



ELK
Asia Pacific Journals

www.elkjournals.com

SIMULATION OF AIR INLET COOLING SYSTEM OF A GAS TURBINE POWER PLANT

Ejiroghene Kelly Orhorhoro

Department of Mechanical Engineering,
Faculty of Engineering, Delta State Polytechnic,
Otefe-Oghara, Nigeria,
kelecom@yahoo.com

Oghenero Wilson Orhorhoro

Department of Electrical and Electronic
Engineering,
Faculty of Engineering, Delta State Polytechnic,
Otefe-Oghara, Nigeria

ABSTRACT

This research work focus on the simulation of air inlet cooling system of a gas turbine power plant using an ASPEN HYSYS simulation software. ASPEN HYSYS is engineering software suite. The user interface is predicated on a library of ready-made user editable component models based in FORTRAN. Operating data for gas turbine unit were collected in every two hours on a daily control log sheet for a period of one month. The daily average operating variable were statistically analyzed and mean values were computed for the period of collection. The performance of the plant was determine by simulation using ASPEN HYSYS software to obtain the compressor work, turbine work. Other results such as Net-power, specific fuel consumption, heat Rate and thermal efficiency was calculated in excel sheet. The results obtained show that decrease in inlet air temperature brings about an increase in power output and thermal efficiency. Also, retrofitting of the existing gas turbine plant with mechanical system give a better performance.

Keywords: ASPEN HYSYS simulation software, Gas Turbine, Air inlet cooling, Temperature,

INTRODUCTION

The performance of a gas turbine power plant is sensible to the ambient condition. The ambient temperature has huge influence on the performance of a gas turbine plant. As the ambient air temperature arises, less air can be compressed by the compressor, thus, the

gas turbine output is reduced at a given turbine entry temperature [1]. Besides, the compression work increases because the limited volume of the air increases in proportionality to the intake air temperature [2,3]. Inlet air cooling and intercooling are two important methods for rising power output of gas turbine cycles.

Gas turbine intake air cooling may cause a small decrease in efficiency because a lot of fuel is needed to make compressor exhaust gas [4]. Gas turbine makes use of ambient air for its operation and its performance is greatly affected by these factors (ambient temperature, ambient pressure, relative humidity) which influence the flow rate of air delivered to the compressor, in terms of weight and physical conditions [5].

An increase in compressor inlet temperature brings about a corresponding increase in the specific work required to compress the air. However, the weight delivered will be increase (because of decrease in specific weight). Consequently, the power output, turbine efficiency and useful work diminish [6]. If the compressor inlet temperatures decrease, the reverse process occurs. This temperature depends on the air aspirated by the compressor. Power and efficiency varies from turbine to turbine, according to cycle parameters, compressor and expanded output and air delivery rate etc. As a result, the variation ratios of gas turbine performance parameter are proportional to design point [7]. Figure 1 shows how power, heat consumption, heat

rate and the delivery rate of the exhaust gases are influence by ambient temperature [8]. (**Refer Fig. 1**)

The inability of a gas turbine engines to perform to an optimum efficiency is as a result of increase in compressor air above ISO condition (15°C) [8]. This research work is aimed at the improving the gas turbine performance and bring it near to ISO conditions.

METHODS AND MATERIALS

SOFTWARE MODELLING AND SIMULATION TOOL

ASPEN HYSYS is engineering software suite. The user interface is predicated on a library of ready-made user editable component models based in FORTRAN. By connecting these components by material heat and work streams and providing appropriate inputs, the user is able to model complex processes. ASPEN is commonly used software platform for process modeling, particularly in the oil and gas industry, Power Generation Company etc.

DATA USED

Operating data for gas turbine unit were collected in every two hours on a daily control log sheet for a period of one

month. The daily average operating variable were statistically analyzed and mean values were computed for the period of collection (**Refer Table 1**).

3.4 MODELLING OF GAS TURBINE UNIT

The basic gas turbine cycle is Brayton cycle. Air enters the compressor where it is compressed and heated. It goes to the combustion chamber; the fuel is burned at constant pressure where the temperature of air is fired to a high temperature (T_3). The resulting high temperature gases enter the turbine where they expand to generate the useful work and the exhaust gases leave the turbine (open-cycle gas turbine engine). Figure 2 shows the schematic diagram of simple Gas Turbine and figure 3 shows the flow chart of model Simple Gas Turbine. (**Refer Fig. 2**)

In Figure 2, the compressor inlet temperature is equal to ambient air temperature since the base-case neglects the cooling effect and simulate the cycle under ISO condition ($T_1 = 15^{\circ}\text{C}$, $P_1 = 101.3\text{kpa}$ and $\phi = 60\%$). There is no pressure drop at inlet and exhaust ducts thus; pressure drop across combustion chamber is taken to be 2% [9]. (**Refer Fig. 3**)

The gas turbine plant consists of compressor, combustion chamber and turbine. In this research work, the inlet cooling technique proposed for the analysis is mechanical refrigeration cooling system. The performance of the gas turbine is evaluated with the proposed cooling technique and compared with values. In the mechanical refrigeration system, the refrigeration vapour is compressed using vapour compression. The vapour passes through the condenser where expansion takes place in the expansion valve, thus, providing the cooling effect. The evaporator helps to chills the incoming air before entering the compressor. The gas turbine power plant is model base on the following assumptions;

- i. All component has adiabatic boundaries
- ii. Plant performance at ISO conditions
- iii. The air and the combustion products are assume ideal characteristics
- iv. Kinetic and potential components of energy are neglected
- v. The ambient conditions of temperature and pressure are at 27.63°C and 101.3kpa
- vi. The vapour entering the compressor is dry saturated and there is no undercooling

- vii. Lower heating value of fuel (LHV) to be 50,000kJ/kg
- viii. The pressure drop in combustion chamber 2%
- ix. Combustion efficiency to be 0.99
- x. Isentropic efficiency for compressor and turbine 100%
- xi. Pressure and temperature of the evaporator to be (2.4371bar, -5)
- xii. Pressure and temperature of the condenser to be (11.5447bar, 45)
- xiii. Work fluid of refrigerant 134a

PROCESS SIMULATION

The first step in creating the model was the selection of a standard set of components and a thermodynamic basis to model the physical properties of these components. The selected components data required for the Gas Turbine simulation are shown in **(Refer Table 2)**.

When the component list was created, HYSYS created a new component list called "Component List-1". The next step was the selection of a 'Fluid Package' for it. The 'Fluid Package' which is the thermodynamic system associated with the chosen list of components **(Refer Figure 4)**.

To account for the reaction that will be taking place in the Combustion Chamber

the reaction methane was added to the process simulation **(Refer Figure 5)**.

Figure 6 shows the process flow sheet for Gas Turbine with Mechanical Refrigeration Unit. **(Refer Fig 6)**

The refrigerant is compressed in the centrifugal compressor unit and this is followed by condensation. The condense vapour is expanded in the expansion valve where it provides the cooling effect. The cold air compressed in the compressor entered the combustion chamber. Hot gases produced in the combustion chamber are expanded in the turbine to produce the work, which drive the compressors.

RESULTS AND DISCUSSION

The performance of the plant was determine by simulation using ASPEN HYSYS software to obtain the compressor work, turbine work. Other results such as Net-power, specific fuel consumption, Heat Rate and Thermal Efficiency was calculated in excel sheet. Table 3 shows the results obtained. **(Refer Table 3)**

The simulation results obtained by incorporating air intake cooling system (mechanical refrigeration system), the ambient air temperature, pressure at inlet and exit, mass flow rate of refrigerant,

mass flow rate of air entering the mechanical refrigeration unit, the ambient air temperature varied at different condition is show in **(Refer Table 4)**.

Figure 7 shows the graph of net power output against ambient temperature. An increases inlet air temperature from 301k to 313k decreases the power output. This lead to approximately 0.135% drop in power loss, this loss can be prevented by cooling the inlet air temperature from 313k to 301k, thus, an approximately 0.136% increase in power output. **(Refer Fig. 7)**

Figure 8 shows the graph of thermal efficiency against ambient temperature. It was observed that as the inlet air temperature increase from 301k to 313k, there was a decrease in thermal efficiencies. Therefore, an approximately 0.0605% drop in thermal efficiency was recorded. This drop can be increase by cooling the inlet air temperature from 313k to 301k which leads to approximately 0.066% increase in thermal efficiency. **(Refer Fig. 8)**

Figure 9 shows the graph of specific fuel consumption against ambient temperature. Increase in ambient inlet temperature from 301k to 313k brings about an increase in specific fuel consumption. This lead to

approximately 2.41% increase in high CO and HC emission. The emission can be prevented by cooling the air inlet temperature from 313k to 301k which will bring about an approximately 2.35% decrease in fuel burning. **(Refer Fig. 9)**

Figure 10 shows the graph of heat rate against ambient temperature. An increase in ambient air inlet temperature from 301k to 313k increase the heat rate. This lead to approximately 0.460 drop in fuel efficiency. This drop can be prevented by cooling the inlet air temperature from 313k to 301k thereby increasing fuel efficiency by 0.462% efficiency. **(Refer Fig. 10)**

CONCLUSION

Simulation model that consist of thermal analysis of gas turbine couple to refrigeration cooler was develop. The performance analysis is based on coupling the thermodynamic parameters of the gas turbine and cooler unit with the other variable. The augmentation of the Gas turbine plant performance is characterized using the power gain ratio (PGR) and thermal efficiency change term (TEC). The performance analysis of the gas turbine shows that the intake air temperature decrease by 27.63°C to 17.79°C while the PGR increase to a maximum of 10.75%.

There was an average increase in power output from 33.794MW to 37.425MW with significant increase in plant thermal efficiencies from 33.279% to 36.855%. Therefore, decrease in inlet air temperature brings about an increase in power output and thermal efficiency.

REFERENCES

- Zhang, W., Chen, L., Sun, F. (2009). Performance Optimization for an open cycle gas turbine power plant with a refrigeration cycle for compressor inlet air cooling. Part 2: power and efficiency optimization. Proceedings of the Institution of Mechanical Engineers, Part A. Journal of Power and Energy 223 (5), pp.515-522
- Mohanty, B., Paloso, G. (1995). Enhancing gas turbine performance by intake air cooling using an absorption chiller. Heat Recovery Systems and CHP 15 (1995) 41-50
- Ana P.P., Claudia, R.A, Edision, L.Z. (2012). Comparison of different gas turbine inlet Air cooling methods. World Academy of science, Engineering and Technology 61:40–45
- Hall, A.D., Strover, J.C., Breisch, R.L. (1994). Gas turbine inlet air chilling at a cogeneration facility. Transaction of the American society refrigerating, and air conditioning engineers.100(1994)595–600
- Tobi, A.I. (2009). Performance enhancement of gas turbines by inlet cooling. International conference on communication, computer and power (ICCCP'09) Muscat, February 15–18:165–170
- Dawaud, B. (2005). Thermodynamic Assessment of power requirement and impact of different Gas Turbine Air cooling technologies at two locations in Oman. Applied Thermal Engineering Vol 25, pp 1579 – 1598.
- Al-Ansary, H.A. (2007). The use of ejector refrigeration systems for turbine inlet air cooling: a thermodynamic and CFD study”. Proceedings of the energy sustainability conference, Long Beach, California, pp. 231-238.
- Mahmood F.G., Mahdi, D.D (2009). A New Approach for Enhancing performance of a gas turbine (case study: Khangiran Refinery). Applied energy, 86: 2750-2759.

LIST OF FIGURES:

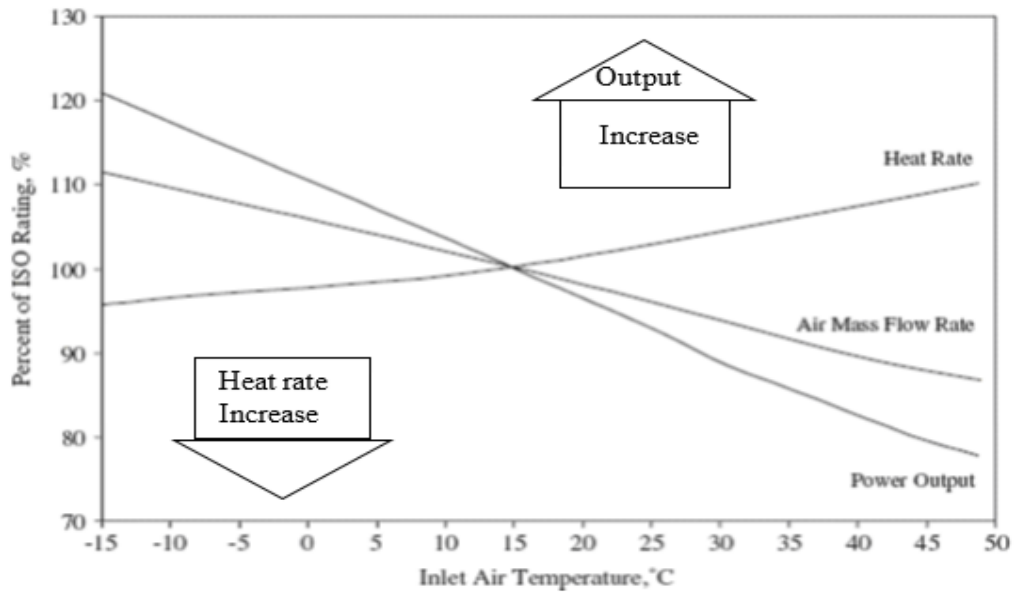


Fig. 1. Influence of external factor on gas turbine performance [8].

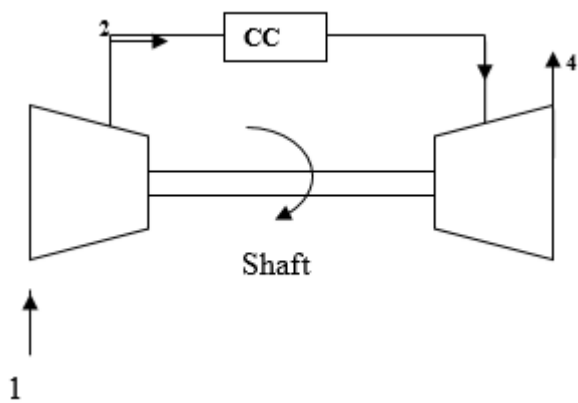


Fig. 2 Schematic diagram of simple gas turbine unit

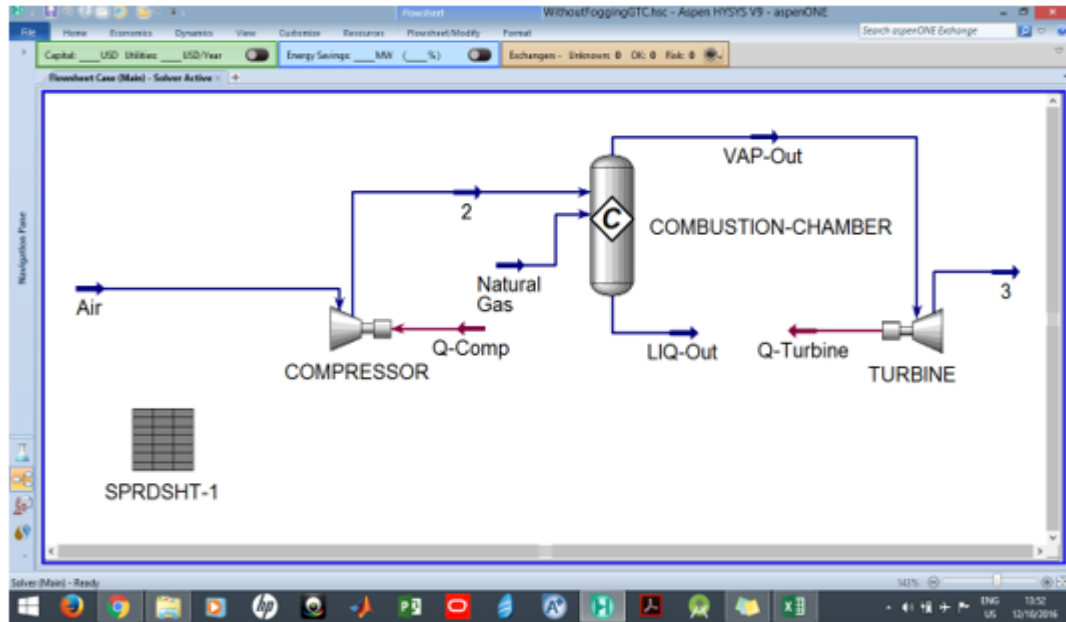


Fig.3 Flow chart model of Gas Turbine.

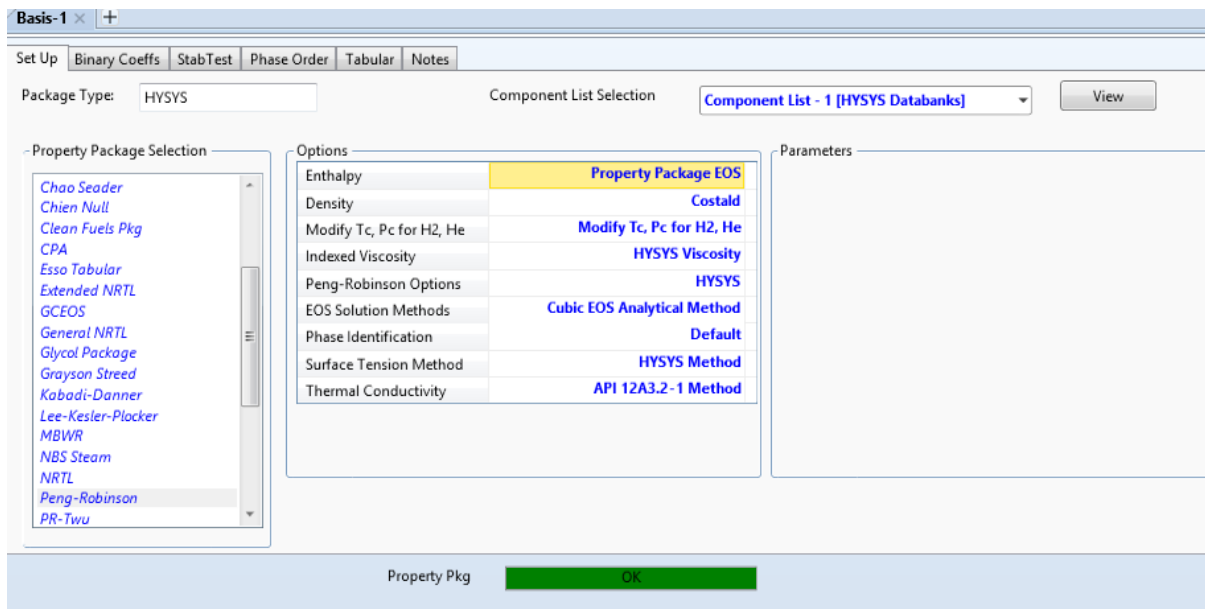


Fig. 4 Select thermodynamics for fluid package

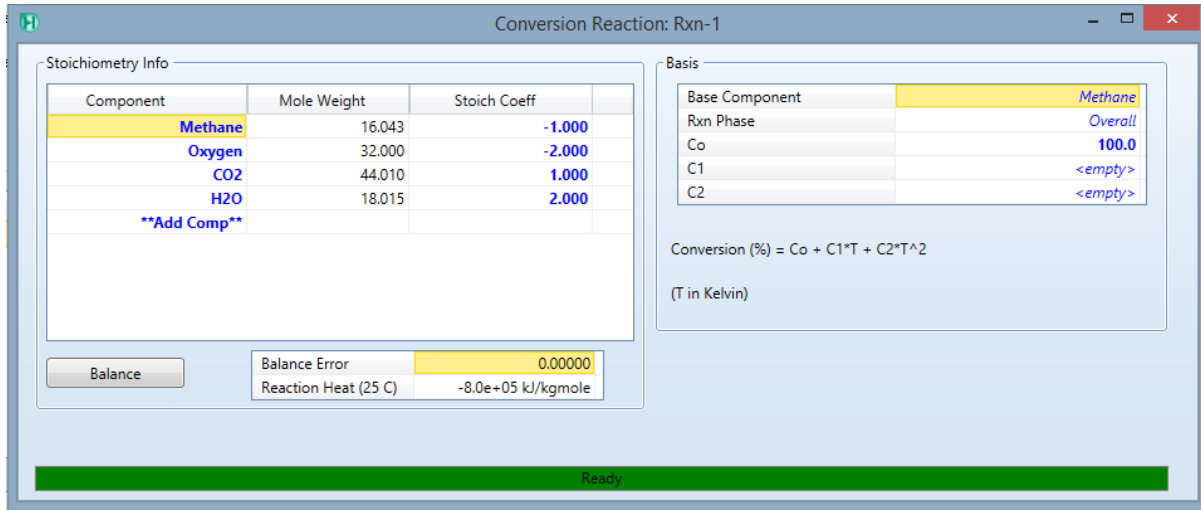


Fig. 5 Parameters for the reaction in the combustion chamber

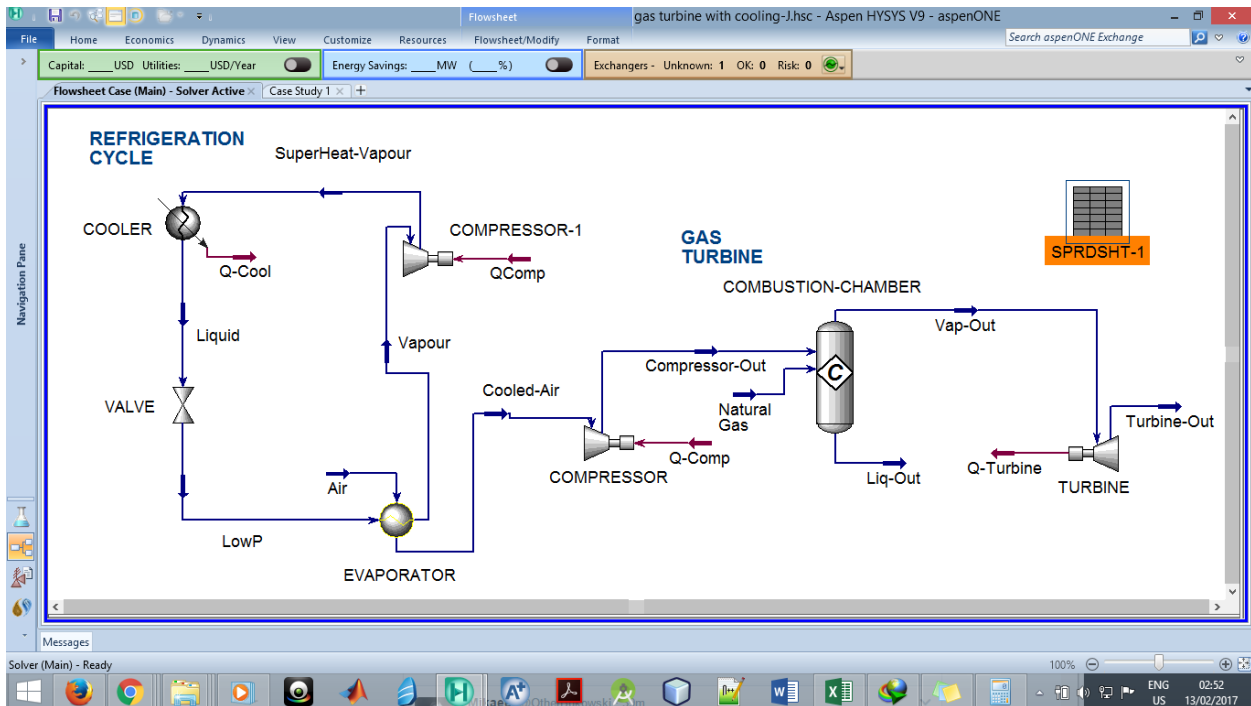


Figure 6. Process Flow sheet for Gas Turbine with mechanical refrigeration Unit

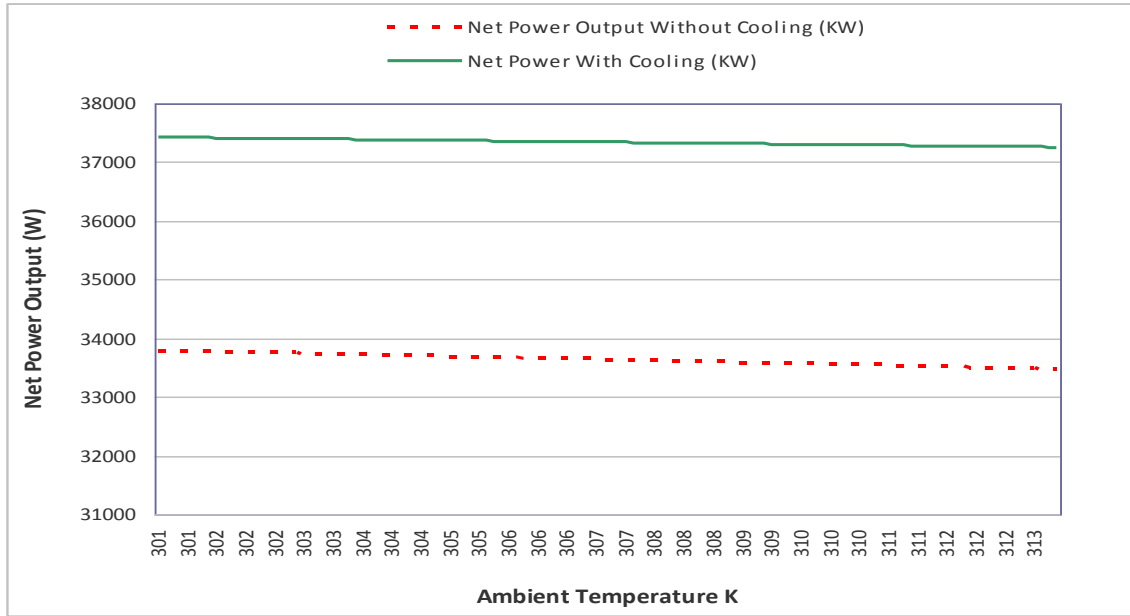


Fig. 7 Effect of Ambient Air Temperature on Net Power Output

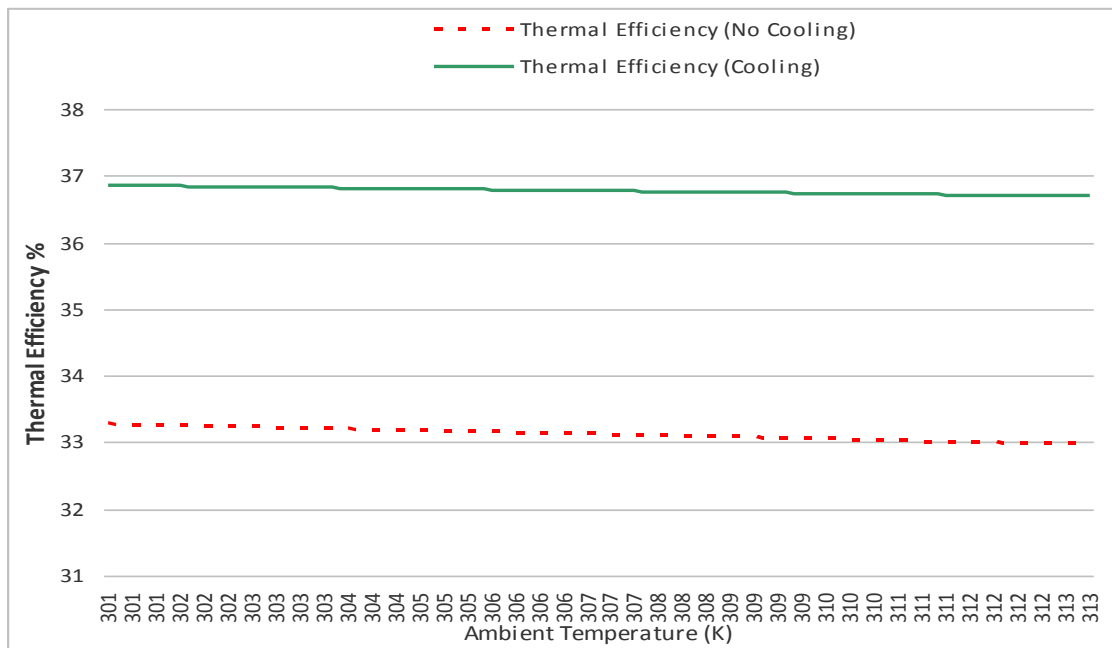


Fig. 8. Effect of Ambient Air Temperature on Thermal Efficiency

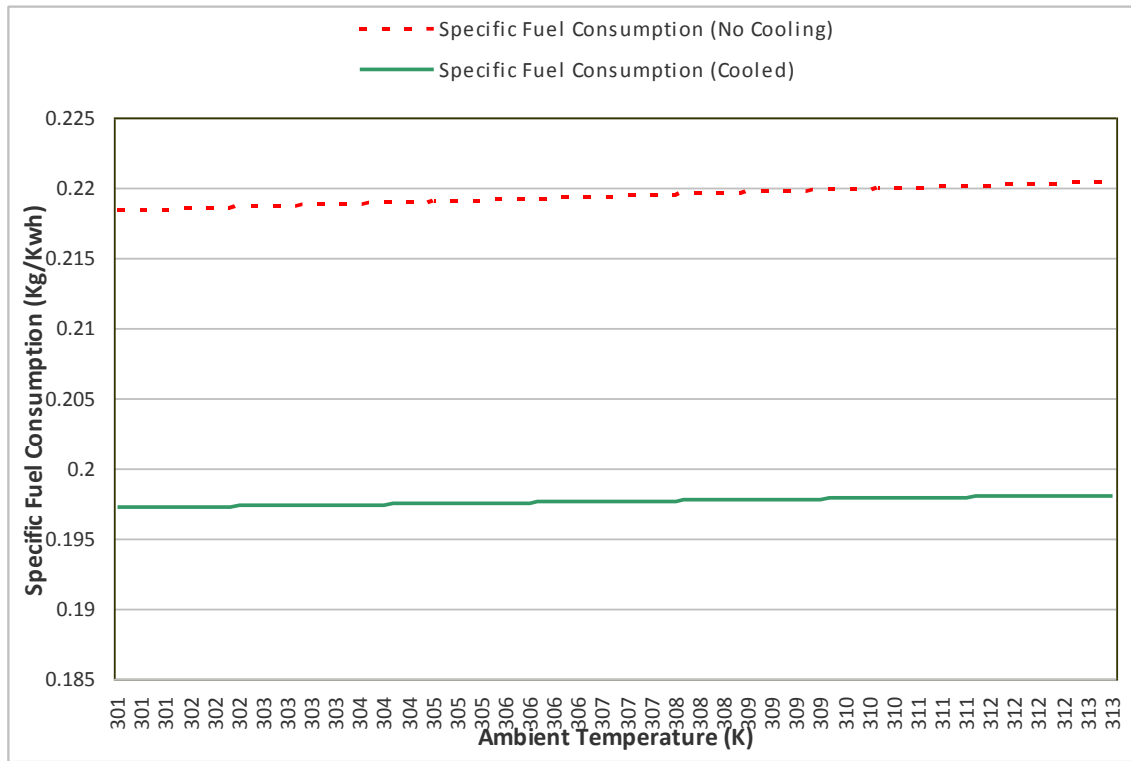


Fig. 9 Effect of ambient air temperature on specific fuel consumption

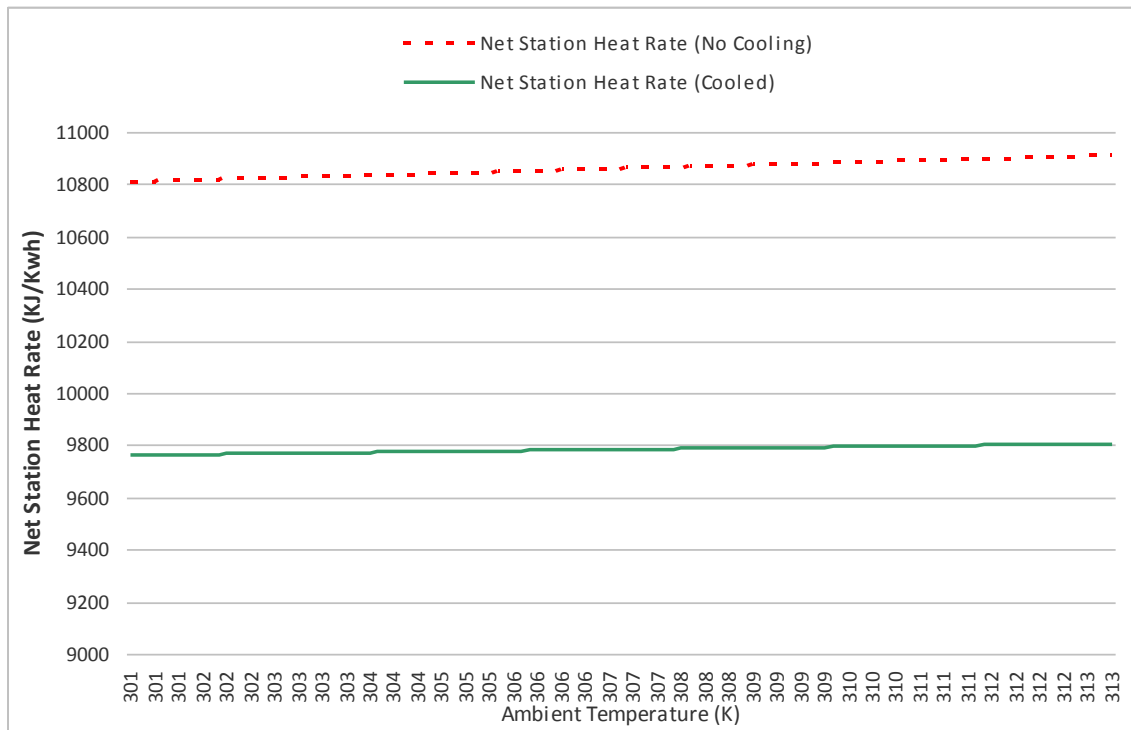


Fig. 10 Effect of ambient air temperature of heat rate

LIST OF TABLES:

Table 1. Operating data for Gas Turbine Unit

Compressor inlet temperature (T_1)	27.63°C
Compressor discharge pressure (P_2)	6.4bar
Compressor discharge temperature (T_2)	308.8°C
Exhaust temperature (T_4)	365.31°C

Table 2. Data use in incorporating Mechanical Refrigeration System into Gas Turbine

S/N	OPERATING PARAMETERS	VALUE	UNIT
1	Mass flow rate of air \dot{m}_a	208.69	Kg/s
2	Mass flow rata of fuel \dot{m}_f	2.050	Kg/s
3	Mass flow rate of exhaust \dot{m}_{exh}	210.74	Kg/s
4	Pressure of fuel gas p_f	2280	Kpa
5	Temperature of fuel gas t_f	328	K
6	Intake temperature to compressor T_1	290.142	K
7	Intake pressure to compressor P_1	101.3	Kpa
8	Exit temperature from compressor T_2	491.7	K
9	Exit pressure from compressor P_2	640	Kpa
10	Turbine pressure P_3	620	Kpa
11	Turbine temperature T_3	917	K
12	Exhaust temperature T_4	577.9	K
13	Exhaust pressure P_4	101.3	Kpa
14	Evaporator temperature	298.1	K
15	Evaporator pressure	243.71	Kpa
17	Centrifugal compressor temperature	312.6	K
18	Condenser temperature	303.1	K
19	Condenser pressure	1154.47	Kpa
20	Expansion valve temperature	246.8	K
21	Isentropic efficiency of compressor	100	%
22	Isentropic efficiency of turbine	100	%
23	Specific heat capacity of air C_{pa}	1.005	kJ/kgK
24	Specific heat capacity of exhaust gas C_{pa}	1.15	kJ/kgK
25	Pressure ratio P_r	6.317	
26	Lower heating value of fuel	50,000	kJ/kg
27	Combustion efficiency	99	%
28	Pressure drop in combustion chamber	2	%

Table 3. Simulated result obtained at simple type gas turbine unit

S/N	Result of simulated simple type gas turbine	Values
1	Compressor power	50255.194kW
2	Turbine power	84049.196kW
3	Net power	33794.002kW
4	Specific fuel consumption	0.2183819kg/kWh
5	Thermal efficiency	33.279%
6	Heat rate	10809.906kJ/kWh

Table 4. Simulation result of incorporating air intake cooling system (Mechanical Refrigeration system)

S/N	Results of simulation	Value
1	Compressor power	41338.639kW
2	Refrigeration compressor power	91.375kW
3	Turbine power	80655.259kW
4	Net power	37425.866kW
5	Thermal efficiency	36.855%
6	Specific fuel consumption	0.197kg/kWh
7	Heat rate	9761.157kJ/kW
8	Regeneration heat effects	370.67KW