THERMAL ANALYSIS OF OPARI GAS TURBINE POWER PLANT

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Abstract
This paper was presented the thermal analysis of one unite of Opari gas turbine power plant ,at the south of Libya. The operation and parameter conditions for one unite of power plant such as Ambient temperature ,pressure ratio, air fuel ratio ,specific fuel consumptions , power , heat rate ,and thermal efficiency were investigated , whereas the thermal analysis of open cycle power plant are made by the operation conditions ,the results was obtained by MATLAB program Software. The operation conditions were strongly affected by the ambient temperature and pressure ratio, in addition the power and thermal efficiency are decreasing with increasing the ambient temperature and air fuel ratio. It was obtained that the heat rate and specific fuel consumption are increased with increasing in ambient temperature.
Keywords: - Gas turbine –Ambient temperature –Pressure ratio- Air to fuel ratio-Thermal efficiency-Power.

1. Introduction

Gas turbine power plant is the technology for the conversion of fossil fuel in to the electric. It has also became very important in terms of future reduction of CO2 emission in the power generation sector. It has introduced to the power industry in 1940s, where it was make a revolutionary self- contacted fossil fueled power plant[1].
After 20 years it became the important mean for meeting the growing peak loads on the utility system, whereas it can be used in a variety of configuration for electric power generation by using it as conventional applications such as simple cycle power plant ,combined cycle power plant or cogeneration conventional applications
The simple open cycle gas turbine power plant is shown schematically in figure(1), whereas it consist of four component, Compressor ,Combustion Chamber, Turbine ,and Generator[2][
Air at ambient conditions is compressed by the compressor to the combustor, fuel is added in the combustor. The combustor product (Fuel+Air) are exit from the combustor and expand in the turbine.
Where the expansion process produces the useful shaft work.
Typically about 50% of the turbine shaft work required to drive the compressor work [3.[
The General Electricity Company of Libya (GECOL) confirmed the connecting of the plant of Obari Gas Station to the public grid, officially by run . "The fourth unit 600 MW was operated by crude oil. This will ensure the stability of the network, after guaranteeing the constant supply of fuel to the station. Later the company worked on the operational tests to run the third unit which increase the plant power a 125 MW.
Opari Gas turbine working as simple Brayton cycle ,where it comprised of three main components: a compressor, a combustor, and a turbine. According to the principle of the Brayton cycle, air is compressed in the compressor. The air is then mixed with fuel and burned under constant pressure conditions in the combustor. The resulting hot gas is allowed to expand through a turbine to perform work.

A schematic of the Brayton (simple gas turbine) cycle is given in Figure 1. Low-pressure air is drawn into a compressor (state 1) where it is compressed to a higher pressure (state 2). Fuel is added to the compressed air and the mixture is burnt in a combustion chamber. The resulting hot gases enter the turbine (state 3) and expand to state 4.[5]

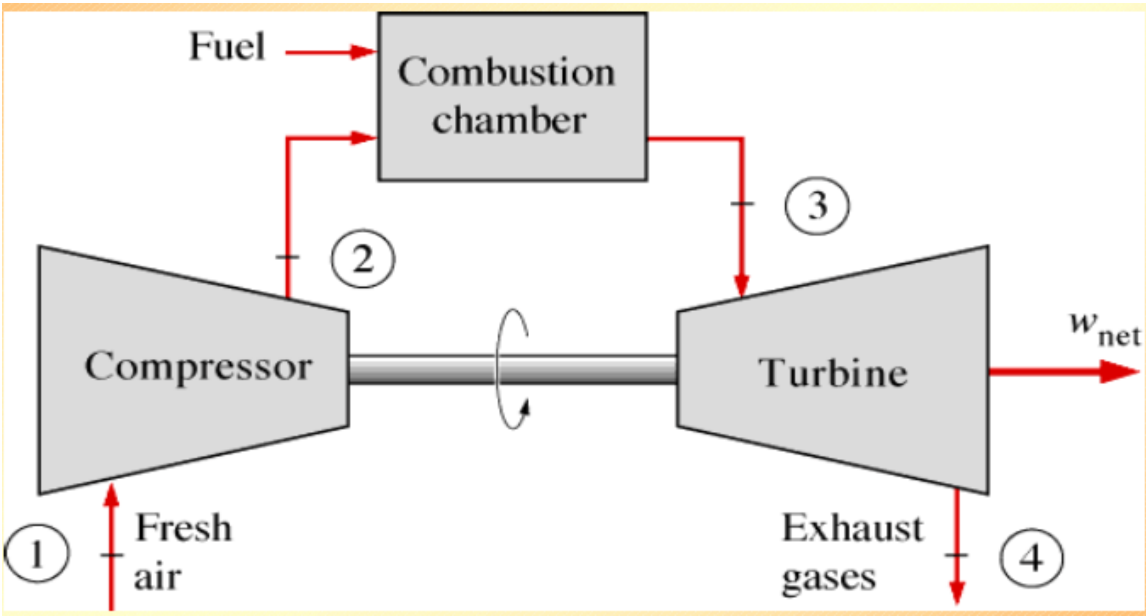

Figure 1 A schematic diagram of the Brayton (simple gas turbine) cycle

The main objective of this paper is to study the effect of changing ambient temperature and pressure ratio on the thermal efficiency ,output power and specific fuel consumption for Opari Gas Turbine Power Plant.

2. Thermodynamic model of Opari Gas Turbine Power Plant (OGTPP)

The main component of OGTPP are Compressor, Combustion Chamber (CC), Turbine , and Generator .

The pressure ratio in the compressor can be defined as:-

$$r_p = \frac{p_2}{p_1} \qquad (1)$$

Where p_1, p_2 are the air inlet pressure and air out let to the compressor respectively.

In the thermal analysis, the deviation from the ideal to the actual behavior in compressor and the turbine is defined Isentropic Efficiency.

The Isentropic Efficiency of compressor and turbine can be calculated referring to Figure (2), where the hard line represents the actual process, and the dotted line represents the isentropic compression and expansion.

The isentropic efficiency for compressor is:-

$$\eta_c = \frac{T_{2'} - T_1}{T_2 - T_1} \qquad (2)$$

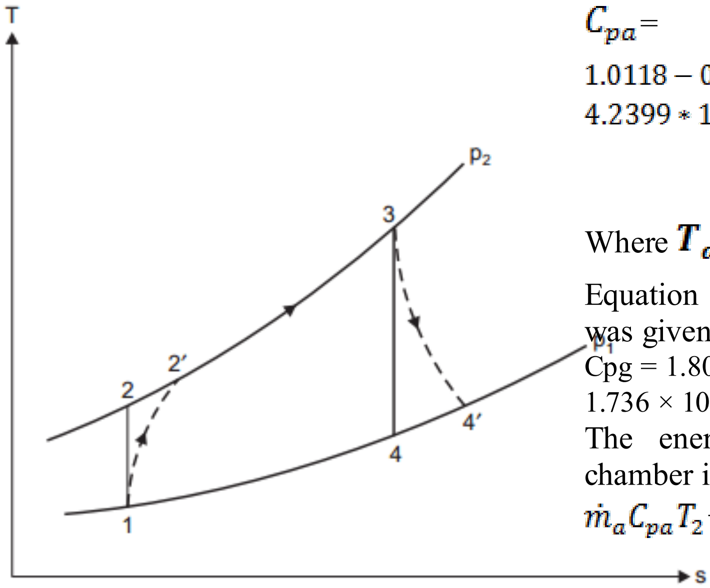

Figure 2 Isentropic Efficiency of compressor and turbine

Where $T_{2'}$ is compressor isentropic outlet temperature, T_1, T_2 are the compressor inlet and out let air temperature respectively .

The actual exit temperature T_2 from the compressor is:-

$$T_2 = T_1\left(1 + \frac{r_p^{k-1/k}}{\eta_c}\right) \quad (3)$$

There are two new variable used for calculation model:-

$$R_{pa} = \left(\frac{r_p^{k-1/k} - 1}{\eta_m}\right), \quad R_{pg} = \left(1 - \frac{1}{r_p^{n-1/n}}\right) \quad (4)$$

Where k=1.4, n=1.33

The compressor work is:-

$$W_c = \frac{c_{pa} * T_1 * R_{pa}}{\eta_m} \quad (5)$$

Where η_m is the mechanical efficiency of the compressor and Turbine , c_{pa} is the specific heat of air for the ranging 200 k <T<800 k

Equation (6) shows the fitted of the specific heat of air:-

$$C_{pa} = 1.0118 - 0.13784 * T_a + 1.9843 * 10^{-4} T_a^2 + 4.2399 * 10^{-7} T_a^3 - 3.7633 * 10^{-10} T_a^4 \quad (6)$$

Where $T_a = \frac{T_1 + T_2}{2}$

Equation (7) shows the specific heat of gas was given by Naradasu et (2007)

$$Cpg = 1.8033 - 2.3127 \times 10^{-3} T + 4.045 \times 10^{-6} T^2 - 1.736 \times 10^{-9} T^3 \quad (7)$$

The energy balance in the combustion chamber is shown in equation (8):-

$$\dot{m}_a C_{pa} T_2 + \dot{m}_f * LHV = (\dot{m}_a + \dot{m}_f) C_{pg} * T_3 \quad (8)$$

Where $\dot{m}_a$ and $\dot{m}_f$ is the mass flowrate of air and fuel respectively.

LHV is the lower heating value of fuel ,T_f is the temperature of fuel in (k), T_3 is the turbine inlet temperature in (k)

After rearranging equation (9), the Fuel Air Ratio f is:-

$$f = \frac{\dot{m}_f}{\dot{m}_a} = \frac{C_{pg} * T_3 - C_{pa} * T2}{LHV - C_{pg} * T_3} \quad (10)$$

The exit temperature (Exhaust) from gas turbine is :-

$$T_4 = T_3(1 - \eta_t * R_{pg}) \quad (11)$$

Where η_t is the isentropic efficiency of Turbine

The shaft work of the turbine is :-

$$W_t = Cp_g * \eta_T * Rp_g * T_3 / \eta_m \quad (12)$$

And the network of gas turbine is:-

$$W_{net} = W_t - W_c \quad (13)$$

The output power from the turbine is:-

$$P = \dot{m}_a * W_{net} \quad (14)$$

Also the heat supplied to the combustion chamber is :-

$$Q_{add} = C_{pg}(T_3 - T_1(1 - R_{pa})) \quad (15)$$

The thermal efficiency of the gas turbine can be determined by equation (16):

$$\eta_{th} = \frac{W_{net}}{Q_{add}} \quad (16)$$

The specific fuel consumption (SFC) can be calculated by:-

$$SFC = \frac{\dot{m}_f * 3600}{\dot{m}_a * W_{net}} = \frac{3600f}{W_{net}} \left(\frac{k_g * f}{kwh}\right) \quad (17)$$

The heat rate

$$HR = \frac{Q_{add} * 3600}{W_{net}} = \frac{3600}{\eta_{th}} \left(\frac{k_j}{k_w\ h_r}\right) \quad (18)$$

3. Result and Discussion

In this paper the effect of sum parameters on the Opari Gas Turbine Power Plant like ambient temperature, compression ratio, and air to fuel ratio on the power output and the thermal efficiency are obtained, The numerical data are represented the energy balance of the open cycle gas turbine by MATLAB-program software.

Numerical data are running the code and discus the effect of the parameters on the performance of gas turbine by plotted data as the curve in figures.

3.1 Effect of Ambient Temperature

Figure (3) represents the relation between ambient temperatures and output power at different values of pressure ratio. from this figure it can be seen when the ambient temperature increases, the output power are decreases, and this is occurred mainly due to reduction of air density with increasing temperature, the higher density of air means that lower compressor work and high thermal efficiency, therefore the ambient temperature have the significant impact on the performance of gas turbine power plant.

3.2 Effect of pressure ratio

Figure (4) shows the relation between pressure ratio and thermal efficiency for different ambient temperatures ,the figure(4)indicators that increasing pressure ratio leads to increase of thermal efficiency, also this figure shows increase of ambient temperature at constant value of pressure ratio tends to decrease of thermal efficiency ,therefore it can be conclusion that the pressure ratio have a significant effect on the performance of the gas turbine

The effect of changing pressure ratio on specific fuel consumption at different value of ambient temperature is showed in fig(5). From this figure it can be noticed that the SFC decreases with increasing the pressure ratio at constant value of ambient temperature , the SFC increases with increasing ambient temperature.

Figure (6) shows the relation between the AFR and thermal efficiency at different ambient temperatures, increasing the ambient temperature lead to decrease the air fuel ratio, due to decreasing the density of air.

Figure (7) shows the relation between air to fuel ratio and power at different ambient temperatures, increasing the ambient temperature means that decreasing in air to fuel ratio, and the power is also decreased.

Figure (8) presents the relation between pressure ratio and thermal efficiency at different turbine inlet temperatures, the thermal efficiency increases with the increase of turbine inlet temperature.

Figure (9) present the relation between pressure ratio and thermal efficiency at different air to fuel ratios, it is clear from the results that the thermal efficiency decreases with the increase of the air fuel ratio. Increasing in the air fuel ratio caused by increasing in the ambient temperature.

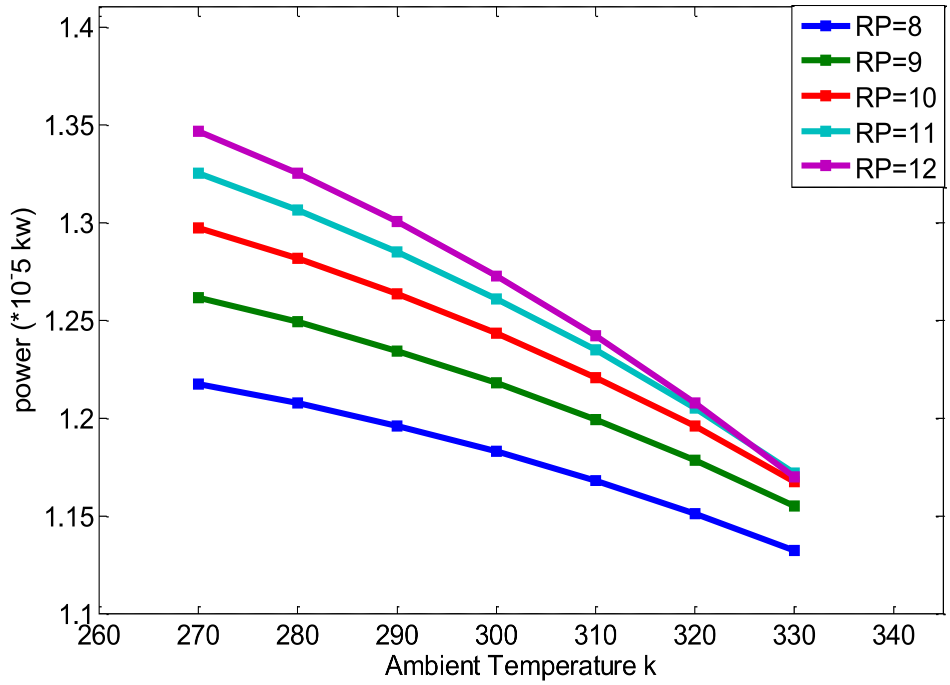

Figure The relation between ambient temperatures and output power with different values of pressure ratio.

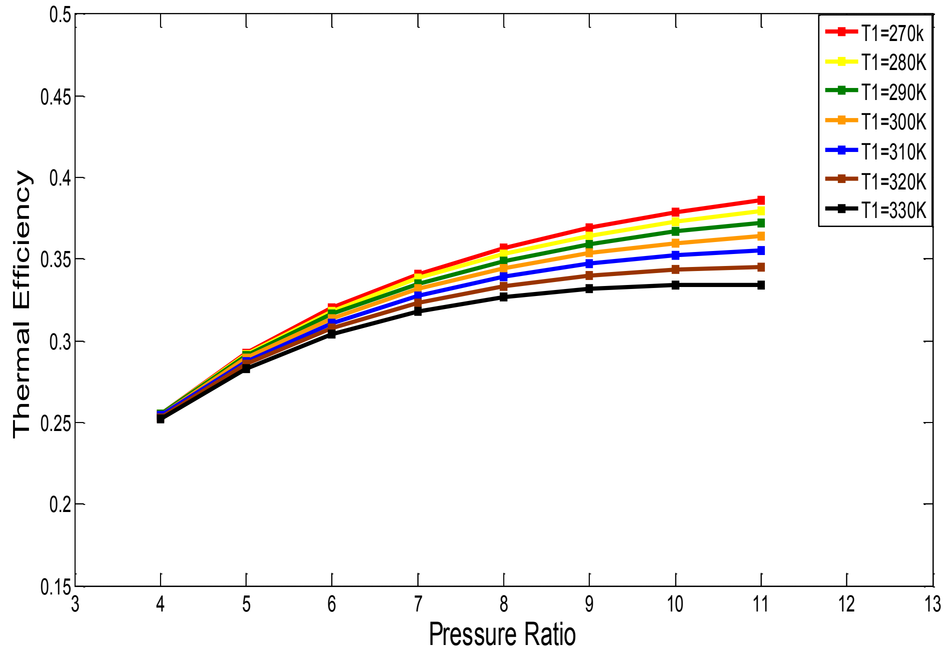

Figure 4 The relation between pressure ratio and thermal efficiency with varying ambient temperature.

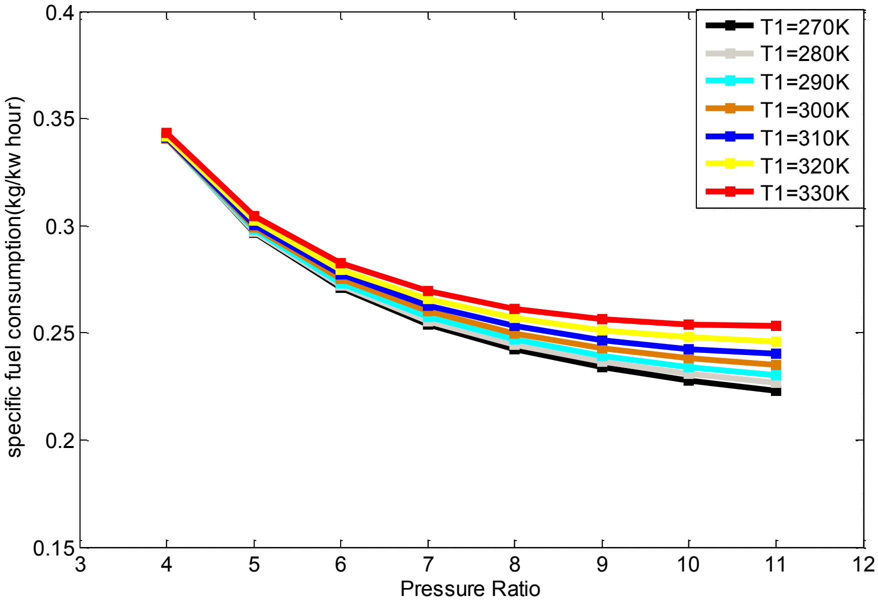

Figure 5 the effect of pressure ratio on a SFC at different values of ambient temperature

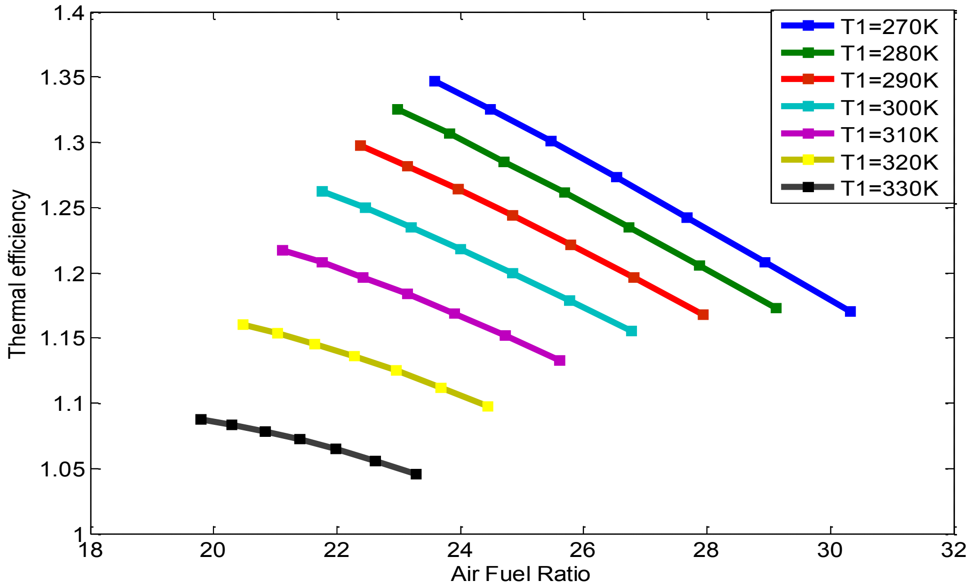

Figure 6 Effect of air to fuel ratio and ambient temperature on the thermal Efficiency

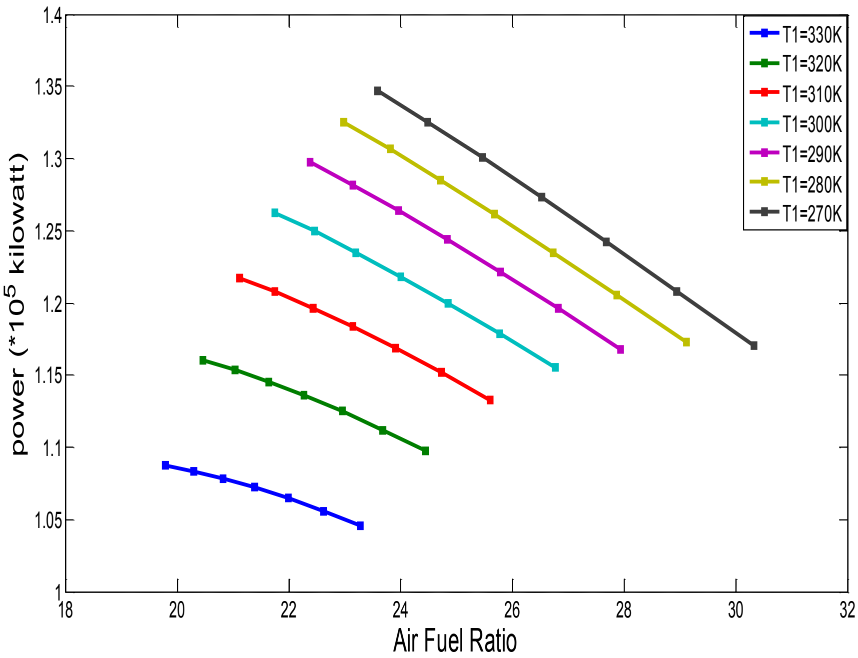

Figure 7 The relation between air to fuel ratio and output power at different values of temperature.

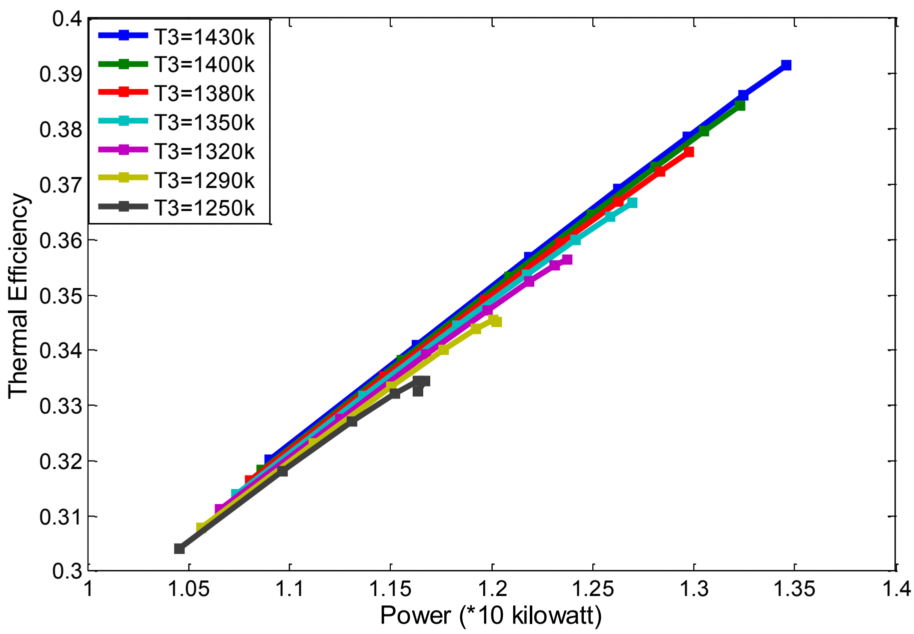

Figure 8 The relation between power output and thermal efficiency at varying turbine inlet temperature

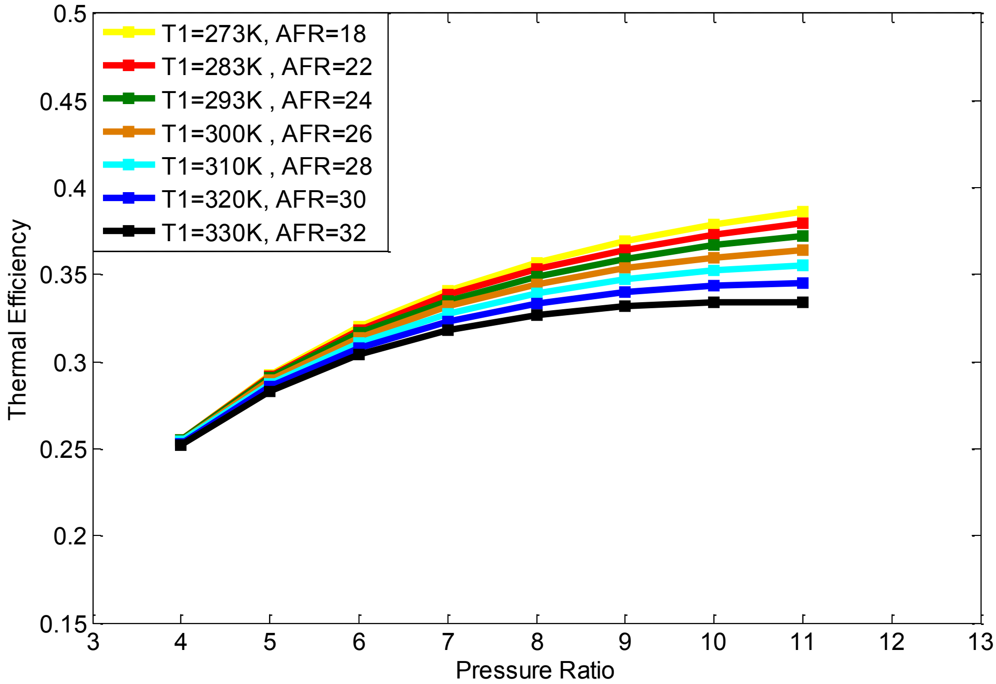

Figure 9 The relation between pressure ratio and thermal efficiency at varying air to fuel ratio

4. Conclusion

Thermodynamic analysis of OGTPP indicated that:

- The output power and thermal efficiency of OGTPP decrease by 10.8% and 12.8% respectively with increasing the ambient temperature from 270 to 330 k at pressure ratio 11.
- The Specific Fuel Consumption of the OGTPP increase by 13.46% when ambient temperature change from 270 to 330 k.

5. References

[1] Harlock .J. H (2003). "Advanced Gas Turbine Cycle", pergamon

[2] William R.Hawthorne:Walter T.Olsen (2015), " Design And Performance Of Gas Turbine Power plant", princeton university press.

[3] Philip W.Paul F.(2004), "Gas Turbine Performance", black well science.

[4] Boyce, M. P. (2012), " Gas turbine engineering handbook", (Fourth Edition). USA: Elsevier Inc, Imprint: Butterworth-Heinemann

[5] Cengel Y. A., & Michael A. (2008), " Thermodynamics an engineering approach", New Delhi: Tata McGraw Hill.

[6] Thirumaleshwar .M.(2014), " Applied Thermodynamics": Software Solutions - Part II (Cycles for Gas turbines and Jet propulsion, Vapor power cycles) 1st ed

[7] Barakat, S., Ramzy, A., Hamed, A. M. and El-Emam, S. H. (2015), " Enhancement of gas turbine power output using earth to air heat exchanger (EAHE) cooling system, " Energy Conversion and Management. 111, 137-146.

[8] Ibrahim TK, Rahman MM, Alla AN (2010), " Study on the effective parameter of gas turbine model with intercooled compression process", Sci. Res. Essays, 5(23): 3760-3770.

[9] Horlock JH (2003), " Advance Gas Turbine Cycles", Elsevier Sci. Ltd., UK.

[10] Mahmood FG, Mahdi DD (2009), " A new approach for enhancing performance of a gas turbine (Case study: Khangiran Refinery)", Appl. Energy, 86: 2750–2759.

[11] Mohanty B, Paloso G (1995), "Enhancing gas-turbine performance by intake air cooling using an absorption chiller", Heat Recovery Sys. CHP, 15(1): 41-50.

[12] Ibrahim, T.K. and Rahman, M.M. (2010), " Effects of Operation Condition on Performance of a Gas Turbine Power Plant", Procedia Engineering, 15, 4216 4223. http://dx.doi.org/10.1016/j.proeng.2011.08.791

[13] Rahman MM, Ibrahim TK, Kadirgama K, Mamat R, Bakar RA (2011), " Influence of operation conditions and ambient temperature on performance of gas turbine power plant", Adv. Mater. Res., 189-193: 3007-3013.

[14] Rahman, M. M., Ibrahim, K. T. and Abdalla N. A.(2011), " Thermodynamic performance analysis of gas-turbine powerplant", International Journal of the Physical Sciences. 6, 14, 3539-3550

[15] Thirumaleshwar .M.2014. Applied Thermodynamics: Software Solutions - Part II (Cycles for Gas turbines and Jet propulsion, Vapor power cycles) 1st ed