NTU Journal for Renewable Energy (2022) Vol. 3 (1): 44 -50
DOI: https://doi.org/10.56286/ntujre.v3i1

IRAQI Academic Scientific Journals

Analysis of Gas Turbine Power Plant Production and Fuel Consumption

Ahmed Nawfal Mustafa[1, a)], Sally Adnan Auda[1, b)] , Obed Majeed Ali[2, c)]

ahmednawfal763@gmail.com, sally@ntu.edu.iq, obedmajeed@gmail.com

[1]Kirkuk Technical College, Northern Technical University, 36001 Kirkuk, Iraq
[2]Renewable Energy Research Unit, Northern Technical University, 36001 Kirkuk, Iraq
Corresponding author: Obed Majeed Ali, obedmajeed@gmail.com
Co-authors: Ahmed Nawfal Mustafa: ahmednawfal763@gmail.com, Sally Adnan Auda: sally@ntu.edu.iq

Received: 18-07-2022, **Accepted:** 12-09-2022, **Published online:** ***29-09-2022

Abstract. The main problem of gas turbine generating units operating in the simple cycle system is their relatively low thermal efficiency, which leads to large thermal energy losses. The current research aims to study the economic analysis of Kirkuk gas power plant. Field data of gas turbine unit for the year of 2019 were used. The results of the study showed that the cost of exported energy is higher than the cost of energy produced. The results showed a 23% increase in the cost of energy produced in summer compared to winter. A decrease in actual production compared to the planned production is observed by 12.8%, where the highest actual production for the month of March was 162,108 MW, while the planned was 186,000 MW. Also, the month of July witnessed a very low fuel consumption rate for natural gas compared to the rest of the months, where the average fuel consumption was 0.273 m3/kW, while the month of January has a high fuel consumption rate for natural gas compared to the rest of the year with average fuel consumption of 0.312 m3/kW. The rate of increase in fuel consumption between July and January was 14.2%, and the results also showed that the ratio of production to design capacity for January was the highest and amounted to 87%, and the highest efficiency reached 33%, while July was the lowest production rate in terms of design capacity, reaching 53% and efficiency of 29.8%.

Keywords: Economic , Gas Turbine , Power Plant Productivity, Fuel Consumption, Actual Production.

Introduction

Electric energy is the vital artery for running the daily business of societies in our time. The demand for electricity all over the world is constantly increasing, and the rate of this increase reaches 8% in developed countries and 25% in developing countries [1]. Recent years have been characterized by a high rate of use of bare stations to produce the electrical energy required to cover the load of the electrical network in Iraq, due to the small size of these units relative to the energy produced, which leads to their need for a short time for construction compared to steam units. According to the manufacturer's data, the gastric units used in these stations are designed to operate in an open cycle system. Therefore, taking into account the specificity of the electric power consumption load curve of the national grid in Iraq, which ranges from 18,000 MW to 20,000 MW in the most sensitive cases, although this load does not cover the actual need of the country [2]. Electricity is considered one of the essential requirements for 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 leadership in the human need for energy, it has become necessary to conserve electrical energy and to search for multiple means and methods to meet future energy requirements by exploiting secondary sources of energy and new energies [3].

The demand for electric power has increased all over the world, in developed countries in particular, and developing countries in general, including Iraq. As a result of the increase in demand for electrical energy, researchers and workers in the field of electrical energy worked to build various generating units, to cover the demand for electrical energy, due to the rapid industrial expansion and high population growth. Thus, reducing energy costs and reducing pollutant emissions, all these demands encouraged researchers and engineers to search for different technologies that are effective, environmentally and economically acceptable [4]. Energy economics represents the specialization that is concerned with the study of energy resources and their distribution within society, and that energy is the ideal field of economic study because it is one of the main requirements for the production of goods and services, and that energy security, sustainability and environmental impact are among the main determinants in the field of studying the economics of clean or environmentally sound energy. With the development of economic activities, the need for energy has become inevitable, and the transition of energy from one main source of fuel to another has accompanied every stage of economic development by relying on traditional energy sources in industrial economies and the main source of growth in developing economies, and in the twenty-first century witnessed the beginning of the transformation. The large increase in energy sources away from fossil fuels towards environmentally sound energy sources was driven by many factors such as the depletion of fossil fuel supplies, environmental impacts, prices and technological progress [5].

Ebigenibo studied the simple Brayton cycle and compared it with the modified Brayton cycle, the modified cycle included adding coolant to the exhaust gas and linking it with the compressed air in order to increase the temperature of the air entering the combustion chamber and thus reduce fuel consumption. Through the results, the efficiency of the modified cycle reached (43.65%) while it reached (35.19%) in the simple cycle, and thus it was clear that the modified cycle is better economically and engineeringly than the simple cycle [6].

A. M. Ahmed et al. studied the energy analysis of a generating unit in the Kirkuk gas power plant located in the south of Kirkuk with a design capacity (65MW) operating in the Brighton Simple Cycle. Data were taken from the station's control system. They showed through the results that the total efficiency of the unit amounted to (33.06%) and the data was represented on the (Sankey Grassmann diagram), and they also showed that it is possible to take advantage of the waste heat in the exhaust by recycling it to the combustion chamber instead of releasing it to the atmospheric air, which can improve the performance of unit in the future [7].

Danook conducted a study on the effect of operating variables on the thermal performance of the unit (GT1) in the power plant in the North Oil Company in the north of the city of Kirkuk with a design capacity (24.8 MW) for the Brighton simple cycle, operating variables: compression ratio, temperature entering the gas turbine, Take the data from the operating control of the station, using the MATLAB simulation. Through the results, it was shown that the increase in the compression ratio and the turbine inlet temperature leads to a decrease in the thermal performance of the unit due to the increase in specific fuel consumption, as the total efficiency of the unit reached (22.68%) [8].

Yildiz Koc et al. made an analytical study of the performance, cost of fuel and emission factors for the simple and compound gas turbine cycle with a

capacity of 50 MW using natural gas and hydrogen as fuel. Turbine exhaust temperature (450°C). Where the system was analyzed for the cases of using both natural gas and pure hydrogen as fuel for simple and compound gas turbine systems, and concluded that the efficiency of the combined gas turbine cycle is higher than the simple gas turbine cycle up to a pressure of 18 bar for both natural gas and hydrogen at a pressure of 18 bar and above. The efficiency of the simple gas turbine cycle is higher than that of the combined gas turbine cycle as the compressor outlet temperature is higher than the turbine outlet temperature. Although H2 has a higher cost to produce unit energy, H2 gas turbine cycles are more beneficial than natural gas in terms of performance, environment and CO2 emissions, and the minimum fuel cost has been calculated as 0.345$/kWh and 0.075$/kWh Watt-hours at 20 bar for a simple gas turbine cycle, while it was 0.322$/kWh and 0.071$/kWh at 4 bar [9].

M. Gorji-Bandpy carried out an external economic analysis of a 140 MW gas turbine in a gas power plant to estimate the unit cost of the product, combining the second law of thermodynamics and economics (thermal economy) using available energy availability (exergy) for cost purposes and optimizing energy systems The analysis shows the deep relationship between unit cost and the change in the compressor pressure ratio and temperature at the entrance to the gas turbine and the efficiency of the turbine and compressor on the unit cost, and the researchers concluded that it is mainly affected by these factors. Achieving the lowest cost at a compressor compression ratio equal to 11.8, turbine efficiency 88.3%, and compressor efficiency 84% [10].

Shamoushaki & Ehyaei Economic and environmental analysis of a gas turbine power plant using Matlab program, where the researchers focused on the total cost and the rate of carbon dioxide emissions, and the variable operating conditions were (compressor pressure ratio, combustion chamber inlet temperature, and gas turbine inlet temperature), The results showed that with the increase in the pressure ratio of the compressor and the gas turbine entry temperature, the rate of carbon dioxide emission decreases. Fuel per unit of energy depends on changing operating conditions that at higher energy efficiencies the overall cost rate is greater [11].

The main problem of gas generating units operating in the simple cycle system is their relatively low thermal efficiency, which results in a large waste of heat energy from the fuel combustion process, which, together with the exhaust gases, is expelled to the external environment, which is equivalent to 60% of the energy of the fuel used. The current research aims to study the economic analysis of a gas power plant and assess the influence of different parameters on the gas turbine power generation.

MATERIALS AND METHOD

Power Plant Components

The gas unit uses a mixture of compressed air and fuel to burn it. The hot gases resulting from combustion pass to the gas turbine through which the heat energy stored in the gases is converted into mechanical energy (rotation). The basic cycle of the gas turbine is called the Brayton cycle, after its inventor, the American engineer George Brayton. Where the atmospheric air passes through the air filters to the unit compressor, which raises the atmospheric pressure to about 17 bar at point (2) and then directs the compressed air to the combustion chamber in which the fuel and air are mixed and ignites the mixture to produce hot gases that pass through the gas turbine and the temperature is The temperature of the gases entering the turbine is about 1200 °C at point (3), then the turbine converts the heat energy stored in gases into mechanical energy that works on the rotation of the turbine shaft and the compressor together. (Exhaust) to the atmosphere at a temperature of about 600 °C at point (4) and with the rotation of the turbine shaft, the shaft of the electric generator of the unit rotates to produce energy At the same time, the main air compressor shaft is self-rotating with mechanical energy [12]. Figure (1) represents the diagram of the Brayton cycle and Gas turbine components.

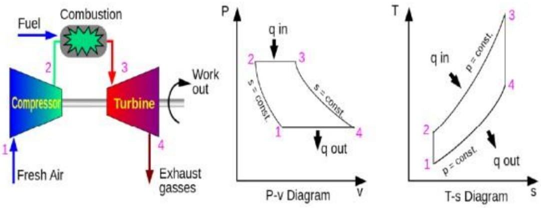

Figure 1. Gas turbine diagram and components

The Kirkuk gas power station was chosen to be researched, as it is located in the Taza district, south of the city of Kirkuk, and it is one of the important stations of the city of Kirkuk. ISO produced by the German Company SIEMENS. Which was completed and put into operation in 2005. This station is designed to operate in a simple cycle and operates on natural gas fuel. Figure 2 depicts A photograph of the (k1) gas generation unit [13].

Figure 2. Kirkuk gas power station.[13]

The station consists of three generating units [13] including Unit k1 which commissioned and put into operation on 12/1/2005. The design capacity is 265 MW. The available capacity is 250 MW. Produced by the German SIEMENS company, the turbine type SGT5-4000F is produced in 2004. It rotates at a speed of 3000 rpm and consists of 15 pressure stages, 24 burners and 4 The unit turbine stages are connected to the national electricity network through a 400 kv line, the output voltage of the unit is 15.7 kV and converted to 400 kV through a main transformer with a shunt capacity of 300 MVA, the unit efficiency is 38.7%, the cooling of the generator is by hydrogen.

The other Unit K2 which commissioned and put into operation on 10/1/2005, design capacity MW 65 Available capacity MW 50 Produced by the German SIEMENS company, the turbine type SGT1000F6, produced in 2004, rotates at a speed of 5400 rpm and consists of 17 pressure stages and 24

torches And 4 turbine phases, the unit is connected to the national electricity network via a 132KV line, the output voltage of the unit is 10.5
KV, and it is converted to 132KV through a main transformer with a shunt capacity of 80 MVA. The efficiency of the unit is 34%, the cooling of the generator is by air.
The last one is Unit K3 which completed and commissioned on 11/24/2013. Its design capacity is 292MW and the available capacity is 280MW. It is produced by the German SIEMENS company. The turbine type is SGTSPAC4000F and produced in 2010. It rotates at a speed of 3000 rpm. It consists of 17 pressure stages, 24 torches and 4 stages of turbine unit. Connected to the national grid through a 400KV line, the output voltage of the unit is 20KV and converted to 400KV through a main transformer with a shunt capacity 370 MVA. The cooling of the generator is by air.

The station operates on the basis of the Brayton Simple Cycle, as the air enters through the House Filter After passing through several stages from the filters to the compressor, which in turn raises the air temperature and pressure, then the compressed air enters the combustion chamber to mix with the fuel (natural gas) to cause a combustion process and this combustion produces waste gases with high thermal energy that enters the gas turbine to expand inside The turbine produces the required work, as part of it is transformed by the shaft to rotate the air compressor and the second part to the electric generator to produce electrical energy. The gas unit is affected by external factors, including temperature and humidity, which in turn affects energy production and efficiency; Because it affects the density of the incoming air and thus the air flow, the axial compressor operates with a constant volumetric flow; This is because the compressor coil has a fixed cross section and thus the volumetric flow depends on the flow velocity, which cannot exceed the sonic velocity in order for the station to be economical. Gas turbines are designed to operate at maximum volumetric flow at full load. If the density of air increases when the air temperature decreases, the mass flow increases through the gas turbine. On the other hand, more fuel is burned if the proportion of air entering the combustion chamber increases and this leads to a constant temperature of the hot gas mixture, resulting in a higher mass flow from the hot gas to the turbine section. This increase in the energy flow through the turbine section increases production, moreover, it is not only a decrease in the inlet air temperature that will lead to an increase in production when an increase in mass flow is required during the combustion process - inside the combustion chamber to increase production, an increase in mass flow is used Air humidification process, using water injection into the combustion chamber to reduce the production of nitrogen oxides [14].

Power Plant Field Data

The field data of the gas turbine unit for the year 2019 was used for unit k1 for all months of the year, where the obstetric unit K2 has stopped working since 2017 due to its entry into comprehensive maintenance of the type of revitalization and major rehabilitation works and the transmission of the unit. Unit k3 has been out of work since 2018 due to work Maintenance. The maintenance completion rate reached 95%, while waiting for the hot commission stage. These experimental field data were collected and described in Table 1. The amount of gas consumed during the months of the year and production of generating units are used to calculate the monthly rate of fuel consumption per megawatt, fuel expenditures, and fuel consumption per cubic meter, the megawatts and expenditures were analyzed for each month during the year 2019.

TABLE 1. Monthly fuel consumption and active power [13]

Month	Fuel consumption/m3	Active power/MWH
January	463:929:	235551
February	53475871	266519
March	559:938:	273219
April	49136663	246952
May	47984478	239378
June	5112:687	24:488
July	49947635	2436:4
August	436:21:3	215615
September	4528::51	223441
October	45:592:3	225171
November	3:675768	:8851
December	5178:599	254195

RESULTS AND DISCUSSIONS

Calculation of Production Cost

Though many sources of renewable energy has been investigated [15] [16] [17] [18] [19] fossil fuel still the dominant fuel in electricity generation. The economic cost of Kirkuk gas power plant for unit K1 was created using the Excel program to obtain the net produced and exported energy and the cost of the produced and exported energy after determining the price of fuel, where the price of natural gas is 50 IQD/KWH, and the comparative analysis shows the results in Table 2. For the months of the year.

TABLE 2. Cost of energy produced and exported

Month	Produced energy(KWH)	Net energy exported(KWH)	Cost of energy produced IQD/KWH	Cost of exported energy IQD
Jan	235551111	234882111	2875	2876
Feb	266519111	265826111	2877	2878
Mar	273219111	272479111	2776	2777
Apr	246952111	246287111	2879	287:
May	239378111	238599111	297:	2:71
June	24:488111	249585111	2:78	2:7:
July	2436:4111	242715111	3377	3378
Aug	215615111	21463:111	3276	3278
Sep	223441111	22254:111	3173	3174
Oct	225171111	224426111	2973	2974
Nov	:8851111	:827:111	2976	2977
Dec	254195111	253477111	2879	287:

In Table 2, the cost of each month of the year for 2019 has been calculated based on the fuel prices provided by the Iraqi Ministry of Oil, where the cost of exported energy is higher than the cost of energy produced. The results showed a 23% increase in the cost of energy produced in the summer compared to the winter, as in the month of JULY it amounted to 22.6 IQD/KWH compared to the winter season in January, which amounted to 17.4 IQD/KWH due to the internal consumption of energy in the plant. To operate units, pumps, and auxiliary devices, and there is energy loss, as the high temperature in the summer increases the temperature of the auxiliary devices, and thus more energy is spent.

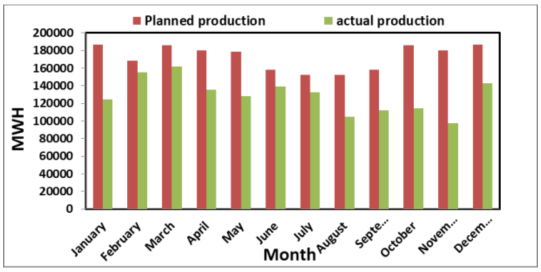

FIGURE 3. Planned and Actual Production of electrical energy Unit k1

Figure (3) shows the planned and actual production quantities for the k1 unit, where a plan is drawn up by the Iraqi Ministry of Electricity for its energy needs by the stations, and the annual plan is sent to the stations, each according to their production capacity, where the figure shows the decrease in the production achieved compared to the planned production by 12. 8%, where the highest actual production reached in the month of march 162108 MW, while the plan was 186000 MW due to the lack of turning off the unit for emergency or periodic maintenance work, while the lowest achieved production was in the month of November by 45.8%, as the actual production amounted to 97740 MW compared to production The plan is 180400 MW due to the unit stopping working for 106 hours for the purpose of replacing air filters, as well as stopping it for 84 hours due to the maintenance work of the North Gas Company, as well as due to the replacement of the thermal valve for the lubrication system.

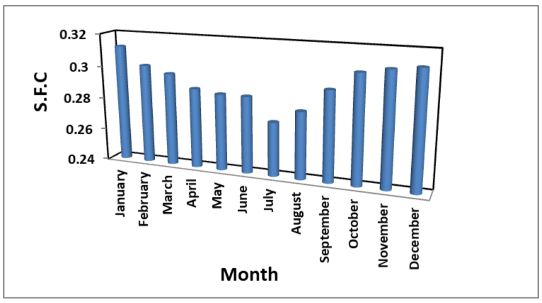

FIGURE 4. Specific fuel consumption for months

Figure (4) shows the relationship between fuel consumption and the months of the year for 2019. We notice from the figure that the month of July had a very low fuel consumption rate for natural gas compared to the rest of the months, where the average fuel consumption was 0.273 M^3/KW, while the month of January had a high fuel consumption rate for natural gas compared to the rest of the year, as the average fuel consumption was The fuel is 0.312M³/KW, and the reason is due to the low temperatures at the compressor inlet, where the air density will increase and therefore the production capacity of the turbine will increase, which will lead to an increase in the work of the compressor and therefore the mass flow of fuel to the turbine will increase to deal with the increase in the flow of air mass and the additional turbine is turned on, and this results in additional fuel consumption when temperatures drop, as the rate of increase in fuel consumption between July & January was 14.2 % and this is economically costly.

production Losses

Table 3 shows the Ratio of production to design capacity, where the design capacity is the ability of the generator to produce a load from the gas turbine, as the production ratio and unit efficiency were calculated for each month during the year 2019, if it is clear from the table that the ratio of production to design capacity increased in January Where it reached 87% and the efficiency was the highest during the year if it reached 33%, while the month of July was the lowest in the production rate in relation to the design capacity, reaching 53% and the efficiency was 29.8%, which is the lowest of the other months, where the ratio of production to the design capacity was between two months January & July is 39%, and the percentage of efficiency decrease between the two months above is 9.6%. This is due to the high ocean temperature in the month of July compared to January, whose temperature reaches the lowest possible and approaches zero, as the more the temperature of the air entering to The compressor will decrease as the density of the air increases, and thus the compression process of the air entering the compressor is of high density, and this will increase the mass flow of air, which in turn needs more fuel; To complete the combustion process and thus increase the generating capacity of the gas turbine.

CONCLUSION

The Current research is devoted to the study of Economic Analysis of Gas Turbine Plant. The following conclusion can be addressed:

The cost of energy exported is higher than the cost of energy produced. The results showed an increase of 23% in the cost of energy produced in summer compared to winter, which amounted to 22.6 IQD/kWh in July, compared to the winter season in January, which amounted to 17.4 IQD/kWh.

TABLE 3. production relative to Design capacity

Month	Design Ability/MWH	Production /MWH	Working hours/h	Stop hours/h	Unit % Efficiency	Ratio of Production to Design Capacity %
Jan	197160	155408	631	113	33	87
Feb	178080	144408	668	4	32.7	82
Mar	197160	162108	730	14	32.2	79
Apr	190800	135841	636	84	31.8	71
May	197160	128267	663	81	31.5	65
June	190800	139377	715	5	30.8	60
July	197160	132593	740	4	29.8	53
Aug	197160	104504	696	48	29.9	58
Sep	190800	112330	720	0	30.7	67
Oct	197160	114060	744	0	30.9	74
Nov	190800	97740	604	116	31.5	79
Dec	197160	143084	744	0	31.8	81

- The actual production decreased compared to the planned production by 12.8% as the highest actual production in March was 162,108 MW while the plan was 186,000 MW. , while the lowest production achieved in November was 45.8%, where the actual production amounted to 97,740 MW compared to the planned production, and the planned 180,400 MW.
- As if the month of July had a very low fuel consumption rate for natural gas compared to the rest of the months, where the average fuel consumption was 0.273 m3/kW, while the month of January had a high fuel consumption rate for natural gas compared to the rest of the year, where the average fuel consumption was 0.312 m3/kW, where the rate of increase in fuel consumption between July and January was 14.2%, and this is economically costly.
- The ratio of production to design capacity in January was the highest, reaching 87%, and the efficiency was the highest during the year if it reached 33%, while July was the lowest in the production rate in terms of design capacity, reaching 53% and efficiency 29.8%, which is The lowest other months where the production to

design capacity ratio between January and July was 39% and the efficiency decline between the two months above was 9.6%.

References

[1] A. Kumar, A. Singhania, A. K. Sharma, R. Roy, and B. K. Mandal, "Thermodynamic Analysis of Gas Turbine Power Plant," Int. J. Innov. Res. Eng. Manag., no. 3, pp. 648–654, 2017, doi: 10.21276/ijirem.2017.4.3.2.

[2] A. Tesfamichael and S. I. Gilani, "The Effect of Ambient Temperature on a Gas Turbine Performance in Part load Operation," 4th Int. Meet. Adv. Thermofluids, vol. 893, no. Imat 2011, pp. 889–893, 2012, doi: 10.1063/1.4704300. [3] A. A. Jadallah and A. A. Al-Kumait, "A Comparative Study on the Performance Augmentation of a Gas Turbine Power Plant," Tikrit J. Eng. Sci., vol. 23, no. 1, pp. 1–9, 2016, doi: 10.25130/tjes.23.1.01.

[4] F. I. Abam, I. U. Ugot, and D. I. Igbong, "Thermodynamic Assessment of Grid-Based Gas Turbine Power Plants in Nigeria," J. Emerg. Trends Eng. Appl. Sci., vol. 2, no. 6, pp. 1026–1033, 2011.

[5] G. Marin, D. Mendeleev, B. Osipov, and A. Akhmetshin, "Study of the effect of fuel temperature on gas turbine performance," E3S Web Conf., vol. 178, pp. 0–4, 2020, doi: 10.1051/e3sconf/202017801033.

[6] S. Ebigenibo, "Comparative ExergoEnvironmental Analysis of Simple and Regenerative Cycle Gas Turbine Plants," Sch. J. Eng. Technol., vol. 22, no. December 2018, pp. 432–443, 2019, doi: 10.21276/sjet.2018.6.12.10.

[7] A. M. Ahmed, A. H. Ahmed, and O. M. Ali, "Analysis of exergy and energy variation of gas turbine power plant in taza-iraq," Int. J. Energy Convers., vol. 9, no. 2, pp. 35–40, 2021, doi: 10.15866/irecon.v9i2.19283.

[8] S. H. Danook, "Thermal performance for electricity generation plant of North Oil Company Kirkuk," pp. 19–21, 2018.

[9] Y. Koç, H. Yağlı, A. Görgülü, and A. Koç, "Analysing the performance, fuel cost and emission parameters of the 50 MW simple and recuperative gas turbine cycles using natural gas and hydrogen as fuel," Int. J. Hydrogen Energy, vol. 45, no. 41, pp. 22138–22147, 2020, doi: 10.1016/j.ijhydene.2020.05.267.

[10] M. Gorji-Bandpy, H. Goodarzian, and M. Biglari, "The cost-effective analysis of a gas turbine power plant," Energy Sources, Part B Econ. Plan. Policy, vol. 5, no. 4, pp. 348–358, 2010, doi: 10.1080/15567240903096894.

[11] Moein SHAMOUSHAKI, "Exergy, Economic And Environmental (3E) Analysis Of A Gas Turbine Power Plant and Optimization by Mopso Algorithm," Exergy Method Therm. Plant Anal., vol. 47, no. 4, pp. 124–134, 2021, doi: 10.31857/s013116462104007x.

[12] M. M. Rahman, T. K. Ibrahim, and A. N. Abdalla, "Thermodynamic performance analysis of gas-turbine power-plant," Int. J. Phys. Sci., vol. 6, no. 14, pp. 3539–3550, 2011, doi: 10.5897/IJPS11.272.

[13] Ministry of Electricity, "Kirkuk gas turbine power plant," Kirkuk CITY-IRAQ, 2005. [14] T. Oyegoke, I. I. Akanji, O. O. Ajayi, E. A. Obajulu, and A. O. Abemi, "Thermodynamic and Economic Evaluation of Gas Turbine Power Plants," J. Eng. Sci., vol. 7, no. 1, pp. G1–G8, 2020, doi: 10.21272/jes.2020.7(1).g1.

[15] N. T. Alwan, S. Shcheklein, and O. Ali, "Investigation of the coefficient of heat transfer and daily cumulative production in a single-slope solar distiller at different water depths," Energy Sources, Part A Recover. Util. Environ. Eff., pp. 1–18, Nov. 2020, doi: 10.1080/15567036.2020.1842561.

[16] N. T. Alwan, S. E. Shcheklein, and O. M. Ali, "Experimental analysis of thermal performance for flat plate solar water collector in the climate conditions of Yekaterinburg, Russia," Mater. Today Proc., vol. 42, pp. 2076–2083, 2021.

[17] N. T. Alwan, S. E. Shcheklein, and O. M. Ali, "Evaluation of the productivity for new design single slope solar still at different saltwater depth," in Journal of Physics: Conference Series, 2020, vol. 1706, no. 1, p. 12002.

[18] N. T. Alwan, S. E. Shcheklein, and O. M. Ali, "Experimental Investigation of Modified Solar Still Productivity under Variable Climatic Conditions," Int. J. Des. Nat. Ecodynamics, vol. 15, no. 1, pp. 57– 64, 2020, doi: 10.18280/ijdne.150108.

[19] O. M. Ali, R. Mamat, and C. K. M. Faizal, "Influence of 1-Butanol additives on palm biodiesel fuel characteristics and low temperature flow properties," in Applied Mechanics and Materials, 2014, vol. 465, pp. 130–136.