$

$$\psi_{loss} = \psi_{in} - \psi_{out} \quad \text{kJ/sec} \qquad (41)$$

$$\eta_{ii} = \frac{\psi_{out}}{\psi_{in}} \qquad (42)$$

4.2.3 Exergy Analysis for Air Pre heater:

$$\psi_{in} = m_g(h_{gi} - T_0 s_{gi}) - m_g(h_{go} - T_0 s_{go}) \text{ kJ/sec} \qquad (43)$$

$$\psi_{out} = m_{ap}\{(h_{apo} - T_0 s_{apo}) - (h_{api} - T_0 s_{api}) + m_{aso}\{(h_{aso} - T_0 s_{aso}) - (h_{asi} - T_0 s_{asi})\} \text{ kJ/sec} \qquad (44)$$

$$\psi_{loss} = \psi_{in} - \psi_{out} \text{ kJ/sec} \qquad (45)$$

$$\eta_{ii} = \frac{\psi_{out}}{\psi_{in}} \qquad (46)$$

V. RESULTS & DISCUSSIONS:

Overall Plant Result:

5.1 Plant Result at Part Load(80% of Designed Load) Condition:

Table 1: First law and Second law Efficiency and Energy and Exergy Destruction.

Components	Efficiency based on first law(η_i)	Efficiency based on second law(η_{ii})	Energy loss (kJ/sec)	Exergy loss (kJ/sec)
Combuster	**99.78**	**53.12**	**465.343**	**169342.34**
Hear recocery system	**84.35**	**67.12**	**23267.3**	**36832.35**
Superheater	**84.32**	**48.11**	**14314 .2**	**41211.44**
Economizer	**83.12**	**42.43**	**60502.4**	**17311.32**
Airpreheater	**64.12**	**48.11**	**11889.4**	**17675.87**
Turbine	**85.34**	**78.11**	**121213.5**	**77854.34**

From the above analysis it is clear that exergy losses and exergy destruction is more in boiler as compared to energy loss. First law analysis gives first law efficiency which is much more than second law efficiency obtained from second law analysis.

Table 2 gives result of exergy analysis for boiler process. It is concluded from the analysis that the combustion process is the major contribution for exergy destruction followed by heat exchanger of boiler system.

Result of Exergy Analysis of Boiler

Boiler process	Exergy Destruction (MW)	Percentage Exergy Destruction (%)	Exergetic Efficiency (%)
Combustion Process	**250.74**	**33.84**	**64.75**
Heat Transfer Process	**183.65**	**42.73**	**65.32**
Total Exergy Loss	**434.39**	**76.57**	**39.76**

Comparison of Energy and Exergy analysis of components of thermal Power Plant.

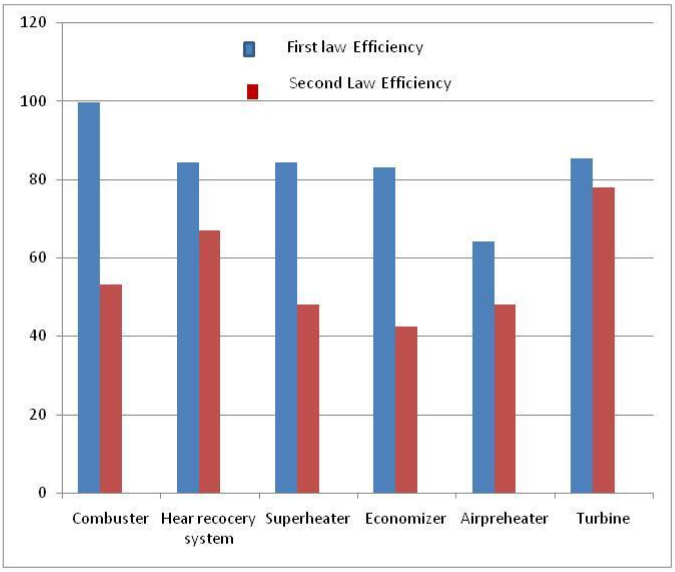

FIG.1 Representation of energy and exergy analysis of different components of steam power plant.

Figure clearly depicts that second law efficiency is much low as compared to efficiency based on first law energy).Exergetic efficiency of combuter is nearly 51% as compared to first law efficiency which is 99%.

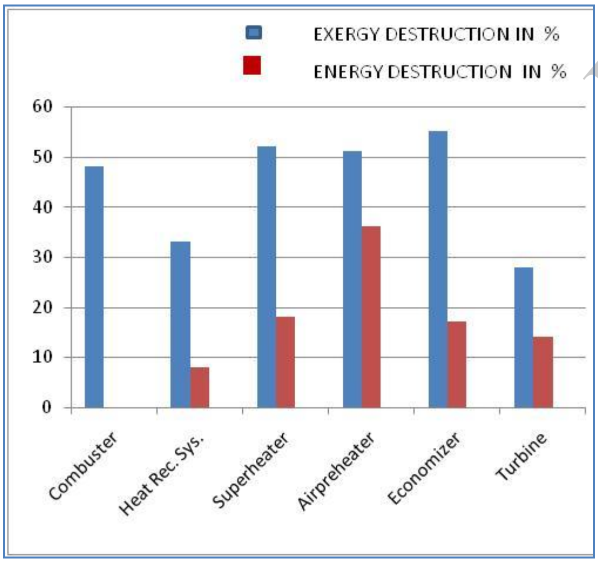

FIG.2 Representation of energy and exergy destruction of different components of thermal power plant.

Fig. 2 is representing energy and exergy destruction of different components , it is clear from yhe figure that exergy destruction is much more than the energy destruction of different components.Maximum exergy destruction is found in economizer which is nearly 55% followed by super heater and air pre heater. Minimum exergy destruction is found in turbine which is nearly 28%. Total exergy destruction of the plant is about 80%.

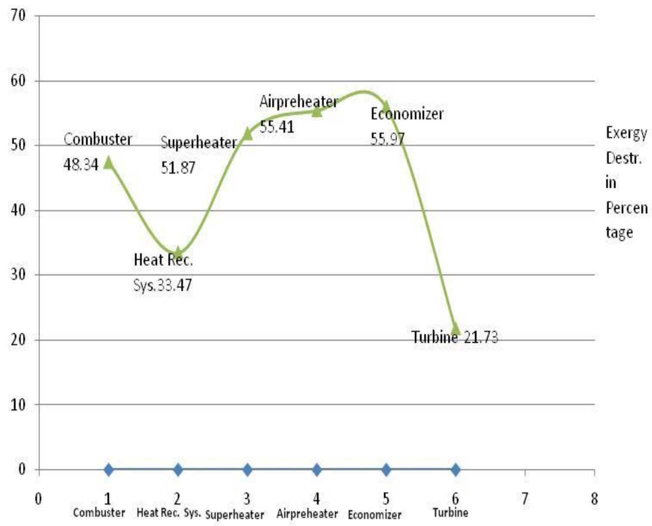

Figure. 3 **Exergy destruction of various components of thermal power plant.**

CONCLUSION

From the analysis it is found that exergy efficiency is much lower than the energy efficiency based on first law. It is also concluded that the Air pre heater Super heater and economizer are main components which contribute to exergy loss.

It is depicted from the analysis that nearly 48% exergy loss takes place in combuster that suggest that combuster is not working adiabatically and combustion is not complete. It is due to irreversibility involved in combustion process, therefore combustor design require some modification to improve plant performance.

The majot energy destruction occurs in heat recovery system which leads to poor heat transfer rate between flue gas and water and air.

Exergy destruction in low pressure turbine is more as compared to high pressure and intermediate pressure turbine and require modification in design or proper maintenance.

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