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Thermal Investigation of Open-Cycle Gas-Turbine Power-Plant With Regenerator

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***Abstract*- This study aims to investigate the effect of regeneration on the output power and the thermal efficiency of the gas turbine power plant. The effect of ambient air temperature, regeneration effectiveness, and compression ratio on the cycle thermal efficiency was also investigated. To study the effect of compression ratio, turbine inlet temperature, air to fuel ratio, and ambient temperature on the performance of gas turbine cycle power plant. To analyze the effects of operation conditions on the power output and efficiency by the energy-balance utilizing Energy Equation Solver (EES) software. To simulate the cycle using EES.**

***Keywords*- Gas turbine; power plant; thermal analysis; regeneration**

I. INTRODUCTION

Increasing the thermal efficiency is the concern of many researchers in the last few decades. Increasing the thermal efficiency results in a decrease in the operation cost by reducing the fuel consumption, which, in turn, reduces the emission of flue gases (COx, NOx) to the environment? Therefore, intensive research activities have been under going to increase the thermal efficiency of thermal power generation of gas and steam turbine cycles. There are different methods are utilized to increase the thermal efficiency of the cycles. Reheating is a process utilized to increase the thermal efficiency of the gas and the steam turbine cycles.

Regeneration is also a procedure utilized to increase the thermal efficiencies of both the simple gas turbine and the steam turbine cycles. Another important procedure to increase the thermal efficiency of the power plant cycle is the combined cycle, which consists of a gas turbine and a steam turbine cycles The open-cycle gas turbines offered low capital costs, compactness, and efficiency close to that of the steam plants.

Nevertheless, after the oil crisis in the 1970s the efficiency of power plants became the top priority, and combined-cycle plants, first in the form of existing steam plant repowering, and later, as specially-designed gas-and steam turbine plants, have become a common power plant configuration [1]. Gas turbines that operate in simple cycles have low efficiencies because the turbine exhaust gases come out very hot and this energy is lost to the atmosphere.Better performance is reached with advanced cycles that take advantage of the energy contained in the turbine exhaust gases to improve the cycle or to transfer energy to combined cycles [2], [3]. In gas-turbine power plant, the temperature of the exhaust gas leaving the turbine is often considerably higher than the temperature of the air leaving the compressor. Therefore, the air leaving the compressor at high-pressure can be heated by transferring heat to it from the hot exhaust gases in a counter-flow heat exchanger, which is also known as a regenerator or recuperate [4].

II.METHOD

1.Model Formulation

Figure 1 shows the gas turbine cycle including regenerator, reheating and inter cooling. Figure 2 shows the T-S diagram of the cycle.

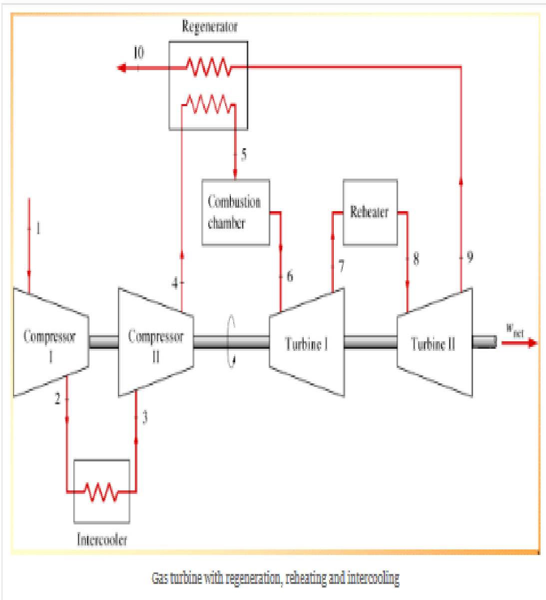

Fig. 1 gas turbine cycle including regenerator, reheating and inter cooling.

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Figure 1 shows a gas turbine plant with regenerator, which is a single shaft turbine. Generally, the principle of the gas turbine cycle is that air is compressed by the air compressor, and transferred to combustion chamber (CC) in order to combine with fuel for producing high-temperature flue gas.

Afterward, high-temperature flue gas will be sent to gas turbine, which connected to the shaft of generator for producing electricity [4]. The purpose of the single shaft turbine is to produce and supply the necessary power required to run the compressor, and is meant for producing the network output. In this regenerative cycle, air after compression enters in to a regenerator where it is heated by the exhaust gases coming from turbine. The preheated air then enters in to combustion chamber, after heated addition to maximum permissible temperature in the combustion chamber. The network output of the cycle is thus proportional to the temperature drop in the turbine.

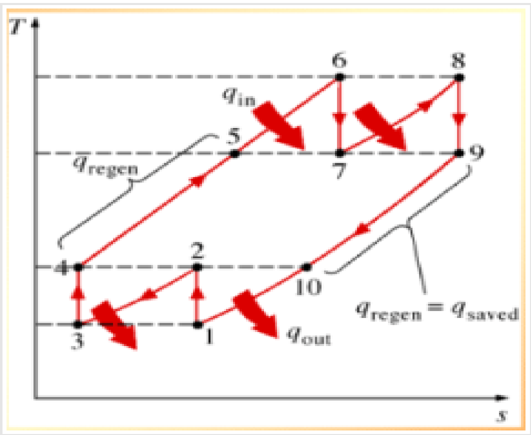

Fig. 2 T-s diagram.

1. Assumptions

- All components are assumed to be a steady state and steady flow processes. The changes in the potential and the kinetic energy of the components are negligible.
- Combined cycle gas turbine operates at steady state.
- Ideal gas laws are applied to the air and the combustion products.
- The fuel is taken as methane and taken as an ideal gas.
- The combustion process in the CC (combustion chamber) is complete and N2 is assumed as inert gas.
- Pressure drop in various components is neglected.
- HRSG taken is dual pressure.
- The thermodynamic analysis of the proposed combined cycle system has been carried out using equation of mass energy and exergy balance.

III. RESULTS

1.Effect Of Ambient Temperature

Gas turbine thermal efficiency is affected by ambient temperature due to the change of air density and compressor work since; a lower ambient temperature leads to a higher air density and a lower compressor work that in turn gives a higher gas turbine output power.

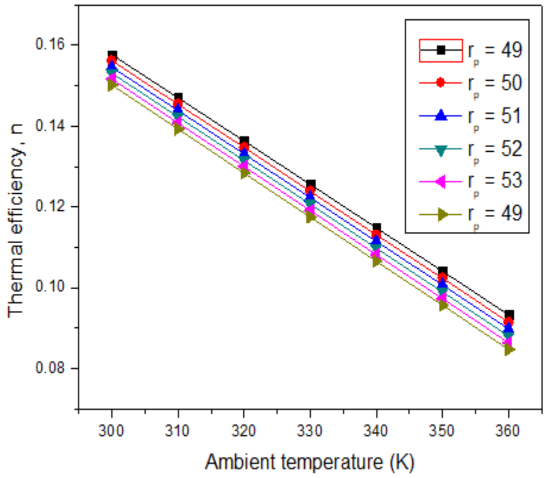

Fig.3 Variation of ambient temperature and pressure ration on thermal efficiency.

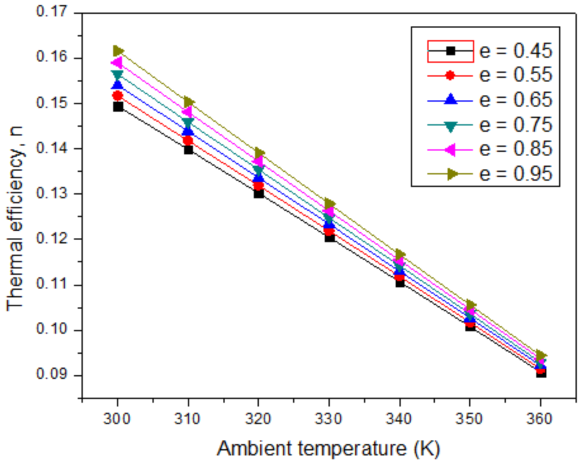

Fig. 4 Variation of ambient temperature and regenerative effectiveness on thermal efficiency.

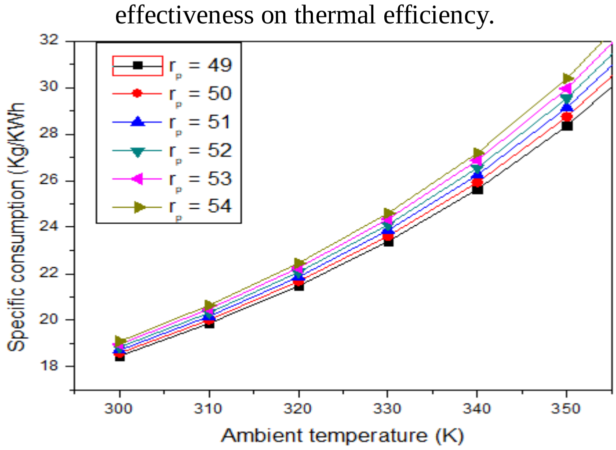

Fig. 5 Variation of ambient temperature and pressure ratio on specific fuel consumption.

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The effect of ambient temperature and regenerative effectiveness on thermal efficiency of gas turbine cycle.It can be seen that the thermal efficiency decreases with increases of ambient temperature while decreases of regenerative effectiveness. The specific work of the compressors increases as the ambient temperature increases [10].

Thus the thermal efficiency for their generative gas turbine cycles is reduced. It shows that when the ambient temperature increases the specific fuel consumption increases too. This is because, the air mass flow rate inlet to compressor increases with decrease of the ambient temperature. So, the fuel mass flow rate will increase, since (AFR) is kept constant. The power increase is less than that of the inlet compressor air mass flow rate; therefore, the specific fuel consumption increases with the increase of ambient temperature.

IV.EFFECT OF COMPRESSION RATIO (r_p)

It shows the variation of the thermal efficiency with compression ratio. The increase in compression ratio means an increase in power output, so the thermal efficiency must increase too.

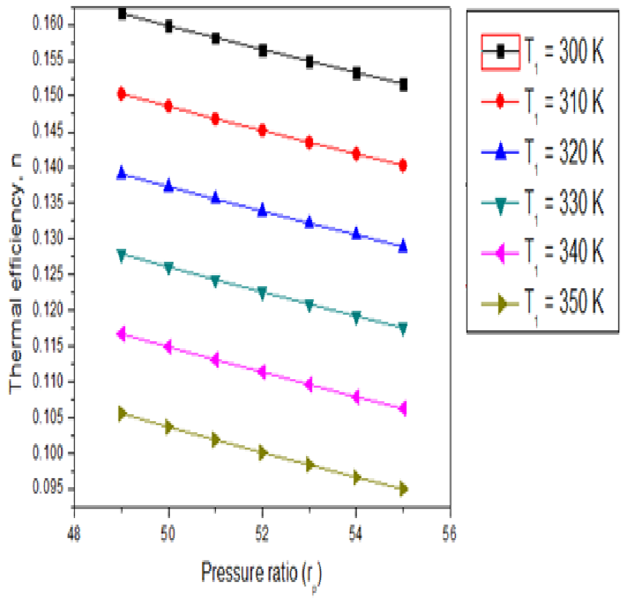

Fig. 6 Variation of ambient temperature and pressure ratio on thermal efficiency.

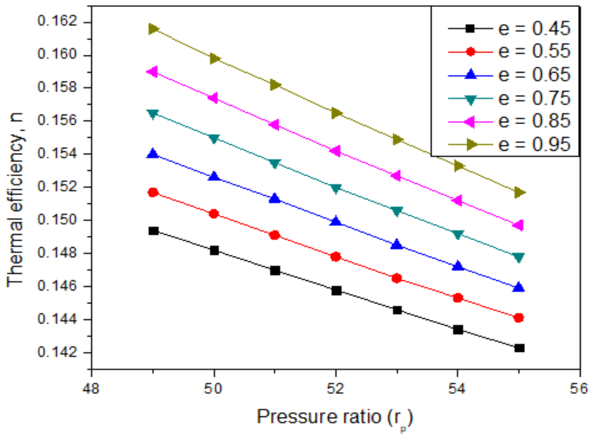

Fig. 7 Gas turbine cycle thermal efficiency versus pressure ratio for different regenerative effectiveness

The thermal efficiency increases with increase of compression ratio for the same inlet temperatures since the compression ratio will raise the temperature of the air entering the combustion chamber which is decreases the heat added, i.e. increases the thermal efficiency. Figure 4.4 also present a relation between regenerative gas turbine cycle thermal efficiency versus compression ratios for different ambient air temperatures, which reveals an opposite relation as the efficiency decreases as inlet air temperature increases.

V.EFFECT OF COMPRESSOR EFFICIENCY

The thermal efficiency increase with increase the compressor isentropic efficiencies, this is mean the thermal losses have been reduced in both compressor and turbine respectively, this lead to increased power output.

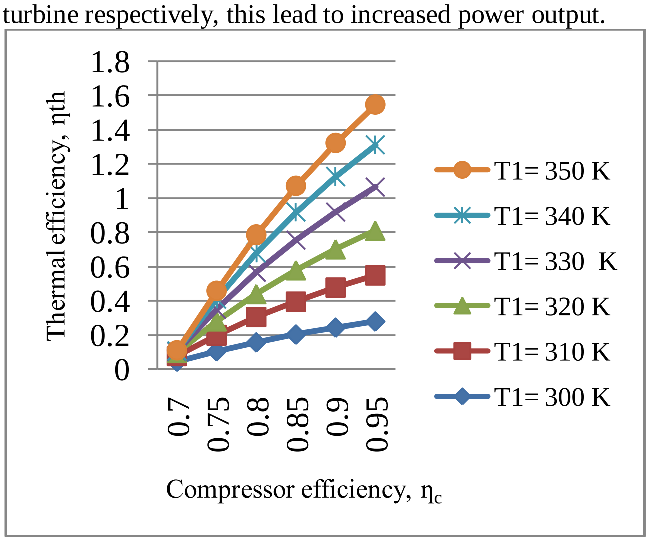

Fig.8 Thermal efficiency versus compression ratio for different inlet air temperature

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Fig.4.6 shows that at constant air temperature, the thermal efficiency increases with increasing of the compression ratio.

VI. EFFECT OF TURBINE EFFICIENCY

The thermal efficiency increased with turbine efficiency at different values for ambient temperatures as shown in above figure. Thermal efficiency has an elective relationship with turbine inlet temperature, the efficiency increases when turbine inlet temperature increases.

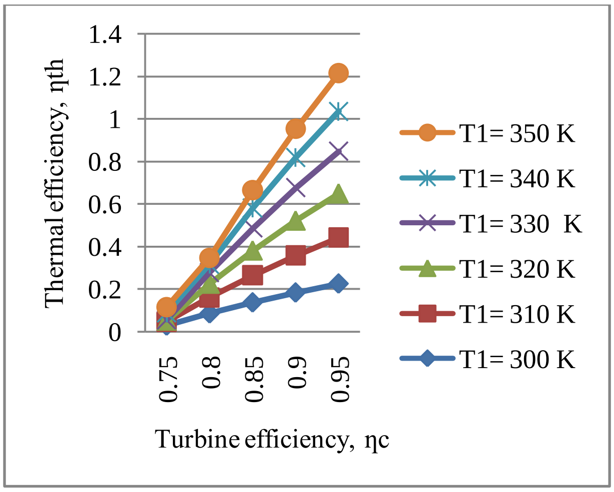

Fig.9 Thermal efficiency versus turbine efficiency for different inlet air temperature.

VII.EFFECT OF TURBINE INLET TEMPERATURE

The relation between turbine inlet temperature and thermal efficiency for different values of ambient temperature is shown below. As the turbine inlet temperature is increased for the same exit temperature, the temperature drop will increase giving higher power potential.

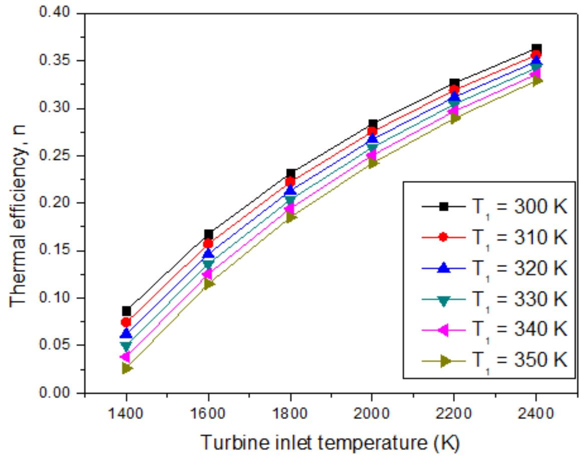

Fig.10: Thermal efficiency versus turbine inlet temperature for different inlet air temperature.

VIII.CONCLUSION

1. The heat duty in the regenerator decreases with the pressure ratio but increases with the decreases ambient temperature and increases TIT this mean increased thermal efficiency.
2. As the turbine inlet temperature is increased for the same exit temperature, the temperature drop will increase giving higher power potential.
3. The thermal efficiency increase with increase the compressor isentropic efficiencies, this is mean the thermal losses have been reduced in both compressor and turbine respectively, this lead to increased power output.
4. The thermal efficiency increases with increase of compression ratio for the same inlet temperatures since the compression ratio will raise the temperature of the air entering the combustion chamber which is decreases the heat added, i.e.increases the thermal efficiency.
5. The thermal efficiency of the simple gas-turbine cycle experiences small improvements at large pressure ratios as compared to regenerative gas turbine cycle.
6. In general, peak efficiency and specific fuel consumption occur at compression ratio in the regenerative gas turbine cycle.
7. The thermal efficiency increases and specific fuel consumption decreases with the regenerator effectiveness.
8. Adding regeneration to simple gas turbine cycle results in the increase of thermal efficiency of the cycle.

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