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EXERGY ANALYSIS FOR GAS TURBINE

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ABSTRACT:

The gas turbine is essential in industry, domestic uses, transportation, and power generation. Accordingly, this research presents a study of exergy analysis for the gas turbine to demonstrate the effect of influential parameters. The parameters are compressor pressure ratio, maximum cycle temperature, and ambient temperature along different months. The result of the parametric study shows that exergy destruction for compressor is reduced, and second law efficiency increases by increasing the pressure ratio of the compressor. When the ambient temperature rises, the compressor exergy destruction increases and second law efficiency decreases. By increasing the maximum temperature of the cycle, exergy destruction in the turbine is reduced and second law efficiency is increased. Exergy analysis helps to evaluate parameters that improve the performance of each component on a single scale, thereby improving the overall cycle. Exergy analysis improvements lead to exergy destruction inhibiting and benefiting from the available energy in the maximum possible way.

Nomenclature

c_p	Specific heat at constant pressure	I	Exergy Destruction
h_e	Specific enthalpy out	$\dot{X}_{heat}$	Exergy rate due to heat transfer
h_i	Specific enthalpy in	$\dot{X}_e$	Exergy rate out
$\dot{m}$	Mass flow rate	$\dot{X}_i$	Exergy rate in
$\dot{Q}$	Quantity of heat		
s	Entropy		
$S_{generation}$	Entropy generation	**Abbreviations**	
T_0	Dead state temperature	EES	Engineering Equation Solver
T_b	Boundary temperature	PR	Pressure Ratio
$\dot{W}_C$	Compressor's work	**Greek symbol**	
$\dot{W}_t$	Turbine's work	Ψ	Specific exergy

X	Exergy	η_{II}	Second law efficiency

1.INTRODUCTION:

Exergy analysis is one of the methods used to estimate the available energy at the site being studied. Due to its significance, many studies have been adopted to enhance the operation of gas turbine cycle-based power plants worldwide.

The present work aims to introduce the exergy analysis for the gas turbine cycle in the hot weather regions, The main target is to enhance the performance of the gas turbine cycle; that is one of the basics in that the power plants operate there.

Obieda [1] discussed that the exergy analysis shows a wide range of information and gives a room for the improvement in the performance of the power plant, as well as being one of the most critical factors that are used to develop the power plants.

Adding it is a vital component in attaining sustainable development as it offers the foundation for a fair estimate of substance's forms of capacity; the procedure of the exergy analysis is very efficient in finding and determining the inefficiencies' locations and spotting the light on them. Also, it is believed that it must be put into consideration before any construction phases to make a detailed analysis of the energy type and the conversion efficiency; and the efficiency of the plant and demonstrate whether it will be of high effectiveness or be that useful to the quality of energy that is available.

Ibrahim [3] discussed the procedure of exergy analysis is efficient in comprehending the process, finding any inefficiencies, and comparing multiple utilized energy quality.

Al-Jundi [4] analysed the exergy and energy for Al-Hussein thermal power plant in Jordan, and it was found that the exergy destruction to the total exergy destruction percentage ratio was noted to be 77% in the boiler, 13% in the turbine, and 9% in the forced draft fan condenser. The results for the exergy and energy efficiencies were found to be 25% and 26%, respectively; however, the main or source with the highest irreversibility in the power plant was found to be the boiler.

Kopac and Hilalci [5] studied the effect of ambient temperature on the efficiency of the regenerative and reheat power plant in Turkey; The ambient temperature conditions were between 5 and 35 ◦C.
It was found that the boiler efficiency defect significantly affected the overall efficacy and the plant's rational efficacy. Also, the ambient temperature had a significant impact on the irreversibility of the boiler. However, it did not have a sensible effect on the plant's other components.

Khaldi and Adouane [6] assessed the performance of a GT (gas turbine) power plant in Algeria based on an exergy analysis. It was found that the plant exergy efficiency is 32.24% at specific design, equipment specifications, and operational inlet conditions. Also, it was affirmed that the combustor is the primary destructor of exergy (an exergy efficiency of 68.48%) and a 58% loss in exergy consumption, exergy rejection through the stack is in second place, not far behind. In contrast, low exergy destruction connected with the turbine and compressor accounts for only 11% of total exergy consumption. More importantly, the power plant and its components, excluding the turbine, are less efficient at off-design operating conditions, defined as 83% load and various environmental conditions assigned on a given day.

The entire power plant's net output power and exergy efficiency is reduced as air temperatures rise, which causes inefficient combustors. At the same time, the compressor and turbine were run at near-constant efficiency. The plant's exergy efficiency can be significantly enhanced by preheating air before entering the combustor. Therefore, the plant's exergy efficiency is increased to 68% by preheating the air to 800 degrees Celsius.

The previously mentioned cases were our primary key for this study to have a kind of interaction between all of them to help to develop operating parameters for the conditions that are in Egypt.

Mainly targeting the Brayton gas cycle components from the joint cycle as it has a high grade of energy content compared to the Rankine steam cycle, which by order will be significantly improved, and the overall efficiency, exergy efficiency of the plant will have an improvement [7,8, 9, 10]**.**

The selection of the components of the gas turbine cycle should be very precise, and no conditions force or limit to select of the efficient component on its function only or from a close point of view, but the whole cycle should be monitored in the selection to get a whole combination of good performance and high efficiency. The gas turbine is of an excellent value in energy production and having the highest efficiency and output became an irreplaceable demand. This parametric study is to enhance the performance of the gas turbine cycle to achieve the highest efficiency, limiting the exergy destruction.

Because of the importance of the gas turbine cycle in industry, domestic use, transportation, and power generation, this study focuses on improving the gas turbine cycle using exergy analysis. This paper deals with the study of the effect of compressor pressure ratio, gas turbine inlet temperature, and the ambient temperature in the hot weather region on the compressor and turbine performance.

2.EXERGY METHODOLGY:

In this work, the following parameters have been studied:

1 Pressure ratio of the compressor.
2 Ambient temperature of air entering the compressor.
3 Gas turbine inlet temperature.

Different equations were evaluated on the EES software to get the required results.

For any control volume under steady-state conditions with negligible potential and kinetic energy variations, mass, energy, and exergy balances can be represented, respectively as follows in the following figure (1) and equations:

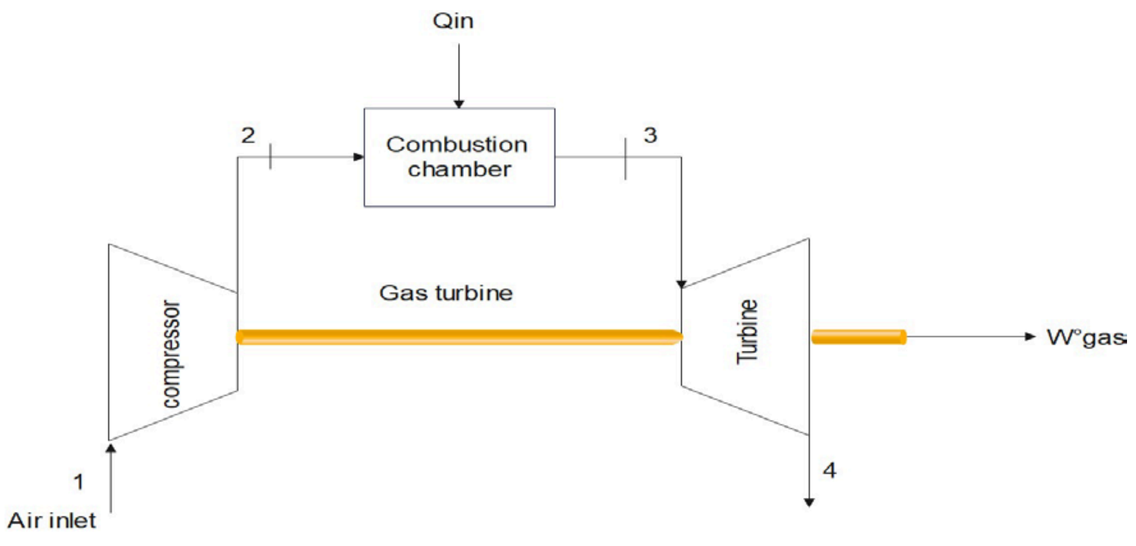

Figure 1 Gas Turbine Cycle Schematic Diagram

$$\sum_{in} \dot{m} = \sum_{out} \dot{m} \tag{1}$$

where $\dot{m}$ is the mass flow rate.

$$\eta_{Rev} = 1 - \frac{T_l}{T_h} \quad (2)$$

where T_l is the lower temperature and T_h is the higher temperature.

$$X = \eta_{Rev} * Q_{in} \quad (3)$$

where Q_{in} is the quantity of heat added to system.

The mass flow rates entering, and exiting are assumed to be constant.

For compressor:

$$I = T_o S_{generation} = \dot{W}_c - \dot{m}_a[\dot{c}_{pa}(T_2 - T_1) - T_o(c_{pa} ln \frac{T_2}{T_1} - R_a \, ln \frac{P_2}{P_1}) \quad (6)$$

W_c is the compressors work, $\dot{m}_a$ is the mass flow rate of air entering the compressor while c_{pa} is the specific heat of air at constant pressure, T_2 is the compressor exit temperature, T_1 is the compressors inlet temperature and T_o is the ambient condition temperature, $\frac{P_2}{P_1}$ is the compressor pressure ratio.

$$\eta_{II} = \frac{\dot{W}_c - I}{\dot{W}_c} \quad (7)$$

where I refer to the exergy destruction.

For turbine:

$$I = T_o S_{generation} = \dot{W}_t - \dot{m}_g[\dot{c}_{pg}(T_3 - T_4) - T_o(c_{pg} ln \frac{T_3}{T_4} - R_g \, ln \frac{P_3}{P_4}) \quad (8)$$

where W_t is the turbine work, $\dot{m}_g$ is the mass flow rate of gas entering, while c_{pg} is the specific heat of gas at constant pressure, T_3 is the turbine inlet temperature, T_4 is the turbine exit temperature and T_o is the ambient condition temperature while P_3 is the gas turbine inlet pressure an P_4 is the gas turbine exit pressure.

$$\eta_{II} = 1 - \frac{I}{\dot{m}_g(X_3 - X_4)} \quad (9)$$

3.RESULTS

The results obtained for this paper were calculated, putting all the previously mentioned points of comparison changed altogether. Results for the mathematical relations were calculated using the EES software, while the figures were plotted using the Sigma Plot software.

The different parameters calculated throughout the present work are summarized in table (1), the deviation in the validation is due to neglecting the efficiency of both the compressor and the turbine.

Table 1 Parameters Study

Parameters	**Values**	**Unit**
PR	*10:19*	-
T_o	*281:311*	*K*
Turbine Inlet Temperature	*1150:1550*	*K*

c_{pa}	1.005	kJ/kg. k
c_{pg}	1.11	kJ/kg. k
$\dot{m}_a$	133	kg/s
$\dot{m}_g$	625	kg/s

First, for the compressor, increasing the pressure ratio of the compressor is reduced the temperature difference between the outlet of the compressor and the combustor's exit. As the outlet temperature of the compressor increases, this will result in decreasing the fuel consumption inside the combustor, it can dedicate that the exergy will increase.

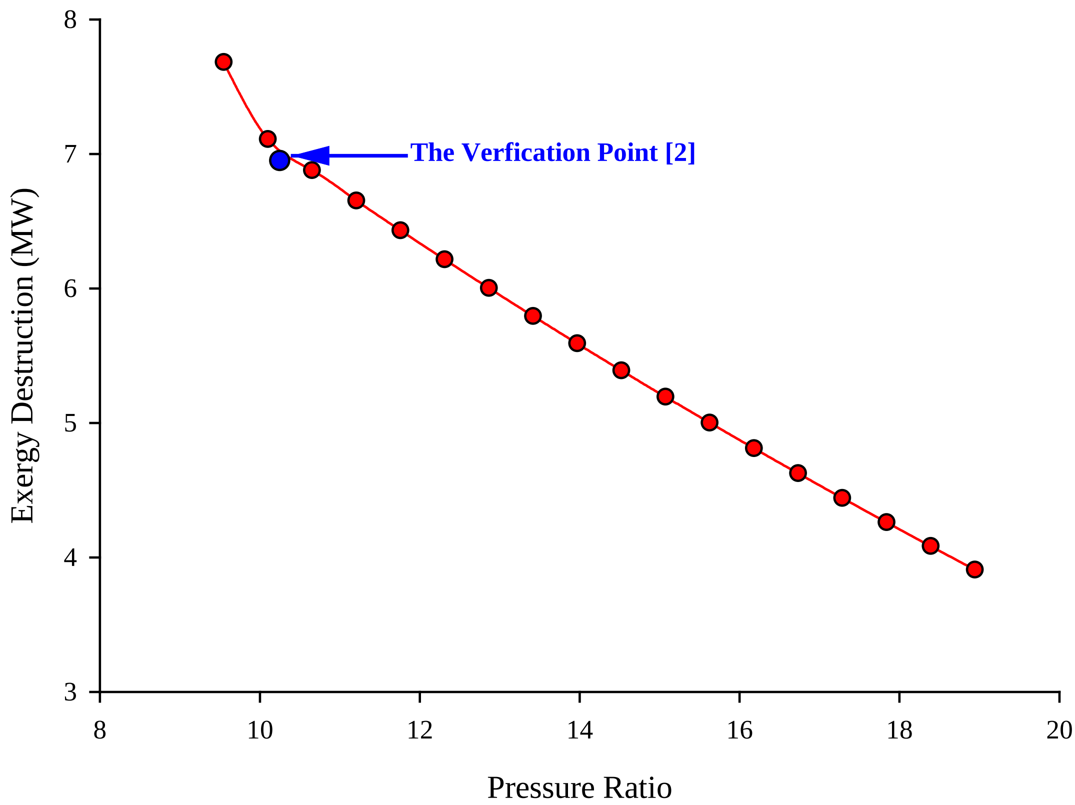

Figure 2 Pressure ratio versus Exergy Destruction in compressor

The following figure shows the effect of increasing the pressure ratio on exergy destruction, it was found as the pressure ratio increases the exergy destruction starts to is reduced and as the value of the pressure ratio increases as the destruction reaches to a very acceptable value. This ensures that the exergy efficiency will have an increase equivalent to the drop in the destruction. The results showed that the pressure ratio between values of 14 and 16, has an acceptable value for the destruction that is required to be limited.

The following figure demonstrates the effect of the increasing of pressure ratio on the second law efficiency, and as it was thought had an increase; where at pressure ratio of 10 the second law efficiency was found to be 86%, but with increasing the pressure ratio from 10 to 12 the values of the second law efficiency was higher than 88%, and likewise the previous figure showed the drop in destruction meets in the following figure and increase in the second law efficiency; the values recommended previously meets values higher than 90% in this figure, which ensures that the pressure ratio increasing will limit the destruction and has a better impact on the whole cycle.

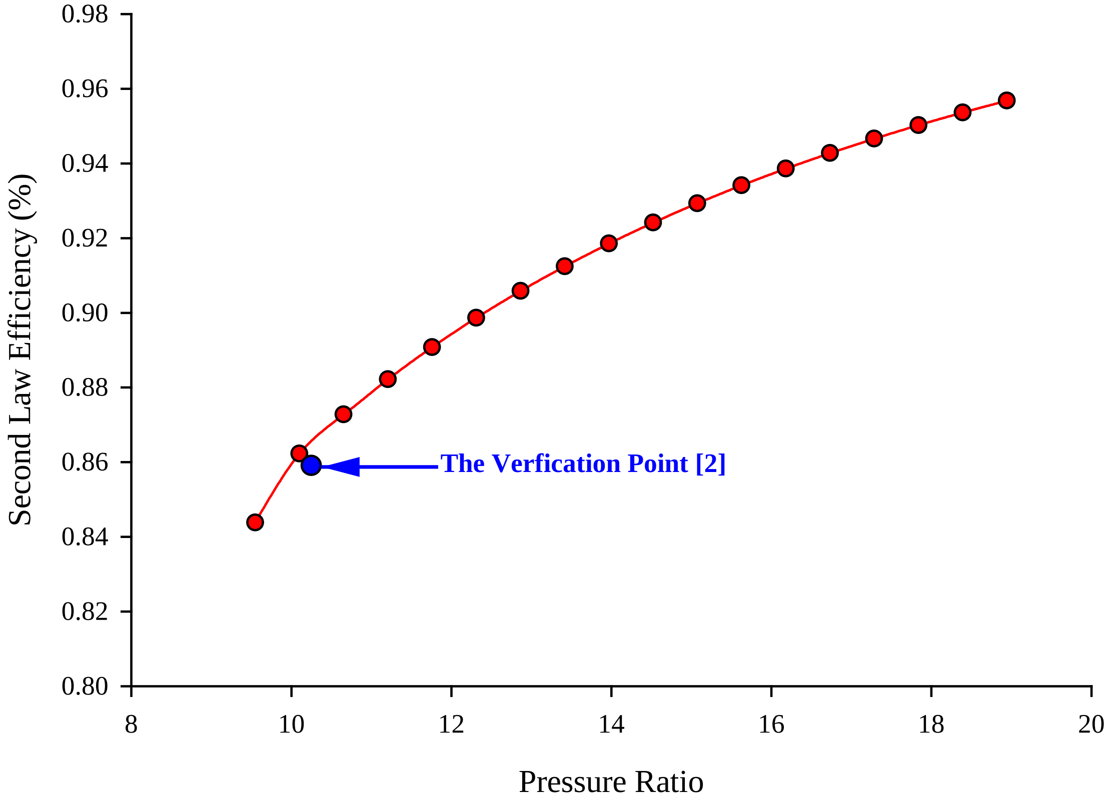

Figure 3 Pressure Ratio versus Second Law Efficiency in compressor

The second parameter that was analyzed was the effect of the ambient temperatures on the destruction values of the compressor; to determine whether it is required to have further investigations on the on the ambient conditions, methods of treatment of the ambient conditions affecting the components as selecting or using an air treatment method.

The values of the ambient conditions were calculated at the mean values of temperatures at the hot weather regions, which varied from 281 K to 311 K, the records of the destruction were close to each other, and the changes were very remarkable at the high-temperature months. However, the effect could not be neglected as it will increase the exergy destruction, which will be more than 1 MW at a pressure ratio of 13.4. It is thought that using an air treatment system to control the ambient conditions will improve the efficiency of the compressor and limit the destruction. This is to ensure that the performance of the whole cycle will not be affected by the high ambient temperatures.

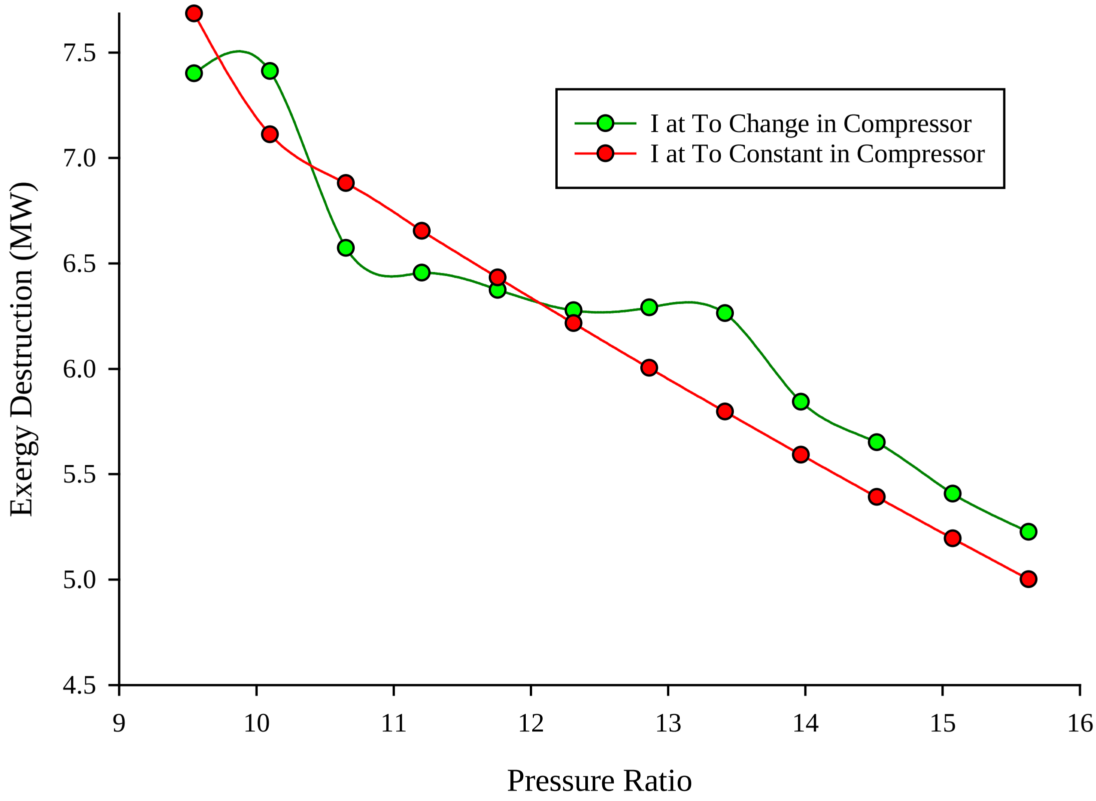

Figure 4 Pressure ratio versus Destruction at ambient condition changes for compressor

Third, the increase in gas turbine inlet temperature was taken into consideration, knowing that the new administrative capital will have H-series turbines; known for their significant performance and ability to sustain higher temperatures and higher stresses due to their inner cooling system.

The present paper aims to discuss the turbine inlet temperature on a wide limit to have it all covered; and have a broader sight of the sites of the best efficiency and limit the destruction within the gas turbine. It was a priority to get the most efficient cycle, and the components themselves were in a good combination with each other. It had a large-scale temperature range from 1150 K to 1500 K, knowing that the highest turbine inlet temperature recorded was 1800 K, and having the blades of the turbine effected by such high temperature would is reduced the lifetime of the gas turbine.

The following figure clears the change in the turbine inlet temperature concerning the destruction to limit it. It is evident that as the turbine inlet temperature increase, the destruction of exergy is reduced. The limitation here might seem simple, but the material of the blade restrains the increase of the turbine inlet temperature and the stresses that the blade could endure so that it might be helpful, but further increases could lead to failure in the gas turbine.

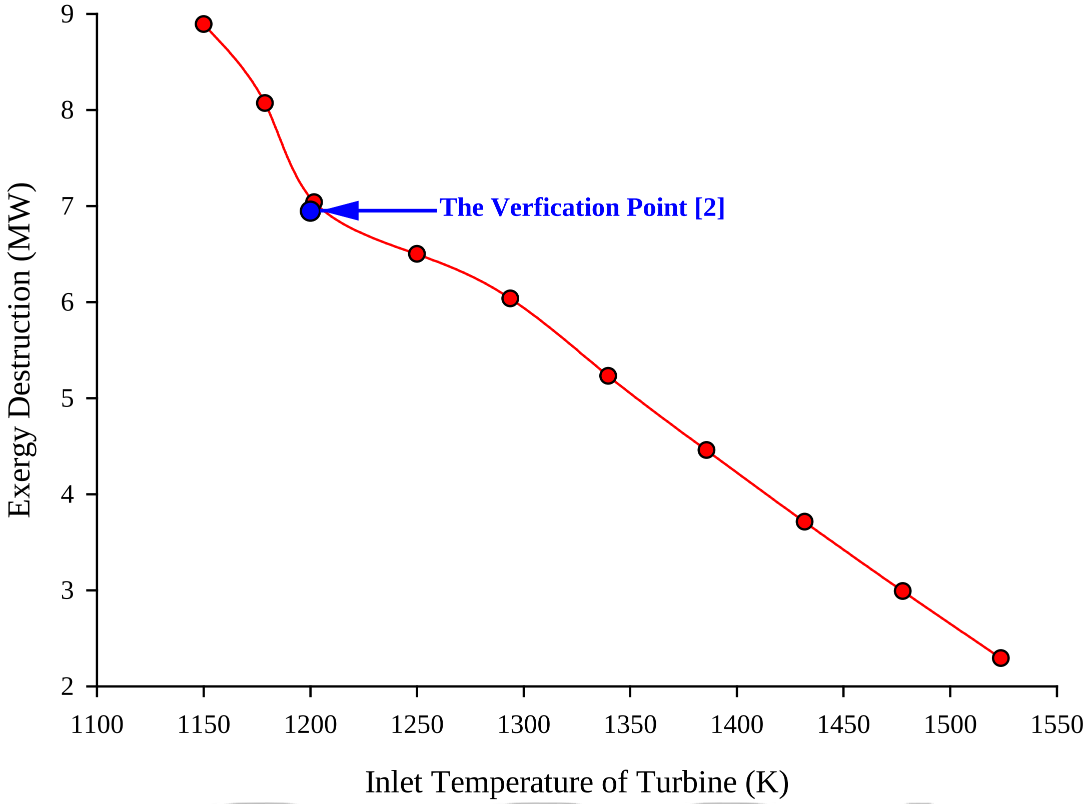

Figure 5 Turbine Inlet Temperature versus Exergy Destruction

The following figure studies the effect of increasing the turbine inlet temperatures on the second law efficiency, it was found that as the turbine inlet temperature increase it will meet an increase in the second law efficiency and at temperatures higher than 1350 K, the efficiency will reach to higher than 95% which is the required target of this study.

The values of the of efficiency meets an increase as the turbine inlet temperature increases, but these values are limited by the used gas turbine and the designing criteria that meets the highest inlet temperature.

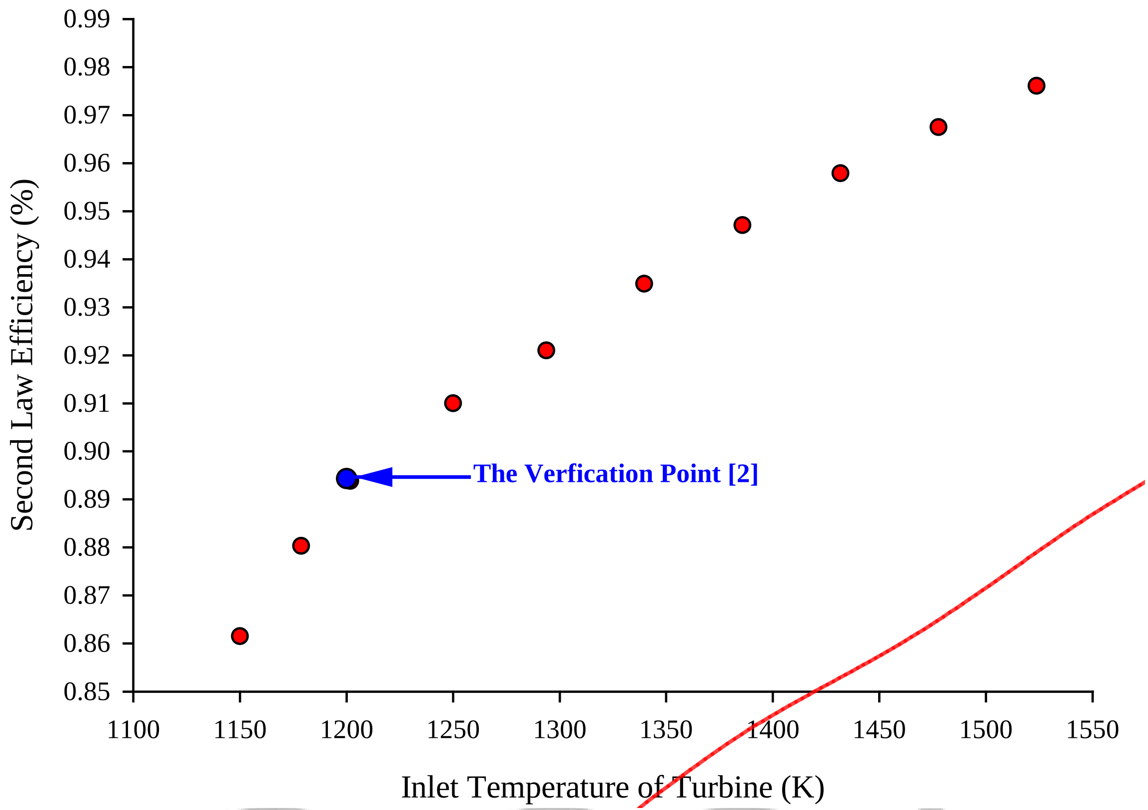

Figure 6 Turbine Inlet Temperature versus Second Law Efficiency

So, combining the previous results will be the guide required from our perspective point of view to have more than one operating condition for the components of the plant; to have an efficient operation for each component on its own, with the whole cycle having relatively high efficiency. However, these improvements are just the beginning of filling the gap available for improvement, but the key to this improvement is the exergy analysis, so systems could be added to improve this cycle, and further improvements could be accomplished to have the best efficiency.

4.CONCLUSION:

From the present work, the following conclusions can be drawn:

1- Exergy destruction is reduced by increasing the pressure ratio.
2- Increasing the pressure ratio makes the second law efficiency increase, reaching values higher than 90%.
3- The effect of the ambient temperature rise makes the exergy destruction increase, second law efficiency is reduced.
4- It is recommended to use an air treatment system to ensure low destruction and high efficiency.
5- The increase in the cycle maximum temperature causes a significant is reduced in the exergy destruction.
6- The increase in the cycle maximum temperature causes the second law efficiency to increase to very satisfying values.

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