

Scientific analysis of the possibility of using hydrogen fuel in gas turbine power stations of Turkmenistan

Shanazar Allakulyyev^{1*}, *Azat Atamyradov*¹, *Atajan Hojalyyev*¹, *Baky Yemshikov*¹, and *Bazarsahet Altyyev*¹

¹State Energy Institute of Turkmenistan, 62, Bayramhan Street, Mary, 745400, Turkmenistan

Abstract. Today, global warming and the increasing demand of people for electricity and thermal energy remain in the focus of attention of international organizations and scientists. For this reason, the use of hydrogen gas, which has high thermal conductivity and is considered a clean energy source, remains relevant today. In this scientific article, it is proposed to use hydrogen together with natural gas in a gas-turbine power plant under the conditions of Turkmenistan, if the fuel consumption in normal condition is 7.7 kg/s, based on the scientific research, fuel consumption is 7.52 kg/s when natural gas and hydrogen are supplied in a ratio of 1%, the amount of natural gas saved was equal to 2.597%, when natural gas and hydrogen were given in a ratio of 10%, the fuel consumption was 6.219 kg/s, the amount of natural gas saved was equal to 19.233%, when natural gas and hydrogen were supplied in a ratio of 20%, the values were 5.216 kg/s and 32.259%, respectively. Also, as a result of the studied scientific sources, it was found that when natural gas and hydrogen are supplied in a ratio of up to 20%, it is not necessary to make any changes to the design of the turbine.

1 Introduction

The growing demand for electricity in Turkmenistan requires further strengthening of the infrastructure of this industry, the installation of large-capacity power stations equipped with several advanced technologies, and at the same time environmental protection remains an important issue.

In order to solve this important task, the Head of our country has adopted the Program on developing energy sector in Turkmenistan, as well as it is an important part of civil engineering in the thermal electric power plants [1].

According to [2], in 2015, the production of electric energy in Turkmenistan is expected to reach 27,010 million kWh, and the export of electric energy in the same year is expected to reach 3.6 billion kWh.

Literature review.

* Corresponding author: Shanazar2020@mail.ru

In this scientific article [3], it is considered possibilities of combined usage of hydrogen with gas, where it isn't required to convert the design of gas turbines, and in consequence of it, they used the mixture 5% of hydrogen and 95% of natural gas. For implementation the given task, they emulated mathematical sample, they considered the ecological problems for the value of main energy feature. Scientific research [4] considers a special interest from point of view technical and economical possibilities, as well as design of power plants with 100 kW power level with steam generating hydro-oxygen installation, in addition it gives an opportunity to choose effective ways of thermal projects of electric power plants in Project Management.

Authors [5] investigated an impact to ecological rate of gas-turbine installation in series GE6FA used as a fuel of various component structure. With the aim minimization of waste disposal and improving production of gas-turbine installation GE 6FA, it is considered the possibilities of usage of hydrogen as a major fuel, for implementation of the given task it is used program complex ASGCPT, as well as in this article it is considered perspective direction of utilization of CO₂ with the usage of high-qualified technology and its future utilization. Special peculiarities of research [6] that is focused on burning hydrogen in the gas-turbine GE 6 FA, for this reason authors used program complex ASGCPT, with the help of that mathematical sample was produced. Within it is considered power level GTU from 40 till 77 MW.

Also, work and scientific research on the production, storage and distribution of hydrogen are conducted around the world, also, quite a lot of work is conducted in the field of energy, where hydrogen is used as a fuel in gas turbine installations and the improvement of the gas turbine system and the turbine itself [7-12].

Focused an attention scientific article above, authors defined the possibilities combined utilization of hydrogen with gas in the thermal electric power plants with 127.1 mWatt. It's granted that the usage of hydrogen will be more effective, as well as production of hydrogen these days is the most expensive.

2 Materials and methods

Diffusion combustion: characterized by the mixing of hydrogen fuel and air in the combustion chamber, the phenomenon of stable combustion and the formation of high levels of NO_x-emission in the combustion product (from 200 ppm to 600 ppm). Gas turbine plants use "dry" premixing, in which case the formation of high levels of NO_x emissions is reduced from 5ppm to 10ppm. The combustion temperature of hydrogen is about $\approx 250^{\circ}\text{C}$ higher than that of natural gas, which in turn increases the demand for NO_x nitrogen oxides and the stability and strength of the blade materials. High reactivity (high ignition rate and spatial spread of the combustion reaction) leads to the risk of flashback (causes the flame to spread from the combustion chamber to the premixer). The energy is low-volume dense, the amount of hydrogen is three times more required than the amount of natural gas at the same output power (heat release capacity). The heat release capacity of natural gas is $\sim 35500 \text{ kJ/m}^3$, and the heat release capacity of hydrogen is $\sim 120000 \text{ kJ/m}^3$ [13].

According to [15], the composition of natural gas produced in Turkmenistan is CH₄=92.3–98%, C₂H₆=3.8%, C₃H₈=0.7%, C₄H₁₀=0.2%, CO₂=1%, N₂=2%.

As is known from the technological thermal scheme of gas turbine plants, air is drawn in from the external atmosphere through the compressor device and compressed in the compressor. Compressed air is mixed with natural gas in the combustion chamber and burned. The gases burned in the combustion chamber are directed to the gas turbine unit. Here, the thermal energy of the combustion gases is converted into mechanical energy, and the thermal energy of the combustion gases is reduced from the temperature level of 900-

1200 °C to the temperature level of 500-545 °C as a result of mechanical work and spreads to the atmosphere [14].

The heat capacity of the combustion chambers, the heat capacity Q_{HC} is defined as the amount of heat released per unit time during complete combustion of the fuel. The heat capacity characterizes the volumetric thermal incandescence, which in turn indicates the compactness and reliability of the combustion chamber. Energy losses in the combustion chamber, in turn, are calculated from heat losses and pressure losses, and based on all heat losses, the efficiency of the combustion chamber is determined η_{HC}^L . Heat loss during incomplete combustion of fuel in the combustion chamber is called chemical and physical incomplete combustion. In modern combustion chambers, these losses should not exceed 1...5% of the total heat consumption in the entire range of operating loads and 1...3% when operating at design loads. These losses usually do not exceed 0.5% of the heat consumed by the heating surface. The fundamental feature of the working phenomenon in the combustion chambers of modern gas turbine installations is the relatively high overall coefficient of air advantage (α). This is directly related to the level of thermodynamic parameters of gas turbine installations. Existing interaction the theoretical combustion temperature of the fuel is significantly higher than the allowable maximum temperature of the gas turbine front circuit. Therefore, in order to reduce the temperature of the working fluid until the gases reach the disks or blades of the gas turbine at the exit from the chamber, a large amount of additional air must be supplied to the combustion chamber through the mixing window.

3 Results and Discussion

In this scientific article we have taken information about energy structure of GTU with power level 127.1 mWatt with the usage of GTI simulator equipped with a Mark VI control program [15]. Rated parameters are presented in Table 1.

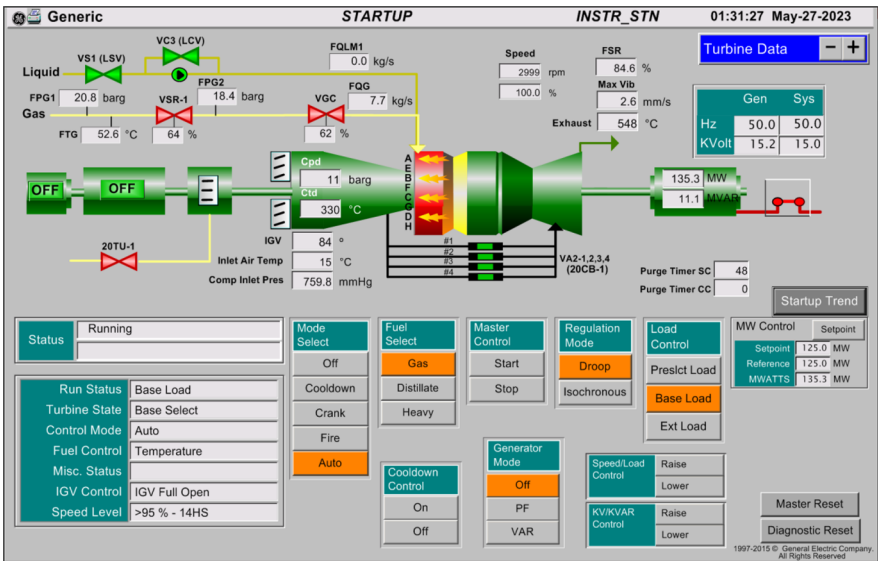


Fig. 1. Energy performance of GTU at an ambient temperature of 15 °C.

As can be seen from Figure 1, the fuel consumption in a gas turbine plant with a capacity of 127.1 MW is $B = 7.7$ kg/s, which corresponds to an ambient temperature of +15°C.

Table 1. GE LM6000 Series Gas Turbine Specifications.

No.	Specifications	Unit of measure.	Value
1	Generator power	MW	127.1
2	Atmosphere pressure	kg/sm ²	1.013
3	Compressor inlet temperature	°C	+15
4	Relative humidity at compressor inlet	%	55
5	Fuel pressure in front of the gas module	kg/sm ²	20.8
6	Number of stages in the compressor	PC.	17
7	Number of stages in the turbine	PC.	3
8	Air flow	m ³ /s	417
9	Compression ratio		11
10	Air temperature after compressor	°C	330
11	Flue gas temperature	°C	548
12	Gas temperature after combustion chamber	°C	1200

In the combustion chamber of gas turbine facilities with a capacity of 127.1 MW, the ability to produce heat during the combined combustion of natural gas and hydrogen fuel is calculated using the following expression:

$$Q_{i,h(comb)}^i=b_1\cdot Q_{i,h(gas)}^i\cdot b_2\cdot Q_{i,h(hyd)}^i \tag{1}$$

Where: $Q_{i,h(comb)}^i$ – low heat release capacity of the combined fuel; b_1 - value of natural gas, %; b_2 - hydrogen value, %; $Q_{i,h(gas)}^i$ – low heat release capacity of gas, 35500 kJ/m³; $Q_{i,h(hyd)}^i$ – low heat release capacity of hydrogen,120000 kJ/m³.

In comparison, 90% of natural gas was used, and 10% of hydrogen was used in combination and in the combined case, the ability to release heat is obtained by density ratio of the gas, and according to [15], the density of natural gas produced in Turkmenistan is equal to $\rho=0.78$ kg/m³.

Table 2. Below shows the low heat release capacity of natural gas combined with hydrogen gas in a gas turbine installation.

No.	Gas content, %	Hydrogen content, %	Low heat release capacity of gas, kJ/m ³	Low heat release capacity of combined gas, kJ/m ³
1	99	1	36345	46596.15
2	98	2	37190	47679.49
3	97	3	38035	48762.82
4	96	4	38880	49846.15
5	95	5	39725	50929.49
6	94	6	40570	52012.82
7	93	7	41415	53096.15
8	92	8	42260	54179.49
9	91	9	43105	55262.82
10	90	10	43950	56346.15
11	89	11	44795	57429.49
12	88	12	45640	58512.82
13	87	13	46485	59596.15
14	86	14	47330	60679.49
15	85	15	48175	61762.82
16	84	16	49020	62846.15
17	83	17	49865	63929.49
18	82	18	50710	65012.82
19	81	19	51555	66096.15
20	80	20	52400	67179.49

Depending on the amount of fuel consumed, in order to reduce the amount of harmful gases emitted into the environment, in the scientific work, it is planned to feed natural gas and hydrogen fuel together into the combustion chamber and perform calculations.

According to these set rates, in the case of hydrogen fuel mixing, the fuel consumption is determined using the following expression:

$$B=\frac{N_e^{GTI}}{Q_{i,h(comb)}^i \Psi_e^{GTI}}$$

(2)

Where: N_e^{GTI} - energy capacity of gas turbine installation, MW; Ψ_e^{GTI} - energy efficiency of a gas turbine installation.

The results of fuel consumption calculations in the case of combined use of hydrogen fuel are shown in Table 3 below.

Table 3. Results of calculations of fuel consumption in the combined use of hydrogen fuel.

Number	Natural gas consumption B, kg/s	The amount of natural gas saved, ΔB,%	Power, MW
1	7.52	2.597	127.1
2	7.35	4.5442	
3	7.186	6.675	
4	7.03	8.701	
5	6.881	10.636	
6	6.737	12.497	
7	6.600	14.286	
8	6.468	16	
9	6.341	17.649	
10	6.219	19.233	
11	6.102	20.753	
12	5.989	22.22	
13	5.880	23.636	
14	5.775	25	
15	5.674	26.311	
16	5.576	27.584	
17	5.481	28.8181	
18	5.390	30	
19	5.302	31.143	
20	5.216	32.259	

As a result of the conducted research work, it was found that when using natural gas and hydrogen in a combined mode, it will help to reduce the consumption of natural gas and of the consumption mixture (Figures 2 and 3).

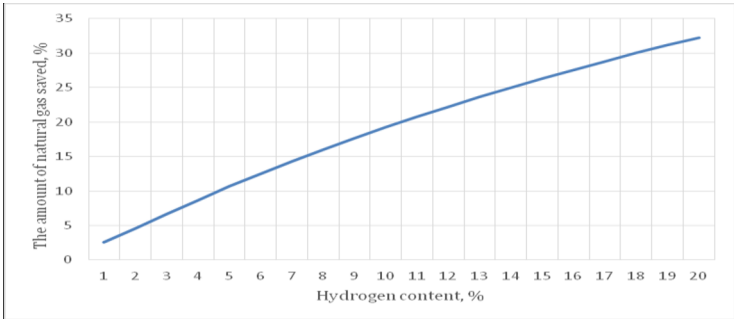


Fig. 2. Graphic dependence of the economy of natural gas on the content of hydrogen in the mixture.

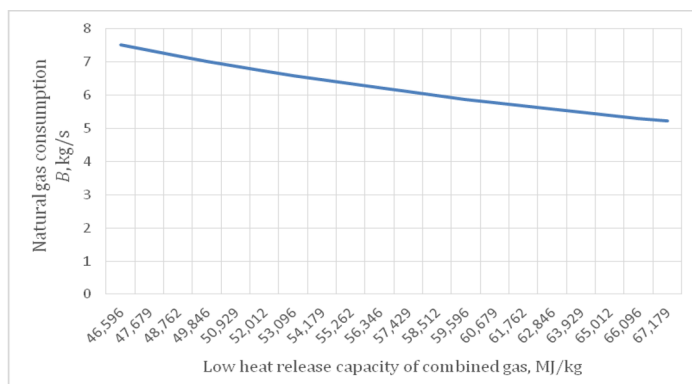


Fig. 3. Graphic dependence of the consumption mixture on the low heat release capacity of combined gas.

4 Conclusion

The use of hydrogen as a fuel in power plants is of particular interest, both scientifically and technically.

The use of hydrogen as the main fuel requires a complete reconstruction of the turbine and its main and auxiliary parts, which in turn requires additional capital costs. For this reason, the use of up to 20% hydrogen and 80% natural gas in gas turbine power plants in Turkmenistan does not require any changes to the existing design.

In this work, it was found that with a 10% hydrogen content, the gas consumption was 6.219 kg/s, and the natural gas saving was 19.233%, and with a 20% gas content, it was 5.216 kg/s, and the natural gas saving was 32.259%.

References

1. Gurbanguly Berdimuhamedov. Electric power might of Turkmenistan 2022 (A.: TDNG)
2. State program of energy saving for 2018-2024 (A.:TDNG)
3. G.E. Marin, B.M. Osipov, A.V. Titov, A.R. Akhmetshin, Simulation of the operation of a gas turbine installation of a thermal power plant with a hydrogen fuel production system, *International Journal of Hydrogen Energy*, **48**, **12**, 4543-4550 (2023)
4. M.M. Sultanov, E.V. Kuryanova, Research of the application of hydrogen as a fuel to improve energy and environmental performance of gas turbine plants May 2021 *Power Engineering Research Equipment Technology*, **23**, **2**, 46-55 (2021)
5. G.E. Marin, B.M. Osipov, A.R. Akhmetshin, Research of the application of hydrogen as a fuel to improve energy and environmental performance of gas turbine plants, *Power engineering: research, equipment, technology*, **23**, **2**, 84-92 (2021)
6. G.E. Marin, D.I. Mendelev, B.M. Osipov, *A study on the operation of a gas turbine unit using hydrogen as fuel*, The International Conference on Aviation Motors (ICAM 2020) *Journal of Physics: Conference Series*, **1891**, 012055 (2021)
7. B.M. Osipov, A.V. Titov, A.R. Khammatov, Investigation of power gas turbine drives on the basis of mathematical models, *Russ Aeronaut*, **53**, 69-72 (2010)
8. G.E. Marin, B.M. Osipov, D.I. Mendelev, *Research on the influence of fuel gas on energy characteristics of a gas turbine*, *E3S Web of Conf* 2019, **124**, 05063 (2019)

9. Y. Ye, J. Lu, J. Ding, W. Wang, J. Yan, Performance improvement of metal hydride hydrogen storage tanks by using phase change materials, *Appl Energy*, **320**, 119290 (2022)
10. C. Cormos, Assessment of hydrogen and electricity coproduction schemes based on gasification process with carbon capture and storage, *Int J Hydrogen Energy*, **34**, 60-77 (2009)
11. E.V. Solomin, P.A. Yunusov, A.A. Kovalyov, V.V. Dolgosheev, Y. Yang, G.N. Ryavkin, M.A. Mayorov, A.Y. Kosarev, Justification of upcoming global energy problems, *Alternative Energy and Ecology (ISJAEE)*, **4**, **6**, 48-60 (2021)
12. P. Chiesa, G. Lozza, L. Mazzocchi, Using hydrogen as gas turbine fuel, *J. Eng. Gas Turbines Power* (2005)
13. M.C. Lee, S.S. Bin, J.H. Chung, S.M. Kim, Y.J. Joo, D.H. Ahn, Gas turbine combustion performance test of hydrogen and carbon monoxide synthetic gas, *Fuel* (2010)
14. K.I. Ibrahim, M.M. Rahman, Effect of Compression Ratio on the Performance of Combined Cycle Gas Turbine, *International Journal of Energy Engineering*, **2**, 9-14 (2012)
15. Sh. Allakulyyev, B. Altyyev, M. Saryyev, A. Hojalyyev, M. Danatarova, *Scientific-technical analysis of the ambient temperature effect on the power of gas turbine installation in the conditions of Turkmenistan. ESDCA-II-2022*, IOP Conf. Series: Earth and Environmental Science, **1045**, 012164 (2022)