A study on the operation of a gas turbine unit using hydrogen as fuel

G E Marin\textsuperscript{1,2}, D I Mendelev\textsuperscript{1,2}, B M Osipov \textsuperscript{1}

\textsuperscript{1} Kazan State Power Engineering University, 420034, Krasnoselskaya St., 51, Kazan, Russian Federation;
\textsuperscript{2} JSC "Tatenergo" branch "Kazan CHP-2", 420036, Tatsevskaya St., 11, Kazan, Russian Federation
E-mail: dylankn@ya.ru

Abstract: The last decade has been driven by the impact of environmental challenges on the energy industry. Decarburization policy is the driver of the global energy transition. Hydrogen can be used as an alternative to natural gas, kerosene, and diesel fuel. A large-scale conversion of generating equipment to hydrogen fuel would significantly reduce carbon impact on the world because the product of hydrogen combustion is water. This paper focuses on the combustion of pure hydrogen in a GE 6FA power gas turbine. A mathematical model has been created in the AS GRET software package. During the simulation, the operation of a gas turbine unit in the load range from 40 to 77 MW was considered. As a result, the dependences of fuel consumption, enthalpy, and air consumption depending on the load were obtained. The value of the heat of the exhaust gases was also obtained.

1. Introduction
Hydrogen is a zero-emission energy source, and therefore is an alternative to fossil fuels. The scope of application of hydrogen is diverse - in particular, it is used as a fuel for internal combustion engines and in combustion chambers of power plants.

One of the important advantages of hydrogen energy is the variety of methods for producing hydrogen. There are several ways to generate hydrogen: [1-4]

1) Steam reforming of methane
2) Coal gasification
3) Water electrolysis
4) Pyrolysis
5) Partial oxidation
6) Biotechnology

Currently the following methods can be considered promising:

1. Coal gasification. This method of producing hydrogen is "gray" due to its significant carbon impact on the world. There are several ways to gasify coal. They differ in thermodynamic parameters, sizes, and principles of coal supply.

2. Water electrolysis. The water electrolysis technology is very attractive from an environmental point of view. It is possible to create installations with a wide range of performance. A positive side effect is oxygen production.

3. Steam conversion of methane. Methane is the main component of natural gas; its concentration reaches 98%. Obtaining hydrogen from methane is the most cost-effective option.
However, hydrogen is explosive when mixed with air. The main problem of using hydrogen is ensuring the safety of both operating equipment and service personnel. Hydrogen can be produced next to electricity-generating equipment, but it is worth noting that an existing gas transmission system can be used for transportation. According to PJSC «Gazprom», the «Nord Stream» gas pipeline can transport up to 70% of hydrogen in the fuel mixture.

2. Materials and methods
This article describes an example of a PG6111FA type gas-turbine unit (GTU) from “GE Energy” (the main characteristics of the gas turbine installation are presented in Table 1) with a rated power of 80 MW. [5]

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               | ºC         | 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       | ºC         | 385         |
| 11  | Flue gas temperature                       | ºC         | 603         |
| 12  | The temperature of the gases after the combustion chamber | ºC | 1325 |

For the study, a mathematical model of a gas turbine engine was created in the software package «Automated System of Gas-dynamic Research of Energy Turbomachines» (AS GRET). The functional diagram of the mathematical model is presented in figure 1; the selection window for elements for the design scheme is presented in figure 2.

Hydrogen with the conditional formula H99.21619 was taken as the fuel for the study. The following parameters were selected as initial data in the calculation:
- Air temperature $T = 288.15$ K (15 ºC);
- Air pressure $P = 101.3$ kPa (0.1013 MPa);
- Air humidity 60%.

The net calorific value of hydrogen is assumed to be $115200$ MJ/kg.

In the simulation, a constant temperature of gases at the outlet after the gas turbine was assumed since the turbine under consideration can operate as a part of a combined cycle power unit. Higher or lower temperatures at the outlet of the GTU can have a negative effect on the steam turbine. [6-12]
Figure 1. The functional diagram of the mathematical model.
AFVS – an air filtering and conditioning system; EG – an electric generator; TC-1- a transition channel between the AFVS and the compressor; C – a compressor; TC -2 – a transition channel between the compressor and the combustion chamber; CC – a combustion chamber; TC -3 - a transition channel between the combustion chamber and the turbine; T – a gas turbine; TC -4 –a transition channel between the turbine and the boiler utilizer; WHB – a waste heat recovery boiler; TC -5 - a transition channel between the waste heat recovery boiler and the chimney; CH – a chimney.

Figure 2. The selection window for elements for the design scheme

The schematic diagram of the investigated installation is shown in figure 3.
Figure 3. The schematic diagram of the investigated installation. 1 — a gas turbine generator; 2 — a multistage compressor; 3 — a combustion chamber; 4 — a gas turbine; $P_{air}$ — an air pressure at the inlet (kPa), $T_{air}$ — an air temperature at the inlet, ($^\circ$C), $G_{air}$ — a mass air flow at the inlet to the gas turbine, (kg/s), $G_{fuel}$ — a hourly fuel consumption, (kg/h), $G_{ex}$ — flue gas flow rate (kg/s), $T_{ex}$ — a flue gas temperature, ($^\circ$C)

3. Results and Discussion
Figures 4-7 show the obtained dependencies of the main energy characteristics of the gas turbine plant in various load ranges.

Figure 4. The dependence of the total inlet air flow rate and outlet gas flow rate on the gas turbine power
Figure 5. The dependence of the efficiency of the gas turbine from the gas turbine power

Figure 6. The dependence of the total hourly fuel consumption on the power of the gas turbine

Figure 7. The dependence of the heat supplied to the waste heat boiler on the power of the gas turbine
4. Conclusion studies

This paper examined the possibility of using hydrogen as a fuel for a gas turbine, looking at how the fuel consumption and energy parameters of the gas turbine plant change depending on the turbine load. [13-15]

The study demonstrated that:
1. A mathematical model of an operating gas turbine unit with a variable fuel type has been created.
2. When operating on hydrogen, the efficiency of a gas turbine practically does not change depending on the load.
3. To operate on pure hydrogen, it is necessary to adjust the automatic control system of the gas turbine
4. When operating on hydrogen, less fuel consumption is required, but this will lead to a serious modernization of the gas turbine fuel system.

References
[1] Marin G E, Mendeleev D I and Akhmetshin A R 2019 Analysis of Changes in the Thermophysical Parameters of the Gas Turbine Unit Working Fluid Depending on the Fuel Gas Composition 2019 International Multi-Conference on Industrial Engineering and Modern Technologies, FarEastCon 2019
[2] Esclapez L, Ma P C, Mayhew E, Xu R, Stouffer S, Lee T, Wang H and Ihme M 2017 Fuel effects on lean blow-out in a realistic gas turbine combustor Combust. Flame
[3] Chiesa P, Lozza G and Mazzocchi L 2005 Using hydrogen as gas turbine fuel J. Eng. Gas Turbines Power
[4] Basha M, Shaahid S M and Al-Hadhrami L 2012 Impact of fuels on performance and efficiency of gas turbine power plants Energy Procedia
[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] Bocci E, Sisinni M, Moneti M, Vecchione L, Di Carlo A and Villarini M 2014 State of art of small scale biomass gasification power systems: A review of the different typologies Energy Procedia
[7] Lee M C, Seo S Bin, Chung J H, Kim S M, Joo Y J and Ahn D H 2010 Gas turbine combustion performance test of hydrogen and carbon monoxide synthetic gas Fuel
[8] Kayfeci M, Keçebaş A and Bayat M 2019 Hydrogen production Solar Hydrogen Production: Processes, Systems and Technologies
[9] Dodds P E, Staffell I, Hawkes A D, Li F, Grünwald P, McDowall W and Ekins P 2015 Hydrogen and fuel cell technologies for heating: A review Int. J. Hydrogen Energy
[10] Blakey S, Rye L and Wilson C W 2011 Aviation gas turbine alternative fuels: A review Proc. Combust. Inst.
[11] Kiernan J G, Foster A D and Harden D T 1978 GAS TURBINE FUELS AND FUEL SYSTEMS, Power Eng. (Barrington, Illinois)
[12] Henke M, Kallo J, Friedrich K A and Bessler W G 2011 Influence of pressurisation on SOFC performance and durability: A theoretical study Fuel Cells
[13] Liu K, Sadasivuni S and Parsania N 2019 Industrial gas turbine engine response and combustion performance to fuel changeovers in compositions and heating values Fuel
[14] Zheng L, Cronly J, Ubogu E, Ahmed I, Zhang Y and Khandelwal B 2019 Experimental investigation on alternative fuel combustion performance using a gas turbine combustor Appl. Energy
[15] Mendeleev, D. I., Galitskii, Y. Y., Marin, G. E., & Akhmetshin, A. R. (2019). Study of the work and efficiency improvement of combined-cycle gas turbine plants. In E3S Web of Conferences (Vol. 124). EDP Sciences.