

Exergy Analysis of Combined Gas Turbine Unit

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Abstract - The present study focused on evaluating the performance of the combined generating unit using the second law of thermodynamics and under different operating conditions, including the external ambient temperature and the compression ratio. The results showed that when the compression ratio changed from 8 to 16, the generated power and thermal efficiency in the Combined unit and the efficiency of the second law of the Combined unit would increase by (4.2%), (9.815%) (8.64%), respectively with the increase in the compression ratio from 8 to 16. In order to find out the amount of exergy destruction, the second law of thermodynamics was used to determine the greatest amount of available destructive energy in all components of the Combined generating unit, starting from the simple gas unit and ending with the Combined generating unit, as the results showed that the exergy destruction relative to the simple gas unit decreases with high the external ambient temperature is from 10 °C to 50 °C and the highest value of the exergy destruction is in the combustion chamber and is estimated at (228.9MW). While the highest value of the exergy destruction was obtained in the steam generation system is (138.9MW) at the external ambient temperature of 10°C, the steam unit was also affected by the increase in the external ambient temperature and the highest value of the exergy destruction is (5.654MW) at the temperature of the external environment The ambient is 50 °C and the maximum amount of energy available destroyed in a combined generating unit is MW (496,356) at an ambient temperature of 10 °C.

Keywords: Exergy Analysis, Combined, Gas, and Turbine Unit.

1. Introduction

Most of the previous studies and research, which dealt with whether the simple gas unit or the combined, focused on the use of the first law of thermodynamics in evaluating the performance of these units [1,2,3].

Those researches and studies were adequate, but they did not give a clear picture of the amount of exergy destruction in every part of the combined and even simple obstetric unit. As a result of the increased demand for electrical energy,

researchers and workers in this field worked to build various generating units to cover the demand for electrical energy, as a result of rapid industrial expansion and high population growth. Thus, reducing energy costs and reducing pollutant emissions, all these demands have encouraged researchers and engineers to search for different technologies that are efficient, environmentally and economically acceptable[4]. Gas units entered the field of electric power generation since the beginning of the last century and were mainly used to cover peak loads and fill the shortage because of the increasing demand for energy in special periods (summer).

2. Components of Gas Turbines

Any simple gas unit consists of a compressor, a combustion chamber and a gas turbine, in addition to the generator in Figure (1).

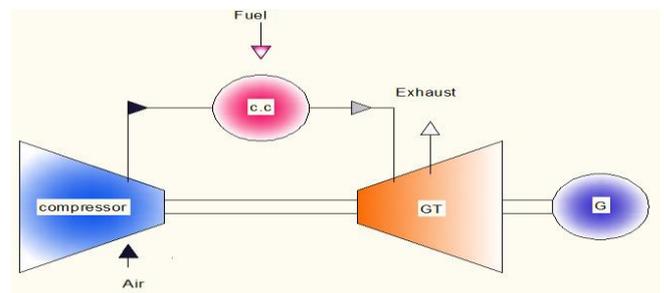


Figure (1): Show the simple gas turbine

Combined Cycle

The combined cycle consists of the simple gas unit (the main unit), which was previously explained, the Heat Recovery Steam Generator (HRSG) and the steam unit (the secondary unit) figure (2).

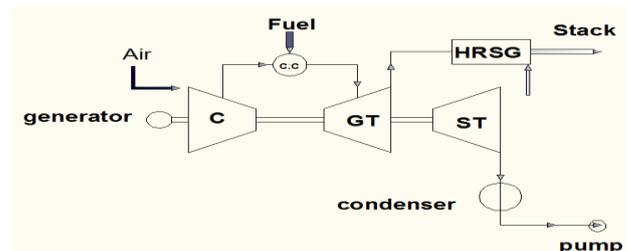


Figure (2): Show the combined cycle diagram

This cycle exploits the available energy dissipated from the exhaust gases through the Heat Recovery Steam Generator (HRSG) system, which takes the heat of the exhaust gases and utilizes it to produce superheated steam at high temperatures and relatively high steam pressure. This steam is used to produce additional capacity through the steam unit (secondary unit)[5].

Heat Recovery Steam Generator (HRSG)

There are many types of steam generating systems that can be used as a linking system between the gas unit and the steam unit, and each has its own advantages and characteristics. Steam generation by heat recovery is one of the most important main parts and represents the backbone of the combined generating unit. Steam generation systems are classified by heat recovery depending on the type of design and the method of connecting the system to the exhaust gas stream, and each type has its own characteristics and characteristics.

1. Single pressure (HRSG) steam generation system.
2. Dual pressure HRSG steam generation system.
3. Multiple pressure steam generation system (Multi-pressure HRSG).

Each of the above pressure levels contains an economizer, evaporator, and roaster, but with different operating and design conditions, according to which it is divided into several stages, namely the high, medium and low-pressure stage.

Steam turbine

It is one of the most important types of turbines used in electric power plants. It is a mechanical device that extracts heat energy from vapor pressure, and converts it into rotating motion. It was invented by Sir Charles Parsons in 1884 [6]. It almost replaced the steam engine, which was powered by a piston. This is primarily due to the increase in its thermal efficiency and the increase in the energy generated from it in relation to weight. Because turbines generate rotating motion, they are particularly well suited to be used to rotate generators that produce electricity at a large scale in power stations—about 80% of the world's electricity is generated by the use of steam turbines.

3. Analysis of the exergy destruction

Exergy analysis is a method that uses the conservation of mass and energy together with the second law of thermodynamics to analyze, design, and improve energy systems. Many engineers, scientists, and researchers suggest that the thermodynamic performance of the process should be better evaluated by performing available energy analysis in

addition to or instead of conventional energy analysis because it appears that exergy provides more insights and is more useful in enhancing efficiency improvement efforts. More than energy analysis because it allows knowing the locations, types and amounts of losses that can be identified [7].

$$\dot{E}_{xd} = \sum j \left(1 - \frac{T_0}{T_j}\right) \dot{Q}_j - (\dot{W}_{cv}) + \sum i \dot{m}_i ex_i - \sum e \dot{m}_e ex_e \quad (1)$$

In the absence of a magnetic field, electric field, etc., and the total available energy can be expressed as

$$E_x = E_{xpH} + E_{xkN} + E_{XPT} + E_{xfCHE} \quad (2)$$

Ignoring potential energy and kinetic energy, the above equation can be rewritten as follows:

$$E_x = E_{xpH} + E_{xfCHE} \quad (3)$$

The exergy destruction in the air compressor will be found from the following equation

$$E_{xdc} = E_{x1} + \dot{W}_c - E_{x2} \quad (4)$$

The chemical energy is calculated if the fuel is methane, according to the following equation [8]

$$\frac{e_{xfCHE}}{LCV} \cong 1.06 \quad (5)$$

After the chemical energy in the combustion chamber has been found, the following equation can be applied to calculate the amount of available energy:

$$E_{x2} + e_{xfCHE} * \dot{m}_f = E_{x3} + E_{xd,c} \quad (6)$$

The equation for the available exergy destruction by the gas turbine is formulated as follows:

$$E_{xdG.T} = E_{x3} - E_{x4} - \dot{W}_{GT} \quad (7)$$

After that, the amount of available exergy destruction in the steam generation system will be calculated for each of the superheated, evaporator and economizer for the high-pressure stage as in the following equations:

$$E_{xd(SH.HP)} = E_{xg1} - E_{xg2} + E_{xw11} - E_{xw12} \quad (8)$$

$$E_{xd(EVP.HP)} = E_{xg2} - E_{xg3} + E_{xw9} - E_{xw10} \quad (9)$$

$$E_{xd(ECO.HP)} = E_{xg3} - E_{xg4} + E_{xw8} - E_{xw7} \quad (10)$$

Also, the amount of available exergy destruction in all parts of the steam generation systems (super heater, evaporator and economizer) at the low-pressure stage will be calculated as shown below:

$$E_{xd(SH.LP)} = E_{xg4} - E_{xg5} + E_{xw6} - E_{xw5} \quad (11)$$

$$E_{xd(EVP.LP)} = E_{xg5} - E_{xg6} + E_{xw4} - E_{xw3} \quad (12)$$

$$E_{xd(ECO.LP)} = E_{xg6} - E_{xg7} + E_{xw1} - E_{xw2} \quad (13)$$

As for the efficiency of the second law of thermodynamics in the steam generation system, it will be calculated as follows:

$$\eta_{II(HRSG)} = \left(\frac{E_{xw6} + E_{xw12} + E_{xw1}}{E_{xg7} + E_{xg4}} \right) \quad (14)$$

As for the amount of exergy destruction and the efficiency of the second law of thermodynamics for the steam unit in a steam turbine for the high pressure and low-pressure stages, they will be found as shown in the following equations:

$$E_{xd(ST.HP)} = E_{xw12} - E_{xw13} - Power_{sthp} \quad (15)$$

$$E_{xd(ST.LP)} = E_{xw13} - E_{xw14} - Power_{stlp} \quad (16)$$

$$\eta_{II(ST.HP)} = \left(\frac{Power_{sthp}}{E_{xw12} - E_{xw13}} \right) \quad (17)$$

$$\eta_{II(ST.LP)} = \left(\frac{Power_{stlp}}{E_{xw13} - E_{xw14}} \right) \quad (18)$$

The efficiency of the second law will be calculated in the combined unit from the following law

$$\eta_{II(CCGT)} = (W_{GT} + Power_{sthp} + Power_{stlp}) / (e_{xfCHE} * \dot{m}_f) \quad (19)$$

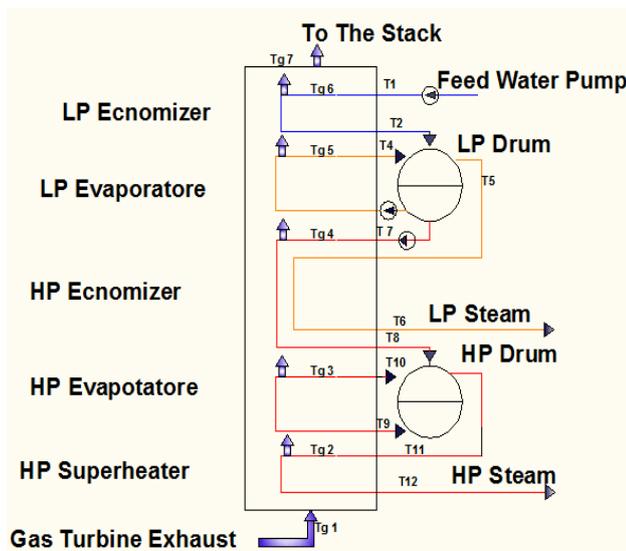


Figure (3): Shows the parts of the dual pressure steam generation system

4. View and Discuss Results

Figure (4) shows the effect of the compression ratio on the temperature of the gases leaving the gas turbine entering the steam generation system, as it was observed that the temperature of the gases leaving the turbine decreased when the compression ratio was increased from 8 to 16, as the turbine occupancy increases as a result of the expansion of gases in Gas turbine.

Figure (5) shows the relationship between the compression ratio and the amount of power generated in the installed unit in the event of a change in the compression ratio from 8 to 16 and at different turbine inlet temperatures.

From the above figure, it can be seen that the generating capacity increases from 136.7 MW to 252 MW, which represents an increase (45.7%). Figure (6) shows the relationship between the compression ratio and the thermal efficiency of the combined unit. When the compression ratio is increased from 8 to 16 and at different turbine inlet temperatures, the thermal efficiency of the combined unit achieves an increase (21.25%).

These results are somewhat identical to those that were presented in [9] when using the same operating conditions.

Figure (7) shows the effect of the compression ratio on the thermal efficiency of the combined unit and on the efficiency of the second law in the combined unit. As the compression ratio increases from 8 to 16, the thermal efficiency in the combined unit increases from 40.6% to 44%, while the second law of the combined unit increased from 43.5% to 48% and the reason for this is to reduce the percentage of the available energy wasted.

In Figure (8) it shows the relationship between the exergy destruction for each part of the simple gas unit when the temperature of the external environment changes from 10 °C to from 50 °C, as it appears from the above-mentioned figure that the highest value of the available wasted energy occurs in a room combustion [10].

Figure (9) illustrates the relationship between the exergy destruction for the steam generation system when the temperature of the external environment changes from 10 °C to from 50 °C. In Figure (10) it shows the relationship between the exergy destruction for each of the steam turbines in the high- and low-pressure stage, and the steam unit when the temperature of the external environment changes from 10 °C to from 50 °C.

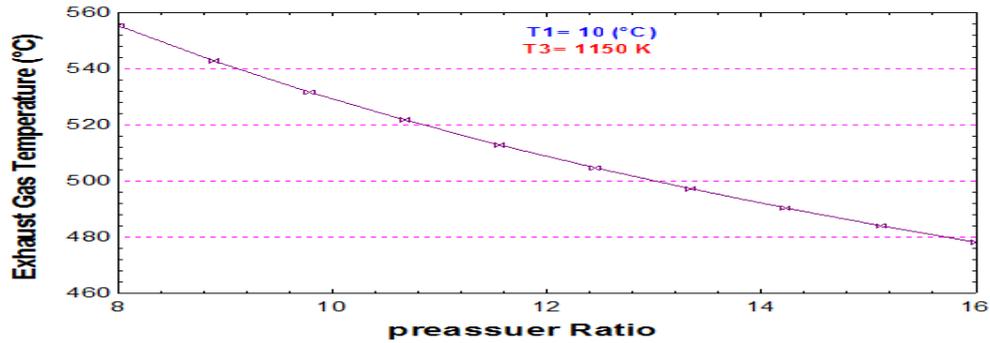


Figure (4): Show the Effect of the compression ratio on the temperature of the exhaust gases of a simple gas unit

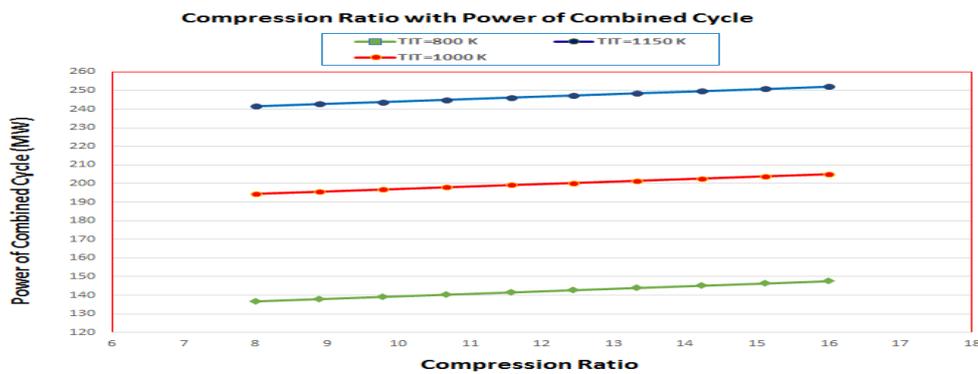


Figure (5): Show the Effect of the compression ratio of the amount of energy generated in the installed unit and at different temperatures of the turbine inlet

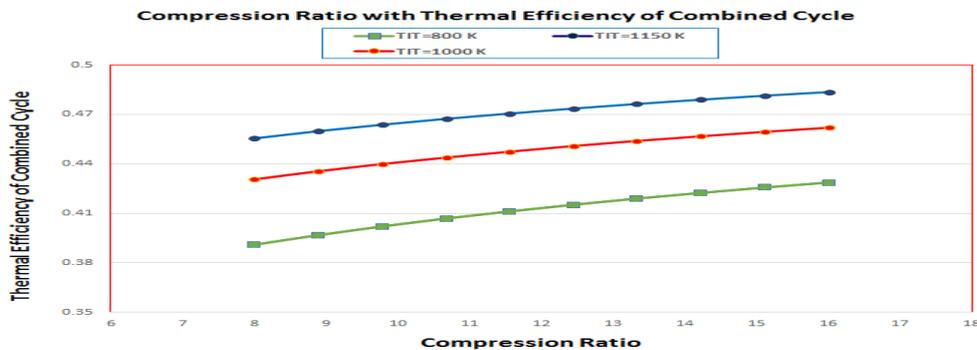


Figure (6): Show the Effect of the compression ratio on the thermal efficiency of the combined unit and at different temperatures of the turbine inlet

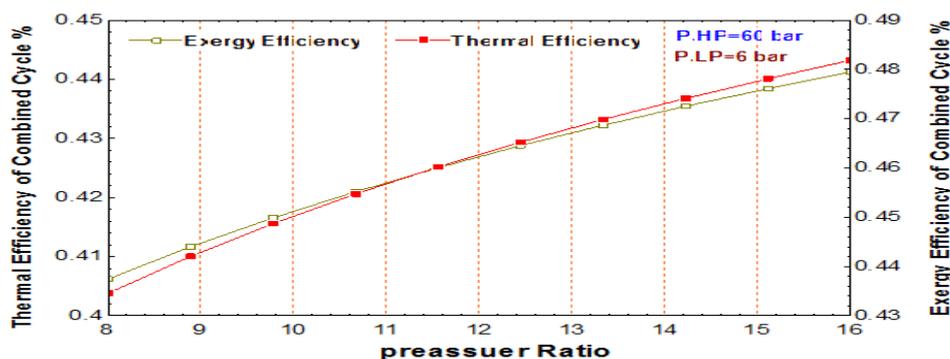


Figure (7): Show the Effect of the change in the compression ratio on the efficiency of the second law and the thermal efficiency of the combined generating unit

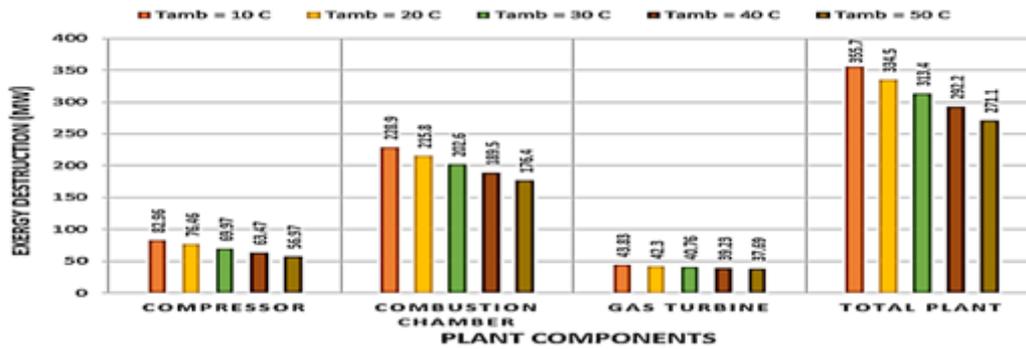


Figure (8): the effect of a change in the temperature of the external environment on the exergy destruction of a simple gas turbine unit

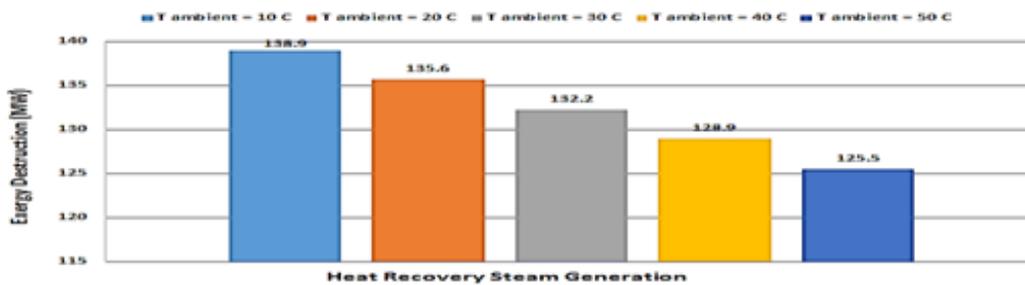


Figure (9): the effect of changing the temperature of the external environment on the exergy destruction of the steam generation system

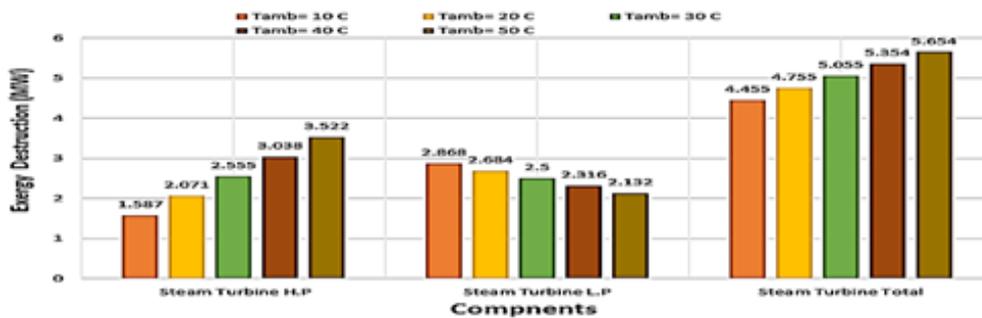


Figure (10): the relationship between the change in the external ambient temperature and the exergy destruction of the vapor unit

5. Conclusions

- When the compression ratio is changed, the temperature of the gases leaving the turbine will decrease when the compression ratio is increased from 8 to 16, while the thermal efficiency of the combined unit and the amount of energy generated in the combined unit and the efficiency of the second law of the combined unit increases by (8.64%) (9.815. %), (4.2%), respectively, when the compression ratio is increased from 8 to 16.
- The amount of exergy destruction for the gas unit decreases with the increase in the temperature of the external environment from 10 °C to 50 °C, and the highest value of the exergy destruction is in the combustion chamber and is estimated at (228.9MW), and the highest value of the exergy destruction in the steam generation system is (138.9MW) at an ambient temperature of 10 °C, while in the steam unit, the highest

value of exergy destruction is (5.654MW) at an ambient temperature of 50 °C, and the highest amount of exergy destruction in a combined generating unit is (496.356 MW) at The ambient temperature is 10 °C.

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