Effect of Gas Turbine Exhaust Temperature, Stack Temperature and Ambient Temperature on Overall Efficiency of Combine Cycle Power Plant

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Abstract—**The gas turbine exhaust temperature, stack temperature and ambient temperature play a very important role during the predication of the performance of combine cycle power plant. This paper covers parametric analysis of effects of gas turbine exhaust temperature, stack temperature and ambient temperature on the overall efficiency of combine cycle power plant keeping the gas turbine efficiency as well as steam turbine efficiency constant. The results shows that out of three variables i.e. turbine exhaust temperature, stack temperature and ambient temperature, the most dominating factor of increasing the overall efficiency of the combine cycle power plant is the stack temperature.**

Keywords: Gas Turbine, Steam Turbine, exhaust temperature, stack temperature, ambient temperature, Combine cycle.

Introduction

Combine cycle plant is used for large base-load generating stations. The ultimate aim is to reduce the cost of power generation. In dual pressure steam cycle power plant, higher efficiency can be obtained by increasing the average temperature at which heat is transfer to steam. But the additional complication would increase the cost of boiler and steam turbine. The economical consideration of the various power plants can be compared by the cost of electrical power production, which depends upon the type and the quality of fuel and to large extent to specific fuel consumption of the power plant. The least expensive power plant is not necessary most economical as its running cost may be high.

In gas turbine the maximum amount of energy not converted to shaft power and is waste in exhaust gasses. The exhaust gasses may be utilized in various ways, if it is wholly used to produce steam generation in the waste heat boiler recovery steam generator for steam turbine with the object to produce shaft power, the efficiency of the plant can be increase and such plant is refer as combine cycle power plant as shown in figure 1.

Heat Recovery Steam Generator (HRSG) are the important component of combined cycle power plant used to recover waste heat from the high temperature of the exhaust of the gas turbines and generate steam. High efficiency, low energy losses and long expected life are the important factors which make combine cycle power plants unique in compression with other type of plants. Behbahani-nia et al. [1] studied the effect of gas pinch point and velocity on the components of the objective functions. Pash & Sanjeev [2] presented a discussion about the parameters that influences the type of circulation and selection of heat recovery steam generator (HRSG). Ongiro [3] develops the numerical method to predict the performance of heat recovery steam generator (HRSG) for design and operations constrains. Ganapathy et al. [4] describe the features of heat recovery steam generator (HRSG) used in cheng cycle system, where a large quantity of steam is injected into the gas turbine to increase electrical power output various authors [5-9] discussed factors affecting heat recovery steam generator (HRSG) design for achieving higher efficiency.

Figure 2 shows the gas and steam conditions in the boiler on temperature- enthalpy diagram. The enthalpy rise between the feed water inlet and steam outlet must equal the enthalpy drop of the exhaust gasses in the heat recovery steam generator (HRSG). The pinch point and the terminal temperature differences cannot be less than 20^0 if the boiler is to be economical size.

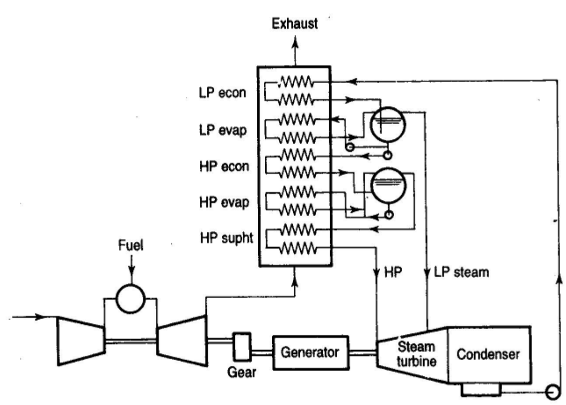

Figure 1

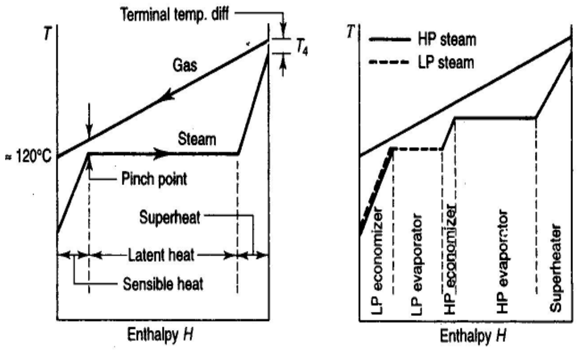

Figure 2

Energy Balance of Gas and Steam in Combined Cycle

The heat from the exhaust gasses from the gas turbine should be sufficient to generate the steam and pressure in the waste heat recovery steam generator (HRSG).

The heat transferred from the exhaust gasses is:

$$q_{ex} = m_g . C_{pg} . (T_4 - T_{stack}) \quad (1)$$

The heat absorbed or gain in the boiler

$$q_{ex} = m_s . (h - h_w) \quad (2)$$

The super heat temperature is fixed by T_4 and the terminal temperature difference, and the enthalpy will depend on the pressure. The pinch point temperature T_p, is fixed by pinch point difference and the saturation temperature of the steam. Therefore, heat balance between steam and exhaust gasses is

$$m_s (h - h_f) = m_g . C_{pg} . (T_4 - T_p) \quad (3)$$

The stack temperature can be obtained from

$$m_s (h_f - h_w) = m_g . C_{pg} . (T_p - T_{stack}) \quad (4)$$

The total power from the combined cycle is $W_{gt} + W_{st}$ and the overall efficiency is given by

$$\eta = \frac{W_{gt} + W_{st}}{Q} \quad (5)$$

Where $W_{st} = \eta_{st} . Q_{st}$

And $Q_{st} = m_g . C_{pg} . (T_4 - T_{stack})$ (6)

This Q_{st} can be expressed in terms of the heat rejection from the gas turbine assuming that the turbine exhausts gas at T_4 is cooled without useful energy extraction from the T_{stack} to the ambient temperature T_a i.e.

$m_g . C_{pg} . (T_4 - T_a)$ or $Q(1 - \eta_{gt})$

Thus

$$Q_{st} = m_g . C_{pg} . (T_4 - T_a) \frac{(T_4 - T_{stack})}{(T_4 - T_a)}$$

i.e. $$Q_{st} = Q(1 - \eta_{gt}) \frac{(T_4 - T_{stack})}{(T_4 - T_a)} \quad (7)$$

The overall efficiency is written as :

$$\eta = \frac{W_{gt}}{Q} + \frac{W_{st}}{Q} = \frac{W_{gt}}{Q} + \frac{\eta_{st} . Q_{st}}{Q}$$

Using equation (7), η can be simplified as

$$\eta = \eta_{gt} + \eta_{st} (1 - \eta_{gt}) \frac{(T_4 - T_{stack})}{(T_4 - T_a)} \quad (8)$$

Effect of operating Temperature on Overall Efficiency of Combined Cycle Power Plant

This study i.e. the effect of turbine exhaust temperature, stack temperature and ambient temperature on overall efficiency of combined cycle power plant is under the assumption of gas turbine efficiency and steam turbine efficiency are 36% and 32% respectively.

Effect of Turbine Exhaust Temperature on overall efficiency of combine cycle power plant for various values of ambient Temperature at the particular value of Stack Temperature

Equation (8) shows that the overall efficiency of the combine cycle power plant is the function of turbine exhaust temperature, stack temperature and ambient temperature but from this equation it is difficult to say that for a particular value of Stack Temperature who the overall efficiency of the combine cycle power plant varies by simultaneous variation of turbine exhaust temperature and ambient temperature. Figure 3 shows that for the particular value of Stack temperature as well as ambient temperature as the turbine exhaust temperature increases the overall efficiency of the combine cycle power plant increases and this is because of increase of steam generation rate in the bottoming cycle i.e. steam power plant. Also at the particular value of turbine exhaust temperature as well stack temperature with increases of ambient temperature the overall efficiency of the combine cycle power plant also increases and the reason is same.

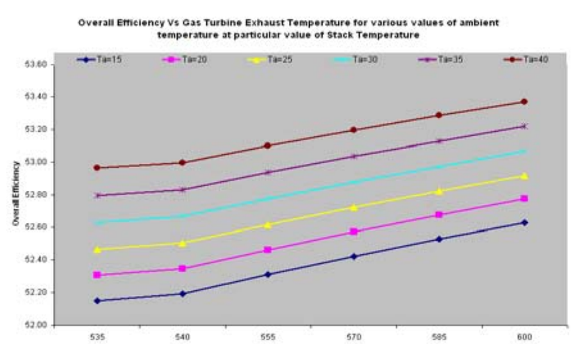

Figure 3

Effect of Turbine Exhaust Temperature on overall efficiency of combine cycle power plant for various values of Stack Temperature at the particular value of ambient Temperature

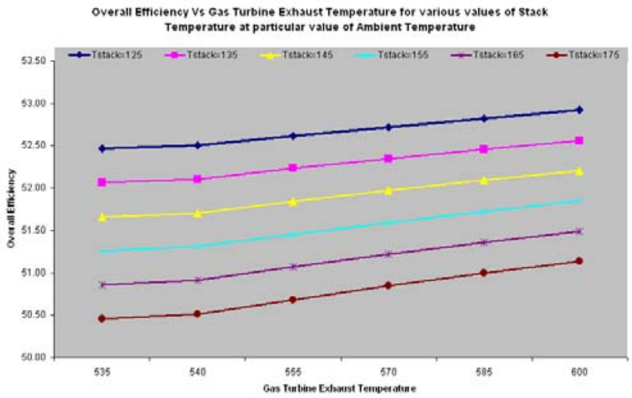

Figure 4

Figure 4 shows effect of turbine exhaust temperature on overall efficiency of combine cycle power plant for various values of stack temperature at the particular value of ambient temperature and the results shows that for the particular value of stack temperature as well as ambient temperature with increases of gas turbine exhaust temperature the overall efficiency of the combine cycle power plant increases.

Combine Effect of Turbine Exhaust Temperature, Stack Temperature and Ambient Temperature on Overall Efficiency of Combined Cycle Power Plant

In figure 3 and figure 4 out of three variables of equation (8) i.e. turbine exhaust temperature, stack temperature and ambient temperature one to two variables are constant. Figure 5 shows combine effect of turbine exhaust temperature, stack temperature and ambient temperature on overall efficiency of combined cycle power plant. The results shows that the peak efficiency of the combine cycle power plant is achieve when the stack temperature is minimum, exhaust temperature as well as ambient temperature is maximum exist simultaneously.

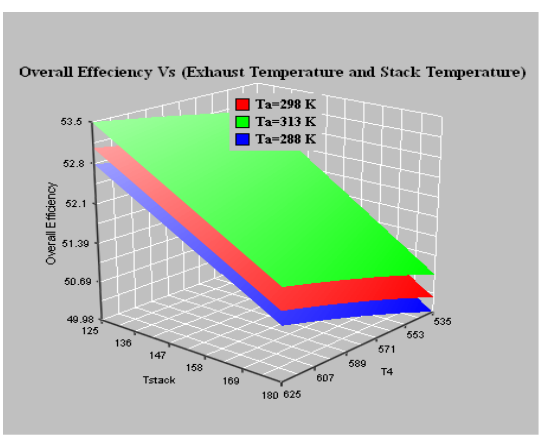

Figure 5

Conclusion

Based on the analysis of this study the following conclusions are made:

- The ambient temperature not in our hand, so order to increase the overall efficiency of combine cycle power plant the stack temperature should be minimum and gas turbine exhaust temperature should be maximum.
- Out of these three variables i.e. turbine exhaust temperature, stack temperature and ambient temperature, the dominating factor of increasing the overall efficiency of the combine cycle power plant is the stack temperature.

NOMENCLATURE

Q	Heat Supplied (kJ/kg)
C_p	Specific Heat at Constant Pressure (kJ/kg)
m	Mass flow rate (kg/hr)
T_4	Temperature at the exhaust of the gas turbine (K)
T_P	Pinch Point Temperature (K)
T_{stack}	Stack Temperature (K)
T_a	Ambient Temperature (K)
h_f	Saturated liquid enthalpy of steam (kJ/kg)
h	Specific enthalpy at steam turbine inlet (kJ/kg)
h_w	Specific enthalpy of steam at HRSG inlet (kJ/kg)
W	Power Output (Kw)
η	Overall efficiency
HRSG	Heat Recovery Steam Generator

Suffix

gt	Gas Turbine
st	Steam Turbine

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