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ORIGINAL ARTICLE

Investigation of Gas Turbine Intake Air Cooling Via Evaporative Media and Its Effects on Cartridge Filters Pressures Drop

EHSAN FARVARESH[1], FARIDEH GOLBABAEI[1*], MANSOUR GHIYASEDDIN[1], ALI BEHDASHTI[2], KERAMATOLLAH NOURI JALIANI[3], MEHRDAD KARIMI[3], and SAEED TOHIDI[4]

[1]Department of Occupational Health Engineering, School of Public Health,Tehran University of Medical Sciences, Tehran, Iran; [2]Managing Director of Imen Sarv Co.; [3]Department of Epidemiology & Biostatics, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran; [4]School of Energy and Environment, Science and Research Campus, Islamic Azad University, Tehran, Iran.

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ABSTRACT

The Aim of this study was to evaluate the effect of Evaporative Media as gas turbine intake air cooling method on pressure drop of cartridge air filters. This study performed under the laboratory condition, using stainless steel test rig with specified dimensions to investigate the role of evaporative media in air cooling as well as its effects on new and used cartridge filters (as representative of clean and loaded filters). Tests were carried out at three five hours consecutive stages including, warm -dry stage (Ta=35-40°C) and relative humidity ([RH] =10-15%), cold - humid stage (Ta=22-27°C and RH=80 to 85%), and, warm-dry stage (Ta=35-40 °C and RH=10-15%) for 3 consecutive days. Findings showed that using evaporative media caused air intake temperature reduction was equal to 12.5 °C. Total pressure drop of cartridge filters was 5.13±0.84 and 3.86±0.14 mbar for used and new filters, respectively. Results of repeated measure test showed that the differences between new and used filters pressure drop was significant (P=0.001). Combined effects of humidity and dust loading on filters pressure drop demonstrated that cartridge filters were not affected by humidity (P=0.75) and the main reason of pressure drop was due to collected dust on filters. It is concluded that using evaporative media systems is suitable method for cooling gas turbine intake and increase turbine efficiency without any significant increase of filter pressure drop in hot-dry climate.

Keywords: *Evaporation media, Air intake, Cooling, Cellulose Ccartridge filter, Gas turbine*

INTRODUCTION

Gas turbines are the most important energy-producing machines that broadly applied in producing electricity, gas transfer stations, petro chemistry industries, oil platform and ships [1, 2]. Environmental conditions of installation site, specially inlet pressure and temperature have greatest influence on gas turbine performance [3]. The effect of ambient temperature on gas turbine performance in various situations differs and in order to getting better control strategies, relevant factors must be considered [4].

During the hot days air density decreased, air mass flow rate dropped, hence causes decreasing power output of the gas turbines. Gas turbines have been designed to operate under standard conditions (International Standards Organization (ISO) defined as

*** Corresponding author:** Farideh Golbabaei, Email: fgolba-baei@sina.tums.ac.ir

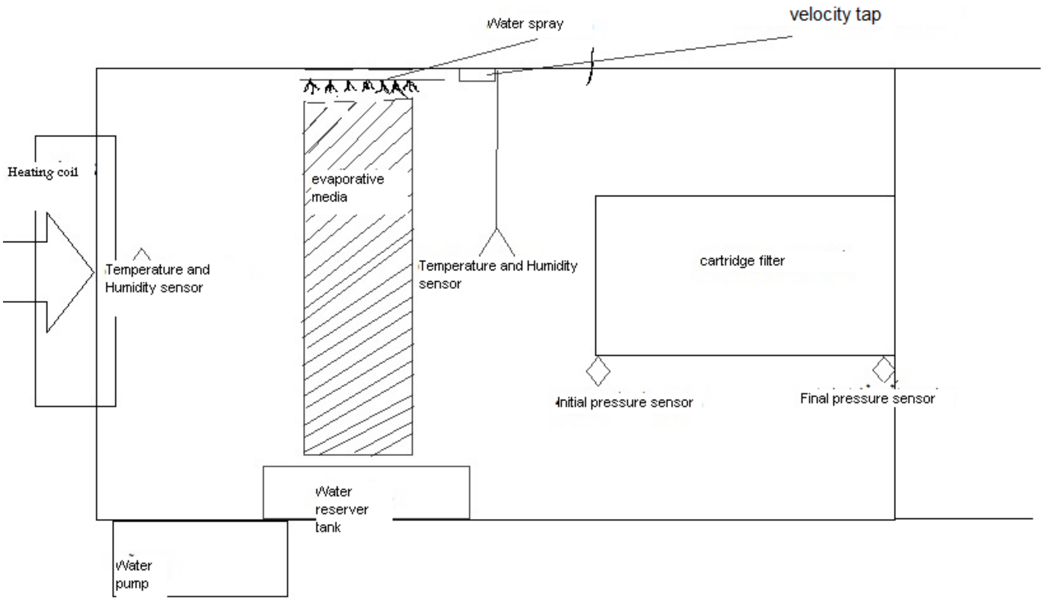

Fig 1. Profile of test rig

59 ^{o}F (15.6 °C) inlet temperature, 14.7 psia inlet pressure, and 60% relative humidity) that by installing in hot-dry environments lose a significant percentage of their production capacity [5-7].

Ambient temperature has a great influence on gas turbine performance and decreases power output due to increasing it. Considering that during the summer electricity demand rises [8], gas turbine inlet air cooling, especially during peak times of power consumption is one of useful method that can be used to increase power generation. Various techniques including chillers, evaporative cooler and Exchange Earth Tube Heat Exchanger (ETHE) are provided to reducing inlet air temperature and increasing the power output and efficiency of gas turbines [8-9]. ETHE is a new method for gas turbine inlet air cooling; in which, heat is transferred to layers of soil and reverse takes place. This method is based on this fact that although atmospheric temperature has cyclic (daily) changes, soil temperature at depth of 2m remains constant [9].

Chillers are the most powerful methods for reducing inlet air temperature and are able to keep inlet air temperature up to 45 °C, but they are very costly [10-13].

Evaporative coolers includes fogging and evaporative media cooler as another alternative cooling methods that by transforming liquid phase to vapor caused air flow cooled [11-13]. evaporation media cooling theory and designing of cooling media, installation, operation, water quality and ways to prevention of water transmission were studied [14] .

A computer simulation of combination evaporation cooler and air cooling system were presented and considered effects of fluctuation at ambient temperature on power output and its efficiency [15]. Using evaporation media reduces NOx in the emission from combustion chambers; and therefore, positive effects of environmental consequences are introduced [16, 17].

Cooling air as much as 10°C will increases approximately 10-6% in electrical power generated [18]. Status of application of evaporative inlet air cooling systems in 3 great power plant including Rajaei, Qom and Fars were studied. Comparing economic and technical aspects showed that using evaporation media system was more effective than fog system [12]. Using wetted media type to cool the gas turbine inlet air in five PG6581and three PG6551 type gas turbine showed that wetted media caused to inlet air temperature drop 12-14 °C and increases 4MW for each of PG6581turbines and 3.5MW for each of PG6551gas turbines [5].

The performance of evaporative air cooling systems study in Saudi Arabia showed strong dependency on climatic conditions as well as are suitable for hot and dry environments [11].

Whereas, the ambient air of gas turbine power plant due to the time of year and geographic location contains natural and anthropogenic particles, to prevent the damages including foreign object damage, erosion, fouling, turbine blade cooling passage plugging, particle fusion, and hot and cold corrosion in gas turbine entrance air filtrations systems are used, for this purpose Air Cartridge Filters widely used in intake air of gas turbines [19].

Due to necessity of using filtration system at turbines inlet and advantages of inlet air-cooling especially through evaporation media this study has been done. It aimed to investigate the effect of air cooling using evaporative media on the performance of new and loaded Cellulose Filter Cartridges in order to incorporate the dust effects of collected dust on filters, under laboratory conditions.

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MATERIALS AND METHOD

This was a cross-sectional analytical study to investigate the effect of evaporative media system on the cooling method of gas turbine air intake cooling in desert regions of Iran in 2011. Moreover this study was done to investigate the effects of evaporative media system on used cartridge filters under laboratory conditions in order to include the combined effects of filter dust loadings as well as air cooling via evaporative media on filter pressure drop. Among desert regions of Iran, Kerman was selected as a sample. This study was established according to climatic characteristics obtained from the Meteorological Organization. For this purpose, the following steps were taken:

Construction of Filter Test System

Test tunnel was made of stainless steel with dimensions of 40 cm×60 cm×60 cm. Air flow through this system was supplied at desired temperature by centrifugal fan with following characteristics: propellant capacity of 1250 m^3/h and maximum static pressure of 4in WG and power of 1.5 KW. This system consists of following sections (Fig 1).

Evaporator Section

This section consists of water storage tank, floater, pump and sprays nozzles for spraying water on top of the evaporator media, and mist eliminator that installed after fan.

Evaporative media

Cellulose pad are like honeycomb and domestically produced. When air passes through it, the available water at pleated media surface evaporates, therefore the passing air cooled.

Filtration Section

It consists of special body for installing filter with opening and quick change ability that made of stainless steel. This section is equipped with GI3422 cartridge filters that Manufactured by Mashhad Behran Filter company.

Instrumentation equipment

It consists of two temperature and humidity sensors with an output ability of 4-20 mA that is installed before and after evaporation media. Also creates appropriate connection for installing Pitot tube at upper section of test tunnel after evaporation media for monitoring total & static pressure of passed air.

A sensor and processor system for measuring the pressure drop with ability of measuring 0 to 20 mbar is installed at test system to measure pressure difference across filter during any desired moment. Finally, the PLC controller with the ability to connect to a computer system to record measured data was installed on the test system for planning system.

Tests

After construction and calibration of the test system, three used cellulose filter cartridges) to considering the combined effects of evaporation media and dust loaded) and two clean filters (The effect of cooling on the filter media) were tested. Tests were carried out in 5 hours duration and three consecutive days.

In the first stage, filters were exposed to inlet air (with air temperature of 35-40°C and relative humidity10-15%) and after 5 hours, with spreading water on evaporation media, the air temperature decreased and relative humidity increased.

Filter has been exposed to this conditions (Ta=22-27°C, RH=80-85%) for 5 hours. Finally the spreading water disconnected and filter was exposed to hot and dry air for 5 hours duration (Ta=35-40^{o}C, RH=10-15%).

Air temperature and relative humidity were measured and recorded before and after filters. In addition, filter pressure drop (resulting from static pressure on both sides of filter) was measured by pressure sensor and its results momentarily recorded.

Used cellulose filter cartridge (GI3422) manufactured by Mashhad Behran filter CO. These filters are made of cellulose synthetic media, with approximately 99% efficiency for particles larger than 0.5μ. Each filter unit surface area is 19 m^2, length of 600 mm and exterior diameter is 325 mm. These filters have been designed to pass air speed of 2 m/s but are

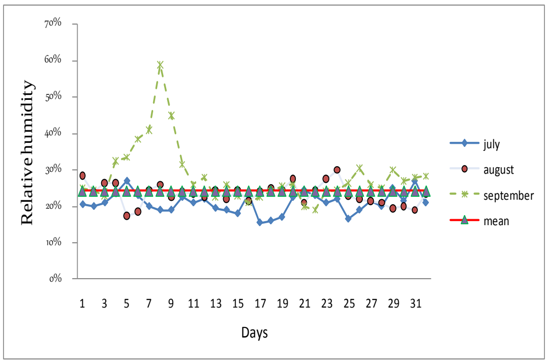
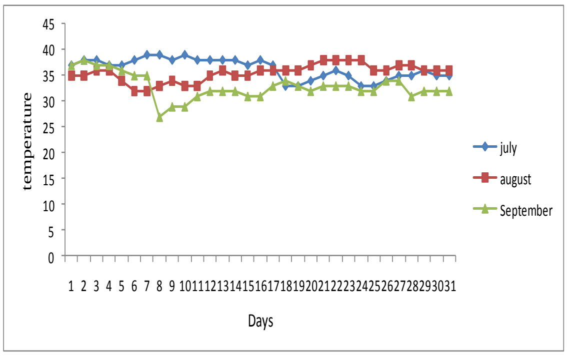


Chart 1-a-Average daily temperature in summer in Kerman



Char 1-b-Trend average relative humidity of ambient air in summer Kerman

Fig 2. Average of 5 latest summers' meteorological data of Kerman City

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Table 1. Mean and standard deviation of air temperature, relative humidity and pressure drop at different test stages for clean and loaded filter

Type of filter	Stage	Humidity # 1 %		Humidity #2 %		temperature# 1 °C		temperature#2 °C		Δp mbar	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Clean filter	Stage 1	11.89	2.53	13.26	2.69	40.21	0.31	40.13	0.79	4.73	0.10
	Stage 2	26.57	4.09	82.32	6.18	39.32	0.41	26.56	1.50	4.79	0.10
	Stage 3	14.24	4.25	23.01	4.07	39.79	0.72	38	3.35	4.27	0.14
Loaded filter	Stage 1	16.26	3.26	18.12	4.05	40.24	0.36	40.30	0.90	6.36	0.12
	Stage 2	29.53	2.69	80.83	5.39	39.96	0.17	27.05	1.15	6.57	0.25
	Stage 3	16.65	2.83	24.46	10.46	39.86	0.23	38.46	2.83	6.38	0.23

Table 2. Mean of pressure drop mbar for clean and dirty cartridge filters in various psychometric conditions

Type of filter	Stage	Average	Standard Deviation	Number	*P* value
Loaded	1	5/17	0.82	45	0.0001
	2	5.13	0.88	45	
	3	5.07	84.0	45	
Clean	1	3.91	0.15	30	0.56
	2	3.84	0.11	30	
	3	30	0.14	3.91	
	Total	3.86	0.14	40s	

capable to passes 4 m/s.

The filters are able to tolerate 2.5 bar final pressure drop and it is not recommended to apply in higher level. In addition, volume flow rate of passing air through air filters was 1250 m^3/h.

Firstly, evaporative media was placed at the air path of inlet air to the filters at test system. Then air velocity through the test system was commensurate with nominal speed (determined for these types of filters (2 m/s)) using Testo 350/xl. Psychometric conditions such as defined in various stages and testing corresponding filters at each stage of the test were monitored using Testo 350/xl to ensure of maintaining its desired speed (2m/s). Temperature, humidity and filters pressure drop under different testing conditions were recorded momentarily and continuously recorded by a computer system. Finally obtained data were analyzed using Excel and SPSS software version 19 to determine the relationship between main variables, repeated measure, ANOVA tests and regression analysis were used.

RESULTS

Analysis of recent 5 years meteorological data of Kerman City showed that climate of this area is warm and dry. During summer season the average temperature is 35-40°C and RH is 10-15% [20]. Fig 2 shows daily changes in mean temperature and relative humidity of Kerman during July, Aug and Sep 2011 (the highest consumption time of year). The energy balance sheet book that published by Ministry of Energy [21] showed

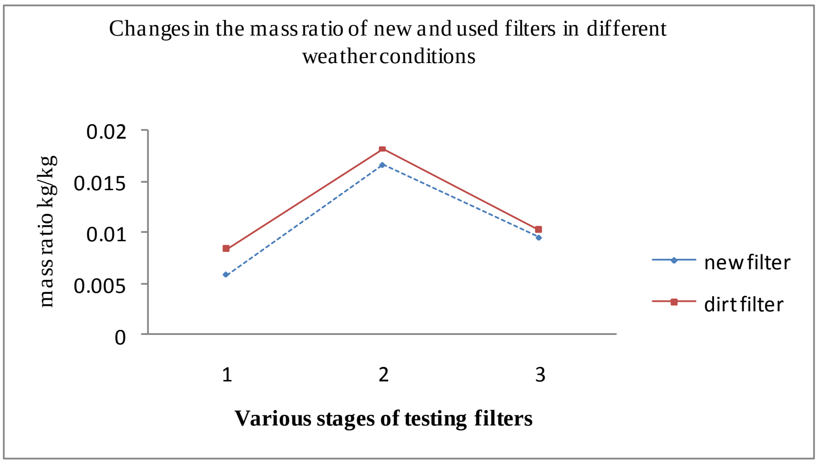

Fig 3. Changes of mass ratio in different test stage

that the maximum consumption of electricity at this area was during day and peak heating time 11 a.m. to 19 p.m.

Results of tests for air cartridge filters (Table 1) under similar condition to Kerman City within warm season and peak of consumption hour show that the amount of temperature and relative humidity under ordinary condition without using evaporation media is 39.13°C and 13.26%, respectively. Meanwhile, by benefiting from evaporation media, temperature is reduced to 26.56°C and RH is increased to 82.32% i.e. applying evaporation media reduces temperature of inlet air into filter as 12.57°C. Study the effects of temperature and humidity on the ability of evaporative cooling media system using the regression method showed that as per one unit increases in ambient temperature, the 0.58°C is added to cooling ability of evaporating media system.

Results of pressure drop test for clean (unloaded) and dirty (loaded) cartridge filters are shown in Table 2. Amount of pressure drop in loaded filters is much greater than clean filters (*P*= 0.0001). Besides, obtained results indicate that the use of evaporative cooling media or in other words stage of humidifying air did not associate with meaningful changes in the increasing in pressure drop (*P*= 0.0001), although according to the Fig. 3 mass ratio of produced steam per each kilogram of passing dry air in cooling stage (stage 2) was higher than dry stage.

Repeated measure test were used to compare the mean of the pressure drop at hot-dry and cold- humid conditions. At this test, the mean of the pressure drop and also interaction between filter and the climatic conditions were tested. Based on the results, the effect of type of filter (clean or loaded) on the pressure drop was significant (*P*=0.0001) and indicates mean difference of pressure drop in loaded and clean filters. Whereas the climatic conditions has not caused significant effects on the pressure drop of filter.

DISCUSSION

Findings of this study shows that using evaporative media can decrease gas turbine inlet air temperature 12.5^{o}C. These results are inconsistence with a study done by Hamid Nabati et al in Iran and El-Awad O.H.M in Sudan [7, 22]. In hot-dry climate in Saudi Arabia, evaporative media was able to reduce air temperature up to 20^{o}C, but due to restrictions on water consumption in this region were not able to exploit it [11].

Total pressure drop of used (5.13+-0.84m/bar) and clean (3.86+-0.14m/bar) cartridge filters in various stages of testing and under various temperature and humidity conditions indicates a higher pressure drop in used cartridge filters compared to cleans. In which, results of repeated measure test confirms this significant differences between used and clean filters (*P*=0.0001), which could be attributed to dust and its concentration. Besides, by using this test the interaction of filter at different stages was studied. The results showed that average pressure drop in loaded and clean filters in the three stages of test does not have statistically significant difference in various psychometric conditions(*P*=0.22). This means hot - dry or cold and humid climate didn't have considerable effect on the filters pressure drop.

The present study indicated that, changes in water content of passing air through filters did not have significant effect on increasing air pressure drop. Non significance of humidify effects on filter pressure drop may be due to short period of humidifying as well as dryness of filters media during humidification intervals so it seems that the main cause of pressure drop increment would be referred to loaded dust on the filter and its concentration.

Using regression analysis the effect of ambient temperature on evaporative cooling media was measured and showed that as per one unit increases in ambient temperature 0.58°C increase in cooling ability of evaporative media system. This is a confirmation to previous studies [12].

Obtained results from comparison of evaporative cooling systems and chillers indicated that evaporative cooling system able to enhance the cooling efficiency of gas turbines and due to energy consumption required for vapor compression in chillers are economically cheaper. In the warmer environments using this method is more efficient [23].

The combination of first and second law of thermodynamics shows that energy losses in the various components of the gas turbine cycle significantly influenced the compressor pressure ratio, gas turbine inlet air temperature and does not get affected by environmental relative humidity [23]. Analysis and simulation on 91 gas turbine performance done to evaluate the sensitivity to ambient temperature in specific conditions and compressor ratios indicated that with increasing cooling power of ambient air, the turbines power increases. That was consistent with our findings [24].

By using linear regression method the effect of temperature and ambient humidity on clean and loaded filters pressure drop were tested which showed that temperature and ambient humidity had a significant effect on loaded filters pressure drop (*P*=0.0001). And per each unit increase in ambient temperature in loaded filters 0.04 mbar added to pressure drop, but in clean filters falls 0.01 m/bar. This means that the ambient temperature has a greater effect on increasing in used cartridge filters pressure drop. Results emphasizing the serious effect of dust loading on the filters pressure drop. Results of a study on the performance of four types of gas turbines showed that as the inlet air temperature raises pressure drop increase which is consistent with our findings [25].

It was expected to increase the pressure drop of the filter, due to increasing water before filtering. Linear regression analysis showed relative humidity did not any effect on filters pressure drop (*P*=0.75). With each unit increases in relative humidity within the test system only 0.004 is added to filters pressure drop, that this increase was not statistically significant. This finding was inconsistent with other findings that showed at low ambient humidity power output increases [7].

CONCLUSION

By using evaporative media system in hot-dry climates such as Kerman, the gas turbine inlet air temperature can be 12.57°C cooler on average. Also using evaporative media system and cooling the air had no effect on increasing pressure drop in filters. The most important factor causing filters pressure drop is the dust loaded condition.

If the nominal speed maintained (determined by manufacturer) encountered air velocity to filters is proportional and prevented from transferring of water droplets on the filters and ultimately prevented from increasing in filters pressure drop.

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The authors declare that there is no conflict of interests.

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