



EFFECT OF INLET AIR COOLING ON THE GAS TURBINE PERFORMANCE USING EVAPORATOR AND VAPOUR ABSORPTION COOLERS AT THE HQ-2 DAUR SSGCL GAS COMPRESSION STATION

Qurban Ali¹, Tanweer Hussain², Ans Ahmed Memon³, Arshad Hussain⁴

¹Department of Mechanical Engineering, Mehran UET Jamshoro 76090, Pakistan

²Professor Department of Mechanical Engineering, Mehran UET Jamshoro
76090, Pakistan

³Lecturer Department of Mechanical Engineering, Mehran UET Jamshoro
76090, Pakistan

⁴Lecturer Department of Science and Technology, Indus University Karachi
75300, Pakistan

¹qurbanrind55@gmail.com; ²tanweer.hussain@faculty.muett.edu.pk;

³ans.memon@faculty.muett.edu.pk, ⁴arshad15me04@gmail.com

Corresponding Author: **Qurban Ali**

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Abstract

A gas turbine is a device that converts the energy of fuel into mechanical energy and is used to derive several types of rotating equipment. One of the major drawbacks of a gas turbine is that the performance (power output and thermal efficiency) of a gas turbine decreases instantly with the rise of ambient temperature. At Daur SSGCL Gas Compression Station, gas turbines are used to derive centrifugal type gas compressors to raise the pressure of natural gas where ambient temperature varies between 7⁰ to 50⁰C which decreases the performance of gas turbines. Inlet air cooling is a method through which the effect of ambient temperature on the performance of gas turbines can be decreased. This technique of cooling intake air increases the performance of gas turbines by increasing air density. There are various types of inlet air cooling but, in this study, two types of inlet air cooling techniques are discussed, one of which is the wetted media evaporative type and the other one is the vapour absorption type. The Evaporative type inlet air cooling technique is suitable for sites with high ambient temperature and low relative humidity and the vapour absorption type is used for a wide range of ambient air temperature. In this study, thermodynamic models of the gas turbine have been developed without inlet air cooling (base case/cycle) with inlet air cooling for analyzing the effects of ambient conditions (temperature and relative humidity) on the performance of the gas turbine. The simulated results obtained from Engineering Equation Solver with inlet air cooling systems (vapour absorption and wetted media evaporator cooler) are compared without an inlet air cooling (base cycle) gas turbine. On comparison of results of a gas

Qurban Ali et al

turbine with inlet air cooling systems to those without inlet air cooling at ambient conditions, $T_0=298.15K$ (25^0C) and $\phi=60\%$ it is found that a gas turbine with an evaporator cooler produces 289kW more power than a base case/cycle and 390kW more output power with vapour absorption inlet air cooling.

Keywords: Gas turbine; Ambient conditions; Daur Sindh Pakistan; Inlet air cooling; Evaporator cooler; Vapour absorption cooler.

List of Notations

| | |
|-----------------|--|
| C_{pa} | Specific heat of air at constant pressure [kJ/kg-K] |
| LHV | Lower heating value of fuel [kJ/kg] |
| HR | Heat rate [kJ/kWhr] |
| \dot{m}_a | Mass flow rate of [kg/s] |
| P | Pressure [kPa] |
| \dot{Q}_{in} | Rate of Heat energy added [kW] |
| r_c | Compression ratio [-] |
| T | Temperature [K] |
| Td | Dry blub temperature [K] |
| Tw | Wet blub temperature [K] |
| \dot{m}_{fu} | Mass flow rate of fuel [kg/s] |
| \dot{m}_t | Total mass flow rate [kg/s] |
| η_{tur} | Isentropic efficiency of turbine [-] |
| η_{bu} | Combustion chamber [-] |
| \dot{W}_{tur} | Total output power of turbine [kW] |
| \dot{W}_{net} | Net output power of turbine [kW] |
| \dot{W}_{co} | Compressor power [kW] |
| \dot{m}_{ew} | Mass flow rate of evaporated water [kg/s] |
| \dot{Q}_{col} | Cooling load [kW] |
| η_c | Isentropic efficiency of compressor [-] |
| C_{pg} | Specific heat at constant pressure of combustion product [kJ/kg-K] |
| SFC | Specific fuel consumption [kg/kW-hr] |
| h | Specific enthalpy [kJ/kg] |
| ξ | Effectiveness of evaporator cooler [-] |
| ϕ | Relative humidity [-] |
| ω | Specific humidity [Kg _{water} /kg _{air}] |
| K | Specific heat ratio [-] |
| Q_{cl_VA} | Cooling load of VA cooling system [kW] |
| Q_{gen} | Heating load of VA cooling system [kW] |

List of Abbreviations

| | |
|-------|--|
| BGT | Base Gas Turbine |
| GT | Gas Turbine |
| SSGCL | Sui Southern Gas Company limited |
| LH | Latent Heat |
| HP | High Pressure |
| LP | Low Pressure |
| VA | Vapour Absorption |
| VC | Vapour Compression |
| RH | Relative Humidity |
| ISO | International Organization for Standardization |
| Lo: | Load on turbine shaft |
| HR | Heat Rate |
| T.E | Thermal Efficiency |

I. Introduction

An industrial gas turbine (GT) converts the energy of fuel into mechanical energy using air as a source of conversion. This mechanical energy can be used to derive several types of rotating equipment. The way gas turbine turns fuel energy into heat energy by using a thermodynamic concept known as the simple Brayton (Joule) cycle. The Brayton (Joule) Cycle, as applied to the gas turbine consists of four stages: (i) Compression (ii) Combustion (iii) Expansion (iv) Exhaust. During compression, the pressure of air increases, while the volume of the air decreases along with the temperature rise. Fuel is applied to the air during the combustion process and ignited at constant pressure. During expansion, work is extracted from the flue gases with the help of a turbine. In the exhaust stage, as the gas stream exits the engine, conditions eventually return to ambient. Although the engine turbine section efficiently extracts energy from the hot gases, the temperature of the gases in the exhaust is typically around 950°F [XIV]. Gas turbines are used for several purposes in the world such as for propulsion, derive mechanical engines, and electricity production. In different regions of the world, weather conditions (temperature and humidity) are different which affect the performance of gas turbines. Gas turbines' performance is often lower than the ISO specification at high ambient temperature because the density of compressor intake air decrease with temperature which decreases the power output and thermal efficiency (T.E) of gas turbines. Other effects of high airstream temperature off compressor are the increase of the rate of heat (HR), reduction in compression ratio, and rise of exhaust temperature. This influence of high temperature on gas turbine output can be decreased by applying several approaches for cooling the intake air of turbines which will drop compressor intake air temperature and enhance the output of the gas turbine. Two main cooling intake airstream methods are (a) evaporative cooling (b) Refrigeration cooling.

In past, many researchers have studied the effect of cooling airstream on the gas turbine performance upgrading. F. Onoroh et al, performed modeling and simulation to study the impact of moisture content and ambient temperature (T_a) on gas turbine performance using MATLAB software. The results obtained show that 0.7% rise in

Qurban Ali et al

temperature, increases the power consumption of compressor 1.65% and 0.5% for 71.4% increase in moisture content. Also, a 1.71% rise in ambient temperature, increases 0.15% specific fuel consumption. One thing more they concluded from results that for 41.7% rise in moisture content decreases fuel consumption by 0.49% [XI]. Muhammad Reza Majadi Yazadi et al, performed a comparative study on GT intake air cooling systems for various climates, in four separate cities of Iran by analyzing energy, exergy, economic and environmental (4e's) quantities of the gas power plant. The results received show that for hot climates absorption cooling system is the best, it increases the net power output of GT 18% and 14%, energy efficiency by 5.8% and 5.5%, exergy efficiency by 2.5% and 1.5% in Bandar Abass and Yazad respectively [XV]. Seyed Mehdi Arabi et al, Studied the impact of various inlet air cooling systems on the performance of the G11 gas turbine at the Zangbagh power station. The results received show that a decrease in temperature of 1°C between 14°C and 50°C of inlet air enhances work rate and efficiency by 0.16MW and 0.085 percent respectively [III]. Saleh S. Baakeem et al, theoretically studied the effect of ambient conditions on the performance of a simple GT for three regions of Saudi Arabia and concluded that maximum annual power production loss in Riyadh, Ad Dammam, and Jeddah are 7.1, 8.2, and 11.2% respectively. When charge air is cooled to 8.9°C or 10.15°C then power generation increases to about 4220kW and 3028kW respectively [IV].

The literature review reveals that one of the major causes of the rapid performance drop of the gas turbine is the rise of ambient temperature. In this study, the area where gas turbine is considered for the study is Daur, Sindh, Pakistan where the ambient air temperature varies between 7°C to 52°C, which is obtained from past recorded data of gas turbine of Hq-2, Daur SSGCL Gas transmission station.

In this work, a thermodynamic model is used to investigate the effect of wetted media type evaporative inlet air cooling and vapour absorption cooling techniques on the Performance of a Solar Taurus-60 gas turbine which is used to derive gas compressor at HQ-2 Daur SSGCL Gas Compression Station at different ambient conditions and then the obtained results with this model are compared with base-case (without intake air cooling). The EES software is used for analyzing the effects of ambient conditions on the performance gas turbine and finally, the results obtained with cooling systems and without cooling systems are compared.

II. The site (Daur Sindh, Pakistan) weather study

In this research, gas turbine performance is analyzed at Daur SSGCL Gas compression station which is located in district Shaheed Benazir Abad (Nawabshah), Sindh province of Pakistan. The investigation of performance is done by computing dry bulb temperature every month and RH on monthly basis. In Daur, summers are hot, humid, and windy and winters are short, cool, and dry and mostly it is clear round the year.

(A) Average temperature in Daur Sindh Pakistan

In Daur Sindh, Pakistan the hot season lasts for 4 months, with maximum average temperature (41-50°C) occurring during April to August. The hottest month of the year in Daur is June with an average temperature of 50°C. The cool season goes

Qurban Ali et al

approximately for 3 months, with a minimum average temperature (7-11°C). The coldest month of the year in Daur is January Figure (1).

(B) Average cloud and relative humidity in Daur Sindh Pakistan

In Daur Sindh, Pakistan the muggier season lasts for 4 months, with maximum average humidity (40-60%) occurring during June to September and the most humid month is August as shown in Figure (2). The Study of this weather condition is important for analyzing the impacts of intake air cooling systems on the performance of the gas turbine. It is relative humidity that limits the performance of evaporative type inlet cooling system significantly.

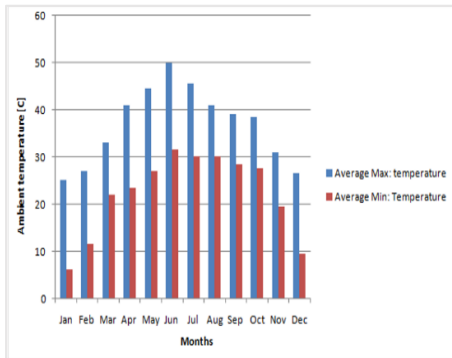


Fig 1. Monthly average maximum and minimum temperature in Daur

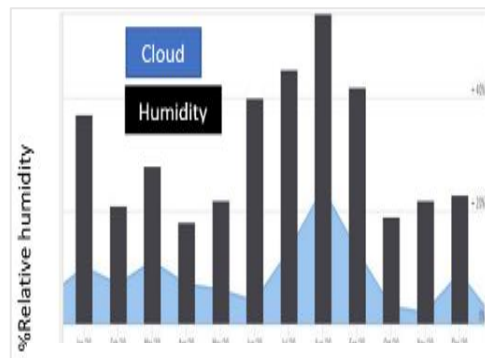


Fig 2. Monthly average cloud and relative humidity in Daur

III. Thermodynamic approach on the gas turbine with and without inlet air cooling systems

In this section thermodynamic models of a gas turbine are developed with and without an inlet air cooling system.

(A) Gas turbine without inlet air cooling system (base cycle)

Thermodynamically, GT works on the Brayton cycle which consists of two isochoric and two isobaric processes. Figure 3. defines the studied gas turbine. The points from 0 to 6 illustrate the thermodynamic states of air, from turbine inlet to exhaust. Pressure and temperature of each point will be calculated by considering Figure (3).

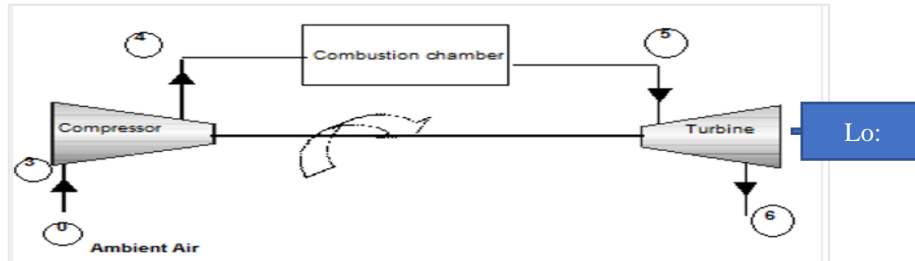


Fig 3. Schematic diagram of gas turbine without IAC/Base cycle/case

The compressor intake temperature is equal to climate temperature by assuming that

there is no drop of pressure at inlet and turbine's exhaust, then in result:

$$P_0 = P_3 \quad (1)$$

Assuming airstream and flue gas products behave as ideal gases then the air pressure at the compressor's outlet is determined as:

$$P_4 = r_c \times P_3 \quad (2)$$

Where r_c is the compression ratio. The exit temperature of the compressor can be estimated as:

$$T_4 = \frac{T_3}{\eta_c} \left[(r_c)^{\frac{k-1}{k}} - 1 \right] + T_3 \quad (3)$$

The above expression is obtained from the isentropic relation of ideal gases and reversible-adiabatic air-compressor efficiency. The isentropic efficiency of air-compressor can be calculated as (Hany Al Ansary, 2015).

$$\eta_c = \left[0.04 - \frac{r_c - 1}{150} \right] \quad (4)$$

With the use of the first law of thermodynamic and assuming specific heat of the air (C_{pa}) is constant when pressure is constant then the power of compressor can be evaluated as:

$$\dot{W}_{co} = \dot{m}_a \times C_{pa} \times (T_4 - T_3) \quad (5)$$

Where \dot{m}_a airflow rate in terms of mass.

In the combustion chamber, fuel is added to the compressed air which burns and produces combustion products. The energy added can be estimated from the energy balance equation as:

$$\dot{Q}_{in} = \dot{m}_a \times C_{pg} \times (T_5 - T_4) \quad (6)$$

Where C_{pg} is burned gas specific heat constant at constant pressure which is a function of average temperature across combustion chamber (Najjar, 2004).

Fuel gas mass flow rate can be evaluated as:

$$\dot{m}_{fu} = \frac{\dot{Q}_{in}}{LHV \times \eta_{bu}} \quad (7)$$

LHV refers to the lower heating value of fuel and η_{bu} combustion chamber efficiency.

The temperature of gases leaving the turbine can be obtained by using polytropic relation of ideal gases as:

$$T_6 = T_5 + \eta_t \times T_5 \left[\left(\frac{1}{r_c} \right)^{\frac{k-1}{k}} - 1 \right] \quad (8)$$

Where T_5 is known as firing temperature of gas turbine which is the design parameter of gas turbine and η_t is isentropic efficiency of gas turbine which can be determined as (Hany Al Ansary, 2015):

$$\eta_{tur} = \left[0.03 + \frac{r_c - 1}{180} \right] \quad (9)$$

Thus, the total power production produced by the turbine can be estimated as:

$$\dot{W}_{tur} = \dot{m}_t \times C_{pg} \times (T_5 - T_6) \quad (10)$$

Where \dot{m}_t is the total mass of working gas which is the sum of air and fuel gas mass flow rate:

$$\dot{m}_t = \dot{m}_a + \dot{m}_{fu} \quad (11)$$

The net power output of turbine can be determined as:

$$\dot{W}_{net} = \dot{W}_{tur} - \dot{W}_{co} \quad (12)$$

Heat rate (HR) and specific fuel consumption (SFC) can be evaluated by using following expressions:

$$SFC = \frac{3600 \times \dot{m}_{fu}}{\dot{W}_{net}} \quad (13)$$

$$(\text{Heat Rate}) HR = SFC \times LHV \quad (14)$$

Finally, the T.E of the gas turbine can be evaluated by:

$$\eta_{th} = \frac{3600}{HR} \quad (15)$$

(B) Gas turbine with wetted media evaporative inlet air cooling system

The cooling through evaporation is for sites with high ambient/climate temperature and relative humidity is low because it decreases ambient air temperature from dry blub to wet blub temperature by using latent heat of vaporization. It is similar to the fogging system however water is not directly injected into the compressor inlet air. Instead, inlet air is allowed to travel through a wet media and latent heat of water evaporation absorbs energy from inlet air. Figure (4) defines the studied gas turbine with an evaporative cooling system for intake air. The points from 0 to 6 illustrate the thermodynamic states of air, from turbine inlet to exhaust.

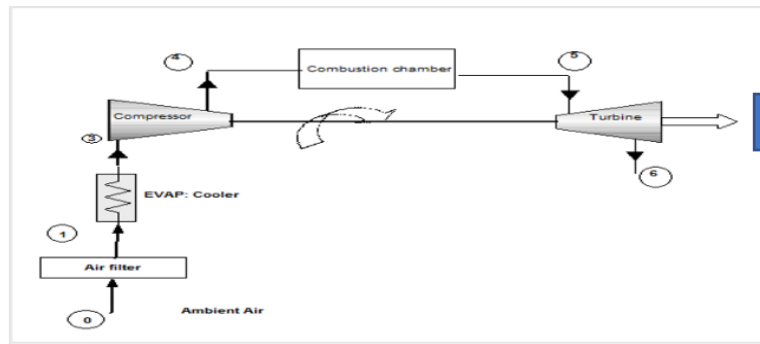


Fig 4. Schematic diagram of a gas turbine with evaporative inlet air cooling system.

As shown in Figure 4, air after passing through air filters it will pass through an evaporator cooler where air cool up to wet blub temperature. The compressor inlet air temperature after evaporator cooler can be determined as:

$$T_{3} = Td_{1} - \xi \times (Td_{1} - Tw_{1}) \quad (16)$$

The mass flow rate of evaporated water in evaporative type inlet air cooling system, neglecting bleed water quantity because it requires a very limited amount for the operation of equipment, can be determined as:

$$\dot{m}_{ew} = \dot{m}_a \times (\omega_1 - \omega_2) \quad (17)$$

Where \dot{m}_a is the mass flow rate of air and ω_1 and ω_2 are the specific humidity of evaporator inflow and outflow air respectively.

The cooling load in evaporative type inlet air cooling can be determined as:

$$\dot{Q}_{col} = \dot{m}_a \times C_{pa} \times (T_1 - T_3) \quad (18)$$

(C) Gas turbine with vapour absorption inlet air cooling

In vapour absorption (VA) inlet air cooling system ammonia is used as refrigerant and aqua ammonia as a solution. It uses heat energy from exhaust gases which provides power to this type of cooling system. In this type of cooling system, when ambient air passes through a heat exchanger in which chilled water circulates the air becomes cool. Figure (5) defines the studied gas turbine with VA cooling system. The points from 0 to 6 illustrate the thermodynamic states of air, from turbine inlet to exhaust.

In VA type of inlet air cooling system, the cooling load due to ambient air can be calculated as (Mohapatra 2014).

$$\dot{Q}_{cl_VA} = COP \times \dot{Q}_{gen} \quad (19)$$

Where \dot{Q}_{cl_VA} is cooling load, \dot{Q}_{gen} is heating load and COP is the Coefficient of performance vapor absorption cooling system.

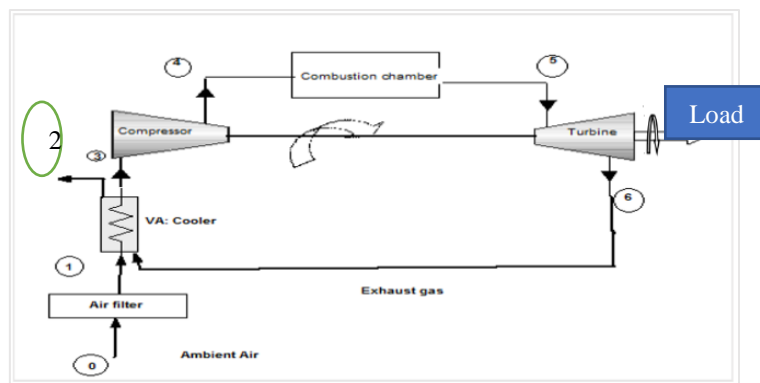


Fig 5. Gas turbine with vapour absorption inlet air cooling system

From above equations 1-19, it can see that the performance (net output power, thermal efficiency and heat rate) of gas turbines depends on ambient conditions, especially on relative humidity and temperature. The above thermodynamic models are developed by considering the Solar Taurus-60 gas turbine installed at Daur SSGCL Gas Compression Station. Table 1 represents the industrial specifications of the Taurus-60 gas turbine.

Table 1 : Design parameters of the typical gas turbine.

| Description | Values | Units |
|-------------------------------|---------------------|--------------------|
| Engine Manufacturer | Caterpillar company | - |
| Max RMP | 14300 | RPM |
| Model | Taurus | 60 |
| Engine power | 5740 | kW |
| Exhaust temperature | 510 | $^{\circ}\text{C}$ |
| Combustion chamber efficiency | 0.93 | - |
| Fuel Type | Natural gas | - |
| LHV of fuel | 45252 | kJ/kg |
| Pressure ratio | 12.2 | - |
| Inlet air flow rate | 21.3 | Kg/s |
| Exhaust flow rate | 77880 | kg/hr |
| Turbine firing temperature | 1037 | $^{\circ}\text{C}$ |

IV. Model Validation

For model validation, equations of base cycle/case (without inlet air cooling) were solved using an Engineering Equation Solver (EES). EES software has been broadly exercised for these sets of problems due to its ability to solve non-linear equations and its one-of features are producing accurate thermodynamic properties of varied fluids. Solar Taurus-60 gas turbine is used to validate the gas turbine model under ISO parameters. The figure shows a comparison of a conventional gas turbine's performance and the computed performance characteristics obtained from gas turbine modeling under ISO conditions. The maximum error of 7.60% occurs in thermal efficiency which is accepted in engineering problems.

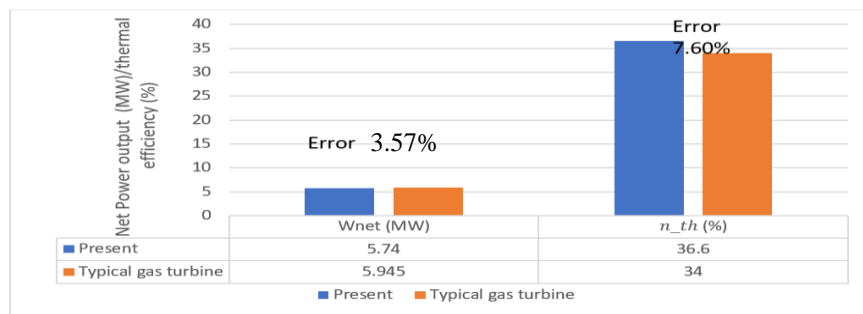


Fig 6. At ISO conditions, a comparison of typical and measured performance parameter for a gas turbine.

V. Results and Discussion

The results of the research are discussed in this section. The simulated results are obtained by analyzing the effect of ambient conditions (T and Φ) of Daur Sindh, Pakistan on the performance (power output and thermal efficiency) of gas turbine installed at Daur SSGCL Gas Compression Station on gas turbine without and with inlet air cooling systems by using EES software. EES models are developed by using thermodynamic models of section III.

(A) Investigation of the effect of ambient conditions of Daur Sindh, Pakistan and inlet air cooling system on the performance of the gas turbine

Figure 7, shows the simulated result of base case/cycle (without inlet air cooling) at ISO conditions by fixing turbine inlet temperature at 1310k. From the graph, it can understand that the output power of a gas turbine decreases with an increase in the temperature of ambient air. The average drop in power output of the studied gas turbine per Kelvin is approximately 25.5kW/k. It is due to the power output of gas turbines directly related to the rate of air mass flow, so as the ambient air temperature goes up the air mass flow rate decreases which decreases the power output of the turbine.

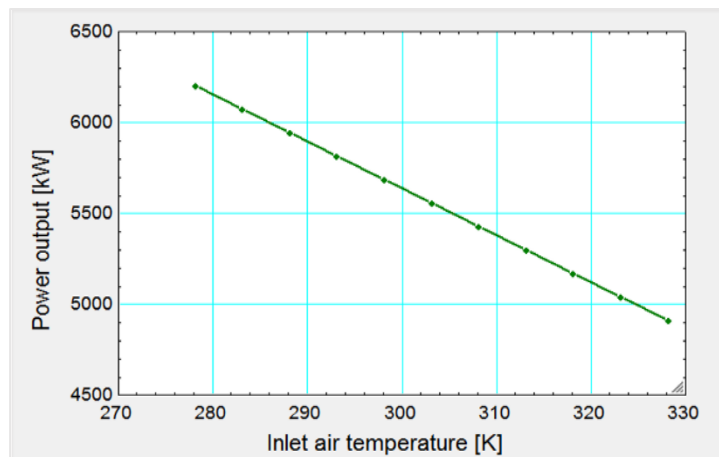


Fig 7. Effect of ambient/inlet temperature on the power output of the gas turbine

Figure 8, represents the simulated result of base case/cycle (without inlet air cooling) under ISO conditions by fixing turbine inlet temperature at 1310k. From the graph, as temperature increases, the (T.E) thermal efficiency of the gas turbine decreases. The average reduction in thermal efficiency of the studied gas turbine per Kelvin is about 0.043%. The above graph is obtained by running EES codes for various ambient temperatures.

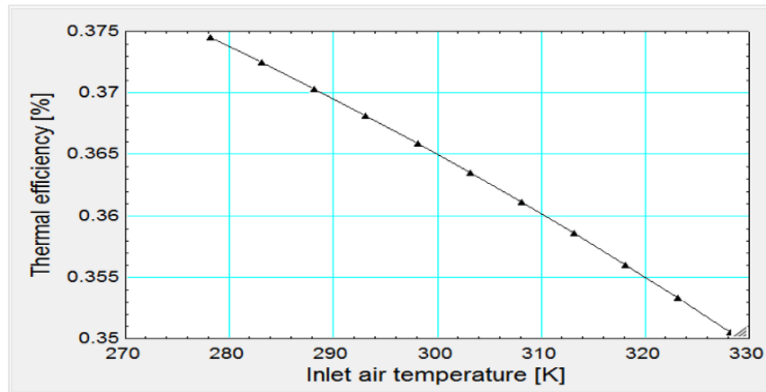


Fig 8. Effect of ambient temperature on the thermal efficiency of gas turbine

Figure 9, shows simulated results of the power output of base case/cycle and turbine with wetted media evaporative type inlet air cooling at various ambient temperatures. From the graph, the output power obtained with the inlet air cooling system is more than without a cooling system. Also, it can see from the graph that power output at lower relative humidity $\phi=20\%$, is more than power output at higher relative humidity $\phi=60\%$. The decrease in power output with an increase in relative humidity occurs because as relative humidity increases the wet bulb temperature increases which limits the temperature drop of the evaporator.

A temperature drop of 280.8K occurs when the intake air temperature is 323.15K at relative humidity $\phi=60\%$, with evaporative type inlet air cooling having effectiveness of 0.89.

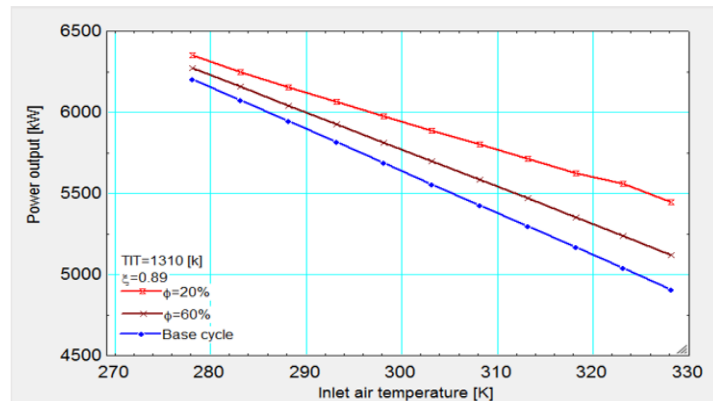


Fig 9. Effect of evaporative inlet air cooler on the power output of G.T

Figure 10, illustrates simulated results of thermal efficiency of base case/cycle turbine and gas turbine with wetted media evaporative type inlet air cooling at various ambient temperatures. From the graph, it can find that the thermal efficiency of a gas turbine with an evaporation type air cooling system is more than the base case/cycle (without inlet air cooling). Further, the thermal efficiency of the turbine is higher at relative humidity $\phi=20\%$ than relative humidity $\phi=60\%$.

Thus, with an evaporative type inlet air cooling system, the power output and the T.E of base case/cycle increase 3.9% and 1.2% respectively at relative humidity $\phi=60\%$ and ambient temperature 323.15K. And the power output and the thermal efficiency of the base case/cycle increase 10.9% and 2.9% respectively with evaporator cooler when relative humidity $\phi=20\%$ and ambient temperature is 323.15K.

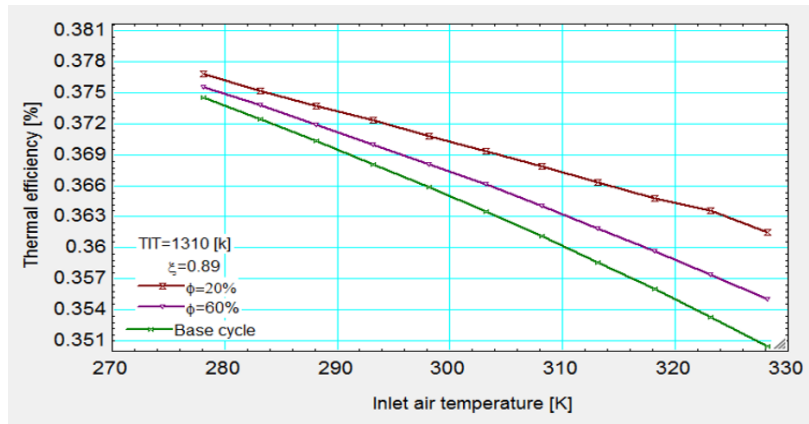


Fig 10. Effect of evaporative inlet air cooler on the thermal efficiency of G.T

Figure 11, shows simulated results of the power output of gas turbine without turbine's incoming airstream cooling (base case/cycle) and with vapour absorption-type turbine's incoming airstream cooling at various ambient temperatures. The below graph indicates that the output power of a gas turbine with vapour absorption inlet air cooling is independent of relative humidity or wet-bulb temperature of the air, however, to avoid ice formation on compressor blades the inlet air temperature of the compressor is fixed. In this study, the temperature of the compressor's inlet is set at 284.15k (10°C). Also, from the graph, it can find that the output power is independent of inlet air temperature because compressor inlet temperature for VA cooling is set at 284.15k (10°C) therefore gas turbine with VA inlet air cooling can be used for a wide range of ambient temperatures. At $T_0=323.15$ (50°C) the output power obtained with inlet air cooling is compared with base cycle it is found that 1037kW increment occurred in power of base cycle with inlet air cooling.

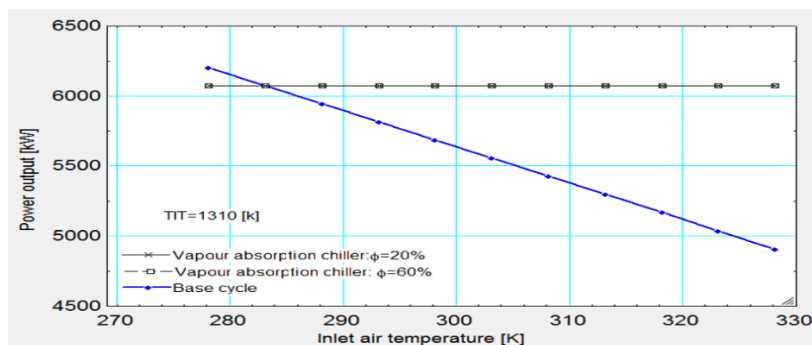


Fig 11. Effect of vapour absorption inlet air chiller on the power output of G.T

Figure 12, demonstrates simulated results of thermal efficiency (T.E) of a gas turbine with base case/cycle and with VA-type air cooling system at various climate temperatures. The graph given below shows that the thermal efficiency of a gas turbine with a VA airstream cooling system presents the same behaviour as power output.

At lower climate temperatures, the thermal efficiency enhancement is less than that of base case/cycle, however, at higher climate temperatures, the effect is more pronounced. Compared to the base cycle, T.E increases by 5.7 percent at $T_0=323.15\text{K}$ (50°C).

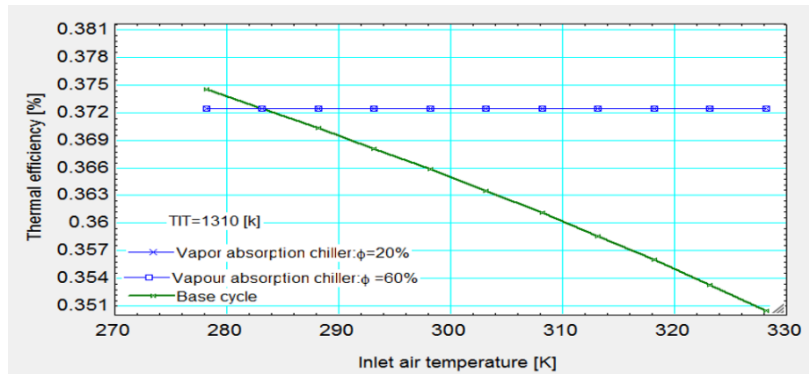


Fig 12. Effect of vapour absorption inlet air chiller on the thermal efficiency of G.T

VI. Comparison of results of the gas turbine without and with inlet air cooling systems

Figure 13, indicates power outputs of the gas turbine without and with inlet air cooling systems at two different climatic conditions, and it is found that power output obtained with systems cooling airstream of the compressor is more than that of BGT/base cycle. Further, the power output obtained with two cooling systems is more for vapour absorption compared to evaporator inlet cooling system.

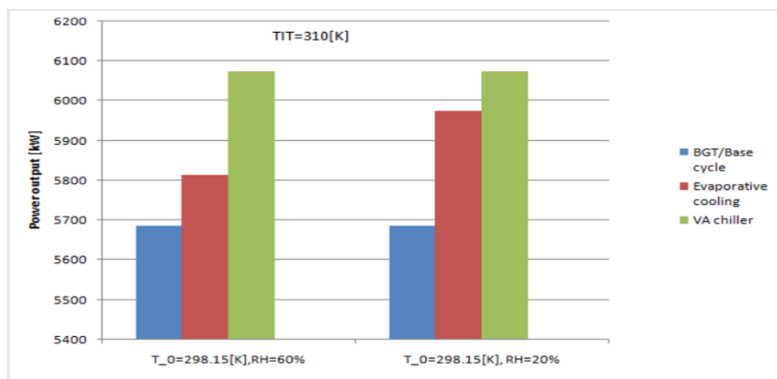


Fig 13. Comparison between power outputs of G.T without and with inlet air cooling

Figure 14, indicates thermal efficiencies of gas turbine without and with air cooling systems at two different ambient conditions. Thermal efficiencies present the same

behaviour as power outputs of a gas turbine with inlet air cooling and without inlet air systems. As indicated in the graph at the same ambient conditions the thermal efficiency obtained with the VA airflow cooling system is more than that of both base cycle and evaporative type inlet air cooling system.

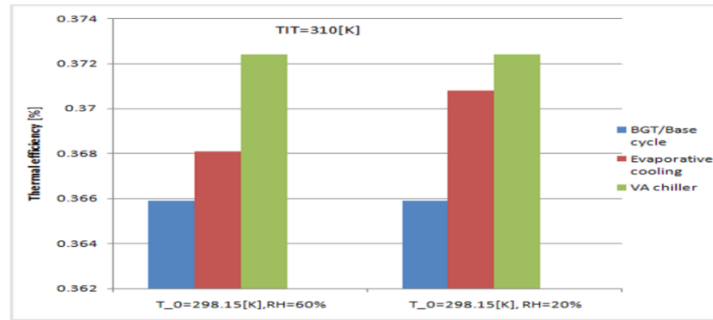


Fig 14. Comparison between thermal efficiencies of G.T without and with inlet air cooling.

VII. Conclusions

After analyzing the effects of ambient conditions and inlet air cooling systems on the power output and thermal efficiency of gas turbines the following findings can be outlined in the light of the results presented.

- The ambient air temperature and relative humidity have a significant impact on the output of gas turbines.
- The output power and thermal efficiency of the gas turbines decreases as the ambient temperature rises.
- At ISO conditions ($\phi=60\%$ and $T_0=15^\circ\text{C}$ or 288.15K) an increase of 298.15K (25°C) in ambient air temperature reduces the power output of gas turbine 13.46% and thermal efficiency 3.16% (Fig 7 and Fig 8.)
- From output powers comparison of gas turbine at Daur Sindh, Pakistan ambient conditions $T_0=298.16\text{K}$ (25°C) and $\phi=20\%$, it is concluded that the power output of gas turbine without inlet air cooling is 5686 kW (Fig 13.) which increases 289 kW with evaporative type inlet air cooling system and 390 kW with vapor absorption-type inlet air cooling system.
- With vapour absorption technique of cooling inlet air the power output of gas turbine increases 24% when air is cooled from 325.15K (52°C) to 283.15K (10°C).

VIII. Acknowledgment

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Conflicts of Interest:

The authors declare that they have no conflicts of interest regarding the paper.

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