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A COMPARATIVE STUDY OF GAS TURBINE INLET AIR COOLING METHODS

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Abstract. *It is well known that gas turbine air inlet cooling (TIC) is a useful method for increasing power output for regions where significant power demand and highest electricity prices occur during the warm months. Inlet air cooling alternatives increase the power output by taking advantage of the gas turbine's feature of higher mass flow rate when the compressor inlet temperature decreases. Nowadays, different methods are available for reducing gas turbine inlet temperature. The first and most cost-effective system is the evaporative systems. Wetted media coolers and fogging systems are methods make use of the evaporation of water to reduce the gas turbine's inlet air temperature. However, the evaporative cooling technique is limited by wet-bulb temperature while the chilling can cool the inlet air to temperatures that are lower than the wet bulb temperature. In the present work, a thermodynamic model of a gas turbine is built to calculate heat rate, power output and thermal efficiency at different inlet air temperature conditions. Then, four cooling methods are implemented and solved for different inlet conditions (inlet temperature and relative humidity): (i) wetted media cooling,(ii) fogging system ,(iii) absorption chiller system and (iv) mechanical chiller. These cooling methods results are simulated at 18% and 60% of humidity relative levels, and comparing with without any cooling technique herein called "base-case". The main objective is show the fogging results against other cooling system tested in previous work. Results showed that when the ambient temperature is extremely high with low relative humidity (requiring a large temperature reduction) the chiller is the more suitable cooling solution. The net increment in the power output as a function of the temperature decrease is also obtained for each cooling method.*

Keywords: *gas turbine, evaporative cooling, chiller system, TIC*

1. INTRODUCTION

Nowadays, gas turbine have been widely used in power generation. Because with increasing consumption of electrical energy gas turbine power plants are presented as the preferable technology to meet this rapid growth due to their construction faster than other conventional plants (Ameri and Behnam, 2011). However, the electricity demand is higher during hot month, usually in the summer, when the ambient temperature has major impact on the gas turbine performance.

The simple gas turbine is compound by a compressor that provide air at high pressure to the combustor chamber, which produce flue gas at high pressure and temperature, the turbine component receive this gas and expand producing shaft power. This engines are designed for ISO conditions, although the operating periods at off-design conditions are greater than in design conditions depending on the place where gas turbine installed (Erdem and Sevilgen, 2006).

Gas turbine performance is highly influenced by the site ambient conditions, because this engines are almost constant volume engine at a specific rotation speed, so when ambient temperature increases the air density reduces and its specific mass is decreased. Consequently, the mass flow rate entering the turbine diminish. Therefore, in hot and dry air climates, such as desert areas of the gulf countries, gas turbine engine power output is dramatically reduced due to the reduction in gas turbine air mass flow (Chaker and Meher-Homji, 2006). According to Ameri *et al* (2007), an increase of 1 °C in ambient temperature is capable to decrease in 0.7 % the power output.

Many works have focused on the ambient conditions effect on the gas turbine performance. For example, Erdem and Sevilgen (2006) using two gas turbine models and average monthly temperature data of seven regions of Turkey, compared values obtained for performance variation, annual electricity production and fuel consumption with standard design conditions values. The authors concluded that an increase in ambient temperatures in hot regions not only decreases electricity production, but it also fuel consumption per unit electricity production and gas turbines having lower turbine inlet temperatures and compressor pressure ratios are much more sensitive to ambient temperatures.

It is well known that one possibility to decrease the air temperature entering gas turbine and improve its performance is to employ inlet air cooling techniques. There are some inlet air cooling system available for gas turbine enhancement which can be classified in: (i) thermal energy storage; (ii) refrigerated cooling (including absorption or mechanical refrigeration); and (iii) evaporative coolers (wetted media and fogging) (Ameri, *et al*, 2007).

Several studies have been developed to test the gas turbine performance by using cooling systems. Salman, Rishack and Mousawi (2011) showed that the augmentation in the firing temperature provides the increase of the power output and the thermal efficiency, nevertheless reduces with increasing the ambient temperature. The efficiency raises with pressure ratio until the maximum value then it reduces. Besides, the work reveals that use of the inlet fogging method improves the efficiency and power output gas turbine due to the decreasing in the compressor inlet air temperature and its effectiveness is better in dry and hot ambient conditions than in hot and humid climate. They also observed that cost of this system is more cheaper than a new gas turbine plant. According to studies of Ameri, Nabati and Keshtgar (2004) the capital cost of the fog system installation is about 40 $/KW and the payback period is around 1.5 year.

Alhazmy and Najjar (2002) have studied the difference between using two types of air coolers, water spraying system and cooling coil. Their results show that spray coolers are capable of enhancing the power and efficiency of the gas turbine power plant besides being cheaper than the cooling coils, but it operates more efficiently at hot and dry climates. While cooling coil offer greater control on the inlet air conditions, however it require a considerable power for operation.

Ameri, Nabati and Keshtgar (2004) studied the Rey Power Plant site climate conditions in the summer and different inlet air cooling systems that can be used to improve gas turbine power output when the engine is installed in regions with severe climate profile. The performance test results showed that applying the fog inlet air cooling increased the plant capacity in 19 MW and economical study concluded that this technique is more cheaper than the installation of a new gas turbine.

Alhazmy, Jassim and Zaki (2006) developed a model to study the effect of the inlet air cooling by mechanical refrigeration and evaporative water spray cooler on the gas turbine performance, their results shown that the power output and efficiency improvements are functions of the ambient conditions and pressure ratio.

Al-Tobi (2009) compared the performance achieved by two gas turbines: single and two shafts engine, when two cooling methods were applied: vapour compression and absorption refrigeration. Using vapour compression refrigeration the single shaft engine presented an increase of 27 % in the power output, while the two shafts achieved 20 %, both simulated to ambient temperature of 50 °C.

Gareta *et al* (2004) proposed a methodology capable of analyzing and comparing different alternatives of the inlet air cooling. The work takes into account economical variables and project parameters to select the better system to combined cycle applications.

Yang et al (2009) presented an analytical method for applicability evaluation of inlet air cooling for gas-steam combined cycle power plant with absorption chiller and inlet fogging system. The comparison between the cooling methods demonstrated that gas turbine in combined cycle with inlet fogging has superior applicability in power efficiency at temperature ambient 15-20 ° and with chilling at temperatures above 25 °C and relative humidity inferior to 0.4.

Chaker and Meher-Homji (2006) analyzed in details the gas turbines behavior with and without fog injection using field data utilized in the oil and gas sector for mechanical drive applications. Important parameters were verified, the power turbine inlet temperature, exhaust temperatures, compressor discharge pressure, the gas generator and power turbine speeds, as increasing stages of fogging are applied. In addition, they discussed the design and control of fogging when applied to aeroderivative engines.

In this context, the objective of the present study is to compare fogging system results with values obtained in previous work (Santos and Andrade, 2012) which evaporative wetted media, absorption and mechanical chiller were tested. Gas turbine power output and thermal efficiency are compared taking account variable site climate conditions (ambient temperature and relative humidity).

2. INLET AIR COOLING SYSTEMS

Currently, there are many inlet air cooling techniques commercially available. Herein, it will be present a brief explanation about fogging system, once the other there methods utilized (mechanical chilling, absorption cooling and evaporative cooling) have been already detailed in previous study (Santos and Andrade, 2012).

During the process involved in the evaporative inlet air cooling , the water droplets evaporate in the air stream, heat of vaporization is absorbed from the air and cooling occurs. Besides, the air temperature reduces, and so, the evaporative cooling produces a higher specific humidity airflow downstream the engine. Thus, according to performance characteristics of this method , evaporative systems work better at lower relative humidity, where the vapor absorption capacity of the air is greater (Gareta, *et al*, 2004).

Evaporative inlet air cooling can be divided in two types: wetted media coolers (conventional evaporative coolers) and water spray coolers or fogging systems (saturated evaporative coolers and overspray or overfogging systems) (Yang et al, 2009). These both techniques utilizes the concept of the cooling air by evaporating water. However, in the conventional evaporative method, water is injected in a surface in which pass the air (wetted media) while in the fogging system, the cooling process in achieved by atomizing water into air stream. In some architectures, the high pressure inlet fogging can also be used to create a compressor intercooling effect by allowing excess fog into the compressor, thus improving the power output significantly (Mee Industries Inc, 2002). Furthermore, in this study the intercooling effect will be neglected and only the evaporative cooling effect will be taken account.

2.1 Fogging System

Inlet fogging is a category of gas turbine inlet air cooling system in which pumps of the high pressure providing water to an array of fogging nozzles located in the inlet air duct after the air filter element (Al-Amiri, *et al*, 2006). Figure 1 shows a typical representation of the fogging system. Amari and Tahvildar (2011) developed a thermodynamic model to estimate of the gain obtained by application of the fogging system in Iran power plants that use the model of gas turbine V94.2. The authors verified an increment of 12-26 MW depending of the geographic region.

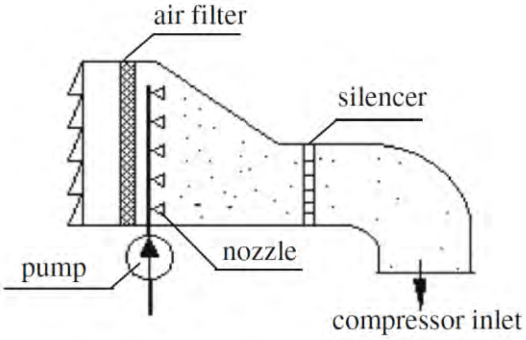

Figure 1. Schematic representation fogging system (Yang, Yang and Cai, 2009).

Although the fogging cooling system may seem a simple process, this method involves important concepts about heat transfer and thermodynamic, and special attention is necessary about nozzles and droplets sizes. Since the droplet diameters present an important relation with the surface area of water exposed to the airstream and consequently with the speed of evaporation (Jones and Jacobs, 2000). In this method the size droplets that vary between 10 to 40 microns and depends of the pressure applied in the water (70 to 200 bar) (Ameri, *et al.*, 2004). Figure 2 exemplifies an array of the atomizer nozzles (Offshore Technology, 2013).

Figure 2. Atomizer nozzles (Offshore Technology, 2013).

It is important to remember that the water used should be demineralized to minimize the potential formation of fouling and corrosion in the compressor blade caused by minerals naturally present in untreated water (Al-Amiri, *et al*, 2006). These feature can involves high costs and sometimes become this cooling system not suitable.

Chaker *et al* (2001) provided a detailed climatic analysis about the capacity of direct evaporative cooling in different regions of the United States. Their study allowed a feel for the sensitivity of operation with inlet fogging. This method allows that evaporation effectiveness reach 100 %, in the other words, the wet bulb temperature can be attained and the relative humidity of the 100 % is obtained. According to Ameri *et al* (2007) the test data have shown that this process can be 100% effective, even in humid regions. The control of the inlet fogging system is made by the comparison between the ambient temperature and the wet bulb temperature so the quantity of water that must be injected is established according to the ability of the ambient conditions to absorb water vapor (Ameri, *et al*, 2004).

During the cooling process, the air follows a line of enthalpy constant due to change phase of the water (evaporation) until to achieve 100 % of relative humidity. In this case the outlet temperature will be equal the wet bulb temperature, as illustrated in Fig. 3.

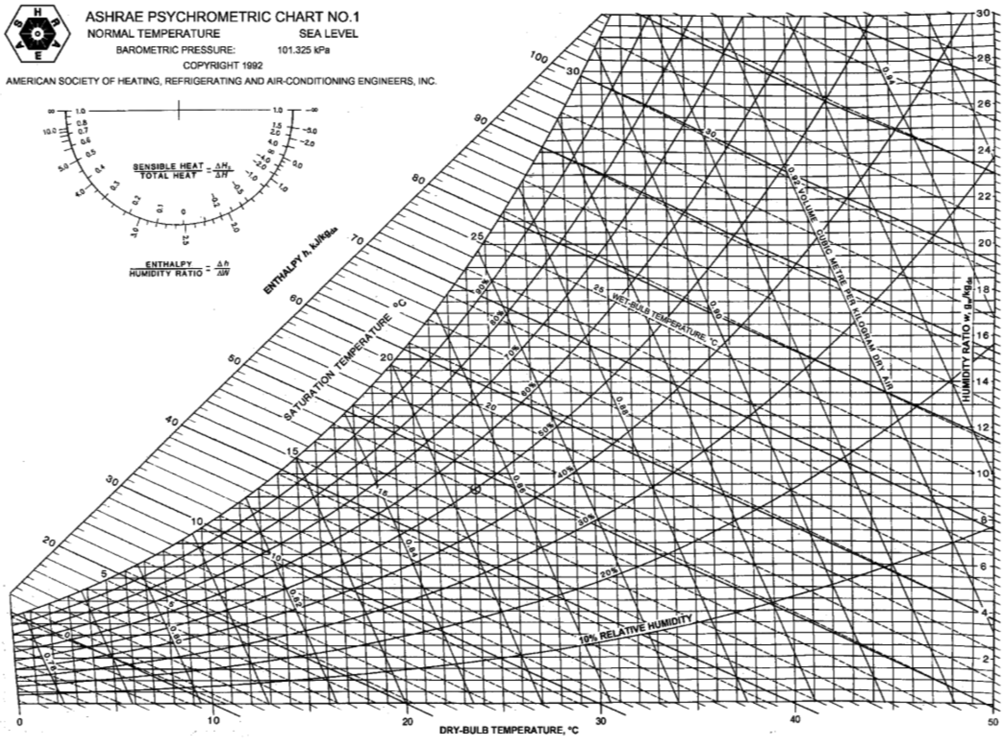

Figure 3. Psychometric process: Fogging system. Adapted from American Society of Heating, Refrigerating and Air Conditioning Engineers (2009).

For example, at dry bulb temperature equal to 40 °C and 30 % of relative humidity, if injection water achieves 100 % relative humidity level, the temperature drop obtained will be 20 °C.

3. GAS TURBINE CYCLE

In the present study, single shaft gas turbine is simulated operating with natural gas. The simple cycle used is illustrated in the Fig. 4, where the stations are specified and the fogging cooling system is introduced before the compressor inlet. Herein, it not will be considered the inlet and exhaust duct losses and e air filter. Thus, temperature after the air filter can be determined as:

$$T_{02} = T_{01} \tag{1}$$

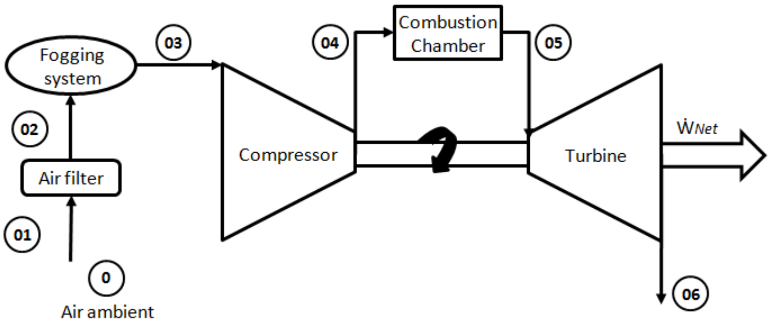

Figure 4. Schematic gas turbine simple cycle with fogging cooling system.

Table 1 shows the values adopted to the main gas turbine parameters. Gas turbine performance calculations are determined following the same methodology shown in Santos and Andrade (2012).

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To determine the compressor inlet air temperature, Eq. 2 can be used:

$$T_{03} = Tb_{02} - \varepsilon\left(Tb_{02} - Tw_{02}\right) \tag{2}$$

Table 1. Technical specifications adopted of the of the selected gas turbine engine.

Type of cycle	Simple, Single shaft, industrial engine
Pressure rate	11
Turbine inlet temperature	1385 K
Air volumetric flow rate	115 m^3/s
Inlet pressure loss	100 mmH_2O
Exhaust pressure loss	200 mmH_2O
Combustion chamber pressure loss	1.2 %
Combustion efficiency	99 %
Compressor isentropic efficiency	85.4 %
Turbine isentropic efficiency	86.8 %
Fuel	Natural gas
Lower Heat Value (LHV)	48,235.63 kJ/kg

Unlike the traditional evaporative cooling, the fogging system is capable to achieve 100 % of effectiveness. Thus, the inlet air total temperature after the cooling process is given by:

$$T_2 = Tw_{02} \tag{3}$$

where Tw_{02} é wet bulb temperature in the outlet of the cooling method.

The amount of water evaporated ($\dot{m}_w$) can be calculated by the Eq. 4:

$$\dot{m}_w = \dot{m}_a\left(\omega_{03} - \omega_{02}\right) \tag{4}$$

where $\dot{m}_a$ is the air mass flow rate and ω_2 and ω_{12} is the air specific humidity in the inlet and outlet of the fogging system, respectively.

The net power obtained from the gas turbine ($\dot{W}_n$) is given by:

$$\dot{W}_n = \dot{W}_t - \dot{W}_c \tag{5}$$

where $\dot{W}_t$ represents the power generated by the turbine component (Eq. 6) and it can be estimated as follows:

$$\dot{W}_t = \dot{m}_T.C_{pg,avg}.\left(T_{05} - T_{06}\right) \tag{6}$$

and $\dot{W}_c$ the power consumed by the compressor (Eq. 7) given by:

$$\dot{W}_c = \dot{m}_a.C_{pa,avg}.\left(T_{04} - T_{03}\right) \tag{7}$$

The specific fuel consumption (SFC) is determined as:

$$SFC = \frac{3600.\dot{m}_f}{\dot{W}_n} \tag{8}$$

Other important gas turbine parameter is the heat rate (HR), calculated by:

$$HR = SFC.LHV \tag{9}$$

Thermal efficiency of the gas turbine is determined by the following equation:

$$\eta_{th} = \frac{3600}{SFC.LHV} \tag{10}$$

4. RESULTS

Figure 5 illustrates the effect of ambient temperature variation in the power output and heat rate. Results are rated in comparison with ISO conditions.

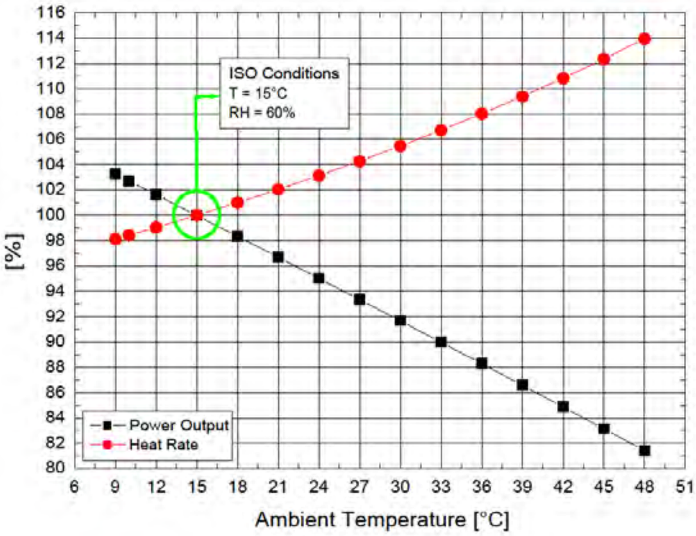

Figure 5. Effect of ambient air temperature on the gas turbine performance.

Under ISO conditions, the gas turbine power output is nearly 37 MW for the Base Case (without any cooling method). However, the power output suffer a reduction of about 8 % when the inlet air temperature increases from 15 °C to 30 C. The heat rate results are also influenced by the inlet air temperature occurring a decrease of ~5.5 % considering the same temperature variation. Thus, it is of extreme importance to employ inlet air cooling methods.

Results obtained with the use of fogging cooling is presented in Fig. 6. It is compared the power output for relative humid levels of 18 % and 60 % , and ambient temperature range of 9 to 48 °C. Power output reduction is observed again as the ambient temperature increases.

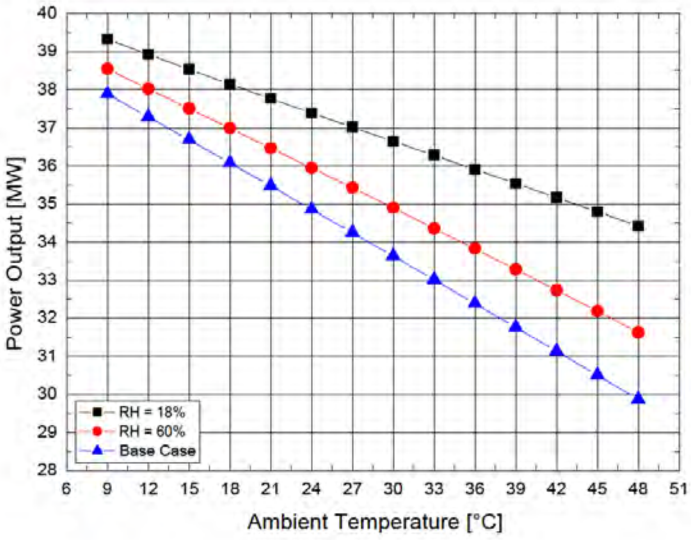

Figure 6. Effect of ambient air temperature on the gas turbine power output employing fogging cooling system.

During this simulation, it was adopted that final value of relative humidity is 100 % for the fogging cooling system (State 3, in Fig. 4) independent of the air ambient inlet conditions (State 0, in Fig. 4). Note that for entire range of ambient temperature studied, the gas turbine power output improvement under relative humidity equal 18 % is greater than that obtained at 60 % level. This same behavior is observed to thermal efficiency results (Eq.7), as presented in Fig. 7.

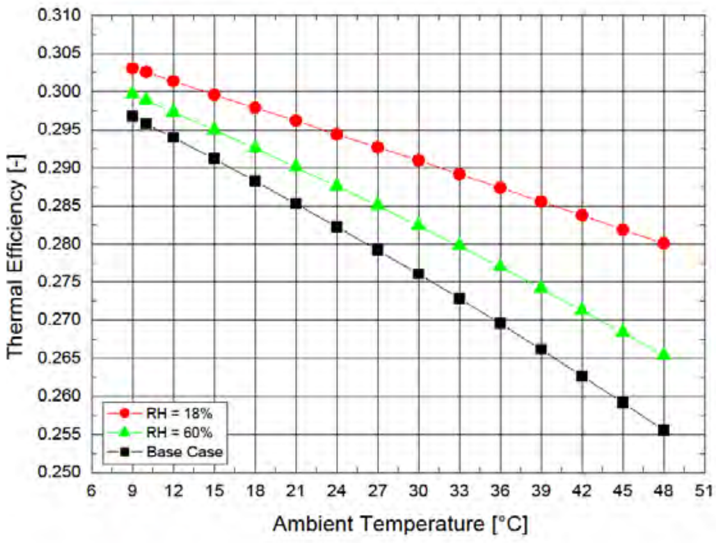

Figure 7. Effect of ambient air temperature on the gas turbine thermal efficiency employing fogging cooling system.

Figure 8 shows the mass flow water consumption demanded by fogging and evaporative wetted cooling as a function the ambient relative humidity. It is verified that the fogging system achieves higher water requirements in comparison with traditional evaporative system, but also provides a little thermal efficiency gain (see Tab. 3). As expected, the fogging system is more efficient at low relative humidity levels. Evaporative wetted media was simulated with a typical evaporative cooling effectiveness (eff) of 0.9.

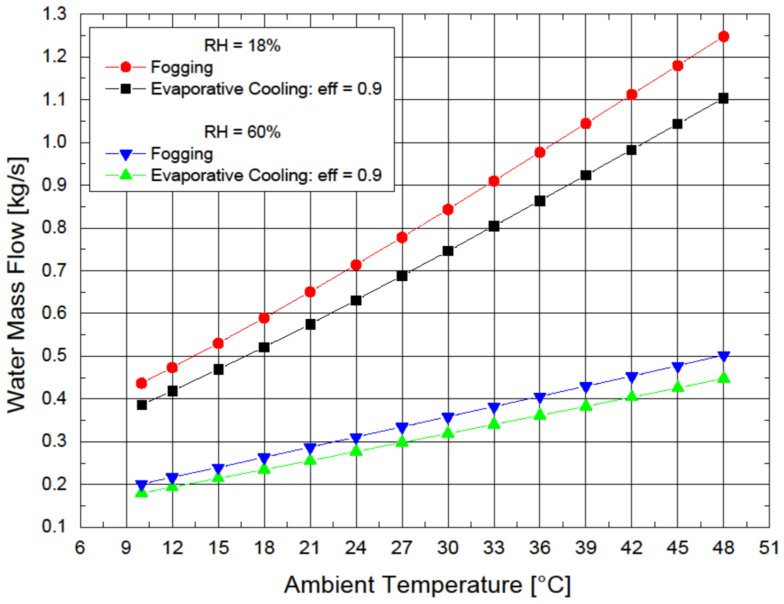

Figure 8. Effect of the relative humidity on the water consumption for evaporative wetted cooling and fogging system.

The compressor inlet cooling method performance can be evaluate by comparing the resultant cooling load. Note that the fogging system offers a better option mainly at lower relative humidity level (see curves at 18% and 60% in Fig. 9). This behavior becomes more relevant as the ambient temperature increases once the wet bulb temperature is always reached by the fogging technique while the evaporative wetted media system is dependent from the apparatus effectiveness.

With the objective of obtain an overview about the gas turbine inlet cooling methods, the obtained results in Santos and Andrade (2012) study are reproduced in conjunction with the present work fogging cooling ones. Tab. 2 and Tab. 3 show power output and thermal efficiency values, respectively.

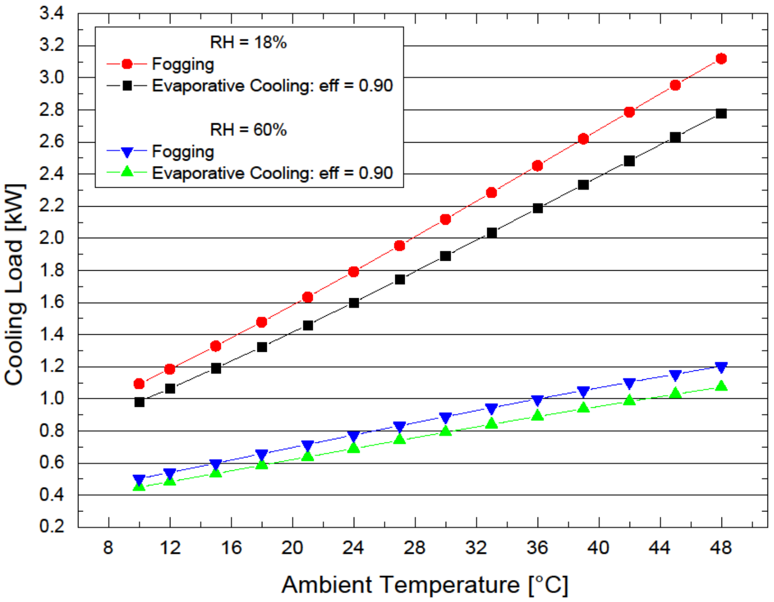

Figure 9. Cooling load of each simulated cooling technique as a function of the ambient relative humidity.

When the ambient temperature increases from 10 °C to 48 C, the base-case (without any cooling method) power output drop is almost 20 % (see Tab. 2). Note that independent of the employed turbine inlet cooling method, the power output decreases as the ambient temperature elevates but the chiller systems (mechanical and absorption) provides lower power output drop in comparison with evaporative cooling methods. Besides, the fogging system offers a little advantage in comparison with the evaporative wetted media (12 % and 13.4 % power output decrease, respectively).

Table 2. Gas turbine power output for each simulated cooling methods.

Ambient Temperature	Power Output at 18% ambient relative humidity				
[°C]	[MW]				
	Base Case	Mechanical Chiller* COP = 4.5	Absorption Chiller*	Evaporative Cooling* eff = 0.9	Fogging
10	37.89	37.68	37.68	39.04	39.20
12	37.69	37.62	37.68	38.76	38.93
15	37.29	37.52	37.68	38.34	38.54
18	36.69	37.43	37.68	37.93	38.15
21	36.08	37.33	37.68	37.53	37.77
24	35.48	37.24	37.68	37.12	37.39
27	34.86	37.14	37.68	36.72	37.02
30	34.25	37.05	37.68	36.33	36.65
33	33.64	36.95	37.68	35.93	36.28
36	33.02	36.85	37.68	35.53	35.91
39	32.39	36.74	37.68	35.13	35.54
42	31.77	36.53	37.68	34.74	35.17
45	31.14	36.30	37.68	34.33	34.80
48	30.51	36.06	37.68	33.93	34.42

* Santos and Andrade (2012).

Table 3 presents the thermal efficiency provided by different turbine inlet cooling techniques and the base-case condition (without cooling) as a function of the ambient temperature. When the ambient temperature increases from 10 C to 48 C, the base-case thermal efficiency drop is almost 14 % while the chiller system offers a constant value because this equipment imposes a fixed compressor inlet temperature (equal 10 C at this case).

On the other hand, the mechanical chiller presents a thermal efficiency drop around 4 % as the ambient temperature elevates. This lower performance is comparison with absorption systems is because the power required to drive the absorption chiller is usually obtained from the turbine exhaust gases while the mechanical chiller consumes part of the output power generated by the gas turbine.

Table 3. Gas turbine thermal efficiency for each simulated cooling methods.

Ambient Temperature	Thermal Efficiency at 18 % ambient relative humidity				
[°C]	[-]				
	Base Case	Mechanical Chiller* COP = 4.5	Absorption Chiller*	Evaporative Cooling* eff = 0.9	Fogging
10	0.296	0.296	0.296	0.302	0.303
12	0.294	0.295	0.296	0.301	0.301
15	0.291	0.295	0.296	0.299	0.300
18	0.288	0.294	0.296	0.297	0.298
21	0.285	0.293	0.296	0.295	0.296
24	0.282	0.292	0.296	0.293	0.294
27	0.279	0.292	0.296	0.291	0.293
30	0.276	0.291	0.296	0.289	0.291
33	0.273	0.290	0.296	0.287	0.289
36	0.270	0.289	0.296	0.286	0.287
39	0.266	0.288	0.296	0.284	0.286
42	0.263	0.287	0.296	0.282	0.284
45	0.259	0.285	0.296	0.280	0.282
48	0.256	0.283	0.296	0.278	0.280

* Santos and Andrade (2012).

When the chiller system are not available as a turbine inlet cooling option (lack of heat recovery system, e.g.), the user can choose for a evaporative method. A comparison between traditional evaporative method and fogging system showed thermal efficiency drops of 8 % and 7. 4%, respectively, considering the 10 C to 48 C temperature range. However, if the ambient temperature is inferior to 21 °C), the fogging method offers the better performance among the four tested cooling techniques (see $T_{ambiente}$ = 12 °C, e.g., in Tab. 3). This occurs because the wet bulb temperature reached by the fogging system is inferior to the pre-fixed compressor inlet temperature utilized by the chillers systems (mechanical and absorption).

5. FINAL REMARKS

At this work, four compressor inlet methods have been compared as a function of the gas turbine ambient conditions (temperature and relative humidity). Results showed that the chiller system are more suitable at higher ambient temperature conditions. On the other hand, if the ambient temperature is inferior to 21 °C (at relative humidity equal to 18 %) the fogging system offers a good cooling solution. However, each turbine inlet cooling method has its limitations, as follow:

- the chiller system requires available exhaust gases heat and under adequate discharge temperature;
- the mechanical chiller requires high input of power to drive the compressor section and various distribution pumps;
- the traditional evaporative system provides a limited temperature drop because it depends from the ambient wet-bulb temperature and the apparatus effectiveness;
- the fogging system also depends of the wet-bulb temperature but even requires available demineralized water.

Furthermore, the final cooling option is not a trivial solution: a trade-off study must be evaluated taking account several features as cost associated with each cooling method, site climate conditions (temperature and relative humidity) and the demineralized water availability. Maintenance and installations costs must be also computed.

6. REFERENCES

Al-Amiri, A. M., Zamzam, M. M., Chaker, M. A. and Meher-Homji, C. B. “Application of inlet fogging for power augmentation of mechanical drive turbines in the oil and gas sector”. In *Proceedings of the ASME Turbo Expo 2006: Power for Land, Sea and Air.* Barcelona, Spain.

Alhazmy, M. M., Jassim, R. K. and Zaki, G. M., 2006. “Performance enhancement of gas turbine by inlet air-cooling in hot and humid climates”.

Alhazmy, M. M. and Najjar, Y. S. H., 2004. “Augmentation of gas turbine performance using air coolers”. Applied Thermal Engineering, Vol. 24, p. 415-429.

AL-Salman, K. Y., Rishack Q. A. and AL-Mousawi, S.J., 2007. “Parametric study of gas turbine cycle with fogging system”. Journal of Basrah Researches - Sciences. Vol. 33, n. 4.

Al-Tobi, I., 2009. “Performance enhancement of gas turbine by inlet air cooling”. In *Proceedings of the International Conference on Communication, Computer and Power - ICCCP09*. Muscat, Oman.

Ameri, M., and Tahvildar , B., 2011. “V94.2 Gas turbine thermodynamic modeling for estimation of power gained by fog system in Iran power plants”. International Journal of Energy Engineering, Vol. 1, n. 1, p. 33-43.

Ameri, M., Nabati, H. and Keshtgar, A., 2004. “Gas turbine power argumentation using fog inlet air-cooling system”. In: ESDA04, 2004, Manchester. In *Proceedings of the 7th Biennial Conference on Engineering Systems Design and Analysis - ESDA 2004*. Manchester, United Kingdow.

Ameri, M., Shahbazian, H. R. and Nabizadech, M., 2007. “Comparison of evaporative inlet air cooling systems to enhance the gas turbine generated power”. International Journal of energy Research, Vol. 31, p. 1483-1503.

American Society of Heating, Refrigerating and Air Conditioning Engineers, 2009. "2009 ASHRAE Handbook-Fundamentals (SI)". *Psychrometrics*, p.1.1-1.16.

Chaker, M., Meher-Homji, C. B., Mee III, T. and Nicholson, A., 2001. “Inlet fogging of gas turbine engines detailed climatic analysis of gas turbine evaporative cooling potential in the USA”. In Proceedings of the ASME Turbo Expo 2001. New Orleans, Lousiana.

Chaker, M. and Meher-Homji, C. B., 2006. “Application of inlet fogging for power augmentation of mechanical drive Turbines in the oil and gas sector”. In Proceedings of the ASME Turbo Expo 2006: Power for Land, Sea and Air. Barcelona, Spain.

Erdem, H. H. and Sevilgen, S. H., 2006. “Case study: Effect of ambient temperature on the electricity production and fuel consumption of a simple cycle gas turbine in Turkey”. Applied Thermal Engineering, Vol. 26, p. 320-326.

Gareta, R., Romeo, L. M. and Gil, A., 2004. “Methodology for the economic evaluation of gas turbine air-cooling systems in combined cycle applications”. Applied Energy, Vol. 29, p. 1805-1818.

Jones, C. and Jacobs III, J. A., 2000. “Economic and technical considerations for combined-cycle performance-enhancement options”. GE Power Systems. Schenectady, Nem York.

Mee Industries Inc, 2002. “Economic benefits of replacing gas turbine media based evaporative cooling with inlet fogging systems”.

Offshore Technology. “Mee Industries – Fogging systems for offshore gas turbines”. 20 Apr. 2013 <http://www.offshore-technology.com/contractors/power/mee-industries/mee-industries5.html>.

Santos, A. P. P. and Andrade, C. R., 2012. “Thermodynamic analysis of gas turbine performance with different inlet air cooling techniques”. In Proceedings of the ASME Turbo Expo 2012 - GT2012. Copenhagen, Denmark.

Yang, C., Yang, Z. and Cai, R., 2009. “Analytical method for evaluation of gas turbine inlet air cooling in combined cycle power plant”. Applied Energy, Vol. 86, p. 848-856.

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