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ABSTRACT: The global concern about energy and fuel cost, environment safety, availability of conventional sources for power generation and fulfillment of energy demand will enhance the adoption of coal & gas based power plants. The rising attention of efficient and resourceful use of energy will support the adopted power generation techniques. The exergy modeling of thermal systems provide the information about cause of losses, to scale the process, and rectifying the components. In this paper, a thermodynamic analysis of coal based nine MW thermal power plant is carried out. The energy-exergy analysis have been carried out for the boiler, turbine, condenser and pump majorly. The result of thermodynamic analysis is computed in terms of 24.12% plant energy efficiency, 35% of plant exergy efficiency and 11% of boiler energy efficiency respectively. The various exergy destruction in the components have been presented in this paper.

Keywords: Energy-Exergy Analysis, Irreversibility Analysis, Rankine thermal power plant.

I. INTRODUCTION

The large amount of heat is transferred between all utilities of thermal power plant and its greatly affect the plant performance. The First Law of Thermodynamic (FLT) is qualitative evaluation of energy, it treat the work and heat interaction with equivalent forms of energy between system and surrounding. The FLT does not provide the information about internal losses, thermal inefficiency due to high grade energy of plant dump in to atmosphere and sustainability. The real performance of thermal system and quality of energy transfer process estimated by the approach of Second Law of Thermodynamic (SLT) called concept of exergy. The term ‘Exergy’ is maximum possible work obtained from a system at a given state when interacting with a environment, its useful quantity that extract from the SLT. It clearly indicates the inefficiencies of a process by locating the degradation of energy. In short exergy efficiency is true or real efficiency and energy efficiency is approximation of real efficiency. The energy-exergy analysis of 9 MW small size of coal based thermal power unit refers live operational data (Average monthly data of February 2015) of Adani Power Gujrat State of India in present analysis. Major units of plant (boiler, turbines, condensar and pump) have been investigated in proposed thermodynamic model. The main objective of energy-exergy modeling to identifying the magnitude of process, cause of losses and rectifying the components. The numerous researches have been conducted on energy-exergy analysis of various thermal systems, power plant components, and renewable energy conversion systems. Dicer and Rosen [2] stated that, why exergy is important for thermal analysis?. They stated that exergy flow rate of a flowing commodity is the maximum rate of work which is obtained from it and it passes reversibly to the environmental state, exchanging heat and materials only with the surroundings. exergy analysis is the theoretical limitations imposed upon a system, clearly pointing out that no real system can conserve exergy and that only a portion of the input exergy can be recovered. Also, exergy analysis quantitatively specifies practical limitations by providing losses in a form in which they are a direct measure of lost exergy. A.Bejan [3] introduced EGM (entropy generation minimization) method, and concluded whenever entropy production is minimized, useful energy is maximized. Khaliq and Kaushik [5] concluded the combustion chamber exergy destruction is 50% of overall exergy destruction of cycle, and effect of intermediate pressure-ratio and effect two stage of reheating on combined GT-ST power cycle performance by using 2nd law thermodynamic approach. Yang et al [6] compared conventional and advanced approach of exergy analysis of supercritical coal thermal power plant. Conventional approach identified exergy destruction of all components, whereas advanced exergy analysis conclude thermodynamic interactions among thermal utilities for energy saving potential. Ahmadi and Dincer [7] analysed efficiency of dual pressure combined cycle
power plant (CCPP), 1st law and 2nd law thermodynamic efficiencies are reduced with the addition of duct burner to HRSG, but power output of CCPP is improved. S.C.Kaushik et al and Aljundi [8,9] review begins with concept of exergy, entropy generation, irreversibility of thermodynamic system and exergy destroyed, and and identify the components having major energy-exergy losses in steam power plant. Gulhane and Thakur [10] investigated amount and source of irreversibilities in 35 TPH capacity of boiler. And also found 76% of exergy destruction at peak load on boiler but 1st and 2nd law efficiency are enhanced. Osueke et al [11] computed maximum exergy destruction 87.3% in boiler, and plant exergy efficiency 11.03% with the effect of water flow in boiler on steam generation and plant output of 75MW of steam power plant, which is located in Sapele-Nigeria. R kumar [12] critically summarized in review of 4-E (energy,exergy,exergonomic and economic) concept for different-different power generation techniques. He addressed the boiler and condenser component have major exergy destruction in case of rankine power cycle, whereas combustion chamber is larger part for exergy destruction in case of gas-turbine power cycle.

II. BRIEF OF STEAM POWER PLANT

The working of coal fired thermal power plant based on Rankine thermal power cycle. The plant size have medium level consisted by major parts 01 boiler unit,03 turbine unit,02 dearators,01 condenser unit, 02 HP heaters,01 pump,etc. Another thermal utilities also provide, the detail of plant layout, dimensions and flow rate values of units are not available due to company privacy policy. The proposed energy-exergy analysis is modeled for major parts of Rankine cycle, boiler, turbines, condenser and pump as per operational data of plant. The plant data is collected in month of February 2015, which is shown in table-1 (a) & (b).

<table>
<thead>
<tr>
<th>Time</th>
<th>CW FLOW</th>
<th>Temperature</th>
<th>Condenser</th>
<th>Ambient Conditions</th>
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<td>CW - OUT</td>
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<td></td>
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<td>(ºC)</td>
<td>(ºC)</td>
<td>(%)</td>
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Table-1 (b) Operation data of 9MW steam power plant

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<th>Extraction 3</th>
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<td>Flow</td>
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</table>
III. ENERGY AND EXERGY ANALYSIS OF NINE MW COAL BASED THERMAL POWER PLANT

All equations of analysis is adopted from fundamental approach of 1st law and 2nd law of thermodynamics, and properties (enthalpy, entropy, specific heat, specific volume, etc) of steam formation referred from steam property table (cited from www.engineeringtoolbox.com/www.spiraxsarco.com) as per steam condition (superheated and saturated) at different pressure-temperature level. PK Nag [1] and Shappiro [4] given energy-exergy equations for power-plant analysis:

$$\eta_{PLANT} = \frac{W_{NET}}{Q_{BOILER}}$$

$$W_{NET} = W_{TURBINE TOTAL} - W_{PUMP}$$

$$W_{TURBINE TOTAL} = W_{TURBINE 1} + W_{TURBINE 2} + W_{TURBINE 3}$$

$$W_{TURBINE 1} = m_{dot_{turbine1}}_steamflow (h_{temp inlet_{turbine1}} - h_{temp exit_{turbine1}})$$

$$W_{TURBINE 2} = m_{dot_{turbine2}}_steamflow (h_{temp inlet_{turbine2}} - h_{temp exit_{turbine2}})$$

$$W_{TURBINE 3} = m_{dot_{turbine3}}_steamflow (h_{temp inlet_{turbine3}} - h_{x2})$$

From enthalpy and entropy balance equation:

$$h_3 = h_2 + x_2 h_{fg2}$$

$$s_1 = s_2 + s_{fg2}$$

$$h_1 = h_{temp inlet_{turbine3}} = 2827.18 KJ/Kg \ldots \text{temp at 180 °C} \text{ (inlet temp of turbine3)}$$

$$s_1 = s_2 = 7.353 kJ/kg-K$$

From steam properties at condenser line pressure of 0.098 bar (absolute)

$$h_3 = h_f = 2376.8 \text{kJ/kg}$$

$$s_f = 7.591 \text{kJ/kg-K}$$

Sp Volume of saturated steam at condenser line v=0.001009 m3/kg

Put all values of entropy and get x2=0.91 and estimate h2s from eq. no7

$$h_2s = 2376 \text{kJ/kg}$$

Now total turbine work (mass flow rate of steam for different turbine provide in plant data table-1 (a)&(b), providing all values of enthalpy as per inlet temperatures Values of turbines)

$$W_{TURBINE TOTAL} = 960 \text{kJ/kg or 8.5 MW (flow rate of steam varying daily with time)}$$

$$W_{PUMP} = \frac{v x d_P}{\rho (P_{BOILER LINE} - P_{CONDENSER LINE})} = m_{dot_{pump}} (h_{4s} - h_f)$$

$$h_4s = 2977.95 \text{kJ/kg}$$

$$s_{fg} = 7.591 \text{kJ/kg-K}$$

Put all values of entropy and get x2=0.91 and estimate h2s from eq. no7

$$h_2s = 2376 \text{kJ/kg}$$

Heat Generated by boiler

$$Q_{BOILER} = m_{dot_{boiler蒸汽}} steamflow (h_{boiler temp} - h_4s).$$

(Steam flow through boiler is 65TPH from data table)

$$Q_{BOILER} = 3196 \text{kJ/kg or 58627 KW}$$

For $$\eta_{PLANT} = W_{NET} / Q_{BOILER} = 24.12\%$$

$$\eta_{PLANT} = W_{NET} / Q_{FUEL} = 11\%$$

(13 TPH of coal feeding with 97 TPH of air)

Exergy Balance Equation:

Exergy flow rate of inlet steam:

$$\epsilon_{t, in} = m_{dot_{steam}} \times cp_{boiler steam} \times To \left[ \frac{T_{boiler}}{To} - 1 - ln \frac{T_{boiler}}{To} \right]$$

(Steam generation inlet temperature is 485±5°C, 75TPH and specific heat of steam 2.21 kJ/kg-k, atmospheric temp To is 298K)

$$\epsilon_{t, in} = 387 \text{kJ/Kg or 7715KW}$$

Exergy flow rate of exhaust steam:

$$\epsilon_{t, out} = m_{dot_{steam}} \times cp_{boiler steam} \times To \left[ \frac{T_{boiler}}{To} - 1 - ln \frac{T_{boiler}}{To} \right]$$
(Steam temperature exhaust is 320 °C, 75TPH and specific heat of steam 2.21 kJ/kg-k, atmospheric temp To is 298K)

\[ \epsilon_{f_{out}} = 260 \text{ KJ/Kg or 5240KW} \]

Rate of exergy decrease- \( \epsilon_{f_{in}} - \epsilon_{f_{out}} = 127 \text{ KJ/Kg or 2475 KW} \) \( \epsilon_{f_{out}} = 0.47 \) \( \epsilon_{f_{in}} \) \( \epsilon_{f_{Usefull}} = 1172.10 \text{ KJ/Kg or 23547.5KW} \) \( \epsilon_{f_{Usefull}} = \frac{m_{dot} \text{ steam}}{h_{1-h4s-To} (s_{1-s4s})}. \)

Rate of exergy loss during steam generation=

\[ \epsilon_{Des_{boiler}} = \frac{127 \text{ KJ/Kg or 2475 KW}}{0.47} \]

Exergy flow rate of wet steam to condenser

\[ \epsilon_{wet \text{ steam to condenser}} = \frac{m_{wet \text{ steam to condenser}}}{h_{2s-hf3-To} (s_{2-sf3})}. \]

Exergy Destruction in boiler

\[ \epsilon_{Des_{boiler}} = \frac{1045.1 \text{ KJ/Kg or 21072.5 KW}}{186} \]

Exergy flow rate of wet steam to condenser

\[ \epsilon_{wet \text{ steam to condenser}} = \frac{m_{wet \text{ steam to condenser}}}{h_{2s-hf3-To} (s_{2-sf3})}. \]

Irreversibility estimation of each components-

\[ IRR = \frac{T_{out}}{T_{in}} \eta \Sigma \Delta S = \frac{T_{out}}{T_{in}} (\Delta S_{boiler} + \Delta S_{turbine} + \Delta S_{condenser} + \Delta S_{pump}). \]

And \( \Delta S = c_{p}ln(\frac{T_{out}}{T_{in}}) \) from 2nd law of thermodynamics.

**IV. RESULT AND DISCUSSION**

The property of steam of parts of plant is taken from steam property chart with variation of pressure-temperature and saturated & superheated state of steam condition as per available data. All values of enthalpy, entropy and specific heat shown in table -2 to Table-5 respectively.

<table>
<thead>
<tr>
<th>Pressure (Kg/cm²)</th>
<th>Temp (°C)</th>
<th>Flow (Kg/s)</th>
<th>Enthalpy (kJ/Kg)</th>
<th>Entropy (kJ/Kg-K)</th>
<th>Sp Heat (kJ/Kg-K)</th>
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</table>
The numerical computation of nine MW coal based thermal power plant is carried out and performance parameters in terms of plant efficiency boiler efficiency, exergetic efficiency of plant and irreversibilities in terms of exergy destruction in various components, exergy destruction ratio of plant is shown in table respectively.

Table-3 Condensor observation

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<th>Vacuum Pr (Kg/cm² gauge)</th>
<th>Temp (°C)</th>
<th>Flow (kg/s)</th>
<th>Enthalpy (kJ/Kg)</th>
<th>Entropy (kJ/Kg-K)</th>
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Table-4 Turbine 1& 2 Observation

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<th>Flow (kg/s)</th>
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Table-5 Turbine-3 Observation

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Table-6 Parametric Result

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<th>Computed Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Out Put (Wnet)</td>
<td>7.3 MW</td>
</tr>
<tr>
<td>Total Turbine Out Put (Wturbine)</td>
<td>8.5 MW</td>
</tr>
<tr>
<td>Boiler Heat Generation (Qboiler)</td>
<td>3196 KJ/KG</td>
</tr>
<tr>
<td>Plant Efficiency (ηPLANT)</td>
<td>24.12%</td>
</tr>
<tr>
<td>Boiler Efficiency (ηBOILER)</td>
<td>11%</td>
</tr>
<tr>
<td>Plant Exergy Destruction Rate</td>
<td>2.1%</td>
</tr>
<tr>
<td>Plant Exergetic Efficiency (ηEExergy)</td>
<td>35%</td>
</tr>
</tbody>
</table>
V. CONCLUSIONS & RECOMMENDATION

The exergy analysis plays deterministic role in identifying the magnitude of thermodynamic processes, cause of losses and rectifying the exergy destruction rate in the components due to energy saving in components (i.e. boilers, condensers in steam power plant).

1. The maximum exergy destruction (irreversibility) as 34%.
2. Exergy Destruction is found to be 2.17 (which is the based on output analysis) and 0.65 based on input.
3. The plant efficiency is 24.12%
4. The second law efficiency is 35%

ACKNOWLEDGEMENT

We express warm thanks to Mr Bhawin, Energy Auditor, Darshan Institute, Badodra, Gujarat, India, who provide all technical facilities related to plant analysis.

REFERENCES


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