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Increasing The Efficiency Of Gas Turbines By Using Part Of The Exhaust Gases

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Abstract- the research aims to Explain the importance of increasing the efficiency of gas turbine stations by using part of the exhaust gas and how to apply this to raising the efficiency of the gas turbine station by using a reheated and a heat exchanger before the combustion chamber and using the combined cycle, and comparing them in terms of efficiency, in terms of operating cost, in terms of life span. Invasive through methodology combines description, application, and analysis methodologies using simulation technology. The results indicated that the heat exchanger reheating method increased the efficiency at a rate ranging from five to 15%, the cost of increasing the efficiency was 33.1%, and the life expectancy of the station was 23years. In comparison, the combined cycle method cost 34.5% and increased the efficiency by a rate ranging from 6% to 18%. The expected lifespan is 22 years, while the emissions rate in the first method was 20% better than the second method.

Keywords- ***sustainability, gas turbines, power plants, exhaust, combined cycle, efficiency.***

I. INTRODUCTION

To achieve complete sustainability, it must be achieved in all aspects of life, including the environment, economy, and society. This concept focuses on balancing these three aspects so that achieving sustainability in one aspect does not affect the other elements. Complete sustainability is described as "the capacity to fulfill present requirements without jeopardizing the ability of future generations to satisfy their own needs, considering all environmental, economic, and social dimensions," with particular emphasis on the environmental aspect. It safeguards the environment and conserves natural resources. (Van der Mensbrugghe, D. 2008). This dimension includes a group of issues, such as reducing pollution, conserving natural resources, such as water, air, and soil, and protecting biological diversity, then the economic dimension focuses on achieving sustainable economic development. This dimension includes a group of issues, such as achieving comprehensive economic growth, achieving social justice, and reducing poverty, and the social dimension focuses on achieving sustainable social development. This dimension includes a group of issues, such as achieving health, education, and social care for all, achieving gender equality, and achieving peace and security. Using clean energy sources means preserving the environment. Using energy sources and searching for more renewable sources means advancing the areas of industry and trade, which It means a rise in the standard of living, and this is what both economic sustainability and social sustainability mean (Liu, G. 2014).
As shown in Figure No. 1, which shows the world's energy sources, danger can be sensed. Therefore, the main concern of all countries has become achieving sustainability in the field of

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energy, whether by searching for new sources of energy or developing anything related to traditional sources of energy, such as generation equipment and generation techniques. Rationalizing consumption and all available tools through which sustainability requirements can be achieved.

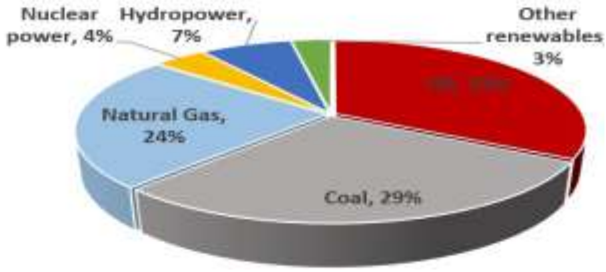

Figure (1): shows the sources of energy in the world

The study aims to clarify the importance of increasing the efficiency of gas turbine stations by using part of the exhaust gas as an effective and important means of developing and achieving sustainability in the energy field. The study also aims to clarify how this can be applied to raise the efficiency of a combined cycle gas turbine station through a methodology that combines the description, application and analysis of methodologies using simulation technology. The importance of the study is due to the importance of the topic itself, which is achieving sustainability in the energy field. The study gains another importance, which is that it is an essential literary reference that can be relied upon by researchers and those working in gas turbine plants (Wheida, E., & Verhoeven, R. 2007).
The study aims to raise the efficiency of the Tobruk Turbine station located in northern Libya, where the Tobruk station was studied. According to the actual data and readings of the station, the turbine station used is a model station... produced by the American company General Motors, with a capacity of185 megawatts. A decrease in the station's efficiency and performance was noted by using a heat recovery system from the exhaust gas in two ways: using a heat exchanger and using the combined cycle of the gas turbine (Phumpradab, K., et, al. 2009).
One of the most critical problems of the study was the technical complexity, as the heat recovery system requires a complex design and additional systems, such as heat exchangers or steam turbines, if used in a combined cycle. This increases the construction, operation and maintenance costs, which may affect the project's feasibility. Also among the most critical challenges is the impact on the environment, as directing the world's gas to another system may lead to an increase in harmful emissions, which requires other equipment and other tasks to control emissions and maintain Environmental standards in addition to the high operating and maintenance costs after that (Gonzalez-Salazar, M. A., Kirsten, T., & Prchlik, L. 2018). Achieving the highest efficiency using exhaust gas requires advanced technologies, such as improvements in the design of thermal systems or steam turbines, and this means relying on advanced technology that may not be available or appropriate in all environments (Pratson, L. F., Haerer, D., & Patiño-Echeverri, D. 2013).

II. Overview of the literature review and analysis

This section will present the most important basic concepts, analytical theories and terms used in the study. We will also provide a historical overview of gas turbines and their development methods. In addition to previous studies related to the subject of the study, the objectives, results, and methodologies used in these studies will be presented, and the points of difference and agreement between these studies and the current study in terms of results and conclusions will be studied.

A. A historical overview of gas turbines and methods of their development.

Gas turbines were previously defined as heat engines that convert the chemical energy in fuel into thermal or mechanical energy used to rotate a turbine to generate electricity. Turbines emerged at the beginning of the first century, and their concept was very simple, not exceeding that it is a straightforward machine used as a mill for air or to rotate certain wheels. Still, it faced many difficulties due to the lack of technologies that help withstand the high temperatures resulting from fuel. Then, after World War II, turbines began to develop rapidly, especially after Brayton's work on the ideal cycle for gas turbines. In the era of globalization and computer science, programming, and artificial intelligence, gas turbines have developed amazingly after using simulation programs and numerical verification methods (Volponi, A. J. 2014).

B. Thermal Analysis of Gas Turbine Unit

To study the distribution of heat energy generated by fuel combustion in the gas turbine unit of a power station and then determine the heat released to the environment by the exhaust gas and electric energy produced by the unit, the thermal analysis unit must be completed. Therefore, in the present study, the thermal analysis of the gas turbine unit under rated conditions was carried out using the following method, which is based on the analysis of the main components of the gas turbine unit (per 1 kg of inlet air into the compressor) and the blade cooling system as a gas turbine unit independent expansion circuit treatment of internal cooling air(Pacca, S., & Horvath, A.2002). Therefore, the process of performing a thermal analysis of a gas turbine unit according to this method can be summarized as follows:

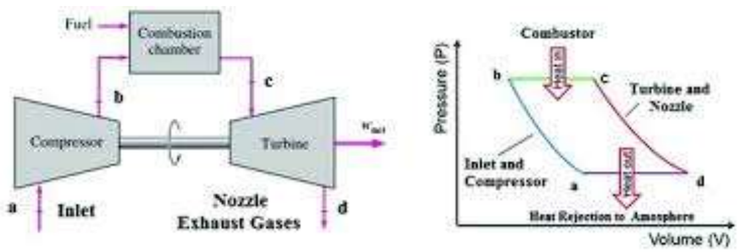

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Figure (2): shows the Brayton Cycle

Available networks for gas turbine plants (*Rao, A. D., & Francuz, D. J. 2013).* (W_{NetGT}) can be obtained from Where:

$$W_{NetGT} = W_T - W_C \quad (1)$$

$$W\_NetGT = m\_a \lfloor(((1 + 1/(A / F))\ C\_P\ T\_$$

$$(1 - r\_PT\verb|^|(K\_(g-1)/K\_g\ )\ )\ )\xi\_T -$$

$$C\_Pa\ T\_1\ (r\_Pc\verb|^|(K\_(g-1)/K\_g\ ) - 1))\ /\ \xi\_c \rfloor \quad (2)$$

Where:

rC: P2 / P1, rT: P3/ P4, m.a: Air mass flow rate, CPa: Air specific heat at constant pressure (Ol'khovskii, G. G,2016)., Ka: Air-specific heat ratio, Kg: gases specific heat ratio, CPg: gases specific heat at constant pressure, T3: Temperature of gases after the combustion chamber, A/F: Air to fuel ratio, rc: Compressor isentropic efficiency, rT: Gas turbine isentropic efficiency.

1.The heat gain (Q_{add}) from the combustion of fuel in the burner can be calculated using the following equation: -

$$Q_{add} = \dot{m}_f \times C_V \times \xi_{CC} \quad (3)$$

Where: CV: Fuel calorific value, CC: Combustion chamber efficiency, m.f: Fuel mass flow rate.

2.The thermodynamic efficiency of the gas turbine cycle can be calculated from thefollowing equation: -

$$\frac{W_{NetGT}}{Q_{add}} \quad (4)$$

η = 1-(TH/TL) (5)

This section will present the applied methodology of the study (Eti, M. C., Ogaji, S. O. T., & Probert, S. D.2006),

Figure (6): shows simulation for actual cycle

which is essentially a combination of several methodologies. The descriptive methodology, through which we will refer to the description of the procedures and their theories; the quantitative methodology, through which the data will be presented and arranged; and the analysis and comparison methodologies, through which we will analyse Data and results and comparison between them to determine the optimal conditions and factors to improve and raise the efficiency of plants (Rice, I. G. 1980). In this section,

A.the applied framework of the study

The applied framework of the study will be presented, followed by the steps, the first step will be collecting, filtering, and organizing data. Academic and practical data will be collected from previous studies, scientific references, the dissertation supervision staff, as well as databases from the Internet

Table (1): shows the data of the power plant.

S/N	Element	Value
1	Station name	Tobruk power plant
2	Turbine type	GT 13E2 gas power plant:
3	Number of turbines	3
4	Manufacturer:	General Electric
5	Fuel used	Nutral gase
6	Turbine capacity (MW)	185 m watt
7	Duty cycle efficiency	34%
8	Air flow rate	650kg/s
9	Carbon dioxide emissions tons per h	500kg/kwper h
10	Operating hours (hours)	24
11	Turbine entry temperature	: 1300°C
12	Air pressure ratio	15:1
13	Number of turbine stages:	3
14	Number of air compressor stages	13
15	Gas exit temperature	550°C
16	Compressor efficiency:	%85

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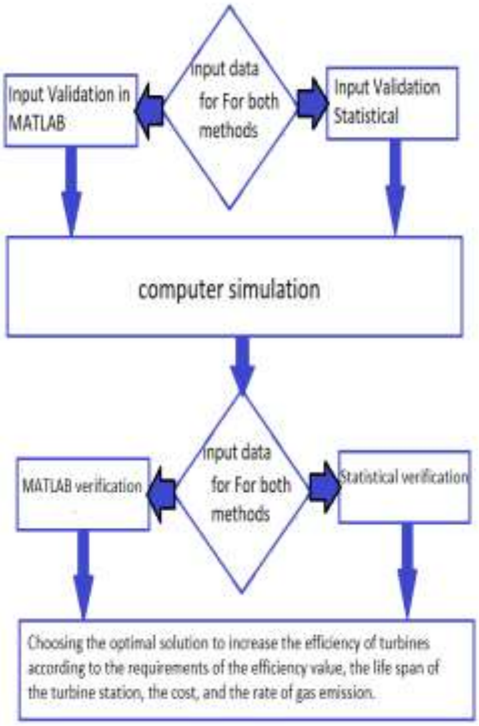

Figure (3): shows Flow chart for application stages

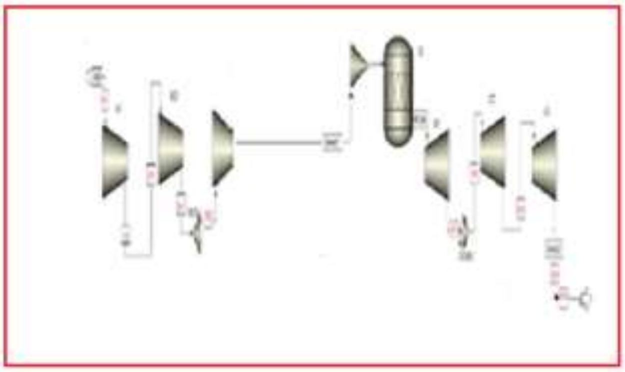

Figure (4): shows simulation for actual cycle

II. SIMULATION OF POWER SYSTEM MODEL

The ASPEN program has been able to perform simulations related to increasing the efficiency, whether using the reheating method. Calculate all variables, including temperatures, pressures, enthalpy, entropy, and efficiencies. The results were verified using MATLAB and ANSYS., ANSYS is one of the distinguished programs in calculations related to thermodynamics, as the development depends on a percentage of hot exhaust gas, and the Aspen program is one of the distinguished programs in simulating turbines. In order to obtain the advantages of the two programs together, the results of mechanical efficiencies and flow charts were extracted using the Aspen program. As for temperatures and pressures, they were verified using the ANSYS program.

A. Increasing efficiency by using combined cycles.

In this way the efficiency of the turbine station will be increased only by using the combined cycle

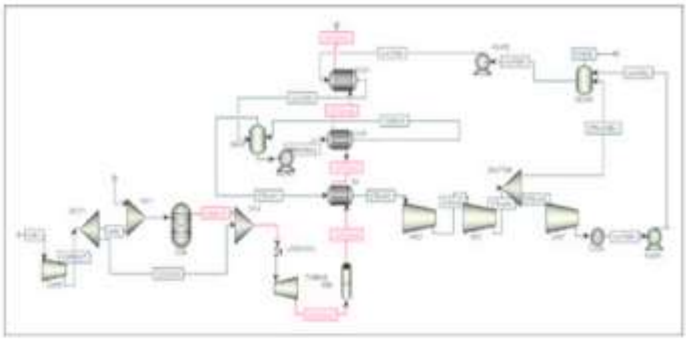

Figure (5): simulation for using combined cycles.

1. Gas turbine:

$$W\_t = Cp * T1 * \left(1 - r^{\frac{\gamma-1}{\gamma}}\right) (6)$$

Where:

W_t: Theoretical work of gas turbine (kJ/kg), Cp: Specific heat of gas at constant pressure (kJ/kg. K), T1: Gas entry temperature into the turbine (K), r: pressure ratio (P2/P1), γ: heat capacity ratio (Cp/Cv)

Isentropic efficiency:

$$\eta\_t = (W\_t / h1) * 100\% \ (7)$$

Where:

η_t: Gas turbine isentropic efficiency (%), h1: Enthalpy of gas entering the turbine (kJ/kg)

2. Steam generator:

Calculation of heat transferred:

$$Q = m\_s * (h\_s2 - h\_s1) (8)$$

Where:

Q: Heat transferred from exhaust gases to water (kJ/s), m_s: water flow rate (kg/s), h_s1: Enthalpy of liquid water upon entry (kJ/kg), h_s2: Enthalpy of saturated steam at exit (kJ/kg), h_s2: Enthalpy of saturated steam at exit (kJ/kg)

3. Steam turbine:

Theoretical work:

$$W\_s = h\_s2 - h\_s3 \ (9)$$

Where:

W_s: Theoretical work of steam turbine (kJ/kg), h_s3: Enthalpy of steam after expansion in the turbine (kJ/kg)

4. Overall efficiency of the cycle:

Thermal efficiency:

$$\eta_{th} = \frac{(W_t + W_s)}{Q_{in}} (10)$$

Where:

η_th: Thermal efficiency of the cycle (%), Q_in: Heat added to

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the cycle (kJ/s)

5.The general model for calculating service life due to thermal corrosion is:

t=A σ n e^Q RT (11)

Where:

t: service life., A and n: constants depending on the material.

σ: mechanical stress, e^Q: activation energy for corrosion.

R: ideal gas constant, T: absolute temperature (Kelvin).

6.Total cost: To calculate the cost increasing the efficiency:

$$Total_{cost} = Cost_{efficiency} + Cost_{fuel} + Maintenance\_cost \quad (12)$$

Table 2: Marginal values of costs according to ((2004) Engineering data book. FPS)

S/N	COST ITEM	Range Assumption
1	Preventive maintenance	1-2 % of FC 1.5 % of FC
2	Maintenance and repair cost (MTC)	5-10 % of FC 5 % of FC
3	Operating Labour cost	(OLC) 6-20 % of TCI 15 % of TCI
4	Laboratory charges	5-23 % of OLC 10% of OLC
5	Supervision cost	10-20 % of OLC15 % of OLC
6	Plant overhead cost	10-15 % of FC 7% of FC
7	Capital charges	5-10% of FC 6% of FC
8	Insurance	0-2 % of FC 1 % of FC
9	Local taxes	0-1 % of FC 1 % of FC
10	Raw material cost	10-50 % product cost
11	Patent and Royalties	10-20 % of MTC
12	efficiency increase	10-20 % of MTC

Table 3: Marginal values of costs according to ((2004) Engineering data book. FPS)

S/N	fuel COST	Range Assumption
1	natural gas cost	40-50% of OLC 45% of OLC
2	Diesel	50-60% of OLC55% of OLC
3	Coal	25-40% of OLC33% of OLC

<u>Increase efficiency by using reheating through a heat exchanger</u>

Despite the importance of this method, there are many Challenges facing the reheating process:

•Construction cost: A reheat system requires a large initial investment to build the necessary heat exchanger, piping and connections.

•Complex maintenance: The system requires regular and specialized maintenance to ensure its efficiency.

•Pressure losses: Passing exhaust gas through the heat exchanger may cause pressure losses, affecting turbine performance

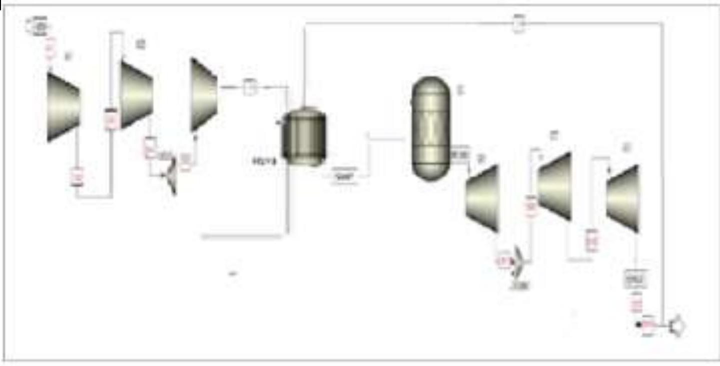

Figure (8): simulation for using reheating through a heat exchanger

$$W\_t = Cp * T3 * (1 - r^{\wedge}((\gamma - 1)/\gamma))$$

Where:

T3: Temperature of air entering the combustion chamber after heating in the heat exchanger (K), The efficiency of isotropic is the same

The heat equation is calculated from the following rate:

$$Q_{ex} = m_a * Cp_a * (T3 - T2) = m_g * Cp_g * (T4 - T5) \quad (13)$$

Where:

Q_ex: Heat transferred in the heat exchanger (kJ/s), m_a: Air flow rate (kg/s), Cp_a: Specific heat of air at constant pressure (kJ/kg. K)

T2: Temperature of air entering the heat exchanger (K), T3: Temperature of air leaving the heat exchanger (K), m_g: Flow rate of exhaust gases (kg/s), Cp_g: Specific heat of exhaust gases at constant pressure (kJ/kg. K), T4: Temperature of exhaust gases entering the heat exchanger (K), T5: Temperature of exhaust gases leaving the heat exchanger (K)

Overall efficiency of the cycle:

Thermal efficiency:

$$\eta_{th} = \frac{(W_t + W_s)}{Q\_in}$$

Where:

η_th: Thermal efficiency of the cycle (%), Q_in: Heat added to the cycle (kJ/s)

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V. results and Discussion

Output:

```
Net efficiency: 32.479%
Exhaust flow rate: 541.13 kg/sec
Exhaust temperature: 486.37 °C
```

Figure (7): shows the actual output OF power plant using MATLAB code.

The results show that the actual efficiency of the station as a whole is 32%. For several reasons, as according to the producing company's data, the efficiency should be 34%, but considering the duration of operation and the lack of good maintenance programs and changing the fuel from natural gas to diesel, the result of this was that the efficiency decreased to 32.4%.

A. Extracting outputs for Combined Cycle case:

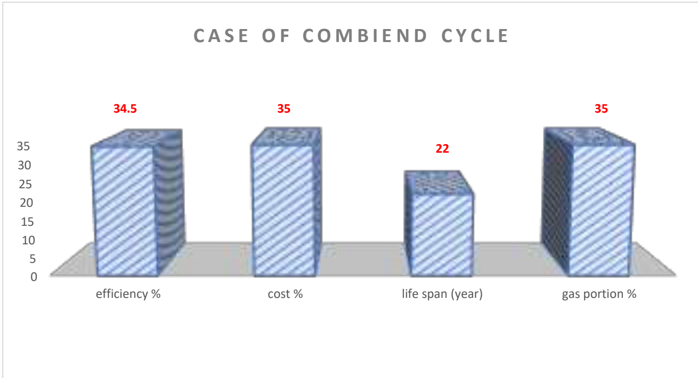
In this section, the results of the case will be presented:
The efficiency of the comprehensive station will be increased by raising the efficiency of the turbine station only by using the combined cycle, by using only a percentage of the exhaust gas, and determining this percentage that achieves the best possible efficiency of the turbine station, the lowest operating costs, the lowest percentage of harmful gas emissions, and the highest lifespan. Default for station.

Output:

```
Best net efficiency: 34.5%
Best reheating percentage: 35%
Best operating conditions:
Reheated turbine inlet temperature: 734.92 °C
Turbine outlet temperature: 516.15 °C
```

Figure (8): shows output of Combined Cycle case.

The figure shows an increase in the efficiency of the total station to reach 34.5%, i.e. an increase of 2.1% over the actual efficiency of the station.



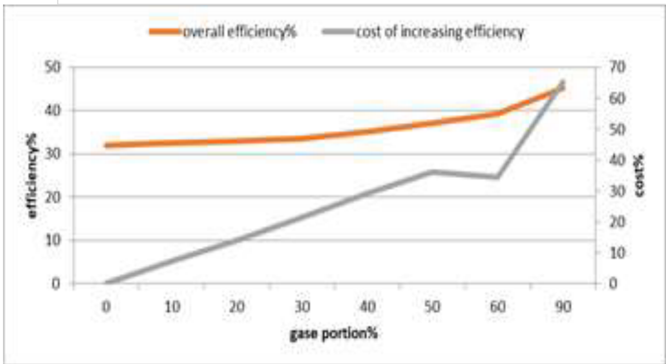


Figure (9): shows the relationship between the percentage of recovered gas, the operating cost, and the efficiency. Combined Cycle case.
It is clear that the relationship is direct between the percentage of recovered gas, the operating cost, the percentage of recovered gas, efficiency, the percentage of recovered gas, and the gas temperature.

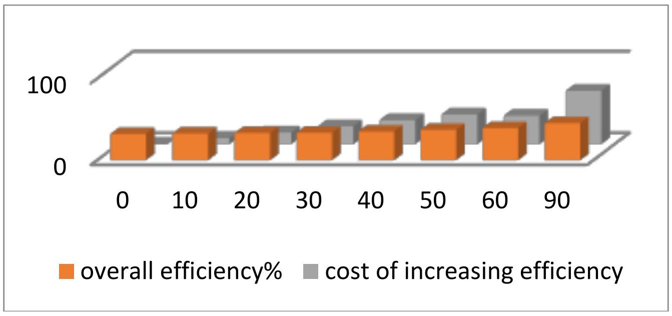


Figure (10): shows relation between gas portion, efficiency, and cost portion. Combined Cycle case.

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Output:

```
estimated life span is 22 years
```

Figure (11): shows the life span in Combined Cycle case
As the outputs of the Met lab program show, the default command for the station is 22 years.

B. Extracting outputs for reheated Cycle case:

In this section, the results of the case will be presented:
The efficiency of the comprehensive station will be increased by raising the efficiency of the turbine station only by using the reheated cycle, by using only a percentage of the exhaust gas, and determining this percentage that achieves the best possible efficiency of the turbine station, the lowest operating costs, the lowest percentage of harmful gas emissions, and the highest lifespan. Default for station.

Figure (12): shows output of the. Combined Cycle case.

It is clear from the figure that the highest efficiency was 34.5% at a recovered gas percentage of 35% at a cost of 35% of the total station cost.

Output:

```
Best net efficiency:33.1%
Best reheating percentage: 55%
Best operating conditions:
Reheated turbine inlet temperature:  755   °C
Turbine outlet temperature: 501    °C
```

Figure 13: shows output of reheated Cycle case.
The figure shows an increase in the efficiency of the total station to reach 33.1%, i.e. an increase 0.7 % over the actual efficiency of the station.

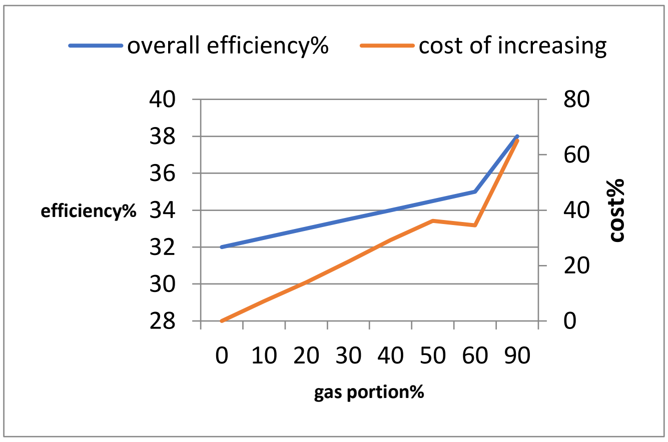

Figure (14): shows the relationship between the percentage of recovered gas, the operating cost, and the efficiency. reheated Cycle case.

It is clear that the relationship is direct between the percentage of recovered gas, the operating cost, the percentage of recovered gas, efficiency, the percentage of recovered gas.

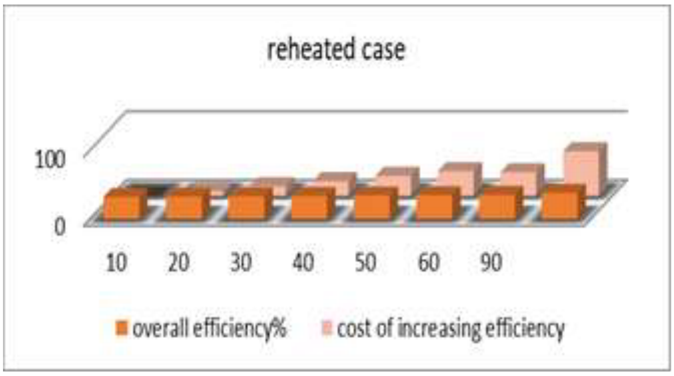

Figure (15): shows relation between gas portion, efficiency, and cost portion. reheated Cycle case.

output:

```
life span is 22 years
```

.

Figure (16): shows the life span in Combined Cycle case
As the outputs of the Met lab program show, the default command for the station is 23 years.

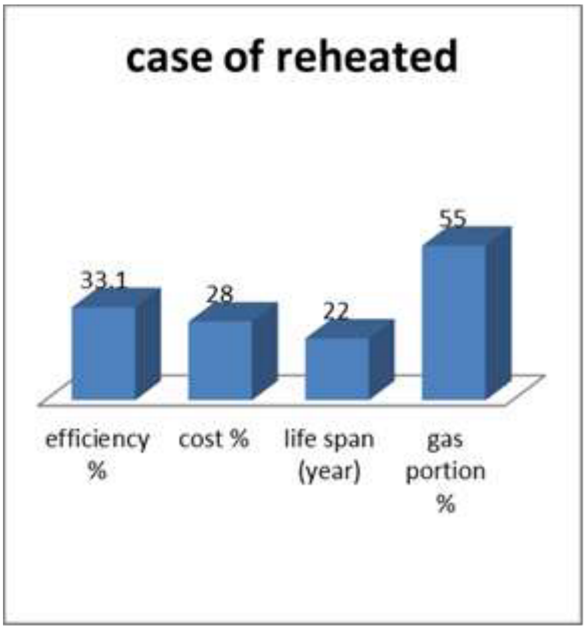

figure (17): shows output of the. reheated Cycle case.

It is clear from the figure that the highest efficiency was 33.1% at a recovered gas percentage of 28% at a cost of 55% of the total station cost.

VI. CONCLUSION

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One of the most important conclusions that can be drawn from this study is that the inverse relationship between the exhaust temperature and the efficiency of the station and the direct relationship between the use of a percentage of the exhaust gas in the heating equipment are two important factors that use the exhaust gas to raise the efficiency of gas turbine stations. However, the circumstances must be considered (Caramellike, R., & Milazzo, A. 2005). The optimum operation, including the cost of raising efficiency and the requirements for operating the station, as the higher the exhaust temperature, the lower the efficiency of the station, and vice versa. Also, because the station's efficiency can be increased by using a certain percentage of exhaust gas, this percentage depends on the operating conditions, maintenance operations, etc. Therefore, the percentage of global gas used to increase efficiency varies under certain operating process conditions. It also varies with the purpose the station is used for, whether it is used to generate electricity in general, to desalinate water (Zhang, G., Zheng, J., Yang, Y., & Liu, W. 2016), or for other purposes. Among the most important conclusions is that simulation programs are very effective tools for analysis and evaluation. The data on turbine stations provides flexibility and accuracy. The final decision is that the efficiency of the stations can be increased, but by small percentages that do not exceed 2 to 4% and depend, as we previously said, on the operating conditions.

VII. Recommendation.

One of the most important recommendations that can be presented through this study is the necessity of achieving a balance between efficiency, cost, and harmful gas emissions. As well as developing research related to this topic through the use of artificial intelligence techniques and the development of new methods that can lead to improving the properties of materials used in improving turbines, in addition to integrating gas turbines with renewable energy sources, the sun and wind, to achieve sustainability in the field of energy.

Declaration of competing interest

I declare that there is no competing interest with any other authors and that there is no interest or benefit that influenced the results of the research.

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