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Gas Turbine Power Augmentation Using Absorption Cooling Technique: A Study of Transient Characteristics

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Abstract

The current study proposed a comparison of different parameters such as dry bulb temperature (DBT), turbine power (TP), generator power (GP), and specific fuel consumption (SFC). The current work also includes a detailed comparison of the variation of characteristic parameters for a simple cycle gas turbine and an absorption cooling technique. Transient simulation is used to analyse the performance characteristics for the above comparison for a typical metrological year (TMY).

Keywords: *Turbine Inlet Cooling, Transient Assessment, Absorption Chiller*

INTRODUCTION

Around the world, the gas turbine cycle (Brayton cycle) produces the most electricity. Gas turbines are widely used for power generation in almost every country due to their ability to start and stop quickly in comparison to other cycles. The compressor in a gas turbine cycle compresses atmospheric air into high-pressure air for use in the combustion chamber. Furthermore, high-pressure air is mixed with the fuel in the combustion chamber and then combusted to produce high-pressure, high-temperature flue gases, which are fed to a gas turbine for power generation.

The mass flow rate of air is directly proportional to the output power generation. Because the compressor in a particular gas turbine cycle has a fixed air volume to supply, the gas turbine is a constant volume cycle. Because the cycle consumes air directly from the atmosphere, the weather has a direct impact on its performance. As a result, the key parameters affecting performance are relative humidity and atmospheric temperature. As a result, different conditions such as heat and cold, as well as atmospheric dryness, have a significant impact on gas turbine performance.

To achieve efficient power generation in today's world, gas turbine performance must be improved. Cooling the air at the compressor's inlet before it enters the cycle is one of the most widely used methods in recent years to improve gas turbine cycle performance. Turbine inlet cooling (TIC) is a technique for increasing gas turbine efficiency.

The goal of turbine inlet air cooling is to cool the incoming air to the compressor inlet using a combination of techniques and technology. The approach will ensure maximum power output while reducing gas turbine power plant fuel consumption and pollution. As a result, the density of the air increases, increasing the power output. The following are some of the TIC techniques that are being researched:

EVAPORATIVE COOLER

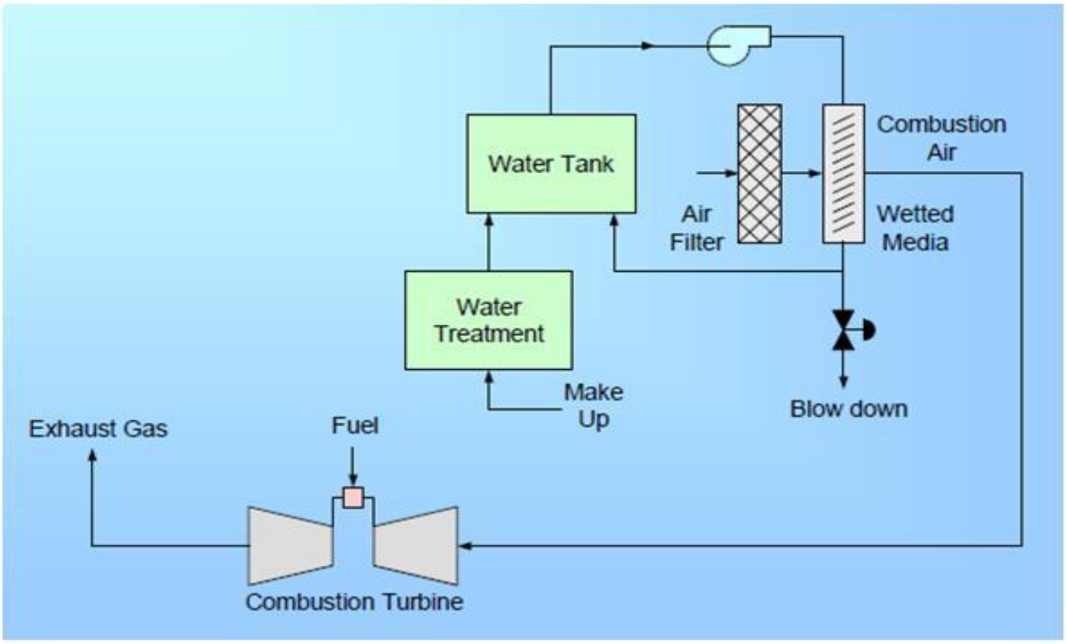

Figure 1 Schematic Diagram

FOGGING SYSTEM

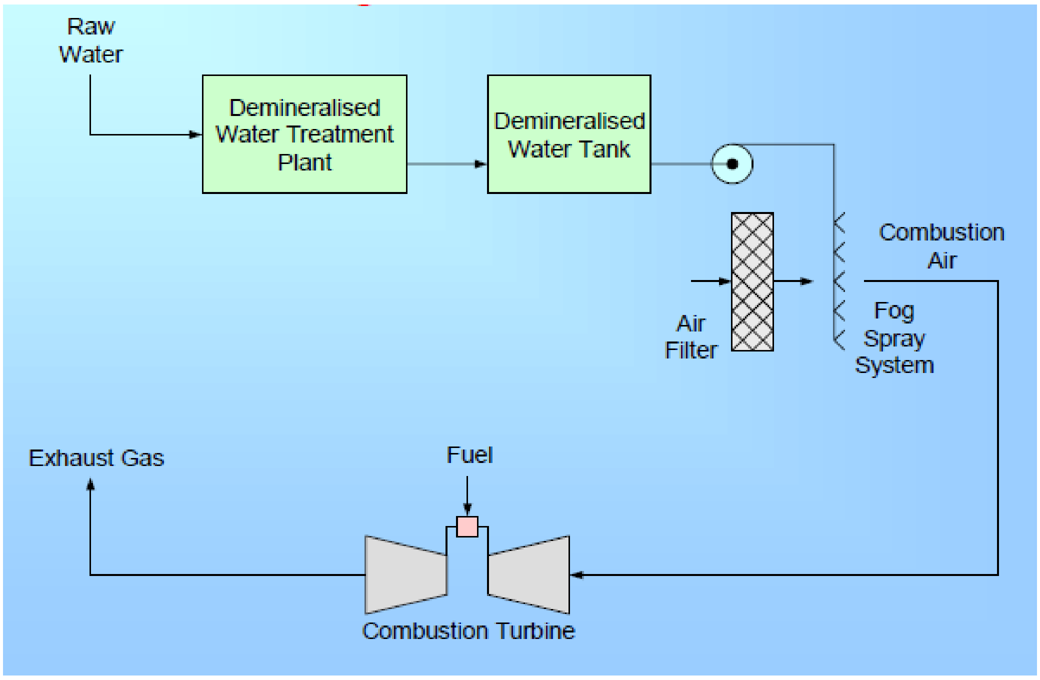

Figure 2 Schematic diagram of Fogging system

MECHANICAL REFRIGERATION SYSTEM

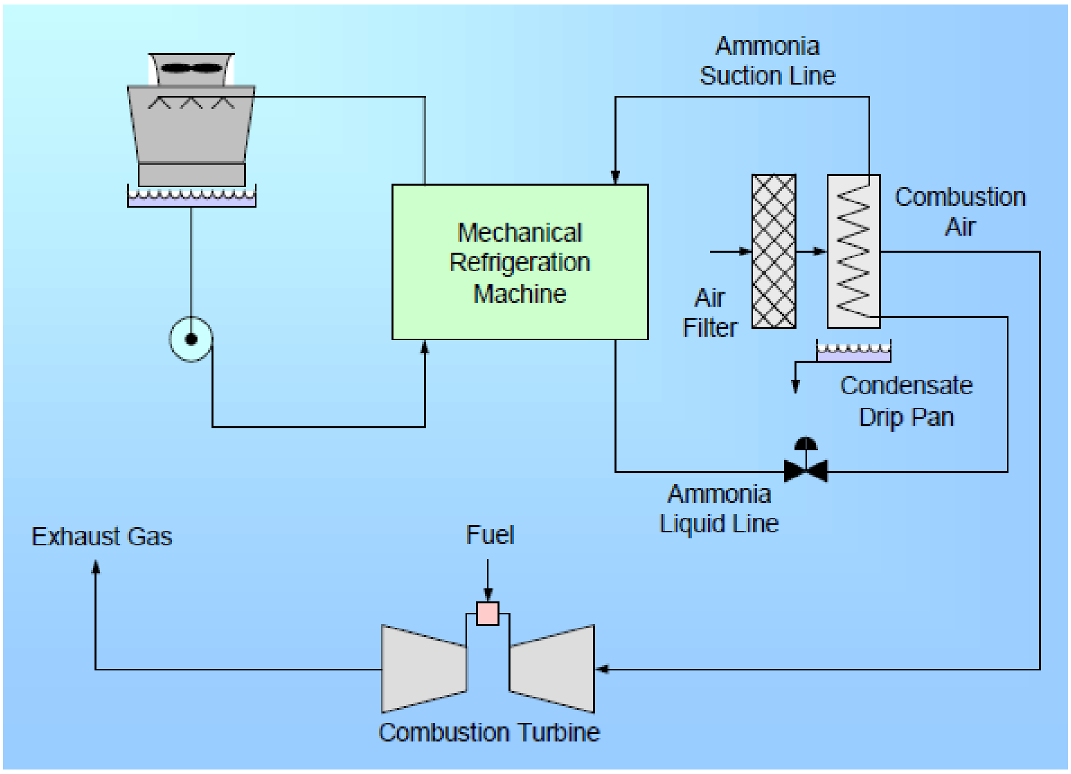

Figure 3 Schematic Diagram of Mechanical refrigeration system

ABSORPTION CHILLER MACHINE

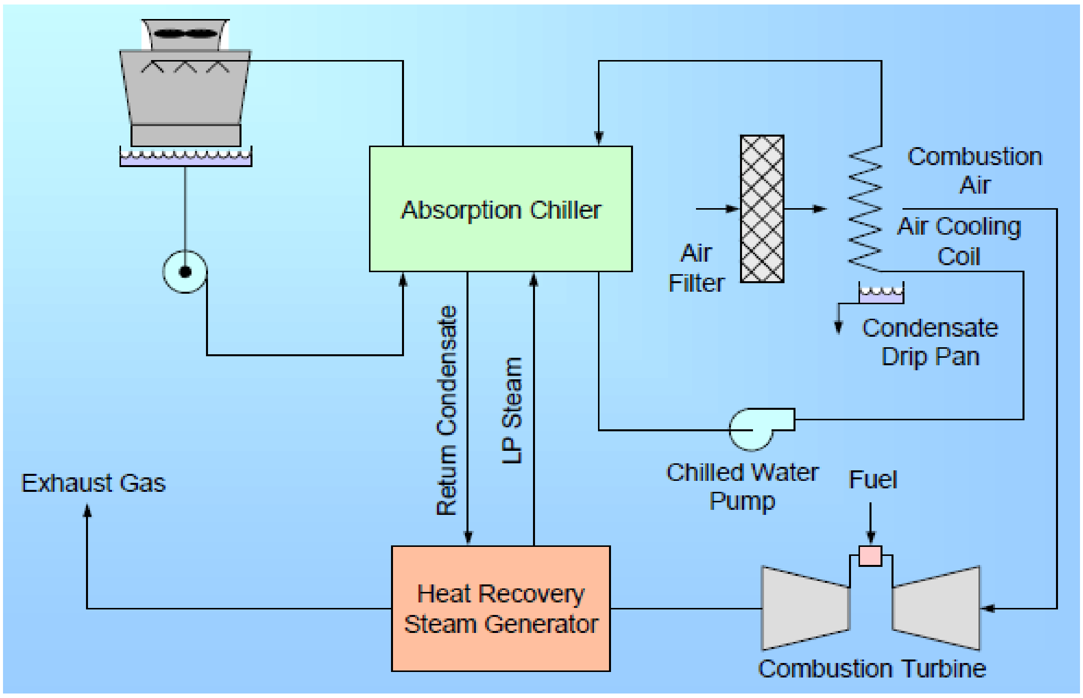

Figure 4 Schematic diagram of Absorption Chiller

Table 1 gives a quick overview of the benefits and drawbacks of each technology studied by [1].

Table 1 A brief review on the advantages and drawbacks for various technologies

Technology	Benefits	Drawbacks
Evaporative Cooling The injection of water into the inlet air stream, thereby cooling the inlet air from its dry-bulb temperature to a point near to its wet-bulb temperature	The unit capital cost is very low • Both the design and the operation al methods are uncomplicated and dependable. • A unit with inlet air-cooling has no time or duration limitations on the length of inlet air-cooling operation	There is a constraint on the amount of power that may be gained owing to the wet-bulb ambient temperature • restriction on incoming air temperature • scaling and water treatment • capacity limitations
High-Pressure Fogging Cooling to wet-bulb temperature at 100% humidity by high-pressure spraying of water droplets into	• a very low parasitic power consumption • A low cost of operating • Both shipping and installation happen quickly.	There is little power increase since the wet-bulb restriction on input air temperature has limited the intake temperature. Waters use is higher than evaporation, making water use more common Demineralized water is necessary, along with additional filters and drainage systems.

air-inlet ducts	• the low-capital-cost • Excess fogging evaporates in the compressor, lowering the amount of work done by the compressor and boosting the power output of the turbine.	• improve the machine's processing capability • the high cost of capital • O&M costs • are quite high • Cumbersome and difficult to use because of the multitude of requirements and rules needed to manage and operate it.
Absorption Cooling Utilizing the waste heat from the CT to drive the heat-driven refrigeration system for cooling the inlet air	There is no restriction on the time or length of intake air-cooling operation due to its low yearly maintenance time This system is low on parasitic power consumption Very quick and easy to install Not responsive to changes in the wet-bulb temperature of the surrounding air The turbine has the potential to produce electricity from the recovered energy.	• This part is not ideal for open-cycle turbines • This reference system requires a greater heat rejection and cooler tower water than other systems . • Lunch delivery and installation time takes 3 more hours to chill each day.
Mechanical Refrigeration The use of vapor compression refrigeration equipment to cool the inlet air	No constraint on the time or length of the intake air-cooling operation with regard to parasitic electric power losses beyond the performance boost that is possible with evaporative or foggy Not responsive to changes in the wet-bulb temperature of the surrounding air Theoretically, no practical constraint exists on the possible inlet air temperature There is no restriction on the time or length of intake air-cooling operation The device is quite simple to design and put together, and it functions properly without problems." a gain in performance that is greater than that from evaporation or fogging	• the high cost of capital • A huge amount of electric power is consumed at peak hours • O&M costs are quite high • A higher level of O&M competence is required • The shipping and installation time is long • The cooling unit will have to be put in an extra chilled-water circuit. • a greater parasitic load than of that of evaporation or fogging

It is difficult to achieve maximum power output without increasing fuel consumption in existing gas-fired power plants. Additional techniques to increase power output (evaporative cooling and fogging system) are less effective and subject to environmental conditions. This prompted us to choose an appropriate method of inlet air chilling (Absorption Chiller) that would result in increased power output and lower specific fuel consumption for the Gas Turbine power plant. In contrast to mechanical chilling systems, which use electricity as an energy source, absorption chillers use hot water, steam, or any other form of waste heat as an energy source.

This makes the absorption chiller a more viable option for power augmentation inlet air chilling. Due to urban heat islands created in densely populated areas consuming energy for space cooling and/or heating loads, energy demand in regions with ample sunlight is increasing day by day. In such regions, absorption cooling systems become more viable options because solar energy can be used to generate steam or hot water, which can then be used as a source of energy for a vapour absorption chiller to generate more power during the summer.

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REVIEW OF THE LITERATURE

In an analysis[2] based on weather data from Bangkok, it was discovered that lowering the temperature from ambient to 15 °C could help increase instantaneous power output by 8 to 13 percent. The intake air to the compressor was cooled using an absorption chiller in this study.

The economic situation for such a cooling plant was also justified, as a 100 MW Gas Turbine plant's maximum cooling load during peak hour is equal to 3800 RT (tonnes of refrigeration), resulting in a maximum increase in power output of 13 MW for the same period. Installing a gas turbine cycle to meet the increase in power output will cost four times as much as the intake air cooling solution.

Similar work was reviewed in [1]combustion turbines generate approximately 42 percent of the Saudi Electric Company's (SEC) annual energy sales, but the turbines experience a 24 percent reduction in system capacity during the summer due to ambient air temperatures as high as 50 °C.

Aqua-ammonia absorption chillers can reduce inlet air temperatures to around 10 °C, according to experience with absorption chiller cooling in countries with ambient air temperatures exceeding 40 °C.

Simulink and NARX models, Gate CycleTM, C++ programming, TRNSYS, and various in-house developed code have all been used to assess power augmentation [3]–[9]. Actual data was also used for techno-economic analysis [10]–[17]. Arid, Semi-Arid, Tropical Wet, Tropical Wet and Dry, Humid subtropical, and Montane are the six types of climatic regions found in India. According to the central electricity administration, gas is used in 11% of the country's thermal power facilities.

However, no comprehensive study of gas-based power plants in India and their techno-economic assessment has been published. India is a country with abundant solar energy, yet it still relies on coal-fired thermal power plants for around 55 percent of its electricity [18].

Summertime in major Indian cities like Ahmedabad, Mumbai, New Delhi, and others, where there is the greatest concentration of air-conditioned buildings, air conditioning accounts for around 40–60 percent of peak power demand. However, such rates will not increase the capacity of power plants, necessitating the use of power augmentation techniques. One of the techniques used to increase power production in gas turbine power plants is to cool the inlet air using an absorption chiller.

Furthermore, during the summer, solar energy, which is plentiful in nature, may be used to operate the absorption chiller machine (VAM), which generates cooling water. The Turbine inlet air will be cooled with this cooling water. Figure 4 illustrates a schematic diagram.

METHODOLOGY

In this article, a simple gas turbine power plant cycle performance analysis was performed for the Ahmedabad, Gujarat location. TRNSYS software is used to perform the transient assessment. The software was used to simulate the gas turbine cycle both with and without inlet cooling. On the user interface window of the TRNSYS software, Figure 6 depicts a simple gas turbine cycle without cooling, and Figure 7 depicts a simple gas turbine cycle with inlet cooling.

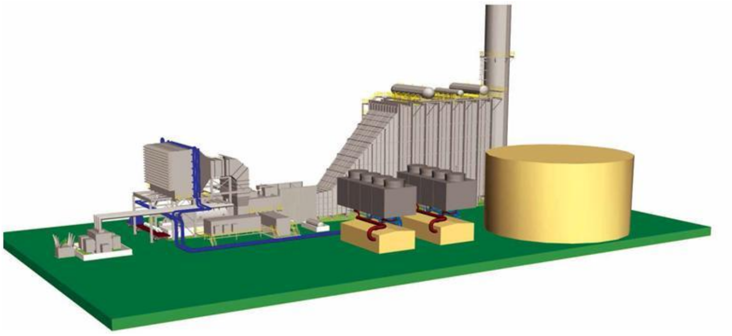

Figure 5 Model of Gas turbine power plant (York Manual)

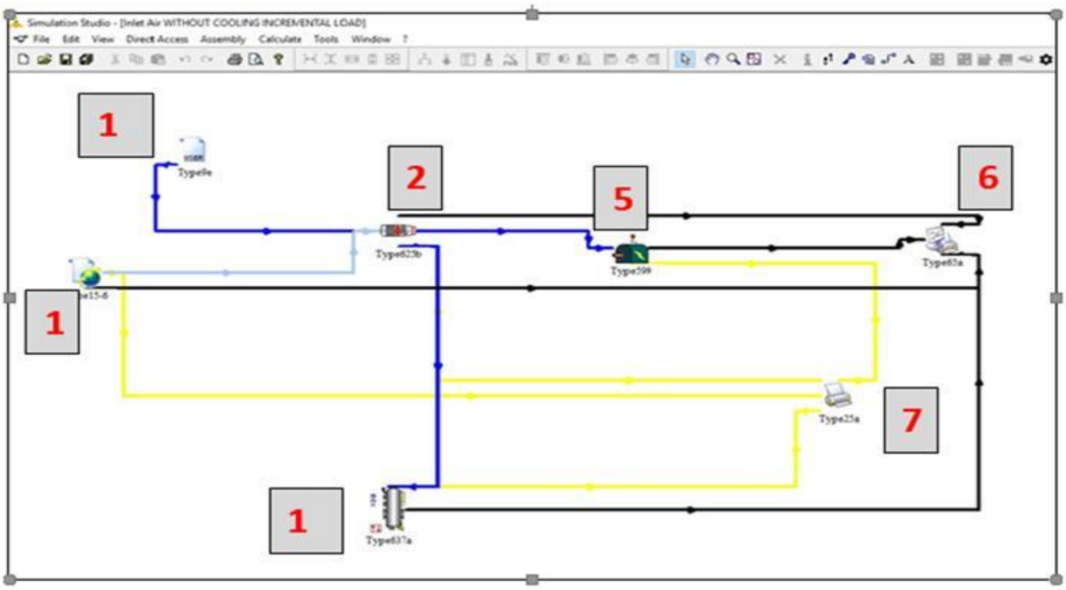

Figure 6 TRNSYS Model of Simple open cycle gas turbine power plant

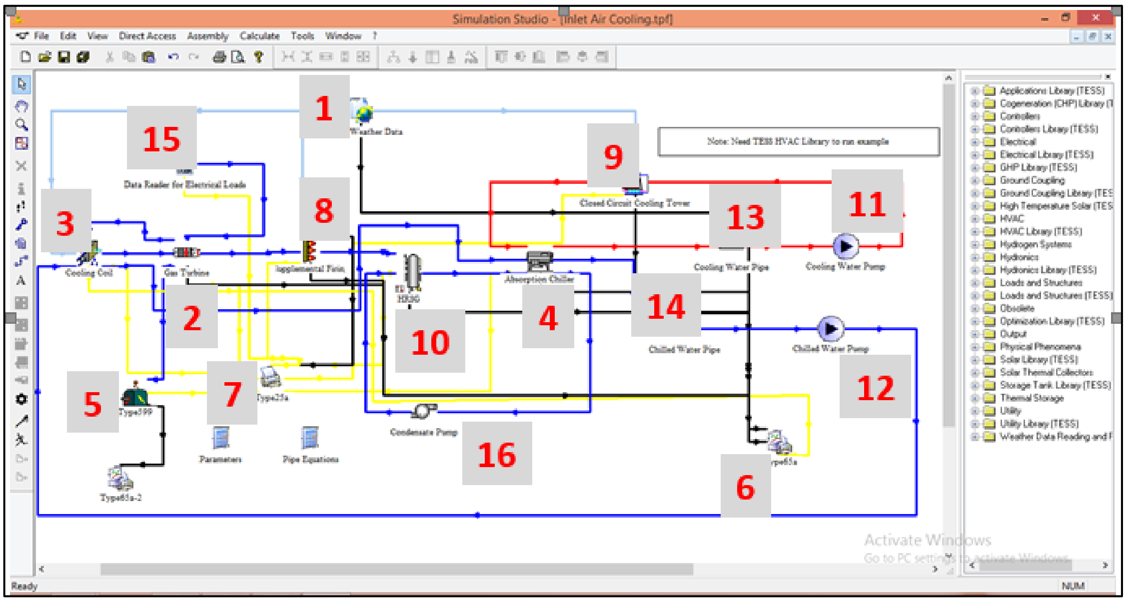

Figure 7 TRNSYS Model of Gas turbine power plant with inlet air cooling

For identification purposes, the components in figures 6 and 7 are labelled with numbers. In Table 2, the components denoted by numbers are as follows:

Table 2. Notations of components in TRNSYS software in Figure 6 and Figure 7

Sr. No.	Components	Sr.No.	Components
1	Weather Data	9	Cooling Tower
2	Gas Turbine	10	HRSG
3	Cooling Coil	11	Cooling Water Pump
4	Steam fired double-effect absorption chiller	12	Chilled Water Pump
5	Generator	13	Cooling Water Pipe
6	Output plotter	14	Chilled Water Pipe
7	Output Printer	15	Electrical Data Reader
8	Supplementary Firing	16	Condensate Pump

Gas turbine parameters for the LM6000 gas turbine from reference article [19] are taken into account for performance analysis in simulation. The required data for gas turbine input and simulation was obtained from the reference article.

Table 3 Output parameters obtained from the TRNSYS analysis

Output data files generated from simulation in TRNSYS	
(37 Columns & 8760 Rows) Excel file contains below mentioned parameters:	
Time (in hours)	Generator Power (kJ/hr)
Exhaust Temperature (°C)	Electrical Load (kJ/hr)
Mass Flow Rate of Exhaust (kg/hr)	Steam Outlet Temperature (°C)
Mass Flow Rate of Air (kg/hr)	Mass Flow Rate of Steam (kg/hr)
Mass Flow Rate of Fuel (kg/hr)	Steam Enthalpy (kJ/Kg)
Dry Bulb Temperature (°C)	HRSG Heat Transfer Rate (kJ/hr)
Cooled Air Temperature (°C)	Cooling Water Temperature (°C)
Cooled Air Flow Rate (kg/hr)	Chilled Water Temperature (°C)
Supplementary Supply Energy (kJ/hr)	Auxiliary Power (kJ/hr)

Supply Outlet Temperature (°C)	Generator Efficiency
HRSG Outlet Temperature (°C)	Absorption chiller coefficient of performance
Turbine Power (kJ/hr)	SFC Specific Fuel Consumption

DISCUSSION AND RESULT

To get a better conclusion from the output data, the simulation was run for a one-year period and month-by-month analysis was performed.

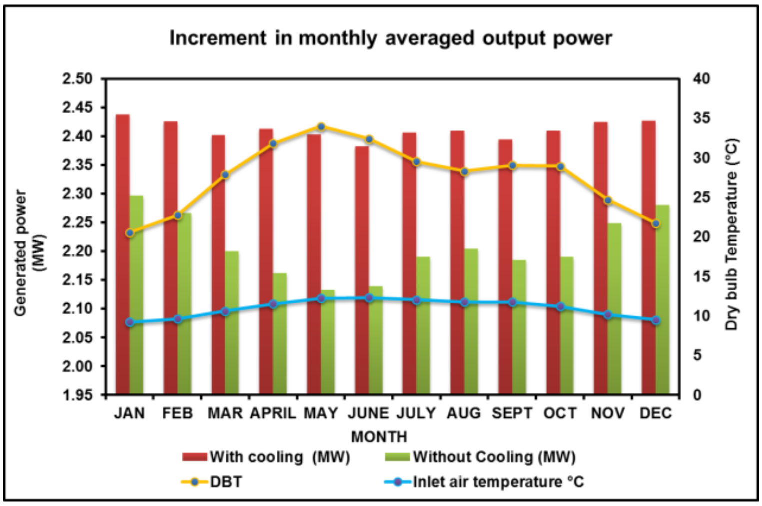

Figure 7 Monthly average Output of Gas turbine power plant at Ahmedabad, India

In the month of May, the output power of the gas turbine power plant increased by 11%, as shown in figure 7. This coincides with an increase in power consumption due to the summer season this month.

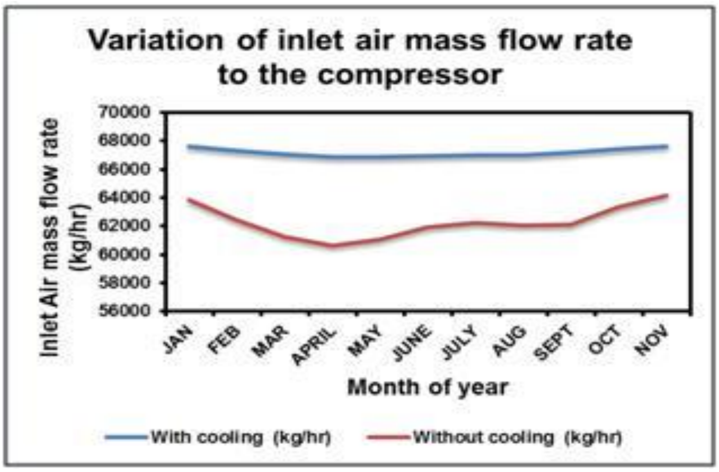

Figure 8 Month-wise variation in Inlet

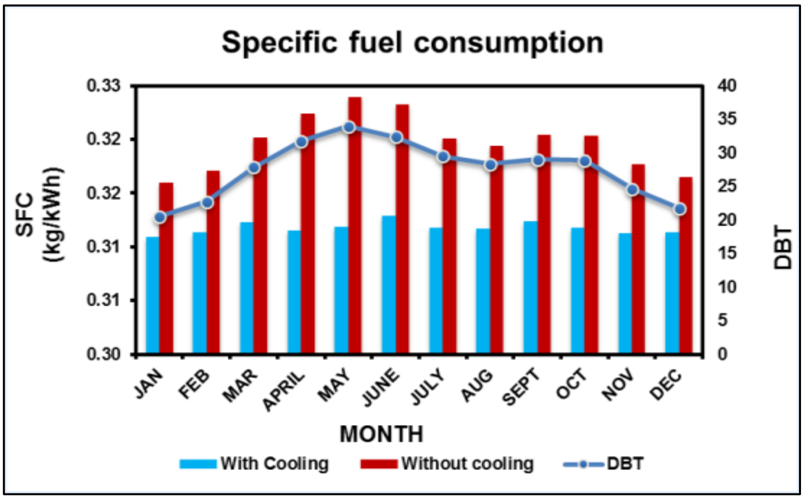

Figure 9 Month-wise variation in corresponding fuel input required

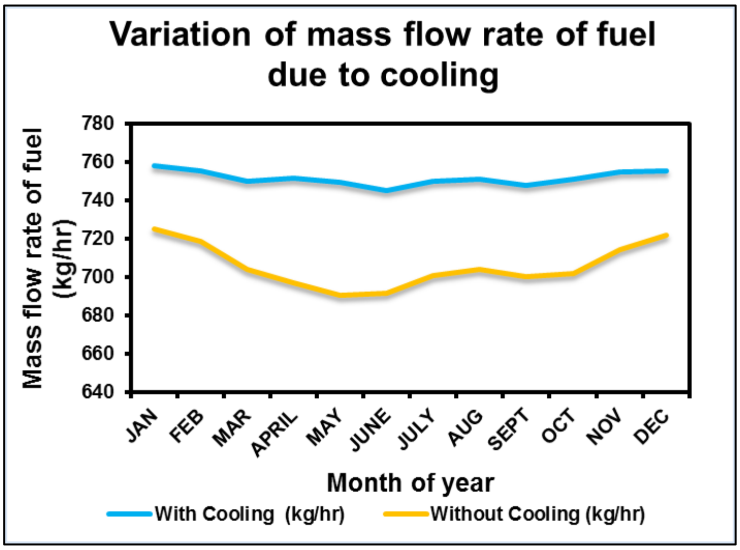

Figure 10 Month-wise variation in specific fuel consumption of Gas Turbine Power plant with and without inlet air cooling

The amplitude of fluctuation in the mass flow rate is decreasing in the case of intake air cooling, as demonstrated in figures 8 and 9. As a result, the intake air cooling approach may provide a consistent supply of power to satisfy the baseload requirement of power. It is important to notice that net power output has increased while particular fuel consumption has decreased.

Figure 10 shows that when the dry bulb temperature raises, the difference between specific fuel consumption with and without cooling rises, providing additional advantage for the summer season.

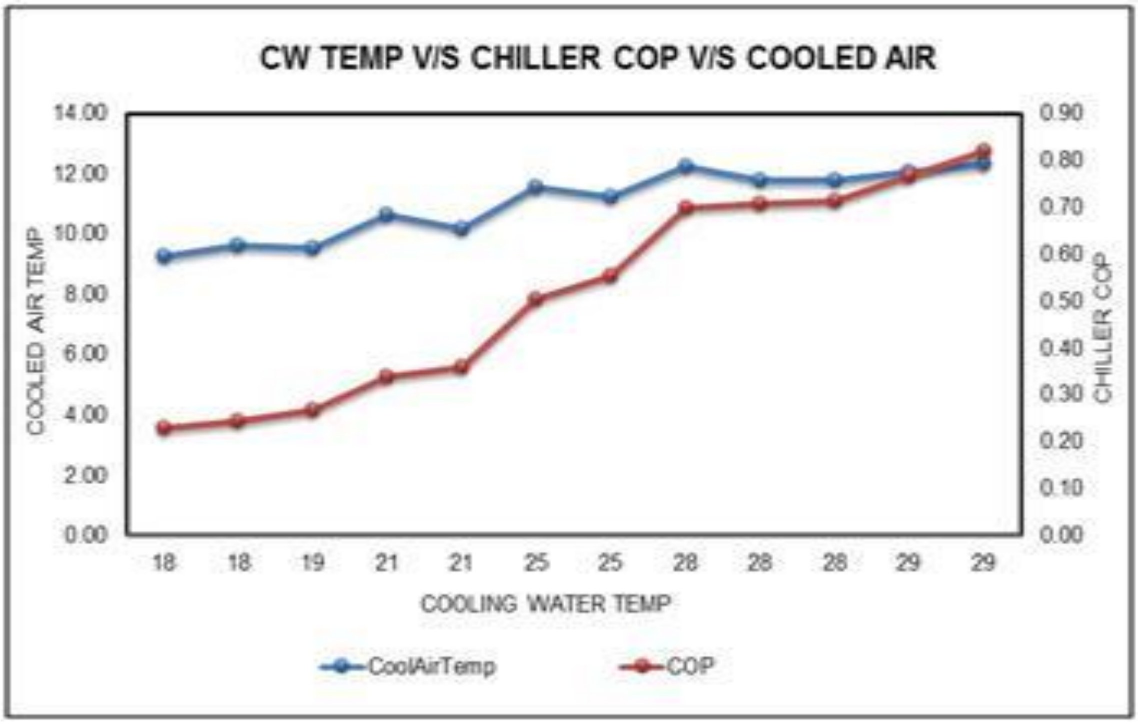

Figure 11 Optimum value of cooling water for Absorption chiller

CONCLUSION AND FUTURE SCOPE

- It is possible to increase the output of a simple gas turbine power plant of 3.6 MW by 10% by using an inlet air cooling technique with an absorption chiller.
- The overall plant efficiency is increased by 0.5 percent by cooling the gas turbine power plant's inlet air supply.
- Also, the net cumulative savings amount to 27.8 million INR per year.
- Using an absorption chiller reduces specific fuel consumption by 20 to 50 percent, which reduces pollution and is good for the environment.
- The chiller COP in Ahmedabad is highest at 29°C cooling water temperature.
- It is possible to simulate an industrial gas turbine LM6000 model using the same technique and simulation tool.
- When the absorption chiller (used for inlet air cooling) is combined with appropriate solar energy collectors, the output characteristics of the LM6000 turbine can also be studied.

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