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Improving the Efficiency of Power Equipment When Burning Hydrogen Fuel

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ABSTRACT
Hydrogen energy is a promising direction. Hydrogen energy equipment is more environmentally friendly and economical. But there are problems with the introduction of hydrogen into the energy sector: production, storage, combustion, operational safety. Hydrogen production depends on technologies, production raw materials. Despite the fact that when hydrogen is burned in the combustion chamber of a gas turbine, NOx and COx emissions are minimal, but they depend on the hydrogen production technology (the largest emissions from steam reforming of methane, the smallest during electrolysis) turbine. The scheme of combustion of pure hydrogen is considered GE 6FA was selected as the turbine under study. As a result of calculations, the main energy characteristics of a gas turbine were obtained at a constant temperature of the exhaust gases (operation as part of a combined cycle power unit). The scheme of a power gas turbine and a waste-heat boiler is also considered, the main characteristics are obtained when the temperature at the turbine exhaust changes. The mathematical model of the turbine was built in the automated complex “AS GRET”.

Keywords: *Gas turbine, Hydrogen, Fuel gases, Operating modes, Thermal station, Efficiency, Power.*

1. INTRODUCTION

The concept of hydrogen energy was born in the 60s and 70s as a reaction to the possible limited world reserves of hydrocarbon fuels. In the 1970s, the main problem was a sharp decline in the world's energy reserves, but at the moment the problem of environmental safety is coming to the fore. In this regard, the use of hydrogen fuel is considered as the main direction for reducing emissions from power equipment [1–3].

Particular interest in research in the field of hydrogen energy in Russia appeared in the period 2020–2021 after the adoption of the hydrogen program “Development of hydrogen energy in the Russian Federation until 2024”. Its goal is to organize priority work on the formation of a high-performance export-oriented hydrogen energy industry in the country, developing on the basis of modern technologies and provided with highly qualified personnel. Also, in many countries of the world, hydrogen development programs have been adopted (Germany, Japan, USA, Australia, etc.). The main directions of development are the development of hydrogen technology, hydrogen energy systems, hydrogen gas turbines [4–6].

The main consumers of hydrogen at the moment are chemical industries. At the moment, the main production technology is steam reforming of methane [7, 8]. This technology is expensive, in order to separate hydrogen from the hydrocarbon feed gas, a large amount of steam is needed and the temperature of the medium is about 85 °C for the endothermic process of methane conversion. In addition to high energy costs, additional environmental pollution occurs. A promising direction is the production of hydrogen by electrolysis, pyrolysis [9–14].

One of the problems of using hydrogen is its transportation to the place of consumption and combustion at the place of consumption [15, 16].

2. SUPPLY OF FUEL GAS MIXED WITH HYDROGEN TO THE COMBUSTION CHAMBER OF A GAS TURBINE

In this study, 3 schemes of hydrogen supply to the combustion chamber of a gas turbine unit are considered (Figures 1–3).

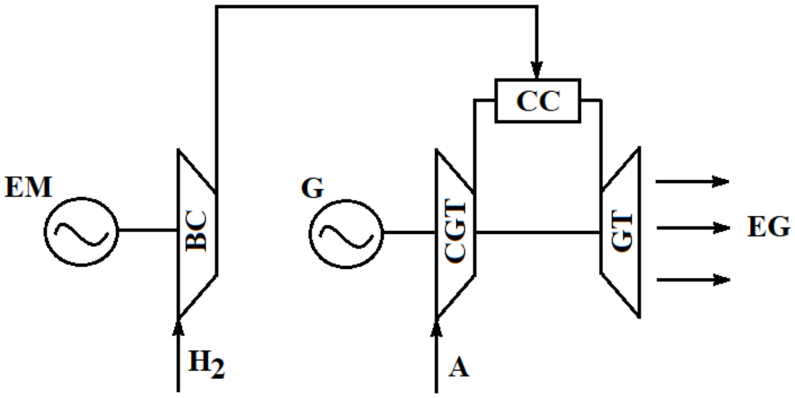


Figure 1 The scheme of combustion of pure hydrogen fuel without admixture of hydrocarbon fuel is presented.

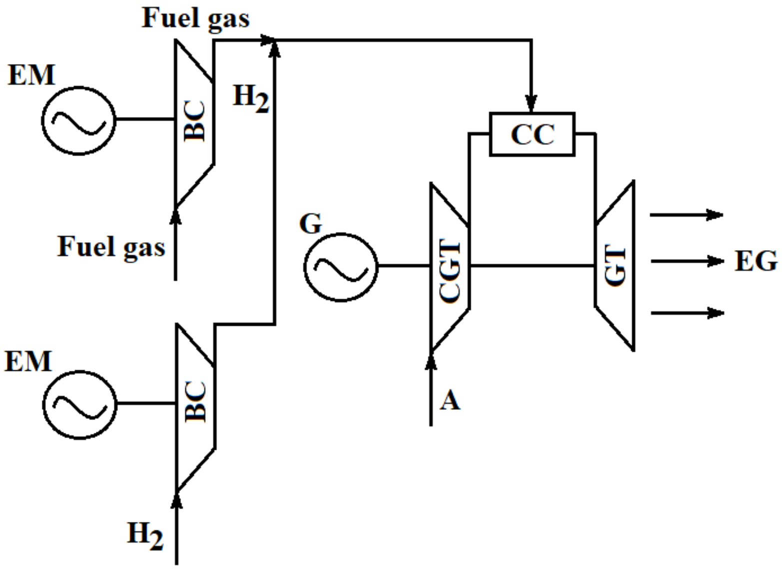


Figure 2 The scheme of combustion of hydrogen fuel mixed with the initial fuel gas (natural gas, liquefied natural gas, biogas, synthesis gas) is presented.

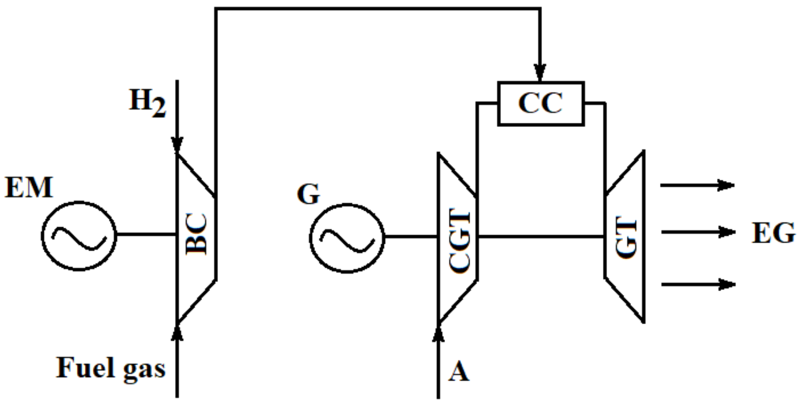


Figure 3 The scheme of displacement of hydrogen fuel and fuel gas is considered.

In Figures 1–3, the following designations are adopted: EM is the electric motor; G is the generator; CC is the combustion chamber; CGT is the compressor; A is the air; EG is the exhaust gases; GT is the gas turbine.

In Figure 1 the scheme of combustion of pure hydrogen fuel (H_2) without admixture of hydrocarbon fuel is presented. The hydrogen fuel is compressed in a booster compressor and then sent to the combustion chamber, where combustion takes place.

In Figure 2 the scheme of combustion of hydrogen fuel mixed with the initial fuel gas (natural gas, liquefied natural gas, biogas, synthesis gas) is presented [17–19]. The considered scheme includes 2 booster compressors. One compressor compresses hydrogen at a low flow rate of 200–600 g/s, the second booster compressor compresses fuel gas at a rate of 5–6 kg/s. In case of dips in the generated turbine load or the need to boost the mode, the second booster compressor is switched on and hydrogen is supplied to the combustion chamber of the gas turbine.

In Figure 3 the scheme of displacement of hydrogen fuel and fuel gas is considered. The fuels are displaced before the booster compressor, then the fuel mixture is sent to the combustion chamber.

In this paper, the first scheme of combustion of hydrogen fuel is considered. A GE 6FA gas turbine was selected for research. The functional diagram is shown in the Figure 4.

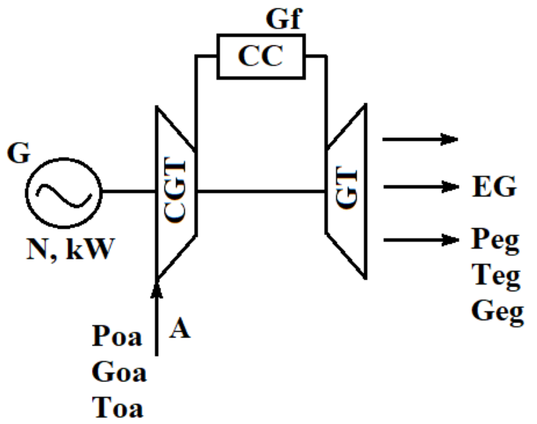


Figure 4 Functional diagram of a GE 6FA gas turbine.

In Figure 4, the following designations are adopted: N is the power, kW; Poa is the ambient air pressure, kPa; Toa is the ambient temperature, ºC; Goa is the ambient air consumption, kg/s; Gf is the fuel gas consumption, kg/s; Peg is the exhaust gas pressure, kPa; Teg is the temperature of the exhaust gases, ºC; Geg is the consumption of exhaust gases, kg/s; EG is the gas turbine exhaust gases.

A mathematical model of the turbine at the "AS GRET" has been created. An approximation of the thermodynamic parameters of a gas turbine has been carried out the error of the obtained values is less than 1 % [20].

The operation of the turbine is carried out within the framework of the operation on the wholesale electricity market [21, 22]. The work shows the minimum load of the gas turbine operation [23].

For the considered turbine, Figure 5 shows the change in power when the ambient temperature changes.

The main problem of reducing the generated power of a gas turbine is associated with an increase in the work of compressing air in the compressor.

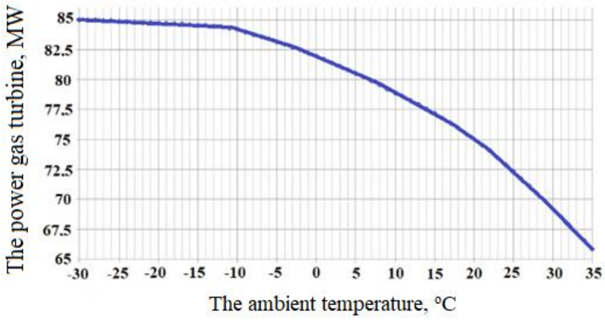


Figure 5 Dependence of the power of the PG6111FA gas turbine on the ambient temperature.

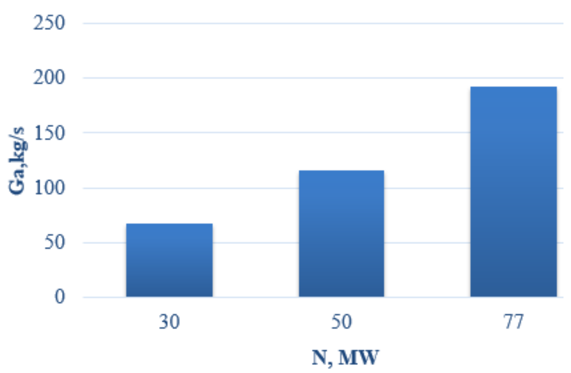
3. VARIABLE OPERATING MODES OF A GAS TURBINE WHEN OPERATING AS PART OF A COMBINED CYCLE POWER UNIT

For research, 3 modes of operation of a gas turbine are considered when operating as part of a combined cycle power unit. Variable modes:

1. N = 30 MW;
2. N = 50 MW;
3. N = 77 MW.

Ambient temperature 15 ºC, pressure 101.3 kPa, humidity 60 %.

Figure 6 the main energy characteristics of the turbine are obtained. (Ga (Figure 6,a), Gf (Figure 6,b), Efficiency (Figure 6,c), NO (Figure 6,d), NOx (Figure 6,f), CO_2 (Figure 6,g), O_2 (Figure 6,h)) depending on power.



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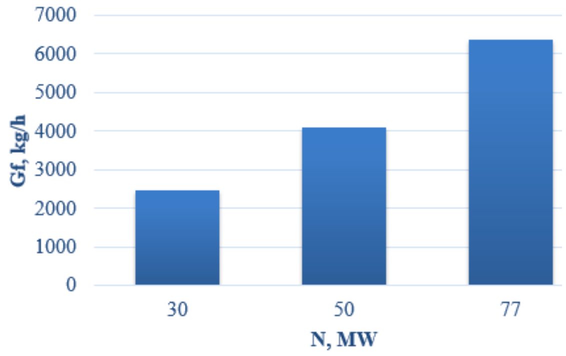

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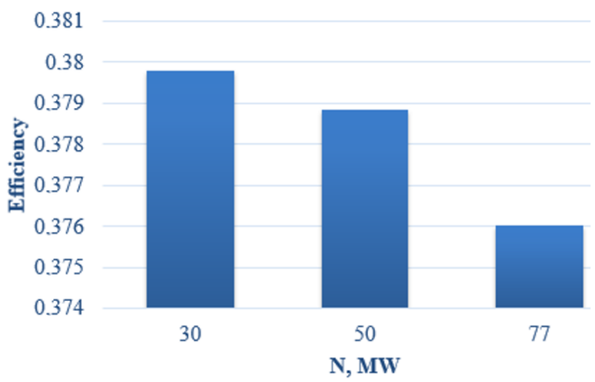

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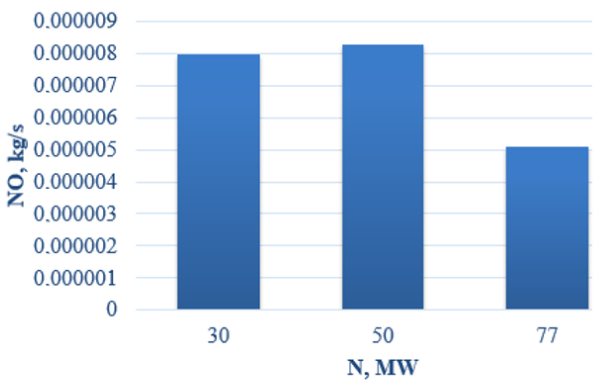

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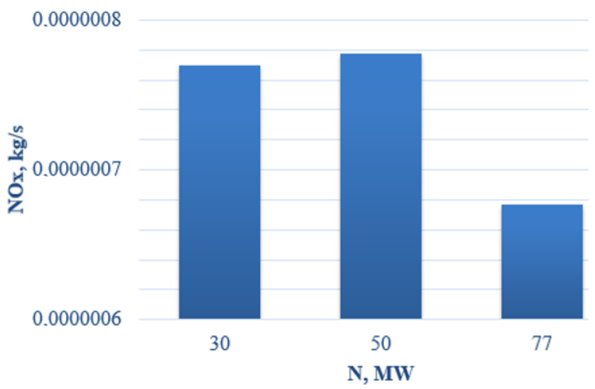

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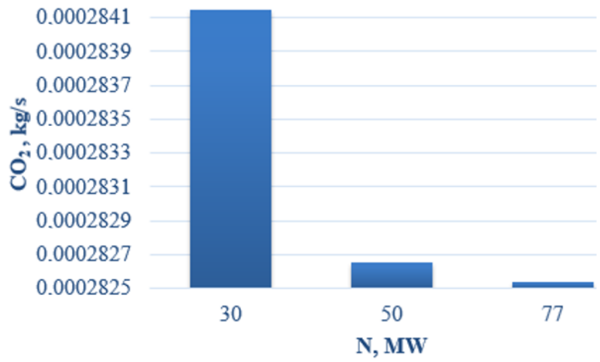

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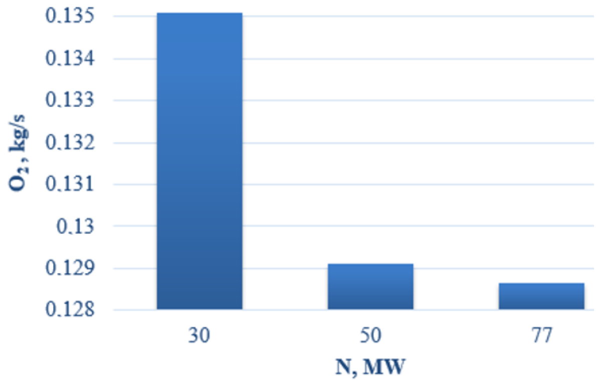


h

Figure 6 The main energy characteristics of the gas turbine.

As a result of the research, a change in the air flow rate at the compressor inlet was obtained, the maximum value of 192.103 kg/s was obtained at a power of 77 MW, Figure 6,a.

The maximum value of the fuel gas consumption was reached at a power of 77 MW and is equal to 6359 kg/h, Figure 6,b.

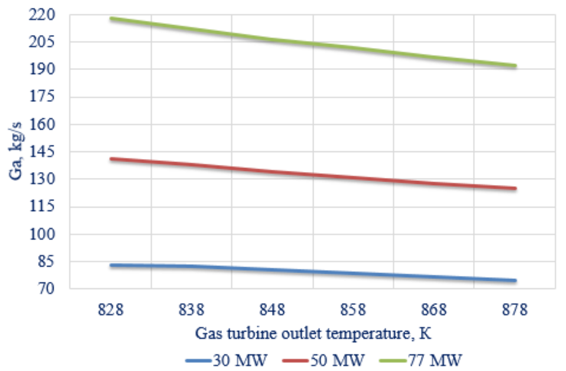
With an increase in the power of the gas turbine, the effective efficiency decreases by 1% to 37.60 %, this is due to the fact that the gas turbine operates according to the law of quantitative and qualitative control, Figure 6,c.

With an increase in power, harmful emissions such as NOx decrease, this is due to the optimal combustion mode in the combustion chamber. Stable operation at rated load reduces gas turbine emissions, Figure 6,f.

With an increase in gas turbine power, CO_2 emissions decrease, this is due to the fact that combustion occurs with an optimal stoichiometric ratio of fuel and air, Figure 6,g.

Determining the amount of O_2 in the turbine exhaust gas is very important, since the exhaust gases can be re-burned. A small amount of O_2 will not allow the flame to be maintained over the entire load range, Figure 6,h.

When the turbine operates as a part of one gas turbine and one waste heat boiler, there is no strict limitation on the temperature of the exhaust gases [24]. The temperature range at the gas turbine outlet from 828K to 878K is considered. The main results are shown in Figure 7 (Ga (Figure 7,a), Gf (Figure 7,b), Efficiency (Figure 7,c)) depending on power).



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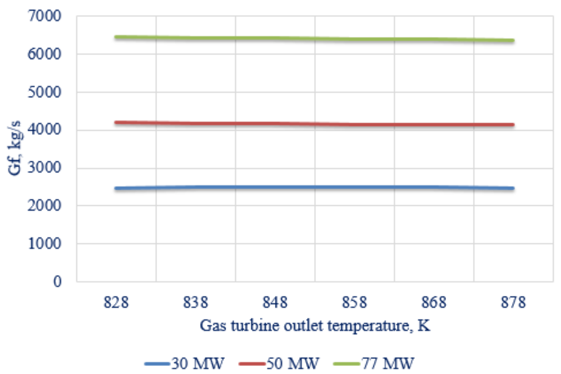

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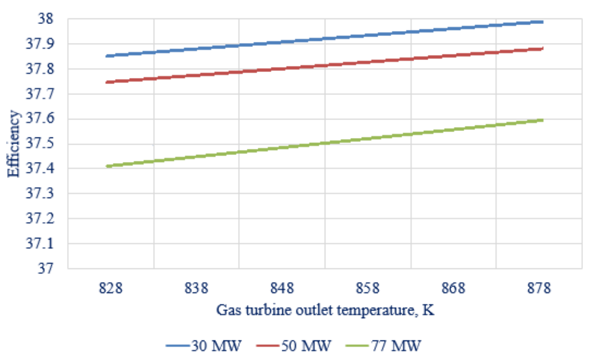

c

Figure 7 Parameters (Ga, Gf, Efficiency) depending on the temperature range (828K to 878K) at the outlet of the gas turbine.

Lowering the temperature downstream of the turbine to 828K is not an effective solution, since at this temperature the amount of air supplied to the gas turbine compressor increases, and this is additional work for compression. In this regard, one can see a decrease in the effective efficiency at a power of 77 MW to 37.4 %, while the air flow is 219.496 kg/s. Fuel consumption also increases by 1.5 % with a decrease in temperature from 878K to 828K to a value of 6456.74 kg/h.

4. CONCLUSION

The article discusses the schemes for supplying hydrogen fuel to a gas turbine. A mathematical model of a gas turbine installation has been created. The main energy and environmental characteristics of the turbine have been obtained both as part of a combined cycle power unit and one gas turbine unit. The obtained results of the study allow predicting changes in the main characteristics of the gas turbine plant in the entire range of loads. It is shown that operation in the nominal mode is the most efficient from the point of view of ecology, CO_2 and NOx emissions will be minimal. During the operation of the gas turbine, it is possible to change the temperature of the exhaust gases, the optimum temperature of 878K has been determined.

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