Assessment of the effect of humidity of air-cooled in the absorption refrigeration machine on the operation of an energy gas turbine

D I Mendeleev¹, ²*, G E Marin¹, ², Yu Ya Galitskii³ and M V Savina¹

¹Kazan State Power Engineering University, 420034, Krasnoselskaya St., 51, Kazan, Russian Federation;
²JSC «Tatenergo» branch «Kazan CHP-2», 420036, Tatsevskaya St., 11, Kazan, Russian Federation;
³OJSC «Network Company», 420094, Bondarenko st., 3, Kazan, Russian Federation

*dylankn@ya.ru

Abstract. Due to the fact that the construction of combined cycle plants has become the main trend in the development of the world heat power industry in the last two decades studies of the operating modes and operation of such equipment are very relevant at the moment. The aim of this work is to study the effect of chilled air in an absorption refrigeration machine on the operation of a stationary gas turbine installation. The operation of a gas turbine installation is affected by the temperature of the surrounding air due to changes in its density and humidity at different temperatures and because of the different useful work of the gas turbine. The standard adopted in the design of gas turbines is 15 °C. An increase in ambient temperature leads to a decrease in the generated power of the gas turbine. The influence of gas turbine power from ambient air can be reduced by means of cooling units for incoming air (absorption refrigeration machine (ARM)), or by modernizing the gas flow part of gas turbines and injecting water or carbon dioxide. This study is devoted to the influence of humidity of air entering the gas turbine compressor from the ARM, where it was previously cooled. It was noted that air humidity affects the efficiency of the ARM and therefore the useful power of gas turbines. The power of a gas turbine can be increased to 7-9 MW when using the ARM.

1. Introduction

At present, the main direction in the modernization of energy capacities is the application of gas turbine technologies. [1-4] Gas turbines are very sensitive to rising ambient temperatures. Summer technological restrictions on electricity generation negatively affect the economic performance of the heat station. This is due to a decrease in gas turbine power. Figure 1 shows the power variation of a GE 6FA gas turbine versus ambient temperature. At an air temperature of 30 °C, the decrease in power is about 7-8 MW (10%). Figure 2 shows the loss in electricity production in one day during a period of high ambient temperatures. [5-8]

Increasing the power of a gas turbine is a promising task. The solution to the problem of reducing the power of a gas turbine due to an increase in air density with increasing air temperature develops in several directions: [9-11]

1) Supply of additional working fluid to the flow part
2) Cascade air-cooling in the compressor
3) The use of refrigeration machines

The supply of additional working fluids and cascade cooling is technically very difficult to implement. In addition to preparing a gas turbine for modernization, constant monitoring of the equipment by personnel is required. Optimal is the use of refrigeration machines.

**Figure 1.** Relationship between the GTU's power and temperature at the compressor inlet.

**Figure 2.** Hourly power generation by the unit and the total deviation from the task for a certain day

(Green - the schedule is fulfilled, yellow - it is fulfilled with minor deviations, red – it was not fulfilled)
2. Materials and methods
Absorption refrigeration machine can be direct and indirect heating, single-stage, two-stage and three-stage. In direct heating machines, the heat source may be gas or other fuel burned directly in the installation. Indirect heating machines use steam or other coolant through which heat is transferred from the source. There are bromistolithium or ammonia ARM. Water is used as a refrigerant in lithium bromide ARM and lithium bromide LiBr is used as an absorbent. In ammonia ARM ammonia NH₃ is used as a refrigerant, and water as an absorbent. Currently, the most common are bromistolitievye ARM.

Without a doubt the three-stage ABXM has the highest refrigeration coefficient but this installation is still too expensive and has not yet been installed. The most optimal option according to our criteria is a two-stage absorption refrigeration machine with the highest refrigeration coefficient (relative to other types of ARM).

The energy company always has turbine selections and excess steam. Which can be used as a working fluid for ARM. Two-stage ARM’s on water vapor are one of the most effective refrigeration supply solutions in the industry.

In this paper we study the effect of chilled air on a gas turbine model GE 6FA (table 1). Research was carried out in a mathematical model - block diagram is shown in figure 3.

Table 1. Technical characteristics of a GTU (PG6111FA)

| No. | Characteristic                                           | Meas. unit | Value       |
|-----|---------------------------------------------------------|------------|-------------|
| 1   | Power at the generator terminals                        | kW         | 80000       |
| 2   | Atmospheric pressure                                    | kgf/cm²    | 1.013       |
| 3   | Compressor inlet temperature                            | °C         | 15          |
| 4   | Relative humidity at the compressor inlet               | %          | 60          |
| 5   | The pressure of the fuel before the gas module          | kgf/cm²    | 25.9 – 30.8 |
| 6   | The number of stages in the compressor                  | pcs        | 18          |
| 7   | The number of steps in the turbine                       | pcs        | 3           |
| 8   | Air flow                                                | m³/s       | 166         |
| 9   | Compression ratio                                       |            | 15.8        |
| 10  | Air temperature after the compressor                    | °C         | 385         |
| 11  | Flue gas temperature                                   | °C         | 603         |
| 12  | The temperature of the gases after the combustion chamber | °C     | 1325        |

Combined cycle power units can be located in various places (regions, countries) with different climatic conditions. In this regard, the effectiveness of their work will be different.

The thermal energy of the cold converted in the absorption refrigeration machine is used to gas turbine compressor inlet with the supplied air. [12], [13-14]
In the evaporator of the absorption refrigeration machine the coolant, circulating through the air filtering and conditioning system heat exchanger is cooled. During ARM operation, electric energy is consumed only for pump drives (circulating water pump, LiBr solution pump, ethylene glycol pump) and steam serves as the main energy resource for producing cold. In AFCS, air is prepared before it is fed to the gas turbine compressor in particular filtration and cooling. Moisture generated by condensation of water vapor contained in the cooled air is desalted water, which is a valuable resource at a power plant, and therefore must be collected and used for its own needs.

Figure 4 shows the connection diagram of the cooling unit to the gas turbine. The heating medium for the ARM can be used as steam from steam turbine selections (if there are steam turbines in the enterprise), steam from the auxiliary collector, steam from a gas turbine recovery boiler or another method suitable according to the ARM parameters to produce the required amount of cold for cooling the volume of air required for the operation of a gas turbine.

It is important to consider the parameters of the cooling circuit ARM. An approximate calculation of the cost of installation and operation is considered in the article.
3. Results and Discussion
Humidity is lower for cooled air and this is achieved by a large amount of gas turbine power.

When working without ARM it happens the other way around - if it rains outside - the load increases, because the air temperature and pressure are the same. [15-18]

When a gas turbine is operating as part of a combined cycle gas turbine unit an increase in power occurs not only in the gas turbine but also in the steam turbine. This occurs due to an increase in the temperature of the exhaust gases and increased vaporization in the recovery boiler. The air cooled and then supplied to the compressor inlet may have different humidity (figure 5).

![Figure 5. The dependence of the power of gas turbines on the ambient air temperature without an absorption refrigeration machine and with it at various values of humidity.](image)

Unlike aerodynamic drag, which affects the power and efficiency of a gas turbine atmospheric pressure and relative air humidity mainly affect the developed electric power of a gas turbine. A change in relative humidity in the temperature range up to 35 °C affects the change in the efficiency of a gas turbine unit very slightly not exceeding 0.05% (rel.) which can be ignored in practical calculations. However, air humidity will affect the efficiency of its cooling - the lower the humidity the more you can lower its temperature under the same conditions of airflow and power ARM (as shown in figure 5).

The second important factor for gas turbines is the quality of the incoming atmospheric air (the absence of aerosol particles, drip moisture, ice, snow and other mechanical impurities). For these purposes, an integrated air purification device is used (air filtering and conditioning system (AFCS)).

Atmospheric air enters the AFCS on the one hand passes through a snow-shelter canopy with a protective net below the intake gate and the AFCS heat exchanger. Further, the air passes through a coalescing filter in which large drops of water are removed from the intake air to reduce its degree of humidity the protective mesh is sent to a two-stage air filter (coarse and fine filter) to purify the air from coarse and fine dust and then it is sent through a muffler into the compressor intake chamber. Between the coalescing filter and the protective grid located in front of the coarse filters there is an air heating collector from the gas turbine selection. In the inlet filter compartment behind the coarse and fine filters there are three balanced emergency air intake flaps designed to protect the air intake from excessive pressure reduction due to a malfunction or clogging of the filters, which can lead to a “collapse”. Balanced safety dampers open automatically if the total pressure drop across the AFCS reaches a threshold value.

The lower the humidity the greater the efficiency of filtering the air and removing impurities from it. This will be especially noticeable in dusty areas. Therefore, in the work, the input guide vane (IGV) is clogged which also leads to a decrease in power. It is necessary to wash periodically the IGV (usually...
the washing takes place during scheduled maintenance). After washing the capacity rises by about 1.5-2%. [19-20]

It can be concluded that despite the insignificant direct influence of the humidity parameter for the operation of the gas turbine the indirect effect is much more important. [20] And the use of dehumidifiers and ARM during the operation of gas turbines it is possible to further increase its efficiency to 2-3% (Figure 6)

![Figure 6. The increase in efficiency of gas turbines when using ARM depending on the ambient temperature](image)

4. Conclusion
In this work, we studied the effect of humidity of air-cooled in the absorption refrigeration machine on the operation of an energy gas turbine:

1. Created a mathematical model of a gas turbine with connected ARM.
2. The use of ARM is an energy-efficient solution that allows you to increase the available capacity of gas turbines.
3. The efficiency of the ABXM depends on several factors, but humidity is lower for cooled air and this is achieved by a large amount of gas turbine power.
4. Using ABCHM and an ambient temperature of +30 °C it is possible to increase the power of a gas turbine by about 9 MW.
5. Operation at nominal equipment parameters extends the service life of not only a gas turbine, but also auxiliary equipment.
6. The longer the warm period the greater the useful use of the ARM and hence the benefit from the use of the installation which allows regions with summer power limitations to more efficiently operate gas and combined cycle power units.

References
[1] Ministry of Energy of the Russian Federation 2009 Energy Strategy of Russia for the Period up to 2030
[2] Ivanova P, Grebesh E and Linkevics O 2018 Optimisation of Combined Cycle Gas Turbine Power Plant in Intraday Market: Riga CHP-2 Example Latv. J. Phys. Tech. Sci. 55 15–21
[3] IEA 2016 Re-powering Markets: Market Design and Regulation during the transition to lowcarbon power systems Int. Energy Agency Electr. Mark. Ser.
[4] Benato A, Stoppato A and Bracco S 2014 Combined cycle power plants: A comparison between two different dynamic models to evaluate transient behaviour and residual life Energy Convers. Manag. 87 1269-1280.
[5] Mendeleev D I, Maryin G E and Akhmetshin A R 2019 Improving the efficiency of combined-cycle plant by cooling incoming air using absorption refrigerating machine *IOP Conference Series: Materials Science and Engineering* **643**, 012099

[6] Mendeleev D I, Galitskii Y Y, Marin G E and Akhmetshin A R 2019 Study of the work and efficiency improvement of combined-cycle gas turbine plants *E3S Web Conf.* **124**

[7] Mohamed O, Wang J, Khalil A and Limhabrash M 2016 Predictive control strategy of a gas turbine for improvement of combined cycle power plant dynamic performance and efficiency *Springerplus* **5** 20

[8] Bahrami S, Ghaffari A, Genrup M and Thern M 2015 Performance comparison between steam injected gas turbine and combined cycle during frequency drops *Energies* **8** 7582-7592

[9] Hou G, Gong L, Dai X, Wang M and Huang C 2018 A Novel Fuzzy Model Predictive Control of a Gas Turbine in the Combined Cycle Unit *Complexity*

[10] Yu F W, Chan K T, Yang J and Sit R K Y 2018 Cooling effectiveness of mist precooler for improving energy performance of air-cooled chiller *Therm. Sci.*

[11] Taufan A, Djubaedah E, Manga A and Nasruddin 2018 Experimental performance of adsorption chiller with fin and tube heat exchanger *AIP Conference Proceedings*

[12] Xue X, Sun T, Shi W and Li X 2017 A Novel Method of Minimizing Power Consumption for Existing Chiller Plant *Procedia Engineering*

[13] Gracheva E and Alimova A 2019 Calculation methods and comparative analysis of losses of active and electric energy in low voltage devices *Proceedings - 2019 International Ural Conference on Electrical Power Engineering, UralCon 2019*

[14] Gracheva E and Alimova A 2019 Calculating Probability of Faultless work of Shop Nets with the Help of Coefficients of Ratio *Proceedings - 2019 International Russian Automation Conference, RusAutoCon 2019*

[15] Herold K E, Radermacher R and Klein S A 2016 *Absorption Chillers and Heat Pumps*

[16] González-Díaz A, Alcaráz-Calderón A M, González-Díaz M O, Méndez-Aranda Á, Lucquiaud M and González-Santaló J M 2017 Effect of the ambient conditions on gas turbine combined cycle power plants with post-combustion CO₂ capture *Energy*

[17] Taufan A, Djubaedah E, Manga A and Nasruddin 2018 Experimental performance of adsorption chiller with fin and tube heat exchanger *AIP Conference Proceedings*

[18] Cozzolino R 2018 Thermodynamic performance assessment of a novel micro-CCHP system based on a low temperature PEMFC power unit and a half-effect Li/Br absorption chiller *Energies* **11**(2) 21

[19] Razak A M Y 2007 Industrial gas turbines: Performance and operability

[20] Alajmi A E S E T, Adam N M, Hairuddin A A and Abdullah L C 2019 Fuel atomization in gas turbines: A review of novel technology *Int. J. Energy Res.* **43**(8) 3166-3181

[21] Benräjesh P and John Rajan A 2017 Design and Analysis of a Two-Stage Adsorption Air Chiller *IOP Conference Series: Materials Science and Engineering*