Enhancing Gas Turbine Performance with Fogging Inlet Air Cooling at Western Mountain Power Plant

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Abstract

Gas turbine power plants are highly sensitive to environmental conditions, especially in hot climates. Fogging is one of the most effective methods for lowering the air temperature in rooms and greenhouses. This research focuses on the use of a fogging inlet cooling system to improve the performance of the Western Mountain Gas Power Plant. The Western Mountain Gas Power Plant is supplied with gas from the Wafa-Mellitah line. HYSYS Aspen program was used to simulate the real data collected from the Western Mountain Power Plant for the second unit gas turbine using the fogging inlet cooling system to cool the air and without installing the system.

The results showed a decrease in the temperature rate of the inlet air by 7% in the case of the presence of the fogging inlet cooling system. In addition, an increase in net power from 131.5 to 143.1 MW resulted in improving efficiency from 35.36% to 38.5% and a total of 4,952,028 kg of greenhouse gases was saved. [1,3].

Keywords: *Gas turbine, Fogging cooling system, Economic analysis ، performance of gas turbine*

تحسين أداء توربينات الغاز باستخدام نظام تبريد الهواء الداخل بالتضبيب في محطة توليد الطاقة بالجبل الغربي

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المستخلص:

تتميز محطات توليد الطاقة بالتوربينات الغازية بحساسيتها العالية للظروف البيئية، وخاصة في المناخات الحارة. ويعد التضبيب أحد أكثر الطرق فعالية لخفض درجة حرارة هواء الغرفة والغازات المسببة للانحباس الحراري ويركز هذا البحث على استخدام نظام تبريد الهواء الداخل بالتضبيب لتحسين أداء محطة توليد الطاقة بالجبل الغربي. يتم تزويد محطة توليد الطاقة بالجبل الغربي بالغاز من خط الوفاء-مليته. وتم استخدام برنامج HYSYS Aspen لمحاكاة البيانات الحقيقية التي تم جمعها من محطة توليد الطاقة بالجبل الغربي للوحدة الثانية من توربينات الغاز لمقارنة البيانات بإستخدام نظام تبريد الهواء الداخل بالتضبيب وبدون تركيب النظام.

وأظهرت النتائج انخفاض معدل درجة حرارة الهواء الداخل بنسبة 7% في حالة وجود نظام التبريد الضبابي الداخل، بالإضافة إلى ذلك، أدى الى زيادة صافي القدرة من 131.5 إلى 143.1 ميجاوات والذي نتج عنه تحسين الكفاءة من 35.36% إلى 38.5% وكذلك تم توفير ما مجموعه 4,952,028 كجم من غازات الاحتباس الحراري. [3،1].

الكلمات المفتاحية: توربينات الغاز، نظام التبريد الضبابي، التحليل الاقتصادي، أداء توربينات الغاز.

Introduction

Electricity is one of the essential requirements of life and the basis of urban development, agricultural development and industrial progress in all societies. As a result of the depletion of traditional energy sources and the continuous increase in human need for energy, it has become necessary to economize on the consumption of electrical energy and search for multiple means and methods to meet future energy requirements by exploiting the heat emitted from gas stations in combined units. Studies and research published in this field have focused on the performance of these gas stations [12].

At present, gas turbine power plants are one of the most widely used power generation technologies. It is a type of heat engine, which converts the chemical energy of fuel into useful mechanical energy. This mechanical energy is used to produce electrical energy through an electric generator. The gas turbine plant consists of three main parts: the compressor, the turbine and the combustion chamber. This type of station is characterized by its low installation costs. Moreover, it does not require a large area for installation and has a high power output per unit volume. The working principle of a gas turbine is based on the Brayton cycle, where air components are mixed with fuel and burned under constant pressure conditions. The resulting hot gas expands through the turbine to produce work. In gas turbines with an efficiency of about 33%, two-thirds of this work is spent compressing the air, and the rest is available for mechanical operation and electricity generation[12,18].

The efficiency of gas turbines is inversely proportional to the ambient air temperature. It is well known that the efficiency of a gas turbine is relatively low when the ambient air temperature is high. The current trend in design is to improve the efficiency and power output of gas turbines by increasing the turbine pressure ratio and reducing the compressor inlet temperature. The performance of a gas turbine generator can be improved by precooling the inlet air. The lower air temperature increases the mass flow through the compressor, which results in a significant reduction in compression work and an increase in gas turbine power output, with a slight improvement in efficiency. In the Western Mountain Power Plant, the inlet air temperature to the gas turbine ranges from 23°C to 45°C. The development of an air cooling system is required to reduce the temperature in the air intake gas turbine to maintain the air at a constant low temperature [2,8,11].

While previous studies have focused on evaporative and other coolings, this research focuses on the fogging cooling system especially in a dry climate.

This system is one of the most effective system in lowering the air temperature and greenhouses In this process, the fluid is first compressed to a medium pressure. The fluid then passes through an intercooler, where it is cooled to a lower temperature at essentially constant pressure. Fogging or water injection is a method by which the power output can be increased. This method increases the capacity of the gas turbine and also reduces CO_2 emissions. As we have explained, this method has been implemented in the gas turbines of the Western Mountain Gas Power Plant, so in light of the economic assumptions adopted at the beginning; this method should be preferred because it shows a unique relationship between the functional and economic characteristics.

Review of the unit studied

The study includes the effect of operational conditions on the performance of the second unit (GT2), date of entry into operation, 2005.

The unit is designed to operate with a load of 156 MW as design capacity and to operate with a load of 140 MW as operational power according to the manufacturer's recommendations (SIEMENS). This gas unit is designed with a simple cycle and a single axis connected directly to the electric generator from the compressor side.

Thus, the unit includes the following basic parts: an axial air compressor, an annular combustion chamber, gas turbine works with an open system to cool the blades with air and then an electric generator.

The Purpose of the Study

The research aims to study the fogging inlet cooling on the performance of the second gas unit in the Western Mountain gas station in terms of thermal performance, fuel consumption, and energy economies.

Simple gas turbine plants consist of:

1- A compressor mounted on the same shaft or coupled to the turbine.

The ambient atmosphere air enters the compressor and is compressed it to pressures ranging from 15 to 20 bar. The compressor consists of a number of rows of blades mounted on a shaft. The shaft connects and rotates the compressor together with the main gas turbine.

2- Combustion chamber.

It is an annular chamber where fuel is burned. Hot gases in the range of 1400 to 1500 C leave the chamber with high energy levels. The chamber and subsequent sections are made of special alloys and designs that can withstand high temperatures.

3- Turbines

The turbine performs the main work of converted energy. The turbine also consists of rows of blades mounted on the shaft and the kinetic energy of the hot gases rotates the blades and the shaft. The temperature of the gases leaving the turbine ranges between 500 and 550 C. The gas turbine shaft is connected to the generator to produce electrical energy [18].

4- Auxiliary systems Such as starting device, auxiliary lubrication pump, fuel system, oil system, air duct system, etc. The figure shows a simple gas cycle.

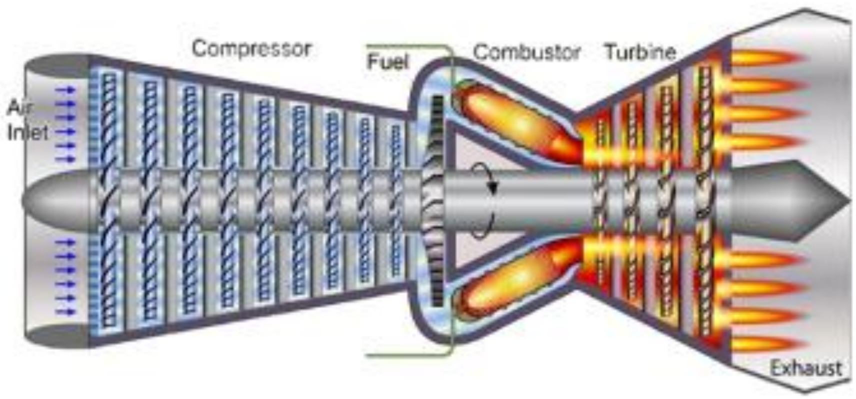

Figure 1: Simple gas turbine plants

The gas turbine is an open cycle, and uses ambient air as a working fluid, but it is greatly affected by ambient conditions that are:

1- Ambient temperature:

The ambient temperature represents the temperature of the inlet compressor in the gas turbine, if the temperature decreases, the air density will increase and which can increase the mass flow rate and reduce the power requirement of the compressor. When the compressed dense air enters the turbine section, it will cause additional expansion and more work produced by the turbine. So in general it can be said: When the compressor inlet temperature decreases, the air density increases, the power produced by the turbine will increase but the compressor capacity will increase, and the mass flow of fuel to the turbine will decrease to handle the increase in the mass flow of air and the additional turbine work [4,17].

2- Ambient pressure: -

As the ambient pressure increases, the air density will increase and the same result will occur in the previous point above.

3- Relative humidity

4- Air density:

As the air density increases, the mass flow of air through the compressor will increase and the same result will occur in the first point. The density of air depends on its temperature, pressure and the amount of water vapor in the air.

The effect of air temperature entering the compressor on the power output of the gas turbine. With a decrease in the air temperature inlet of the Compressor, the air density will increase and thus the flow out of the compressor will increase and an additional flow will enter the turbine. As a result, an increase in the power output (note that the velocity of the compressed air is almost constant regardless of the air density, because the axis speed is constant at different loads.

The performance of a gas turbine (GT) is a function of the ambient temperature (compressor inlet temperature). As a result, any decrease in ambient temperature will increase the available load of the gas turbine. Each decrease of 1 °C will increase the available load by 24.1 MW. However, it should be noted that the load of a gas turbine is not constant at the rated capacity all the time [11,16].

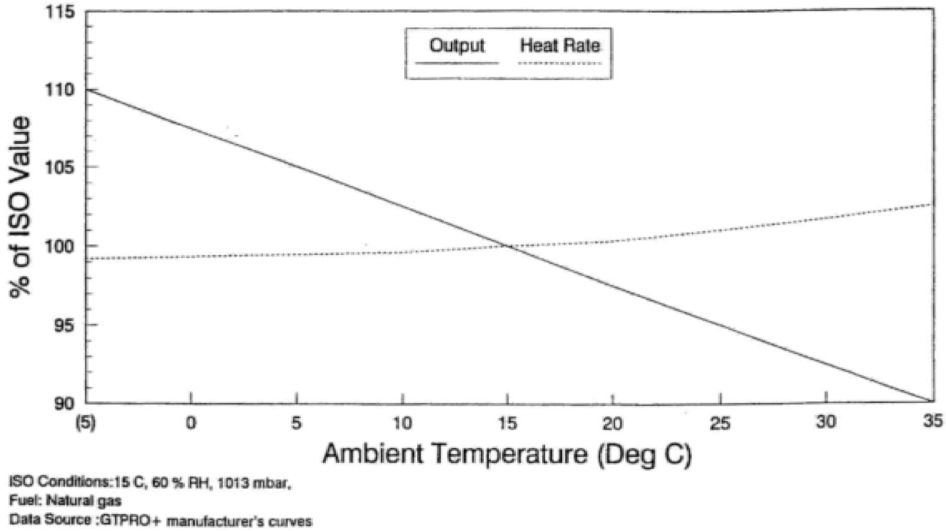

Figure 2: Effect of relative humidity on gas turbine load increase when using cooling or fogging systems.

The following diagram and table are for a Siemens V94.2 gas turbine located in one of the power generation stations. There are important assumptions to present this table, which are assuming that the maximum expected load was calculated, the power factor is equal to (1) [6].

Note: The power factor is the ratio between the effective power and the apparent power, and it is equal to the cosine of the phase angle, which is the difference between the voltage and current angles. Therefore, it is a numerical value that has no unit of measurement ranging from (0 – 1). In power stations, it is preferable and sought to have the power factor as large as possible, as the degree of the power factor increases, the amount of effective power increases and the value of the Ineffective power decreases or stored capacity. Because a load with a low power factor draws more current than a load with a high power factor for the same amount of useful power transmitted. Higher currents increase the power lost in the distribution system, and require larger wires and other equipment. Because of the costs of larger equipment and wasted energy, electric companies typically charge higher rates to industrial or commercial consumers. The goal of any electric utility is to have a power factor of 1. If the power factor is less than one, they must supply more current to the user in order to use a given amount of power. To do this, they incur more line losses.

1- Since the load limit controller restricts or limits the gas turbine load to (173 MW) as a maximum, even if the ambient temperature is (5°C) for example, the load cannot be increased to the corresponding maximum (175 MW in this case) for this reason.
2- If the national control center is requested to increase the gas turbine load to the maximum expected load, this certainly means that the gas turbine will automatically switch to the turbine outlet temperature controller when the compressor inlet guide vane opens 100%.
3- This table was prepared assuming dry weather conditions (i.e. low relative humidity <35%).
4- Natural gas fuel was assumed as the fuel used in operation. The case is different when using gas oil fuel because the controller settings are lower in case of gas turbine operation with gas oil fuel.
5- In case there are several gas turbines in the station, which certainly do not have the same performance nor the same control unit settings, it is not expected that all gas turbines will produce the same maximum load at the specified ambient temperature.

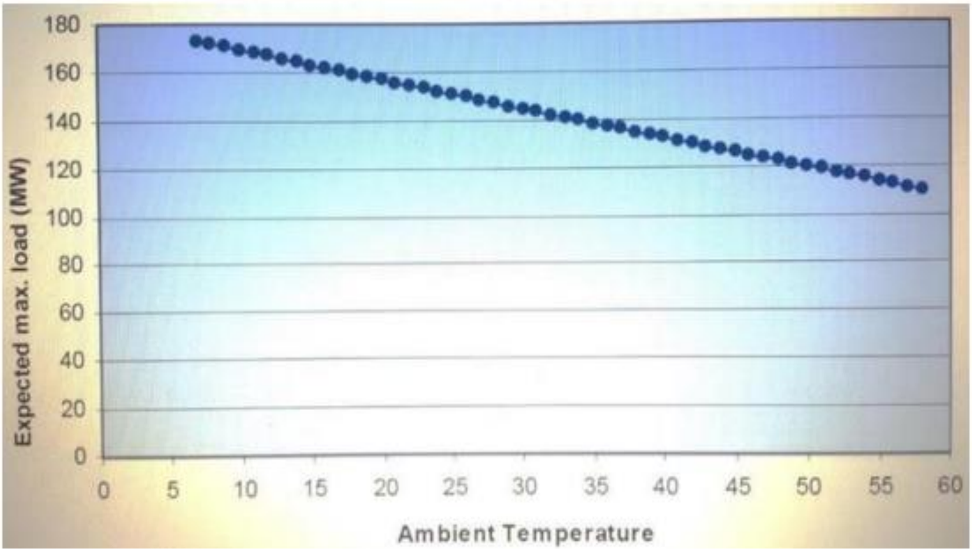

Figure 3: Electrical power output of the gas turbine versus compressor inlet temperature

Table 1. The variation of the electrical power generated by the gas turbine with the ambient temperature (compressor inlet) (Siemens V94.2 gas turbine) [6]

Ambient Temp.	Max. expected	Ambient Temp.	Max. expected	Ambient Temp.	Max. expected
7	173	25	151	43	128.68
8	171.8	26	149.76	44	127.44
9	170.6	27	148.52	45	126.2
10	169.4	28	147.28	46	124.96
11	168.2	29	146.04	47	123.72
12	167	30	144.8	48	122.48
13	165.8	31	143.56	49	121.24
14	164.6	32	142.32	50	120
15	163.4	33	141.08	51	118.76
16	162.16	34	139.84	52	117.52
17	160.92	35	138.6	53	116.28
18	159.68	36	137.36	54	115.04
19	158.44	37	136.12	55	113.8
20	157.2	38	134.88	56	112.56
21	155.96	39	133.64	57	111.32
22	154.72	40	132.4	58	110.08

Gas Turbine Inlet Air Cooling System

Why is the inlet air of a gas turbine cooled in the summer?

Gas turbines work by taking in the surrounding air, compressing it, injecting fuel into it, and igniting the mixture to power the turbine and generate electricity. During the summer, the rising temperatures cause the surrounding air to expand, causing it to decrease in density, which in turn reduces the flow of air mass taken into the turbine.

In addition, as the inlet air mass flow decreases, the volume of fuel injected into the combustion chamber also decreases, as the gas turbine is designed to maintain a constant air-to-fuel ratio for optimal combustion. As a result, the power output of the gas turbine decreases. It is generally observed that power output decreases by 0.6 to 0.8% for every 1°C increase in ambient temperature. The purpose of cooling the inlet air is to increase the density and mass flow of the inlet air by lowering its temperature, while at the same time increasing the volume of fuel injected in order to restore the reduced power output. This approach allows the power plant to maintain a constant supply of electricity at reasonable costs without having to invest in building new power generation facilities at high costs [8,16].

Fogging system for cooling the inlet air of gas turbines

It is generally known that the power of gas turbines that draw in ambient air and use it to drive the turbines decreases in the summer. One way to combat this problem is by using a fogging system to cool the air entering the compressor [9].

This system utilizes the evaporation heat as the fog evaporates, effectively lowering the temperature of the air entering the duct, increasing its density, and recovering the output energy during the summer. The gas turbine inlet air cooling system generates a fog consisting of water droplets with an average diameter of 10 to 30 micrometers, which cools the surrounding air through the evaporation heat of the fog. This system typically cools the air by 2 to 4 degrees Celsius, with the possibility of reducing the temperature by a maximum of 20 degrees Celsius in areas with high temperatures and low humidity, such as the Middle East and North Africa [3,7].

Gas turbines work by taking in the surrounding air, compressing it, injecting fuel into it, and igniting the mixture to drive the turbine and generate electricity. During the summer, the rising temperatures cause the surrounding air to expand, causing it to become less dense, which in turn reduces the flow of air mass taken into the turbine.

Figure 4: Fogging inlet cooling systems

How Fogging
Cooling System Works

A high-pressure fog system includes a high-pressure centrifugal pump that delivers demineralized water to the fog nozzle where the fog is mixed with air to ensure proper saturation after the air filter elements. The fog then provides cooling as it evaporates in the gas turbine inlet duct. As the air is compressed through the compressor stages of the gas turbine engine, the temperature and pressure of the incoming air increases while the volume decreases. The air can reach 100% relative humidity at the compressor inlet thus giving the lowest possible temperature without cooling (wet bulb temperature) [3]

Thermodynamic analysis of gas turbines

The air and combustion products are assumed to behave as ideal gases. The gas turbine process is based on the Brayton cycle. Air enters the compressor and is compressed and heated afterwards, goes to the combustion chamber, fuel is burned at constant pressure and then the air temperature is raised to ignition temperature. The high temperature output gases then enter the turbine where they expand to generate useful work. Some of the work developed by the gases passing through the turbine is used to drive the compressor and the rest is used to generate electrical power. When the heat is exhausted to the atmospheric air, the cycle is known as open cycle power plant [9,17]. Using the multi-feed relation for the ideal gas and knowing the isentropic efficiency of the compressor, the discharge temperature (T2) can be determined using equation (1)

$$T_2 = \frac{T_1}{\eta_c}\left(r_p^{\ \frac{\gamma_{-1}}{\gamma}} - 1\right) + T_1. \qquad (1)$$

Where T_1 is the ambient temperature, η_c is the isentropic efficiency of the compressor and T_2 is the compressor discharge temperature (CTD). The work of the compressor (W_c) can be estimated using the first law of thermodynamics, which is given by Eq. (2):

$$W_C = m_a * C_{Pa}(T_2 - T_1). \qquad (2)$$

Where m_a is the mass flow rate of air and C_{Pa} is the specific heat of dry air at constant pressure. It is determined as a function of the average temperature across the compressor. The heat released by the combustion discharge pressure is given by Equation (3):

$$Q_{in} = m_a + m_f \times C_{pg}\,(T_3 - T_2). \qquad (3)$$

BY Knowing the fuel gas heat value (FHV), the natural gas mass flow rate is given by Equation (4)

$$m_f = \frac{Q_{in} \backslash FHV}{\eta_{combustor}}. \qquad (4)$$

Where $\eta_{combustor}$ is the efficiency of the combustion chamber. The temperature leaving the turbine can be expressed by Equation (5):

$$T_6 = T_5 - \eta_t T_4 \left[1 - \left(\frac{1}{(P5 \backslash P6)}\right)^{\frac{\gamma-1}{\gamma}}\right] \qquad (5)$$

Where $\boldsymbol{\eta_t}$ is the isentropic efficiency of the turbine and $\boldsymbol{P6}$ is the ambient pressure. Hence, the turbine power is given by Equation (6):

$$\dot{W}_T = C_{pg} \times (T_5 - T_6). \qquad (6)$$

The net power obtained from the gas turbine is given by Equation (7):

$$W_{net} = W_T - W_C. \qquad \mathbf{(7)}$$

The specific fuel consumption (SFC) can be determined using equation (8):

$$SFC = \frac{3600 * m_f}{W_{net}}. \qquad \mathbf{(8)}$$

Heat Rate (HR) can be determined using Equation (9):

$$HR = SFC \times LHV. \quad (9)$$

The thermal efficiency of gas turbines is given by the formula (10):

$$\eta_{th} = \frac{work\ output}{Heat\ supplied} = \frac{W_{net}}{Q_{in}}. \quad (10)$$

Work ratio is given by equation (11):

$$\text{Work Ratio} = \frac{Net\ Work\ output}{Gross\ Work\ output}. \quad (11)$$

Simulation of Gas Turbine with and without Fogging cooling System

Table 2 :Design characteristics and specifications of the studied gas unit.

Properties	The symbol	Unit		
		GT2		
Compression ratio	r_p	12		-
Maximum temperature	T_3	1100		^{o}C
Temperature of combustion gas discharge to the surroundings	T_{ex}	536 536		^{o}C ^{o}C
Minimum temperature	T_1	15		^{o}C
Compressor exit temperature	T_2	315		^{o}C
Calorific value of fuel	LHV	43000		kJ/kg
Electrical energy produced by	W	156		MW
Design efficiency of the gas	η	34.7		%
Fuel type	-	NG		-
Date of entry into service	-	2005		-

Table 3: Operating parameters of the second unit of the Ruwais Gas Power Plant on June 2, 2024 at 12:00 p.m.

s/n	Operating Parameters	Values	Unit
1	Mass flow rate of air through compressor	432	Kg/s
2	Temperature of inlet air to compressor (T_1).	28	^oC
3	Pressure of inlet air to compressor (P_1).	1.013	bar
4	Outlet temperature of air from compressor	346	^oC
5	Outlet pressure of air from compressor (P_2).	9.4	bar
6	Fuel gas (natural gas) mass flow rate (m_f).	7.43	Kg/s
7	Fuel temperature	10	^oC
8	Inlet pressure of fuel gas.	20	bar
9	Inlet temperature of gas turbine (T_3).	1042	^oC
10	Maximum exhaust temperature of T. outlet.	524	^oC
11	Installed capacity.	131	MW
12	Isentropic eff. of compressor.	85.523	%
13	Isentropic eff. of Turbine.	94.196	%
14	Specific heat capacity of air (C_{pa}).	1.005	KJ/kg.k
15	Specific capacity of gas (C_{pg}).	1.15	KJ/kg.k
16	Lower Heating Value (LHV)	40360	KJ/kg.k

Fog System cooling of Gas Turbine assumptions for the simulation

- The air contains 23.3% oxygen and 76.7% nitrogen by mass.
- The combustion process was assumed to be a conversion reaction in HYSYS.
- The conversion is 100% in the reactor.
- In the compressor, the isentropic efficiency was 88%, while the isentropic efficiency of the turbine was 95%.
- The natural gas component is methane 100%.
- The natural gas comes directly into the feed line at a pressure of 20 bar and a temperature of 10°C.
- The mechanical loss is assumed to be 97%.
- No conversion energy losses were assumed.
- The pressure drop across the combustion chamber was assumed to be 2%.

- The pressure, temperature of the surrounding air and the mass flow rate of the air are constant.

Operating parameters of fogging cooling system

Table 4: operating parameters of fogging system

Operating parameters	Value	Unit
Pump energy	91.38	kW
Water in temperature	20	℃
Fogging pressure	100	bar
Water mass flow rate	7	kg/s

Aspen HYSYS was used to model the simple gas turbine and the gas turbine with fog units. The first step in creating the model was to select a standard set of components and a thermodynamic basis for modeling the physical properties of these components. When the component list was created, HYSYS created a new component list called the Component List. The next step was to select a "fluid package" for it. The "fluid package" is the thermodynamic system associated with the selected component list. The "Simulation Environment" was entered to begin building the process model. The icons for the pump, mixer, separator, compressor, transfer reactor, and turbine were clicked from the model panel and placed on the flowsheet in Figure 5 . The combined mixer and separator modules are used to simulate the fog unit. When the inlet air enters the fog unit, a high-pressure pump then diverts the demineralized water to a fog nozzle operating at high pressure, where it is sprayed onto the hot air in the mixer. However, the hot air mixed with the fog to ensure proper saturation of the air before leaving the mixer, then the saturated air enters the separator where the steam and water separate, while the water that is not evaporated by the incoming hot air leaves the bottom [7,13]

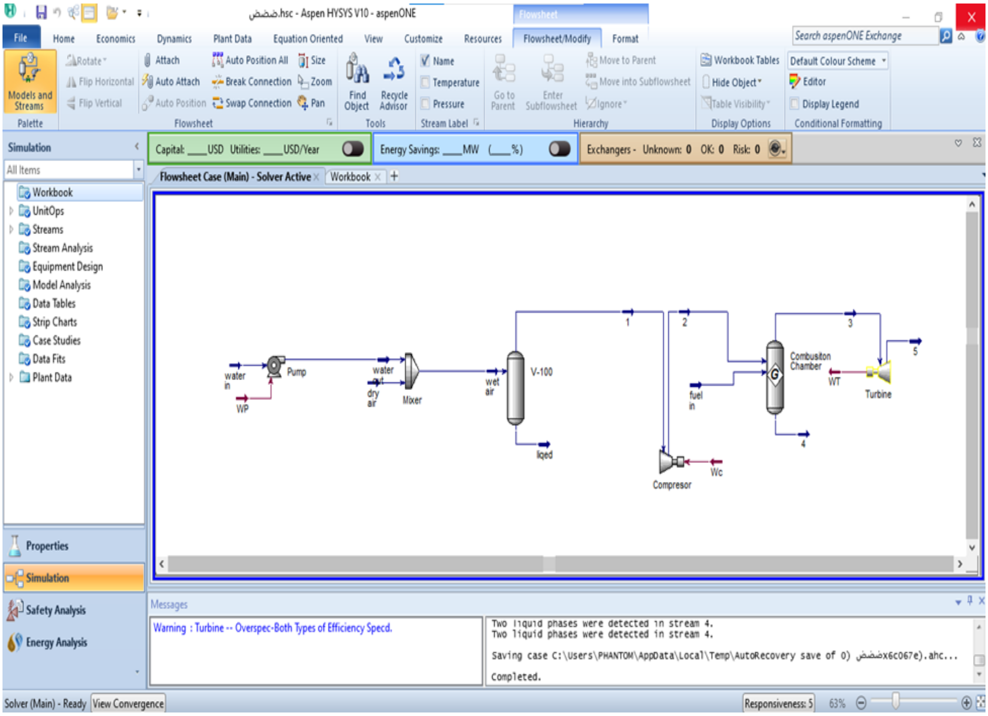

Figure 5 : Schematic diagram of the simulated turbine model without the fogging cooling system in Aspen Hysys

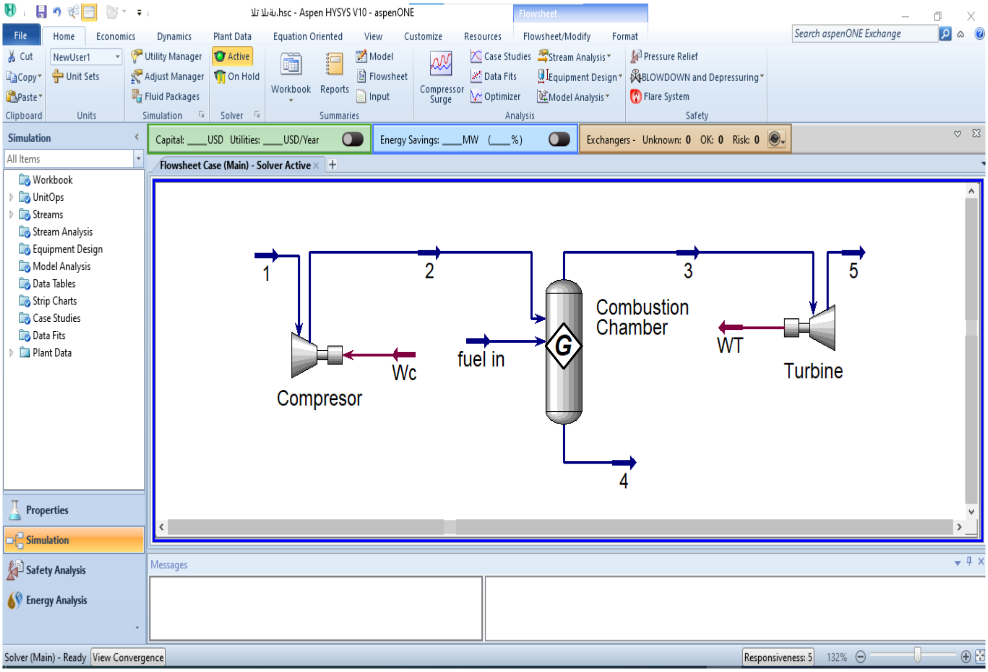

Figure 6: Schematic diagram of the simulated turbine model with fogging cooling system in Aspen Hysys

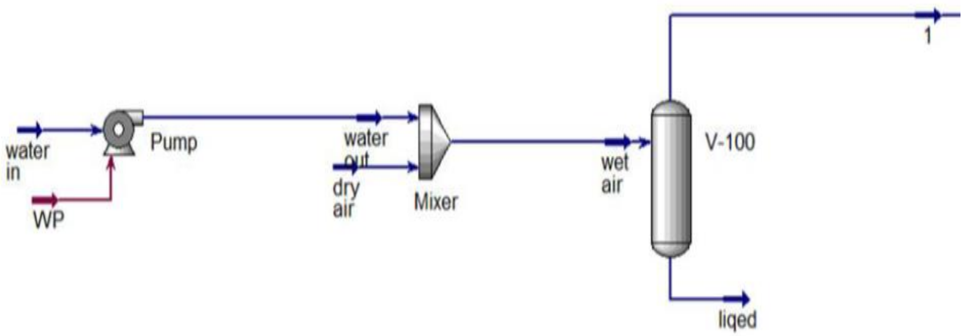

Figure 7: Fogging cooling Unit in Aspen Hysys

Result and discussion from Aspen HYSYS

Aspen HYSYS software was used to simulate the performance of the gas turbine plant. The results obtained are shown in Table (5). To understand the effect of changing the input variable such as temperature on the net power output, thermal efficiency, specific fuel consumption and heat rate, a sensitivity analysis of the gas turbine system was performed using Aspen. The results were used to compare the performance of the unit when combined with an air intake cooling system (high-pressure fog). Table 6 shows the comparison of performance with and without the fog system.

Table 5: Aspen HYSYS software results

Item	Without fogging system	With fogging system	Units
Compressor exit Temp.	346	281	°C
Turbine Temp.	1043	977	°C
Exhausted Temp.	524	478	°C
Compressor power	143.2	122.9	MW
Turbine Power	274.7	266	MW
Net Power	131.5	143.1	MW
Thermal efficiency	35.36	38.5	%
Specific fuel consumption	0.2034	0.1896	kg/kwh
Heat rate	8215.3	7658	kJ/kwh

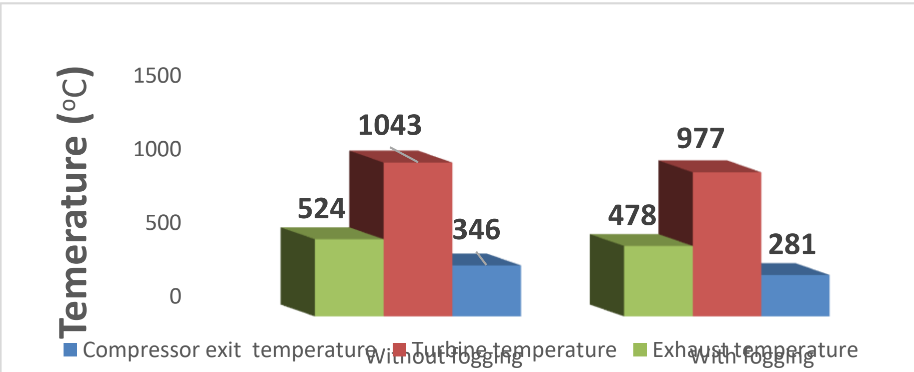

Figure 8: Representing output results with and without fogging cooling unit

SFC is an engineering term used to describe the fuel consumed by an engine per unit of power produced. In gas turbine engines, it is the ratio of the mass of fuel consumed to the engine output power. It is measured in kilograms per kilowatt-hour or kilograms per megawatt-hour and is best when the value is at its minimum.

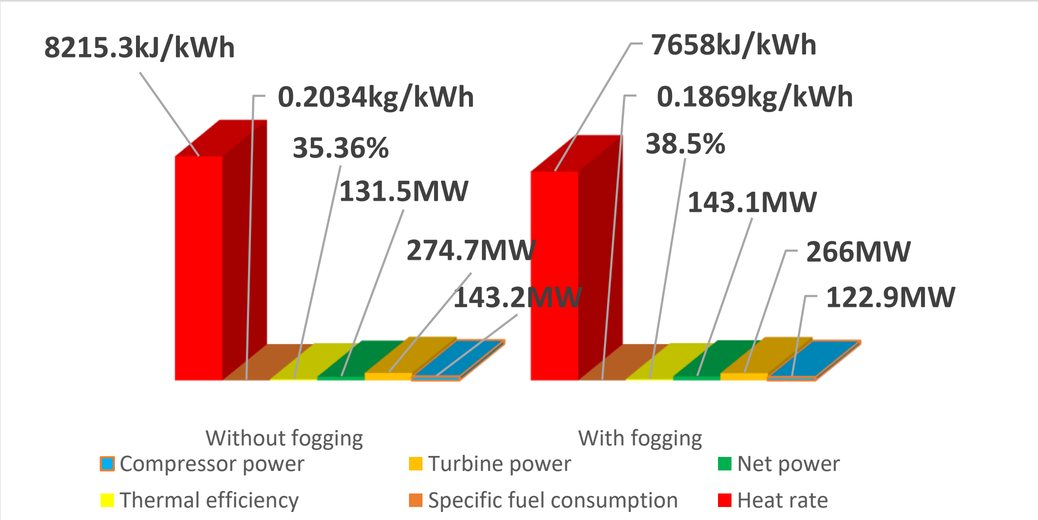

Figure9: Temperature requirements for power plant with and without fogging cooling unit

As shown in Figure 8, the SFC obtained from the power plant simulation when no fog was incorporated was 0.2034 kg/kWh, while the SFC for the plant with fog was 0.1869 kg/kWh. Comparing the two SFC values indicated that operating the plant with fog provides better fuel economy/efficiency and cost-effective operation. Gas turbine power plants worldwide uses natural gas, as it is a clean energy resource that burns with lower emissions. Thermal efficiency is the ratio of the work done (output) by the system to the heat input or heat supplied to it. As shown in Figure (8), a thermal efficiency of 38.5% was obtained from the result of the simulated power plant with the fog system, while a thermal efficiency of 35.36% was obtained from the result of the simulated power plant operating without the fog system.

From a thermodynamic point of view, a system with a high thermal efficiency is likely to produce more work output and is more reliable than a system with a low thermal efficiency. This means that operating a power plant with a fog system that produces a higher thermal efficiency will produce more work output. This is essential in power plant operations in terms of increasing profits, as industrial operators are not concerned with non-value-added activities that may affect production output. Net power is a property related to the amount of energy transferred per unit time by a system. As shown in Figure (8), the net power obtained (143.1 MW) from the power plant simulation is higher when the fog system is integrated than the net power obtained (131.5 MW) when the system is operating without fog system. This means that the work requirement will decrease and the required output will increase when the system is operating with fog system integrated. For compressor work and turbine work, 122.9 MW and 266 MW were obtained from the fog system power plant simulation, whereas 143.2 MW and 274.7 MW were obtained from the non-fog system power plant simulation. This is the power required to operate the turbine and compressor. From the above values, the power requirements for these two systems are relatively lower when the power plant is operating with fog system than when it is operating without fog system. Temperature is vital for the operation of compressors and turbine systems in a power plant, but achieving one unit of temperature for efficient operation of the plant comes at a cost. The simulated temperature requirements for both the compressor and the system are shown in Figure (9).

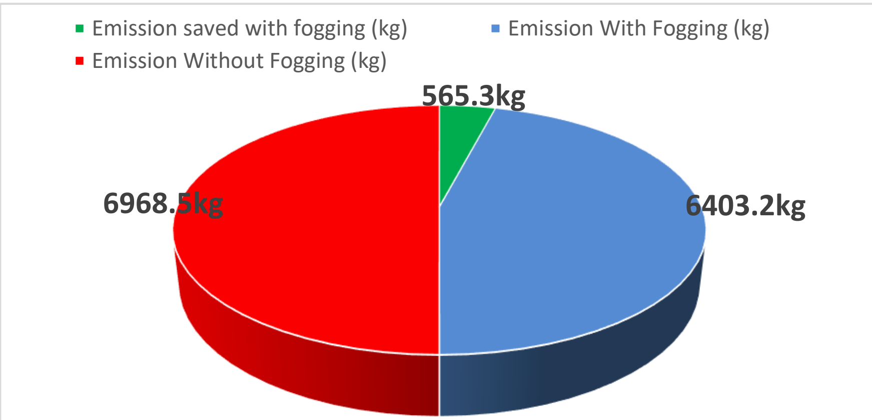

Figure 10: Emission savings from a power plant operating with and without a fogging cooling unit.

It can be seen in Figure (9), both the compressor exit temperature and the gas turbine inlet and exhaust temperature operating with a fog system, which requires a lower temperature compared to when the fog system is not installed. The lower temperature requirement provides a significant advantage in terms of the cost required to reach the mentioned equipment temperature. Another point is that materials with high conductivity and thermal properties may be required when the temperature requirements are high and this is where the importance of the fogging cooling system comes into play.

Greenhouse Gas Emissions

Equation (12) was used to calculate the greenhouse gas emission from fuel (natural gas) for both stations. Greenhouse gas emissions = Fuel consumption × CO_2 emission factor ....(12) .

When fuel GHG emission = GHG emission by fuel type (kg/GHG);

Fuel consumption = Amount of fuel burned in kg/kWh;

Emission factor GHG fuel = GHG emission factor by fuel type (kWh) for CO_2.

Thus, the calculation of greenhouse gas emission with fog unit Specific fuel consumption = 0.1869 kg/kWh; CO_2 emission factor for natural gas = 34260.008 kWh;

Greenhouse gas emission with fog 0.1869 ×34260.008 = 6403.2 kg/h.

Calculation of greenhouse gas emissions without fog unit Specific fuel consumption = 0.2034 kg/kWh;

Natural gas CO_2 emission factor = 34260.008 kWh;

Greenhouse gas emissions without fog = 0.2034 × 34260.008 = 6968.5 kg/h;

Emissions saved with fog = 6968.5 - 6403.2 = 565.3 kg/h.

The total emissions generated when the power plant operates with fog system, without fog system, and the total emissions saved using fog system are shown in Figure (10).

Greenhouse gases are a type of gases that absorb and emit radiant energy within the thermal infrared range. Increased greenhouse gas emissions lead to effects such as global warming, climate change, etc.

Since the beginning of the industrial revolution, human activities have been a major emitter of greenhouse gases. Figure (10) shows a comparative graph showing the greenhouse gas emissions from Ruwais Power Plant operating with and without fogging.

From the emission analysis presented in this section. It can be seen that operating the power plant with fogging emits more than 6403.2 kg/h of greenhouse gases. while operating the power plant without fogging emits more than 6968.5 kg/h. Comparing the two calculated values when integrating the fogging system into the power plant operation and when the power plant operates without fogging, it can be seen that the fogging system saved about 565.3 kg/h for the power plant operation. Assuming the power plant is operated every day for 365 days, a total of 4,952,028 kg of greenhouse gases will be saved when the fog system is incorporated into the operation of the power plant. This is a green technology that can go a long way in reducing the global emissions rate from power plants, which are now designed in many forms for industrial purposes. For example, Renewable Energy Power Plants (REPPs) which also use gas turbines are designed not only for investment purposes but also to maximize the use of resources (sun, water, wind) and reduce raw materials such as aluminum, iron, silicon, etc.

Conclusion

In this the present study the simulation results has been obtained by a developed computational model using Aspen HYSYS software, which gives the influence of operating conditions on the gas turbine power plant. The resulted data of this study concluded that a decrease in the temperature rate of the inlet air by 7% in the case of the presence of the fogging inlet cooling system. In addition, an increase in net power from 131.5 to 143.1 MW resulted in improving efficiency from 35.36% to 38.5% and a total of 4,952,028 kg of greenhouse gases was saved. Operating the plant with fogging cooling system also, provides better fuel economy/efficiency and cost-effective operation.

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