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Modeling and Performance Assessment of AN SGT5-2000E Gas Turbine in AZURA Power Plant

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ABSTRACT

This study evaluates the performance of the SGT5-2000E gas turbine at the Azura Power Plant, Benin City, Nigeria, under a simple cycle configuration using GasTurb 14 software. Simulations were conducted to examine the effects of varying ambient temperature, relative humidity, and turbine inlet temperature (TIT) on key performance parameters. The results revealed that increased TIT significantly improved both power output and thermal efficiency. For instance, a TIT of 1109.7 °C resulted in a power output of 159.5 MW, a thermal efficiency of 35.14%, and a heat rate of 10,228 kJ/kWh. Ambient temperature variations demonstrated an inverse relationship with power output and thermal efficiency, with lower temperatures yielding higher performance. Similarly, increased relative humidity positively influenced power output and reduced specific fuel consumption. These findings highlight the critical influence of environmental conditions and TIT optimization on the operational efficiency of gas turbines in simple cycle mode, providing valuable insights for enhancing performance in similar energy setups.

KEYWORDS: Gas Turbine, Simple cycle, Power generation, Efficiency, Ambient Temperature.

I. INTRODUCTION

The demand for steady and reliable electric power has risen globally, driven by industrialization, urbanization, and the need for sustainable energy solutions [1]. Energy plays a vital role in a country's economic development, and its significance is expected to increase in the coming years due to higher demand [2]. In Nigeria, a country with a burgeoning population and expanding industrial sector, a stable electricity supply is critical for economic development and improving the quality of life of the people. The energy sources available for power generation are: fossil fuels, nuclear energy, hydropower, Wind energy, solar energy, biomass and biofuels, geothermal energy, and tidal energy. Of these energy sources available, thermal (80%) and hydro (20%) are dominantly used in Nigeria [3]. Reliance on fossil fuels causes greenhouse gas emissions, threatening global warming and its impacts, making regulation essential [4], leading to the need for lower-emission power plants and renewable energy sources. A gas turbine is a power source that is: reliable, cheap, flexible, and less environmentally polluting, it also presents a highly efficient means of power generation due to its ability to produce large quantities of energy in a compact, self-contained assembly [5]. The uses of gas turbines include power generation, oil and gas industry operations, marine propulsion, and aviation [6].

However, the performance of all machines including the gas turbine reduces as a result of wear and tear of the machine parts.

This study aims to model and perform a performance assessment of the SGT5-2000E Gas Turbine unit of the Azura power Plant, Benin City, Edo State, Nigeria, using the Gasturb 14 software. The specific objective is to evaluate the performance of the SGT5-2000E gas turbine in the simple cycle configuration.

A gas turbine is an internal combustion engine that uses fuel combustion to generate power [7], [8], [9]. It consists of a combustion chamber, a compressor, a turbine, and a generator. It is used to generate electricity, provide propulsion for airplanes, ships, and other vehicles, and industrial applications such as gas compression and power generation.

Egware and Obanor [10], analysed the energy performance of the SGT5-2000E gas turbine at Azura Power Plant using MATLAB. They evaluated thermal efficiency, specific fuel consumption, and energy output under simple cycle configurations. Results highlighted a 1.16% decrease in power output and a 1.58% reduction in efficiency for every 1°C increase in ambient temperature, but exergy losses were not addressed.

Lebele and Asuo J.M [11] investigated the Performance analysis of a 20 MW gas turbine power plant by energy and exergy methods. The energy analysis was based on the First Law of Thermodynamics, while the exergy method was used based on the second Law of Thermodynamics. The locations and magnitude of losses that inhibited the performance of the power plant were identified by balancing the system equations. The internal losses associated with each plant component were estimated for improvement to be made to such components for maximum power output. The result obtained revealed that energy efficiency was 20.73 %, while the exergy efficiency was 16.39 %; but the exergy loss of 38.62 % in the combustor was the largest among the components of the plant. The work was done for the Kolo Creek power plant station in Ogbia Local Government Area of Bayelsa State. Also, the plant has been in existence for more than 15 years.

Salihu and Akim-Yusuf [12] investigated the impact of cooling inlet air on gas turbine power output. The authors conducted simulations of the power output using different cooling methods, including evaporative cooling, absorption chilling, and mechanical chilling, to analyze their effects on gas turbine performance under varying ambient conditions. Four cases: simple gas turbine simulation without cooling, an evaporative cooling method utilizing inlet air humidity to cool the air, an absorption chilling method using waste heat to cool the inlet air, and a mechanical chilling method cooling air regardless of its properties and composition analyzed. The study concluded that all cooling methods increase the power generated by the gas turbine, with varying degrees of effectiveness. Evaporative coolers performed best in drier areas with access to water, while absorption chillers offered the most significant power output improvement but required extensive modifications. Mechanical chillers provided a similar benefit with fewer modifications. The gap in this study is the lack of detailed analysis of the long-term economic feasibility and sustainability of implementing different cooling methods in real-world gas turbine operations.

In a study by Oyedepo et al. [13] energy and exergy analyses were conducted on eleven gas turbine units at three different stations in Nigeria. Energy losses in each component of the gas turbine power plants using the first law of thermodynamics were conducted, and exergy consumption and destruction in the components using the first and second laws of thermodynamics were calculated. The methodology included utilizing energy and exergy analyses to assess plant performance, analyzing energy and exergy fluxes at the inlet and exit of devices in the power plant units, determining energy and exergy losses in key components like combustion chambers, gas turbines, and heat recovery steam generators (HRSG), and providing constructive suggestions to enhance system efficiency.

Ahmed et al. [14] conducted a thermal analysis of a gas turbine power plant to improve performance efficiency. A parametric study of the gas turbine cycle modelled with an intercooler and regeneration turbine was carried out. It involves simulating the thermal efficiency, specific fuel consumption, and net power output under varying temperature limits and compressor pressure ratios. Using simple gas turbine cycle calculations with realistic parameters, the authors investigated the impact of increasing turbine inlet temperature on cycle efficiency and work output. The conclusion drawn from their analysis was that increasing the turbine inlet temperature does not necessarily lead to a rise in cycle efficiency but rather an increase in the work done. This suggests that optimizing the turbine inlet temperature is crucial for maximizing the performance efficiency of a gas turbine power plant.

The significance of this study is to provide critical insights into optimizing the performance of the SGT5-2000E gas turbine in simple cycle configuration under varying operational conditions, including ambient temperature, turbine inlet temperature (TIT), and relative humidity

II MATERIALS AND METHODS

2.1 Materials

The following materials were employed for the study:

i. Monthly operating data: collected from the Azura power plant in Benin City, Nigeria, for the period January to December 2022.

ii. Meteorological data: These are regional weather conditions that include, ambient temperature, pressure, and relative humidity obtained from the Nigerian Meteorological Agency (NIMET). These data helped to ensure that the simulations accounted for local environmental conditions.

iii. specifications: The Siemens Energy technical manuals were consulted for information on the gas turbine specifications, as shown in Table 3.1 below.

iv. Gasturb 14 software: This software is selected because it can simulate both simple and combined

cycles and ensure accurate modelling of the gas turbine's performance under varying conditions.
v. HP EliteBook core i5 laptop: This is a high-performance laptop that ensures seamless installation and operation of the Gasturb 14 software, facilitating efficient data analysis and simulation.

2.1.1 Simulation Tools

The tool for this simulation is the Gasturb 14 software. The Gasturb 14 software is widely adopted for the simulation of the performance of gas turbines due to its ability to model both design-point and off-design conditions. Saravanamuttoo et al. [15] presented theoretical foundations for gas turbine performance modelling, emphasizing the importance of simulation tools in understanding the behavior of gas turbines. Kurzke [16] provided a detailed description of the capabilities of the software, including its ability to model the effects of ambient temperature and humidity.

2.2 Method

2.2.1 Gas turbine Nomenclature

The nomenclature used for the stations in GasTurb 14 is as follows:

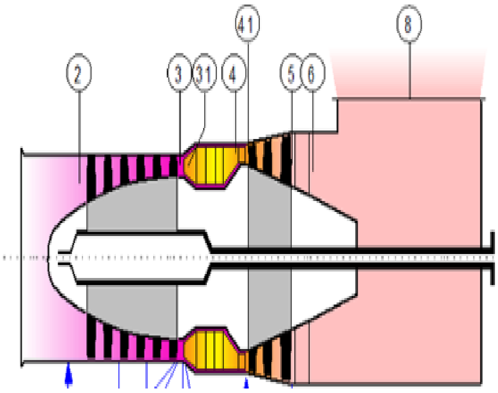


Figure 1. Gas turbine Nomenclature (source: Gasturb 14 [15])

i. Station 2: Ambient air entering the compressor.
ii. Station 3: Air exiting the compressor and entering the combustor.
iii. Station 4: Combustion gases exiting the combustor and entering the turbine.
iv. Station 5: Exhaust gases exiting the turbine to the atmosphere, through the exhaust stack.

2.2.2 Thermodynamic Processes:

The thermodynamic processes are shown in the figures below:

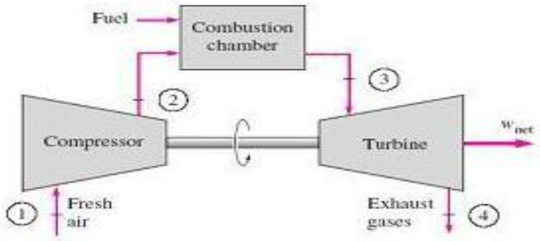
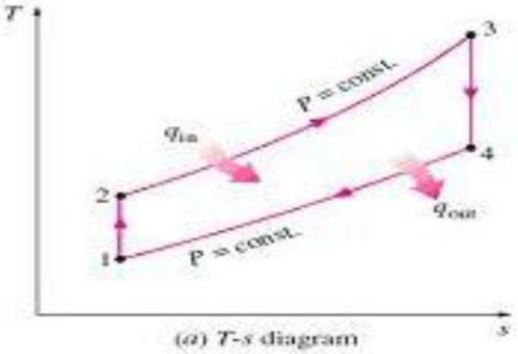
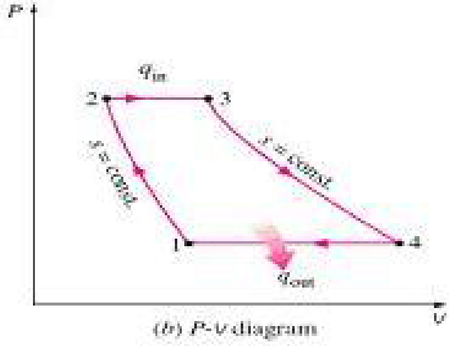


Figure 2 A simple cycle gas turbine.



(a) T-s diagram

Figure 3 T-S diagram of a gas Turbine



(b) P-v diagram

Figure 4 PV diagram of a gas turbine.

i. Compression (1 → 2): Air is compressed in the compressor.
ii. Combustion (2 →3): Fuel is added, and the air-fuel mixture is burned.
iii. Expansion (3→ 4): Hot gases expand in the turbine to produce work.
iv. Exhaust (4): Gases are released into the atmosphere.

2.2.3 Mathematical Models:

The thermodynamic properties at each station were analyzed under steady-state, one-dimensional flow, and isentropic assumptions for ideal components:

i. **Compressor Work (Wc.):**

$$W_c = \dot{m} \cdot C_p \cdot (T_3 - T_2) \quad (1)$$

ii. **Turbine Work (Wt.):**

$$W_t = \dot{m} \cdot C_p \cdot (T_4 - T_5) \quad (2)$$

iii. **Net Power Output (Wnet):**

Wnet = Wt – Wc (3)

iv. Thermal Efficiency (ηth):

ηth = Wnet / (ṁf · LHV) (4)

ηth = thermal efficiency.

2.2.4 Step-by-Step Procedures

Step 1: Software Installation and Setup

The Gasturb 14 software was installed on the high-performance HP EliteBook laptop, the license key was installed to unlock the advanced simulation features of the software, and the workspace configuration was done to enable thermodynamic modeling of the gas turbine.

Step 2: Data Collection and Processing

i. Operational data was collected from the Azura power plant from January to December 2022. The data collected include the monthly value of the turbine inlet temperature, mass flow rate, exhaust temperatures, power output, and site conditions.

Where: WC = Work done by the compressor,
WT = Work done by the turbine,
Wnet = Net work done by the gas turbine
LHV = Lower heating value of fuel,

ii. Data on the site's ambient condition were collected from the Nigeria Meteorological Agency (NIMET), and they include ambient temperature, relative humidity, and atmospheric pressure.

iii. Turbine specifications like compression ratio, fuel type, etc. were also obtained from the manufacturer's design data.

Step 3: input parameters in Gasturb 14 software

To simulate the gas turbine accurately, the Gasturb software requires precise input parameters. These parameters are:

i. Cycle type: The cycle type is selected from the Gasturb Selection Page after the gas turbine application is selected from the application menu. Based on this study's objective, the simple cycle configuration was used during the simulation.

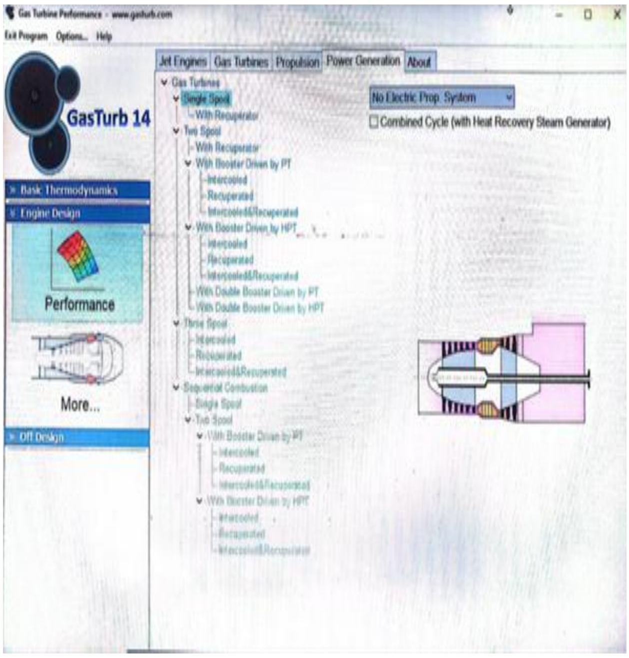


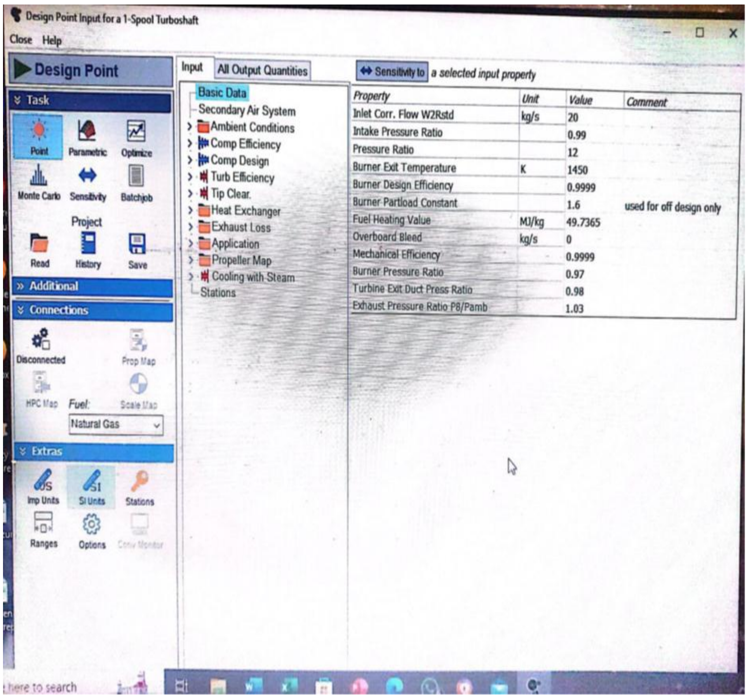
Figure 5 GasTurb 14 configuration selection page

ii. Data: The Pressure Ratio (rc) is the ratio of outlet pressure to inlet pressure (P2/P1). For the SGT5-2000E, this is approximately 12.8:1, the mass Flow Rate (m): Air entering the compressor, approximately 558kg/s, and the efficiency (Ƞc): Isentropic efficiency of the compressor, typically 89-92%.

iii. Combustor Data: The SGT5-2000E gas turbine uses natural gas as the primary fuel, with a calorific value of 50 MJ/kg. It also burns other fuels. Combustion Efficiency (Ƞcomb): Defined as the efficiency with which fuel energy is converted into heat (98-99%). Turbine Inlet Temperature (T3): This critical value defines the maximum allowable temperature in the system (typically 1,150°C).

iv. Turbine Data: Pressure Isentropic efficiency (Ƞt): Determine the efficiency of energy extraction during a gas expansion (91 -94%).

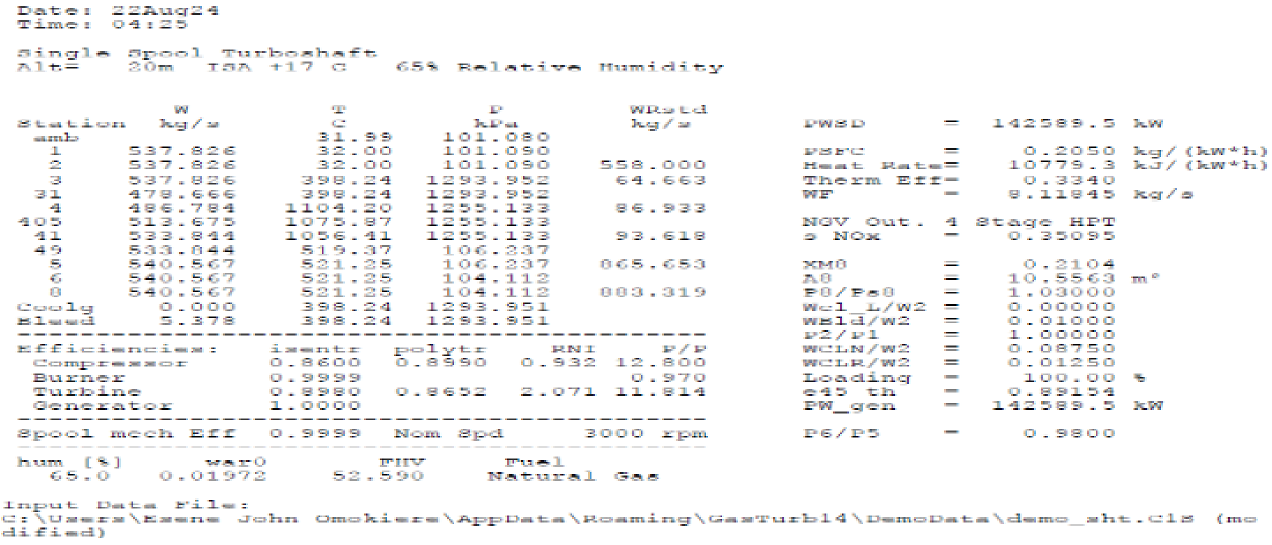
v. Ambient Conditions: the ambient conditions used are ambient temperature (T0): or measured conditions, Pressure(P0): Atmospheric pressure, and relative humidity which are all site-specific values.



Property	Unit	Value	Comment
Inlet Corr. Flow W2Rstd	kg/s	20	
Intake Pressure Ratio		0.99	
Pressure Ratio		12	
Burner Exit Temperature	K	1450	
Burner Design Efficiency		0.9999	
Burner Partload Constant		1.6	used for off design only
Fuel Heating Value	MJ/kg	49.7365	
Overboard Bleed	kg/s	0	
Mechanical Efficiency		0.9999	
Burner Pressure Ratio		0.97	
Turbine Exit Duct Press Ratio		0.98	
Exhaust Pressure Ratio P8/Pamb		1.03	

Figure 6 GasTurb 14 parameter input page.

Step 4: Run Simulation: Start the simulation and allow the software to calculate the performance of the gas turbine. The software uses the input data and operating conditions to simulate the performance across various load conditions and ambient environments. When the simulation is completed, the results are displayed on the summary page as shown in Figure 7. On successful simulation, the performance parameters of the gas turbine are copied from the summary page and station data page and presented in a table presented in Table 1.



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 Date: 22Aug24
 Time: 04:25

 Single Spool Turboshaft
 Alt=   30m   ISA +17 C    65% Relative Humidity


             W           T           P          WRstd
 Station   kg/s          C          kPa         kg/s        PWSD        =   142589.5 kW
  amb                  31.99     101.080
   1      537.826      32.00     101.090                    PSFC        =     0.2050 kg/(kW*h)
   2      537.826      32.00     101.090     558.000        Heat Rate=     10779.3 kJ/(kW*h)
   3      537.826     398.24    1293.952      64.663        Therm Eff=      0.3340
  31      478.666     398.24    1293.952                    WF          =    8.11845 kg/s
   4      486.784    1104.20    1255.133      86.933
 405      513.675    1075.87    1255.133                    NGV Out. 4 Stage HPT
  41      533.844    1056.41    1255.133      93.618        s NOx       -    0.35095
  49      533.844     519.37     106.237
   5      540.567     521.25     106.237     865.653        XM8         =     0.2104
   6      540.567     521.25     104.112                    A8          =    10.5563 m²
   8      540.567     521.25     104.112     883.319        P8/Ps8      =    1.03000
 Coolg      0.000     398.24    1293.951                    Wcl_L/W2    =    0.00000
 Bleed      5.378     398.24    1293.951                    Wbld/W2     =    0.01000
 -------------------------------------------------------    P2/P1       =    1.00000
 Efficiencies:     isentr   polytr     RNI     P/P          WCLN/W2     =    0.08750
  Compressor       0.8600   0.8990   0.932  12.800          WCLR/W2     =    0.01250
  Burner           0.9999                   0.970           Loading     =     100.00 %
  Turbine          0.8980   0.8652   2.071  11.814          e45 th      =    0.89154
  Generator        1.0000                                   PW_gen      =   142589.5 kW
 -------------------------------------------------------
 Spool mech Eff    0.9999   Nom Spd       3000 rpm          P6/P5       =     0.9800
 -------------------------------------------------------
 hum [%]      war0         FHV       Fuel
   65.0     0.01972      52.590    Natural Gas

Input Data File:
C:\Users\Esene John Omokiere\AppData\Roaming\GasTurb14\DemoData\demo_sht.CIS (mo
dified)
```

Figure 7 GasTurb 14 results summary page.

III. RESULTS AND DISCUSSIONS

The results obtained from the simulation of the SGT5-2000E gas turbine, using Gasturb 14 are tabulated in Table 1 below

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Table 1. Results obtained from simulating the SGT5-2000E gas turbine in a simple cycle.

Month	Ambient Temperature (C)	Relative Humidity %	Turbine inlet Temperature (C)	0utput Power (kW)	Specific fuel consumption. kg/(kW*h)	Heat rate kg/(kW*h)	Thermal efficiency
March	35	79	1102.7	140467.4	0.2065	10857.8	0.3316
Feb.	35	77	1103.7	142093.2	0.2055	10808	0.3331
Jan	32	65	1104.2	142589.5	0.205	10779.3	0.334
December	31	76	1104.7	144494.5	0.2029	10668.9	0.3374
November	30	82	1105.2	147424.7	0.2008	10561.4	0.3409
October	29	84	1105.7	148523.2	0.2004	10541.3	0.3415
September	27	88	1106.7	150548.2	0.1997	10501.9	0.3428
April	25	81	1107.8	151685.6	0.2	10520.4	0.3422
August	24	89	1108.2	155513.5	0.1967	10344.2	0.348
May	23	84	1108.8	154725.9	0.1983	10429.1	0.3452
June	22	86	1109.2	158892.8	0.1945	10228	0.352
July	21	92	1109.7	159545.7	0.1948	10244.6	0.3514

3.1 Results and discussion of the effect of Ambient temperature on the gas turbine performance parameters

To study the effect of ambient temperatures on the gas turbine's performance parameters, the SGT5-2000E gas turbine was simulated under varying ambient temperatures. The graphs and discussions below show the relationship between the ambient temperature and the performance parameters.

3.1.1 Power Output vs. Ambient Temperature:

The variation of power output with ambient temperature is shown in Figure 2.

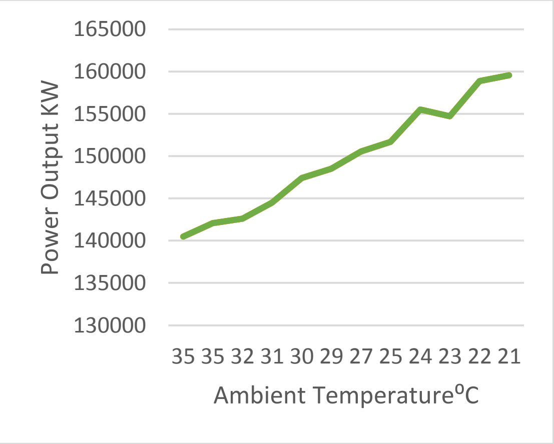

Figure 2. A graph of Power output against Ambient Temperature.

Figure 2 shows a declining trend in power output as ambient temperature increases. The performance of the gas turbine is strongly influenced by ambient conditions, as higher temperatures reduce air density, thereby decreasing the mass flow rate of air entering the compressor. The power output drops from 159,545.7 kW at 21°C to 140,467.4 kW at 35°C, reflecting a significant decline in performance under higher ambient temperatures. This reduction in power output under higher ambient temperatures leads to reduced efficiency and overall performance, especially in regions with warmer climates. This implies that to maintain efficiency, cooling technologies or intake air cooling systems must be considered, as emphasized in operational studies for gas turbines. This is in line with the report by [10], that for the SGT5-2000E, power output reduces by 1.16% per degree Celsius increase in ambient temperature. [18], also discussed how this phenomenon arises due to the thermodynamic limitation of Brayton cycles under varying environmental conditions, and [19] also reported a reduction in power and efficiency as a result of high air inlet temperature.

3.1.2 specific Fuel Consumption vs. Ambient Temperature:

The variation of the specific fuel consumption of the SGT5-2000E gas turbine with ambient temperature is shown in Figure 3.

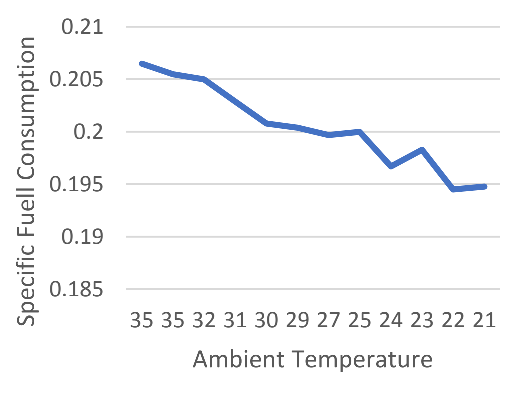

Figure 3. Graph of Specific Fuel Consumption vs Ambient Temperature.

Figure 3 is a graph of specific fuel consumption vs ambient temperature and it indicates that SFC increases with rising ambient temperature. As the air density decreases, the compressor requires additional work to compress the air, resulting in more fuel consumption to maintain the same output level. The graph shows that SFC rises from 0.1945 kg/kWh at 21°C to 0.2065 kg/kWh at 35°C, highlighting the inefficiency introduced by higher ambient temperatures. Higher SFC signifies a decrease in thermal efficiency. In power plants, this leads to increased operational costs due to higher fuel consumption. Thus, optimizing ambient conditions or incorporating cooling systems is critical for enhancing performance. This finding is in line with [10] who observed a 1.58% increase in SFC for every 1°C rise in ambient temperature.

3.1.3 Thermal Efficiency vs. Ambient Temperature:

The variation of the thermal efficiency of the SGT5-2000E gas turbine with ambient temperature is shown in Figure 4.

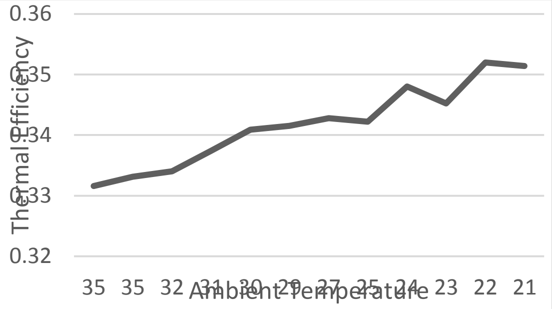

Figure 4. A graph of Thermal Efficiency vs, Ambient Temperature.

Figure 4 is a graph of thermal efficiency vs. ambient temperature. The graph reveals that thermal efficiency decreases with increasing ambient temperature. This is due to the higher work required by the compressor and the reduced network available for power generation. The Thermal efficiency declines from 35.2% at 21°C to 33.16% at 35°C, highlighting the impact of temperature on the overall system efficiency. This decreased thermal efficiency underlines the need for ambient temperature control measures to optimize performance. Additionally, it underscores the challenge power plants face in tropical climates, where higher operational costs and lower outputs are prevalent. [14] and [10] both reported similar trends, confirming that maintaining low ambient temperatures can significantly enhance thermal efficiency.

3.2 Results and discussion of the effect of Relative Humidity on the Performance Parameters.

To study the effect of relative humidity on the performance parameters of the gas turbine, the SGT5-2000E gas turbine was simulated under varying conditions of relative humidity. The below graphs and discussions show the relationship between the relative humidity and the performance parameters.

3.2.1 Power Output vs. Relative Humidity:

The variation of the power output of the SGT5-2000E gas turbine with relative humidity is shown in Figure 5 below.

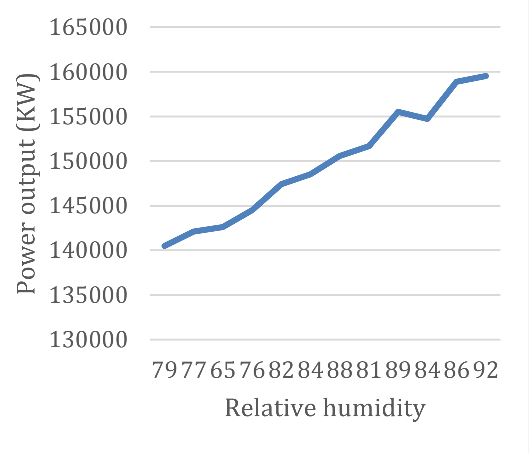

Figure 5. A graph of power output vs. Relative humidity

The graph illustrates that as relative humidity increases, the power output also increases, demonstrating a direct relationship between the two quantities. The power output shows a gradual increase from around 79% to 92% as the relative humidity moves from around 140,000KW to 165,000KW. This suggests that an increase in relative humidity favours the operation of the SGT5-2000E gas turbine.

3.2.2 Efficiency vs. Relative Humidity:

The variation of the thermal efficiency of the SGT5-2000E gas turbine with relative humidity is shown in Figure 6 below.

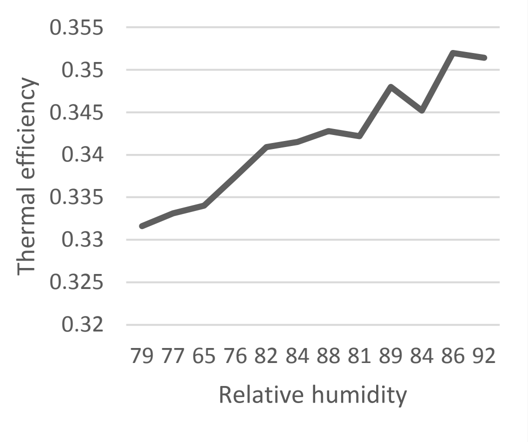

Figure 6. A graph of Thermal efficiency vs. Relative Humidity.

This graph indicates the relationship between thermal efficiency and relative humidity. The trend shows an increase in thermal efficiency with a rise in relative humidity. Thermal efficiency rises steadily from approximately 0.325 at 79% relative humidity to about 0.355 at 92% relative humidity, showcasing a gradual improvement. Higher Relative Humidity: Increased relative humidity improves the system's thermal efficiency, likely due to enhanced cooling mechanisms or a more favourable working environment for the turbine. This suggests that operating the turbine in humid conditions could yield better energy conversion rates, aligning with efficiency-driven engineering designs. [14], and [10] emphasize the critical role of environmental parameters, such as relative humidity, in improving turbine performance and efficiency. The findings align with their assertion that higher humidity enhances gas turbine efficiency by improving air cooling at the compressor inlet.

3.2.3 Specific Fuel Consumption vs. Relative Humidity:

The relationship between the specific fuel consumption of the SGT5-2000E gas turbine with relative humidity is shown in Figure 7 below.

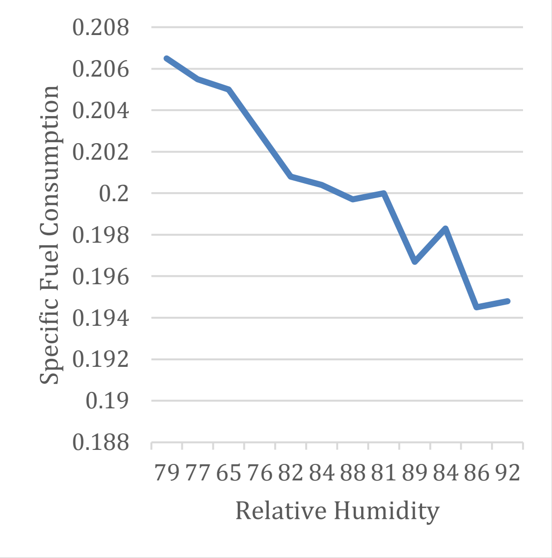

Figure 7 A graph of specific fuel consumption vs. Relative humidity.

The graph illustrates the relationship between specific fuel consumption (SFC) and relative humidity. The trend shows a decrease in specific fuel consumption as relative humidity increases. Specific fuel consumption decreases from approximately 0.206 kg/kWh at 79% relative humidity to around 0.188 kg/kWh at 92% relative humidity. The trend demonstrates a consistent decline, with minor fluctuations. The decline in SFC suggests that higher relative humidity reduces the amount of fuel required per unit of energy produced. This improvement in efficiency may be attributed to enhanced cooling effects at higher humidity levels, which improve turbine operation and combustion stability. [14], highlighted the importance of environmental factors, including relative humidity, in influencing fuel efficiency, observing that increased humidity improves combustion conditions and reduces specific fuel consumption due to lower inlet temperatures and better compression. This aligns with the observed trend, as the SFC decreases with rising humidity, reinforcing the positive impact of ambient conditions on turbine performance.

3.3 Results and discussion of the effect of Turbine Inlet Temperature (TIT) on the Performance Parameters

To study the effect of turbine inlet temperature on the performance parameters of the gas turbine, the SGT5-2000E gas turbine was simulated under varying ambient temperatures. The below graphs and discussions show the relationship between the turbine inlet temperature and the performance parameters.

3.3.1 Power Output vs. Turbine Inlet Temperature:

The variation of the power output of the SGT5-2000E gas turbine with turbine inlet temperature is shown in Figure 8 below.

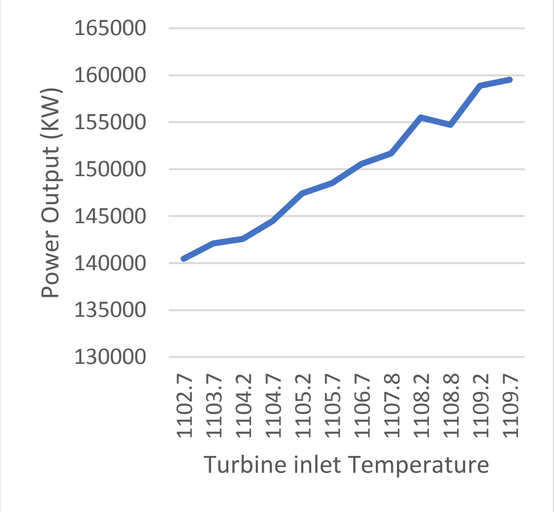

Figure 8. A graph of power output vs. Turbine inlet Temperature.

Figure 8 demonstrates the relationship between power output (kW) and turbine inlet temperature (TIT) (°C). It indicates that power output increases as the turbine inlet temperature rises. The power output starts at approximately 140,000 kW at 1102.7°C and steadily increases to around 160,000 kW at 1109.7°C. The increase in power output is consistent, with minor fluctuations, showing a strong positive correlation between TIT and power output. Higher turbine inlet temperatures allow for more energy extraction from the combustion gases, leading to increased power output. This trend underscores the importance of advanced materials and cooling systems to withstand the high thermal stresses associated with increased TIT.

Egware and Obanor [10] emphasized the significance of turbine inlet temperature in enhancing gas turbine performance. They noted that higher TIT improves power output by increasing the thermal efficiency of the cycle. This aligns with the observed trend in the graph, demonstrating the pivotal role of TIT in optimizing power generation and system performance.

3.3.2 Thermal Efficiency vs. Turbine Inlet Temperature:

The variation of the efficiency of the SGT5-2000E gas turbine with turbine inlet temperature is shown in Figure 9 below.

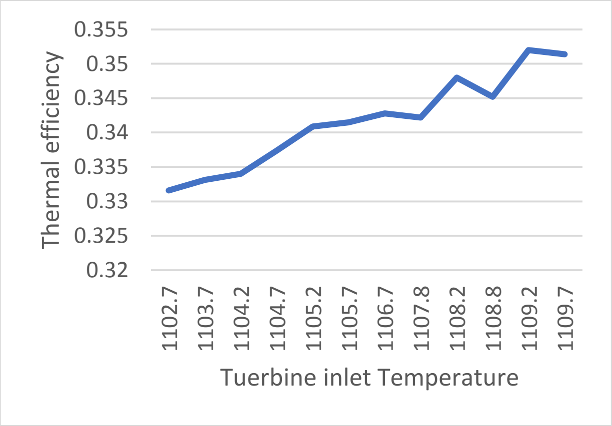

Figure 9. A graph of Thermal efficiency Vs. Turbine inlet temperature.

Figure 9 illustrates the relationship between thermal efficiency and turbine inlet temperature (TIT). The trend shows that thermal efficiency improves as TIT increases. The thermal efficiency starts at approximately 0.325 at a TIT of 1102.7°C and increases steadily to about 0.355 at a TIT of 1109.7°C. The trend reflects a consistent improvement, with minor fluctuations observed between 1107.8°C and 1109.2°C. Higher TIT enables better energy extraction from combustion gases, which leads to improved thermal efficiency. This improvement reflects the optimization of thermodynamic processes within the turbine. [14] highlighted the critical role of turbine inlet temperature in improving gas turbine thermal efficiency. They noted that increasing TIT enhances the efficiency of the Brayton cycle by reducing the irreversibility in the thermodynamic process. This aligns with the observed trend in the graph, where higher TIT corresponds to increased thermal efficiency, further emphasizing the importance of TIT in turbine performance optimization.

3.3.3 Specific Fuel Consumption vs. Turbine Inlet Temperature:

The variation of the specific fuel consumption of the SGT5-2000E gas turbine with turbine inlet temperature is shown in Figure 10 below.

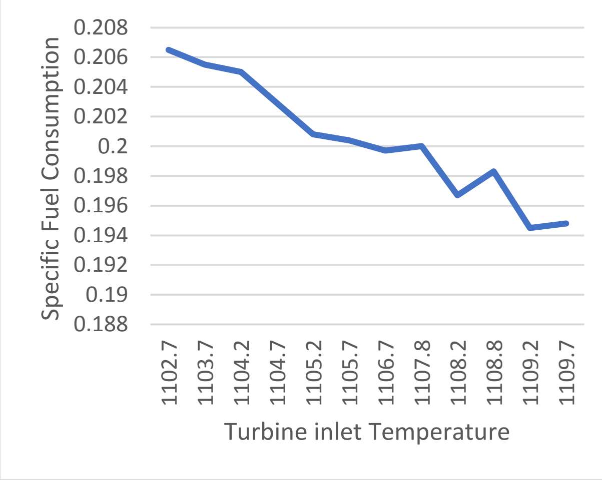

Figure 10 A graph of Specific fuel Consumption Vs. Turbine inlet temperature.

Figure 10 displays the relationship between specific fuel consumption (SFC) (kg/kWh) and turbine inlet temperature (TIT) (°C). It indicates that SFC decreases as TIT increases. Specific Fuel Consumption starts at approximately 0.206 kg/kWh at a TIT of 1102.7°C and decreases steadily to about 0.188 kg/kWh at a TIT of 1109.7°C. The reduction is consistent, with minor fluctuations, particularly between 1107.8°C and 1109.2°C. As TIT increases, the turbine operates more efficiently, reducing the amount of fuel required to produce a unit of energy. This reflects better utilization of the thermal energy available from the decline in SFC directly translates to lower operational costs, as less fuel is consumed for the same power output. [14] and [20] noted that higher turbine inlet temperatures significantly reduce specific fuel consumption by enhancing thermal efficiency and optimizing the Brayton cycle's performance. This aligns with the observed trend in the graph, where SFC decreases as TIT increases, underscoring the benefits of operating turbines at higher temperatures to improve fuel economy and system performance.

IV. CONCLUSION

Based on the simulation results; the following conclusions have been drawn:

1. An increase in ambient temperature lowers the density of air compressed and admitted into the combustion chamber, reducing the amount of oxygen available for combustion. This leads to decreased power output, thermal efficiency, and specific fuel consumption.
2. An increase in relative humidity increases the density of air compressed and admitted into the combustion chamber, leading to an increased quantity of oxygen available for combustion. The overall effects are increased power output, thermal efficiency, and reduced specific fuel consumption.

Based on the findings from this study, it is recommended that adaptive strategies be implemented for the SGT5-2000E, as its performance is sensitive to environmental factors such as ambient temperature and relative humidity. These strategies could include the installation of inlet air cooling systems and humidity control measures. Such modifications would help stabilize performance under varying operating conditions, reduce specific fuel consumption, and optimize power generation.

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