JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

# A Technical Review to Enhance The Power Generation from Gas Turbine Based on Inlet Cooling System.

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***Abstract :***

As Compressor in take air cooling in gas turbine power plants is considered to be very important and feasible requirements nowadays. The methods for the compressor intake air cooling are evaporative coolers, refrigerated inlet cooling systems, thermal energy storage systems and Desiccant cooling system. The power output of a gas turbine depends on the flow of mass through it. This is precisely the reason why on hot days, when air is less dense, power output falls off. A rise of 1°C temperature of inlet air decreases the power output by 1%. The aim of this paper is to review up to date techniques that were developed to cool inlet air to gas turbine. It is found that the power consumption of the cool inlet air is of considerable concern since it decreases the net power output of gas turbine. In addition, the mechanical chiller auxiliary power consumption is very high compared to media type evaporative coolers. Furthermore, the reviewed works revealed that the efficiency of evaporative cooler largely depends on moisture present in the air. The gas turbine power augmentation through inlet air chilling is effectively used to boost power during high ambient temperature usually synchronous with on-peak power generation, allowing levelling of gas turbine power output.

***Keywords*** **- Gas Turbine, Absorption Cooler, Evaporative Cooler, Thermal Energy Storage Systems, Decicant Cooling system , Dry Bulb Temperature , humidity ratio.**

## I. INTRODUCTION

The adverse effect of high ambient air temperatures on the power output of a gas turbine is two fold: as the temperature of the air increases, the air density decreases and thus the air mass flow. The reduced mass flow directly causes decrease in the power output of a gas turbine. On the other hand, the higher intake air temperature results in an increase in specific compressor work. Thus the use of high temperature ambient air results in a net decrease in the gas turbine output. As shown in ***Figure2***, turbine power output is a linear inverse function of temperature. The power correlation factor is a factor which when multiplied with the power output of gas turbine cycle operating at ambient inlet air conditions will give the corresponding power output at chilled air temperature . Gas turbine air cooling has been studied recently to raise the performance to peak power level during hot seasons when high atmospheric temperatures cause a significant reduction in its net power output. Gas turbines are constant volume machines; at a given shaft algorithm a set of classification training, a successful explosive growth in the hybrid intelligent system in many diverse areas such as robotics [11],medical diagnosis[12],natural language understanding [13] industrial equipment [14] manufacturing control[15] and various applications[16]. speed, they always move the same volume of air. In gas turbines, since the combustion air is taken directly from the environment, their performance is strongly affected by weather conditions (Mahmoudi et al., 2009). Power rating can drop by as much as 20 to 30%, with respect to international standard organization (ISO) design conditions, when ambient temperature reaches, 35 to 45°C. One way of restoring, operating conditions is to add an air cooler at the compressor inlet (Sadrameli and Goswami, 2007). The air cooling system serves to raise the turbine performance to peak power levels during the warmer months when the high atmospheric temperature cause the turbine to work at off-design conditions, with reduced power output (Kakaras et al., 2004). The performance of a gas turbine power plant is sensible to the ambient condition. As the ambient air temperature arises, less air can be compressed by the compressor since the withdrawing capacity of compressor is given, and so the gas turbine output is reduced at a given turbine entry temperature. Additionally, the compression work increases because the limited volume of the air increases in proportionality to the intake air temperature (Xiaojun et al., 2010). Inlet air cooling and intercooling are two important methods for rising power output of gas turbine cycles. However, gas turbine intake air cooling may cause a small decrease in efficiency because a lot of fuel is needed to bring compressor exhaust gas equal to the same gas turbine entry temperature. This paper introduces technical review for inlet air cooling system that is used to improve the performance of the gas turbine power plants. The gas turbine inlet air cooling system describes and compared in detail evaporative coolers, refrigerated inlet cooling systems, thermal energy storage systems and Desiccant cooling system.

## INLET AIR COOLING SYSTEM

The gas turbine inlet air cooling methods can be divided into four categories including the evaporative cooling method , Refrigerated inlet cooling systems, Thermal energy storage systems and Desiccant cooling system (Kamal and Zuhair M, 2006). The detail review will be presented subsequently.

### 1.1. Evaporative cooling methods

Evaporative methods are among the most widely used power augmentation techniques. This is primarily because the machinery is cheaper, and the installation and operating costs are also lower. These methods and related technical issues have been subject of several studies (Chaker M., 2002). Evaporative coolers are divided into two main subcategories: ***the first subcategory includes media-based methods.*** As shown in ***Figure 1***, the inlet air passes through a wet media causing the water to evaporate. The evaporating water needs to absorb its evaporation enthalpy, and the absorbed enthalpy decreases the dry bulb temperature of the air. The humidity ratio is increased while the enthalpy remains constant. ***Fogging is another evaporative cooling method*** in which demineralized water is converted to the fog by means of high pressure nozzles. This fog cools the air down in a manner similar to the previous method. Evaporative cooling techniques are most effective in hot and dry climates but not so effective in humid climates. (Mazzei P, 2002, Pons M, 2000). **Figure1.**

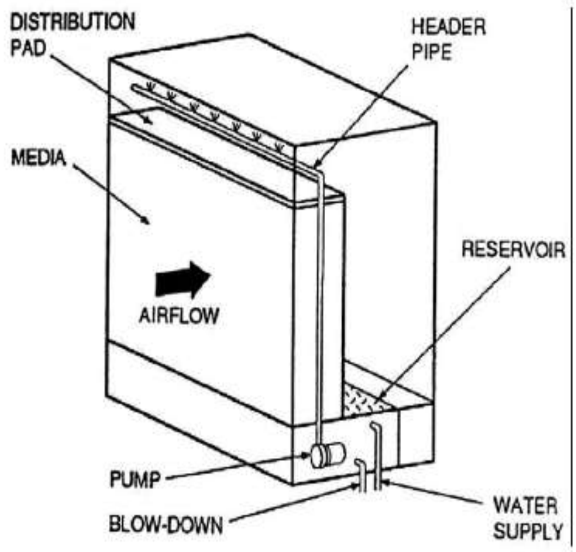


**Figure1.** Schematic of the media of evaporative cooler

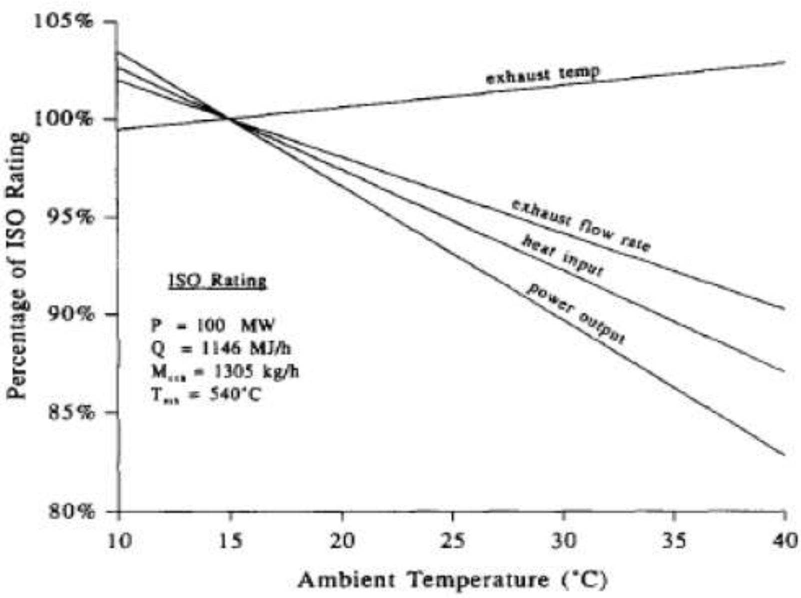


**Figure2**. Gas turbine parameter as function ambient temperature

## 1.2. Refrigerated inlet cooling systems

Refrigerated inlet air cooling systems are more effective than evaporative cooling systems; because air dry bulb temperature is lower in these systems. However, the price of the machinery, and the installation, and operating costs are much higher. Two main subcategories of refrigerated cooling systems are ***mechanical refrigeration and absorption cooling***. In mechanical refrigeration, a centrifugal, screw, or reciprocating compressor is utilized for compression of refrigerant vapour. These systems have extremely high power consumption and so many auxiliary equipments such as heat exchangers, pumps, compressors, and expansion valves are also needed. Chlorofluorocarbon refrigerants are normally used in these systems. These systems cause certain environmental problems too. In addition to environmental issues, high power consumption, high capital and maintenance cost, and poor part load performance are other deficiencies of mechanical refrigeration systems. For a literature review of mechanical refrigeration systems see (Alhazmy,2004). Absorption chillers use the heat provided by gas, steam, or gas turbine's exhaust for cooling the water which acts as refrigerant. Lithium bromide is used as absorber in these systems. Part load performance of these systems, in comparison with mechanical refrigeration systems, is fairly good. Some researchers have recently conducted studies dealing with the absorption cooling systems (Ameri M., 2004, Mohanty B.,1995). Depending on the specifics of the project, a combination of evaporative and refrigerating cooling systems might be the best choice. Possibility of such combination should be studied prior to selection of any particular type of inlet cooling system.

## 1.3. Thermal energy storage systems

According to Ameri et al. (2005), The gas turbine can take advantage of off-peak and mid-peak energy cost by using mechanical chillers and thermal energy storage systems. Thermal energy storage (TES) may be defined as temporary storage of energy at high or low temperature for use when it is needed. Thermal storage could be accomplished as sensible heat storage or as latent heat storage. Sensible heat storage media includes water, sand, oil, etc. In latent heat storage, storage is accomplished by change in the physical state of the storage medium with or without change in its temperature. Latent storage media can store relatively large amounts of energy per unit mass compared to sensible heat storage media and hence result in smaller and lighter storage devices with lower storage losses and high efficiency (Kakaras et al., 2006). The study of the use of mechanical indirect cooling where air is cooled using chilled water supplied by an ice thermal storage system.

The storage is charged during off-peak periods by a chiller whose capacity is strongly reduced, which is shown in ***Figure 3***. The available time for charging the ice storage system was reported to be 18 h and the mechanical capacity required was reduced by 66% (Ebeling and Halil, 1992). This reduces the consumption to 15 kW/MWGT as compared to 50 kW/MWGT (Ondryas and Wilson, 1993). Furthermore, the efficiency of the system was not affected because the chiller is stopped during peak periods. Direct external melting system was used in the study due to the low temperature (~ 0°C) it can provide. The author concluded that using of such system would provide 21 to 25% increase in power output when inlet air is cooled down to a temperature of 10°C. Again, a recommendation not to drive the inlet air temperature near 0°C was made to prevent ice build up on the compressor blades, since the chilled inlet air shall be at 100% relative humidity due to moisture condensation during the chilling process. Mechanical chillers utilizing centrifugal compressor with Freon refrigerant was used as an alternative inlet air cooling system in order to increase the gas turbine power output in hot seasons. The power output would increase by 0.36% with each 1°F inlet temperature reduction. Based on 35°C and 20% relative humidity for the ambient air, the power boost has been estimated at 15.5%. Air cooling temperatures have been recommended not to reach values below 7.0°C to safeguard against potential ice build up in the compressor suction line (Lucia et al., 1994).

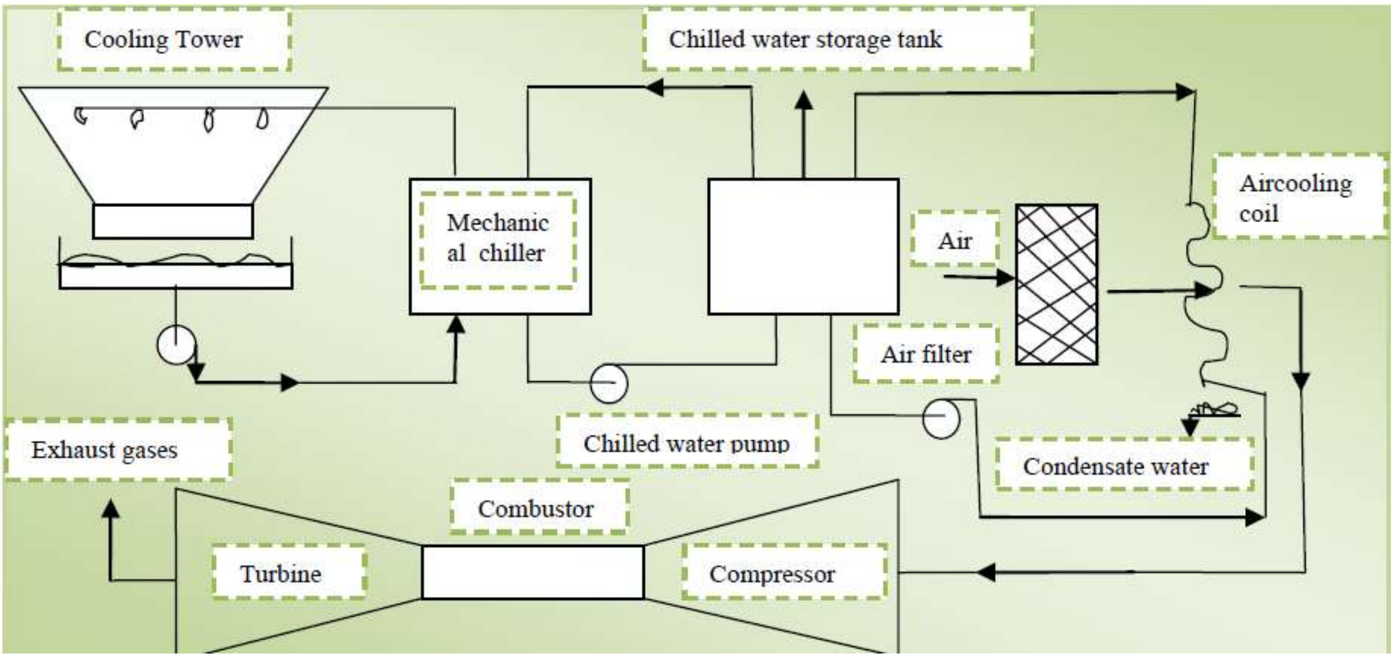


**Figure 3**. Thermal energy storage systems (mechanical chiller with water storage tank)

### 1.4. Desiccant cooling system

Materials that absorb and hold water vapour are called desiccant materials. Commercial desiccants absorb and release large amounts of water vapour depending on moisture available in their environment. The process of absorbing moisture in the desiccant material is classified as either absorption or adsorption depending on whether the material goes through a chemical or a physical change. Absorbing materials require strictly careful precautions during storage and operation especially in warm and humid environments and are not commercially used. Desiccant wheels are normally made of adsorptive materials such as silica gel, activated alumina, lithium chloride lithium bromide, etc. A structure, in which the substance is deposited, supports adsorptive material and a honeycomb-like pattern is formed. As shown in ***Figure 4***, desiccant cooling system is a system utilizing a desiccant wheel to remove humidity from the ambient air. The resulted dry air is hot due to the latent heat of dehumidification and must be brought back to a lower dry bulb temperature by allowing the excess heat to escape. This is done, in our study, by using an IEC. Then, the air can be cooled by a DEC in which air becomes re-humidified by spraying water. To ensure the continuous operation of the plant, it is necessary to regenerate the desiccant material. Regeneration of the desiccant is by heating in an unsaturated air stream. After drying, it should be cooled so that it will be able to absorb the moisture again. The regeneration of the air, in our system, is performed by using the exhaust air of the gas turbine. In combined cycle systems, steam can be utilized for regeneration purpose. Furthermore, because of the fact that inlet cooling systems are used only in summers, it is also possible to use solar assisted desiccant cooling systems in which regeneration is by means of solar energy (Davanag, 1999).

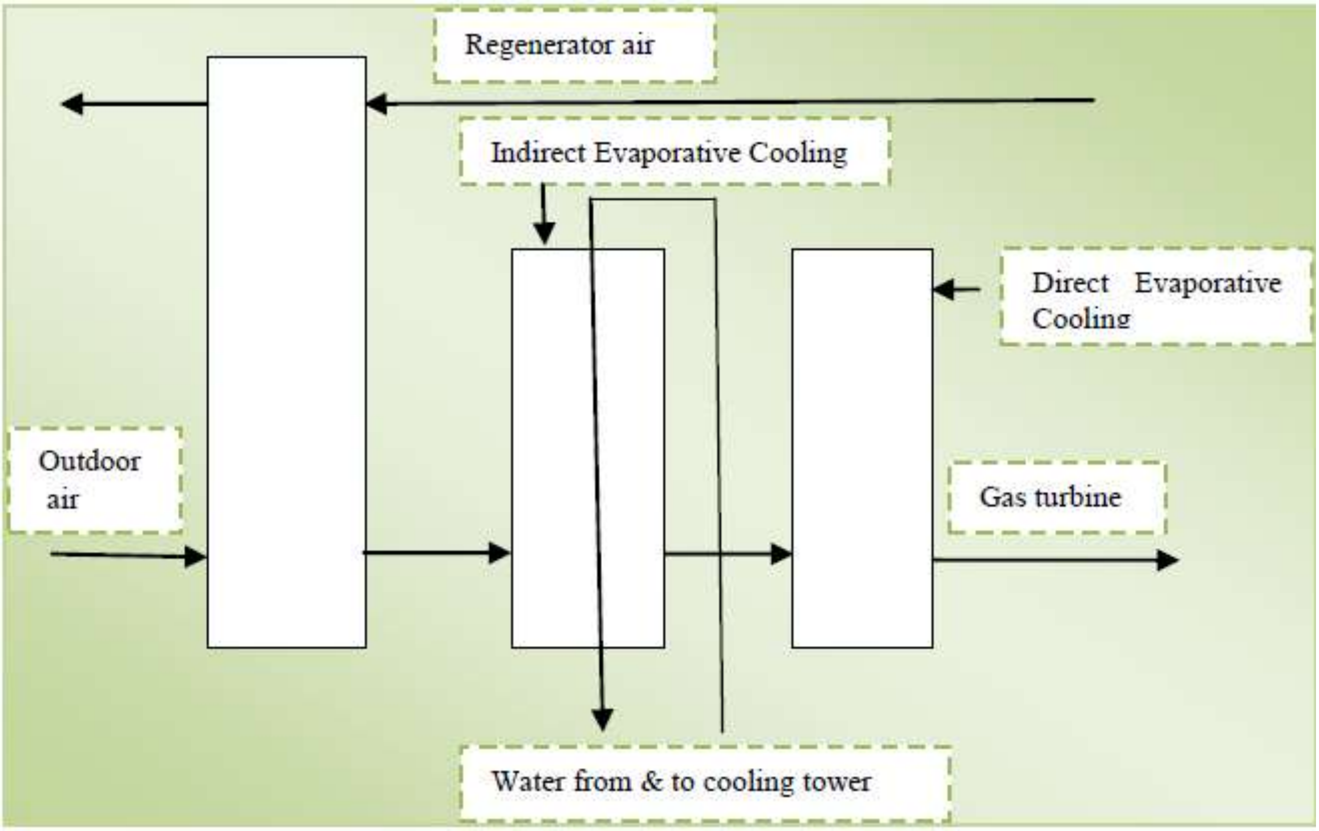


**Figure 4**. Schematics of the desiccant-based evaporative cooling system.

## DISCUSSION

From the forgoing review of literature, in cogeneration gas turbine generators, aqua-ammonia and two-stage LiBr absorption system were explored as booster for the gas turbine power output without affecting the thermal efficiency of the cogeneration unit. All the aforementioned technologies can be used in conjunction with gas turbine generators to boost the power output in hot months with various degrees of effectiveness. The evaporative cooler is an old system used to cool down the gas turbine inlet air temperature. However, it is simple in design, have a short installation time and low capital and maintenance cost. Unfortunately, this technique is limited by the wet bulb temperature of the inlet air and the gas turbine generator capacity may not be increased by more than 12% in best cases even in dry climates. Water carry-over is another problem associated with the use of evaporative coolers. Mechanical chillers increase the capacity of gas turbine generators better than evaporative coolers because they can produce any air temperature required by the designer. However, the main disadvantage of this technique is not associated with high capital cost nor with the space required, but it is associated with its high consumption of electricity which reduces the potential power output increase of the gas turbine generator. Mechanical chiller (refrigerated inlet cooling systems) with thermal energy storage systems such as water and ice storage systems can be used as inlet air cooling system to boost the gas turbine generator power in hot months in countries which adopts variable price for selling electricity, off-peak and on-peak, and have no shortage of electricity production. The exhaust gases of gas turbines carry a significant amount of thermal energy which can be used as a heat source to drive the generator of a vapour absorption chiller such as: aqua-ammonia absorption chiller, two-stage LiBr chiller and single stage LiBr chiller that serves as a cooling system to cool the inlet air during hot periods before admitting to the gas turbine compressor. However, the COP of aqua- ammonia chiller is relatively lower than that of LiBr chiller for the same operating conditions, require high capital cost of refrigeration and large plot space while the two-stage LiBr chiller is mainly used when high COP is required and boost the power output in cogeneration gas turbines. The effort to boost the power output during hot periods for a simple gas turbine unit without cogeneration, a single stage LiBr absorption chiller seems a feasible solution to be investigated thermally and economically due to its relatively high COP and low capital cost of refrigeration. As per author's knowledge, a very little work has been undertaken in previous work. The hybrid system demonstrated a higher gain in power output and efficiency than evaporative cooling for a simple gas turbine, independent of ambient air temperature.

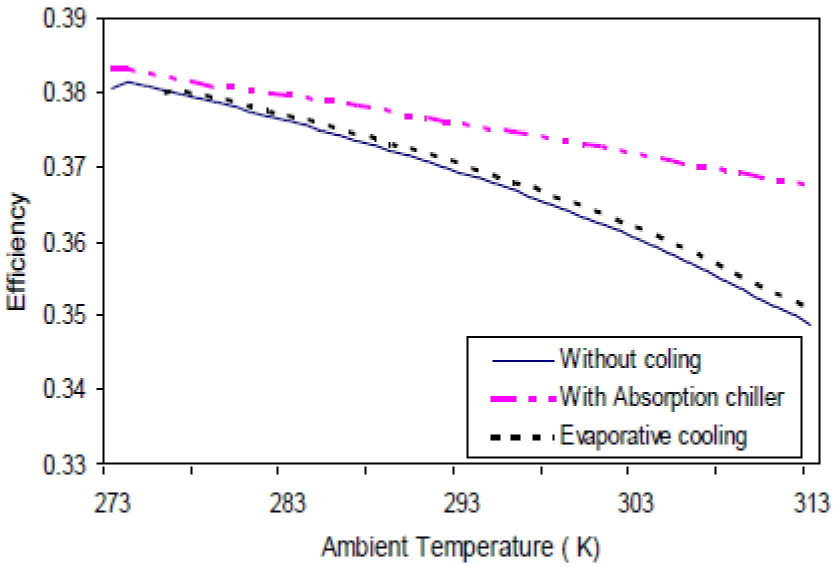


**Figure 5** Efficiency vs. Ambient Temp.

According to Sullerey, ***Figure 5*** shows the variation in efficiency as a function of ambient temperature, for a simple gas turbine cycle, for a relative humidity value of 60%. The work output of the gas turbine falls by around 10% when the ambient temperature increases from ISO conditions to 30oC. The evaporative cooling of the inlet air increases the power output and efficiency of the turbine. The effectiveness of the evaporative cooler depends on the relative humidity of the ambient air**. Figure 6** shows the effect of ambient air humidity on the performance of the evaporative cooler. With increase in ambient air humidity the amount of water evaporated in the cooler is reduced and so the effectiveness of the evaporative cooler.
Absorption chiller utilizes the exhaust energy to produce the cooling effect. This increases the efficiency of the gas turbine (***Figure 5***). Moreover, cooling by the absorption chiller is not affected by ambient air humidity (***Figure 6***). So,

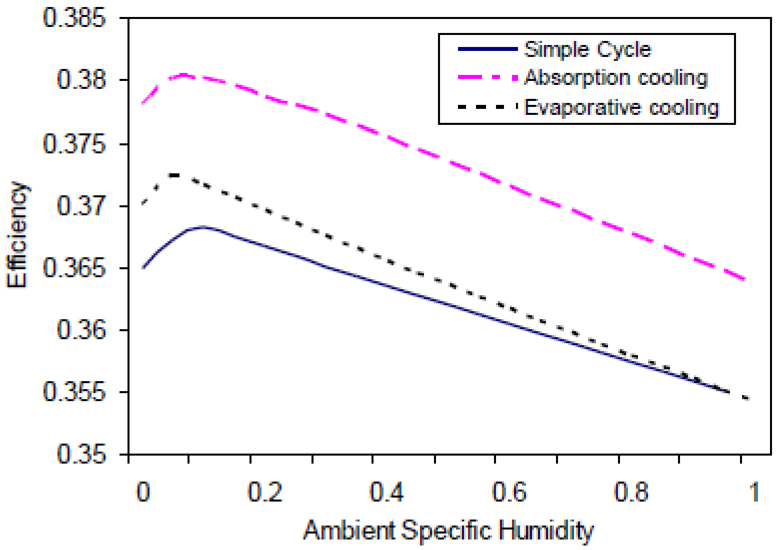


**Figure 6** Efficiency vs. Ambient Specific humidity

absorption chiller is equally efficient in humid weather, where evaporative coolers prove to be inefficient.

## CONCLUSIONS

In the present review, the development occurred in the inlet air cooling system that is used to improve the performance of the gas turbine power plants had been classified. The following list summarizes the conclusion drawn:
**1.** The diversity used of system to achieve the cooling function reflects the necessity of this technique in improving the performance of the gas turbine power plants.
**2.** The success of evaporative cooling in reducing the high air temperature depends on relative humidity of the ambient air.

These types of systems are economical and suitable for hot and dry climates rather than hot and humid ones.
**3.** Absorption systems are similar to vapour-compression air conditioning systems except the pressurisation stage. The absorption cooling technique demonstrated a higher gain in power output and efficiency than evaporative cooling for a simple cycle gas turbine, independent of the ambient conditions.
**4.** The absorption chiller system for inlet air cooling of the gas turbine increases the peaking capacity of the gas turbines during the hot ambient operation.

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