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Thermodynamic Analysis of Irreversible Regenerative Gas Turbine Cycle

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Abstract:

The present paper describes the energy analysis of an irreversible regenerative gas turbine power cycle. Gas turbine cycle model is simulated in MATLAB environment considering a real Brayton cycle having irreversibility and regeneration. The effect of thermodynamic parameters such as pressure ratio, regeneration effectiveness and turbine/compressor isentropic efficiency on specific power output and thermal efficiencies are examined. It was found that incorporating regeneration in gas turbine cycle results in an increase in the output power of the cycle and a subsequent decrease in the exhaust gas temperature. The results also show a significant increase in the thermal efficiency of the cycle when regeneration is included in cycle by utilizing turbine exhaust to heat the compressed working fluid. A 67.9% increase in efficiency was observed for the optimum pressure ratio value of 6 for the regenerative case compared to non-regenerative one. The above heat engine model represents a real case scenario which when juxtaposed with the ideal cycle without regeneration helps us to discern the differences between the two.

Keywords — **Irreversibility, Regeneration, Brayton cycle.**

I. INTRODUCTION

Rising energy consumption, opening of electricity markets and environmental issues are the main concerns for researchers and scientists. Increasing the thermal efficiency results in reduction in fuel consumption and also reduces the emissions. Numerous research activates are going on to increase the thermal efficiency of power generation Such as increasing pressure ratio, reheating, regeneration, combined cycle power plants etc.

Gas turbine power plants works on the basis of Brayton cycle. Thermodynamic analysis based on first law analysis was applied for designing power plants at first stage. Also regeneration process has significant effect on cycle efficiency. The aim of this study is to examine the effect of regeneration and different parameters on gas turbine cycle to increase the thermal efficiency. Further, all the fluid friction losses in the compressor and turbine are incorporated by an isentropic efficiency term.

II. LITERATURE REVIEW

Ibrahim and Rahman [2] investigated the effects of isentropic efficiency and reheat on performance of Gas Turbines. Patil, Pawase and Deore [3] went one step further to include the effect of intercooling on the SFC and specific work output of a regenerative, reheated Gas Turbine cycle. The effect of ambient air temperature is also included in their analysis. Wu and Chen [4] analysed the performance of an endoreversible regenerative system with a keen focus on reducing the irreversibility losses in the hot and cold heat exchangers. Al-Sood and Matrawy [5] studied the effects of 1st and 2nd law efficiency, ecological coefficient of performance and exergy loses based on a range of operating

parameters such as inlet conditions to first stage and second stage turbine and heat transfer coefficient-area product of the complete heat exchanger. Mahmood and Tariq [6] performed multi criteria optimization in which turbine inlet temperature, ambient air temperature, compression ratio and effectiveness were used to select the optimum configuration. They observed that regeneration with low compression ratio lead to high efficiency values. Kumar and Kaushik [7] discussed the power optimization of irreversible regenerative Brayton cycle with isothermal heat addition. They proved that the introduction of two heat additions significantly enhanced model efficiency by 20 percent compared to conventional cycle. Their analysis considered isothermal pressure drop ratio, pressure drop recovery coefficients and heat capacitance rate of working fluid among other parameters. Chen, Sun and Kiang [8] assessed the performance of a closed regenerative Brayton cycle using the technique of finite time thermodynamics (FTT). Kaushik and Tyagi [9] also used the FTT technique to maximize the power output with respect to the working fluid temperatures. They observed that the effect of cold side effectiveness is more pronounced for the power output while the effect of regenerative effectiveness is more pronounced for the thermal efficiency. Other researchers [10-12] have also worked on the same domain to improve their understanding of power analysis and efficiency of the regenerative Gas Turbine cycle. The present study is undertaken with an aim to provide an in depth analysis of the same.

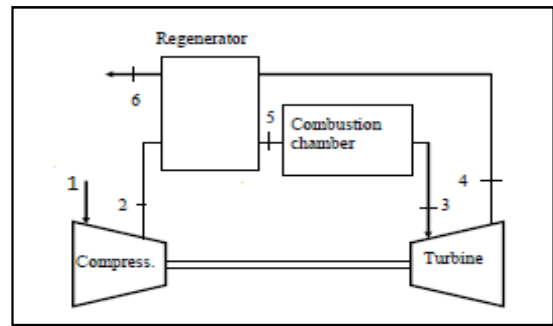## III. THERMODYNAMIC ANALYSIS

A. System Configuration

Fig. 1(a) Schematic diagram of the system layout

Figure 1(a)shows the regenerative gas turbine cycle, and Figure 1(b) shows the T-S diagram of the cycle. Regeneration is a thermodynamic processthat utilizes the heat energy in the exhaust gases from the gas turbine toheat the air entering to the gas turbine. Heat exchange process takes placebetween the exhaust gases and compressed air by utilizing shell and tube type heat exchanger.
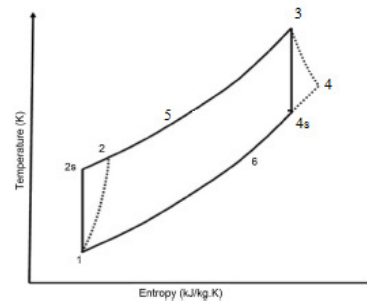

Fig. 1(b) T-s diagram of the cycle

B. Assumptions used in present analysis:

1. No pressure and heat losses

2. Inlet temperature and pressure(T_1=303K,P_1=1 bar, Isentropic Turbine & Compressor efficiency=0.85, Effectiveness=0.85)

3. Isentropic compressor and turbine efficiencies

4. Effectiveness of heat exchanger

IV. ENERGY ANALYSIS

Energy analysis based on first law of thermodynamics is performed to find the thermodynamic performance of irreversible regenerative gas turbine cycle

The compressor pressure ratio (r_p) can be defined as below:

$$r_p = P_2 / P_1 \qquad (1)$$

The isentropic efficiency of the compressor expressed as

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

The work of the compressor (W_c)

$$W_C = \dot{m}c_p(T_2 - T_1) \qquad (3)$$

The effectiveness of regenerator (ε) are considered in this study.

$$\varepsilon_{reg} = \frac{(T_5 - T_2)}{(T_4 - T_2)} \qquad (4)$$

The isentropic efficiency of the turbine expressed as

$$\eta_e = \frac{(T_3 - T_4)}{(T_3 - T_{4S})} \qquad (5)$$

The work produced from the turbine is determined by the following equation.

$$W_T = \dot{m}c_p(T_3 - T_4) \qquad (6)$$

The network of the Gas Turbine (W_{net}) is calculated by Equation

$$W_{net} = W_T - W_C \qquad (7)$$

Thermal efficiency of Gas Turbine cycle is given by:

$$\eta_{th} = \frac{(W_T - W_C)}{\dot{m}c_p(T_3 - T_2)} \qquad (8)$$ without regeneration

$$\eta_{th} = \frac{(W_T - W_C)}{\dot{m}c_p(T_3 - T_5)} \qquad (9)$$ with regeneration

V. RESULTS AND GRAPHS

1) *Effect of pressure ratio on work output:* Fig.3 shows the effect of pressure ratio on the net power output of irreversible regenerative brayton cycle.
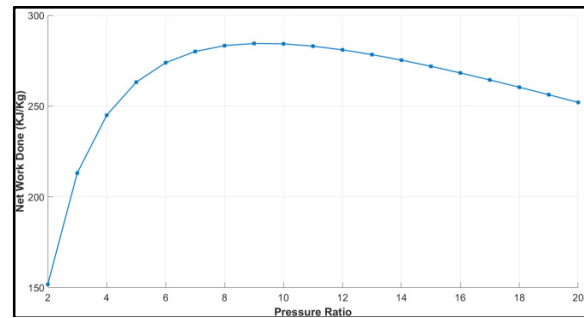

Fig 3 Power output vs. Pressure ratio (2 to 20)

Fig.4 shows the effect of pressure ratio on the thermal efficiency of irreversible regenerative brayton cycle for both cases with and without regeneration.
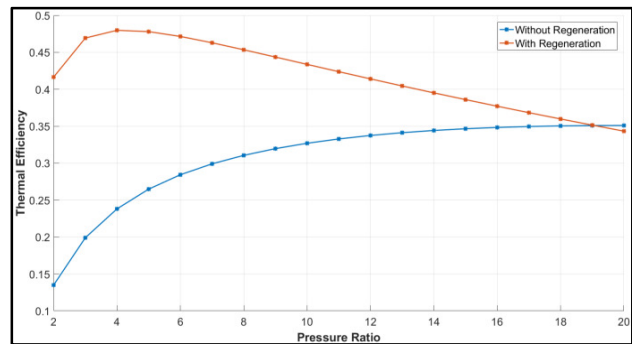

Fig 4 Thermal efficiency vs. Pressure ratio with and without regeneration

2) *Effect of regeneration on thermal efficiency:* Fig.5 shows the effect of effectiveness of regenerator on the thermal efficiency of irreversible regenerative brayton cycle for both cases with and without regeneration.
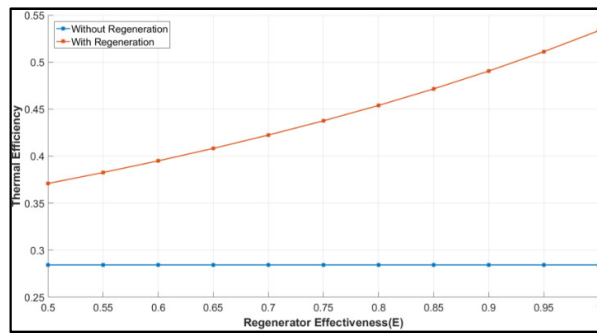
Fig 5 Thermal efficiency vs. Effectiveness for the 2 cases

3) *Effect of compressor efficiency on thermal efficiency for different turbine efficiencies:* Fig.6 shows the effect of compressor efficiency on the thermal efficiency of irreversible regenerative brayton cycle for efficiencies of turbine.
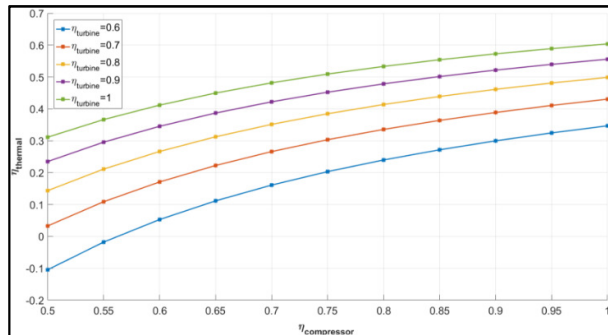

Fig 6 Thermal efficiency (regenerative) vs. Compressor efficiency for different turbine efficiencies

V1. CONCLUSIONS

The conclusion from this study leads to following important points. There certainly is a jump in the thermal efficiency of the system due to regeneration. However, with an increase in the pressure ratio, this increase gradually starts decreasing until at a certain value (Rp=19 in this case) when both the efficiency values for regenerative and non-regenerative case become equal. Also note that the net work output is independent of the cycle is independent of the regeneration effect. Further, it is observed that the efficiency value is strongly dependent on the compressor and turbine isentropic efficiency. As these loses in turbine and compressor decrease, the efficiency enhances as can be seen in figure 6. Lastly, the net work is not linearly related to pressure ratio. It claims its highest value around Rp value 8 and then starts to descend. This goes to show that work output and efficiency do not attain optimum values at a single point only.

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