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EVALUATION OF THE PERFORMANCE OF POLYMER ELECTROLYTE MEMBRANE FUEL CELL (PEMFC) DESIGNED IN DIFFERENT SIZES

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Keywords

Fuel cell, membrane, performance, polymer electrolyte

Abstract

Fuel cells, the technology of the future, are devices that create electrical energy by combining hydrogen and oxygen as a result of a chemical reaction and release heat with H_2O as waste. Since electricity is produced without combustion, less pollution occurs. The part where the chemical reaction takes place in the Polymer Electrolyte Membrane (PEM) fuel cell consists of the membrane. In this study, the fuel consumption of different sizes (5-25-50 cm^2) of fuel cells was investigated and the factors affecting the performance were determined experimentally. First of all, the PEM fuel cell was installed, and appropriate amounts of Hydrogen (H_2) and Oxygen (O_2) were sent to the fuel cell according to the characteristics of the established cell. During the study, the performances of different sizes of fuel cells were determined. The behavior of the fuel cell was determined according to the C-H ratio values in the fuel cell and power values were found according to the produced current. The performance of fuel cells was evaluated according to their size and the amount of electrical energy they would produce was calculated. In this case, it was determined that the fuel cell with a surface area of 5 cm^2 was the most efficient in C60H60, 25 cm^2 in C60H46 and 50 cm^2 in C60H46, respectively.

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FARKLI EBATLARDA TASARLANAN POLİMER ELEKTROLİT MEMBRANLI YAKIT HÜCRESİ PERFORMANSLARININ DEĞERLENDİRİLMESİ

Anahtar kelimeler

Yakıt hücresi, mebran, polimer elektrolit, güç performansı

Öz

Geleceğin teknolojisi olan yakıt hücreleri hidrojen ile oksijenin kimyasal reaksiyon sonucu birleşmesi ile elektrik enerjisinin meydana gelmesini ve atık olarak H_2O ile ısı açığa çıkmasını sağlayan cihazlardır. Yanma olmaksızın elektrik üretildiği için daha az kirlilik meydana gelmektedir. Polimer Elektrolit Membran (PEM) yakıt hücresindeki kimyasal reaksiyonun oluştuğu kısım membran zardan oluşmaktadır. Bu çalışmada farklı boyutlardaki (5-25-50 cm2) yakıt hücrelerinin yakıt sarfiyatı ile ilgili incelemeler yapılarak performansa etki eden faktörler deneysel olarak belirlenmiştir. Öncelikli olarak PEM yakıt hücresi kurulumu yapılmış, kurulan hücrenin özelliklerine göre uygun miktarlarda Hidrojen (H_2) ve Oksijen (O_2) yakıt hücresine gönderilmiştir. Çalışma esnasında değişik boyutlardaki yakıt pillerinin performansları belirlenmiştir. Yakıt hücresindeki C-H oranı değerlerine göre yakıt hücresinin davranışı belirlenmiş ve üretilen akıma göre güç değerleri bulunmuştur. Boyutlarına göre yakıt hücrelerinin performansları değerlendirilerek üretecekleri elektrik enerji miktarları hesaplanmıştır. Bu durumda; yüzey alanı 5 cm^2 olan yakıt hücresinin C60H60'da, 25 cm^2 olanın C60H46'da ve 50 cm^2 olanın C60H46'da en verimli olduğu tespit edilmiştir.

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1. Introduction

Fuel cell, an electrochemical device, combine fuel (hydrogen) and oxidant (oxygen) and convert the resulting energy directly into electrical energy, waste heat and water. They are classified according to electrolyte types (Mogorosi, Oladiran and Rakgati, 2020). Fuel cells are globally divided into 6 types; Alkaline Fuel Cells (AFCs), Phosphoric Acid Fuel Cells (PAFCs), Molten Carbonate Fuel Cells (MCFCs), Solid Oxide Fuel Cells (SOFCs), Proton Electrolyte/Exchange Membrane Fuel Cells (PEMFCs) and Direct Methanol Fuel Cells (DMFCs). A brief summary of the general features of these 6 types of fuel cells is shown in Table 1.1 (Ebrahimi, Kujawski, Fatyeyeva and Kujawa 2021, Li, Kujawski and Rynkowska, 2019)

Table 1.Characteristics of fuel cell types (Ebrahimi et al., 2021; Li et al., 2019)

Fuel Cell Type	Electrolyte Type	Operating temperature	Productivity	Fuel
Alkaline Fuel Cells (AFCs)	Potassium hydroxide solution	Room temperature up to 250 ˚C	60% - 70%	H_2 - O_2
Proton Electrolyte/Exchange Membrane Fuel Cells (PEMFCs)	Proton Exchange Membrane	Room temperature up to 100 ˚C	40% - 60%	H_2 - O_2 or Air
Direct Methanol Fuel Cells (DMFCs)	Proton Exchange Membrane	Room temperature up to 130 ˚C	20% - 30%	CH_2OH - O_2 or Air
Phosphoric Acid Fuel Cells (PAFCs)	Phosphoric acid	160 ˚C – 220 ˚C	55%	Natural Gas, Biogas, H_2 - O_2 or Air
Molten Carbonate Fuel Cells (MCFCs)	Molten mixture of alkali metal carbonates	620 ˚C – 660 ˚C	65%	Natural Gas, Biogas, Coal gas, H_2 - O_2 or Air
Solid Oxide Fuel Cells (SOFCs)	Ceramic that conducts oxide ion	800 ˚C – 1000 ˚C	60% - 65%	Natural Gas, Biogas, Coal gas, H_2 - O_2 or Air

Since the fuel cell type that constitutes our study subject is Proton Exchange Membrane Fuel Cells, information about these fuel cells will be given and in the following sections, the performance evaluations of polymer electrolyte membrane fuel cells designed in different sizes will be explained.

1.1 Proton/Polymer Electrolyte/Exchange Membrane Fuel Cells

Scientific studies on proton exchange membrane fuel cells received noteworthy interest because of its broad and various implementations in electrochemical devices, chemical sensors, supercapacitors, batteries and power generation, leading to the planning of membrane electrode setups operating in distinct types of fuel cells. (Hammes-Schiffer and Soudackov, 2008; Kraytsberg and Ein-Eli, 2014; Kreuer, Paddison, Spohr and Schuster, 2004). PEMFCs are among the promising electrochemical manufacturing gadgets because of their superior productivity, eminent power intensiy and energy sources (Cleghorn, Springer, Wilson, Zawodzinski, Zawodzinski, and Gottesfeld, 1997; Li, Jensena, Savinell, and Bjerrum, 2009). They are known to have similar configurations to redox flow batteries (RFBs) type gadgets. These two device types have the potential to convert the chemical energy present in the energy vectors gained from renewable sources into electrical energy. However, the absence of liquid components that make PEMFCs more useful for use in mobile devices makes them advantageous over RFBs (Zhang and Sun, 2021). Figure 1 shows a schematic diagram showing the components of a single PEMFC. These alternative energy sources provide the opportunity to obtain energy from hydrogen and synthetic or bio-synthetic fuel and can operate more efficiently and with environmental sustainability than thermal engines (Scott and Shukla, 2004; Whittingham, Savinell, and Zawodzinski, 2004). Fuel cells which utilized for a diverse of technological applications, such as in mobile phones, portable electronic devices, and etc. are electrochemical devices (Campanari, Manzolini, and García de la Iglesia, 2009; Cano, Banham, Ye, Hintennach, Lu, Fowler, and Chen, 2018; Zhang and Shen, 2012).

The polymer electrolyte membrane, which forms the main component of the electrochemical device, also provides proton conductivity by ensuring the transport of protons from the anode part to the cathode part (Haile, Boysen, Chisholm and Merle, 2001). Membranes containing perfluorosulfonic acid polymers are widely utilized among various types of fuel cells due to their eminent conductivity properties and strong mechanical and chemical characteristics. Among these, Nafion® is one of the best known. These membranes are utilized in high relative humidity environments and temperatures below 90 °C. Nafion® was developed and marketed by DuPont before the 2000s. Nowadays, it is utilized as low-temperature PEM by various researchers and companies. The expensive production processes of Nafion-type membranes and the intense decrease in proton conductivity, which is important for system performance in low hydration-high temperature (above 90 °C) situations, are important disadvantages of these membranes in their operation as low-temperature PEMFCs. As a result of these limitations, the production process of PEMFCs that can operate at higher temperatures, taking into account the absence of water, has been initiated (Pineri and Eisenberg, 1987; Samms, Wasmus, and Savinell, 1996).

Figure 1. shows the different components of a single PEMFC. The core of a PEMFC is the MEA (Membrane Electrode Assembly), which consists of two catalytic materials that act as anodic and cathodic electrodes, separated by a PEM (Cruz-Martínez, Tellez-Cruz, Guerrero-Gutiérrez, Ramírez-Herrera, Salinas-Juárez, Velázquez-Osorio, and Solorza-Feria, 2019).

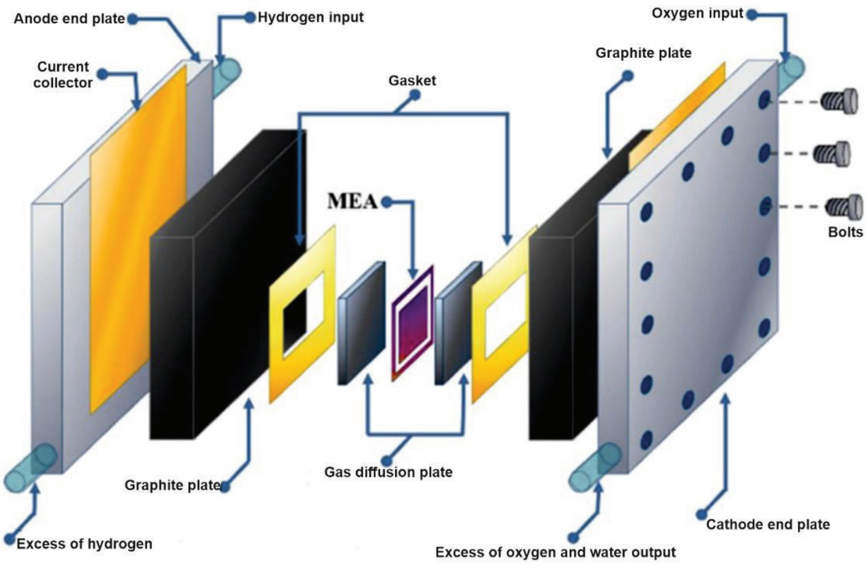


Figure 1. Different elements of a PEMFC (Cruz-Martínez et al., 2019)

1.2 Operating Principles of Proton Electrolyte/Exchange Membrane Fuel Cells

The operating principle of PEMFCs is that H2 fuel oxidizes at the anode, releasing electrons and forming protons. Electrons and protons then flow to the cathode through the external circuit and proton exchange membrane tightly placed between the anode and cathode, respectively. At the cathode, they combine with dissolved oxidizing O2 to produce water and heat. Fuel cell processes facilitate reactants moving through bipolar gas channel plates into GDLs (Gas Diffusion Layers). The function of GDLs is to spread the reactants over the catalyst layer with a more even distribution. In the catalyst layer, the reactants are then transported by diffusion and advection for an electrochemical reaction (Figure

2.). PEM can transport protons and dissolved water, but gases cannot penetrate (Magorosi,Oladiran, and Rakgati, 2020).

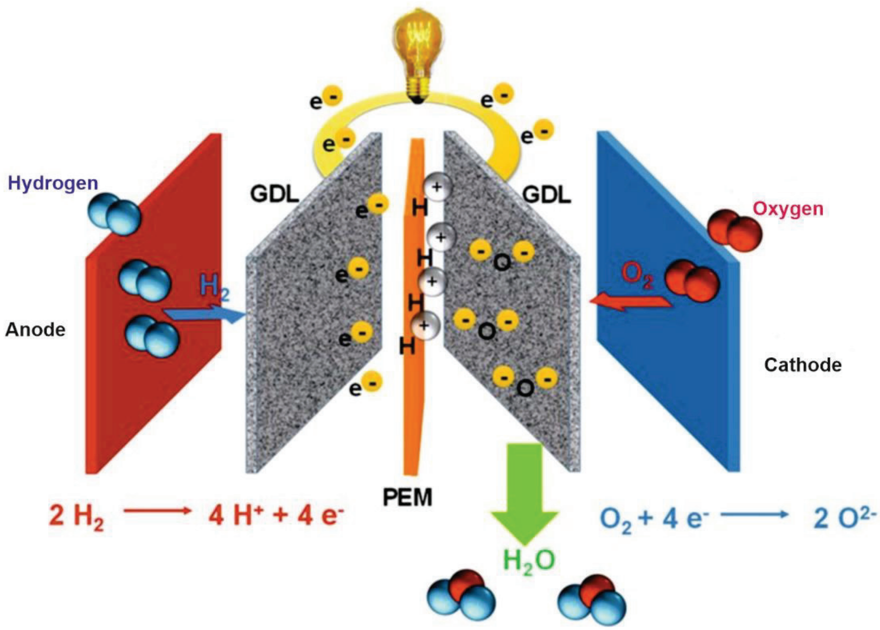


Figure 2. The operating principle of PEMFC (Magorosi et al., 2020)

1.3 Enhancement of Proton Exchange Membranes (PEMs)

Studies on the enhancement of new membranes with conductive properties for PEMFC implementations has increased recently (Esmaeili, Gray and Webb, 2019). The development of new environmentally and human-friendly alternatives to fossil fuels and efforts to reduce the concentration of carbon dioxide in the atmosphere have led scientists to conduct research on polymers that are stable and can operate over wide ranges. Among the many PEMFCs synthesized for these purposes, three need to be particularly noted (Wang, Chen, Mishler, Cho and Adroher, 2011). The first are those containing PFSA (Perfluorosulfonic Acid). For instance, Nafion is utilized quite intensively and is the most studied polymer in the fuel cell industry (Mauritz and Moore, 2004). Its use has led to a broad range of implementations, including in chlor-alkali processing technologies (Ito, Maeda, Nakano, and Takenaka 2011; Vidakovic-Koch, Gonzalez Martinez, Kuwertz, Kunz, Turek, and Sundmacher, 2012). Microbial fuel cells (Bakonyi, Koók, Rózsenberszki, Tóth, Bélafi-Bakó, and Nemestóthy, 2020; Chae, Choi, Ajayi, Park, Chang, and Kim, 2008), among others has become widespread, and merchant

Nafion type membranes of distinct coarseness can be purchased from various establishments.

The second main group consists of sulfonated aromatic polymers. The most studied sulfonated polymers are sulfonated poly ether ether ketone (SPEEK) and sulfonated poly arylene ether ketone (SPAEK) polymers. Poly ether ether ketone (PEEK), based on a linear polymeric basis, is a semi-crystalline polymer with a glass transition temperature of 143 °C and a melting point of 343 °C. This fluorine-free polymer shows high thermal stability and chemical resistance. The proton conductivity of the polymer can be significantly increased by the sulfonation feature of the aromatic position (Carbone, Pedicini, Portale, Longo, D'Ilario, and Passalacqua, 2006). This enables operation at temperatures where electrochemical reaction rates increase (Kaliaguine, Mikhailenko, Wang, Xing, Robertson, and Guiver, 2003).

The third and final class of polymers are those associated with heterocyclic systems containing derivatives of polybenzimidazole (PBI) (Escorihuela, Olvera-Mancilla, Alexandrova, del Castillo and Compañ, 2020). Recently, the synthesis of PBI-based polymer types that perform well as PEMFCs in several new fields has been achieved (Escorihuela et al., 2020; Liu, Khan, Lee, Kim, Akhtar, and Han, 2013; Wang, Ni, Liu, Gong, and Wang, 2018). The high thermal stability of PBI polymers and their derivatives has led to the idea of considering them as potential polymers as high-temperature PEMFCs. Despite its superb mechanical and thermal stability, pure PBI has low conductivity and these membranes need to be supported with inorganic acids which is by far the most commonly used (Aili, Henkensmeier, Martin, Singh, Hu, Jensen and Qingfeng, 2020).

2. General Information

2.1 Previous Studies

There are many factors that affect the performance of PEMFCs. As a result of the literature research, it has been determined that performance evaluation has been tried to be determined by applying different methods in many different applications. Considering the developing technology over the years, it has been determined that the structures of fuel cells have been tried to be improved with innovative processes and performance evaluations have been carried out in this direction. In order to better emphasize the importance of the subject, this section provides information about some recent studies. (Han, Park and Chung, 2016) presented an operation optimization method and demonstrated its implementation to a PEMFC system. For this purpose, researchers studied on the optimization problem to maximize system efficiency. Many types of modeling were developed with the help of artificial neural networks and semi-empirical equations.

Optimization values showed that the efficiency difference could reach 1.2-5.5% depending on the power output range. As a result of the study, the difference between the measured and predicted values was determined to be insignificant. This showed that the proposed method was successful in increasing the system efficiency of the fuel cell. (Vazifeshenas, Sedighi and Shakeri, 2016) examined the effect of composite flow field application in PEMFC by utilizing computational fluid dynamics. Validation studies were carried out using simulations. Observations were made using different reactant parameters. It was determined that especially the way the reactants were distributed on the surface affected the system performance. (Mubin, Bahrom, Azri, Ibrahim, Rahim, and Raihan, 2017) developed mathematical thermodynamic modeling and examined its effect on PEMFC performance. The efficiency of the model was figured out by applying the energy conversion gadget equations on thermal efficiency and was found to be 33.8%. It was found that the voltage output performance of PEMFC could be increased by increasing the input pressure and temperature of hydrogen. (Özgür and Yakaryilmaz, 2018) examined the 1 kW Horizon H-1000 XP PEMFC in their study on exergy and energy analysis. In the study, a test device was established and system efficiency analysis was carried out in accordance with the laws of thermodynamics. In the established mechanism, pure hydrogen was used directly as fuel. By changing the operating temperature and pressure, the performance of the system was examined with experimental and exergy-based parameters. The energy efficiency of the fuel cell was determined as 45.58% in the experimental examination and 41.27% in the parametric examination. (Parnian, Rowshanzamir, Prasad, and Advani, 2018) examined SPEEK-based membranes containing SeO2 nanoparticles in terms of performance and durability parameters. Various membranes were synthesized and their physicochemical properties were analyzed through tests such as TGA, XRD and FESEM. As a result of mechanical and thermal analyses, it was determined that the nanocomposite membrane had more advanced properties than the pure SPEEK membrane. (Toghyani, Nafchi, Afshari, Hasanpour, Baniasadi, and Atyabi, 2018) examined the effect of compression pressure on the performance of a PEMFC in terms of three different channel widths. The deformation of the GDL due to compression pressure was modeled and used as input in the Computational Fluid Dynamics (CFD) model. In the study, factors such as temperature distribution and mole fraction were also examined to determine the geometry with the best performance. As a result of the study and experiments, it was determined that when the channel width was reduced, the flow rate increased and the performance of PEMFC increased. (Huang, Ding and Zou, 2020) studied waste heat recycling by combining a thermoelectric generator and cooler with a PEMFC. For this new modeling in their research, they also derived a series of analytical formulas to examine the power output factor. The parameter known as the ecological performance coefficient was determined as the objective function in evaluating the system performance. When compared with the individual fuel cell, it was determined that the maximum power density and ecological performance coefficient of this new hybrid system increased by 1.42% and 4.47%, respectively. When the Thompson effect was examined, it was determined that it might have a negative impact on the system performance to some extent. (Nalbant, Colpan and Devrim, 2020) conducted a mathematical modeling study of a high-temperature PEMFC with a natural gas-fed energy system. In the study, analyzes were made by examining the effects of some basic parameters (operating temperature, etc.) on system performance (various efficiency values). It was determined that the parameter that has the greatest impact on system performance is the anode stoichiometric ratio. Wilberforce and Olabi (2020) investigated the application of using an artificial neural network (ANN) to determine voltage and current in a proton exchange membrane fuel cell with a membrane area of 11.46 cm2. Performance predictability for group data processing method (GDPM) as well as feed-forward back propagation (FFBP) neural networks have been used to predict the current and voltage obtained from the PEMFC under investigation. The research revealed that the GDPM neural network outperformed the FFBP neural network. Therefore, the study recommended GDPM neural network as the best model to predict the performance of a Proton Exchange Membrane Fuel Cell. Additionally, it was determined that an increase in the reactant flow rate had a direct effect on the performance of the fuel cell, but this was directly proportional to the total irreversibilities in the battery. And therefore it was necessary to make the hydrogen flow lower for the fuel cell to operate economically. (Omran, Lucchesi, Smith, Alaswad, Amiri, Wilberforce and Olabi, 2021) studied the mathematical modeling of a PEMFC combined with a resistive load. In the study, the electric current parameter was determined by the intersection of the polarization curve and used as the input value to determine the PEM fuel cell performance. Differences varied between 2% and 6% depending on the applied load resistance. A controlled current source was used to simulate the variation of fan power consumption with stack temperature ranging from 36.5 W at 23 °C to 52 W at 65 °C. Both the model and the experiments showed an overall PEMFC system maximum efficiency of approximately 48%.

3. Material and Method

In this study titled Evaluation of the Performance of Polymer Electrolyte Membrane Fuel Cells (PEMFC) Designed in Different Sizes, a device called Scribner 850e Multi Range Fuel Cell Test System was used to carry out the tests. Research and publication ethics were complied with in this study. The Model 850 Multi-Range Fuel Cell Test System features a complete test station for the operation and measurement of PEM/DMFC fuel cells. The Model 850 is ideal for single-cell and short-stack fuel cell research and university programs. The Model 850 combines a computer-controlled device with fuel processing hardware in an integrated benchtop unit. The 850 uses the proven 890 as the basis for the electronic payload design. The powerful FuelCell® software package is included in the system to control station operation (The Model 850 Fuel Cell Test System, 2023). Photos of the 850e Multi Range Fuel Cell Test System used to perform the tests are given in Figure 3.

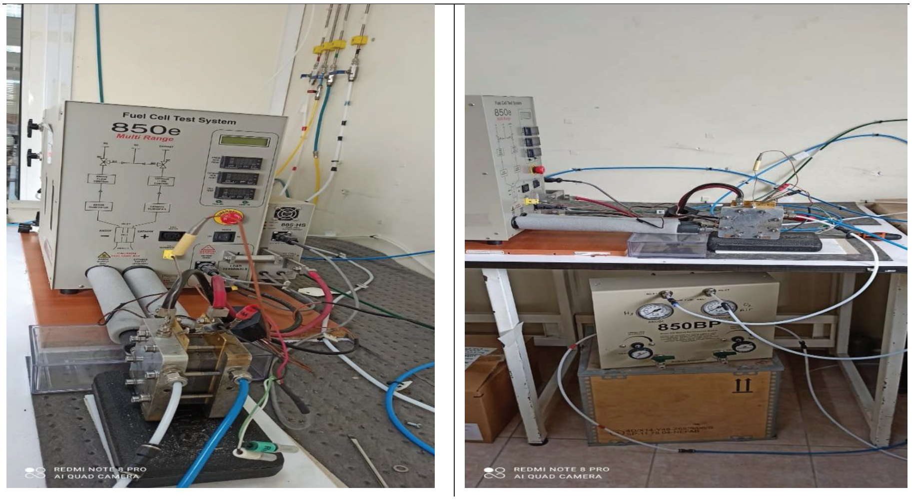


Figure 3. Views of the 850e Multi Range Fuel Cell Test System

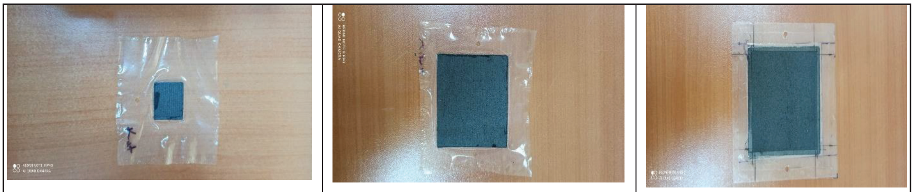
In addition to the information mentioned above, the 850e Multi Range Fuel Cell Test System has some important advantages and features. Table 3.1 provides information summarizing the features of the 850e Multi Range Fuel Cell Test System (The Model 850 Fuel Cell Test System, 2023).

Table 2. Various Features of the 850e Multi Range Fuel Cell Test System (The Model 850 Fuel Cell Test System, 2023)

1. Multiple current range electronic load options: 5/25/50 A or 10/50/100 A, 100 W, 20 V
2. Convenient for PEM cells up to 50 cm^2.
3.User-friendly computer-controlled cell operation and FuelCell® software for experimentation
4. Temperature controlled high performance 316L stainless steel humidifiers and heated gas transfer lines
5. Computer control of anode and cathode mass flow rates

6. Automatic control of N2 purge gas into the cell
7. Detection of pressure loss for reactant and purge gases
8. Current, voltage or power control modes
9. Continuous real-time cell resistance and IR-free voltage measurement with current interruption
10. Two high impedance reference inputs for full cell voltage plus half cell data
11. Cell main terminals tolerant to a non-insulated cell and detection inputs
12. Automatic Water Filling for Humidifiers
13. Detection of alarm conditions and automatic hardware

During the experiments, 5 cm^2, 25 cm^2 and 50 cm^2 electrodes were used as Membrane Electrode Assemblies (MEA). The appearances of the MEAs used in the experiments are shown in Figure 4.



(a) (b) (c)

Figure 4. MEAs used in the experiments (a) 5 cm^2, (b) 25 cm^2 and (c) 50 cm^2

Before starting the analysis and experimental performance tests of PEMFC, suitable materials were selected for the components of the fuel cell to be used. In the selection of these materials, parameters such as desired electrical and heat conduction, gas permeability, adequate mechanical strength and chemical stability, suitable and cheap in high-volume manufacturing methods, corrosion resistance and low density are important. In order to calculate the voltage produced in fuel cells, energy must first be explained. In addition, it is not possible to obtain full efficiency during the reaction. Since full efficiency cannot be achieved, lost heat occurs. Not all of the heating value of hydrogen can be used efficiently. Gibbs free energy, which expresses the energy difference between reactants and products and useful energy, is defined as follows.

The cell polarization curve obtained by subtracting activation, ohmic and condensation losses from the theoretical cell voltage was calculated. Anode and cathode activation losses are considered the same, but the majority of losses occur at the cathode due to the slowness of the oxygen reduction reaction.

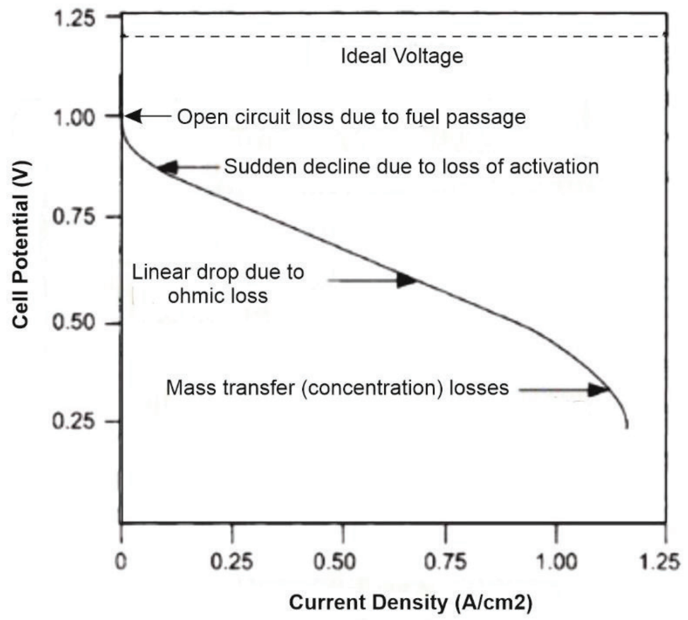


Figure 5. Voltage-Current Density Characteristic of Fuel Cell

$$V_K = V_{akt} + V_{ohm} + V_{kon} \tag{1}$$

The value of Gibbs free energy can be taken at different values for different temperatures. Negative values indicate that energy is released. ΔS in the Gibbs free energy formula expresses the lost energy (entropy) resulting from the reactants and the products occured as a result of the reaction, as seen in expression (2).

$$G0 = \Delta H - T.\ \Delta S \tag{2}$$

Theoretically, the maximum fuel cell efficiency is calculated by assuming that all Gibbs free energy is converted into electrical energy.

$$W_{elk} = V_r \cdot Q \tag{3}$$

$$Q = n \cdot F \tag{4}$$

$$G_0 = -n \cdot F \cdot V_r \tag{5}$$

$$V_r = -\frac{\Delta H - T \cdot \Delta S}{n \cdot F} \tag{6}$$

In order to examine the test results accurately, measurements were made with the Hydrogen Control System. The temperatures of hydrogen and oxygen gases before they entered the system were determined and it was checked whether the system worked as desired at these temperatures. In order for the system to work properly, the temperature, humidity and flow rate values of the fuels were determined.

4. Results and Discussion

PEM fuel cells with sizes of 5 cm^2, 25 cm^2 and 50 cm^2 were used in the study. The performances of fuel cells of different sizes were compared. As a result of this comparison, it was determined which fuel cell size had the best performance. There are gas flow channels on the surface of the bipolar plate for the distribution of reactant gases within the fuel cell. Channel geometry may be different. In addition, the flow direction of the reactants in the fuel cell system can be equal or opposite as desired. The selection and optimization of the bipolar plate gas flow channel pattern greatly affects the performance of the fuel cell.

In three fuel cells, the current density value corresponding to the decreasing voltage value increased. These large increases continued up to 1V for the three-cell fuel cell and 0.5V for the single-cell fuel cell, and the increases in current density after these values decreased. Losses may take different forms depending on the number of cells. These losses may occur due to reasons such as disruptions in the stack connection, pressure drop due to friction, and increase in the number of transitions through which the reactants move.

It can be seen in Figure 6 that the amount of electrical power to be produced increases due to the increase in the number of cells in the PEM fuel cell.

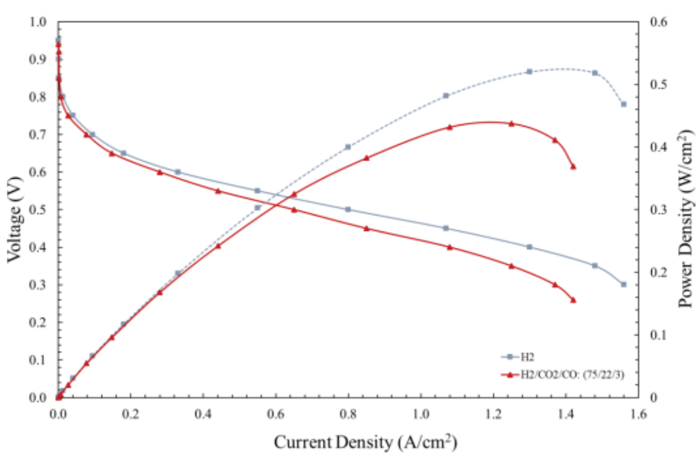


Figure 6. Electrical power to be produced due to the increase in the number of cells

As seen in Figure 4.1; when measurements were made within these given values range, it was observed that there was not much difference in volt values when the temperature values were increased at certain intervals. The appropriate temperature for the system was 10 °C, humidity was 20%, 9.8 Volt, 9.4 A. Current values were taken, checking the change in Watt values and looking at the system performance, the results were given in Table 4.1-2-3.

If we consider the value of approximately 25-50 cm2 here, it is observed that the electrical power obtained from fuel cells increases up to this value and starts to decrease at 5 cm2. The maximum electrical power values obtained from these three fuel cells are calculated as 2.40E+00 W, 9.88E+00 W and 19.89 W. This is due to the decrease in the resulting current density. This again occurs due to losses depending on the size of the fuel cell.

Table 3. Power data according to C-H ratio of a fuel cell with a surface area of 5 cm^2

C-H ratio in fuel cell	Current I (mA/cm^2)	Power (Watts)	Temperature (°C)	RH_Anode (%)	RH_Cathode (%)
C60H45	2,49E+03	2,40E+00	6,00E+01	4,83E+01	4,83E+01
C60H60	2,64E+03	2,75E+00	6,05E+01	5,02E+01	5,06E+01
C70H55	2,55E+03	2,51E+00	7,06E+01	5,01E+01	5,02E+01
C70H70	2,59E+03	2,67E+00	7,03E+01	9,91E+01	9,91E+01

Table 4. Power data according to C-H ratio of a fuel cell with a surface area of 50 cm^2

C-H ratio in fuel cell	Current I (mA/cm^2)	Power (Watts)	Temperature (°C)	RH_Anode (%)	RH_Cathode (%)
C60H46	9,74E+02	9,88E+00	6,04E+01	4,98E+01	4,98E+01
C60H60	9,42E+02	9,66E+00	6,04E+01	9,81E+01	9,74E+01
C70H55	8,29E+02	7,88E+00	6,98E+01	5,01E+01	5,07E+01
C70H70	7,62E+02	8,18E+00	7,00E+01	9,91E+01	9,83E+01
C80H65	5,80E+02	4,54E+00	7,98E+01	5,24E+01	5,29E+01

Table 5. Power data according to C-H ratio of a fuel cell with a surface area of 50 cm^2

C-H ratio in fuel cell	Current I (mA/cm^2)	Power (Watts)	Temperature (^oC)	RH_Anode (%)	RH_Cathode (%)
C60H46	9,74E+02	19,89E+00	8,04E+01	5,98E+01	5,98E+01
C60H60	9,42E+02	19,87E+00	9,04E+01	10,81E+01	10,71E+01
C70H55	8,29E+02	17,81E+00	8,98E+01	9,01E+01	9,17E+01
C70H70	7,62E+02	18,10E+00	7,00E+01	9,90E+01	9,13E+01
C80H65	5,80E+02	17,50E+00	7,98E+01	5,24E+01	5,29E+01

5. Conclusions and Recommendations

In the study, PEM fuel cells with sizes of 5 cm^2, 25 cm^2 and 50 cm^2 were produced. The performances of fuel cells of different sizes were compared. The behavior of the fuel cell was determined according to the best operating temperatures and C-H percentage values, and power values were found according to the current generated. The results obtained in the current study;

- PEM fuel cell efficiency decreases because ion transfer decreases at high temperatures.
- Due to the increase in the amount of catalyst used in the fuel cell, hydrogen production increased, which in turn reduces the efficiency of the fuel cell.
- It was determined that the fuel cell with C60H60 content with a surface area of 5 cm^2 showed the best performance.
- It was determined that the fuel cell with C60H46 content with a surface area of 25 cm^2 showed the best performance.
- It was determined that the fuel cell with C60H46 content with a surface area of 50 cm^2 showed the best performance.
- It was concluded that large surface area and low temperatures should be preferred in fuel cell cell production.

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