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تأثير المعاملات الخارجية وتركيب الوقود على أداء التوربينات الغازية في محطات توليد الطاقة الكهربائية

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Impact of Ambient Parameters and Fuel Composition on Performance of Gas Turbine Power Plants

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الملخص
تقدم هذه الدراسة تقييمًا لتأثير المعاملات الخارجية على أداء التوربينات الغازية في محطات توليد الطاقة الكهربائية. لقد تم إجراء هذه الدراسة على محطة توليد الطاقة المشتركة في شمال بنغازي (BCCPP) خلال عام 2023 . حيث يعمل التوربين الغازي لتوليد الطاقة في هذه المحطة بوقود الغاز الطبيعي لثلاث وحدات توربين غازي من نوع "GT13 E1" بسعة إجمالية قدرها 450 ميجاواط، ووحدة وقود الغاز نموذج GT13E2 بسعة 160 ميجاواط. كما تعمل الوحدات الغازية التي تم إنشاؤها في نظام دورة بسيطة مع إمكانية دورة مشتركة. وتتغير كفاءة وإنتاج الطاقة الكهربائية للتوربين الغازي بناءً على الظروف الخارجية المحيطة بالمحطة. وتؤثر كمية هذه التغيرات بشكل كبير على إنتاج الكهرباء واستهلاك الوقود وإيرادات المحطة. إن الهدف من هذه الدراسة هو التحقيق في تأثير المعاملات الخارجية مثل درجة الحرارة الخارجية، وكتلة التدفق، والرطوبة النسبية، وتركيب الوقود على أداء التوربينات الغازية. ويُلاحَظ أن القدرة تنخفض بسبب انخفاض معدل تدفق الهواء الجوي (تنخفض كثافة الهواء مع زيادة درجة الحرارة) وتنخفض الكفاءة لأن الضاغط يتطلب مزيدًا من الطاقة لضغط الهواء ذو درجة حرارة أعلى. كما تمت دراسة تأثير درجة حرارة مدخل التوربين على أداء محطة توليد الطاقة بالتوربين الغازي المستخدمة لتوليد الكهرباء مع المعاملات المؤثرة. وقد أظهرت العلاقة بين هذه المعاملات ودرجة حرارة مدخل التوربين تبعية كبيرة على هذه الدرجة. من ناحية أخرى، يمكن للتوربين الغازي العمل بوقود متنوع لتوليد الطاقة. حيث يعتمد تأثير تركيب الوقود على تركيب الكيميائي وخصائصه الناتجة، وبشكل خاص نسبة الهيدروجين - الكربون(H / C) ، لذا يمكن أيضًا أن يؤثر تركيب الوقود على أداء التوربين.

الكلمات المفتاحية: محطة توليد الطاقة، التوربين غازي، توليد الطاقة، الأداء، المعاملات الخارجية، خصائص الوقود، الكفاءة.

Abstract
This study presents an assessment of ambient parameters impact on the performance of gas turbines (GT) power plants. The study was performed on the Benghazi North Combined Cycle Power Plant (BCCPP) through year

2023. The power generation of this plant is running by natural gas fuel for three gas turbine units’ type "GT13 E1" with a total capacity of 450 MW, and gas unit module GT13E2 with a capacity of 160 MW. The gas units that were created are operated in a simple cycle system with the possibility of a combined cycle. Efficiency and electric-power output of GT vary according to the ambient conditions. The amount of these variations greatly affects electricity production, fuel consumption and plant incomes. The objective of the present study is to investigate the effect of the ambient parameters such as ambient temperature, flow mass, relative humidity and fuel composition on the performance of gas turbines. It is observed that the power decreases due to reduction in air mass flow rate (the density of the air declines as temperature increases) and the efficiency decreases because the compressor requires more power to compress air of higher temperature. The influence of turbine inlet temperature of the performance of a gas turbine power plant utilized for electricity has been done with the impact parameters. The correlation of these parameters with the turbine inlet temperature showed close dependence on this temperature. On the other hand, gas turbine can run on a wide variety of fuels to produce power. Depending on the fuel composition and resulting properties, specifically the hydrogen–carbon ratio (H/C), so the fuel composition can also affected on the turbine performance.

Keywords: Power plant, gas turbine, power generation, performance, ambient parameters, fuel characterizations, efficiency.

Introduction

Several gas turbines are being widely used for power generation in several countries all over the world. Obviously, many of these countries have a wide range of climatic conditions, which impact the performance of gas turbines [1]. Gas turbines are increasingly used in combination with steam cycle, either to generate electricity alone, as in combined cycles, or to cogeneration both electrical power and heat for industrial processes[2].

Electrical energy can be obtained from hydrocarbon fuels like coal, oil and gas, and primary energy flows like solar energy, wind energy and geothermal energy. The use of natural gas in the power sector is expected to increase over the next 20 years as it gains share from coal but falls back by 2050 as the use of renewables accelerate.

The different options for generating power from natural gas all deal with how the chemical energy of the gas is converted to mechanical rotational energy to drive the generator, as shown in Figure 1. Although there are many different types of generators for different application [1].

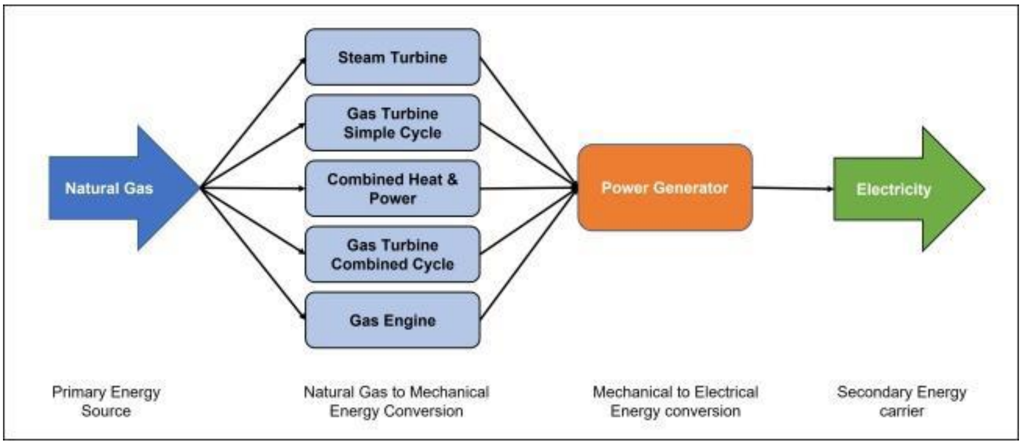


Figure 1: Options for power generation from natural gas

Gas Turbines Components

Gas turbines are combustion engines which consist of three components: a preliminary compressor, the central combustion chamber and the actual turbine (Figure 2). The design, performance and size of gas turbines differ depending on the application and area of use. However, their working principle is always the same, and is based on the thermodynamic cycle process according to James Prescott Joule (“Joule process”).

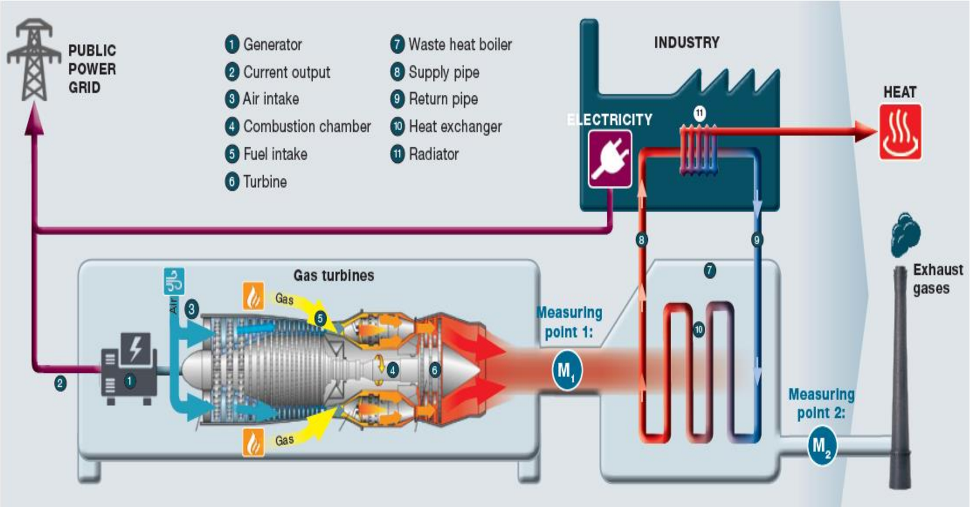


Figure. 2: Schematic combustion process of a gas turbine with heat recovery boiler. Monitoring combustion process at measurement point 1 (M1), monitoring emission limit values at measurement point 2 (M2) [3]

Gas turbine engines use natural gas as a fuel gas, which is a mixture of hydrocarbons, the composition of which depends on the specific gas field. The gas composition determines the combustion process occurring in the combustion chamber, and the composition of the combustion products. When operating in the wholesale electricity market, a gas turbine unit (GTU) must produce the same power regardless of the gas composition[4-7].

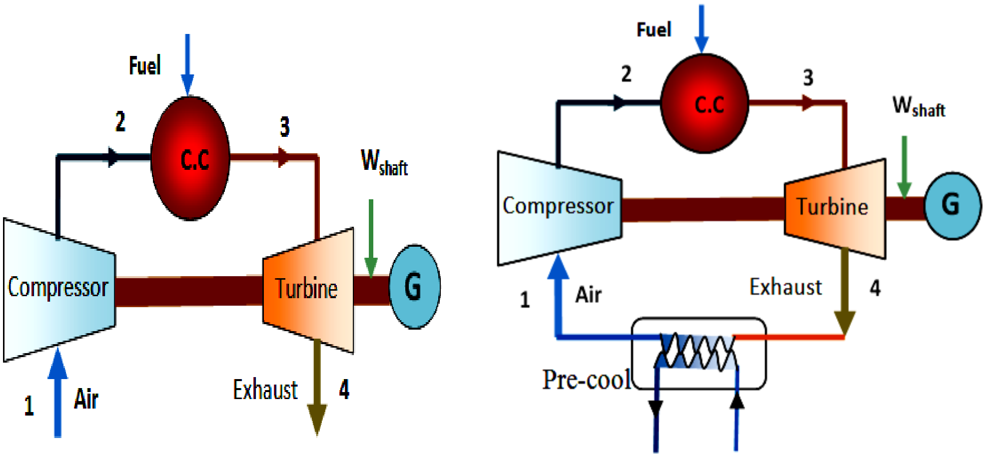
Classification of Gas Turbines

Different arrangements of the GT components have developed in the past. Some of these arrangements are appropriate for power generation and the others used to mechanically drive applications such as compressors and pumps[8]. In this section, GT was classified based on the working cycle, components arrangements. Figure 3 illustrates the simple gas turbine cycles.

Gas Turbine Cycle

A cycle describes what happens to air as it passes into, through and out of the gas turbine. The cycle usually describes the relationship between the space occupied by the air in the system (called volume, V) and the pressure (P) it is under. The Brayton cycle (1876), shown in graphic form in Figures 4 and 5 as a pressure-volume diagram, is a representation of the properties of a fixed amount of air as it passes through a gas turbine in operation.

The P-V and T-S diagrams of an ideal Brayton cycle are shown in Figures 4 and 5. Notice that all four processes of the Brayton cycle are executed in steady-flow devices; thus, they should be analyzed as steady-flow processes.



(a) Open cycle (b) Close cycle

Figure 3: Simple gas turbine cycles

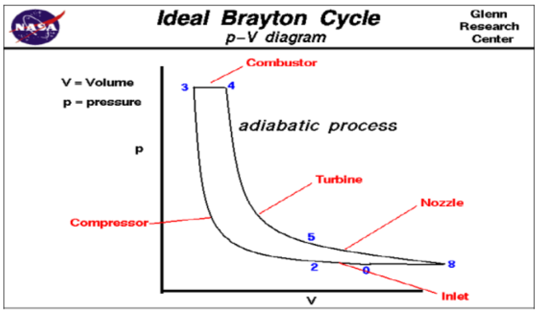


Figure 4: P-V Diagram

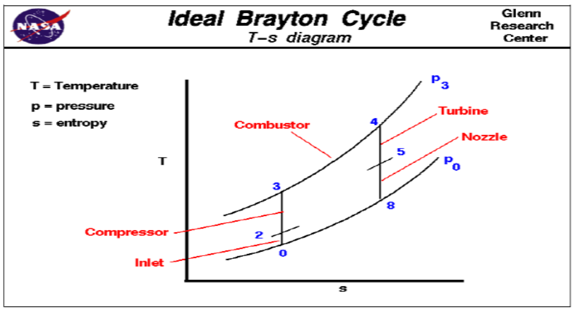


Figure 5: T-S Diagram

Location of Study

This study was performed on the Benghazi North Combined Cycle Power Plant (BCCPP) which located at north of Benghazi city. The power generation of this plant is running by natural gas fuel. Figure 6 an overview depicts the BCCPP of this study.

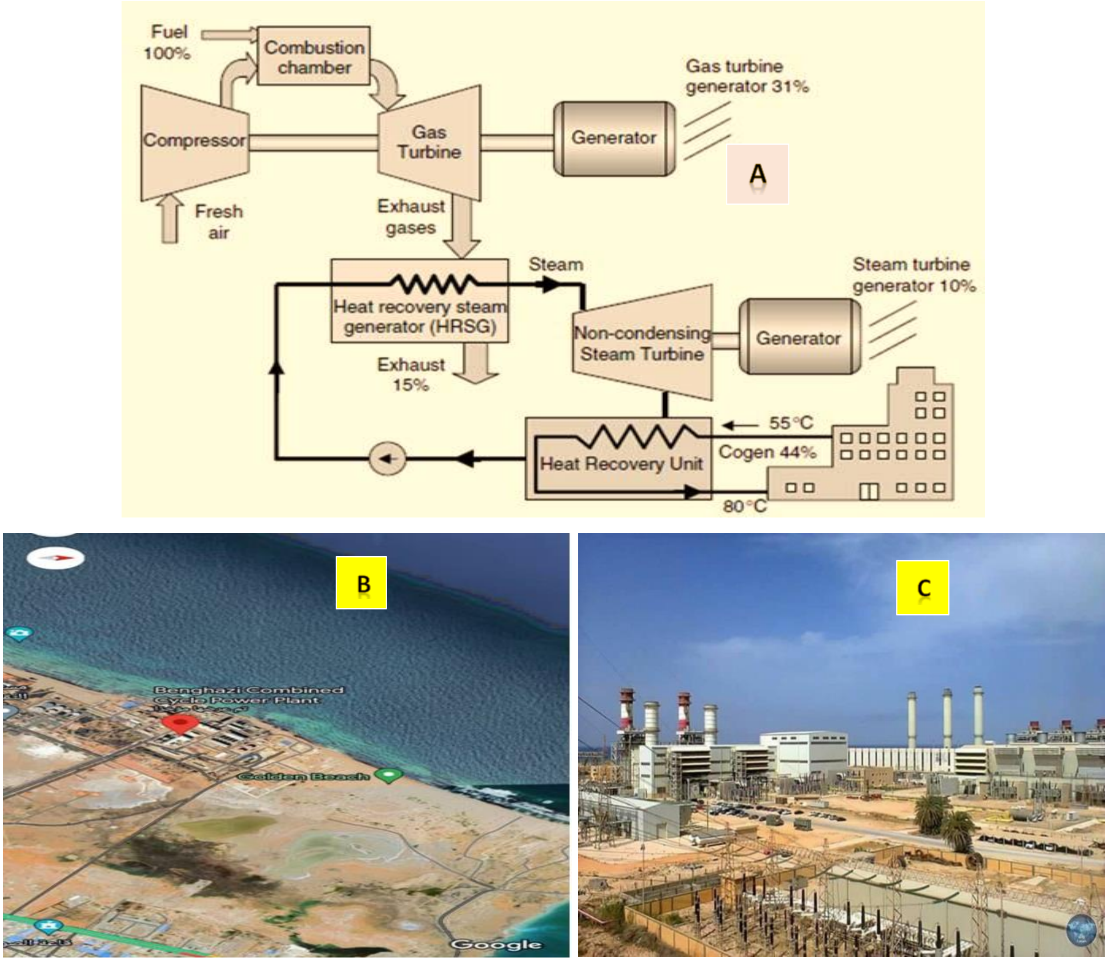


Figure. 6: Overview of Benghazi Combined Cycle Power Plant (BCCPP): A- simplified diagram of the combined cycle; B- Satellite image shows BTPP location; C- Photo shows BCCPP.

The Benghazi North Combined Cycle Power Plant (BCCPP) is located north of Benghazi, in northern part of Libya. The Benghazi north power plant is the main power source in the eastern wing of the general electricity network of Libyan. Figure 6 shows Benghazi combined cycle power plant.

The general electricity company (GECOL) was contracted in 1995 with ABB (Swiss-Swedish multinational company) to install three gas turbine units' type "GT13 E1" with a total capacity of 450 MW, these units Alstom company (multinational connected to the public network for electricity, where these units operate by fuel gas and light oil in simple cycle system. After that in 2001 the company was contracted for install additional gas unit module GT13E2 with a capacity of 160 MW. However, the gas units that were created are operated in a simple cycle system with the possibility of a combined cycle.

Problem Statement

Basically, gas turbine which operates at lower turbine inlet temperatures will result in low performance and decrease efficiency. Lower efficiency of gas turbine means the lower power output is produced. To increase the performance of gas turbines there have several approaches.

However, the problem of this study is trying to answer the following questions:

1. What are the different parameters affecting on turbines performance?
2. What are the fuels composition and characterization required for the plant?
3. How far the fuel type affecting on turbines performance?

Objectives Of Study

The main aims of this study are including the following:

1. Assessment the power plants turbines performance throughout various parameters.
2. Determination the utilizing natural gas characteristics as fuel.

Methodology

The methodology involved the collection of operational data from logsheets of the turbine unit of plant under consideration. The plant network can be obtained according to Alobaid et. al., [9] and Petruzzi et. al [10]. The applied equations are suggested as following:

$$h_1 + \frac{v_1^2}{2} + gZ_1 + W = h_2 + \frac{v_2^2}{2} + gZ_2 + q \qquad (1)$$

since , $W = q + (h_1 - h_2) + \frac{(v_2 - v_1)^2}{2} + (Z_2\, g - Z_1\, g)$

$$W = h_2 - h_1 = C_p (T_2 - T_1) \qquad (2)$$

Taking in consideration that the mass flow is constant (all units of the work and energy of heat will be in (*kJ /kg*) and the total energy input to the system is equal to the total energy output.

Equations of gas turbine net work:

From Temperature-entropy diagram for basic gas turbine engine with friction:

$$W_{comp} = h_{2'} - h_1 = C_{pa} (T_{2'} - T_1) \qquad \text{Compressor work} \qquad (3)$$

$$W_{turb} = h_{3'} - h_{4'} = C_{pg} (T_{3'} - T_{4'}) \qquad \text{Turbine Work} \qquad (4)$$

$$W_{net} = W_{turb} - W_{comp} = C_{pg} (T_{3'} - T_{4'}) - C_{pa} (T_{2'} - T_1) \qquad \text{Net Work} \qquad (5)$$

Equations of gas turbine heat addition and efficiency :

$$Q_{in} = h_{3'} - h_{2'} = C_{pg}(T_{3'} - T_{2'}) \qquad \text{Heat addition} \qquad (6)$$

$$\eta_{th} = \frac{w_{net}}{Q_{in}} = \frac{C_{pg}\,(T_{3'} - T_{4'}) - C_{pa}\,(T_{2'} - T_1)}{C_{pg}\,(T_{3'} - T_{2'})} \qquad \text{Thermal efficiency} \qquad (7)$$

Equation for power output:

Since the flow is constant, by neglecting the flow mass and extracted equations, so resulting units will be in (KJ/Kg). Take the mass flow in consideration and multiply it by the network the result be the power output.

$$P_{output} = W_{net} * m \qquad \text{Power output} \qquad (8)$$

Equations for isentropic efficiency:

Isentropic efficiency is a parameter to measure the degree of degradation of energy in steady-flow devices. It involves the comparison between the actual performance of a device and the performance that would be achieved under idealized circumstances for the same inlet and exit state.

$$\eta_C = \frac{(T_2 - T_1)}{(T_{2'} - T_1)} \qquad \text{Compressor isentropic efficiency} \qquad (9)$$

$$\eta_T = \frac{(T_{3'} - T_{4'})}{(T_{3'} - T_4)} \qquad \text{Turbine isentropic efficiency} \qquad (10)$$

Results and Discussion

The investigated study for Benghazi North Combined Cycle Power Plant (BCCPP) was conducted throughout year 2023 to estimate the impacts of the ambient temperature, operation parameters and fuel composition on the turbine performance. It includes energy changes by ambient temperature, compression ratio, relative humidity and fuel characterizations.

Effect of Ambient Temperature

Efficiency and electric-power output of gas turbines vary according to the ambient conditions. The amount of these variations greatly affects electricity production, fuel consumption and plant incomes. Since ambient conditions are dependent upon the place where gas turbine is installed, they cannot be changed. At the same time, the amount of performance variation with the ambient conditions also depends on the gas turbines design parameters. Therefore, in order to determine the actual performance variation with the ambient conditions, gas turbine design parameters and ambient conditions of the installed place should be known.

Data of ISO conditions in this calculation has been obtained from the logsheet, which records the daily analogue and digital readings concerning the gas turbine unit. The ambient temperature of this calculations was at standard reference conditions for gas turbines (ISO 3977) whereas T_1 =15°C (59°F and ambient pressure = 1013 KPa (14.7 Psia). The other parameters that concerning of this calculations were presented in Table 1.

Table 1: Power plant operation parameters

T_1 °K	$T_{3'}$ (TIT) °K	m_{air} Kg/s	m_{gas} Kg/s	Cp_{gas}	γ_{gas}	η_C %	Cp_{air}	γ_{air}	η_T %	p_2/p_1 bar
288	1343	528.6	9.8	1.005	1.3	0.86	1.11	1.4	0.86	14

Influence Parameters Calculation

Calculating Compressor Temperature

From given T_1 and pressure ratio (P_2/P_1), T_2 can be calculated as following:

$$T_2 = T_1\left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} = 288\ (14)^{0.286} = 612\ ^{o}K$$

From Equation (9), calculate the actual temperature $T_{2'}$ using compressor isentropic efficiency:

$$T_{2'} = \frac{(T_2 - T_1 + \eta_C * T_1)}{\eta_C} = \frac{(612-288+0.86*288)}{0.86} = 664.7\ ^{o}K$$

6.2.2. Calculating Turbine Outlet Temperature

As dealing with the process isentropically, also as mentioned that no pressure drop during the heat addition process and that the pressure leaving the turbine is equal to the pressure entering the compressor, then consider P_2=P_3 and P_1= P_4.

From given $T_{3'}$ and pressure ratio (P_3/P_4) = (P_2/P_1). T4 can be calculated isentropically:

$$T_4 = \frac{T_{3'}}{\left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}}} = \frac{1343}{(14)^{0.25}}$$

From Equation [10], the actual temperature $T_{4'}$ using turbine isentropic efficiency:

$$T_{4'} = T_{3'} - \eta_T * (T_{3'} - T_4) = 1343 - (0.86) * (1343 - 694.6) = 785\ ^{o}K$$

Since , $T_1 = 288\ ^{o}$ K $T_{2'} = 664.7\ ^{o}$K $T_{3'} = 1343\ ^{o}$K $T_{4'} = 785\ ^{o}$ K

Referring to the previous equations:

$$W_{Comp} = h_{2'} - h_1 = C_{pa}\,(T_{2'} - T_1) = 1.005\ (664.7 - 288) = 378.6\ KJ/Kg$$

$$W_{Turb} = h_{3'} - h_{4'} = C_{pg}\,(T_{3'} - T_{4'}) = 1.11\ (1343 - 785) = 619\ KJ/Kg$$

$$W_{net} = W_{Turb} - W_{Comp} = C_{pg}\,(T_{3'} - T_{4'}) - C_{pa}\,(T_{2'} - T_1)$$

$$= 619 - 378.6 = 241 \text{ KJ/Kg}$$

$$p_{output} = W_{net} * m \quad = 241 * 528.6 = 127.393\ Mw$$

Thermal Efficiency Calculation

From Equation [8] at $T_1 = 15\,^o$ C thermal efficiency of the turbine =

$$\eta_{th} = \frac{W_{net}}{Q_{in}} = \frac{C_{pg}\,(T_{3`} - T_{4`}) - C_{pa}\,(T_{2`} - T_1)}{C_{pg}\,(T_{3`} - T_{2`})} = \frac{241}{1.11\,(1343 - 664.7)} = 32\ \%$$

By applying the same procedure of calculations at various ambient temperatures through year 2023 from January to November months, we getting the results that presented in Table 2.

Table 2: Results of flow mass and power output at different air inter temperatures

Month	$T_1\,^{\circ}C$*	Pressure ratio (r_p)	T_1 ^0K	$T_{3`}$ ^0K	$T_{4`}$ ^0K	W_c Kj/Kg	W_T Kj/Kg	W_{net} Kj/Kg	m_a Kg/s	P_{output} MW	η_{th} (%)
1	15	10.20	288	1340	783.3	378.9	617.9	239	544	130	32.0
3	20	11.92	293	1351	789.8	385.4	622.9	237.5	529	125.7	31.7
5	25	12.66	298	1360	795	392	627.2	235.2	488	114.8	31.5
7	30	12.85	303	1368	799.7	399	630.8	231	401	93	31.0
9	28	12.32	301	1364	797.4	396.5	628.9	232.4	445	103.4	31.3
11	23	11.05	296	1357	793.3	389.8	624.8	235.9	504	119	31.6
* Months average ambient temperatures											

The graphic representation of the obtained results between the ambient temperature and thermal efficiency, power output and flow mass parameters revealed an inversely relationship, whereas the increasing of ambient temperature leads to the decreasing of these parameters as shown in Figures 7, 8 and 9.

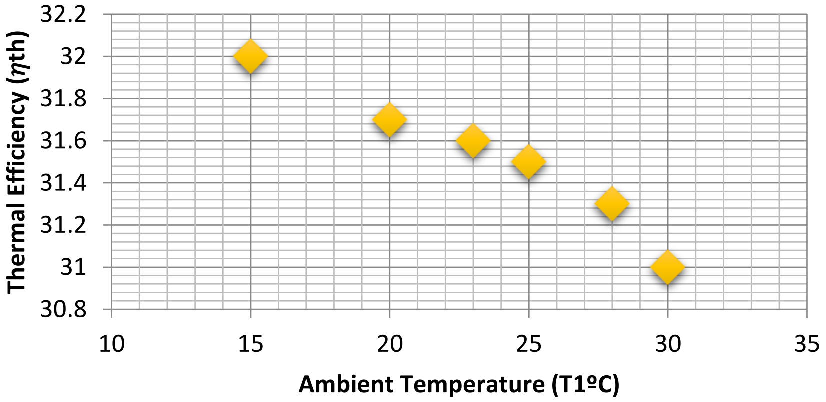


Figure 7: Relationship between ambient temperature and thermal efficiency

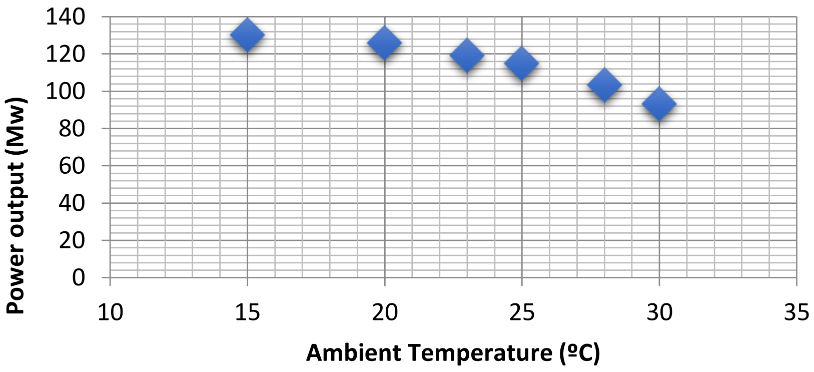


Figure 8: Ambient temperature against power output

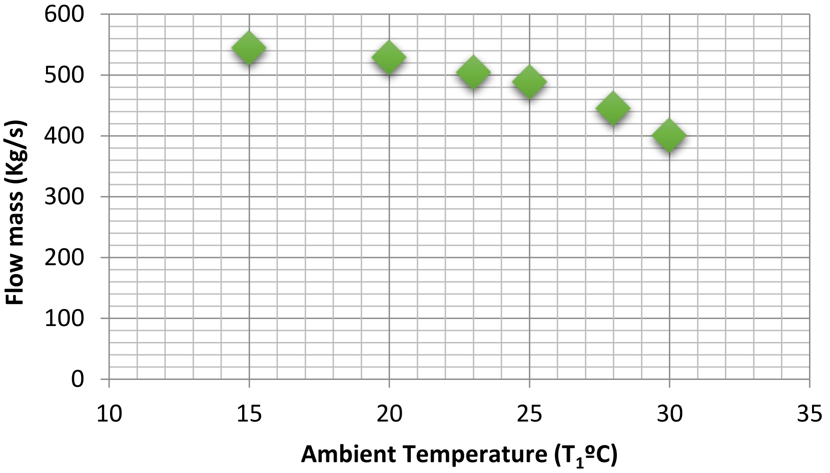


Figure 9: Ambient temperature against versus flow mass

On the other hand, the relationship between flow mass and power outputted a proportional behaviour, whereas the power output is increasing with increasing of flow mass as illustrated in Figure 10.

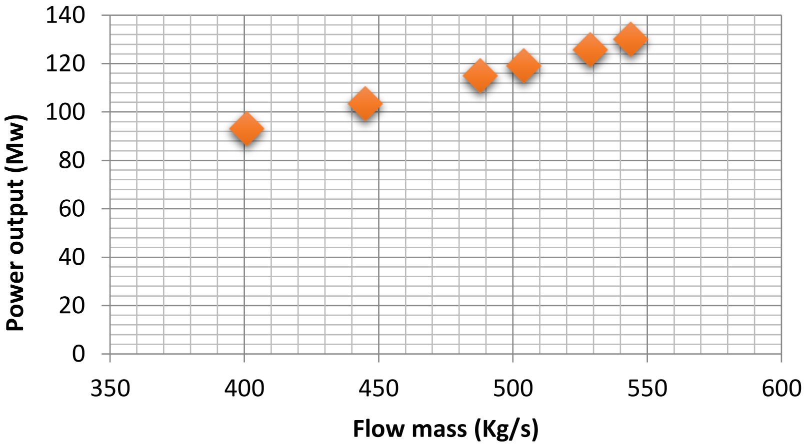
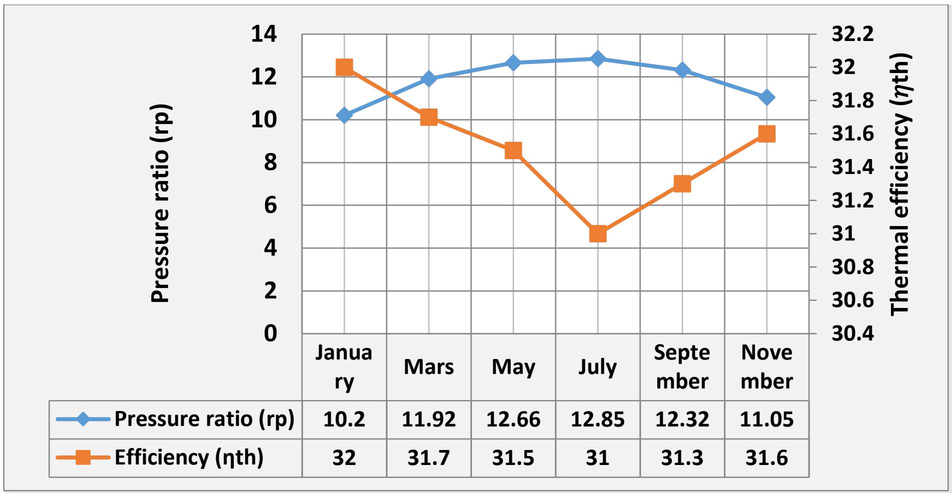


Figure 10: Relationship between flow mass and power outputted

Figure 11 shows the effect of r_p on the overall thermal efficiency for one year of unit operation and indicates that r_p is inversely related to unit efficiency, where an increase in r_p leads to a decrease in thermal efficiency through July and September months, whereas after this months the r_p was increased with an increase in thermal efficiency. Due to the rise in the relative humidity of the air, this result agrees with the results of references [11-14].

Humidity Impacts on Turbine Performance

Moisture in the intake air of a gas turbine can affect its operation and performance in two different ways: by possible condensation in the inlet and by changing the gas properties throughout the cycle. Condensation can be controlled by restricting engine operation with limits on relative and absolute humidities. Two fundamental correction approaches for the effects of humidity on major engine parameters can by performed. Both methods correct parameters as a function of absolute humidity, yielding corrections of between 0.1 and 0.8%, for high humidity test conditions.

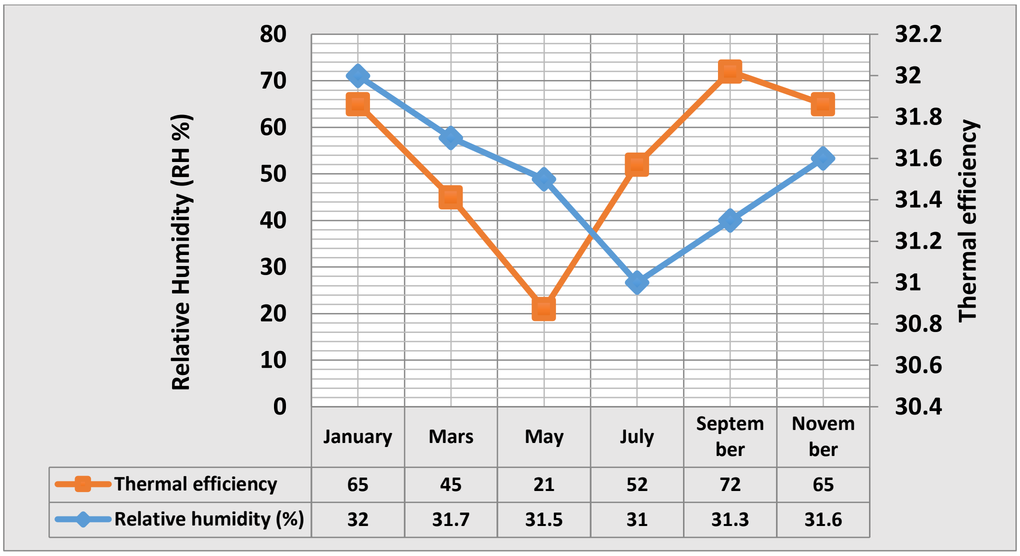


	January	Mars	May	July	September	November
Pressure ratio (rp)	10.2	11.92	12.66	12.85	12.32	11.05
Efficiency (ηth)	32	31.7	31.5	31	31.3	31.6

Figure 11: Effect of compression ratio on thermal efficiency

As we know that the Power Plant (BCCPP) under consideration located at the coastal area of Benghazi city. Generally, the coastal areas characterized by higher moisture due to evaporation processes and increasing water vapour in the atmosphere, consequently the increasing of relative humidity.

The relationship between relative humidity and thermal efficiency revealed an inversely relation. Figure 12 indicates that relative humidity (RH) affecting on the values of thermal efficiency, regardless of the air temperature, where the highest values of RH were recorded through January and Mars months, while the lowest thermal efficiency was recorded in May month.



	January	Mars	May	July	September	November
Thermal efficiency	65	45	21	52	72	65
Relative humidity (%)	32	31.7	31.5	31	31.3	31.6

Figure 12: Effect of relative humidity on thermal efficiency

Impact of Fuels Composition

Work from a gas turbine can be defined as the product of mass flow, heat energy in the combusted gas (Cp), and temperature differential across the turbine. The heat energy is a function of the elements in the fuel and the products of combustion.

Some general observations can be made when considering attributes of the hydrocarbon fuel being used, in particular the hydrogen–carbon ratio (H/C).

General Observations to Remember.

Figure 13 shows the total effect of various fuels on turbine output. This curve uses methane as the base fuel.

Natural Gas Fuel Characterizations

Natural Gases Properties

The determination of chemical composition of the natural gas fuel is an important factor to estimate the fuel specifications and quality indicators e.g. heating values (HHV & LHV), Wobbe index (WI), and methane number (MN).

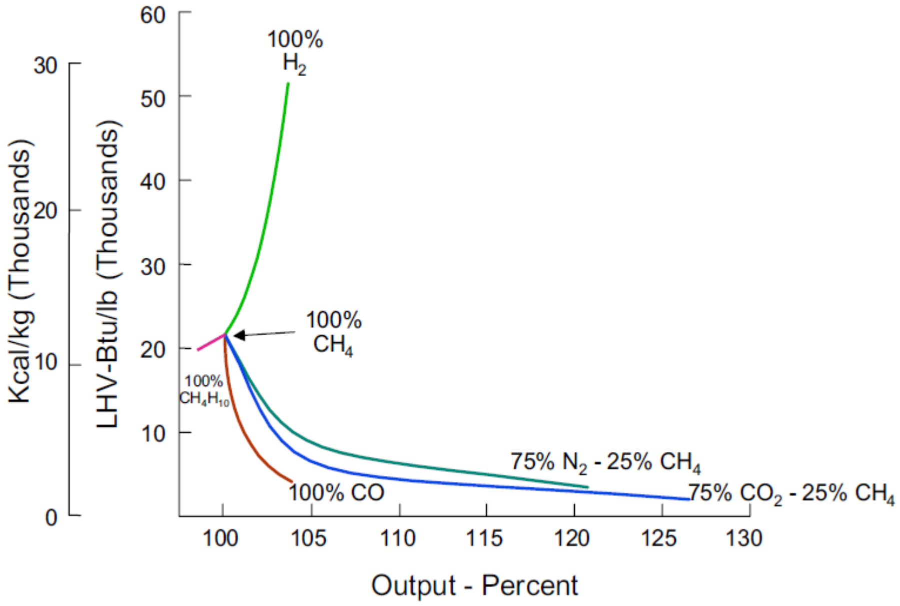


Figure 13: Effect of fuel heating value on output

Table 1 presents the chemical composition of the utilized natural gas fuel for power plant. On the other hand, the natural gas pseudocritical and pseudoreduced properties were calculated to estimate gas mixture specific gravity (SG), molecular weight (Mw) and compressibility factor (z) as shown in Table 2.

Table 2: Chemical composition of gas fuel for power plant

Components	*Mol. fraction*	*Critical press.*	*Critical temp.*	*Mol. weight*	$y_i p_{ci}$	$y_i T_{ci}$	$y_i M_i$
	y_i	p_{ci} (psi)	T_{ci} (°R)	M_i			
CH_4	0.782	673.1	343.0	16.043	526.36	268.23	12.55
C_2H_6	0.102	708.3	549.6	30.070	72.25	46.88	3.07
C_3H_8	0.052	617.4	665.6	44.097	32.10	34.61	2.30
C_4H_{10}	0.011	550.7	765.3	58.123	6.08	8.42	0.64
C_5H_{12}	0.020	489.0	845.6	72.150	9.78	16.91	1.44
C_6H_{14}	0.003	439.7	914.2	86.177	1.32	2.75	0.26
CO_2	0.012	1071.1	547.6	44.010	12.85	6.57	0.53
N_2	0.009	187.5	227.2	28.013	1.86	2.27	0.28
H_2S	0.010	493.1	672.4	34.08	4.93	6.72	0.34
$\sum$	1.001				$p_{pc}=$ 667.53	$T_{pc}=$ 393.36	$Mw=$ 21.41
Specific gravity			$SG = Mw/29 = 21.41/29 = 0.74$				
Pseudoreduced pressure (p_{pr})			$p_{pr}=\frac{p}{p_{pc}}=\frac{1500}{667.53}=2.43$				
Pseudoreduced temp. (T_{pr})			$T_{pr}=\frac{T+460}{T_{pc}}=\frac{570}{393.36}=1.45$				
Compressibility factor (z)			0.87				

Natural Gas Fuel Quality Indicators

Heating Value Types

1. Higher heating value (HHV): HV with latent heat included. Appears to be low efficiency.
2. Lower heating value (LHV): LV with latent heat excluded. Appears to be high efficiency.
3. Gross heating value = High heating value (HHV).
4. Net heating value = Low heating value (LHV).

Calculation Gross Heating Value of Natural Gases

The gross heating value of natural gases can be calculated for ideal gas according to Equation (9) [15]:

$$L_{c\,ideal} = \sum_i y_i L_{ci} \tag{9}$$

The above Equation can be used to calculate the gross heating value, and in many cases the units must be converted from ideal gas to real gas at standard conditions by dividing the ideal value on compressibility factor (z) at standard conditions according to Equation (10):

$$L_c = \frac{L_{c\,ideal}}{z} \tag{10}$$

The compressibility factor (z) can be estimated at standard conditions by applying Equation (11):

$$z = 1- \left(\sum_i y_i \sqrt{1 - z_i}\ \right)^2 \tag{11}$$

The gross heating values and Wobbe Index of natural gas fuel was calculated and presented in Tables 3.

The calculating heating value of natural gas fuel was 1240.26 *Btu/scf* with calorific value 30,105 (KJ/Nm^3). These values demonstrate that are within the range of required and specifications of natural gas fuel heating value for turbines of power plants. In General these index parameters quality are relay on the chemical composition of the natural gas utilized in turbines for power plants.

Wobbe Index of Natural Gases

The calculated Wobbe Index for natural gas fuel has been carried out and presented in Table 3. The Wobbe Index of a gas fuel with a specific gravity is 0.74 is 1441.77 heating value.

However, this gas ranges of specific gravities within the typical range mentioned in the literature survey of Wobbe index.

Methane Number of Natural Gas Fuel

Methane number has been calculated for the natural gas and presented in Table 3; whereas, the obtained results revealed a high number of MN (3120.10) which means high efficiency and hence lower CO_2 and a good performance of generating turbines.

Table 3: Quality indicators for natural gas fuel

Components	Mole fraction y_i	Gross heating value (Btu/scf) L_{ci}	$y_i L_{ci}$	Compressibility factor (z) Standard conditions	
				z_i	$y_i\sqrt{1 - z_i}$
CH_4	0.782	1009.7	789.59	0.9980	0.0349
C_2H_6	0.102	1768.8	180.42	0.9919	0.0092
C_3H_8	0.052	2517.5	130.91	0.9825	0.0069
C_4H_{10}	0.011	3262.1	35.88	0.00354	0.0110
C_5H_{12}	0.020	4009.6	80.20	0.00065	0.0199
C_6H_{14}	0.003	4756.2	14.27	0.00081	0.0030
CO_2	0.012	0.0	00.0	0.9943	0.00009
N_2	0.009	0.0	00.0	0.9997	0.00016
H_2S	0.010	0.0	00.0	-	--
$\sum$	1.001		1231.27 Btu/scf		0.08515

Gross heating value for ideal gas and compressibility factor at standard conditions	z = 1- ($\sum_i y_i\sqrt{1-z_i}$)^2 = 1- $(0.08515)^2$ = 0.9927
Gross heating value as real gas (GHV)	$L_c = \frac{L_{c\,ideal}}{z} = \frac{1276.25\ BTU/scf}{0.9927}$=1240.26 *Btu/scf*
Wobbe Index	$WI = \frac{HHV}{\sqrt{SG}} = \frac{1240.26}{\sqrt{0.74}} = 1441.77$
Calorific value	CV = 30,105 (KJ/Nm^3)
Methane number	MN = 3120.10

However, Table 4 presents the characterizations of different fuel types and how can each type have affected on the turbine performance according to the fuels heating values.

Table 4: Higher heating value (HHV) and lower heating value (LHV) for various fuels

Fuel type	Higher heating value (HHV)		Lower heating value (LHV)		LHV/HHV
	Btu/Ibm	Kj/Kg	Btu/Ibm	Kj/Kg	
Methane	23,875	55,533	21,496	49,997	0.09003
Propane	21,669	50,402	19,937	46,373	0.9201
Natural gas	22,500	52,335	20,273	47,153	0.9010
Gasoline	19,657	45,722	18,434	42,877	0.9378
No. 4 oil	18,980	43,938	17,804	41,412	0.9425
Source: Based on Babcock and Wilcox (1992) and Petchers (2002).					

CONCLUSIONS

In light of the previous study the performance assessment of gas turbines (GT) was carried out. The power output and thermal efficiency of the gas turbines are strongly influenced by the ambient temperature (T_1), pressure ratio (r_p), relative humidity, flow mass (Kg/s) and the turbine entry temperature. High r_p and high turbine inlet temperature produces high power output and thermal efficiency. The comparison of performance parameters (r_p, power output and thermal efficiency) showed the variation between the ISO rating, field data and calculated output of the gas turbines. However, the following conclusions can be drawn using various parameters:

1. The net output power and thermal efficiency of a GT cycle declines as inlet air temperature is increased.
2. The thermal efficiency is affected by increased both ambient temperature, pressure ratio and relative humidity.
3. GT performance is more impacted by ambient temperature than relative humidity.
4. Efficiency is increasing with the increasing of pressure ratio (r_p).
5. GT performance is also affected by natural gas fuel composition.
6. Natural gas fuel quality relay on the indicators of heating values (HHV, LHV), Wobbe index (WI), methane number (MN) and other parameters.

References

[1] Amir Abbas Zadpoor, Ali Hamedani Golshan, (2006) Performance improvement of a gas turbine cycle by using a desiccantbased evaporative cooling system, Energy 31, 2652–2664.

[2] F. Haglind, (2008) A review on the use of gas and steam turbine combined cycles as prime movers for large ships, Part III: Fuels and emissions, Energy Convers. Manage. 49 (12) 3476-3482.

[3] Testo Whitepaper testo 350 www.testo.com

[4] Madhlopa, A. (2018) Gas Turbine Fuels and Fuel Systems in Principles of Solar Gas Turbines for Electricity Generation, Green Energy and Technology, 27-49.

[5] Alajmi, A., Adam, N.M., Hairuddin, A.A., and Abdullah, L.C. (2019) Fuel atomization in gas turbines: A review of novel technology, International Journal of Energy Research, Review, 43(8), 3166-3181. doi: 10.1002/er.4415.

[6] Khudair, O.A., Abass, K.A., Abed, N.S., Ali, K.H., Abdul Aziz, S., and Shaboot, A.C. (2018) Theoretical Investigation For The Effect of Fuel Quality on Gas Turbine Power Plants in Ibn Al-Haitham, 1st International Scientific Conference on Biology, Chemistry, Computer Science, Mathematics, and Physics (IHSCICONF), 1003. doi: 10.1088/1742-6596/1003/1/012022.

[7] Liu, K.X., Sadasivuni, S., Parsania, N. (2019) Industrial gas turbine engine response and combustion performance to fuel changeovers in compositions and heating values, Fuel, Article, 242(4), 507-519. doi: 10.1016/j.fuel.2019.01.030.

[8] Razak, A. (2007) Industrial gas turbines: performance and operability, Elsevier, 2007.

[9] Alobaid, F., Ströhle, J., Epple, B., & Kim, H. G. (2009). Dynamic simulation of a supercritical once-through heat recovery steam generator during load changes and start-up procedures. Applied Energy, 86(7-8), 1274-1282.

[10] Petruzzi, L., Cocchi, S., & Fineschi, F. (2003). A global thermo-electrochemical model for SOFC systems design and engineering. Journal of Power Sources, 118(1-2), 96-107.

[11] Khaljani, M. Khoshbakhti Saray, R. and Bahlouli, K. (2015) "Comprehensive analysis of energy, exergy and exergo-economic of cogeneration of heat and power in a combined gas turbine and organic Rankine cycle," Energy Convers. Manag., vol. 97, pp. 154–165, 2015, doi: 10.1016/j.enconman.02.067.

[12] Sarkar J. (2012) Research 6/C E. analysis of a coal-based 210 M. thermal power plant. pd. Bhattacharyya, "Analysis of parameters affecting the performance of gas turbines and combined cycle plants with vapor absorption inlet air cooling," Arch. Thermodyn., vol. 33, no. 4, pp. 23–40, 2012, doi: 10.1002/er.

[13] Ibrahim, T. K. and Mohammed, M. N. (2015) "Thermodynamic Evaluation of the Performance of a Combined Cycle Power Plant," Int. J. Energy Sci. Eng., vol. 1, no. 2, pp. 60–70, [Online]. Available: http://www.publicscienceframework.org/journal/ijese.

[14] B. EH, F. S, and A. B, (2017) "Exergy Analysis for Brayton and Inverse Brayton Cycles with Steam Injection," J. Appl. Mech. Eng., vol. 06, no. 06, 2017, doi: 10.4172/2168-9873.1000292.

[15] Edmister, W., and Lee, B., (1986) Applied Hydrocarbon Thermodynamics, Vol. 1, 2nd ed. Houston: Gulf Publishing Company, 1986, p. 52.