

Exergy Analysis of Gas Turbine Power Plant

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Abstract— The exergy analysis is carried out by conducting mass, energy and exergy balance of each component in the gas turbine plant. Parametric analysis of the influence of various factors namely compression ratio (r_p), compressor inlet air temperature (AT) and turbine inlet temperature (TIT) on irreversibilities of each and every component of gas turbine plant is carried out. Exergy analysis revealed that most sensitive components in gas turbine plant were combustion chamber.

Keywords— gas turbine power plant; first law efficiency; second law efficiency; compression ratio; compressor inlet air temperature; turbine inlet temperature, irreversibility.

I. INTRODUCTION

Gas turbines have been successfully used for cogeneration. Gas turbine cogeneration system (GTCS) requires improvement in thermodynamic performance with reduced expenditure. Bejan et al. [1] developed analysis methodology for GTCS. Kotas [2] developed a method to determine chemical and physical exergies for various components. Srinivas et al. [3] studied the efficiency of GTCS with single, dual and triple pressure heat recovery steam generator (HRSG). Ganapathy et al. [4] have performed an exergy analysis on an operating 50 MW unit of lignite fired steam power plant at Thermal Power Station-I, Neyveli Lignite Corporation Limited, Neyveli, Tamil Nadu, India. The distribution of the exergy losses in several plant components during the real time plant running conditions has been assessed to locate the process irreversibility. Kamate and Gangavati [5] studied exergy analysis of a bagasse based cogeneration plant of a sugar factory, using backpressure and extraction condensing steam turbine. In the analysis, exergy methods in addition to the more conventional energy analyses are employed to evaluate overall and component efficiencies and to identify and assess the thermodynamic losses. Dincer and Rosen [6] present effects on the results of energy and exergy analysis of variations in dead state properties. Dincer et al. [7] presented an efficiency analysis, accounting for both energy and exergy considerations, of a design for a cogeneration based district energy system. A case study is considered for assist the plant engineer in decision making, possible optimization and also locate areas where losses are maximum.

The objective of this research therefore, is to perform an exergy analysis on a 112.4 MW single shaft open cycle active gas turbine plant and determine the effect of operating thermodynamic variables on the performance of the gas turbine plant. The operating parameters investigated include:

compressor inlet temperature (AT), compressor pressure ratio (r_p) and turbine inlet temperature (TIT).

II. THERMODYNAMIC ANALYSIS

A. Description of plant

The gas turbine power plant is an open cycle single shaft system located at Genting Lanco, Vijayawada. The power plant uses natural gas of low heat value (LHV) in kJ/kg. The simplified schematic diagram of the plant is shown in Fig.1. The system consists of an air-compressor (C), combustion chamber (CC) and a gas turbine (T).

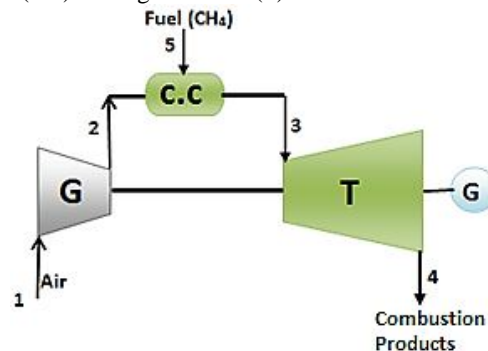


Fig. 1 Gas Turbine Power Plant

B. Analysis Procedure

The plant was divided into different control volumes and exergy balances were determined for each component. Energy and exergetic performance criteria based on the daily operating data were performed on the entire plant, which are: irreversibilities. The operating data considered were: compressor inlet temperature (AT), turbine inlet temperature (TIT) and compressor pressure ratio (r_p). Data outside the technical design parameters for operating conditions were simulated and their effect on the first law and second efficiency of the plant was critically studied. The gas turbine power plant models are developed on the following assumptions: (i) the exergy value of air entering the compressor is assumed zero, (ii) all components have adiabatic boundaries, (iii) plant performance at ISO conditions, (iv) Ideal gas mixture principles apply for air and combustion products, (v) Fuel (natural gas) is taken as methane and modelled as an ideal gas (vi) Combustion in combustion chamber is complete and N_2 is treated as inert, (vii) Heat loss from combustion chamber is 2% of lower heating value (LHV)

of fuel, (viii) All other components operate without heat loss, (ix) Kinetic and potential components of exergy are neglected and (vi) the ambient conditions of temperature and pressure are 25 C and 1.013 bar.

A computer program was developed to simulate gas turbine power plant, in which control volume analysis of each component was performed using mass, energy and exergy balances for determining thermodynamic properties at every key position (Figure 1).

III. ENERGY AND EXERGY ANALYSIS

The steady state exergy balance equation for a control volume according to (Kotas,1995) is

$$\dot{E}x = \sum_j \left(1 - \frac{T_0}{T_j}\right) \dot{Q}_j + \dot{W}_{CV} + \sum_i \dot{m}_i e_i - \sum_e \dot{m}_e e_e \quad (1)$$

The subscripts i refer to conditions at inlet, e and j exits of control volume boundaries and o is the reference state. The components exergy balance is carried out using equation (1).

The compression process from 1-2 in Fig. 1 is obtained as follows:

$$\dot{E}x_{c_1} = \dot{m}_a c_p^h (T_1 - T_0) - T_0 \dot{m}_a (s_1 - s_0) \quad (2)$$

$$\text{and } s_1 - s_0 = c_p^s \ln \left(\frac{T_1}{T_0}\right) - R \ln \left(\frac{p_1}{p_0}\right) \quad (3)$$

Where $\dot{E}x_{c_1}$ is the exergy rate of the air entering to the compressor unit.

$$\dot{E}x_{c_2} = \dot{m}_a c_p^h (T_2 - T_0) - T_0 \dot{m}_a (s_2 - s_0) \quad (4)$$

$$\text{and } s_2 - s_0 = c_p^s \ln \left(\frac{T_2}{T_0}\right) - R \ln \left(\frac{p_2}{p_0}\right) \quad (5)$$

Where $\dot{E}x_{c_2}$ is the exergy rate of the air leaving the compressor unit

$$\dot{W}_c = \dot{m}_{air} c_p^h (T_2 - T_1) \quad (6)$$

\dot{W}_c is the power input rate to the compressor,

$$\dot{I}c = \dot{W}_c + \dot{E}x_1 - \dot{E}x_2 \quad (7)$$

$\dot{I}c$ is the total exergy destruction rate in the compressor, T_1 and T_2 are the compressor inlet and exit temperatures, respectively; p_1 and p_2 are the compressor inlet and exit pressures, respectively, c_p^h and c_p^s are mean molar isobaric

heat capacity for evaluating enthalpy and entropy changes. They are expressed in equation (8) and (9).

$$c_p^h = \frac{1}{T - T_0} \int_{T_0}^T \bar{c}_p dT \quad (8)$$

$$c_p^s = \frac{1}{\ln \left(\frac{T}{T_0}\right)} \int_{T_0}^T \bar{c}_p dT \quad (9)$$

\bar{c}_p is obtained in a polynomial form as a function of temperature as given in equation (10)

$$\bar{c}_p(T) = a + b^2 T + c T^2 + d T^3 \quad (10)$$

The values of a, b, c and d are constant characteristics of the gas considered and obtained from standard tables.

The combustion process is stage 2-3 from figure 1. The exergy flow rate in the combustion chamber is obtained from equation (1). In the combustion chamber, the shaft work is zero and equation (1) reduces to:

$$\sum_i \left(\dot{E}x_f\right)_i + \sum_{in} \dot{E}x_2 = \sum_{out} \dot{E}x_3 + \dot{I}_{cc} \quad (10)$$

\dot{I}_{cc} is the combustion chamber irreversibility. $\dot{E}x_f$ is the fuel exergy rate which is expressed in equation (11)

$$\begin{aligned} \dot{E}x_f &= \dot{E}x_{ph} + \dot{E}x_{ch} \\ &= \dot{m}_{fuel} (c_p^h (T_5 - T_0) - T_0 \left[c_p^s \ln \left(\frac{T_5}{T_0}\right) - R \ln \left(\frac{p_5}{p_0}\right) \right] \\ &\quad + \sum_i x_i e_{i0} + RT_0 \sum_i \ln \gamma_i x_i) \end{aligned} \quad (11)$$

Where $\dot{E}x_{ch}$ is chemical exergy, x_i is mole fraction of constituent's elements and e_{i0} is standard molar exergy of each constituent of the natural gas species.

The expansion process is process 3-4 from Fig. 1. The irreversibility rate or exergy destruction rate in the turbine is obtained as in equation (12) (Kotas, 1995).

$$\begin{aligned} \dot{W}_T &= \left(\dot{m}_{fuel} + \dot{m}_{air}\right) c_p^h (T_3 - T_4) \\ \dot{I}T &= \dot{E}x_4 - \dot{E}x_3 - \dot{W}_T \end{aligned} \quad (12)$$

Where $\dot{E}x_3$ and $\dot{E}x_4$ are the exergy rate of the flue gas entering

to and from the turbine unit, \dot{w}_T is the power output rate from the turbine.

IV. RESULT AND DISCUSSION

Fig. 1 shows the variation of irreversibility rates of the system components (compressor, combustion chamber and gas turbine) with pressure ratio. From the figure it is observed that irreversibilities of combustion chamber and gas turbine plant finely increases and then decreases with pressure ratio. However no significant influence of pressure ratio on compressor and turbine irreversibilities is observed.

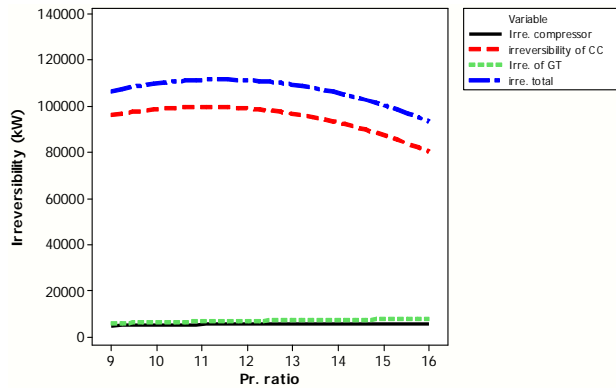


Fig. 1 Irreversibility rates of components verses pressure ratio

Fig. 2 shows the variation in irreversibility rates of gas turbine plant components which are compressor, combustion chamber and gas turbine. From figure it can be observed that compressor inlet temperature has insignificant effect on gas turbine plant components.

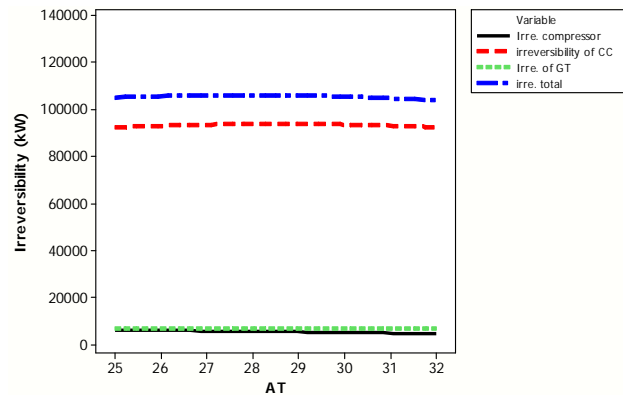


Fig. 2 Irreversibility rates of components verses compressor inlet temperature

Fig. 3 shows the irreversibility rate of compressor and gas turbine has no significant change as turbine inlet temperature increases. From the figure it is observed that irreversibilities of combustion chamber and gas turbine plant decreases with turbine inlet temperature increases.

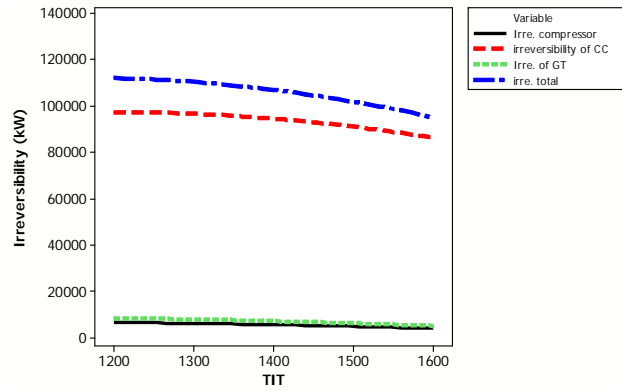


Fig. 3 Irreversibility rates of components verses turbine inlet temperature

V. CONCLUSIONS

A thermodynamic model has been developed for parametric study and performance evaluation of the gas turbine plant. From the results obtained it can be concluded that

- Irreversibilities of combustion chamber and gas turbine plant finely increases and then decreases with pressure ratio.
- Compressor inlet temperature has insignificant effect on gas turbine plant components.
- Irreversibilities of combustion chamber and gas turbine plant decreases with turbine inlet temperature increases.

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