Analysis of Increasing Efficiency of Gas Turbines by Using Absorption Refrigerator (AR)

Nassipkul Dyussembekova[1], Andrey Kibarin[2], Dias Umyshev[1] and Saulesh Minazhova[1]
[1]*Department of Power Engineering, Satbayev University, Satbayev Str. 22a, Almaty, Kazakhstan*
[2]*Department of Thermal Power Installations, Almaty University of Power Engineering and Telecommunications, Baitursynov Str. 126/1, Almaty, Kazakhstan*
nassipkuldyussembekova@gmail.com, umishev_d@mail.ru, s.minazhova@gmail.com

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Abstract: The paper presents an analysis of the gas turbine power plant's (GTPP) operation. It is shown that in summer the efficiency of GTPP is significantly reduced due to the high air temperature on the inlet of the compressor. In the summer, the efficiency and, accordingly, the production of electric energy is reduced due to high temperatures of the ambient air. This article presents an analysis of the possibility of increasing the efficiency of the gas turbine engine. The analysis shows that the use of absorption refrigerator (AR) in hot periods of the year, in which the outside air temperature exceeds 20 degrees is the optimal solution. The analysis showed that the use of AR allows to increase efficiency and specific heat consumption by 3 %, capacity by 14 % (5,5 % annually) MW and reduce fuel consumption by 2,5-3 %. The experience of modernization of gas turbine unit (GTU) is available, for the installation of AR it will be required about 2500 million tenge (6000 US dollars). Taking into account the economic effect of 740 million tenge, a simple payback period for the introduction of air cooling systems at GTPP will be about 4 years.

1 INTRODUCTION

The prospect of using gas turbines at an industrial facilities in Kazakhstan compared with other types of heat engines [1] is associated with their high energy intensity, autonomy, which does not require additional energy. The efficiency of the gas turbines depends on a large number of factors. One of the most important elements of the gas turbine is air compressor. In most cases, 50 % of the output of the turbine is consumed by a compressor connected by a single shaft in a gas turbine.

Under normal conditions, the air content of the gas-air mixture reaches 98 %. In the warm period of the year, the thermo physical properties of air changes. An increase in temperature and a reduction in air density lead to a decrease in the electric power of the gas turbine unit [2-18, 21] which increases in the specific fuel consumption.

Cooling of the inlet air can compensate these negative factors. The main methods of cooling are following: the use of evaporative coolers, fine dispersion of air behind the filter and the use of refrigeration machines - the latter allows you to obtain the maximum depth of cooling.

The authors [2] studied the influence of temperature decrease on the compressor suction to 12 °C. The results showed that the use of cooling increases the generation of electrical energy in the case of evaporative systems by 27,5 %, in the case of chillers by 32,11 %. The study [3] of reducing the temperature at the suction of GTU compressors used in the production of propane by 1 °C and increased the production of electrical energy by 0,53 %, and the thermal efficiency by 0,22 %. With a decrease in the air temperature at the inlet of compressor from 40 to 15 °C, propane production rises by 245 barrels per day or 40 m^3/day, which leads to savings of 18 thousand dollars a day. The payback period according to [3] is 8,5 months with 100 % use of these installations.

The results of studies [4] showed that at an ambient temperature of 37 °C, cooling by absorption coolers led to an increase in the production of electrical energy to 25,47 %, and a thermal efficiency of up to 33,66 %, which reduced the cost of electrical energy by 13 %. The use of evaporative coolers increased power by 5,56 % andefficiency by 1,55 %.

The authors of [5] showed that at a temperature before the turbine is equal to 1700 K, a compression ratio of 23 and an ambient temperature of 313 K with the use of vapor compression coolers, the generation of electrical energy increased by 18,4 %, and the efficiency increased by 4,18 %. However, it is noted that in geographic regions with low relative humidity and low temperatures, the preferred scheme is the use of vapor compression units

The authors [6] presented a new type of coolers, which is called indirect evaporative cooling system. This system is a humidifier and a vapor compression unit. At 45 °C the use of this cooler led to an increase in power by 15 % and efficiency by 9 %. The use of these chillers with mechanical chillers (dry cooling towers) resulted in a power increase of power by 7,81 % and an efficiency by 2,24 %. But the latter have a higher cost, which increases the payback period.

Articles [7-8] present the results of the study of evaporative coolers at the inlet to gas turbine plants with steam injection. The results showed that by using the evaporative coolers, the efficiency of the turbine increased by 6,91 %, and the electric power by 16,42 % for simple cycles, and for the combined-cycle plant, the power increased by 17,34 %.

In addition to these authors, there are many different ways to increase the efficiency of the turbine, by reducing the air temperature at the entrance to the gas turbine unit [9-15]. Especially interesting the use of ammonium-water absorption cooler in [13]. Energy and exergetic analyzes showed that the heat station produced an additional 9440 kW of energy, thereby increasing the thermal efficiency by 1,193 % and the exergy efficiency by 1,133 %. In winter time, the increase in power does not exceed 400 kW.

The article analyzes the operation of the GTPP at an industrial facility. All data are taken from the equipment passports and the results of the energy analysis.

2 ANALYSIS OF POWER GENERATION

The main purpose of GTPP is the supply of electric energy, the excess amount of electric energy is intended for export. According to 2017, electricity for production needs is 75 %, and electricity exports are 25 %.

There is no system for utilizing the heat of exhaust gases after GTU. In the design documentation of the power plant, it is stipulated that in the future the system of using the heat of exhaust gases after turbines should be introduced.

3 ANALYZED AIR COOLING SYSTEM

Cooling with a secondary coolant (cold water). This cooling is combined with energy conservation systems or with cooling heat exchangers, the refrigerant into which is supplied directly from the chiller. Unlike direct refrigerant cooling, these systems consume the energy of the pumps. Due to the fact that the piping of the direct cooling systems is low (due to the standard chiller size), and the cold water circulates in the channels under low pressure more freely in comparison with the primary refrigerant, the system is practically protected from leaks. In addition, it is easy to install, maintain and operate. Such systems are most preferably used in GTUs operating in the base mode for a long period of time.

As the source of heat, AR uses the heat of the exhaust gases GTU, steam or hot water. The AR scheme is shown in Figure 1.

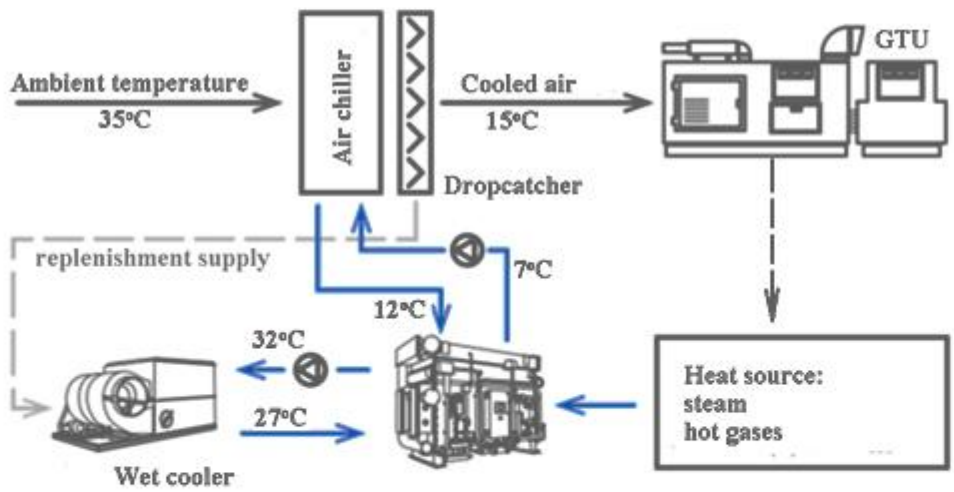

Figure 1: Structural scheme of AR.

4 MATHEMATICAL MODELING

A gas turbine is a heat engine that converts chemical energy of the fuel into potential energy and after that potential energy into a mechanical energy. Depending on what is installed on the turbine shaft, this can be electrical energy or mechanical compression energy of the compressor. The gas turbine consists of three main elements: an air compressor, a combustion chamber and a gas turbine itself. The principle of the gas turbine operation is as follows: from the atmosphere, the air is taken up by the compressor, after which it is supplied to the combustion chamber at elevated pressure, where liquid or gaseous fuel is simultaneously supplied from the gas compressor. In the combustion chamber the air is divided into two streams: one stream in the amount necessary for combustion enters the fire tube, the second flows around the flame tube from the outside and is mixed with the combustion products to decrease from the temperature. The combustion process in the chamber occurs at an almost constant pressure.

The gas, obtained after mixing and combustion, enters the gas turbine, expanding, completing the work, then discharging into the atmosphere (Fig. 2).

Unlike the steam-turbine unit, the GTU's useful power is 30-50 % of the turbine's power. The useful power fraction can be increased by increasing the gas temperature in front of the turbine or by lowering the temperature of the air sucked in by the compressor. In the second case, the work required to compress the air in the compressor is reduced.

In mathematical modeling, Water Steam Pro program [22] was used, which allows to calculate the parameters of gases, in particular air and combustion products. Before the analysis, the results obtained by the program were compared with the passport data of gas turbine units. The results are shown in Figure 3. The error in the data does not exceed 4%, which indicates a sufficiently reliability.

The calculation of gas turbine units main parameters, such as efficiency, power were calculated according to [4, 22-27].

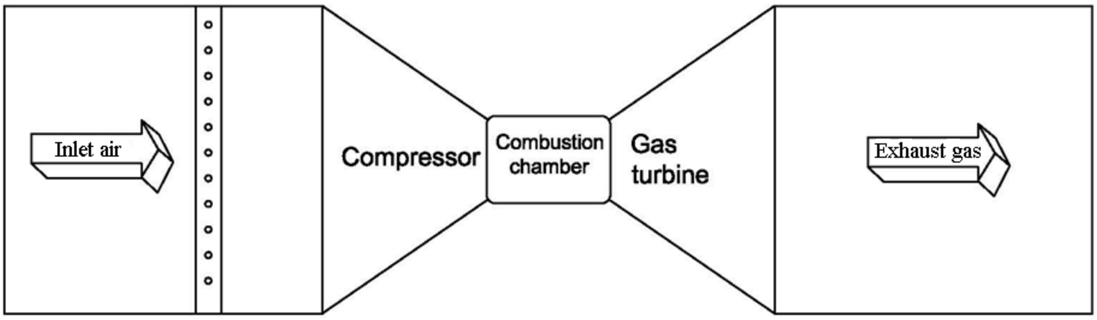

Figure 2: Schematic diagram the gas turbine.

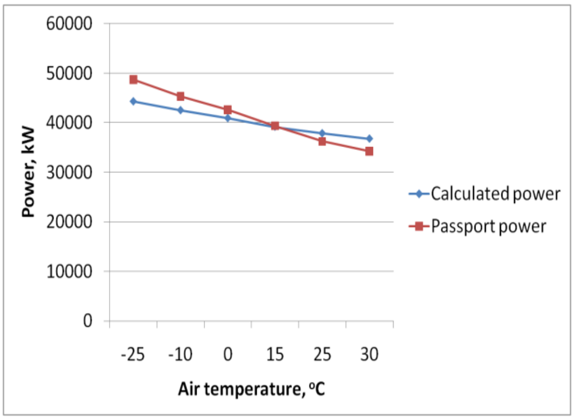

Figure 3: Approbation of the program for calculations.

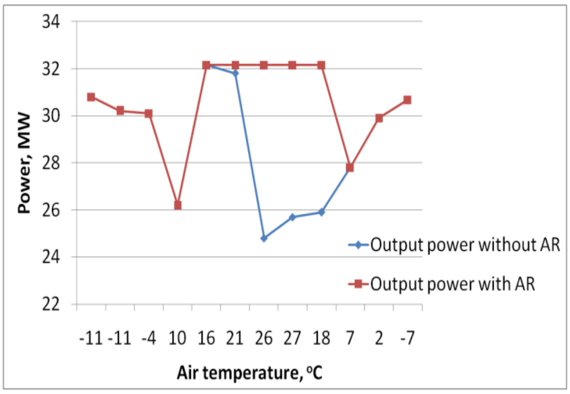

Figure 4: Power depending on air temperature.

5 RESULTS

Figure 4 presents an analysis of the power calculation for various real statistics on the outdoor air temperature in Western Kazakhstan, where gas turbine plants are operated. It can be seen from the graphs that when the temperature rises above 21 degrees there is a significant drop in power up to 7 MW. This is due to the increase in air temperature, which leads to an increase in the specific operation of the compressor.

Figure 4 shows that when AR is used, it is possible to reduce the temperature at the compressor inlet to an optimum of 15 °C. This allows to significantly increase turbine power. Taking into account the fact that AR does not need high power, this circumstance indicates a great potential for implementation. In the hottest period, the power difference is 7 MW, which is a significant indicator.The average increase in power in hot period is 14 %, the average annual increase in power is equal to 5,5 %.

Figure 5 shows the dependence of the efficiency of GTU on the outside air temperature. As can be seen from the figure, in the hot months, there is a significant reduction in efficiency up to 3 %. This is particularly noticeable in the range 21-18 ° C. The use of AR allows a significant increase in efficiency in a hot period of time. In the rest of the time, it is assumed that AR will be shut off or else cold will be used elsewhere.

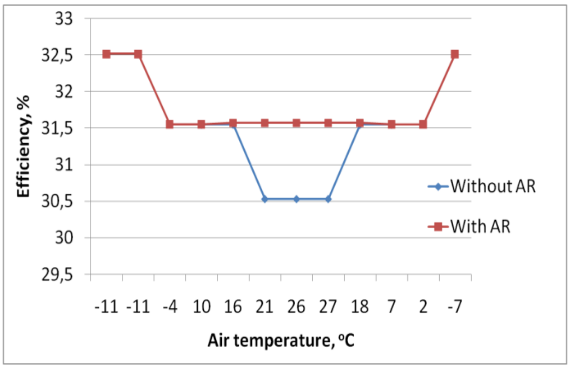

Figure 5: Dependence of efficiency from ambient air temperature.

Figure 6 shows the dependence of the specific heat consumption on energy production. As can be seen from the graphs, the presence of AR allows a significant reduction in the specific heat consumption. In the hot period between 16 and 18 degrees, the average heat consumption is reduced by 3 %.

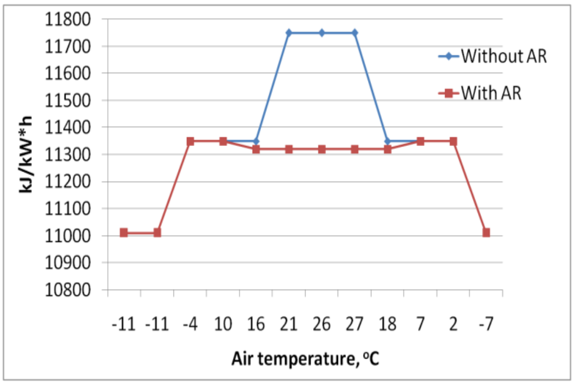

Figure 6: Specific heat consumption.

Reducing the specific heat consumption leads to a significant reduction in fuel consumption (Fig. 7). In hot months, the difference is 2,5-3 %. Considering the number of hours that fall for a hot period of 2160 hours, the annual fuel economy is 14,2 thousand m^3.

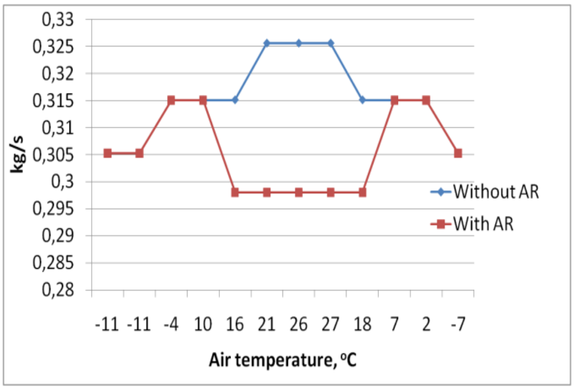

Figure 7: Fuel consumption per second.

6 ANALYSIS OF THE POSSIBILITY OF INCREASING THE EFFICIENCY OF GTTP

As the temperature increases, the specific heat consumption increases, which in turn leads to a decrease in the efficiency by 4 %. This negative factor can be eliminated by cooling the air supplied to the gas turbine.

For climatic conditions of the Republic of Kazakhstan, the period of demanded air cooling at the entrance to the turbine will be the end of April - September, that is, about 150 days. If we assume an average power increase of 14 %, then the additional power will be:

$$\Delta P = P_{guar}*0,14*150*24 = 504\ P_{guar}MWh$$

Let, for example, the guaranteed capacity of four operating turbines P_{guar} = 147 MW, then an additional GTPP will be produced in a year:

$$\Delta P_{annual} = 147*0,14*150*24 = 74088\ MWh$$

Taking the cost of electricity at the level of 10 tenge (3 US cents) per kWh, we will get an economic effect at the level of:

$$E_{annual} = 74088*10 = 740880 \text{ thousand tenge (1949684 US dollars)}$$

At the same time, for the life cycle of the air cooling system (about 30 years), the GTPP will additionally generate about 1270,000 MWh of electric energy.

7 CONCLUSION

The analysis shows that the use of AR in hot periods of the year, in which the outside air temperature exceeds 20 degrees is the optimal solution. The analysis showed that the use of AR allows to increase efficiency and specific heat consumption by 3%, capacity by 14 % (5,5 % annually) MW and reduce fuel consumption by 2,5-3 %. The experience of modernization of GTU is available, for the installation of AR it will be required about 2500 million tenge (6000 US dollars). Taking into account the economic effect of 740 million tenge, a simple payback period for the introduction of air cooling systems at GTPP will be about 4 years.

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