Energy Analysis of Thermal Power Plant

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Abstract — Energy analysis helps designers to find ways to improve the performance of a system in a many way. Most of the conventional energy losses optimization method are iterative in nature and require the interpretation of the designer at each iteration. Typical steady state plant operation conditions were determined based on available trending data and the resulting condition of the operation hours. The energy losses from individual components in the plant is calculated based on these operating conditions to determine the true system losses. In this, first law of thermodynamics analysis was performed to evaluate efficiencies and various energy losses. In addition, variation in the per-cent age of carbon in coal content increases the overall efficiency of plant that shows the economic optimization of plant.

Index Terms — Energy, efficiency, thermal power plant, first law analysis, energy losses, optimization, coal.

1. INTRODUCTION

Thermal Power Plant is converter of fossil fuel energy to electricity in which during a cycle, steam is used to spin a turbine driving electrical generator to produce electricity. The first thermal power plant was built by Sigmund Schuckert in Ettal 1878. In the power plant a steam engine drove 24 dynamo generators.

fig1 : power plant cycle

The condenser is a heat transfer device or unit used to condense a substance from its gaseous to liquid state, typically by cooling in it. In doing so, the latent heat is given up by the substance and will transfer to the condenser coolant. Use of cooling water or surrounding air as the coolant is common in many condensers. The main use of a condenser is to receive exhausted steam from a steam engine or turbine to condense the steam. The benefit being that the energy which would be exhausted to the atmosphere is utilised. A steam condenser generally condenses the steam to a pressure significantly below atmospheric. M. Rafiee et al presented in his paper—Improving the Efficiency of Thermal Power Plant Using Thermoelectric Material, about the use of thermoelectric material or specifically the use of Thermoelectric Generator to produce electricity from the wasted heat in the condenser. It shows an increase of about 3.3% of the power plant (from 33% to 36.33%).(1) Vikram Haldkar et al experimentally showed in his paper-condenser maintains a very low back pressure on the exhaust side of the turbine. Secondly, the exhaust steam condensate is free from impurities. Condenser pressure dependence on cooling water temperature is obtained for the given water flow rate. It is experimentally shown that with cooling water increasing, pressure in the condenser will also increase.(2)

V.V Prosorov presented in his paper, Decrease of the corrosion products in water coolant for increasing the efficiency and improving the safety of a nuclear power plant, the corrosive behaviour of oxidised steel in water to which inhibitors or oxygen have been added is studied. Pre-oxidation of steel makes it possible to decrease the amount of oxygen of inhibitors. The concentration of corrosion products and correspondingly their accuracy in the neutron flux of a nuclear reactor and the amount of radio-nuclides can be decreased.(3) Shailendra Pratap Singh et al presented in his paper—High cooling water inlet temperature (t₁) leads to higher saturation temperature and corresponding rise in condenser saturation pressure for a design specified cooling water temperature rise and temperature terminal
difference. There are two effects caused by the cooling water inlet temperature. The primary one is to alter the steam saturation temperature and secondary is the fact that the heat transfer of the cooling water film in contact with condenser tubes change with temperature of the water. (4) Shuguo and Xinglou have done research on the comparative study of vertical fin flat tube and wave fin flat tube depending on six wind conditions - the heat transfer coefficients, flow losses, heat dissipation and average surface temperature change. The search proved that in vertical fin tube, air flow space is larger and turbulence intensity is lowered as par with wave fin flat tube. The flow losses is 28.3% less and reduces the power demand of cooling fans.

2. ANALYTICAL APPROACHES

a. Energy analysis of combustion chamber.

Combustion chamber is the most important part of the boiler. The combustor in a boiler is usually well insulated that causes heat dissipation to the surrounding almost zero. It also has no involvement to do any kind of work (w=0). In addition, the kinetic and potential energies of the fluid streams are usually negligible. Then only total energies of the incoming streams and the outgoing mixture remained same for analysis [2]. The conservation of energy principle requires that these two equal each other’s that is shown in the figure

\[ \text{Energy balance equation for any system} \]
\[ E_{\text{in}} - E_{\text{out}} = m_p (h_p - h_g) = m_w (h_s - h_w) + Q \]

Where,

\[ n_{\text{HE}} = \frac{m_w}{m_p} \left( \frac{h_{\text{up}} - h_{\text{at}}} {h_p - h_g} \right) \]

b. Energy analysis of boiler drum (i.e. heat exchanger)

The boiler is considered as a single cross-flow steam production chamber. The performance of the steam production chamber plays an important role of the boiler efficiency. Heat is transferred from the hot fluid to the cold one through the wall separating them. Heat exchanger is a device where two moving fluid streams exchange heat without mixing. A heat exchanger typically involves no work interactions (w=0) and negligible kinetic and potential energy changes for each fluid streams [3]. The outer shell of the heat exchanger is usually well insulated to prevent any heat loss to the surrounding medium.

c. Energy analysis of turbine.

Energy balance equation for turbine and Work done by turbines actually = 18000 kW

Balancing equation for bleeding mass [5]
\[ W_t = m_3 (h_3 - h_4) + (m_3 - m) (h_4 - h_5) \]

Energy loss
\[ Q = m_3 h_3 - (m_3 - m) (h_3 - h_4) - m (h_4 - h_5) - W \]

Efficiency
\[ \eta = 1 - \]

\[ \text{Fig. 2 Schematic diagram of Combustion Chamber} \]

Therefore, the total heat released by complete combustion of 1 kg of coal is [1]

\[ HHV = 33.91C + 143 \left( H - \frac{2}{g} \right) + 9.094S \text{ MJ/Kg} \]

In energy efficiency case, we assume that the combustion chamber there is no heat losses [4]. Therefore, \( \eta = 100\% \)

\[ \text{Fig. 3 Schematic diagram of Heat Exchanger} \]

Energy balance equation for any system

\[ E_{\text{in}} - E_{\text{out}} = m_p (h_p - h_g) = m_w (h_s - h_w) + Q \]

Heat loss
\[ Q = m_p (h_p - h_g) - m_w (h_s - h_w) \]

Where,

\[ n_{\text{HE}} = \frac{m_w}{m_p} \left( \frac{h_{\text{up}} - h_{\text{at}}} {h_p - h_g} \right) \]
d. Energy analysis of condenser

Energy balance equation for condenser is-

\[ Q_{\text{given}} = (m_3 - m) (h_3 - h_2) + m (h_3 - h_7) \]  
\[ Q_{\text{rej}} = (m_3 - m) (h_5 - h_1) \]  
So, from the above equation we get,

\[ Q_{\text{rej}} = (mc \cdot cp) (t_5 - t_4) \]  

Energy balance
\[ Q_{\text{loss}} = m_5 (h_5 - h_1) - Q_{\text{rej}} \]  

Efficiency
\[ \eta = 1 - \frac{Q_{\text{loss}}}{m_5 (h_5 - h_1)} \]

Fig. 5 Schematic diagram of Turbine

Fig. 6 Cooling Tower Type Condenser

Heat given to the system
\[ Q_{\text{given}} = (m_3 - m) (h_3 - h_2) + m (h_3 - h_7) \]  

Heat rejection
\[ Q_{\text{rej}} = (m_3 - m) (h_5 - h_1) \]  

So, from the above equation we get,

With the growing need of the coal, which is an non renewable source of energy and depleting with a very fast pace, it is de-sirable to have such optimal techniques (better quality of coal) which can reduce the energy losses in the coal fired boiler and improves its performance these create impact on production and optimizations uses of energy sources. In addition this study shows the better quality of coal giving the high per-formance of plant and even though the consumption of coal is been reduced that creates economic condition for overall plant.

4. REFERENCES

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NOMENCLATURE

c – Carbon
h – Hydrogen
o – Oxygen
s – Sulphur
E – Rate of energy
dE system/ dt – Rate of change
C p = Specific heat capacity, kJ/kg0C
E = Rate of energy
m = Mass flow rate, kg/s
Q = Energy losses
s = Specific entropy, kJ/kg
T = Temperature0C
η = Energy efficiency