Journal of Farayandno – Vol. 17 – No. 77 (2022): pp. 24-37

National Iranian Oil Refining and Ditribution Company (NIORDC)

Journal of Farayandno

Research Paper

Modeling of hybrid system of solid oxide fuel cell and Rankine cycle fed with synthesis gas

Omid Kohzadi [1], Mohsen Mansouri [2*]

[1] MSc, Department of Chemical Engineering, Ilam University, Ilam, Iran

[2] Associate Professor, Department of Chemical Engineering, Ilam University, Ilam, Iran

Received: 1 Feb 2022 **Accepted:** 1 May 2022

1. ABSTRACT

In this study, a solid oxide fuel cell fed with synthesis gas derived from industrial waste water was combined with a Rankine power generation cycle was analyzed and investigated using thermodynamic relationships. First, the solid oxide fuel cell was independently simulated and the quantities such as output voltage, current density and output power of the fuel cell were calculated. Then, the power cycle that equipped with a gas turbine combined with a solid oxide fuel cell was investigated according to the output results of the fuel cell simulation using thermodynamic analysis. In current study, fuel cell output voltage as a function of current density was reported, and the effect of temperature and pressure increasing on output fuel cell voltage was reported. The analysis of this system showed that with the increase in temperature and pressure, the output voltage of the solid oxide fuel cell increased. The varation in the output power of the fuel cell against the current density at three operating temperatures of 1073, 1173 and 1273 K were also calculated, the results showed that the power of the fuel cell increases with the increase in temperature. Also, the total efficiency of the hybrid system by increasing in fuel cell operating temperature increased.

Keywords: Hybrid System, Fuel Cell, Rankine Cycle, Modeling.

2. INTRODUCTION

One of the solutions that is considered to reduce energy consumption today is the optimal use of the chemical energy of fossil fuels. As one of the most important methods, the use of a system that, in addition to generating electricity, uses the heat produced during the process to create heating and cooling. For this reason, in the last few years, the use of heat produced by fuel cells has also been considered [1].

In 2002, Chan et al. studied a solid oxide fuel cell system with internal reforming; they extracted two parameters in operating pressure and fuel flow in the studied process and their effect on the performance of each of the equipment and the whole system. These researchers found that the efficiency increases with the increase in the pressure of the system, and this is the case that the efficiency decreases with the increase in the fuel flow rate. They were also able to achieve a total (thermal) efficiency of 80% by modeling this system [2]. In 2019, by studying a solid oxide fuel cell and a three-phase gas-steam system, researchers determined and reported the key parameters of this system, including operating temperature and pressure, air-to-fuel ratio, compressor compression ratio, combustion chamber temperature, and steam pinch point. In this article, two objective functions of exergy efficiency and electricity costs have been discussed and investigated by the authors, which were calculated by optimizing this system by the objective functions of the mentioned important parameters of the system [3]. In 2019, Habib Al-Zadeh and colleagues developed a solid oxide fuel cell hybrid system, a biomass gasification system with different gasification agents, and a solid oxide electrolyzer that received its electricity from the output power of the gas turbine. Check out. They investigated the three gasification agents of air, oxygen and carbon dioxide, and the results showed that oxygen had a better overall thermodynamic and economic performance in the gasification system [4]. In a research, a multi-generation energy system based on solid oxide fuel cell and gas turbine along with carbon dioxide absorption and storage process consisting of organic Rankine cycle with internal heat exchanger, liquefied natural gas regasification cycle, water-lithium absorption refrigeration cycle Bromide,

* m.mansouri@ilam.ac.ir

Please Cite Thise Article Using:

Kohzadi, O., Mansouri, M., "Modeling of hybrid system of solid oxide fuel cell and Rankine cycle fed with synthesis gas", Journal of Farayandno – Vol. 17 – No. 77, pp. 24-37, In Persian, (2022).

photovoltaic/thermal with concentrator, wind farm and advanced alkaline electrolyzer, was modeled by Khojaste Efatpanah et al [5].
In previous studies, less research has been done on the combination of solid oxide fuel cell and power cycle fed by synthesis gas. The aim of this study is to model and investigate a hybrid system of a solid oxide fuel cell and a Rankine cycle with carbon monoxide and hydrogen fuel (from synthesis gas).

3. THEORETICAL MODELING

In this research, compressed synthesis gas (produced fuel from industrial effluents) is considered as a feed for a simultaneous electricity and heat production system. At the beginning of the process, the feed entered the solid oxide fuel cell with an internal reformer and turned into hydrogen as fuel cell feed. The hydrogen produced during the reforming process in the fuel cell participates in the overall electrochemical reaction of the cell in the presence of oxygen from compressed air. This exothermic reaction leads to the generation of electricity. The hot gases resulting from the reactions enter a combustion chamber where the unreacted gases react and the temperature of the exhaust gases rises. These hot gases enter a gas micro-turbine after the preheater converters in order to generate more electric power. Then these gases, which still have high temperature and exergy, enter a boiler to produce steam. The produced steam acts as the working fluid in the Rankine cycle. In such a way that by passing through the steam turbine, it generates power, and the steam output from the turbine, whose energy has been reduced, passes through a cooling water condenser, turns into water condensate and returns to the cycle. In order to model the above process, the following assumptions were considered: 1: The system is stable. 2: There are no temperature changes with time in the fuel cell. 3: Distribution of temperature, pressure, concentration of materials and speed of flows in fuel cell channels were considered uniformly. 4: The pressure drop in the reformer was neglected. 5: The reactions of cathode, anode and overall solid oxide fuel cell are as follows:

Anode	$H_2 + O^{2-} \rightarrow H_2O + 2e^-$	$CO + O^{2-} \rightarrow CO_2 + 2e^-$	(1)
Cathod	$\frac{1}{2}O_2 + 2e^- \rightarrow O^{2-}$	$\frac{1}{2}O_2 + 2e^- \rightarrow O^{2-}$	(2)
Overall	$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$	$CO + \frac{1}{2}O_2 \rightarrow CO_2$	(3)

4. RESULTS AND DISCUSSION

The effect of the operating temperature of the fuel cell in the hybrid system on the voltage changes versus its current density is presented in Figure 1. By examining the effect of current density on fuel cell performance, it was concluded that with increasing current density, fuel cell voltage decreases. This result is due to the fact that with the increase of the current, the value of the current resistance and finally the voltage drop increases, which causes the overall voltage of the fuel cell to decrease. Of course, at lower current densities, the performance of the battery is opposite to the temperature. Because the voltage drops are negligible. Also, at very high currents (more than 8000 A/m^2), the voltage drop of the fuel cell is much more noticeable. Pirkandi and colleagues have reported results similar to this research.
Figure 2 shows the effect of current density on battery voltage at different pressures. By observing this figure, it can be concluded that, like the effect of temperature, the voltage of the fuel cell decreases with the increase of the current density. But as the pressure increases, the battery voltage increases. By observing this figure, it can be seen that the behavior of the graph is non-linear, the behavior similar to this study for the effect of temperature and pressure on voltage changes in terms of current density was reported in Pirkandi et al.'s research.

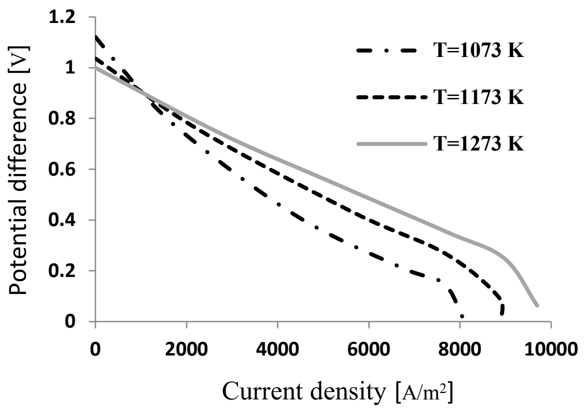

Figure 1. The effect of current density on fuel cell voltage at different temperatures

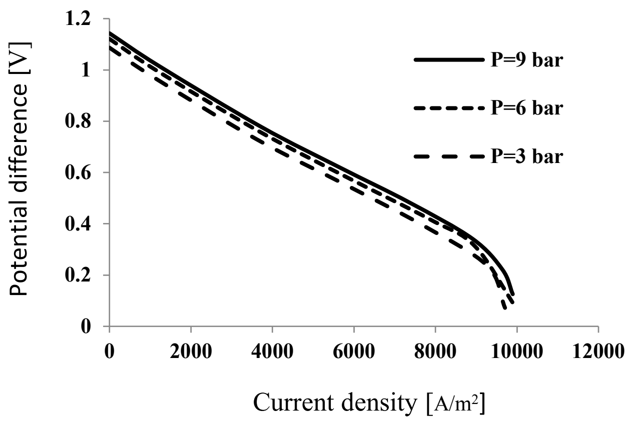

Figure 2. The effect of current density on fuel cell voltage at different pressures

5. CONCLUSION

In this research, the solid oxide fuel cell hybrid cycle combined with a power generation Rankine cycle was simulated and investigated, and the following results were obtained from this research:

- As the current density increases, the fuel cell voltage decreases and as the temperature increases, the cell voltage increases.
- With the increase in pressure, the battery voltage increased and the slope of the fuel cell voltage changes decreased.
- As the current density increases, the power of the fuel cell increases and then decreases.
- The power of the fuel cell increased with the increase in operating temperature.
- By increasing the operating temperature of the fuel cell, the overall efficiency of the hybrid system increases.

6. ACKNOWLEDGEMENT

M. Mansouri thanks the University of Ilam, for the award research fellowship.

7. REFERENCES

[1] F. C. Handbook, West Virginia, USA: EG&G Technical Services, US Dep. Energy, Off. Foss. Energy, Natl. Energy Technol. Lab. Morgantown, 2000.

[2] Chan, S.H., Ho, H.K. and Tian, Y., Modelling of simple hybrid solid oxide fuel cell and gas turbine power plant. Journal of power sources, 109(1), pp. 111-120, 2002.

[3] Ehyaei, M.A. and Rosen, M.A. Optimization of a triple cycle based on a solid oxide fuel cell and gas and steam cycles with a multiobjective genetic algorithm and energy, exergy and economic analyses, Energy Conversion and Management, vol. 180, no. 15, pp. 689-708, 2019.

[4] Habibollahzade, A., Gholamian, E. and Behzadi, A., Multi-objective optimization and comparative performance analysis of hybrid biomass-based solid oxide fuel cell/solid oxide electrolyzer cell/gas turbine using different gasification agents. Applied Energy, 233, pp. 985-1002, 2019.

[5] Khajeste Efat Panah, S., Production and application of green hydrogen in a multiple generation energy system based on solid oxide fuel cell and gas turbine with the approach of increasing power production and reducing CO2 emissions, Shahrood University of Technology, Faculty of Mechanics and Mechatronics, 2021.