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IMPROVING THE EFFICIENCY OF SEAWATER DESALINATION AND POWER GENERATION GAS TURBINE PLANTS

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A B S T R A C T

In light of the water and energy crises around the world in general and Libya in particular, and the constant endeavor to provide visions and solutions to resolve these crises. This study is one of the efforts to contribute to this topic, as the study aims to increase the efficiency of a desalination plant that operates with gas turbines. The study aims to increase the efficiency of the total plant (the desalination plant that operates with turbines) by using part of the exhaust gas resulting from operating the turbines in the presence of a combined cycle. The study also aims to clarify how this can be applied to raise the efficiency of the total station, taking into account achieving the highest efficiency, the lowest cost rate, and the lowest environmental pollution rate while maintaining the default for the station. This was done through different methodologies, as the descriptive method was used. To describe the variables and data, the quantitative and scientific methodology in collecting data, determining the applied framework, and the comparison methodology in comparing the results. The analysis methodology was also used to analyze and evaluate the results. The results indicated that the best way to raise the station's overall efficiency is to use the combined cycle with a higher percentage of exhaust gas. The obtained efficiency is 34.5%, with a total cost of 20% and an emissions rate of 35%, while maintaining the plant's life span as 35% of the exhaust gas was used.

Keywords: desalination plant; Gas turbines; exhaustive Gas; combined cycle; efficiency; pollution rate; life Span.

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1. Introduction

Sustainability in the energy sector refers to the utilization of energy that fulfills the requirements of present generations without jeopardizing the ability of future generations to satisfy their energy demands. It can be defined in another way as the balance between economic, social, and environmental needs in energy, a balance between the present and the future. Sustainability in water entails the responsible and judicious management of water resources to guarantee their availability for present generations without infringing upon the rights of future generations. [1] This management includes a set of procedures, strategies, and policies that aim to balance the increasing need for water and the preservation of aquatic ecosystems. In light of the urgent need for the conservation of the environment, reducing carbon emissions, ensuring energy security, and achieving sustainable development, many studies are being conducted on this topic [2].

The study aims to raise the overall efficiency of a gas turbine station powered by natural gas in the Tobruk region in Libya by improving productivity, whether water productivity or energy productivity, by using part of the exhaust gases, which usually have a high temperature, and benefiting from this heat by using the combined cycle. The highest efficiency is obtained, preserving the life span and achieving the difficult equation, which is the lowest cost, the lowest rate of polluting emissions to the environment, and maintaining the life span of the station as a whole. In any system [3], when thinking about raising the efficiency of this system, this system is composed of several components, as in the case of a desalination plant that operates with gas turbines. There are multiple possibilities for increasing efficiency. All elements of the system may be raised, or certain major components may be raised, or even the efficiency of a single element may be raised until, in the end, we obtain the highest efficiency that can be obtained with the lowest cost, the lowest rate of gas emissions, and maintaining the life span [4].

In this study, this strategy was implemented, where three methods were compared to determine the best way to achieve the desired goal, which is to achieve the highest efficiency of the station, the lowest cost, and the lowest emissions rate while maintaining the life span of the station. The first case was to

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raise the efficiency of the turbine station only, and the second case was to raise the efficiency of the desalination plant only, which is approximately 700 meters away from the gas turbine plant. The third case is to raise the efficiency of the turbine and desalination plants together, as shown in figure 1.

The study's actual and real challenge is achieving the highest possible efficiency at the lowest possible cost and maintaining the station's life while achieving the lowest rate of harmful gas emissions that pollute the environment. This is done while using part of the exhaust gas and controlling it. However, this requires complex and difficult techniques due to the scarcity of studies and research. Which are the four variables linked to the percentage of exhaust gas that can be used: life expectancy, emission rate, highest efficiency, and lowest cost? The real challenge in the mission is to achieve the highest possible efficiency at the lowest possible price and to maintain the station's lifespan on the one hand. On the other hand, what is required is to raise the total efficiency of the station, which includes many components, including the desalination plant and the turbine station, and the presence of a large distance of more than 700 meters between the two stations [5]. The importance of the study is due to the significance of the topic itself, which is achieving sustainability in the field of energy and water by raising the efficiency of a desalination plant operating with gas turbines, where the highest efficiency is obtained. The lowest cost is achieved to increase this efficiency and achieve the lowest harmful gas emissions while maintaining the plant's life span. Through simulation methodology, the Aspen programs are used in addition to MATLAB to achieve and determine the best and most optimal conditions to raise the efficiency of the water station that operates with gas turbines [6].

2. Basic concepts and analytical theories

In this part of the study, some basic concepts and analytical theories related to the use of a percentage of exhaust gas to increase the efficiency of gas turbine desalination plants will be presented so that the study will be more effective and flexible [7].

2.1. Basic concepts

Combined Cycle Power Plants (CCPP) are more efficient.

More efficient than GT plants, hot exhaust from the GT generates steam for a second generator, enabling combined cycle plants to convert about 40% of fuel energy into electricity. Typically used to meet medium demands, these plants produce lower NO_x and CO_2 emissions than GT plants [8].

Cheat and power (CHP) systems use recovered heat in processes such as heating and desalination, reducing transmission losses and doubling the efficiency of fossil fuel plants. These systems reduce costs and emissions and improve service quality and reliability [9].

2.2. Working principle

A combined cycle power plant functions by integrating the initial phase of the Brayton cycle with the Rankine cycle, as depicted in figure 2. During the Brayton cycle, the air is entropically compressed in an air compressor and subsequently directed to the combustion chamber, where it is heated through fuel combustion. The resultant hot gas traverses the turbine blades, producing electricity, while the exhaust is directed to a heat recovery steam generator (HRSG). In the Rankine cycle phase, the steam generated by the HRSG acts as the working fluid, which is routed to the steam turbine for additional electricity generation. The exhaust from the steam turbine is then condensed into water within the condenser and recirculated to the steam generator via a water pump. as shown in figure 3 [11, 12].

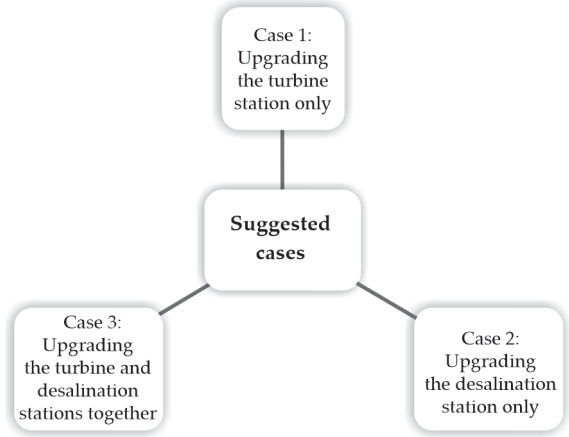


Fig. 1. Shows the suggested cases to increase the total efficiency of the station

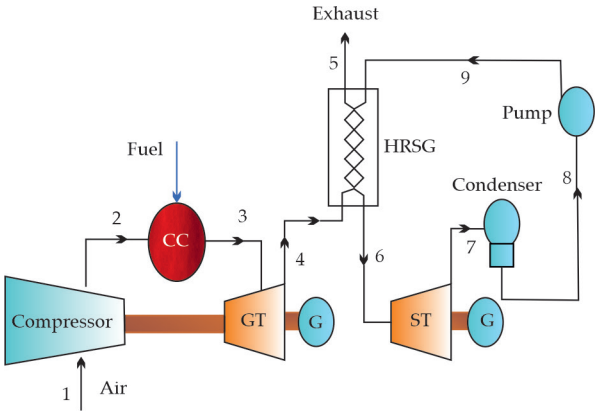


Fig. 2. Shows (CCPPS)

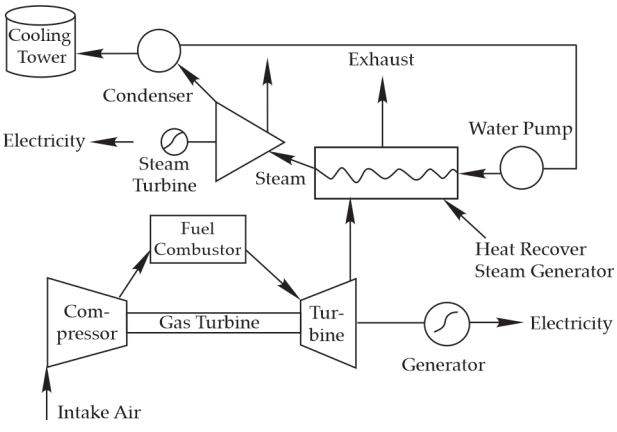


Fig. 3. Operational theory of single pressure CCPP

2.3. Thermal analysis of gas turbine unit

A thorough thermal analysis is essential to assess the distribution of heat energy generated from fuel combustion in a power station's gas turbine unit and quantify the heat released to the environment by exhaust gases and the electric energy produced [13]. In this study, thermal analysis of the gas turbine unit was conducted under rated conditions using a method focused on analyzing the primary components of the gas turbine unit (per 1 kg of air entering the compressor) and the blade cooling system as an independent expansion circuit for internal cooling air treatment. This approach provides a systematic way to perform a comprehensive gas turbine unit thermal analysis [14].

3. Method and methodology

A model was formulated and developed using a methodology based on accurate description, scientific analysis, and comparison that can predict and diagnose eye diseases. The model was trained to conclude the applied methods of the study, which is a combination of several methodologies. The descriptive method, through which we will refer to the description of the procedures and their theories; the quantitative methods, through which the data will be presented and arranged; and the analysis and comparison methodologies, through which we will analyze Data and results and comparison between them to determine the optimal conditions and factors to improve and raise the efficiency of desalination and generation plants. In this chapter, the applied framework of the study will be presented, followed by the steps [15].

According to the study's practical framework (fig. 4), the first step will be collecting, filtering, and organizing data. Academic and useful data will be collected from previous studies, scientific references, the dissertation supervision staff, and databases from the Internet. Data for the two stations will be obtained directly from the site and officials in my institution: energy and water. This data, which will be filtered in line with the principles of scientific research and reliability, as well as the actual conditions of the two stations, will then be organized into a framework that supports the steps of the study. After that, the data will be mathematically modeled in MATLAB as equations related to calculating efficiency, capacity, productivity, operating costs, and thermal calculations, whether for the quantities of exhaust gas used or for the operating stages of the desalination and operation plants. Through this modeling.

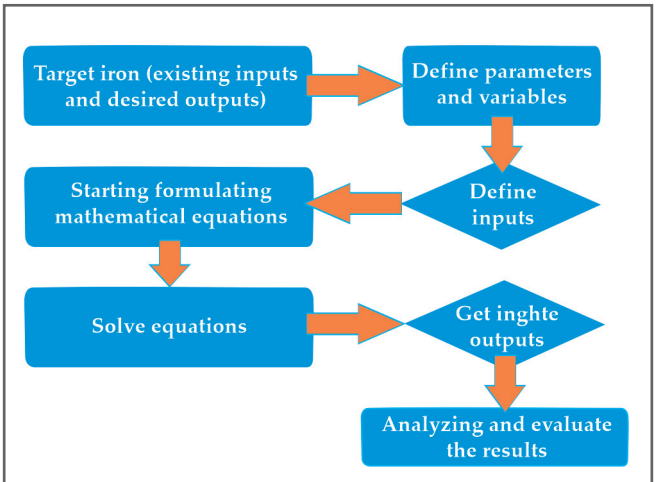


Fig. 4. Shows the applied framework for the study

3.1. Enhancing the efficiency of the gas turbine power plant with a combined cycle (case 1)

1. Gas turbine:

$$Wet = C_p \cdot T_1 \cdot (1 - r^{((\gamma-1)/\gamma)}) \quad (1)$$

where: Wet – Theoretical work of gas turbine (kJ/kg); C_p – Specific gas heat at constant pressure (kJ/kg. K); T_1 – Gas entry temperature into the turbine (K); r – pressure ratio (P_2/P_1); γ – heat capacity ratio (C_p/C_v).

Isentropic efficiency:

$$\eta_t = (W_t / h_1) \cdot 100\% \quad (2)$$

where: η_t – Gas turbine isentropic efficiency (%); h_1 – Enthalpy of gas entering the turbine (kJ/kg).

2. Steam generator:

Calculation of heat transferred:

$$Q = m_s \cdot (h_{s_2} - h_{s_1}) \quad (3)$$

where: Q – Heat transferred from exhaust gases to water (kJ/s); m_s – water flow rate (kg/s); h_{s_1} – Enthalpy of liquid water upon entry (kJ/kg); h_{s_2} – Enthalpy of saturated steam at exit (kJ/kg).

3. Steam turbine:

Theoretical work:

$$W_s = h_{s_2} - h_{s_3} \quad (4)$$

where: W_s – Theoretical work of steam turbine (kJ/kg); h_{s_3} – Enthalpy of steam after expansion in the turbine (kJ/kg).

4. The overall efficiency of the cycle:

Thermal efficiency:

$$\eta_{th} = ((W_t + W_s)) / Q_{in} \quad (5)$$

where: η_{th} – Thermal efficiency of the cycle (%); Q_{in} – Heat added to the cycle (kJ/s) [16].

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

$$t = A \sigma n e Q R T \quad (6)$$

where: t – service life; A and n – constants depending on the material; σ – mechanical stress; Q – activation energy for corrosion; R – ideal gas constant; T – absolute temperature (Kelvin), Total cost.

6. To calculate the cost of increasing the efficiency:

$$\text{Total cost} = \text{savings from Increased Efficiency} = \\ = (\text{Baseline Efficiency-New Efficiency}) \times \text{Fuel Cost} \times \\ \times \text{Energy Produced } \{\text{Savings from Increased Efficiency} \quad (7)$$

where: Investment Cost – The investment cost of new equipment or system modifications needed to increase efficiency, such as the costs of modifying turbines or installing additional steam generators; Operation Cost – he operational cost of modifications, which includes additional maintenance costs, fuel costs, and any additional cost of repairs or parts [17]; Savings from Increased Efficiency – Savings resulting from increased efficiency, which includes saving on fuel thanks to increased productivity and reduced waste.

3.2. Increasing the efficiency of the reverse osmosis plant (case 2)

In this case, the efficiency of the Desalination station will be increased by using only a percentage of exhaust gas and determining this percentage that achieves the best possible efficiency for the station, the lowest operating costs, the lowest percentage of harmful gas emissions, and the highest expected life of the station.

To calculate the efficiency of a desalination plant that operates with reverse osmosis, it is necessary to study several factors, including the quantity of treated water, the quality of the resulting water, energy consumption, and the efficiency of removing salts and impurities. There are several ways to measure general efficiency, as it can be calculated as the product of multiplying the energy consumption efficiency by multiplying the prohibition efficiency of the same salts by the product. Efficiency recovery ratio divided by 10000 [18].

1. Salt Rejection Efficiency

The salt removal efficiency is calculated using the following equation:

$$R=(1-C_pC_f)\times 100R \quad (8)$$

where: R is the rejection rate (salt removal efficiency) in percentage; C_p is the salt concentration in the produced water (permeability) in mg/L; C_f is the salt concentration in the feed water in mg/L.

2. Recovery rate

The recovery percentage is calculated using the following equation:

$$Y=Q_pQ_f\times 100Y \quad (9)$$

where: Y is the percentage recovery; Q_p is the produced water flow rate (permeability) in cubic meters/hour; Q_f is the feedwater flow rate in cubic meters/hour.

3. Energy efficiency

Energy efficiency can be calculated using the following equation:

$$E=\frac{P_{total}}{Q_p} \quad (10)$$

where: E is the specific energy consumption in kilowatt-hours per cubic meter of water produced; P_{total} is the total energy consumed in kilowatt-hours; Q_p is the amount of water produced in cubic meters.

4. Overall efficiency of the station

The overall efficiency of the plant can be calculated using the following equation:

$$\text{Overall Efficiency}=$$
$$=\frac{\text{Energy Efficiency Salt Rejection Efficiency Recovery Rate}}{10000} \quad (11)$$

5. The percentage of pollution and emissions are calculated from the following equation:

$$\text{Total pollution rate}=E\text{CO}_2+E\text{NO}_x+E\text{CO} \quad (12)$$

where: $E\text{CO}_2$ = Mass burned (kg) × Emission factor; $E\text{NO}_x$ = = Mass burned (kg) × Emission factor; ECO = Mass burned (kg) × Emission factor CO.

4. Results and discussion

4.1. Results of the actual station

The results show that the station's actual efficiency is 32%. According to the producing company's data, the efficiency should be 34% for several reasons. Still, considering the duration of operation, the lack of good maintenance programs and the change of fuel from natural gas to diesel, the efficiency decreased to 32.4% (fig. 5).

4.2. Results of case 1

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 rate of harmful gas emissions, and the highest lifespan. Default for station.

The figure 6 shows an increase in the total station's efficiency to reach 34.5%, i.e., a rise of 2.1% over the actual efficiency.

The figure 7 shows a comparison between the outputs

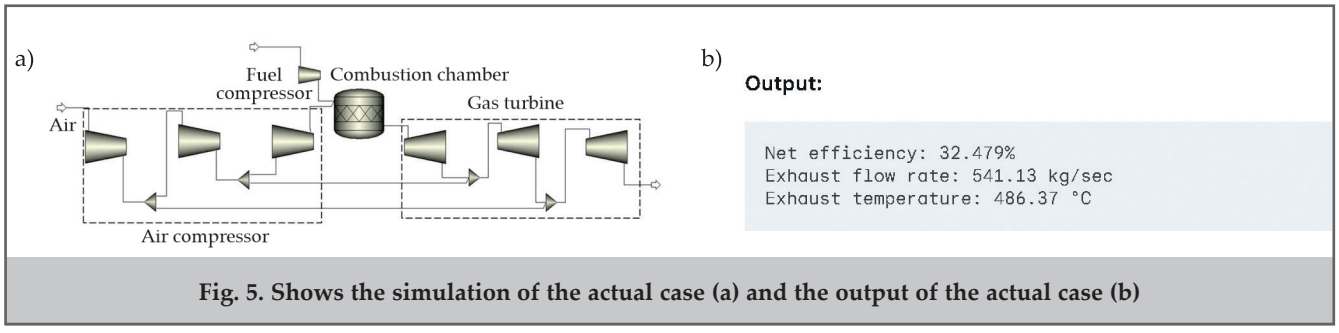


Fig. 5. Shows the simulation of the actual case (a) and the output of the actual case (b)

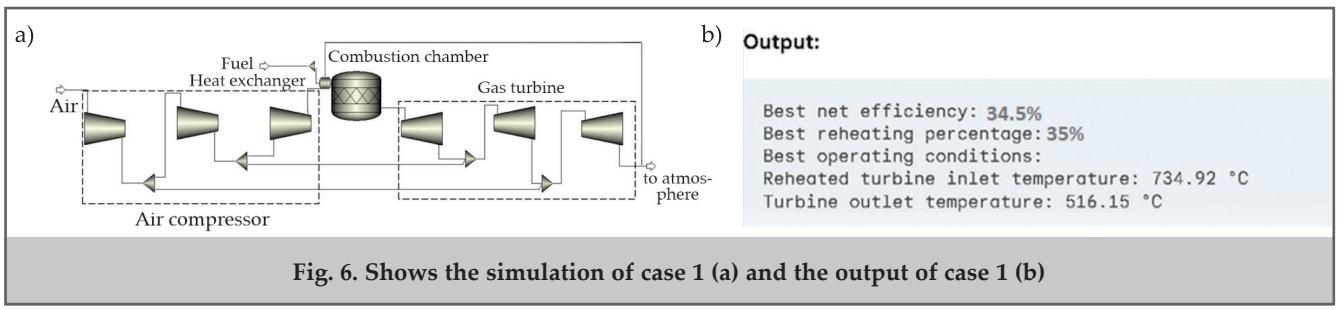


Fig. 6. Shows the simulation of case 1 (a) and the output of case 1 (b)

of the first case, where the optimal efficiency that could be obtained at the lowest cost, most extended lifespan, and lowest pollution rate was 34.5%, compared to a cost of 20% of the total cost of the station, compared to the percentage of recovered gas 35% (fig. 8). The default lifespan is 22 years, and the rate of harmful gas emissions is 35% (fig. 9).

4.3. Results of case 2

The simulation of increasing the overall efficiency of the station by increasing the efficiency of the desalination station only.

The figure 10 shows an increase in the total station's efficiency to reach 33.1%, i.e., a decrease of 0.7 % over the actual station's efficiency.

The figure 11 shows a comparison between the outputs of the first case, where the optimal efficiency that could be obtained at the lowest cost, longest lifespan, and lowest pollution rate was 33.1%, compared to a cost of 40% of the total cost of the station, compared to the percentage of recovered gas 55% (fig. 12). The default lifespan is 21 years, and the lowest rate of harmful gas emissions is 28% (fig. 13).

4.4. Results of case 3

The simulation of raising the overall efficiency of the station by raising the efficiency of the desalination station and the turbine station.

The figure 14 shows an increase in the total station's efficiency to reach 33.8%, a rise of 1.4% over the actual station's efficiency.

The figure 15 shows a comparison between the outputs of the first case, where the optimal efficiency that could be obtained at the lowest cost, longest lifespan, and lowest pollution rate was 33.8%, compared to a cost of 35% of the total cost of the station, compared to the percentage of recovered gas 35% (fig. 16). The default lifespan is 20 years, and the rate of harmful gas emissions is 33% (fig. 17).

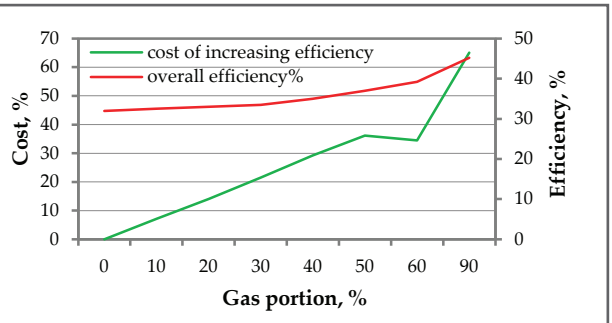


Fig. 7. Shows illustrate the correlation between the proportion of recovered gas, operating costs, and efficiency in a combined cycle (case 1)

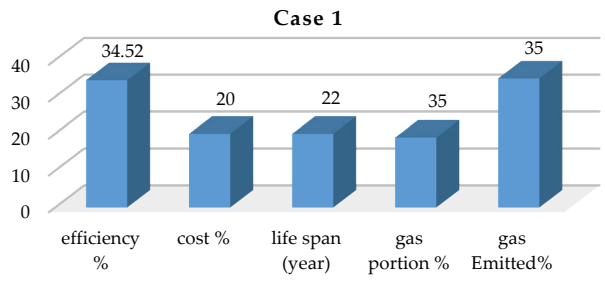


Fig. 8. Shows the life span in the combined cycle (case 1)

a) **Output:**

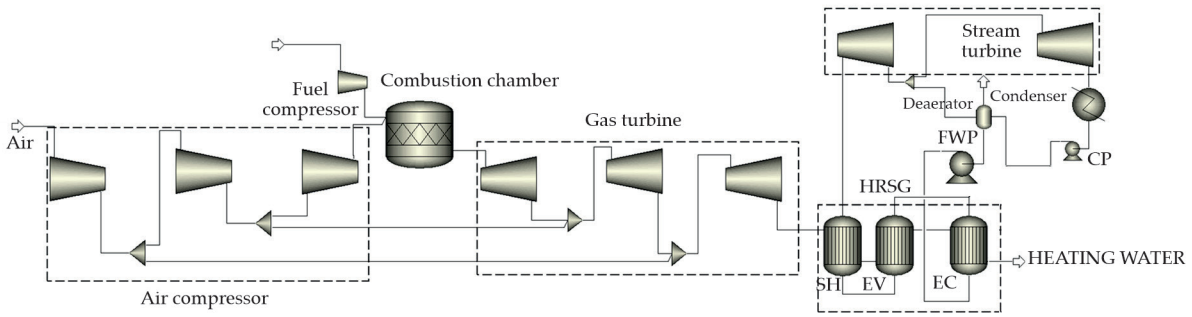
```
estimated life span is 22 years
```

b) **Output:**

```
Hazardous gas emissions rate: 35%
```

Fig. 9. Shows the life span in the combined cycle case 1 (a) and the Hazardous gas emissions rate of case 1 (b)

a)



b) **Output:**

```
Best net efficiency: 33.1%
Best reheating percentage: 55%
Best operating conditions: 28%
Reheated turbine inlet temperature:  755   °C
Turbine outlet temperature:    516 °C
```

Fig. 10. Shows the simulation of case 2 (a) and the output of case 2 (b)

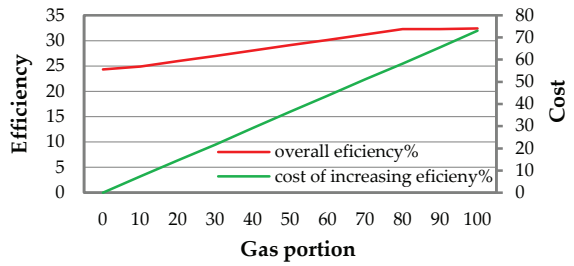


Fig. 11. Shows illustrates the correlation among the proportion of recovered gas, operational expenses, and the efficiency of case 2

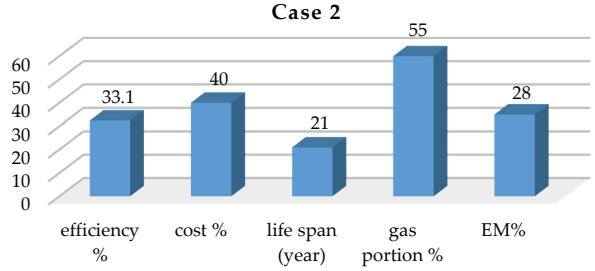


Fig. 12. Shows the output of case 2

a) **Output:**

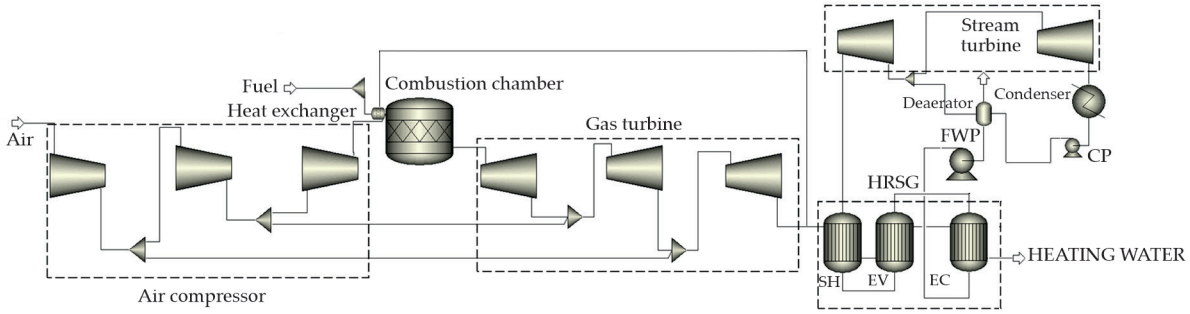
```
estimated lifespan :21 years
```

b) **Output:**

```
Hazardous gas emissions rate:28 %
```

Fig. 13. Shows the lifespan of case 2 (a) and the Hazardous gas emissions rate of case 2 (b)

a)



b) **Output:**

```
Best net efficiency: 33.8 %
Best reheating percentage:      35.00%
Best operating conditions:
Reheated turbine inlet temperature: 738.5   C
Turbine outlet temperature: 516     °C
```

Fig. 14. Shows the simulation of case 3 (a) and the output of case 3 (b)

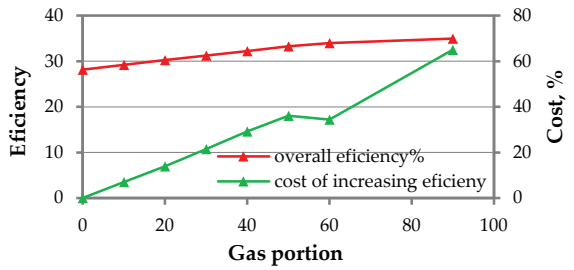


Fig. 15. Shows illustrates the correlation between the amount of recovered gas, operational costs, and the efficiency of case 3

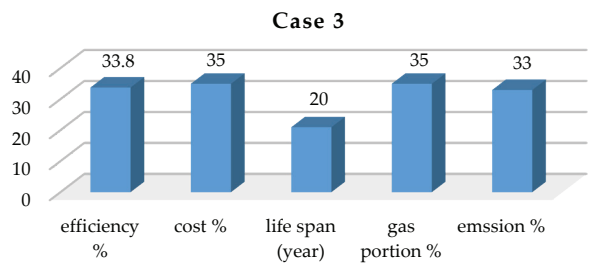


Fig. 16. Shows the output of case 3

a) **Output:**

```
estimated lifespan :20 years
```

b) **Output:**

```
Hazardous gas emissions rate:33 %
```

Fig. 17. Shows the life pan of case 3 (a) and the life span of case 3 (b)

Conclusions

Among the most important conclusions that were drawn from this study are the following:

1. In any mechanical system, it is possible to increase the efficiency of one of its components. We can obtain high efficiency and a low cost of raising efficiency while maintaining the life span of all components. But this ingredient must be chosen with great precision, as it must be the basic ingredient.
2. Raising the efficiency of the total plant by using a percentage of the exhaust gas in the desalination plant is very important to achieve sustainability and improve productivity in energy and water production, but raising the efficiency using the first case, which is raising the efficiency of the turbines only, and this may be due to the distance between the turbine plant and the desalination plant [19].
3. Circumstances must be taken into consideration. Optimal operation, including the cost of increasing efficiency and the station's requirements. The higher the exhaust temperature, the lower the station's efficiency, 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., the rate of global gas used to increase efficiency varies under certain operating process conditions. It also varies depending on the plant's purpose, whether it is used to generate electricity for water desalination or other purposes [20].
4. Simulation programs are very effective tools for analysis and evaluation. 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 mentioned previously, on the operating conditions. [21, 22].
5. Sustainability in energy and water guarantees a sustainable future, especially given the global energy crisis, the growing population, and the global water crisis in general and in Libya in particular.

Recommendation

One of the most important recommendations presented through this study is balancing efficiency, cost, and harmful gas emissions and choosing the correct method to raise the efficiency of the total station by selecting the most effective component. The nature of development and the purpose of increasing efficiency must be considered in choosing this component. Relying on modern and computerized technologies in such studies gives complete flexibility for dealing with, inferring, and analysing data. Also, one of the most important recommendations is the necessity of developing research related to this topic through artificial intelligence techniques and developing new methods that can improve the properties of materials used in improving turbines. In addition to integrating gas turbines with renewable energy sources, such as sun and wind, to achieve sustainability in the energy field.

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