Characteristics Study of Gas Turbine Performance with using surface geothermal energy: Case Study of Iraq

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Abstract. The study aims to improve the performance of the Al-Mansourieh gas power plant located in Iraq with a production (4 × 732 MW). By proposing a new (cooling/heating) system for air that entering the compressor by using groundwater (well water) as a renewable energy. FCU-Unit system operates according to the annual season. The calculations for the study was carried out in two stages, the first one included the thermodynamic analysis of the proposed system and finding the optimal design of space for heat exchanger. By another calculation, the amount of cooling water it was between (14.5 - 87) kg / s and the rate of airflow that reached (1.87m3/h). While the second part of this study included calculating the ideal and actual efficiency through the introduction of the actual conditions for the work of the turbine which took into account the pressure losses in the turbine inlet, exhaust pressure losses, combustion chamber pressure losses, combustion efficiency, and compressor and turbine efficiencies. Analytical results showed that heat efficiency and net capacity decrease in proportional to increasing air temperature. While the quantity of specific fuel consumed and the average heat increasing too with increasing air temperature. There for this study encouraging strongly that considering the air cooling before entering the combustion to improve the efficiency.

1. Introduction
The gas turbines are widely being used for producing electricity to own a large power-to-weight and power-to-volume ratio [1, 2]. The efficiency of gas turbines is also high when compared to piston engines, which make it easy to use in the field of transport such as ships, and aircrafts or industrial sectors. In the field of energy generation, gas turbines have often been chosen when fast start and shut down on demand is required. This is especially needed for compensating peak loads over the daytime [3]. Several studies and research have been noted that gas turbine cycle has low thermal efficiency ranged between 15-25% [1] which is highly affected by ambient temperature. The operating life is relatively short and consumes more fuel (compared with steam power plants). It has become necessary to improve the performance of this type of turbines to improve the efficiency. For example, one of the guaranteed and economical ways of cooling the air inside the turbine is by using cooling techniques of turbine entry like a “fog system” [4, 5]. Natural gas is a strong competitor to other fuels used to generate electricity. In Iraq after 2003 electricity production using gas reached 50% [6] by compared with other power plants.
Figure 1 and 2 show the geographical map of the distribution of these types of stations in the study area. The pollutant emissions from gas turbines are about one-third lower than using fossil fuels like (coal, clean coal converted to gas (coal gas) or heavy fuel oil) [7,8].

![Figure 1. Gas Stations in Service Southern Iraq - 2019 [9].](image1)

![Figure 2. Gas Stations in Service Southern Iraq - 2019 [9].](image2)

In southern Iraq, 21 gas stations have 75 gas units producing 4378 MWH of electrical energy. In contrast, 10 gas stations are located in middle Iraq having 59 gas units producing 4128 MWH.
Some serious research and studies carried out back to 1940 [8] and then developed between the 1960s and 1970s, particularly with the revolution of clean energy idea [9]. Groundwater for cooling purposes in Iraq is a recent experience that has been represented by experimental working to explore the possibility of using geothermal energy for air conditioning applications due to its great impact on providing alternative energy rather than polluting the environment.

_AL-Yasiri et al (2014) used groundwater to adapt the two classrooms in the Najaf Institute south of Iraq. It was found that it was very effective, especially if larger cooling systems were used to reach lower temperatures and average well water temperatures (August) at a depth of 75 meters equal to 20 °C [20]._ Al-Samari et al (2018) also found a very promising opportunity to use geothermal energy for air-conditioning applications in the Iraq climate. It has also been shown that well water temperature in Baghdad, Iraq is constant all season at around 24 °C and is the same as the current study area [18]. Tawfeeq (2016) shows that a geothermal heat exchanger's thermal efficiency in northern Iraq's Kirkuk city is the best efficient and renewable energy for heating facilities, but not alternative energy. The digital thermocouple reported the groundwater temperature at 100 m in (January) is 23.7 °C [21]. Based on the previous studies, it was determined that well depth was about 75 m, to achieve an ideal temperature of 20 °C. Intention to ensure that the study area contains sufficient quantities of water, a study H.Jalu et al (2017) proved that Al-Mansourieh contains (244 wells) with a discharge of (3-10.5 L / sec) [19]. This is encouraging and does not affect the storage of groundwater. The water must return to another well at a distance of 500 m after its departure from the planned cooling system to be injected into the ground to gain the benefits of it.

2. Gas stations in Iraq, problems and challenges

The operating conditions surrounding the gas turbine are important for its direct impact on the energy generated and the actual performance, such as weather factors (temperature, humidity, and air pressure), fuel type specifically used for fuel consumption (Consumed Specific Fuel SFC) and mechanical (operational effects). The ambient temperature has a direct effect on the air that enters and exits the compressor. In especially (at the study area) reaches more than 45°C during the summer [10]. This contradicts the design specifications of these units which depend on the 15 °C entry temperature, which are not available in Iraq except in the early morning hours and after midnight. This temperature rise adversely affects the compression ratio (stagnation pressure), which adversely affects the compressor’s efficiency. In comparison, fuel requirements (Fuel System) directly impact the energy supplied.

Iraq has significant natural gas reserves, but it imports gas from Iran that is suffering from many specification issues, including high sulfur content and high humidity, which caused many transportation problems and added another problem in electricity generation [11]. The key question becomes apparent about how the amount of air entering the compressor can be increased and the temperature reduced. But this issue is met with difficulties because of the mixture of air and fuel in the combustion chamber with a percentage of water (cooling) in the air, causing corrosion and mechanical problems, which demanded revolutionary solutions. The compression ratio is directly proportional to the temperature within the compressor and negatively impacts the turbine work.

The reduced ambient temperature increases the air that reaches the compressor and increases the flow rate, thus increasing the compressor’s operating requirements. There are works available that have previously shown that reducing the temperature of inlet air by one degree Celsius would increase the net energy output by around 1-2 present and increase the thermal efficiency by about 0.4-1 present [12,13,14]. In comparison, it induces the unit’s thermal efficiency loss of 0.1% and 1.47 MW. It rises in the summer to hit more than 20% of total efficiency [15] and that is showing in Figure 3 [16]
The pressure release impact extends to the area of flame recycling which causes a change in fuel flow rate, fluctuation in heat release rate, and flame retention. This presents a significant challenge for designers and researchers, as well as one of the most critical issues to be tackled in Iraq, as this form of power plant contributes to 49 per cent of Iraq's overall electricity supply [17]. Another such approach is to use "Geothermal Energy" to cool the air that reaches the gas turbine. What's promising is the water temperature in Iraq's well is around 25°C [18]. This system can also be used as a heat exchanger during different times of the year (June, July, August, and September).

3. Methodology.
In this study, the information of Al-Mansourieh gas power plant from April to August 2019 were recorded. Figure 4 shows the geographical location of the power plant.

Figure 3. Effect of inlet ambient temperature on the gas turbine performance [16].

Figure 4. Administrative map of Al-Mansourieh city [19].
The thermodynamic mathematical analysis depends on the equations that do in two parts:
1-The first one using analysis of the simple cycle of an open gas turbine (Actual cycle).
2-The second one deals with the analysis of the suggested method (Geothermal Energy).

4. Materials and Methods.
A gas power plant faces a lot of technical challenges for air cooling. Hence this approach works by using a heat exchanger to show the possibility of using geothermal energy to cool the air before it reaches the compressor. It is not a recent practice to use well water for purposes (cooling or heating).

4.1. Design and operation
Practical applications have shown that the air under the dew point is cooled (Fan Coil Unit) and produced "sensible heat" around (4-20) kW as a cooling load [22]. FCU mechanism for heating or cooling (Chilled Air) heat exchanger is mechanically operated. It is a simple heat exchanger unit, or 'coil' and fan. The heat exchanger surface area can be improved by increasing the number and length of the heat exchanger pipes, with the heat exchanger pipes reducing in diameter [23]. Despite the high cost, as typically they allow better use of the heat exchanger, the FCU (draw by units) is considered thermally superior of another kind. With good thermal insulation work to ensure they are not affected by the ambient temperature, particularly for feeding tubes and air ducts.

The current study suggested two schemes, the first shown in Figure 5, while the second included the actual system used in the fogging system (gas power plant). The proposed device works according to the annual season and uses it in the heat exchanger to use groundwater as a liquid (air cooling/heating), which can be a part of renewable energy. The new system is simple and does not require a compressive refrigeration device or any other means of cooling.

![Figure 5. Suggested Cooling System.](image-url)
4.2 Theoretical Design of Convection.

The heat exchanger surface area may be increased by increasing the number and length of the heat exchanger pipes, with the heat exchanger pipes decreasing in diameter. Due to its proximity to the study area [Al-Samari] [18] has approved the results of the experiment. Thus, it was determined that the temperature of the water coming out of the heat exchanger was +12 degrees from the one entering it. Before starting the proposed cooling system design, it is necessary to calculate the amount of water required for cooling. By combining the mass and energy balances the rearranging gives [24]:

\[
E_{in} = E_{out} \\
m_1 = m_3 = m_{water} \\
m_3 = m_4 = m_{air} \\
m_{water}(h_2 - h_1) = m_{air}(h_3 - h_4) \\
m_{water} = \frac{m_{air}(h_3 - h_4)}{(h_2 - h_1)}
\]

- \(h_1\) and \(h_2\) is shown equal enthalpy for the heat exchanger inlet and outlet water (kJ / kg) respectively in table 1.
- Water exists at both the inlet and the outlet as a compressed liquid.
- \(m.\) = mass flow rate (kg / sec).

| Table 1. Water properties at the efficiency of the heat exchanger is 85%. The properties taken from table 7 Compressed liquid water @ P=5Mpa [24] |
|-------------------------------------------------|
| T (water in) | 20°C | \(h_1=h_f1\) | 88.61 kJ/kg |
| T (water out) | 32.5°C | \(h_2=h_f2\) | 140.7 kJ/kg |

- And \(h_3\) and \(h_4\) equal enthalpy for the outlet and inlet air for the heat exchanger respectively (kJ/kg) can be calculated by the equation (4). And the results gathered in a table 2.

\[
\text{Air Enthalpy} = 1.007 \times \text{Air T in } ^\circ\text{C} - 0.026
\]  

| Table 2. A slightly more complex table with a narrow caption. |
|-------------------------------------------------------------|
| Properties for \(\text{Air}_{\text{in}}\) | Properties for \(\text{Air}_{\text{out}}\) |
| \(T_{^\circ\text{C}}\) | \(h_3\) (kJ/kg) | \(T_{^\circ\text{C}}\) | \(h_4\) (kJ/kg) |
| 30 | 30.184 | 25 | 25.149 |
| 35 | 35.219 | 25 | 25.149 |
| 40 | 40.254 | 25 | 25.149 |
| 45 | 45.289 | 25 | 25.149 |
| 50 | 50.324 | 25 | 25.149 |
| 55 | 55.359 | 25 | 25.149 |

- \(m_{air} = 150\) kg/s (according to the specifications of the Al-Mansourieh power plant (peck period).

However, the \(m_{water}\) of the cooling water are determined by input \((h_1, h_2, h_3, h_4\) and \(m_{air}\)) in equation (3) and the result can be shown in Figure 6.
Heat exchanger design needs to choose the type of material that used in construction. So, it became necessary to identify the specifications of groundwater in the study area that showed high levels of salts [25]. So, Al2Cu alloy has been chosen for its advantages in corrosion resistance and good heat conductivity [26]. By using equation (5), the heat convection area for the cooling process in the heat exchanger is calculated.

$$ Q = UA_s \Delta T_{lm,CF} F $$  (5)

• Where $Q$ = Rate of heat transfer in the heat exchanger. Its calculated by using properties of equation (1):

$$ Q = mC_p(T_{h,in} - T_{h,out})_{water} $$  (6)

$$ U = \frac{1}{h_{i} + h_{o}} $$  (7)

• $U$ is overall heat transfer coefficient in (W/m² °C). That is done based on $h$ the unit of the ordinary convection coefficient or by using table (13-1) [24]. Water-to-air in finned tubes (water in tubes) $U=30–60$ W/m² °C $U=34.8$ W/m² °C

• $\Delta T_{lm,CF}$ represented the log mean temperature difference and calculated by using equation (8):

$$ \Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln[\Delta T_1/\Delta T_2]} $$  (8)

$$ \Delta T_1 = T_{h,in} - T_{C,out} $$  (9)

$$ \Delta T_2 = T_{h,out} - T_{C,in} $$  (10)

From table 1:

• $\Delta T_1 = 17.5$ °C & $\Delta T_2 = 5$ °C

• Accordingly, $\Delta T_{lm} = 10$ °C

• $F$ represented the correction factor for the average mean temperature difference, its value ranges given (1-0.8)[16]depending on two temperature ratios P and R that equal 0.952[27].
Through compensation the following values in the equation (5):

\[ Q = 2727 \text{ kW}, \ U = 34.8 \text{ W/m}^2 \cdot {\degree}C, \ F = 0.952 \text{ and } \Delta T_{lm} = 10{\degree}C \]

The effective surface area \( A_s = 8.23 \text{ m}^2 \) and can be used to determine precisely the dimensions of the heat exchanger.

\[ GPM = \frac{TR \times 12000}{500 \times \Delta T_{water}} \]  \hspace{3cm} (11)

- Where \( TR = \) Tonnage of FCU = 5
- \( \Delta T_{water} = CHWR - CHWS = 17.5 \text{ }{\degree}C \)
- \( CHWR = \) Chilled water return from FCU
- \( CHWS = \) Chilled water supply to FCU
- \( GPM = 6.857 \text{ Or } 1.87 \) (m3/h / flow rate)

4.3 Heat Exchanger Design Guidelines.

After doing the calculations, heat exchanger specifications are defined by the table 3.

**Table 3. Heat exchanger specifications**

| Coil Units | FCU-Unit |
|------------|----------|
| OD (Outside diameter) 50 mm | Four-pipe fan coil units have two (2) supply pipes and two (2) return pipes. |
| Wall thickness 2 mm | fan coil unit concealed within the area that it serves. |
| Patterns Rotated Square | |
| Pt (Tube-Pitch) 62.5 mm | Fan Type Backward inclined airfoil |
| Pass partitions 6 tube | Typical Max Efficiency 90% |
| | Hydraulically Remote Ductwork Length = 300 m |
| | Fittings (50% of piping) Length = 152 m |

Figure 7 gives a clear and complete picture the required steps to explain the calculation for the suggestion a new (cooling/heating) FCU-Unit system.
Figure 7. Flow chart for the new System.

Start

Improve the performance of the Al-Mansourieh gas power plant

Using renewable energy by suggestion a new (cooling/heating) FCU-Unit system

FCU-Unit system operates according to the annual season

Fan Coil Unit

Use ground water as a liquid for air (cooling/heating)

Identify the specifications of groundwater in the study area

Air under the dew point is cooled, and produced "sensible heat" around (4-20) kW as a cooling load

Calculate the amount of water required for cooling @ (peck period)

Input $(h_1, h_2, h_3, h_4)$ and $(m_{air})$

$\sum M_{in} = \sum M_{in}$

If not improved

Design: FCU-Unit, Coil Units

Calculate thermal efficiency

If optimization

No

$\eta_{TH}$ with Ideal and Actual thermal efficiency

Compare $\eta_{TH}$ with Ideal and Actual thermal efficiency

End
5. Result and Discussions
The results can be divided into two parts, first part includes a study of the available heat exchanger in the Al-Mansourieh gas power plant, which represents the basic design according to the collected data which clearly shown in Tables (4, 5, 6, 7, 8 and 9).

### Table 4. Fuel Specifications (Gas Fuel).

| Composition         | Average | Symbol | Unit   |
|---------------------|---------|--------|--------|
| Methane             | 94      | CH4    | %vol   |
| Ethan               | 4.4     | C2H6   | %vol   |
| Propane             | 0.7     | C2H8   | %vol   |
| Butanes             | 0.04    | n-C4H10| %vol   |
| Hexanes             | 0.480   | C6H14  | %vol   |
| Heptane             | 0.57    | C7H18  | %vol   |
| Nitrogen            | 0.3     | N2     | %vol   |
| Carbon dioxide      | 0.0     | CO2    | %vol   |
| Hydrogen Supplied   | 4.1 PPM | H2S    | %vol   |
| Lower Heating Value | 0       | LHV    | kJ/kg  |
| Wobbe index         | 3       | Wlnet  | kJ/m3  |
| Density             | 1       | ρ      | kg/m3  |

### Table 5. Properties of input and output for turbine system.

| Pressure ratio (rp) | Exhaust Temp (°C) | Turbine Limiting Temp (°C) | Compressor Exit Temp (°C) | Inlet Ambient Temp (°C) | Reading Time |
|---------------------|-------------------|-----------------------------|---------------------------|-------------------------|--------------|
| 13.7                | 460               | 1045                        | 86.61                     | 41                      | 5:00 PM      |
| 13.3                | 458               | 1049                        | 75.41                     | 36                      | 7:00 PM      |
| 13.4                | 455               | 1043                        | 52.48                     | 25                      | 9:00 PM      |
| 13                  | 448               | 1028                        | 47.89                     | 23                      | 11:00 PM     |
| 12.8                | 450               | 1086                        | 41.44                     | 20                      | 1:00 AM      |
| 12.5                | 458               | 1090                        | 30.87                     | 15                      | 3:00 AM      |
| 12.3                | 464               | 1099                        | 47.11                     | 23                      | 5:00 AM      |
| 12.3                | 469               | 1105                        | 53.26                     | 26                      | 7:00 AM      |
| 11.7                | 473               | 1103                        | 66.64                     | 33                      | 9:00 AM      |
| 11.72               | 478               | 1086                        | 68.69                     | 34                      | 11:00 AM     |
| 12.71               | 485               | 1077                        | 86.84                     | 42                      | 1:00 PM      |
| 13.8                | 490               | 1073                        | 91.02                     | 43                      | 3:00 PM      |

### Table 6. Gas Turbine properties.

| DESCRIPTION          | UNITS | TAG NO   | SET.RANGE |
|----------------------|-------|----------|-----------|
| Turbine Limiting Temperature | °C    | CJP10DT902 | < 2300    |
| T fire               | K     | MBM10FT005 | < 2115    |
| Inlet ambient temp   | °C    | MBL10CT005 | 5.0 - 55  |
| Turbine intake temp  | °C    | MBA10CT165 | 5.0 - 55  |
| Compressor exit temp | °C    | MBA10CT170 | 200 - 450 |
| interdict temp       | °C    | MKA10CY015 | < 900     |
Table 7. Compressor properties.

| DESCRIPTION                             | UNITS | TAG NO  | SET.RANGE |
|-----------------------------------------|-------|---------|-----------|
| Gen. Cooling Air Inlet Temp No.1°C      |       | MKA10CT015 | < 55      |
| Gen. Cooling Air Inlet Temp No.2°C      |       | MKA10CT020 | < 55      |
| Gen. Cooling Air Outlet Temp            | °C    | MKA10CT025 | < 75      |
| Gen. Phase U Winding Temp               | °C    | MKA10CT030 | < 100     |
| Gen. Phase V Winding Temp               | °C    | MKA10CT035 | < 100     |
| Gen. Phase W Winding Temp               | °C    | MKA10CT040 | < 100     |
| Instrument Air Pressure                 | barg  | QFA20CP005 | 5.7 - 7.2 |
| Labyrinth Seal Air Pressure             | barg  | MBH10CP005 | > 1       |
| Interstage Bleed Pressure               | barg  | MBH10CP010 | 2.0 - 5.0 |

Table 8. Presser System properties.

| Time of reading | Turbine Intake pressure-bar | Compressor exit Pressure-bar | Turbine Interdict Pressure ratio -rp | Pressure-bar |
|-----------------|-----------------------------|------------------------------|-------------------------------------|-------------|
| 5:00 PM         | 1.003                       | 13.4                         | 2.85                                | 13.35992    |
| 7:00 PM         | 1.006                       | 13.4                         | 2.84                                | 13.32008    |
| 9:00 PM         | 1.001                       | 13.5                         | 2.88                                | 13.486513   |
| 11:00 PM        | 1.007                       | 13.4                         | 2.86                                | 13.306852   |
| 1:00 AM         | 1.003                       | 14.1                         | 2.99                                | 14.057827   |
| 3:00 AM         | 1.002                       | 14                            | 2.98                                | 13.972056   |
| 5:00 AM         | 1.003                       | 13.5                         | 2.88                                | 13.459621   |
| 7:00 AM         | 1.001                       | 13.4                         | 2.85                                | 13.386613   |
| 9:00 AM         | 1.004                       | 13.5                         | 2.85                                | 13.446215   |
| 11:00 AM        | 1.003                       | 13.8                         | 2.94                                | 13.758724   |
| 1:00 PM         | 1.004                       | 13.7                         | 2.91                                | 13.645418   |
| 3:00 PM         | 0.997                       | 13.6                         | 2.9                                 | 13.640923   |

Table 9. Properties of input and output temperature in the system.

| T1-Inlet ambient temp (°C) | T2-Compressor exit temp (°C) | T3-Turbine Limiting temp (°C) | T4-Exhaust temp (°C) |
|---------------------------|------------------------------|-------------------------------|----------------------|
| 11                        | 370                          | 1165                          | 507                  |
| 10                        | 369                          | 1169                          | 507                  |
| 8                         | 365                          | 1163                          | 502                  |
| 6                         | 360                          | 1148                          | 496                  |
| 11                        | 380                          | 1206                          | 519                  |
| 19                        | 380                          | 1210                          | 518                  |
| 21                        | 394                          | 1219                          | 533                  |
| 24                        | 396                          | 1225                          | 536                  |
| 22                        | 395                          | 1223                          | 535                  |
| 14                        | 383                          | 1206                          | 521                  |
| 13                        | 380                          | 1197                          | 518                  |
| 13                        | 379                          | 1193                          | 617                  |

To calculate the efficiency:

By using the equation number (12) depending on table number (11)&(12) From table (A-2)[24] @

\[ T_i \ (\text{Compressor inlet Temperature}) \], \ C_p \ \text{equal} = 1.005 \text{KJ/Kg. K and } \gamma = 1.4 \]
The total work of compressors is calculated from the equation:

\[ \eta_{\text{th}} = \frac{W_{\text{net}}}{q_{\text{in}}} = 1 - \frac{q_{\text{out}}}{q_{\text{in}}} = 1 - \frac{C_p(T_4-T_3)}{C_p(T_3-T_2)} \]  

(12)

The total work of compressors is calculated from the equation:

\[ W_{\text{tot}} = C_p \ast \left( T_2' - T_1 + T_4' - T_3 \right) / \eta_m \]  

(13)

Figures 8, 9 and 10 clearly show the difference between the actual and ideal efficiency and it was found that based on the suggested model, the compressor power increased by 8% and the efficiency was improved by 12%.

![Figure 8](image8.png)  
**Figure 8.** The deference between Ideal and Actual thermal efficiency.

![Figure 9](image9.png)  
**Figure 9.** The temperature of the combustion chamber and the temperature entering to the turbine.
The second part of the results depends on the calculation of heat exchanger specifications. And considering that the air input temperature for the compressor was fixed according to the proposed system. It has become possible to calculate the efficiency expected from the implementation of the new system. Figure 11 shows a comparison between the actual efficiency of the plant and the efficiency of the new system.

6. Conclusions
The amount of oxygen entering the combustion chamber represent an essential and crucial factor that controlling the power plant effectiveness and efficiency. In summer season which is the climate here in Iraq very dry and sever (the ambient temperature about 50 C). Therefore, the study of the opportunity using well water (is about 24 C constant annually) for entering air cooling showed a very promising improvement with no important additional cost.
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