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Review IJICEGT

Study on Effects of Mass Flow Rate and Compressor Pressure Ratio on Gas Turbine Cycle Performance

Ali Kamranpey*

Abstract

Gas turbines are rotating machines that work based on the energy of gases from combustion. A gas turbine consists of a compressor to compress the air, a combustion chamber to combust the fuel and air, and a turbine to convert the energy from the hot gases into mechanical energy. Gas turbines have many advantages over steam turbines, such as small volume, quick installation, quick start-up, easy operation and the possibility of using different fuels in them. For this reason, in the last twenty years, the production of this type of turbines has increased twenty times. Researchers have always tried to increase the efficiency of the gas turbine by studying the gas turbine cycle and its individual components and parameters. The purpose of this research is to investigate mass flow rate and compressor pressure ratio on gas turbine performance. The results showed that with the increase in mass flow rate, the net work of the cycle increases with a constant slope. Also, the results showed that the increase in the compressor pressure ratio has a direct effect on the work of the compressor, the work of the turbine and the net work of the cycle and causes them to increase, which is more intense at the beginning, but after a specific range it is less intense. In addition, the results showed that by increasing the compressor pressure ratio from 8 to 20, the gas turbine cycle efficiency increases from 47.5% to 60%. The results of this research lead to a better understanding of the effect of thermodynamic parameters on the gas turbine cycle and can help researchers to find optimal conditions.

Keywords: Gas turbine, energy, compressor pressure ratio, mass flow rate, performance, efficiency

INTRODUCTION

A gas turbine is a type of internal combustion engine of rotating equipment machines that operates on the basis of the energy of favorable gases produced from the combustion of different fuels. It is mainly used in fossil fuel power plants, but versions of gas turbines are also used in helicopter engines, engines of some passenger planes, engines of fighter planes and turbine engines of some types of ships.

*Author for Correspondence

Ali Kamranpey

E-mail: Ali.Kamranpey1367@gmail.com

Researcher, Department of Mathematics, University of Guilan, Rasht, Iran

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In each gas turbine, there is a compressor to compress air, a combustion chamber to mix fuel with air and burn it, and a turbine to convert the internal energy of hot and high-pressure gases into mechanical energy. Part of the mechanical energy produced in the turbine is consumed in rotating the compressor of the gas turbine compressor and the rest of the produced energy, according to the intended application for the gas turbine, may cause the rotation of the electric generator (turbogenerator), or in speeding up to contribute to the air (turbofan and turbojet) or to be consumed directly in the same production way (turbofan, turboprop and turboshaft). Fortunately, in recent years, we have seen a significant and rapid development of the gas turbine engine, which is added to their applications daily.

HISTORY AND RESEARCH BACKGROUND

In 1791, a design engineer named John Barber designed a machine that was similar to today's gas turbines in terms of processes and operation. He originally designed this turbine to move a carriage without using the power of four-legged animals like horses. Then in 1904, a gas turbine construction project was carried out by the German scientist Franz Stolz in Berlin, during which the world's first axial compressor was used in its construction process, but ultimately this project was unsuccessful. During the following years, various engineers, researchers and scientists worked on the idea of the gas turbine, so that the General Electric Company of the United States of America, which is the largest gas turbine manufacturer in the world today, opened its gas turbine division in 1980. But at the same time, the first gas turbine to produce electrical energy was built in 1939 at the Brown, Bowery & Sea company in Switzerland, and its final capacity was a meager 4 megawatts.

In recent years, extensive studies have been conducted in the field of gas turbines [1–8]. The main goal of these studies was to better understand gas turbines and optimize their performance [9–12]. Researchers have tried to optimize the individual components of gas turbines such as inlets [13–18], compressor [19–21], combustion chamber [22–24] and related components such as atomizers [25–34], turbine [35–37] and outlet nozzle [38–40], aerodynamics of airfoils [41–50] to increase the overall efficiency of gas turbines [51–53]. The purpose of this study is to investigate the effects of mass flow rate and compressor pressure ratio on compressor work, turbine work, net work and gas turbine cycle efficiency.

Basis of Gas Turbine Cycle Operation

The basis of gas turbine processes in terms of thermodynamic science is based on the Brayton cycle, which can be seen in Figure 1. During this process, the air is continuously compressed and then the combustion takes place under constant pressure conditions and the high pressure and hot air is released in the turbine, and the air returns to its original pressure. In fact, friction and turbulence cause that:

- Do not compress the air inside the gas turbine compressor in a random way. This causes the compressor outlet temperature to be higher than ideal to reach a certain pressure ratio.
- The air expansion in the turbine should not be random. As a result of this problem, with the constant rate of temperature decrease in the turbine, the reduction of the function pressure will be more than that and a lower amount of expansion should be provided for the work efficiency inside the turbine.
- Available pressure drop in the air intake, combustion and exhaust sections. This issue is the reason that the pressure ratio available for work production is reduced. A decrease in pressure in the air inlet section causes a pressure drop in the compressor inlet and, as a result, a decrease in the inlet pressure of the combustion chamber and turbine. The decrease in the pressure inside the chamber and the exhaust respectively results in a drop in the input pressure to the turbine and an increase in the output pressure of the turbine.
- If the turbine inlet air temperature increases, the efficiency of gas turbines increases; Consequently, it is better to choose this temperature as high as possible. But in this case, there are limitations in terms of the strength threshold of the components of the combustion chamber and turbine blades; As a result, these parts are referred to as hot parts, they are made using high temperature resistant materials such as superalloys.

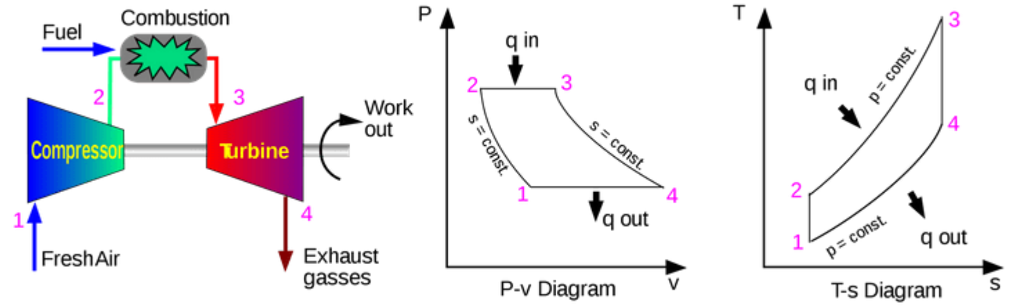

Figure 1. Gas turbine cycle [54, 55].

Research Method

The method used in this research is based on coding and Engineering Equation Solver (EES) software was used for this goal. The governing equations of the gas turbine have been coded and then their effects have been investigated with some variables. The equations governing the gas turbine cycle are as follows:

The cycle function is as follows:

2-1Isentropic Densities (Inside Compressor)

$$q_c - w_c = h_2 - h_{1.} \; w_c = h_2 - h_1, W_c = m_c(h_2 - h_1),\; h_2 - h_1 = Cp(T_2 - T_1)$$

3-2constant pressure increase heat (inside combustion chamber)

$$q_H - w_{2-3} = h_3 - h_2,\; q_H = h_3 - h_2,\; Q_H = m_f \times LHV = m \times (h_3 - h_2)$$
$$h_3 - h_2 = Cp(T_3 - T_4)$$

4-3Isentropic Expansion (inside turbine)

$$q_{3-4} - w_t = h_4 - h_3$$
$$w_t = h_3 - h_4,\; W_t = m_t\,(h_3 - h_4), h_3 - h_4 = Cp(T_3 - T_4)$$
$$q_L = (h_4 - h_1),\; h_4 - h_1 = Cp(T_4 - T_1), Q_L = m \times (h_4 - h_1)$$

4-1 Constant Heat Reduction (Ambient)

P_1=P_4

The thermal efficiency of the cycle is ideally defined as the compressor pressure ratio:

$$\eta_{th} = \frac{W_{net}}{Q_h} = 1 - \frac{T_1}{T_2} = 1 - 1/(rp)^{(k-1)/K}$$

Also net work can be obtained from the following relation:

$$w_{net} = w_t - w_c, W_{net} = W_t - W_c$$

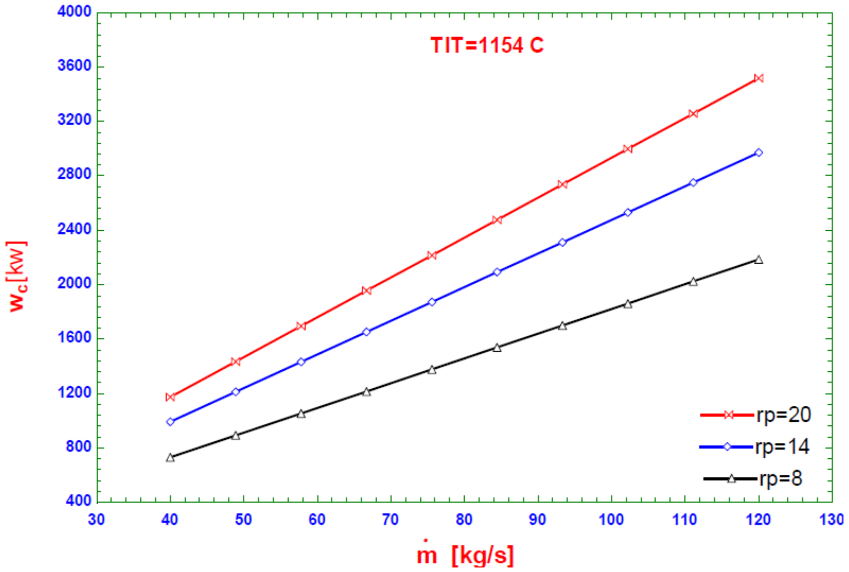

Figure 2. Change of compressor work according to mass flow rate and compressor pressure ratio.

RESULTS AND DISCUSSION

Figures 2–4 show the results of this study. The results show that with the increase in the mass flow rate, the net work of the cycle increases with a constant slope. Also, the results show that the increase in compressor pressure ratio has a direct effect on compressor work, turbine work and net work of the cycle and causes them to increase.

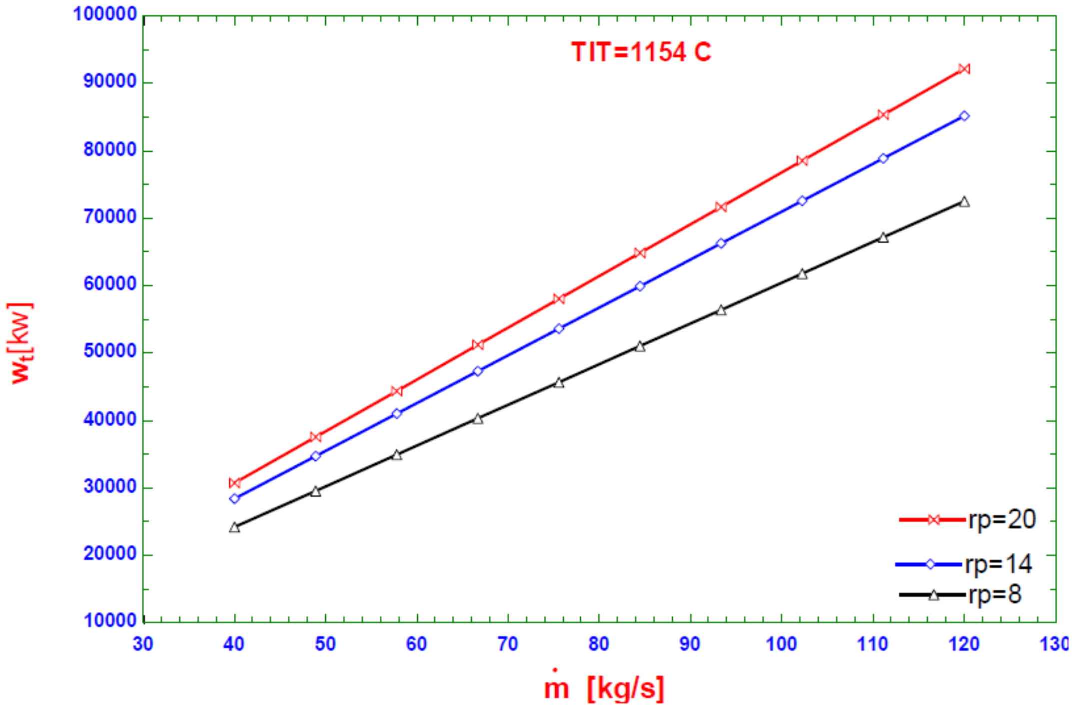

Figure 3. Change of turbine work according to mass flow rate and compressor pressure ratio.

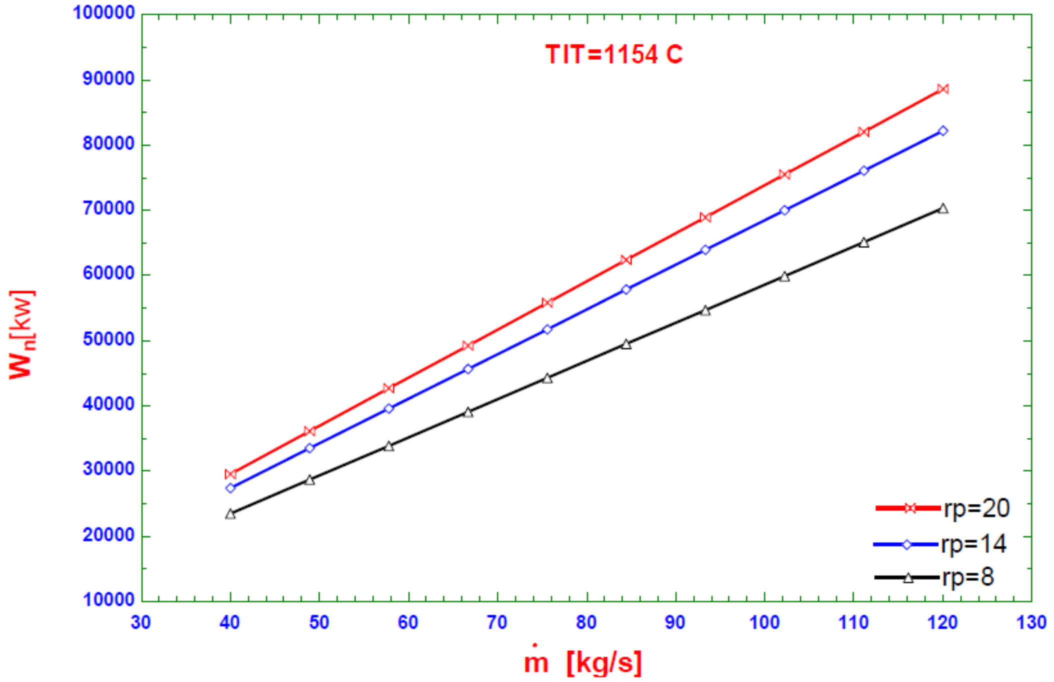

Figure 4. Change of gas turbine cycle net work in terms of mass flow rate and compressor pressure ratio.

The efficiency of the gas turbine cycle depends on the compressor pressure ratio. The results shows that by increasing the compressor pressure ratio from 8 to 20, the gas turbine cycle efficiency increases from 47.5% to 60%.

The gas turbine cycle efficiency is as follows:

$$rp = 8 \Rightarrow \eta = 0.4751$$

$$rp = 14 \Rightarrow \eta = 0.5579$$

$$rp = 20 \Rightarrow \eta = 0.6036$$

CONCLUSION

Gas turbines are widely used in various industries, including power plant and aerospace industries, so studying them is important. The purpose of this research is to investigate the fluid mass rate and compressor pressure ratio on gas turbine performance. In summary, the results showed that:

- As the mass flow rate increases, the net work of the cycle increases with a constant slope.
- Increasing compressor pressure ratio has a direct effect on compressor work, turbine work and net work of the cycle and causes them to increase. This increase is more intense at the beginning, but after a net range it is less intense.
- The results showed that by increasing the compressor pressure ratio from 8 to 20, the efficiency of the gas turbine cycle increases from 47.5% to 60%.

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