Investigation of Processes in the "Reformer-Fuel Cell" System by the Mathematical Modeling Method

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Abstract: This study involved the creation of a mathematical model and the research of the "reforming-fuel cell" system with the aim of obtaining optimal operating parameters for a solid oxide fuel cell. Based on the results of reforming system modeling in ASPEN PLUS simulation software, the exergy efficiency of the reformer was calculated. The results were used to determine the optimal parameters for the steam conversion process of hydrocarbon fuels. Also, in the ANSYS software package, the technical parameters of the fuel cell operation were calculated - the temperature of the fuel cell at the outlet of the anode, the current density at the outlet of the fuel cell, as well as the composition of the exhaust gases. As a result of the study, technological parameters were calculated, which allow us to draw a conclusion about the influence of gas composition on the output parameters of the fuel cell. For various molar compositions of synthesis gas, the efficiency of the fuel cell, the temperature at the anode outlet, and the current density were calculated. Based on the simulation data obtained, it can be concluded that the most optimal temperature range for the steam conversion reactor operation will be between 1125-1200K under conditions without a catalyst. This same range corresponds to the highest exergetic efficiency which was calculated for this reactor and amounted to 67.3%. Additionally, based on various gas compositions within this range, the calculation of the current density was performed, reaching a maximum value of 5000 A/m². For the same range, the electric efficiency of the fuel cell was also calculated, with its maximum being 62.25%. According to the values of the exergetic efficiency of the reformer and the electrical efficiency of the fuel cell, the obtained calculations made it possible to conclude about the most optimal composition of the obtained synthesis gas.

Keywords: Reformer, Modeling, System, Syntes-gas, Fuel.

1. Introduction

In the context of increasing demand for renewable energy sources, fuel cells represent a highly efficient, clean, and sustainable energy conversion source. Fuel cells can be divided into six different categories depending on the types of electrolyte and fuel used [18, 19, 20]. Among them, solid oxide fuel cells (SOFCs) attract significant attention due to their high efficiency, cost-effectiveness, and ability to use various types of fuel, in addition to hydrogen, such as hydrocarbons, coal gas, alcohols, ammonia, etc. [1,23]. Despite achieving comparable current densities with hydrogen, some degradation issues caused by these types of fuels affect the long-term stable operation of SOFCs [2].

This type of fuel cell is currently well-studied due to its advantages and wide usage profile in stationary installations.

A drawback is that SOFCs are only conductive at high temperatures. Therefore, the system needs to be heated. However, the final efficiency remains high if cogeneration of electricity and heat is considered. Indeed, in sectors with medium to large electricity needs SOFCs can be used as a suitable energy device. The lack of long-term stability is one of the main problems of commercializing SOFC technology.

The SOFC consists of a negatively charged electrode (anode), a positively charged electrode (cathode) and an electrolyte placed between the two electrodes. These three components are called the membrane electrode assembly (MEA) [24]. The interface between the electrode and electrolyte, where the electrochemical reaction occurs, is called the Triple-phase boundary (TPB).

The operation of SOFCs begins with the supply of hydrocarbon fuel and oxygen respectively to the anode and cathode. Hydrogen is supplied from the anode side, and oxygen from the cathode side in opposite directions to the interfaces with the electrolyte. Oxygen ions formed as a result of the chemical reaction on the cathode migrate through the dense solid electrolyte for further reaction to form water. The electrodes must also have electron conductivity to be able to transfer electron flows from the collector to the reaction sites or from them to the cathode collector to the reaction sites or from the latter to the electron collector.

The main consumables in the operation of a fuel cell are hydrogen and oxygen. Oxygen in sufficient quantities is in the air, so the question of its supply is not acute during the operation of the fuel cell, but with hydrogen everything is different.

The use of pure hydrogen, by conducting water electrolysis, will undoubtedly provide a continuous supply of fuel in the required quantity, however, such a solution will lead to all the generated electricity being directed to conduct electrolysis, which will not allow connecting additional electricity consumers to the installation, and the hybrid installation will operate in heat generation mode. If you buy ready-made hydrogen, or buy electricity for the operation of electrolysis plants separately, then in this case the profitability of constructing this installation is reduced due to increased capital and production costs. Additionally, the production costs are dependent on the operating parameters of the fuel cell. Papers [21] and [22] examined the economic performance of various fuel cells and provided an economic analysis.

The fuel cell can also operate not on pure hydrogen. By providing the fuel cell with a nominal hydrogen concentration, the installation can achieve higher electrical and thermal powers. It has been suggested to use not pure hydrogen, but to perform reforming of hydrogen-containing gases, such as oil industry waste, "propane-butane" mixture, biogas, etc. to obtain synthesis gas - a mixture with a high hydrogen concentration, containing CO, CO_2, as well as some of the hydrocarbons that have not undergone the conversion process [3].

There are 4 main methods of hydrocarbon reforming:

1. Steam reforming
2. Catalytic/Oxidative reforming
3. Autothermal reforming
4. Dry reforming

The operation of each of the reforming methods is determined by the parameters specific to each of these methods: pressure, temperature in the reactor, the ratio of mass flows of chemical reaction components, etc.

Steam reforming is one of the most effective methods for reforming hydrocarbon fuel.

The basis of the steam reforming method is based on the following chemical equations [4]:

$$C_nH_m + nH_2O \rightarrow nCO + \left(n + \frac{m}{2}\right) H_2(\Delta H^0_{298} > 0) \tag{1}$$

$$CO + H_2O \rightleftarrows CO_2 + H_2(\Delta H^0_{298} = 41{,}2\ kJmol - 1) \tag{2}$$

$$CO + 3H_2 \rightleftarrows CH_4 + H_2O(\Delta H^0_{298} = 206{,}2\ kJmol - 1) \tag{3}$$

The relevance of this work lies in the calculation of technological characteristics (temperature, current density, energy efficiency), which allows drawing a conclusion about the proportionality of the gas composition to the output parameters of the fuel cell.

Let's consider the scheme of a hybrid installation with a reformer, a SOFC stack, and a combustion chamber (Fig. 1) [6].

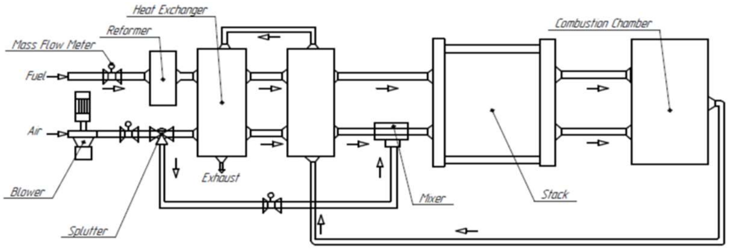

Figure 1. Scheme of the hybrid system

The SOFC stack is a key component of the system. Its main function is to convert the chemical energy of oxygen and fuel directly into electrical energy through electrochemical reactions. The subsystem consists of: reformer, heat exchanger, exhaust gas combustion chamber, desulfurizer, dehydrator, air compressor, air storage tank, cooling water tank and monitoring system as shown in Figure 1. They perform functions such as gas transportation, heat exchange and exhaust gas cleaning.

The process is as follows: Natural gas is sent to the desulfurization unit; the sulfur-free fuel is partially reformed in the adiabatic pre-reforming unit before entering the fuel cell stacks; the reformer is a steam reforming reactor with a fixed bed in which all higher hydrocarbons are converted into methane, hydrogen and carbon oxides; at startup steam is supplied from an external water supply; preheated by cathode exhaust gases before entering the fuel cell stacks cathode air is supplied by the fan; the outgoing heat exchange gas is distributed between the heat recovery unit and the catalytic afterburning chamber; in the catalytic afterburning chamber, the outgoing anode gases are fully oxidized, ensuring an extremely low level of emissions.

Conversion of natural gas takes place in the reformer. Natural gas is mixed with steam and heated to a high temperature. Then the synthesized gas goes to the SOFC stack. The heat exchanger further heats the synthesis gas with the products of the exhaust gases, then the exhaust gases are discharged.

The SOFC stack is assembled from several individual cells. The voltage generated by one cell is very low, usually less than 1V (the working voltage is about 0.6-0.9V), and the power density is less than 2W/cm2 [17]. As a result, the output voltage and output power of one cell are very limited. To get the output power that meets the needs, the cells are connected in series or parallel, forming an SOFC stack. In addition, since the gas tends to seep through the edge of the electrode, the edge of the electrode is closed with a sealing material. Under high temperature conditions, SOFC stack components are subject to performance deterioration due to both material change and chemical reactions with each other.

In SOFC, the cathode mainly performs the functions of air transport, catalysis of electrode reactions and current conduction. In SOFC with cathode support, the cathode also plays the role of a support for the entire SOFC cell structure. Therefore, the cathode material must have a strong electrochemical catalytic ability for oxygen reduction to reduce cell activation losses and improve its performance. The cathode material should also have high electrical conductivity to reduce ohmic losses. At the same time, due to the high operating temperature of the SOFC, the cathode material must have good chemical stability in an oxidizing atmosphere. At the same time, it should not enter into chemical reactions with neighboring materials.

2. Literature Review

Currently, the processes in the "reformer-fuel cell" system are summarized in several literature sources. In the work [5], an analysis of reliability (air supply, fuel supply, mechanical stresses caused by changes in temperature or uneven distribution of temperature, etc.) and initial requirements to the system was conducted, and was found that the main problems arose specifically in the operation of the SOFC. However, with proper operation, the "reformer-fuel cell" system demonstrates the potential of sufficiently high reliability.

Steam reforming of methane is the most important process for the production of hydrogen and syngas on an industrial scale [7]. One of the possible uses of methane steam reforming is the use of its synthesis gas for high-temperature fuel cells, such as SOFC, since high-temperature fuel cells can use both hydrogen and carbon monoxide in electrochemical reactions. Due to its endothermic nature, the process of methane steam reforming requires a large amount of heat to obtain synthesis gas. In traditional reforming installations, part of the obtained methane is partially burned for heating, which leads to significant fuel losses. There are several existing methods to bypass this problem. For example, one can use the heat generated in the high-temperature fuel cell [8, 9], or carry out so-called direct internal reforming. The reforming process takes place directly on the SOFC anode [10], which is a catalyst for the reaction of methane reforming with steam [11]. This solution allows to utilize the heat released in the course of SOFC electrochemical reactions and helps to properly design the fuel cell temperature control system [12]. However, this procedure has not yet reached commercial potential due to the occurrence of thermal stresses inside the fuel cell and the phenomena of carbon formation.

Several research groups are engaged in combining methane steam reforming with fuel cells. Nishino et al.

[13] prepared a model of intra-element steam reforming of methane and discussed methods of smoothing the temperature field inside the system. It was shown that the correct design of the steam reformer helps to cool the cell. Later, the model was used by Nishino and Szmid [14] for the analysis of the SOFC installation in combination with the biogas steam reformer.

Brus [15] experimentally studied the kinetics of reforming on the catalyst and successfully implemented it in the computational fluid dynamics (CFD) model of methane steam reformer. This model can be used in combination with high-temperature fuel cells. Sciazko and co-authors [16] analyzed the kinetics of the methane steam reforming reaction, using the generalized least squares method for modeling SOFC. Mozdzierz et al. [8] conducted parametric studies of the methane steam reforming reaction and concluded that adaptation of the heating zones and localized catalyst density can significantly help in managing the process.

M. Mozdziers and others carried out numerical calculations for the study of the operation of heat exchange type steam reforming of methane [7-8]. From their work, it can be seen that the degree of conversion of methane strongly depends on the amount of enthalpy entering the system. The amount of energy released by the fuel is enough for the instantaneous activation of the steam reforming reaction of methane upon contact of gases with the catalyst, while in the control case, thermal energy is needed to heat the gases, which leads to a slow conversion of methane in the inlet part. However, these phenomena practically do not affect the temperature profile inside the heating channel due to the low thermal conductivity of the partition wall, from which it can be concluded that the thermal conductivity of the wall material should be as high as possible. When fuel consumption is low, heat is transferred more efficiently, even if the wall is characterized by low thermal conductivity. In this case, the amount of hydrogen produced is the highest among the results presented in this article, and methane is almost absent from the output of the heat exchange unit. Also, their work shows that synthesis gas can be effectively used in a fuel cell. This is one of the possible applications of reforming with post-combustion heating. In the above case, a high steam to methane ratio, which is not always desirable, positively affects the efficiency of the cell. The problem of relatively poor cell characteristics (potential and power), which arises in the considered case, can be solved by connecting the heat exchange units in stacks.

3. Problem statement

The main task of this work is the creation of a mathematical model and study of the operation of a fuel cell in the "reforming-fuel cell" system, with the aim of obtaining optimal operation parameters of the solid oxide fuel cell. This research conducts an analysis of various compositions of synthesis gas, obtained as a result of calculations in the "ASPEN PLUS" software, and then their further processing in the "ANSYS 2023 R1" software. The efficiency, the temperature of the fuel cell, as well as the current density for different gas compositions were calculated, which helps to choose the most optimal parameters for the operation of SOFC.

4. Materials and methods

In the first stage, of the calculation scheme was carried out which includes the following streams: the stream of the original fuel (fuel gas), the stream of water vapor (w), the mixture stream (mix), the streams of the liquid (water) and gaseous phase of synthesis gas (s-g). A mixing block and a chemical reaction block were also used. Figure 2 shows the process flow diagram (PFD):

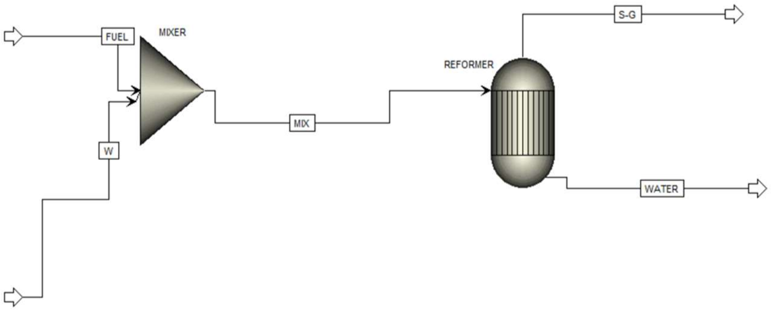

Figure 2. Process flow diagram of steam reforming system in "ASPEN PLUS" software

In the reactor block of chemical reactions, parameters are indicated under which the steam reforming process takes place (usually the process occurs at a pressure of 10 bar and a temperature range from 600 to 1200 K). The selected parameters are determined by the required conversion efficiency of the reforming process, determined by the ratio of the formed molar fraction of hydrogen to the original molar fraction of the hydrocarbon; exceeding temperatures over 1200 K is not recommended due to the possibility of thermal decomposition of hydrocarbons (as a result of which carbon will be formed).

To determine the dependence of the output electric power of the fuel cell on the composition of the supplied synthesis gas, several of its compositions were calculated. They were obtained as a result of changing the operating temperature in the range from 775 to 1067.5 K of the steam conversion process of the original fuel (Table 1), calculated in the model of the reformer. The pressure at which the process of reforming hydrocarbons takes place is taken as 1 bar.

Table 1: Initial fuel composition

Element	*Research fuel mass fraction, %*
O_2	*0.588*
N_2	*4.101*
H_2	*3.868*
CH_4	*21.3*
C_2H_6	*19.063*
C_2H_4	*3.217*
C_3H_8	*23.37*
C_3H_6	*3.599*
C_4H_{10}	*17.33*
C_5H_{12}	*3.538*
Sum of C_6	*0.92*
Sum of C_7	*0.22*
CO_2	*0.745*
H_2S	*0.3991*

The second stage involved an investigation of the fuel cell operation on various synthesis gas compositions using the "ANSYS-Fluent" software.

The geometric model was built using "ANSYS-Geometry" in accordance with specifications in realistic stack designs. Flows enter/exit the stack (fuel cells) through gas inlets/outlets (manifolds). Each fuel cell block consists of an electrolyte and adjoining porous electrodes with a gas distribution channel system and interconnections. Therefore, there are 900 repeating blocks for the electrochemically active area of the 30-element stack (Fig. 3). The Table 2 presents input data for fuel cell modeling in "ANSYS FLUENT."

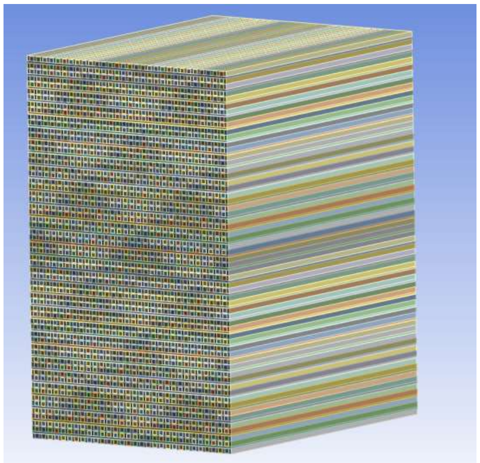

Figure 3. Model of a solid oxide fuel cell stack created in ANSYS 2023 R1 software

In the Ansys Workbench software, a grid with tetrahedral cells totaling 55 million was created (Fig. 4). The quality of the grid was 0.979. The computational grid was built using mathematical equations for the conservation of mass and charge, substance transport, heat exchange, ionic and electronic charge balance. Then the computational grid was processed in "ANSYS-Mesh". It should be noted that the model is planar with 30 channels. By trial and error, it was found that orthogonal quality of about 0.95 was sufficient for accurate calculations in the "ANSYS-Fluent" module.

Table 2: Input data for fuel cell modeling in "ANSYS-FLUENT"

Parameter	*Value*
Input temperature, K	*998*
Fuel flow rate, kg/s	*0.0000154*
Oxygen flow rate, kg/s	*0.0000226*
Relaxation factor	*0.3*
Electrolyte thickness, m	$1.5*10^{-5}$
*Specific electrolyte resistance, Ohm*m*	*0.3*
Constants of AC exchange density at the anode, A/m²	*5300*
Constants of AC exchange density at the cathode, A/m²	*2300*
Reference values of the molar fraction of hydrogen, water, oxygen	*0.5*

The main task of a mathematical model formation is to determine the method of calculating kinetic and thermodynamic parameters of processes. This model uses the method of calculating parameters at critical points for ideal Peng-Robinson gases.

The aim of the study was to consider the influence of different gas compositions on the operation of the solid oxide fuel cell as a whole.

Then they were analyzed in the universal software system "ANSYS 2023 R1". Technical parameters of the fuel cell operation, such as: fuel cell temperature, current density and the composition of the exiting gases were considered.

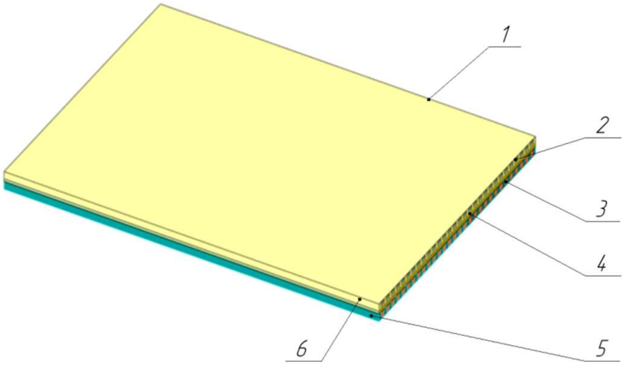

Figure 4. 3-d model of a 30-channel planar SOFC. 1 - Interconnection; 2 - anode channels; 3 - cathode channels; 4 - electrolyte; 5 - cathode; 6 - anode

5. Results

As a result of model calculation in the specified range, a graph of dependence of mole fraction of the component of synthesis gas composition on the temperature of the steam conversion process was obtained (Fig. 5).

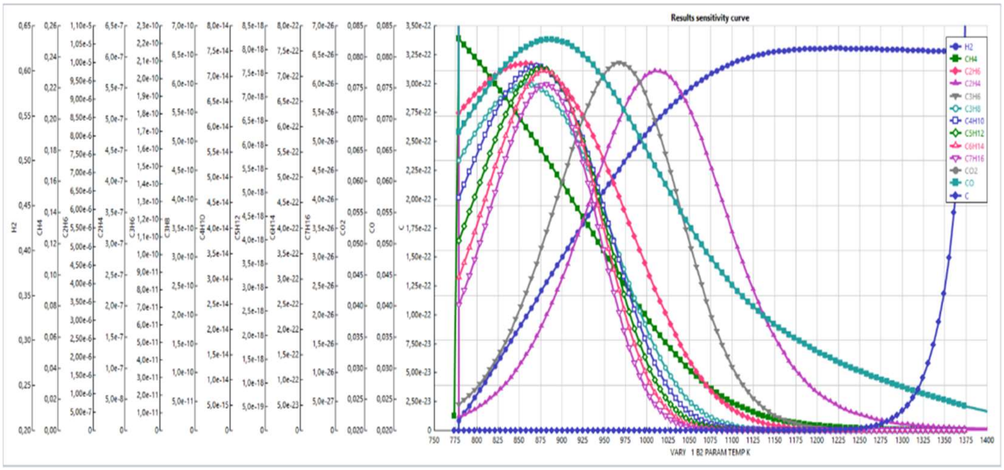

Figure 5. Result of calculation in the "ASPEN PLUS" software

As can be seen from the diagram, the peak of hydrogen formation is in the temperature range 1125-1200 K. The introduction of more heat will not lead to an increase in hydrogen formation, but will lead to a decrease in the molar fraction of carbon dioxide (CO_2) and carbon monoxide (CO) due to their thermal decomposition into carbon and oxygen. When the temperature reaches 1250 K, a significant increase in the molar fraction of carbohydrate is observed, which does not lead to an increase in the efficiency of the process, but leads to the deposition of carbon on the anode and\or in the reformer space.

Since vapor conversion of hydrocarbons can take place in the fuel cell space, synthesis gas containing methane can be fed into the fuel cell, since it will be further converted into hydrogen, carbon dioxide and carbon monoxide in the anode chamber space due to the energy released as a result of the exothermic reaction taking place in the fuel cell.

In this regard, a range dominated by the mole fraction of methane, 775-1100 K, was chosen.

By varying the temperature in the given range at constant pressure, several variants of synthesis gas composition were calculated

In all variants, the mole fraction of O_2 remained unchanged (Table 3). The variants of gas compositions were distributed in ascending order by hydrogen.

For each variant of synthesis gas, according to the formed mathematical model, the amount of heat required for the steam conversion reaction was calculated.

Table 3. All synthesis gas variants

№ variants	*Composition of gases, mol*					
	CH_4	*H_2*	*H_2O*	*CO*	*CO_2*	*O_2*
1	*0.0034*	*0.58*	*0.18*	*0.051*	*0.051*	*0.21*
2	*0.0278*	*0.585*	*0.17*	*0.048*	*0.048*	*0.21*
3	*0.002*	*0.594*	*0.18*	*0.163*	*0.035*	*0.21*
4	*0.0229*	*0.601*	*0.162*	*0.0456*	*0.0456*	*0.21*
5	*0.021*	*0.603*	*0.164*	*0.045*	*0.045*	*0.21*
6	*0.0172*	*0.609*	*0.0433*	*0.0433*	*0.1614*	*0.21*
7	*0.013*	*0.614*	*0.157*	*0.04*	*0.04*	*0.21*
8	*0.0107*	*0.617*	*0.039*	*0.039*	*0.156*	*0.21*
9	*0.0088*	*0.619*	*0.038*	*0.038*	*0.154*	*0.21*
10	*0.0073*	*0.621*	*0.0369*	*0.0369*	*0.153*	*0.21*

For each synthesis gas variant, according to the formed mathematical model, the amount of heat required for the steam conversion reaction was calculated. According to formula (4), the exergy efficiency of the reformer, was calculated on the basis of the obtained values, which resulted in the synthesis gas composition variants shown in Table 3.

$$\eta_e = \left(0.0000539 * \sum_{i=1}^{i} {Q_{li}}^{s-g} \times \mathrm{x}_i + 0.0000539(T_i - 20) \times \sum_{i=1}^{i} c_i^{s-g} \times \mathrm{x}_i\right) /$$

$$(0.0000154 * \textstyle\sum_{i=1}^{i} {Q_{li}}^{t-g} \times \mathrm{x}_i + 0.0000385 \times H_{H2O} + 0.0000154(400 - 20) \times \sum_{i=1}^{i} c_i^{s-t} \times \mathrm{x}_i + Q) \quad (4)$$

where– Q_{li}^{s-g} – lower heat of combustion of the i-th element in the synthesis gas, x_i – mass fraction of the i-th element in the synthesis gas composition, ${Q_{li}}^{t-g}$ – is the net calorific value of the i-th element in the fuel gas composition c_i^{s-g} – specific heat capacity of the i-th element in the synthesis gas composition, c_i^{t-g} – specific heat capacity of the i-th element in the fuel gas composition, H_{h2o} – enthalpy of water, Q - heat supplied to the reformer.

Figure 6 shows the graph of dependence of the exergetic efficiency of the reformer on the composition of the synthesis gas obtained.

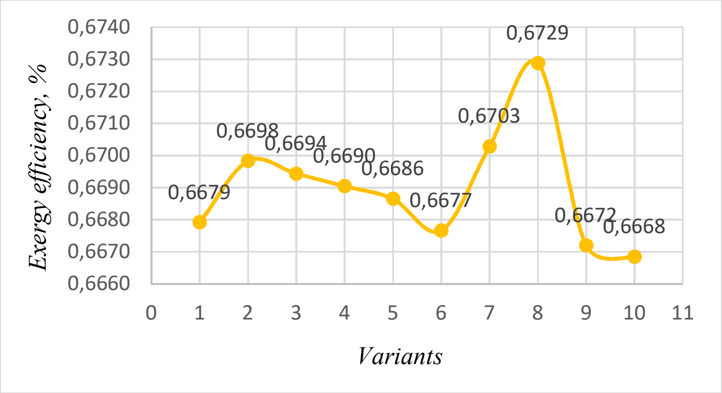

Figure 6. Exergy efficiency dependence to reformer based on composition of synthesis gas.

As can be seen from the graph, the value of exergy efficiency tends to maintain the average value, but points 7,8,9 and 10 have a strong deviation from the trend line, which is due to a nonlinear change in the enthalpy of steam supplied to the reformer and the composition of synthesis gas.

As a result of mathematical modeling in "ANSYS-FLUENT", the calculated technological characteristics were obtained, which allow us to conclude that the composition of gases is proportional to the output parameters of the fuel cell. The efficiency, fuel cell temperature, and current density for different gas compositions were calculated.

Table 4 shows the data obtained as a result of mathematical modeling. The variants are arranged according to the synthesis gas variants from Table 3.

Table 4. Data obtained in Ansys-Fluent module

№	Current Density, A/м^2	Anode outlet temperature, K	O_2, mol	CO mol	CH_4 mol	CO_2 mol	H_2O mol	H_2 mol
1	4907.746	1312.5	0.045	0.015	0.0037	0.0219	0.1384	0.2486
2	4782.87	1311.6	0.0469	0.0191	0.0139	0.0288	0.1434	0.2295
3	5002.54	1331.7	0.0438	0.0675	0.001	0.0314	0.1569	0.243
4	4888.76	1311.9	0.0454	0.0162	0.0065	0.0238	0.1405	0.2449
5	4858.27	1311.1	0.0458	0.0181	0.0105	0.0268	0.1443	0.2392
6	4879.389	1311.3	0.0456	0.0175	0.0086	0.0258	0.1474	0.2424
7	4849.019	1311.3	0.046	0.0183	0.0114	0.027	0.1488	0.2381
8	4899.24	1312.1	0.0453	0.0158	0.0053	0.023	0.1399	0.2465
9	4901.45	1312.5	0.0453	0.0154	0.0044	0.0226	0.1389	0.2475
10	4679.82	1313.1	0.0484	0.0203	0.0017	0.0307	0.1532	0.2268

Figures 7,8,9 show the main parameters that resulted from the calculations in ANSYS-Fluent.

The efficiency was calculated by the formula:

$$\eta_{э} = \frac{n*I*U*Q_{tg}}{q_t*F}, \tag{5}$$

Where n — number of cells;

I — current density, A/m^2;

U — voltage, V;

Q_{tg} — net calorific value of synthesis gas, kJ/kg;

q_t — synthesis gas flow rate, kg/sec;

F — area of the fuel element, м^2.

Based on the results of analyzing the output current density as a function of synthesis gas composition, the following graph is plotted (Fig. 7). Current density is the most important parameter to determine the efficiency of the fuel cell. The highest density is in the third variant and the lowest current density is in the tenth variant. It depends on the predominance of components such as: H_2O and H_2, and CO. Further analysis showed that the greatest influence on the efficiency of the system as a whole has the current density, therefore it is necessary to strive for the maximum value of current density.

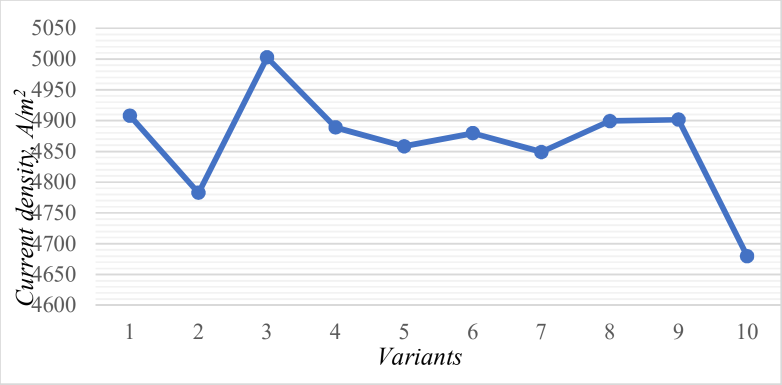

Figure 7. Current density at the different variants of synthesis gas composition.

When analyzing the temperature dependence on the molar synthesis gas composition, it was shown that the higher the outlet temperature, the more heat can be obtained from the fuel cell. Further this heat can be directed to useful needs. Figure 8 shows the graph of temperature variation from synthesis gas composition. The graph shows that the maximum temperature is in variant 3 and the minimum temperature is in variant 5. The greatest influence on the temperature is the fraction of H_2, CO and CO_2. Variant 3 has the maximum temperature and current density. In variants 4-10 the temperature is quite stable; its fluctuations are from 1311 to 1313 K.

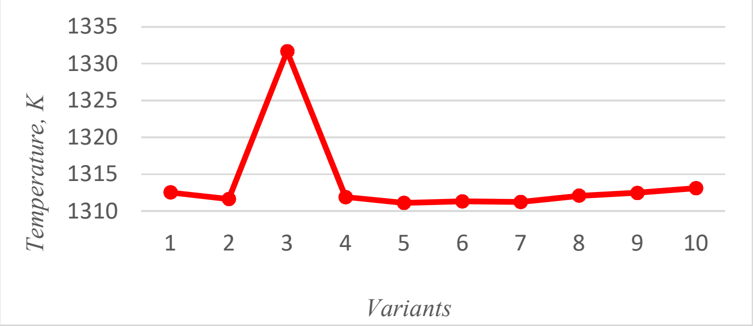

Figure 8**.** Outlet temperature at the different variants of synthesis gas compositio.

Figure 9 shows the graph of the change in the efficiency of the system depending on the molar composition of synthesis gas. From the graph we see that the maximum in the third variant (62.157%), the minimum in the tenth (58.146%). In the third variant the molar fractions of H_2O, H_2 and CO predominate, in the tenth variant CO_2 predominates, which is not reactive and therefore does not give energy as a result of chemical reaction. Separately, it should be noted that the coefficient in all variants ranges from 0.58 to 0.622. The greatest influence on the efficiency is the current density. The correlation with the current density is traceable.

Figure 9. Efficiency of the system at the different variants of synthesis gas composition.

On the basis of the values of energy efficiency of the fuel cell obtained as a result of calculations at different variants of synthesis gas composition, it can be concluded that the 3rd variant, in which the content of H_2O, H_2 and CO prevails, is preferable, because at such composition of synthesis gas the highest current density, and, consequently, higher energy efficiency.

For the formation of 3 variants of synthesis gas composition it was required to spend 0.03087 kW of thermal energy, at the reaction operating temperature of 840 K and pressure of 1bar. The ratio of mass flow rate of water to the initial fuel remains unchanged throughout all stages of modeling and is 2.5.

6. Conclusion

The use of methane steam reforming system with SOFCs is a promising area of development. Using the heat of SOFCs for the internal reforming reaction, it is possible to significantly increase the energy efficiency. As a result of the study, calculated technological characteristics were obtained, which allow us to conclude that the composition of gases is proportional to the output parameters of the fuel cell. The exergy efficiency, the temperature at the fuel cell anode outlet, and the current density for different molar compositions of synthesis gas were calculated. Based on the values of the exergy efficiency of the reformer and the electrical efficiency of the fuel cell, and the calculations obtained, a conclusion was made about the most optimal composition of the synthesis gas obtained. Different variants of synthesis gas compositions were presented. In case of variant 3, the current density, efficiency and temperature were maximized. From the results of the study, it can be seen what role a particular molar fraction of a chemical element has. Molar fractions of H_2 and CO have the greatest role on the growth of current density and energy efficiency.

Acknowledgment

The results of this work were obtained with the financial support of the Ministry of Science and Higher Education of the Russian Federation on the topic "Study of processes in hybrid power plant on fuel cells and gas turbine" (project code: FZSV-2022-0001).

This study is also financed by the European Union-NextGenerationEU, through the National Recovery and Resilience Plan of the Republic of Bulgaria, project № BG-RRP-2.013-0001-C01.

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Paper submitted: 10.12.2024
Revised: 21.02.2025
Paper accepted: 27.02.2025