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Technical and economic analysis to determine best cooling method for cooling of air intake in Qom power plant on the basis of energetic and exergetic analysis

Mahmood Haghanikhah*[1], Saeid Rasouli[2]

[1] Department of Mechanical Engineering, Khomeinishahr Branch, Islamic Azad University, Khomeinishahr/Isfahan, Iran
[2] Department of Mechanical Engineering, Khomeinishahr Branch, Islamic Azad University, Khomeinishahr/Isfahan, Iran

Abstract

In this article using of different cooling system of air intake to the compressor has been compared to determine which one would have the best effect. The analysis have been done on a power plant which based in Qom and analysis is based on energetic, exergetic and economical aspects of the installing a cooling system. The Qom power plant use gas cycle with two regenerative boilers and two vapor turbine which modeled in ThermoFlow software. By means of different energetic and exergetic analysis and also economic issues, fog cooling system have been selected as the most appropriate one among other cooling system. This cooling system would cause increase in net output power from the plant and increase in efficiency of both gas cycle. Moreover fog cooling system plays an important role in decreasing heat rate of gas cycle and power plant.

Keywords: *fog cooling system, increasing of energy and exergy, energy analysis, exergy analysis, technical and economic analysis.*

1. Introduction

Using of gas turbines for producing electrical power has been emerged in different countries and this method is a popular way to run a power plant. The most demand of Iran electricity is supplying from gas cycle power plant and these plants using fossil fuels to run it is important to improve their efficiency to decrease fossil fuel consumption besides decreasing air pollution.

Efficiency and net power of the gas turbine would decrease in the case of increasing air intake temperature and humidity. Decreasing output powers of the plants in the warm seasons of a year get to trouble and should be avoided. To avoid this phenomenon it is common to cool down air intake of the compressor. On the other hand because of variety of climate in different zones it is impossible to find a way which is appropriate for all of climates. As a result it is important to study different methods to find the best approach for any special zone conditions. Cooling of air intake to the compressor is an independent method which is considered for increasing efficiency of already running turbines. There are different approaches to cooling air intake which is developed on the basis of every zone circumstances which briefly includes: Evaporate cooling (media and fog), refrigeration cooling (by means of absorption chiller cooling system) and methods for saving chill (Ice maker). Cooling of any centigrade of air intake leads to increasing output power as much as 0.5 to 1 percent [1]. It is important to analyses different aspects of cooling methods to determine appropriate method for this purpose the best way is to simulating the gas turbine in exact conditions.

2. Comparison between methods of air intake to the compressor

Firstly two important cooling system would be presented: Evaporate cooling (media and fog) and refrigeration cooling (by means of absorption chiller cooling system)

2.1. Methods of evaporating cooling

A: air intake evaporating cooling by media method: In this method air is cooled by means of crossing

* **Corresponding author: Mahmood Haghani khah**
Email: Mahmood.Haghanikhah@iaukhsh.ac.ir

from media plates. The plates are cooled by water passing them. Media plates are made from Cellulose fibers and are made in the form of waves. A cluster of these plates together makes an evaporating cooler. (Fig.1). Media plates are made in spiral or honeycomb form to increase contact area between water and air in order to enhance evaporating efficiency. [1,2]

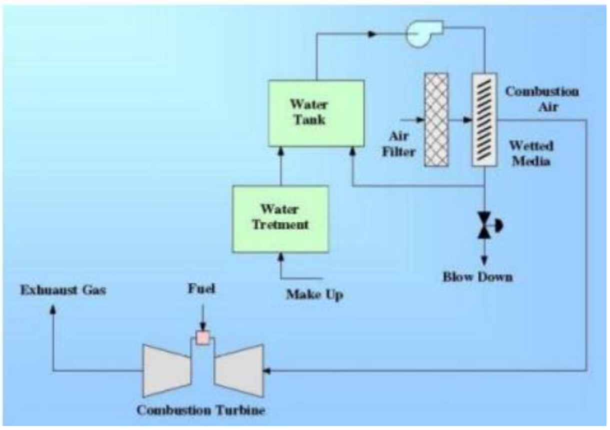


Fig. 1 Schematic of media cooling system in a gas turbine system

B: production of fog with high pressure is taking to consideration and utilized from 20 years ago. Cooling is done by millions small particles with dimensions between 4 to 6 micrometer. There are some reports showed that this method have 100 percent efficiency in high humidity condition. In this system water droplets have Brownian motion in the air, which means that every water particles can move in every direction and changing the direction of motion by collision to another particle.

In this method the water firstly filtered, deionized and demineralized then pumped into special nozzles by means of high pressure pumps. The nozzles are sensitive and have fine orifices with installed in a special array which let water into the air passage in fog form. In this method the water should have special considerations to prevent nozzles from obstruction and staining. By diffusion of water small droplets to the air passage heat transferred from passing air to the water droplets and as a result passing air temperature drops down [5]. An intelligent control system defines amount of fog which necessary to achieve desired temperature by means of measuring Dry-bulb temperature and relative humidity. The control system adjusts the amount of fog which necessary for surrounding condition by activation or deactivation of every fog sprinklers [1, 2].

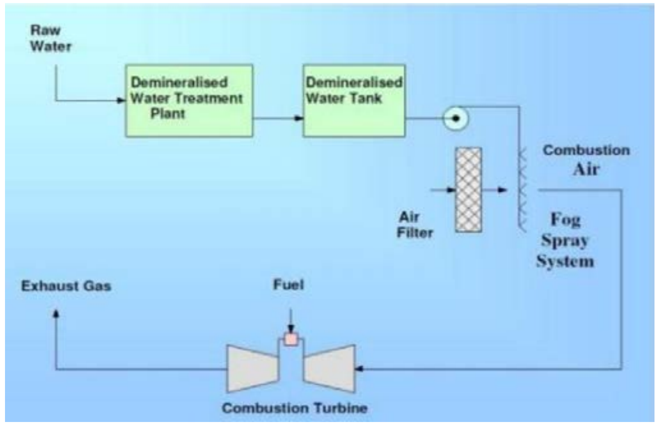


Fig. 2 schematic of fog evaporation system in a gas turbine cycle

2.2 Refrigeration cooling methods

A: cooling of air intake with Cooling Absorption systems

In this method absorption chiller use steam made in the heat recovery steam generator. Cooled water in the absorption chiller passing into an air cooling coil leads to chilling of air intake to the compressor. In the absorption for completing the cycle and cooling two components are used. One of them utilized as an absorption unit while another one utilized as refrigeration unit. Refrigeration liquid of the chiller is water and lithium bromide or ammonia usually used as absorption component (Fig. 3). Running energy of the system can be supplied from heated water, vapor or direct flame. As a result electrical energy consumption of this system is mostly lower than vapor compression chillers which make absorption chillers cost effective

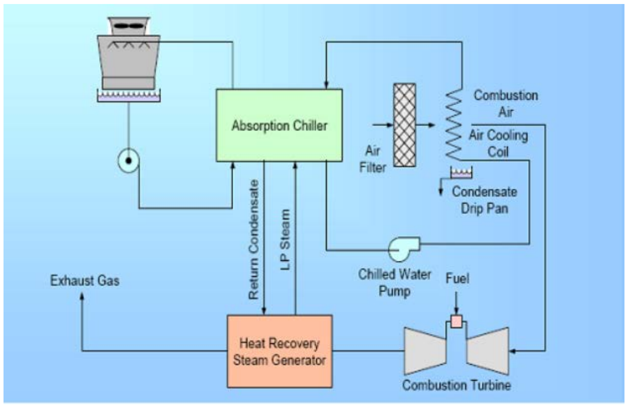


Fig. 3 schematic of absorption cooling system in a gas turbine cycle

3. Case study specifications

Qom power plant includes 4 MW-701D gas turbine made by Mitsubishi. Each of the turbines theoretical capacity is 128.5 Mega Watts. The power plant starts working in 1993. The plant conversion into combined cycle has been done in 1997 by ABB, for this purpose ABB installed 4 heat recovery steam generators and 2 vapor turbo generator which each of them have 100 MW theoretical capacity [3].

.4 Technical and economical assessment of three cooling system in Qom power plant.

In technical assessment some parameters should be considered
-Cost of water consumed by the cooling system
-Cost of annual maintaining
-Income from power selling for the power plant
-Cost of fuel consumption increasing as power production rises.
-Primary cost of buying and installing components and equipment.
By calculation of technical and economical assessments for each of above statements return on investment could be derived [5].

4.1 Water consumption of the cooling system

Damienwater needed for a fog cooling system in warm seasons of the year is calculated by Thermoflow software which showed that it needs 8468582 liter monthly. The cost of every cubic meter of this water which includes non-processed water costs and filtering costs which equals to 7 USD. For a power plant with 4 units in 6 warm month of the year total cost of water consumption becomes:

$$8468.582 \times 7 = 59280.074 \ USD$$

4.2 Water consumption by media system

Necessary water for warm seasons of a year for a media cooling system calculated by Thermoflow software for every unit is 7550586 liter. The cost of every cubic meter of water equals to 0.2 USD then for a plant with 4 unit total cost of water for this system in 6 warm months of a year equals to:

$$7550.586 \times 0.2 = 1510.1172 \ USD$$

4.3 Primary cost of buying and installing components and equipment for fog cooling system

If maximum increase of power producing by the plant is assumed to be 12MWh, by considering cost of installing components and equipment equal to 50 $/kWh [6]. Then primary costs of fog system for a plant with 4 units equals to:

$$50 \times 4 \times 12 \times 1000 = 2400000 \ USD$$

4.4 Primary cost of buying and installing

components and equipment for media cooling system
If maximum increase of power producing by the plant is assumed to be 10MWh, by considering cost of installing components and equipment equal to 50 $/kWh. Then primary costs of fog system for a plant with 4 units equals to

$$50 \times 4 \times 10 \times 1000 = 2000000 \ USD$$

4.5 Primary cost of buying and installing components and equipment for absorption cooling system

If maximum increase of power producing by the plant is assumed to be 17MWh, by considering cost of installing components and equipment equal to 128

\$/kWh . Then primary costs of fog system for a plant with 4 units equals to

$$128 \times 4 \times 17 \times 1000 = 8704000 \ USD$$

4.6 Cost of annual maintenance for Fog cooling system

The manufacture of fog system announced that annual maintenance of the fog cooling system equals to %2 of primary cost of the system [7]. Then:

$$0.02 \times 2400000 = 48000 \ USD$$

4.7 Cost of annual maintenance for media cooling system

For the media cooling system annual maintenance cost is the same as fog system, then

$$0.02 \times 2000000 = 40000 \ USD$$

4.8 Cost of annual maintenance for absorption cooling system

For absorption system annual maintenance is as high as %5 of primary cost of the system [8], then:

$$0.05 \times 8704000 = 435200 \ USD$$

4.9 Plant proceeds from the sale of electrical power

By considering price of each Kilowatt-hour, 0.024 USD, then total increasing income of the power plant by every cooling system would be:

For Fog system:

$$44850.924 \times 0.024 \times 1000 = 1'076'422.176 \ USD$$

For Media cooling system:

$$38127.024 \times 0.024 \times 1000 = 915'048.576 \ USD$$

For absorption cooling system:

$$64776.732 \times 0.024 \times 1000 = 1'554'641.568 \ USD$$

4.10 Cost of fuel consumption increasing as power production rises.

Cooling of air intake to the compressor cause increasing humidity, density and mass flow of air intake. so fuel consumption in combustion chamber increase. Fuel consumption for a combined cycle in a period of 6 warm month has been calculated and results are reported in table (1):

Table 1: excessive fuel consumed in 6 warm month of a year

Surplus fuel consumed		
Fog cooling system	Media cooling system	Absorption cooling system
1826733.6	1570966.3	2588785.9

For calculating total increase in cost of fuel consumed, every cubic meter of natural gas which is used as fuel in this plant, as high as 0.033 USD in Iran, therefore for a plant with 4 unites surplus fuel consumption price for 6 month would be:

In fog cooling system

$$1826733.6 \times 1.3386 \times 4 \times 0.033 = 326'035.41 \ USD$$

In Media cooling system:

$$1570966.3 \times 1.3386 \times 4 \times 0.033 = 280'386.06 \ USD$$

In absorption cooling system:

$$2588785.9 \times 1.3386 \times 4 \times 0.033 = 462'046.5 \ USD$$

4.11 Total annual cost in fog cooling system:

Total cost of fog cooling system includes surplus fuel consumption, water demand and annual maintenance would be:

$$280'386.06 + 1510.1172 + 40000 = 321'896.1172 \ USD$$

4.12 Total annual cost in media cooling system:

Total cost of media cooling system includes surplus fuel consumption, water demand and annual maintenance would be

$$280'386.06 + 1510.1172 + 40000 = 321'896.1172 \ USD$$

4.13 Total annual cost in absorption cooling system:
Total cost of media cooling system includes surplus fuel consumption and annual maintenance would be:

$$462'046.5 + 435200 = 897246.5 \ USD$$

4.14 Price of surplus power production for different cooling system:

Surplus power production in power plant with different cooling system have different price, for each kilowatt-hour in every method of cooling it would be

For fog cooling system:

$$\frac{433'315.484}{44850924} = 0.00966\left(\frac{USD}{KWh}\right)$$

For Media cooling system:

$$\frac{321'896.1172}{38127024} = 0.00844\left(\frac{USD}{KWh}\right)$$

For absorption cooling system:

$$\frac{897246.5}{64776732} = 0.01385\left(\frac{USD}{KWh}\right)$$

4.15 Payback period calculating for different cooling system:
One of the most important issues in economic justification is return of investment. Return of investment is defined by:

$$PB = \frac{initial \ investment}{earnings \ in \ period - costs \ in \ period} \quad (1)$$

For each of 3 cooling system payback period showed in table (2). As shown in table (2) the most time period for payback of investments belongs to absorption cooling system and least payback time belongs to media system. On the other hand price of the electrical power which paid to the plant affect the above analysis

Table 1 payback period comparison different cooling method

Payback period		
Fog system	Media cooling system	Absorption cooling system
5.82 year	3.8 year	15.87 year

5. Technical analysis of cooling systems in power plants.

Table (3) shows the fact that most increase in power of the gas cycle and power produced by the power plant is achieved by absorption cooling system. Also fog cooling system may cause reasonable increase in the plant power.

As shown in fig (4) with cooling down intake air flow, energetic and exergetic efficiency of gas cycle rise up. The most efficient combined gas cycle is happened with absorption chiller cooling system and gas cycle with fog cooling system is the second most efficient among all of possible systems. fig (5) shows comparison between effect of different cooling system on power plant energetic and exergetic efficiency. The highest efficiency belongs to a power plant with fog cooling system and the second most efficient power plant belongs to one have absorption chiller cooling system.

Table 2: power increased in gas cycle and in whole power plant by different cooling systms

	Power increased	Percentage of power increased

	Gas cycle	Power plant	Gas cycle	Power plant
Fog cooling system	10815.156	44992.28	10.74	7.62
Media cooling system	9172.590	38123.30	9.1	6.45
Absorption cooling system	16481.646	64776.73	16.37	10.95

5.1 Heat rate for gas and combined cycle

As it shown in fig (4) by cooling air intake into the compressor heat rate of gas cycle and power plant would fall down. Minimum heat rate in gas cycle occurs when absorption chiller is used as cooling system and minimum heat rate in power plant occurs when fog cooling system is used.

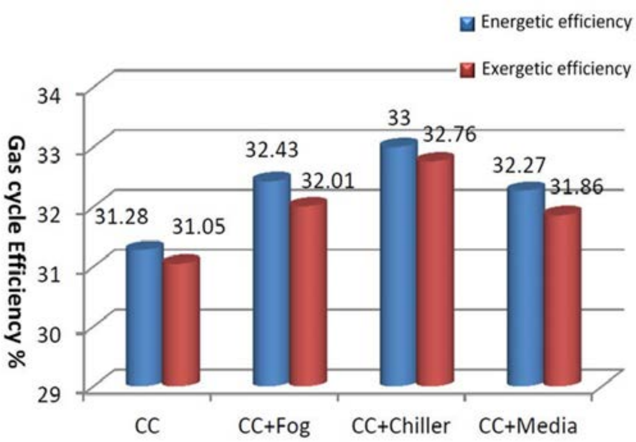


Fig. 1 comparison between energetic and exergetic efficiency in a gas cycle

5.2 Temperature of input and output gases of gas turbine

As shown in fig (6), by cooling of input air to the compressor, temperature of output gasses from gas turbine decreases, while the minimum temperature of output gas from gas turbine happens when absorption cooling system is used

Fig. 2 comparison between energetic and exergetic efficiency in power plant

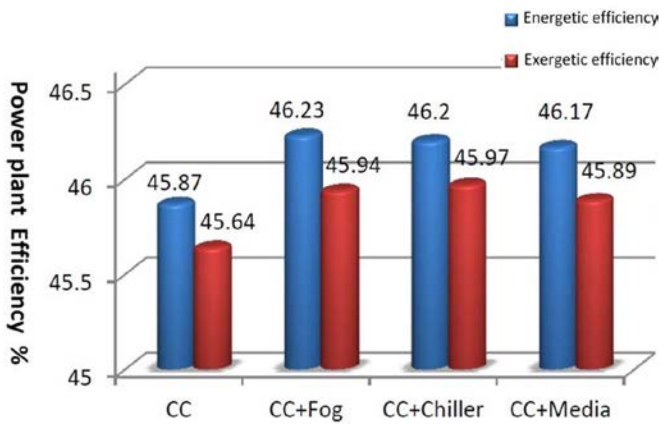
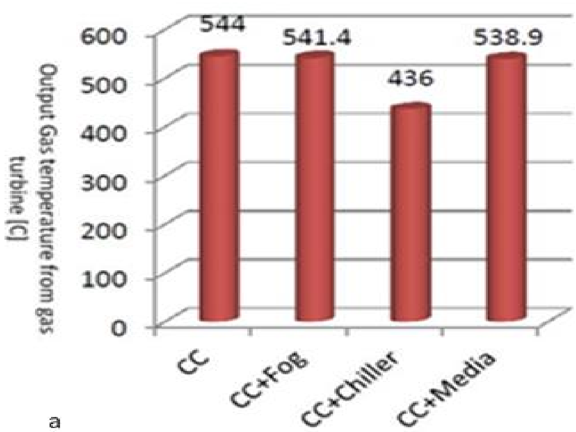


Table 3: heat rate of gas cycle and power plant in different combined cycles

	Gas cycle heat rate		**Power plant heat rate**	
	Amount kJ/kWh	Decreasing percent %	Amount kJ/kWh	Decreasing percent %
Without cooling	11593	-	7888	-
With absorption chiller cooling	10909	6.29%	7804	1.04%
With fog cooling	11121	4.25%	7787.59	1.11%
With media cooling	11182	3.68%	7797.24	0.95%

6. Selection of fog cooling system for cooling of air intake to the compressor

In this part on the basis of previous parts data and by use of criterions for prioritization of plans, which presented in this section, fog cooling system has been chosen as the most appropriate method of cooling of air intake of compressor for Qom gas cycle. Table (6) shows the comparison of effect of three cooling system (Fog cooling system, absorption chiller and media cooling system) on the power plant performance and determine the best and worth case by ranking the cooling system .Table (5) determine valuation of three cooling system and criterions of this valuation listed with respect to the importance of each one (the most important criterion determined as the first one). In this analysis by defining A, B & C for ranking of each cooling system in the defined parameter the best approach has been determined. These parameters are the criterions that determine which system is the best one among other approaches [5].



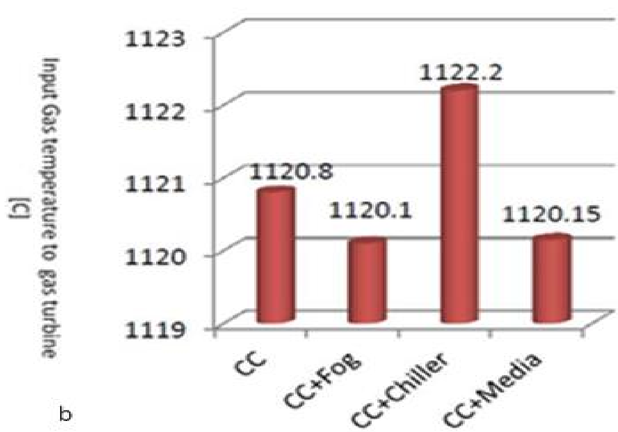


Fig. 3 a &b: comparison between temperature of input and output gas from Gas turbine in different cooling method

7-Conclusions

On the basis of the survey on the technical issues, energetic and exergetic efficiency increase rate, output net power from the gas cycle and the power plant, economical aspects, water consumption, extra power production, extra fuel consumption, annual maintenance costs, cost of extra power production and payback period of investment, different cooling system plans have been compared, the analysis showed that payback period of investment for fog cooling system would be 5.82 year which is appropriate for this power plant and as economical aspect it is totally valuable. On the other hand the fog system would be used for a period of 6 month of a year while during this time period it would be used 6 hour in a day, which cause annual maintenance cost as low as possible. Finally on the basis of analyzing all aspects of effect of cooling system together, fog cooling system has been selected for cooling of air intake to the compressor of Qom power plant.

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First Author Mahmood HaghaniKhah born in 1985.He received his Bachelor’s degree in mechanical engineering in 2010 from Mohajer University, Isfahan, Iran. He received his master of mechanical engineering in the field of heat exchange in 2015 from Azad university of Khomeinishahr, Isfahan, Iran.

Second Author. Saeid RasouliJazi received his Master of Science degree in biomechanical

engineering from Sharif University of Technology in 1992, he also received his Ph.D. degree from Ollom-Tahghighat branch of Azad university in 2006. He is currently faculty of khomeineiShahr Azad university and his research interests includes: heat transfer in FGMs, analysis of heat exchange systems and fluid bed engineering.