Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

Influence of Surrounding Air Temperature and Humidity upon the Performance of a Gas Turbine Power Plant

Alaa Ahmad Sammour[1,2,*], Oleg V. Komarov[1], Farkad A. Lattieff[3], Mohammed A. Qasim[4], Ahmad Yousef Saleh[2,5]

[1] Turbines and Engines Department, Ural Federal University, Yekaterinburg 620002, Russia
[2] Mechanical Power Engineering Department, Mechanical and Electrical Faculty, Al Baath University, Homs, Syria
[3] Energy Department, University of Baghdad, Baghdad, Iraq
[4] Nuclear Power Plants and Renewable Energy Sources Department, Ural Federal University, 620002 Yekaterinburg, Russia
[5] Institute of Energy, Peter the Great St. Petersburg Polytechnic University, Saint Petersburg 195220, Russia

ARTICLE INFO

Article history:
Received 19 August 2023
Received in revised form 7 November 2023
Accepted 19 November 2023
Available online 15 December 2023

ABSTRACT

Nowadays, energy demand continuously rises while energy stocks are dwindling. Using current resources more effectively is crucial for the world. A wide method to effectively utilize energy is to generate electricity using thermal gas turbines (GT). One of the most important problems that gas turbines suffer from is high ambient air temperature especially in summer. The current paper details the effects of ambient conditions on the performance of a gas turbine through energy audits taking into account the influence of ambient conditions on the specific heat capacity (C_p), isentropic exponent (γ_h) as well as the gas constant of air (R_h). A computer program was developed to examine the operation of a power plant at various ambient temperatures and relative humidities. The ambient temperatures ranged from 0 to 45 ºC, with relative humidities from 10 to 90%. The obtained results show that a GT operated at increased inlet air temperatures is characterized by lower net power and thermal efficiency. At higher inlet air temperatures, increased relative humidity has a slight positive impact on the GT cycle net power and its thermal efficiency. Net output power of the GT decreased from 93.3 MW at 15 °C to 70 MW at 45 °C. Its efficiency decreased from 32.32% at 5 °C to 28.3% at 30 °C. Although fuel consumption is reduced, the heat rate as well and the specific fuel consumption (SFC) are enhanced. SFC increased by 5.36% with a 10 °C temperature rise in temperature at a constant relative humidity. Therefore, use of a gas turbine with inlet air cooling and humidification is appropriate for improved GT efficiency.

Keywords:
Gas turbines; ambient conditions; performance; energy

1. Introduction

A gas turbine (GT) is a heat engine in which hot flue gases, produced by burning fuel, drives a turbine that is used to generate power. Every GT has three basic components, an air compressor, a turbine and combustion chamber [1-4]. The turbine shaft is connected to a generator, which produces electrical energy through rotation of an electrical generator shaft [4-8]. GTs play an

* *Corresponding author.*
E-mail address: alpharam.eng@gmail.com

https://doi.org/10.37934/arfmts.112.1.2237

extremely important role in power generation, marine power plants and aircraft [9-12]. They are an essential component of every combined cycle power plant. There are numerous economic benefits to using gas turbines to generate electricity. GTs are compact, lightweight, and efficient, as well as highly flexible and reliable in operation. Other attractive features include their quick startup capability and remote operation. Their high reliability and compact size with a high power-to-weight ratio makes GTs an ideal power plant for aircraft and marine operations. A wide variety of liquid and gaseous fuels can be used in GTs, depending on the particular design and application. The fuel type and inlet air ambient conditions impact GT output power. Higher engine performance can be achieved with cooler compressor inlet air as its condition greatly impacts GT performance [1,8,13]. GT performance characteristics, in particular, output power and efficiency, are affected by changes in compressor parameters. Previous research has shown that cooler inlet air results in a higher air mass flow rate, and thus more power is produced by the turbine.

Several researchers have analyzed GT performance to determine how ambient temperature impacts optimal operation. Wan and Chen [14] analyzed GT performance at different temperatures by studying the thermodynamic characteristics and thermal properties of various working fluids. Their results showed that power generation decreased by 22.6% with increased ambient air temperatures from 5 to 35 °C. Additionally, the power output of a gas turbine and of steam were reduced by 17.0% and 16.2%, respectively. Glazar *et al.,* [15] did a thermodynamic examination of selected power plant Their results reveal that overall efficiency decreases while SFC increases with ambient air temperature. Şen *et al.,* [16] experimentally investigated the influence of inlet temperature changes on electricity production for a power plant burning natural gas. According to their results, power output as well as GT efficiency declined with increased ambient temperature, which requires an air-cooling system to improve both power and efficiency. According to Ahmed and Oudah [17], inlet air at reduced temperature increases the power output of a repowered CCPP, as well as its overall thermal efficiency. Hashmi *et al.,* [18] examined the impacts of cooling inlet air on the performance of an industrial GT. Their results revealed that the intake air temperature has a great influence on GT performance. Yazdi *et al.,* [6] documented the impact of utilizing inlet fogging, which is a type of absorption cooling, as well as heat pump systems, to improve turbine performance by means of cooling inlet air in four different areas. Their results indicate that cooling inlet air has the potential for output power augmentation. Liu *et al.,* [19] analyzed GT performance with a novel inlet air cooling system using the cooling effect of liquefied natural gas. Their results demonstrated that power plant performance was improved utilizing this cooling system.

Although the ambient conditions effects on gas turbine plants performance have been extensively carried out, previous studies examined the impacts of environmental factors on the gas turbine performance considering the specific heat capacity (C_p), isentropic exponent (γ_h) and the gas constant of air (R_h) constant. However, they change in varying degrees according to different operating conditions. Additionally, previous studies took the effect of relative humidity on the mass flow value into account, but neglected the effect of relative humidity on other thermodynamic properties. Therefore, the aim of this study is to determine to what extent the gas turbine performance is affected by relative humidity and temperature. In the current study, we present a thermodynamic analysis of the properties of air as a working gas for a power plant. Operating parameters of the active gas turbine used in the city of Jandar, in Syria, are simulated to evaluate the effect of ambient conditions on the performance. Furthermore, the influence of ambient temperature and humidity is evaluated using a commercial computer program.

2. Plant Description

The power plant examined in the current study is located in Homs City, in central Syria. It entered service in 1994. The power house is equipped with two Mitsubishi GT MW-701 type units [15]. Typically, GT power plants have four essential components, as shown in Figure 1, that include a combustion chamber (CC), an air compressor (AC), an electrical generator (EG) and a turbine. Such GT plants operate on the Brayton cycle. When air enters a compressor, it undergoes compression to 10.7 bars, which increases its temperature at the compressor outlet. Compressed air is passed through a combustion chamber, where it is heated by burning fuel. Mixing, burning, dilution, and cooling are functions achieved in a combustion chamber. As a result, when gas leaves the combustion chamber and enters a GT, it is a mixed gas with an average temperature. Hot gases exiting the combustion chamber expand in the GT. This produces mechanical power before release into the atmosphere. Part of the mechanical energy generated by a GT is utilized to turn the air compressor shaft, while the remaining energy used to produce electrical power.

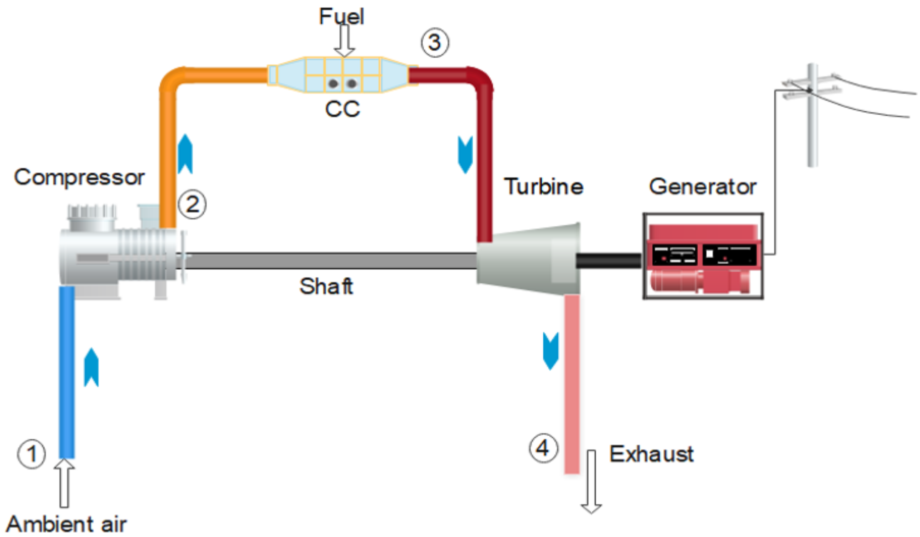

Fig. 1. Schematic diagram of the gas turbine in the current study

3. Mathematical Modelling

Several simplifying assumptions were made to calculate the energy, mass and exergy balances of the various parts of the gas turbine in the current study. These assumptions included the following:

i. For ambient conditions, only temperature and relative humidity are taken into consideration.
ii. Natural gas was used as fuel in the combustion chamber, and its composition and properties are shown in Table 1.
iii. Auxiliary electrical power as well as kinetic and potential energies were not considered.
iv. The ISO environmental parameters are 15 ºC, 1.013 bar, and 60% relative humidity.

Each unit was treated as a distinct and separate entity. Analysis of each control entity at steady state is as follows [22].

Table 1
Properties and composition of natural gas

Component	Mass (%)	LHV (MJ/kg)	HHV (MJ/Kg)
CH_4	74	50	55.5
C_2H_6	13.1	47.80	51.9
C_3H_8	5.1	46.35	50.35
C_4H_{10}	3.2	45.75	49.5
N_2	4.1	0	0
CO_2	0.5	0	0
Total/Average	100	47.1	52.02

3.1 Air Compressor

Air at an ambient pressure, P_1, and temperature, T_1, is drawn into an AC. The temperature at the AC outlet (T_2) is affected by the pressure ratio (r_P), AC isentropic efficiency (η_c) and the specific heat ratio (γ). Compressed air temperature can be expressed as [22,23]:

$$T_2 = T_1 + \frac{T_{2s}-T_1}{\eta_c} = T_1\left(1 + \frac{r_P^{\frac{\gamma_a-1}{\gamma_a}}}{\eta_c}\right) \quad (1)$$

When blade cooling is not considered, compressor work can be expressed as [24]:

$$W_c = \dot{m}_{dry.air} * C_{p.a}(T_2 - T_1) + \dot{m}_v * (h_{v2} - h_{v2}) \quad (2)$$

where $\dot{m}_{dry\ air}$ equals the dry air mass flow, $C_{p.a}$ is the dry air heat capacity and $\dot{m}_v$ is the mass flow rate of water vapor. Psychometric determination of the thermodynamic properties of moist air are determined under specified dry and wet bulb temperatures as well as its relative humidity.

The moist air mass flow rate can be defined by [25]:

$$\dot{m}_{humid\ air} = \dot{m}_{dry\ air} + \dot{m}_v \quad (3)$$

where $\dot{m}_{humid\ air}$ is humid air mass flow rate. For specified conditions, the dry air rate is [7]:

$$\dot{m}_{dry\ air} = \frac{v * \rho_{humid}}{(1+\omega)} \quad (4)$$

The specific humidity is normally defined as [19,20]:

$$\omega = 0.622\,\frac{P_v}{Pa} \quad (5)$$

where P_v and Pa respectively represent the partial pressures of water vapor and dry air.

Given Eq. (3):

$$\dot{m}_{humid\ air} = \dot{m}_{dry\ air}(1+\omega) \quad (6)$$

Relative humidity is, by definition, the ratio of the actual vapor partial pressure (P_v) to the vapor partial pressure (P_v) when air is saturated at a given temperature. Normally, it is calculated as [6]:

$$\varphi = \frac{P_v}{P_{vs}} \tag{7}$$

where P_{vs} is the partial pressure of saturated vapor.

$h_{v2} - h_{v2}$ in (2) is the enthalpy change of water vapor from the inlet to the outlet of an AC, approximated as [26]:

$$h_{vi} = 2501.3 + 1.8723\, T_i \tag{8}$$

where T is the temperature of vapor in ºC, and (i) denotes state points 1, 2 or 3.

3.2 Combustion Chamber Model

In a CC, moist air coming from the AC and fuel are inlet fluids. Exhaust fluids are flue gases and water vapor as combustion products. Analysis of combustion chamber operations entails an energy balance as:

$$\dot{m}_{dry\ air} C_{pa}(T_2 - T_1) + \dot{m}_v h_{v2} + m_f LHV \eta_{cc} + m_f C_{pf} T_f = C_{pg}\left(\dot{m}_{dry\ air} + m_f\right) T_3 + \dot{m}_v h_{v3} \tag{9}$$

where LHV is the lower heating value of the fuel in kJ/kg, m_f represents the fuel mass flow rate in kg/s, C_{pf} and C_{pg} are the specific heat capacities for fuel and combustion gases in kJ/kg.°C, respectively. T_3 represents an inlet turbine temperature in °C, T_f is fuel temperature in °C, η_{cc} is AC efficiency, h_{v3} is saturated vapor enthalpy exiting the combustion chamber in kJ/kg.

Given Eq. (9), a fuel to air ratio is:

$$\dot{m}_f = \frac{\dot{m}_{dry\ air}\left(C_{pg} * T_3 - C_{pa} * T_2\right) + \dot{m}_v (h_{v3} - h_{v2})}{\eta_{cc} * LHV + C_{pf} * T_f - C_{pg} * T_3} \tag{10}$$

Heat generated due to fuel combustion with compressed air can be determined as:

$$Q_{add} = \dot{m}_f LHV \eta_{cc} \tag{11}$$

3.3 Turbine Model

If the inlet temperature of flue gas, pressure ratio (πt) and turbine efficiency (ηt) are known, a flue gas outlet temperature (T4) can be calculated as [7]:

$$T_4 = T_3 \left(1 - \eta_t * \left(1 - \frac{1}{r_t^{\frac{\gamma_g - 1}{\gamma_g}}}\right)\right) \tag{12}$$

The isentropic exponent γ_g for flue gases is:

$$\gamma_g = \frac{C_{pg}}{C_{pg} - R_g} \tag{13}$$

R_g, a gas constant for flue gases, is defined as [26]:

$$R_g = 287.1 + \frac{212.9}{AFR} - 197.9\left(\frac{1}{AFR^2}\right) \tag{14}$$

where AFR is the air to fuel ratio.

The energy output produced by the gas turbine shaft can be determined as:

$$W_t = \dot{m}_g C_{pg}(T_3 - T_4) \tag{15}$$

The mass flow rate of flue gases is comprised of three fluxes:

$$\dot{m}_g = \dot{m}_f + \dot{m}_{dry\ air} + \dot{m}_v \tag{16}$$

Substituting Eq. (16) in Eq. (15) yields:

$$W_t = (\dot{m}_f + \dot{m}_{dry\ air}(1+\omega))C_{pg}(T_3 - T_4) \tag{17}$$

From the GT output power and the work absorbed by the AC, net output power is:

$$W_{net.t} = (w_t - w_c) * \eta_m * \eta_G \tag{18}$$

GT efficiency η_{th} is calculated as:

$$\eta_{th.GT} = \frac{W_{net.t}}{\dot{m}_f * LHV} \tag{19}$$

The heat rate, an estimate of the heat necessary to produce a unit of electricity, is:

$$HR = \frac{3600}{\eta_{th.GT}} \tag{20}$$

The gas constant of moist air, $R_{h,}$ is given by [26]:

$$R_h = \frac{8.3143}{MW_h} \tag{21}$$

where, MW_h is the humid air molecular weight, given by [26]:

$$MW_h = \frac{1}{\left(\frac{V_f}{18.015}\right) + \left(\frac{A_f}{28.79}\right)} \tag{22}$$

V_f is the mass fraction of vapor given by:

$$V_f = \frac{\omega}{\omega+1} \tag{23}$$

A_f is the dry air mass fraction, and can be calculated as:

$$A_f = 1 - V_f \tag{24}$$

4. Methodology

The reference operating conditions are the fixed ISO ambient parameters, 15 ºC, 60% RH, and 100% design load. Engineering Equation Solver (EES) was utilized in this study for calculation of various parameters [27]. Its advantages include having accurate thermodynamic parameters of diverse working fluids and its capacity to solve non-linear equations. EES is a mathematical software program that has been extensively used for solving thermodynamic problems. All the expressions employed the analysis done in the current study involve mass, energy and momentum equilibrium. Additionally, EES has been widely used for numerous academic and engineering purposes. For example, it has been employed for analyses of double pressure steam boilers having duct burners for a repowering power plant, and for analyzing the overall performance of gas turbines [28,29]. Additionally, it has been used for evaluation of several GT components and various combined cycle power plants to consider exergy destruction [25]. Nevertheless, the validity of the software was assessed before proceeding to the main analysis. OriginPro 2021b was used to plot various figures [30,31]. The obtained results were compared with a base-case cycle. This analysis was done in a way that the intake air temperature and relative humidity were varied while other parameter values were fixed. The impacts of ambient conditions on the thermodynamic response of the system were examined by changing the ambient air temperature to values from 5–45 ºC using three different relative humidities.

5. Validation

For the purpose of calculation validation of the obtained results, a comparison was done using operational data [32]. Table 2 gives a comparison between the performance of the gas turbine plant and the results obtained from the model of the current study. The maximum SFC error is 3.38%. It can be observed that simulation outcomes coincide quite well with the measured values, demonstrating acceptable agreement. The model was validated with operational data under ISO conditions.

Table 2
Comparison of operational and calculated parameters for the power plant at ISO condition

Description	Unit	Ref (Qasim *et al.,* [32])	This study	*Error [%]
GT output	(MW)	93.9	93.27	-0.6808
Heat Rate	(kJ/kW-hr)	11.45	11.746	2.602
Exhaust gas temperature	(K)	797.12	800.4	0.411
Exhaust gas flow	(kg/sec)	304.24	303.2	-0.3451
SFC	(Kg/kW-hr)	0.24	0.248	3.38
GT efficiency	-	0.3412	0.306	0.263

*Error [percentage] = (computed - Ref) × 100/ Ref.

6. Results

P-v and T-s plots can be used to explain the effects of higher inlet air temperatures on the output power of a gas turbine. Path 1–2–3–4 in Figure 2(a) and Figure 2(b) depicts an ideal Brayton cycle under ISO conditions, while path l' –2' –3–4 illustrates an actual cycle at higher inlet air temperatures. The required AC power for a given mass flow at ISO is depicted as the region, 1-a-b-2, in Figure 2(a) and Figure 2(b). The area 1'-a-b-2' represents the required AC power per unit mass flow under elevated inlet temperatures, which are higher values than the ISO parameters. The output turbine power is the identical, so, the net power output for a given mass flow rate declines.

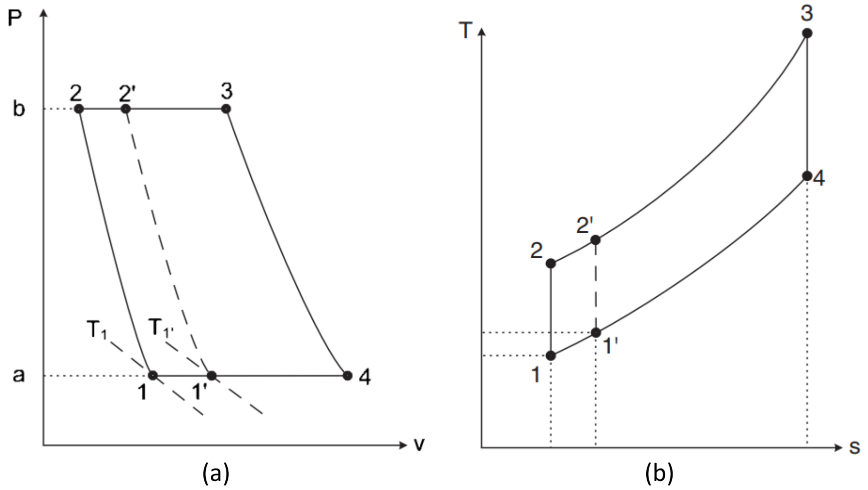

Fig. 2. Impact of elevated ambient temperatures expressed on (a) P–v and (b) T–s diagrams

The gas constant, R_h, and specific heat at constant pressure, C_p, increase with the ambient temperature while the specific heat ratio, γ, declines, as shown in Figure 3. This illustrates variation of gas properties with ambient temperature at constant relative humidity of 60%. Also, the variation in $R_h$is small compared with $C_p$and R_h. Increasing C_p means increasing the specific work of the AC and its power is directly proportional to the specific heat capacity. Increasing R_h results a greater air humidity entering the compressor thus lowering its mass flow rate, as shown in Figure 4.

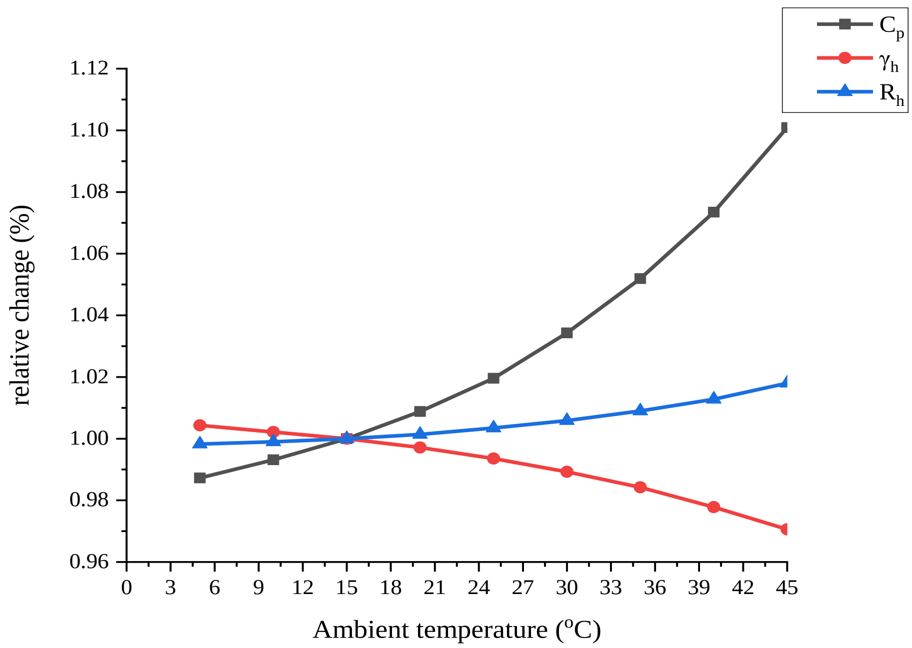

Fig. 3. Variation of C_p, R and γ of dry air with ambient temperature

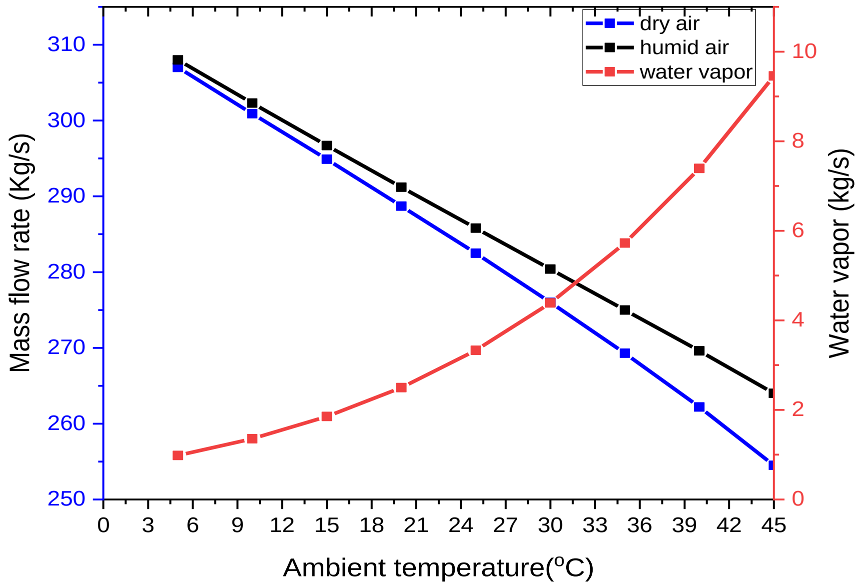

Fig. 4. Variation of mass flow of humid and dry air as well as the water vapor with ambient air

In Figure 4, as ambient air temperature increases, both the dry and humid mass flow rates drop while the water vapor mass flow increases as a result of greater specific humidity. These parameters will very negatively impact gas turbine performance. An increased specific humidity reduces the air mass flow in the gas circuit since the atomic mass of H_2O is less than N_2 and O_2 [26]. For a given volume, moist air has a lower mass than dry air, so, moist air is less dense. The resulting lower density air reduces the humid-air mass flow-rate entering the AC [26]. Figure 5 shows a variation of dry air and water vapor mass fraction with ambient air. According to these results, between 5 and 45 °C, using a 40 °C temperature difference with a 60% relative humidity, there is a 3.27 % decrease in dry air mass fraction while the vapor mass fraction increases by the same value.

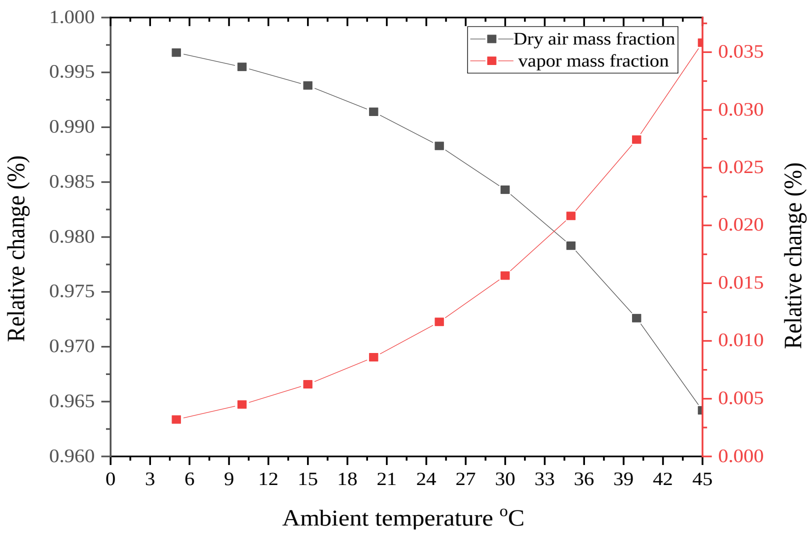

Fig. 5. Variation of dry air and the water vapor mass fraction with ambient air at relative humidity of 60%

The impacts of inlet air temperature on the AC specific work are shown in Figure 6. These results indicated that with increased air inlet temperature, more specific work must be done by the compressor. Hence, gas turbine efficiency is decreased with increased compressor inlet temperature [7]. Notably, when the inlet air temperature is increased from 15 to 45 °C, the compressor specific work increased by 4.78% at 60% relative humidity, as seen in Figure 6 The results demonstrate that relative humidity has a noticeable effect at a higher inlet air temperature, as more water vapor is contained by the air, resulting in a decreased density. When the inlet air temperature is 35 °C, there was a 6.18% decrease in AC specific power as relative humidity is increased from 10 to 90%.

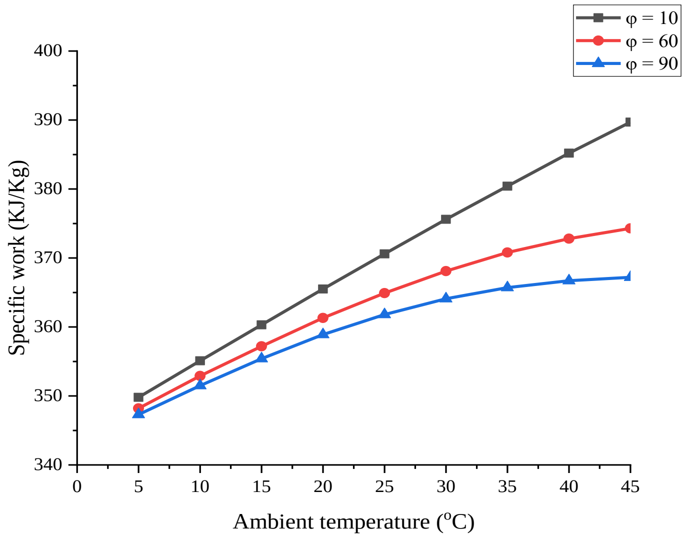

Fig. 6. Compressor specific work versus air inlet temperature

Figure 7 demonstrates the ambient temperature and relative humidity impacts the net output power of a GT. At decreased temperature, no variation in output power is observed. With higher temperatures, increased relative humidity results in greater output power. This is foreseen as a decline in turbine power is expected to be less than the reduction in compressor power, increasing the net GT output power. With reduced air mass flow rate, the compressor and turbine power requirements are diminished, as can be seen in Figure 4 and Figure 5. The loss in turbine power is less than that of compressor power since more fuel is supplied to the CC, leading in a greater gas flow rate. In Figure 7, with increased relative humidity, output power increases. This figure demonstrates that ambient temperature has significant influence on GT performance. As a GT runs at different ambient temperatures, output power is greater at lower temperatures than at higher temperatures. As ambient temperature is increased, the output power of a GT is reduced since it is directly related to the air mass flow rate. With increased dry bulb temperatures, the density of the air passing through the unit decreases. This necessitates more compressor work to generate less useful turbine work. The results indicate that when the relative humidity was 10%, the power output dropped from 92.037 MW at 15 °C to 76.87 MW at 30 °C and to 67.9 MW at 40 °C. Additionally, when the relative humidity was 90%, the power output decreased from 94 MW at 15 °C to 81.28 MW at 30 °C and to 75 MW at 40 °C.

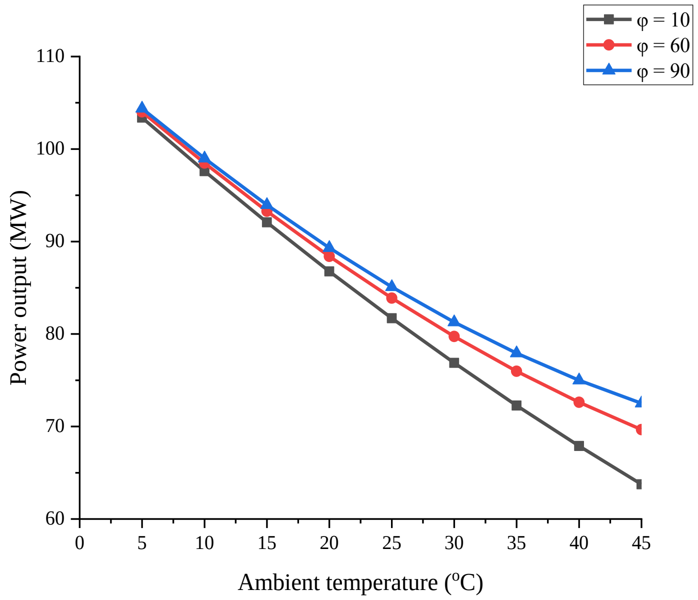

Fig. 7. Variation of output power as a function ambient temperature and relative humidity

Figure 8 is a plot of cycle efficiency with intake temperature at various relative humidities. It was found that efficiency drops with increased ambient air temperature, as expected. The compressor specific work and exhaust temperature increases with the ambient temperature. Thus, GT thermal efficiency was reduced. At a constant relative humidity of 60%, GT efficiency was reduced from 32.32% at 5 °C to 28.3% at 30 °C. The effects of the relative humidity on thermal efficiency are presented in Figure 8. The results show no impact at lower ambient temperatures, while at higher temperatures (> 310 K), increased relative humidity enhances efficiency.

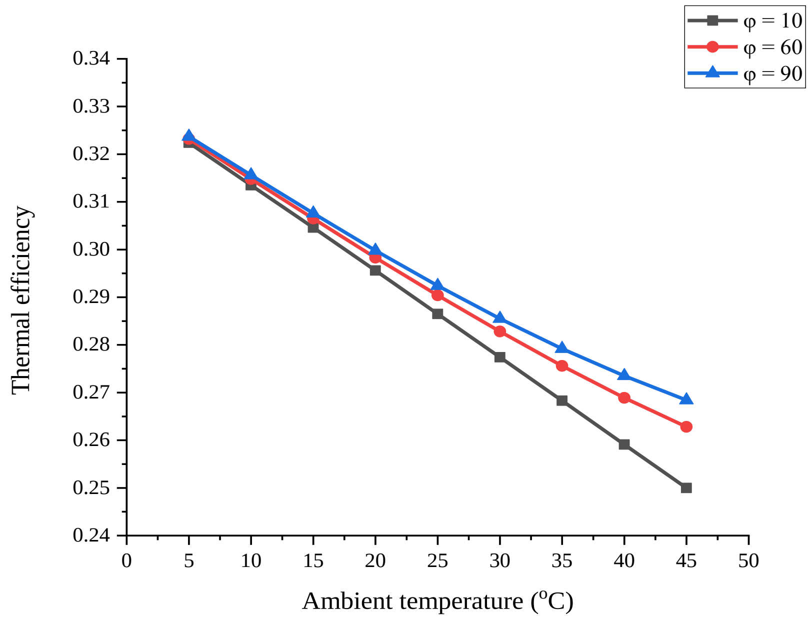

Fig. 8. Variation of efficiency as a function of ambient temperature and RH

Figure 9 illustrates that the specific fuel consumption rises with ambient temperature. At higher ambient temperatures, variation of specific fuel consumption is more significant. This figure shows the dependence of specific fuel consumption on temperature and relative humidity. The specific fuel consumption increased by 5.36% with a 10 °C increase in temperature at constant relative humidity of 60%. As the air to fuel ratio was maintained constant, higher specific fuel consumption means that more fuel is required to provide the same output.

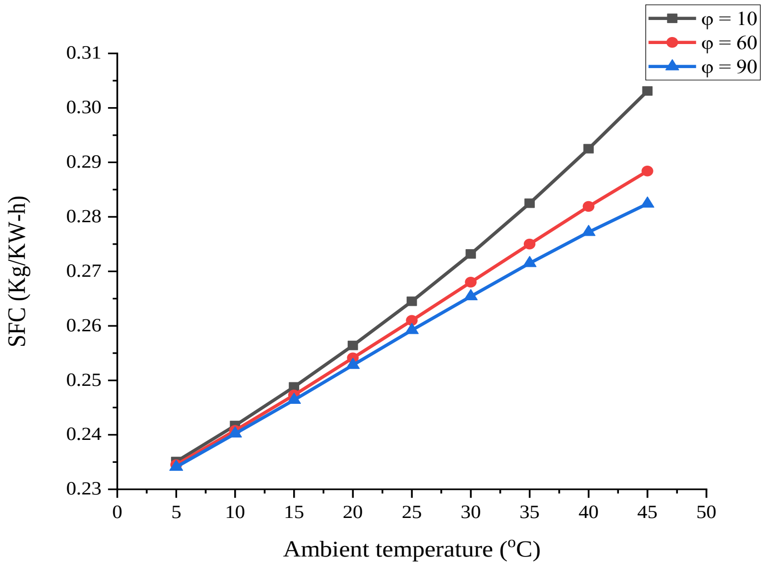

Fig. 9. Variation in specific fuel consumption according to ambient temperature and relative humidity

Figure 10 depicts the impacts of inlet air temperature on air and fuel flow rates. It is well-established that the density of air decreases as air temperature increases. The turbine inlet temperature in this research was maintained constant (1100 °C) according to manufacturer specifications. With lower intake air density, the mass flow rate of fuel is reduced for the same turbine inlet temperature [33]. Additionally, the outlet temperature of a compressor increases with inlet air temperature. This will decrease the fuel mass flow to maintain a fixed inlet temperature, resulting in reduced output power and cycle efficiency. In Figure 10, clearly, at constant relative humidity of 60%, as the ambient air temperature is increased from 15 °C to 45 °C, fuel consumption shows a 12.8% decline.

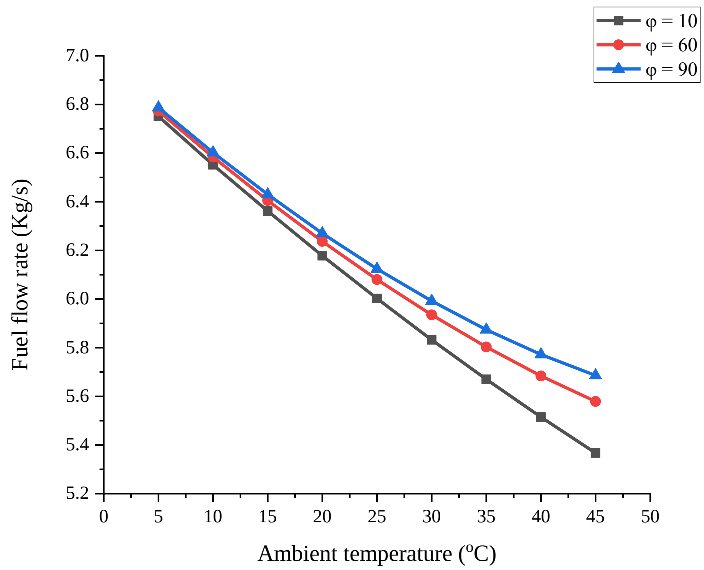

Fig. 10. Variation of fuel mass flow rate with ambient temperature and relative humidity

Figure 11 is a correlation between exhaust gas and ambient temperatures. The energy value of waste exhaust gas was 211 MW at an ambient temperature of 15 °C. When this temperature was increased to 20 °C, energy generation decreased by 1.42%. When the inlet air temperature was increased to 35 °C, energy lost in exhaust gases decreased by 5.21%.

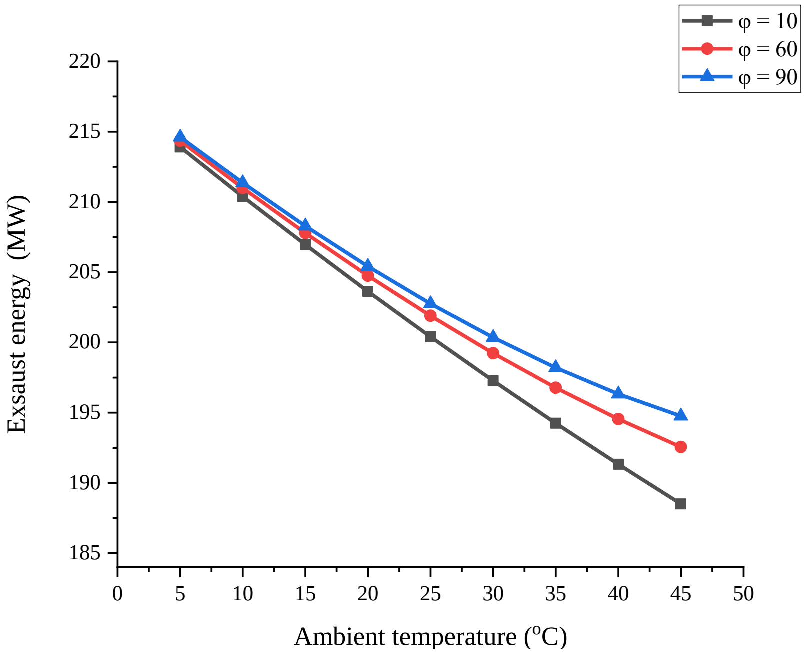

Fig. 11. Variation exhaust energy with ambient temperature and relative humidity

7. Conclusions

Using various inlet air flow temperatures and relative humidities, an energy study of a gas turbine found that:

i. The net output power and thermal efficiency of a GT cycle declines as inlet air temperature is increased.
ii. A slightly positive effect was observed on the net output power and thermal efficiency of the GT cycle with increased relative humidity.
iii. The influence of relative humidity can be better observed at higher inlet air temperatures.
iv. The heat ratio and specific fuel consumption both increase with inlet air temperature. They are slightly affected by increased relative humidity.
v. As ambient temperature increases, fuel consumption and energy losses in exhaust gases are reduced.
vi. GT performance is more impacted by ambient temperature than relative humidity.

Thus, this type of research work is a remarkable opportunity to understand the thermal performance of processes using modelling to determine the losses in power output and efficiency. Future research should examine the exergy of the sub-processes, the impacts of high humidity and temperature on their exergy, and the potential advantages of various methods of inlet air cooling. Equipping a plant with a cooling system to reduce inlet air temperature entering a compressor will result in a significant improvement in overall plant performance.

Acknowledgement
This research was not funded by any grant.

References
[1] Sammour, Alaa Ahmad, Oleg V. Komarov, Mohammed A. Qasim, Samair Almalghouj, Ali Mazen Al Dakkak, and Yang Du. "Ambient conditions impact on combined cycle gas turbine power plant performance." *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* 45, no. 1 (2023): 557-574. https://doi.org/10.1080/15567036.2023.2172100
[2] Salleh, Hamidon, Amir Khalid, Syabillah Sulaiman, Bukhari Manshoor, Izzuddin Zaman, Shahrin Hisham Amirnordin, Amirul Asyraf, and Wahid Razzaly. "Effects of fluid flow characteristics and heat transfer of integrated impingement cooling structure for micro gas turbine." *CFD Letters* 12, no. 9 (2020): 104-115. https://doi.org/10.37934/cfdl.12.9.104115
[3] Khattak, M. A., N. S. Mohd Ali, N. H. Zainal Abidin, N. S. Azhar, and M. H. Omar. "Common Type of Turbines in Power Plant: A Review." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 3, no. 1 (2016): 77-100.
[4] Sofia, Evi, Nandy Putra, and B. Ali Gunawan. "Evaluation of indirect evaporative cooling performance integrated with finned heat pipe and luffa cylindrica fiber as cooling/wet media." *Journal of Advanced Research in Experimental Fluid Mechanics and Heat Transfer* 3, no. 1 (2021): 16-25.
[5] Yacob, Noraishah Shafiqah, Hassan Mohamed, and Abd Halim Shamsuddin. "Investigation of palm oil wastes characteristics for co-firing with coal." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 23, no. 1 (2021): 34-42. https://doi.org/10.37934/araset.23.1.3442
[6] Yazdi, Mohammad Reza Majdi, Fathollah Ommi, M. A. Ehyaei, and Marc A. Rosen. "Comparison of gas turbine inlet air cooling systems for several climates in Iran using energy, exergy, economic, and environmental (4E) analyses." *Energy Conversion and Management* 216 (2020): 112944. https://doi.org/10.1016/j.enconman.2020.112944
[7] Umar, Hamdani, Teuku Muhammad Kashogi, Sarwo Edhy Sofyan, Razali Thaib, and Akram Akram. "CFD Simulation of Tesla Turbines Performance Driven by Flue Gas of Internal Combustion Engine." *Journal of Advanced Research in Applied Mechanics* 98, no. 1 (2022): 1-11. https://doi.org/10.37934/aram.98.1.111

[8] Martin, Awaludin, Nur Indah Rivai, Rahmat Dian Amir, and Nasruddin Nasruddin. "Exergoeconomic analysis of 21.6 MW gas turbine power plant in Riau, Indonesia." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 84, no. 1 (2021): 126-134. https://doi.org/10.37934/arfmts.84.1.126134
[9] Bahambary, Khashayar Rahnamay, and Brian Fleck. "A study of inflow parameters on the performance of a wind turbine in an atmospheric boundary layer." *Journal of Advanced Research in Numerical Heat Transfer* 11, no. 1 (2022): 5-11.
[10] Komarov, Oleg V., Viacheslav A. Sedunin, Vitaly L. Blinov, and Alexander V. Skorochodov. "Parametrical diagnostics of gas turbine performance on site at gas pumping plants based on standard measurements." In *Turbo Expo: Power for Land, Sea, and Air*, vol. 45660, p. V03BT25A012. American Society of Mechanical Engineers, 2014. https://doi.org/10.1115/GT2014-25392
[11] Matjanov, Erkinjon. "Gas turbine efficiency enhancement using absorption chiller. Case study for Tashkent CHP." *Energy* 192 (2020): 116625. https://doi.org/10.1016/j.energy.2019.116625
[12] Mat Noh, Nor Amelia Shafikah, Baljit Singh Bhathal Singh, Muhammad Fairuz Remeli, and Amandeep Oberoi. "Experimental Study on Waste Heat Recovery from an Internal Combustion Engine Using Thermoelectric Generator." *Journal of Advanced Research in Applied Mechanics* 72, no. 1 (2020): 25-36. https://doi.org/10.37934/aram.72.1.2536
[13] Khattak, M. A., A. Arif, A. Hannan, F. Syukri, and H. Hamid. "Design and planning of a nuclear power plant in Malaysia: A feasibility report." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 3, no. 1 (2016): 67-76.
[14] Wan, Anping, and Ting Chen. "Performance degradation analysis of combined cycle power plant under high ambient temperature." *Thermal Science* 26, no. 2 Part C (2022): 1897-1906. https://doi.org/10.2298/TSCI210221226W
[15] Glazar, V., V. Mrzljak, and T. Gubic. "Thermodynamic Analysis of Combined Cycle Power Plant." In *14th International Conference Heat Transfer, Fluid Mechanics and Thermodynamics*, pp. 355-341. 2019.
[16] Şen, Günnur, Mustafa Nil, Hayati Mamur, Halit Doğan, Mustafa Karamolla, Mevlüt Karaçor, Fadıl Kuyucuoğlu, Nuran Yörükeren, and Mohammad Ruhul Amin Bhuiyan. "The effect of ambient temperature on electric power generation in natural gas combined cycle power plant-A case study." *Energy Reports* 4 (2018): 682-690. https://doi.org/10.1016/j.egyr.2018.10.009
[17] Ahmed, Y. S., and H. M. Oudah. "Influence of ambient temperature on the performance of repowered combined cycle power plant." *The Iraqi Journal for Mechanical and Material Engineering* 17, no. 1 (2017): 40-56.
[18] Hashmi, Muhammad Baqir, Mohd Amin Abd Majid, and Tamiru Alemu Lemma. "Combined effect of inlet air cooling and fouling on performance of variable geometry industrial gas turbines." *Alexandria Engineering Journal* 59, no. 3 (2020): 1811-1821. https://doi.org/10.1016/j.aej.2020.04.050
[19] Liu, Zuming, Iftekhar A. Karimi, and Tianbiao He. "A novel inlet air cooling system based on liquefied natural gas cold energy utilization for improving power plant performance." *Energy Conversion and Management* 187 (2019): 41-52. https://doi.org/10.1016/j.enconman.2019.03.015
[20] Sammour, Alaa Ahmad, Oleg V. Komarov, Mohammed A. Qasim, and Ahmad Yousef Saleh. "Investigation of the Influence of Ambient Conditions on the Thermodynamic Characteristics of Air as a Working Fluid for Gas Turbines." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 106, no. 1 (2023): 182-196. https://doi.org/10.37934/arfmts.106.1.182196
[21] Daoud, Raid W., Ahmed H. Ahmed, Wadhah H. Al Doori, Ataalah H. Jassim, Anmmar M. Ahmed, and Zaid H. Ali. "Exergy and Energy Analyses of 70 Mw Gas Turbine Power Plant Using Fuzzy Logic Control." In *2021 International Conference on Engineering and Emerging Technologies (ICEET)*, pp. 1-6. IEEE, 2021. https://doi.org/10.1109/ICEET53442.2021.9659610
[22] Blumberg, Timo, Marwan Assar, Tatiana Morosuk, and George Tsatsaronis. "Comparative exergoeconomic evaluation of the latest generation of combined-cycle power plants." *Energy Conversion and Management* 153 (2017): 616-626. https://doi.org/10.1016/j.enconman.2017.10.036
[23] Alnasur, Fawzi Sh, and Mushtaq A. Al-Furaiji. "Estimation the performance of gas turbine power station with air cooling fog system." In *Journal of Physics: Conference Series*, vol. 1973, no. 1, p. 012040. IOP Publishing, 2021. https://doi.org/10.1088/1742-6596/1973/1/012040
[24] Saif, Mohd, and Mohammad Tariq. "Performance analysis of gas turbine at varying ambient temperature." *International Journal of Mechanical Engineering and Technology (IJMET)* 8, no. 1 (2017): 270-280.
[25] Baakeem, Saleh S., Jamel Orfi, and Hany AlAnsary. "Performance of a typical simple gas turbine unit under saudi weather conditions." *International Journal of Fluid Mechanics & Thermal Sciences* 1, no. 3 (2015): 59-71.
[26] Elfeituri, Idris A. "Exergy Based Performance Analysis of a Gas Turbine Unit at Various Ambient Conditions." *International Journal of Energy and Power Engineering* 11, no. 6 (2017): 777-786.
[27] Klein, Sanford A., and Gregory Nellis. *Mastering EES*. F-Chart Software, 2013.

[28] Rohani, V., and M. Ahmadi. "Using double pressure heat recovery steam generator equipped with duct burner for full repowering a steam power plant and its analysis by exergy method." *International Journal of Materials, Mechanics and Manufacturing* 2, no. 4 (2014): 309-316. https://doi.org/10.7763/IJMMM.2014.V2.148

[29] Pathirathna, Kuruppulage Asela Buddhika. "Gas turbine thermodynamic and performance analysis methods using available catalog data." *Master's thesis, University of Galve* (2013).

[30] Qasim, Mohammed A., Vladimir I. Velkin, and Sergey E. Shcheklein. "Experimental and Implementation of a 15 × 10 TEG Array of a Thermoelectric Power Generation System Using Two-Pass Flow of a Tap Water Pipeline Based on Renewable Energy." *Applied Sciences* 12, no. 15 (2022): 7948. https://doi.org/10.3390/app12157948

[31] Qasim, M. A., Velkin, V. I., Mohammed, M. F., Sammour, A. A., Du, Y., Salih, S. A. A., Aljashaami, B. A., & Gulmurodovich, S. P. (2023, June 1). Design of a multi-level inverter for solar power systems with a variable number of levels technique. *International Journal of Power Electronics and Drive Systems (IJPEDS)*, *14*(2), 1218. https://doi.org/10.11591/ijpeds.v14.i2.pp1218-1229

[32] Sammour, A. A., Komarov, O. V., Qasim, M. A., Kassam, B., & Dakkak, A. M. A. (2023). Studying the effect of compressor ambient operating conditions on gas turbine performance. *Intelligent biotechnologies of natural and synthetic biologically active substances: XIV Narochanskie Readings*. https://doi.org/10.1063/5.0178698

[33] Al-Fahed, S. F., F. N. Alasfour, and H. K. Abdulrahim. "The effect of elevated inlet air temperature and relative humidity on cogeneration system." *International Journal of Energy Research* 33, no. 15 (2009): 1384-1394. https://doi.org/10.1002/er.1552