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Investigation of Regenerative Gas Turbine Performance under the Influence of Dynamic Atmospheric Conditions in India Using Energy and Exergy Analysis

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ABSTRACT

India is a country with sunshine throughout the year and most of the cities have very high ambient temperatures, particularly in the summer months. Since gas turbines also play a major role in contributing to electricity demand and their net power output is adversely affected by ambient temperature, it is essential to study their performance disparity under dynamic varying ambient conditions. In the present work, four hot summer months March, April, May, and June which are most common in major states of India are selected for the study. The atmospheric data obtained from the meteorological data for the city of Vijayawada, Andhra Pradesh, India, is used. The various performance characteristics like the network output, first-law efficiency, second-law efficiency, and specific fuel consumption of regenerative gas turbine (RGT) cycle are evaluated for a hot summer day in each selected month and the results are discussed. According to the findings, the ambient temperature and relative humidity have a significant impact on the network output and, consequently, the first law efficiency of a RGT cycle. The first law efficiency, second law efficiency and specific fuel consumption values are 44.42%, 42.86% and 0.1483 kg/kWh respectively at 2.30 p.m. for all four months. However, the network output of 241.53 MW is observed at 5.30 p.m. in the May month where the corresponding value at ISO condition is 255.94 MW.

1. INTRODUCTION

As the global population increases and economic activities expand, energy demand has been rising steadily. According to the International Energy Agency (IEA), global energy demand is expected to increase by 4.6% in 2021, and 3% on average per year from 2022 to 2030 [1]. This growth is driven by emerging economies, particularly in Asia, where rising incomes and urbanization lead to higher demand for electricity, transportation, and industrial processes. In India, energy demand is still increasing exponentially due to various factors such as population growth, urbanization, and industrialization. India is the second most populous country in the world, and its population is expected to reach 1.64 billion by 2050. The rapid urbanization and industrialization of the country have also contributed to the increase in energy demand. For example, in the transportation sector, the number of registered motor vehicles in India has increased from 55 million in 2001 to over 250 million in 2021, and this trend is expected to continue. This increase in the number of vehicles has led to a significant rise in the demand for gasoline and diesel fuels which are primary sources of energy for the transportation sector in India.

Similarly, the industrial sector in India has witnessed substantial growth over the past few decades. According to the Central Electricity Authority, the industrial sector is the largest consumer of electricity in India, accounting for around 45% of the total electricity consumption in the country. The demand for energy in the industrial sector is expected to increase as new manufacturing facilities are established, and existing ones expand. So nevertheless, energy demand is ever-growing and it is essential to address this issue by promoting sustainable energy options, such as renewable energy sources like solar and wind power, and implementing energy-efficient practices across all sectors of the economy.

Gas-powered thermal power stations (GPTPS) are also playing an important role in meeting this energy demand because of the availability of natural gas which is the main fuel in these plants. According to the Central Electricity Authority, India's gas-based power plants have a total installed capacity of 24824 MW as of October 31, 2022. According to India's power generation growth plans, GPTPS will produce a significant portion of the country's electricity during the next ten years The main drawback with simple gas turbine is that its exhaust gas temperature is significantly higher than the compressor's exit air temperature. So, a considerable amount of energy is lost to the atmosphere as waste which reduces the efficiency of the system. To overcome this problem, a regeneration method is adopted to make it a heat recovery system. The recuperated gas turbines have many applications due to their low fuel consumption. These units are mainly used in power-generating sets in industries, tracked vehicles, helicopter propulsion, hybrid automobiles, and in cogeneration systems. The work required in a compressor is given by the equation as under:

$$W_c = T_{a,i} C_{pa} [r_c^{\frac{\gamma_c - 1}{\gamma_c}} - 1] \quad (1)$$

where, T_{ai} is the inlet air temperature, C_{pa} is the constant pressure specific heat of air, r_c is the pressure ratio of the compressor and γ_c is the adiabatic index of air across the compressor. From Eq. (1), it is obvious that the compressor work and, consequently, the first law efficiency of the gas turbine cycle are significantly influenced by the incoming air temperature. Figure 1 depicts how ambient temperature affects net power output and power generation efficiency.

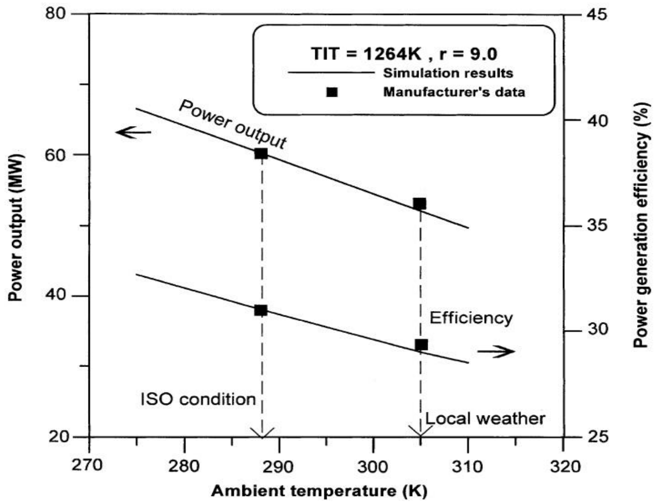

Figure 1. Effect of entry temperature on the power output and power generation efficiency of the GT [2]

Figure 1 shows the variation in power output and power generation efficiency of a gas turbine unit with respect to ambient temperature. The ISO conditions specified as pressure 1.01325 bar, temperature 15℃, relative humidity 60%, and local weather temperature as 32℃. As gas turbines are known to be constant volumetric air flow rate machines, with an increase in ambient temperature air density decreases which causes a less mass entry to the turbine. Hence the decreased power output and thermal efficiency resulted with an increase in ambient temperature. With this fundamental concept, it becomes clear that the performance of a gas turbine cycle is significantly influenced by the atmospheric air temperature.

In many parts of the world nowadays, gas turbine generators are regarded as one of the most powerful power-producing units. There are diverse climatic conditions in different geographic places, such as dry and wet weather (humidity), with high or low average temperatures for air. The far deserts have hot and dry weather compared to coastal regions with relatively high humidity levels. In general, gas turbines are machines with stable air mass flow, and the amount of power they produce is quite sensitive to changes in the temperature of the atmosphere. Most of the places in India are subjected to very high temperatures during the hot summer months, with a consequent reduction in power output.

Baakeem et al. [3] have researched how the environment affects gas turbine performance in the Arab Gulf. They have investigated how the Gulf of Mexico's average daily temperature and humidity affect the efficiency of gas turbines in 6 different cities. The findings showed that, with the exception of two locations, every location saw a loss in electricity output as a result of the cities' hot climates. They also came to the conclusion that power loss during the hot summer owing to high ambient temperatures may be significantly decreased by incorporating inlet air conditioning techniques into existing gas turbine units.

Ameri and Enadi [4] have analyzed the performance of a gas turbine power plant in Iran by exergy analysis using thermodynamic modeling. They have developed a computer code for simulation by using Matlab software. Exergo-economic analysis was also carried out to assess the cost of each flow line of the system. It was concluded from the analysis that with increasing compressor pressure ratio and GT unit inlet temperature, total exergy of the cycle increases. According to the results of the exergy analysis, the combustion chamber (CC) is the component that causes the most exergy destruction when compared to the other components in the cycle.

Haseli [5] has opinioned that minimization of the entropy generation rate across the system components does not necessarily lead to an improvement in the thermal efficiency of the cycle. However, it always leads to optimum performance in energy conversion systems.

To investigate the effects of crucial operating parameters such as compressor pressure ratio, gas turbine intake temperature, and compressor inlet temperature, Memon et al. [6] modeled the gas turbine cycle. The entire cycle performance and CO_2 emissions have been estimated. The analysis also looked into the energy destruction and efficiency of each cycle component. Multiple polynomials were used in regression modeling to determine how operational parameters and performance traits relate to one another. They concluded that cycle performance and CO_2 exhaust emissions are significantly influenced by operational conditions. The ideal compressor inlet temperature was 288K, the ideal turbine inlet temperature was 1600K, and the ideal compressor pressure ratio was 23.2 for best performance.

Ebadi and Gorji-Bandpy [7] conducted exergetic analysis for a medium size gas power plant located in Mahashahr, Iran. By mass, energy and quantitative exergy balance for each component, they estimated the exergetic efficiency under the influence of variation in gas turbine entry temperature. From the results it was confirmed that exergetic efficiency and exergy destruction rate were strongly influenced by gas turbine inlet temperature.

Martin et al. [8] have done exergoeconomic analysis for a gas power plant in Indonesia. For the analysis they used logbooks recorded data of the Pekanbaru Unit. It was observed from the results that the combustion chamber suffered the largest rate of exergy destruction. From the economic analysis total cost of exergy destruction loss for the plant was also estimated.

Abdalla et al. [9] evaluated the performance of a regenerative gas turbine power plant situated in Sudan. The results of the parametric study revealed that the power output of a regenerative gas turbine unit was strongly influenced by the compression ratio, inlet air temperature to the compressor, and effectiveness of the regenerator. The study also suggested that multistage expansions on the turbine side with reheat units in between stages along with multistage compressions with intercooling in between stages would enhance the thermal efficiency of the regenerative cycle plant.

Ahmed et al. [10] have studied the performance of 150 MW gas turbine plant at Kirkuk unit by its dataflow sheet using energy and exergy analysis. Various losses across each component of the unit were analyzed using first and second law of thermodynamics. They have represented the results by the Sankei diagram and Grassmann diagram. Overall, it was concluded that first law efficiency is higher than second law efficiency and inversely proportional to the ambient temperature.

Observations from the literature review:

(1) While many academicians have looked at how ambient temperature affects gas turbine performance, most of them have mainly concentrated their analyses on gulf countries like the Gulf of Mexico, Iran, Indonesia, Sudan, etc.

(2) The performance of gas turbines under the influence of dynamic variation in ambient temperature under Indian climatic conditions has not received much attention.

(3) It is crucial to research how ambient temperature affects the power output and hence efficiency of gas turbine power plants since India, a rapidly developing nation, needs a constant supply of electricity throughout the year and experiences extremely high atmospheric temperatures for nearly four hot summer months.

The novelty of the present work:

(1) Performance evaluation of the RGT cycle under the influence of dynamic ambient temperature variation in the hot summer months of India is evaluated.

(2) Variation of performance parameters like network output, first law efficiency, second law efficiency, and specific fuel consumption of RGT cycle with respect to change in dynamic ambient conditions on hot temperature day of each four summer months are evaluated.

To achieve these objectives the present work is carried out in the following steps:

(1) A Thermodynamic model of a gas turbine unit is selected for the study.

(2) For the analysis, four hot summer months—March, April, May, and June—that are present in the most states of India are chosen, and meteorological data for Vijayawada, India, is collected.

(3) To understand how first-law efficiency and power output vary in these dynamic fluctuation settings, in-depth analyses of energy and exergy are required which have been addressed in the present work.

2. METHODOLOGY

2.1 System description

The present work is done on a model of a RGT cycle which comprises of an axial flow air compressor having 17 stages that draw atmospheric air, and compress the air for supporting combustion in the combustor. The compressed air from the compressor first enters the regenerator where its temperature was raised because of heat transfer from the exhaust gases coming from the turbine. Then heated air from the regenerator enters the combustor. Natural gas is burned in the combustor since methane gas comprises 95% of the mass of natural gas, so it is considered a major fuel in the combustor. The high-pressure and temperature flue gases expand through the 3-stage gas turbine and generates power. The gases after expansion in the turbine are directed to pass through the regenerator. The compressor, gas turbine, and generator are mounted on the same shaft. In the present work, energy and exergy analysis of the natural gas-fired regenerative gas turbine cycle were carried out. A schematic diagram of a regenerative gas turbine system is shown in Figure 2. The input data used in this analysis is shown in Table 1.

Assumptions:

(1) The system is operating at steady state conditions

(2) Potential and Kinetic energy changes are negligible.

(3) Air and gas are considered as ideal-gas mixtures.

(4) Fuel is supposed to be pure methane, and its temperature is constant and equal to the ambient temperature.

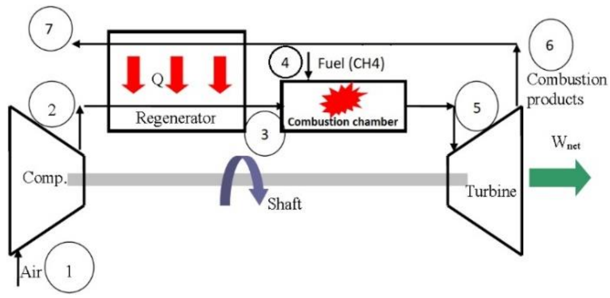

Figure 2. Regenerative gas turbine power plant

Table 1. Input data for RGT

The dead state	P_0=1.01325 bar & T_0=298.15 K.
Compressor pressure ratio	15.4
Gas turbine inlet temperature	1600 K
Capacity of RGT @ ISO condition	255.940 MW
Pressure loss in Combustion chamber	5%
Combustion efficiency	98%
Air side and gas side pressure drop	5%
Effectiveness of regenerator	75%
Compressor mechanical efficiency	98%
Generator efficiency	98%
Compressor isentropic efficiency	90%
Turbine isentropic efficiency	92%

2.2 First law analysis

Compressor Work (kW)

$$\dot{W}_C = \dot{m}_{air}(h_2 - h_1)/\eta_{mech} \tag{2}$$

A complete combustion equation applied to Combustor yields the following [11]:

$$\begin{aligned} CH_4 + x\left(O_2 + 3.76N_2 + 4.76\left(\frac{M_{da}}{M_{wv}}\right)\omega_a H_2O\right) \\ \rightarrow CO_2 \\ + \left(2 + 4.76\,x\left(\frac{M_{da}}{M_{wv}}\right)\omega_a\right)H_2O \\ + (x-2)\,O_2 + 3.76\,x\,N_2 \end{aligned} \tag{3}$$

Gas Turbine Work (kW)

$$\dot{W}_{GT} = \dot{m}_{gas}(h_5 - h_6) \tag{4}$$

Gas Turbine Net Work (kW)

$$\dot{W}_{RGT,net} = (\dot{W}_{GT} - \dot{W}_C) \times \eta_{gen} \tag{5}$$

Lower heating value (LHV_F) and Specific exergy (ex_F) of fuel are taken as 50019 kJ/kg and 52146 kJ/kg respectively [12].

Specific fuel consumption (kg/kWh)

$$sfc = \frac{\dot{m}_F \times 3600}{\dot{W}_{RGT,net}} \quad (6)$$

The first law efficiency of RGT [13],

$$\eta_1 = \left(\frac{\dot{W}_{RGT,net}}{\dot{m}_F \times LHV_F} \right) \times 100 \quad (7)$$

The second law efficiency of RGT [13],

$$\eta_2 = \left(\frac{\dot{W}_{RGT,net}}{\dot{m}_F \times ex_F} \right) \times 100 \quad (8)$$

2.3 Weather data months

In the present work, the regenerative gas turbine performance is investigated for four hot summer months particularly suited to Indian climatic conditions. The four months considered are March, April, May, and June in Vijayawada city of Andhra Pradesh. The weather data for these months is taken from the Meteorological data of Vijayawada city. The data include ambient temperature and relative humidity variation with time of the day in a peak temperature day of each month.

3. RESULTS AND DISCUSSION

From the first and second law analysis for a RGT cycle, the various performance characteristics like network output, first law efficiency, second law efficiency and specific fuel consumption are evaluated and the results are plotted.

Figures 3 and 4 depict the hourly variation of temperature and relative humidity respectively in a hot summer day for four months. From the Figure 3, it is observed that for all four months considered in the analysis, the temperature is always above the ISO temperature at any point of time in the day. It is also observed that there is a close resemblance in the variation of temperature for March and April months. However, May and June months have close approximation up to the noon and after 2.30 p.m. there is a considerable variation in the peak temperature between May and June months. Also, it is observed that 1℃ temperature variation between March (38℃) and April (37℃) months at 2.30 p.m. However, same difference of 1℃ is also observed between May and June (40℃) at the same time. The highest temperature of 41℃ is observed in the month May at 2.30 p.m.

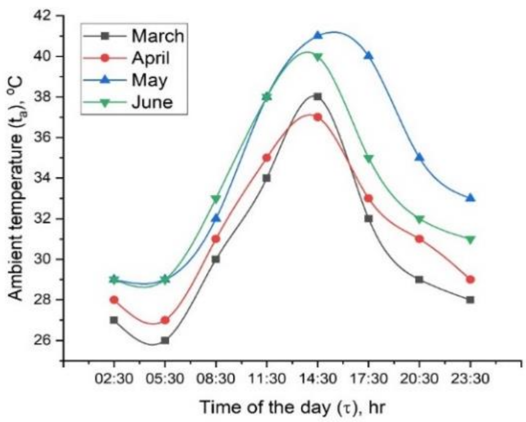

Figure 3. Ambient temperature Vs. time of the day (peak temperature day of the month)

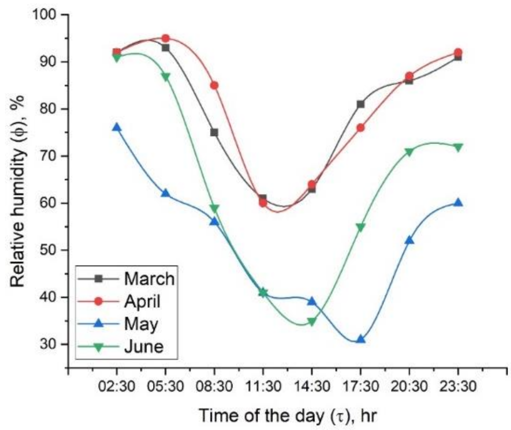

Figure 4. Relative humidity Vs. time of the day (peak temperature day of the month)

From Figure 4, it is evident that as the time of the day increases from 5.30 a.m. onwards the relative humidity decreases up to 11.30 am for March and April months, decreases up to 2.30 p.m. for June month, decreases up to 5.30 p.m. for May month and thereafter increases and attains a maximum value at 11.30 p.m. for four months. Minimum relative humidity of approximately 60% is observed at around 11.30 a.m. in low peak temperature months of March and April. Similarly, low relative humidity of around 35% is observed in the month of June at about 2.30 p.m., and the lowest value of 30% relative humidity is observed in the month of May at 5.30 p.m.

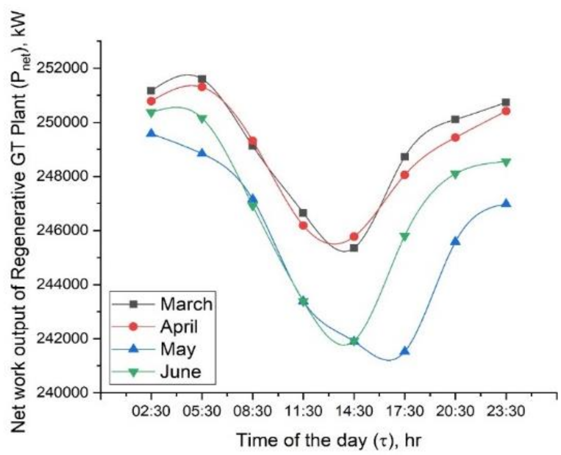

Figure 5. Network output of regenerative GT plant Vs. time of the day (peak temperature day of the month)

From the Figure 5, it is observed that for all four months considered in the analysis, the network output is maximum during early hours (i.e., at 5.30 a.m.) and late night hours (i.e. 11.30 p.m.) because of low temperature and high relative humidity exists at those times. But as the time of the day increases, the network output gradually decreases and attains minimum value in the afternoon at 2.30 p.m. for March, April and June months and 5.30 p.m. for May month. However, between these four months also, March and April have superior network output when compared with May and June. The reason for this is the peak temperature attained is low and relative humidity attained is nearer to ISO condition in these months when compared with May and June months. This clearly indicates that variation of atmospheric temperature and relative humidity plays a significant role in the network output from RGT cycle. The minimum network output in March, April, and June months are found to be 245.35 MW, 245.77MW, and 241.93MW respectively at 2.30 p.m. Moreover, lowest network output of 241.53 MW is resulted in the May month at 5.30 p.m. where it has ambient temperature of 40°C and lowest relative humidity of 31% which also emphasizes the influence of atmospheric conditions on the performance of RGT cycle.

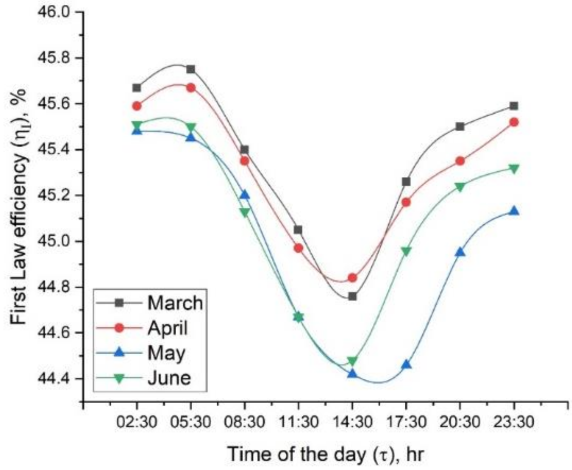

Figure 6. First law efficiency Vs. time of the day (peak temperature day of the month)

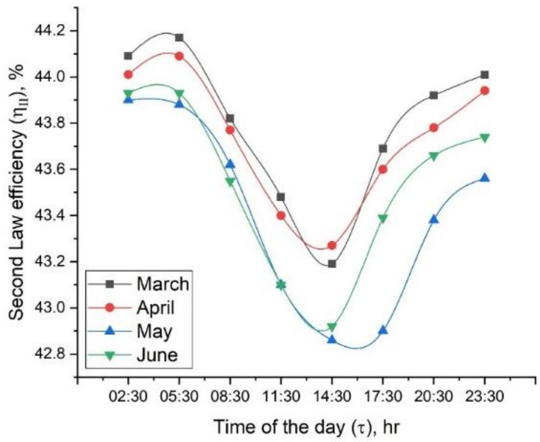

Figure 7. Second law efficiency Vs. time of the day (peak temperature day of the month)

Figures 6 and 7 depict the First law efficiency and Second law efficiency variation with respect to the time of the day for a peak temperature day in the month. From the Figure 6, it is observed that the as the time of the day increases, from morning 5.30 a.m. onwards the first law efficiency decreases continuously up to 2.30 p.m. for all four months. As the network output from the plant decreases with respect to time of the day i.e., the temperature of ambient increases, the efficiency decreases. Minimum first law efficiency observed in March, April, May and June months at 2.30 p.m. for all four months and it is found to be 44.75%, 44.84%,44.42%, and 44.48% respectively. The reason for such variation is peak temperature occurs at that time in all the months. Between these four months also first law efficiency is superior in March and April because apart from high ambient temperature the relative humidity is nearby ISO value, whereas in May and June months, apart from high ambient temperature relative humidity is very low and falls around 50% of ISO value. Hence it is concluded that both ambient temperature and relative humidity play an import role in first law efficiency. The trends of network output and first law efficiency are exactly similar because they are directly proportional to each other.

From the Figure 7 it is also evident that Second law efficiency curves have the exact same variation as First law efficiency curves and two are differ by mechanical exergy. The value of second law efficiency is always lower than the first law efficiency, because, when the pressure of fuel is increased from ambient level to combustor pressure level, exergy increment (i.e., mechanical exergy) results. Henceforth, the exergy of the fuel due to heat addition is equal to exergy associated with the calorific value of the fuel plus mechanical exergy. Obviously, the second law efficiency of the cycle is always lower than first law efficiency.

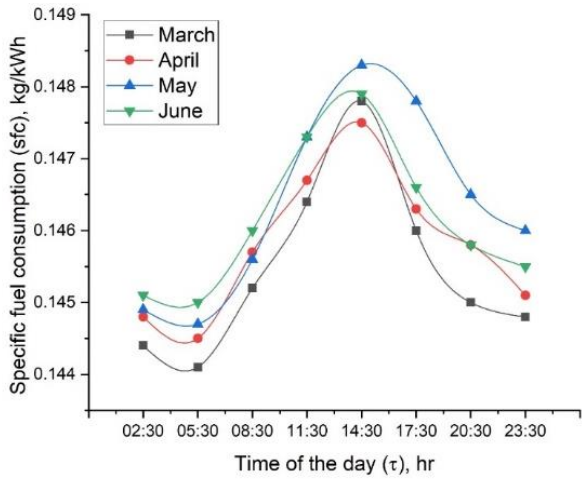

Figure 8. Specific fuel consumption Vs. time of the day (peak temperature day of the month)

Figure 8 shows the variation of Specific fuel consumption with respect to the time of the day for a peak temperature day in the month. The quantity of fuel used to generate one unit of output power is referred to as specific fuel consumption. So minimum specific fuel consumption is desired which is obtained at the same time of 5.30 a.m. for all months where the power produced is maximum. Similarly, maximum specific fuel consumption which is not desired occurs almost at 2.30 p.m. for all months. However, for the month of May maximum specific fuel consumption of 0.1483 kg/kWh resulted at the same time of 2.30 p.m.

Limitations of the present work:

(1) As the ambient temperature variation is dynamic during the daytime and day-to-day, it is difficult to evaluate the performance parameters at a particular specified ambient temperature pertaining to a particular moment in the day/month. Hence for each month considered in the analysis, from the meteorological data taken, the peak temperature day (i.e., Maximum temperature occurred day in a month) data is used in the evaluation of performance characteristics to know the influence of ambient temperature and relative humidity.

(2) Since the present research work's main focus is to study the influence of ambient conditions on the performance of the RGT cycle, the meteorological data is selected at a particular region in India, and the analysis has to be confined to a gas turbine installed on that particular region i.e., this analysis is

region bounded analysis and should take place separately for other regions.

4. CONCLUSIONS

Meteorological data of the city Vijayawada, Andhra Pradesh, India was taken for four hot summer months March, April, May, and June which are prevailing in most of the states in India. The performance of the RGT cycle was evaluated using energy and exergy analysis, to understand the influence of dynamic ambient conditions. On the day of the maximum temperature in each month, the analysis is conducted using the hourly variation in temperature and relative humidity. Each month's net power generation, specific fuel consumption, and first law efficiency are calculated over the course of selected four months. Additionally, the exergy efficiency of the power system was also calculated. The current analysis led to the following results.

(1) The ambient temperature is higher than the ISO temperature at any time throughout the day for all four months considered.

(2) The network output of a regenerative gas turbine unit drastically decreases with an increase in time of the day (i.e., with increase in temperature) and it attains minimum value for March, April, and June months at around 2.30 p.m. and lowest in the month of May month at 5.30 p.m.

(3) The second law efficiency of the cycle is always lower than first law efficiency for a gas turbine.

(4) The specific fuel consumption depends upon the net power production and hence it has a maximum value when the network output is lower i.e., at 2.30 p.m. for all the four months considered and have highest for the month May among the four months.

(5) Since the results obtained are based on dynamic variation of ambient conditions from meteorological data pertaining to a specified region in India, this type of analysis can be extended to any other region in India by taking the data belongs to that region.

So, it is emphasized as a conclusion that the ambient temperature and relative humidity both have a significant impact on the operation of the regenerative gas turbine unit.

Scope for Future work:

As evident from the results, the power output from the RGT cycle drastically decreases with an increase in ambient temperature, to compensate for such a loss, particularly during peak day times in the summer months, it is essential to provide some cooling techniques to the entry air to the compressor to send it at low temperature which increases air density and hence power output. Some of the cooling techniques suggested are evaporative cooling, inlet fogging, incorporating thermal energy storage (TES) system, etc.,

Furthermore, a detailed exergy analysis can be carried out to know the irreversibility/exergy destruction rate among the different RGT components which gives better insight into the energy dissipation.

REFERENCES

[1] IEA. (2022). World Energy Outlook 2022, IEA, Paris. https://www.iea.org/reports/world-energy-outlook-2022, License: CC BY 4.0 (report); CC BY NC SA 4.0 (Annex A)

[2] Wang, F.J., Chiou, J.S. (2004). Integration of steam injection and inlet air cooling for a gas turbine generation system. Energy Conversion and Management, 45(1): 15-26. https://doi.org/10.1016/S0196-8904(03)00125-0

[3] Baakeem, S.S., Orfi, J., Alaqel, S., Al-Ansary, H. (2017). Impact of ambient conditions of arab gulf countries on the performance of gas turbines using energy and exergy analysis. Entropy, 19(1): 32. https://doi.org/10.3390/E19010032

[4] Ameri, M., Enadi, N. (2012). Thermodynamic modeling and second law based performance analysis of a gas turbine power plant (exergy and exergoeconomic analysis). Journal of Power Technologies, 92(3).

[5] Haseli, Y. (2018). Specific entropy generation in a gas turbine power cycle. Journal of Energy Resources Technology, Transactions of the ASME, 140(3): 032002. https://doi.org/10.1115/1.4037902/442912

[6] Memon, A.G., Memon, R.A., Harijan, K., Uqaili, M.A. (2014). Thermo-environmental analysis of an open cycle gas turbine power plant with regression modeling and optimization. Journal of the Energy Institute, 87(2): 81-88. https://doi.org/10.1016/J.JOEI.2014.03.023

[7] Ebadi, M.J., Gorji-Bandpy, M. (2005). Exergetic analysis of gas turbine plants. International Journal of Exergy, 2(1): 31-39. https://doi.org/10.1504/IJEX.2005.006431

[8] Martin, A., Rivai, N.I., Amir, R.D. (2021). Exergoeconomic analysis of 21.6 MW gas turbine power plant in Riau, Indonesia. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, 84(1): 126-134. https://doi.org/10.37934/ARFMTS.84.1.126134

[9] Abdalla, M.E., Pannir, S., HusseinAhmed, A., Mahjob, A., Ahmed Abdalla, S. (2021). Regenerative gas turbine power plant: performance & evaluation. 25th International Compressor Engineering Conference at Purdue, May 24-28, 2021. https://docs.lib.purdue.edu/icec.

[10] Ahmed, A.H., Ahmed, A.M., Hamid, Q.Y. (2020). Exergy and energy analysis of 150 MW gas turbine unit: A case study. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, 67(1): 186-192.

[11] Bassily, A.M. (2013). Modeling, analysis, and modifications of different GT cooling techniques for modern commercial combined cycle power plants with reducing the irreversibility of the HRSG. Applied Thermal Engineering, 53(1): 131-146. https://doi.org/10.1016/j.applthermaleng.2013.01.002

[12] Srinivas, T., Gupta, A.V.S.S.K.S., Reddy, B.V. (2007). Parametric simulation of steam injected gas turbine combined cycle. Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy, 221(7): 873-883. https://doi.org/10.1243/09576509JPE418

[13] Vadlamudi, T.C., Kommineni, R., Katuru, B.P. (2022). Exploration of turbine blade cooling strategies for performance boosting and CO2 emissions reduction of combined cycle with steam injection based gas turbine. International Journal of Ambient Energy, 43(1): 2239-2250. https://doi.org/10.1080/01430750.2020.1730956

NOMENCLATURE

h	specific enthalpy (kJ/kg)
$\dot{W}$	work (kW)
$\dot{m}$	mass flow rate (kg/s)
x	molar air (kJ/kmol of CH_4)
M	molecular weight (kg/kmol)
ω	humidity ratio (kg of w.v/kg of d.a)
η	efficiency(%)
ex	specific exergy (kJ/kg)
φ	relative humidity (%)
τ	time(hr)
η_I	first law efficiency(%)
η_{II}	second law efficiency(%)
P	network output (kW)
sfc	Specific fuel consumption (kg/kWh)

Greek symbols

ω	humidity ratio (kg of w.v/kg of d.a)
η	efficiency(%)
φ	relative humidity (%)
τ	time(hr)
η_I	first law efficiency(%)
η_{II}	second law efficiency(%)

Subscripts

a	air, ambient
C/Comp	compressor
da	dry air
F	fuel
wv	water vapor
net	net
gen	Generator
gas	Gas

Abbreviations

CC	combustion chamber
GT	gas turbine
RGT	regenerative gas turbine
ISO	Indian standard organization
wv	water vapor
net	net
gen	Generator
gas	Gas