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Pressure analysis investigation of PEM electrolyzer cell used for green hydrogen production

Yeşil hidrojen üretimi amaçlı kullanılan PEM elektrolizör hücresinin basınç analizi incelemesi

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Pressure Analysis Investigation of PEM Electrolyzer Cell Used for Green Hydrogen Production

Highlights

- *Hydrogen production without greenhouse gas production*
- *Increasing cell efficiency of PEM electrolyzer*
- *Pressure distributions in a PEM electrolyzer cell*
- *Pressure and production relationship in PEM electrolyzer cells*

Graphical Abstract

In this study, a large pressure fluctuation between 0-1.6 seconds in a PEM electrolyzer cell with a constant flow rate of water was investigated. In addition, the effect on the hydrogen gas produced per unit was investigated by changing the geometric parameters of the electrolyzer cell.

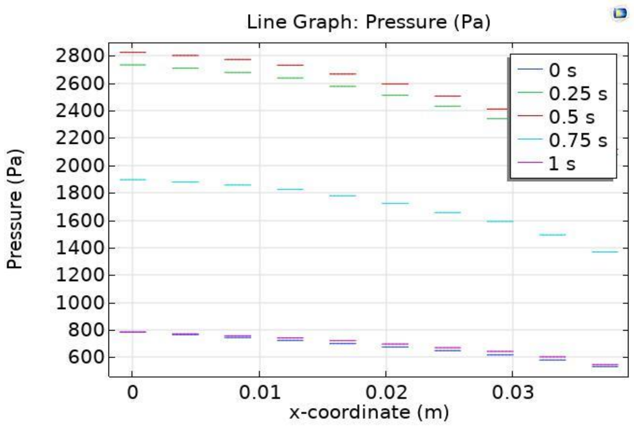

Figure. *Pressure change in the cell from the start of the analysis to the 1st second*

Aim

In this study, the effect of pressure distribution in a PEM electrolyser cell with CFD analysis was investigated by changing the model parameters. When the pressure fluctuations started and when they ended and the effect of these fluctuations on production were examined.

Design & Methodology

A detailed literature review was made and the studies in this field were carefully examined. The geometry created in the computer environment was analyzed with the COMSOL software.

Originality

Similar studies and analyzes in this area have been made on the basis of oxygen, and as far as is known, there is no similar study related to green hydrogen production.

Findings

Changing the channel number and channel length of the designed PEM electrolyzer cell affects the pressure fluctuations and production amounts in the system. The geometry of the PEM cell can be changed to avoid unwanted pressure fluctuations.

Conclusion

Hydrogen production per unit area per unit second decreases as the number of channels increases at a constant inlet flow rate In an electrolysis cell with a constant water flow inlet, the number of channels and the unit gas production amount and pressure distribution can be regulated.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Pressure Analysis Investigation of PEM Electrolyzer Cell Used for Green Hydrogen Production

Araştırma Makalesi / Research Article

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ABSTRACT

Increasing environmental concerns with climate change have led many people around the world to demand urgent action, forcing national governments to seek alternatives to carbon-based fuels. In the light of all this, it is of critical importance for our civilization that carbon-based energy sources are rapidly replaced by renewable and sustainable sources without carbon emissions. For this reason, the use of these clean energy sources and the efficiency of the processes in their production is a very important issue. In this study, 3-dimensional, two-phase (hydrogen and water) computational fluid dynamics (CFD) analysis was performed in a polymer electrolysis membrane cell (PEM). Analysis took place for 30 seconds. The water flow rate was kept constant at 260 ml/min. As a result of the analysis, pressure, gas volume fraction and velocity data in the manifolds and in the electrolysis channels where the electrolysis process takes place were interpreted. While the pressure change in the cell was quite high in the range of 0-1.8 seconds from the beginning of the flow, it was observed that a balance was formed in the pressure distribution after 1.8 seconds. It is understood that the number of channels in the model is a factor for the pressure inside the manifold and the cell. However, it was observed that the unit gas production amount in the cell also changed along the channels.

Keywords: Green hydrogen, CFD, pressure analysis, electrolysis, PEM, two phase flow.

Yeşil Hidrojen Üretimi Amaçlı kullanılan PEM Elektrolizör Hücresinin Basınç Analizi İncelemesi

ÖZ

İklim değişikliğiyle beraber yükselen çevresel kaygılar, dünyada birçok insanın acil eylem talep etmesine yol açarak, ulusal hükümetleri karbon kaynaklı yakıtların alternatiflerini aramaya mecbur bırakmıştır. Tüm bunların ışığında karbon kaynaklı enerji kaynaklarının yerini süratle karbon emisyonu olmayan yenilenebilir ve sürdürülebilir kaynakların alması medeniyetimiz için kritik bir öneme sahiptir. Bu sebeple bu temiz enerji kaynaklarının kullanımı ve üretimindeki proseslerin verimliliği oldukça önemli bir konudur. Bu çalışmada bir polimer elektroliz membran hücresinde (PEM), 3 boyutlu, iki fazlı (hidrojen ve su) hesaplamalı akışkanlar dinamiği (CFD) analizi yapılmıştır. Analiz 30 sn boyunca gerçekleşmiştir. Su akış hızı 260 ml/dk olarak sabit tutuldu. Analiz sonucunda manifoltlarda ve elektroliz işleminin gerçekleştiği elektroliz kanallarında basınç, gaz hacim fraksiyonu ve hız verileri yorumlandı. Akış başlangıcından itibaren 0-1.8 sn aralığında hücre içindeki basınç değişimi oldukça fazlayken, 1,8.saniyeden sonra basınç dağılımında bir dengenin oluştuğu gözlemlenmiştir. Modeldeki kanal sayısının manifold ve hücre içindeki basınç için bir faktör olduğu anlaşılmıştır. Bununla birlikte hücredeki birim gaz üretim miktarının da kanallar boyunca değiştiği gözlemlenmiştir.

Anahtar Kelimeler: Yeşil hidrojen, CFD, basınç analizi, elektroliz, PEM, iki fazlı akış.

1. INTRODUCTION

Throughout their history, people have tried to use energy for their own benefit. From the discovery of fire to the industrial revolution, both the energy source and the way of application have changed in line with the level of their civilizations. With the industrial revolution and the discovery of the steam engine, energy and energy-based inventions are central to the development of our civilization. However, technological advances and the use of energy have led to the development of each other and have caused each period without energy to become unbearable. In today's civilization, the source of the energy we use in obtaining electrical energy, which is indispensable in our lives, and in transportation is carbon-based fuels such as gasoline and diesel.

As a world that is no longer a luxury but accustomed to the technology we need for the continuation of our lives, the supply of energy resources is a very important issue. Since the last quarter of the last century, many conflicts have arisen in the world due to energy sharing and sharing of energy resources. It is accepted by almost everyone that these conflicts will continue.

Another fact is that the fossil fuels used as an energy source are not sustainable and will run out one day. At

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this point, the use of alternative energy sources will become important. For this reason, it is aimed to use renewable and sustainable energy resources efficiently in the world and in our country.

In the near future, an economy based on green hydrogen obtained from renewable energy sources will be formed in the world and it will positively affect all other sectors. For this reason, the use of hydrogen and hydrogen fuel cells should be taken into account in the technological developments of vehicle manufacturers, the transportation sector, the energy industry and even domestic use vehicle manufacturers. [1]

There is a reason at the root of mankind's search for an energy source, which has shifted from wood, coal, oil, and natural gas to hydrogen, a carbon-free fuel throughout history. This is due to the fact that the use of fuels with a high C/H ratio and the high damage to the environment and living spaces are known and trying to prevent this. [2]

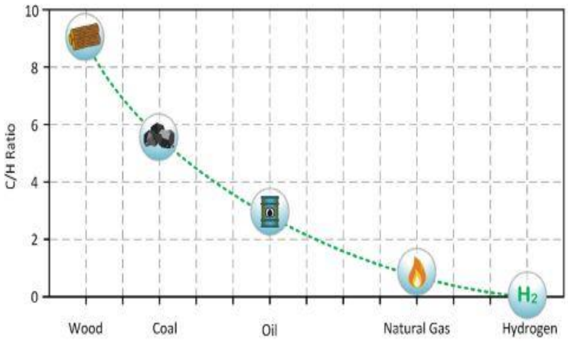

Figure 1. Change of carbon and hydrogen ratio of fuels over centuries [3]

Greenhouse gas emissions from industrialization increased substantially in the middle of the 19th century. The amount of CO2 in the atmosphere is regulated by many natural factors in the carbon cycle. Although these natural factors absorb the CO2 emissions released every year, the CO2 emissions released since about 1950 have started to exceed the capacity of these natural factors. This has resulted in a steady increase in the proportion of greenhouse gases in the atmosphere since 1950.

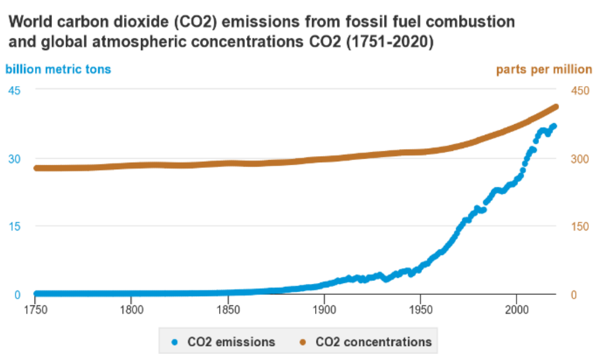

Figure 2. World carbon dioxide (CO2) emissions from fossil fuel combustion and global atmospheric concentrations CO2 (1751-2020) [4]

According to all these emission values, it is clear that our civilization has reached a breaking point. If serious measures are not taken regarding the release of these emission values, it is inevitable to face environmental disasters caused by emission rates. It is obvious that the average temperature of the world increases with increasing emissions and this situation causes a major climate problem. With the increase in average temperatures, the glaciers are melting at an increasing rate day by day. Increasing melting of glaciers is also accelerating climate change. The only way to get out of this circle of negativities that trigger each other is to take immediate steps to reduce emission values. In addition, the weather events observed due to the increasing average temperature increase their severity every year. For this reason, typhoons and storms that we have not seen until now occur. The loss of life and property increases with each passing year.

Failure to reduce carbon emissions may cause irreparable damage to our basic living spaces, from our diet to the quality of the air we breathe. along with these, the yield and quality of the products (rice, corn, wheat, etc.) produced with modern agriculture will decrease, and serious problems are foreseen in growing these products. In addition, natural events such as floods, hurricanes, and typhoons caused by increased evaporation will occur more frequently, the climate balance and seasonal cycles will shift, and as a result of all these, the life of all Earth creatures will be endangered.

In these days when the effects of carbon emissions are so great that they can no longer be ignored, the most important point of combating carbon emissions is to first identify the sources that cause it and to help the alternatives develop in a short time.

In order to reduce harmful emissions and reduce dependence on fossil fuels, it is necessary to use clean and sustainable energy sources. Alternative sources that can replace fossil fuels are alternative energy sources such as geothermal, solar, wind, wave, which are more reliable in terms of lower emission production and sustainability. With the help of these renewable energy sources and developing technology, carbon emissions can be significantly reduced.

The latest data on CO2 emissions in 2021 shows a re-increase in emissions compared to 2020, which was strongly affected by covid-19 globally. CO2 emissions in 2021 increased by 5.3% compared to 2020.

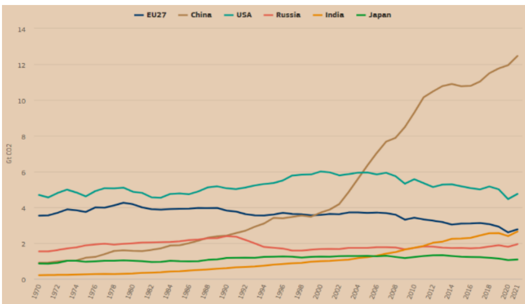

Figure 3. CO_2 emissions 1970-2021 [5]

Since the beginning of the 21st century, global fossil CO2 emissions have increased steadily compared to the previous three decades, mainly due to the increase in fossil CO2 emissions from China, India and other emerging economies. The COVID-19 crisis slowed the global economy in the first half of 2020, interrupting global growth in CO2 emissions, followed by a recovery in 2021. [5]

In Turkey, on the other hand, according to greenhouse gas inventory statistics, energy-related emissions have the largest share of CO2 equivalent with 70.2%. After energy, agriculture with 14%, industrial processes and product use with 12.7% and waste sector with 3.1%. [6]

If we continue to look at Turkey's CO2 emission statistics, energy-related emissions increased by 319% in 2021 compared to 1990, increased by 90% compared to 2005, and increased by 6% compared to 2020. CO2 emissions due to industrial facilities, which is another item, increased by 139% in 2021 compared to 1990, 49% compared to 2005, and 11% compared to 2020. CO2 emissions from buildings increased by 170% in 2021 compared to 1990, 81% compared to 2005, and 15% compared to 2020. CO2 emissions from transportation increased by 178% in 2021 compared to 1190, by 109% compared to 2005, and by 3% compared to 2020. Apart from these, carbon emissions from other sectors increased by 182% in 2021 compared to 1990, 113% compared to 2005, and 6% compared to 2020. [5]

Figure 4. Fossil CO2 emission by sector of Turkey [5]

Table 1. Fossil CO_2 emission by sector of Turkey [5]

Year	CO_2 emissions Mt CO_2/yr	CO_2 emissions per capita t CO_2/cap/yr	CO_2 emissions per unit of GDP PPP t CO_2/kUSD/yr	Population
2021	449.725	5.321	0.169	84.514M
2020	416.514	4.968	0.174	83.836M
2005	244.745	3.604	0.197	67.903M
1990	150.428	2.790	0.221	53.922M

All these statistics show that we are in a critical period when we need to put the age of carbon-based resources behind us and enter the age of hydrogen. Although hydrogen is a clean energy solution, it is a clean solution that the world is rapidly gaining interest in.

Hydrogen is an element discovered in the 1500s. It has the simplest atomic structure and is the most common element in the universe. It is a colorless, odorless, completely non-toxic gas that is 14.4 times lighter than air. It is the most basic fuel in the thermonuclear equation, which is the source of heat on the basis of the Sun and other stars in the universe. It turns into a liquid at -252.77 ^{0}C under atmospheric pressure.

Hydrogen is the fuel that gives the most energy per unit mass of all known combustibles. 1 kg of hydrogen provides the energy of 2.1 kg of natural gas or 2.8 kg of oil. Hydrogen is not found free in nature, it exists in compounds. The most well-known compound is water, the source of our life. Apart from these, it is also found in the form of organic compounds. In energy systems where it is used as a fuel, the product released to the atmosphere as a result of the combustion reaction is water or water vapor. Apart from water vapor, environmental pollutants such as carbon dioxide (CO2) and carbon monoxide (CO) do not occur that increase the greenhouse effect.

Since it is found in nature as compounds, it must go through a number of processes to obtain it. [1] For this reason, the costs incurred are not less at all.

Table 2. Calorific Value Tables

Fuel	Calorific Value (kJ/kg)
Cow dung cake	6000-8000
Wood	17000-22000
Coal	25000-33000
Petrol	45000
Kerosene	45000
Diesel	45000
Methane	50000
CNG	50000
LPG	55000
Biogas	35000-40000
Hydrogen	150000

As there are many methods for obtaining hydrogen gas, efficiency studies of these methods are a very popular academic subject today. Main methods of hydrogen production;

- Thermochemical Methods (Coal gasification, methane-steam reforming, non-catalytic partial oxidation, production from natural gas…)
- Electrolysis
- Renewable Energy(Sun,Wind)-Hydrogen Systems

Hydrogen is one of the most important resources that will help us to make the climate more protective, some of the products and practices that we do not want to give up in our modern society and civilization. Hydrogen is sometimes called the “champagne of energy transformation” because it is so valuable and must be reserved for use in special situations.

According to 2019 prices, the cost of producing one kilogram of green hydrogen is 5 US dollars, while the production of the same amount of blue hydrogen is 3.5 dollars and the cost of gray hydrogen is 1.5 dollars. [7]

Today, the cost of green hydrogen production is quite high. However, with the development of technology in the near future, green hydrogen production costs are expected to decrease. Between 2010 and 2019, the costs of solar photovoltaics decreased by 82%, the cost of ground-based solar power plants by 47%, the cost of onshore wind power plants by 40%, and the cost of offshore wind power plants by 29%. [8] Today, the costs of electrolysers have fallen by around 60% and are expected to continue to decline. [9] According to estimates published by BloombergNEF, the production cost of green hydrogen may decrease to 0.8-1.6 dollars/kg before 2050. This price is almost equal to the gas price of $6-12/MMbtu and also shows that it competes with current gas prices in some countries. [10] Wood Mackanzie predicts that green hydrogen production costs will fall by as much as 64% on average to equal fossil-based hydrogen by 2040. [11]

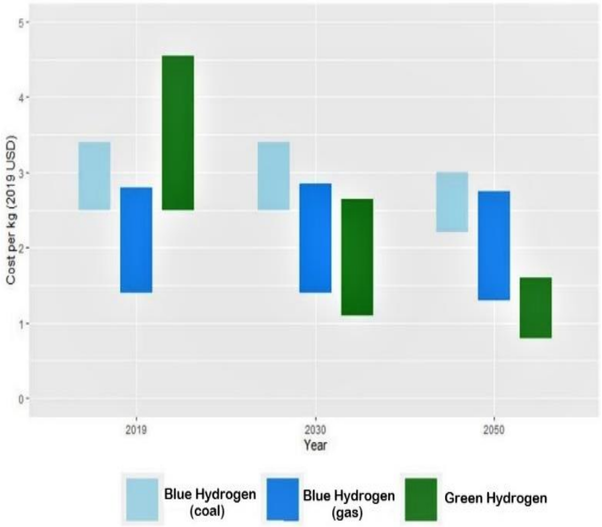

Figure 5. Global cost of hydrogen [6]

In the light of all this information, the electrolyzer systems used in hydrogen production and the efficiency of fuel cells using hydrogen as an energy source are important research topics.

Tijani et al. simulated a computer-generated flow plate to evaluate pressure gradients. In the simulation results, they observed that the sharpness and smoothness of the pressure gradients changed according to the design of the platen, and that the velocity fields acted in positive correlation with the pressure curves. [12]

Alvares-Gallegos et al. simulated velocity profiles of a laboratory electrolyzer using ANSYS-FLUENT. Using the Navier-Stokes equations in the solution, the electrode edges are divided into 7 sections and the depth of the channels is divided into 3 planes. They observed that the flow generated as a result of the simulation is strongly influenced by the manifold at both the inlet and outlet of the channel. [13]

Lim et al. performed a three-dimensional CFD simulation of a PEM cell electrolyzer and evaluated its performance under different conditions. They observed that the results of the model and the results of the in-house experiment were compatible. They observed a good agreement between CFD analysis results and experimental measurement results at varying cell voltages. [14]

Taymaz and Özdemir found that PEM fuel cell performance largely depends on the geometry, configuration and size of the flow channels. This CFD analysis investigated with Ansys-Fluent investigated the effect of flow field configurations on steady-state cell performance. [15]

İlbaş, Çimen and Kümük developed solid oxide fuel cell models and investigated the numerical effects of cell configuration on performance. These effects are demonstrated by polarization and power curves using COMSOL software. As a result of the study, they observed that the planar SCF performance is more efficient than the cylindrical SCF performance. [16]

Taymaz and Özdemir investigated the effect of reagent humidification on cell performance. After the CFD analysis, they found that reducing the relative humidity of the cathode inlet gas from 100% to 10% at high current densities significantly increased the performance. [17]

Sözen and Yağcı researched Turkey's energy efficiency and renewable energy efficiency between the years 2015-2017. According to the total factor efficiency results, they found that Turkey showed a 1% decline in energy efficiency and 12% in renewable energy efficiency. [18]

İlbaş ve Candan, investigated the effect of CO2 in methane and hydrogen on combustion instability. They observed that combustion instability decreases for higher CO dilution rates.[19]

2.MODELS AND PARAMETERS

In this problem, velocity vectors, fluid volumes and pressure distributions in the inlet and outlet manifolds and electrolysis channels of a PEM electrolysis cell are investigated.

Hydrogen gas is produced along the electrolysis channels defined on the electrode surfaces.

Cathode reaction:

$$2\,H_2O\,(s) + 2\,e^- \rightarrow H_2\,(g) + 2\,OH^- \quad (1)$$

Anode reaction:

$$2\,OH^- \rightarrow 1/2\,O_2\,(g) + H_2O\,(lq) \quad (2)$$

Net reaction:

$$H_2O\,(s) \rightarrow H_2\,(g) + O_2\,(g) \quad (3)$$

$$2\,H_2O(s) \rightarrow O_2\,(g) + 4H^+ + 4e^- \quad (4)$$

PEM electrolyzer cells consist of a proton membrane that allows only protons to pass, an anode catalyst layer in which water is broken down by electrochemical reaction and hydrogen is formed, a cathode catalyst layer in which hydrogen is formed, and electrode layers that undertake the task of transmitting and removing liquids and gases to the catalyst surfaces at the same time, where electricity is applied. Water entering the cell from the anode inlet decomposes into hydrogen and oxygen gas in the anode catalyst layer.

Assuming 0.625 mg/sec water inlet from the inlet, an inlet boundary condition is introduced into the program. On the outlet side, a pressure condition has been introduced instead of the flow rate. a fixed wallbird is set for all other boundaries. Finally, a gravitational vector in the -z direction is defined all around the cell.

The simulation was analyzed in 2 separate steps. It is a single-phase stagnant flow system with no hydrogen production as the first step. When this solution is finished, it contains the initial conditions for the two-phase flow, from which hydrogen will then be produced. The two-phase flow simulation lasting 30 seconds starts after the single-phase flow is completed.

Table 3. Parameters

23	Number of electrode channels
118*0.889	Electrode channel lengths
22,5[deg]	Rotation angle, inlet/outlet
0.889[mm]	Channel height
2[cm]	Inlet/outlet channel length
1.27[cm]/2	Radius of inlet tube
2.07[mm]	Channel width
260[ml/min]	Inlet water flow rate, full cell

$$\text{Re}=\frac{\rho u D}{\mu} \tag{5}$$

$$\text{Re} = \frac{\rho u D}{\mu} = \frac{10000\ x\ 1.3\ x\ (\ 2\ x\ 0{,}889\ x\ E-3)}{E-3} = 2300$$

Thanks to these 3D line datasets, the relevant values could be read from the relevant parts and used in the creation of the graphs.

The velocity input and pressure output are used as boundary conditions at the inlet and outlet. The force effects caused by gravity are processed in the whole model such that the gravity vector acts downwards in the -z direction.

In FEM analysis, smooth and high quality mesh is very important for solution results. Two different types of meshes are used in this model. Manifold inlet and outlet parts are formed from triangular meshes. Electrolysis channels are formed from thin square meshes. Figure 6 shows the mesh in this study.

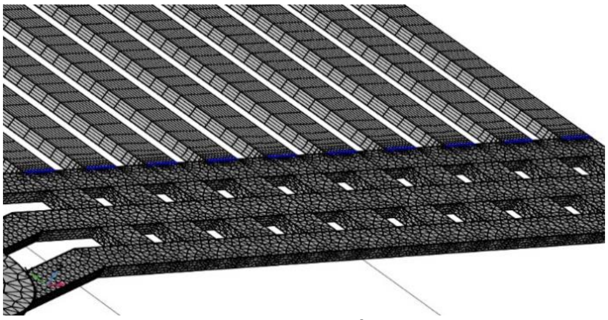

Figure 6. The mesh of the model

The statistics of the completed mesh operation are as follows;

Mesh verticles: 222857

Tetrahedra: 400116

Pyramids: 1840

Hexahedra: 100280

Triangles: 87862

Quads: 72036

Edge elements: 22206

Vertex elements: 1174

The analysis was made in the Mixture model, Laminar Flow module of the Comsol software. The 23-channel solution took 120 hours 39 minutes 54 seconds on a computer using an Intel i7 7th Generation processor. The 10-channel solution took 72 hours 35 minutes 52 seconds on a computer using an Intel i7 7th Gen processor.

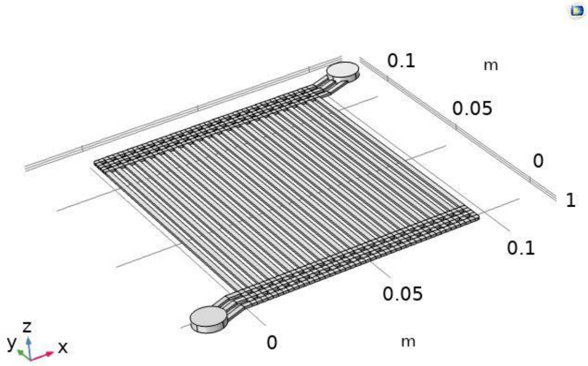

Figure 7. Isometric view of the PEM cell

There is no overheating problem in PEM electrolyzers as there is water flow inside the cell. However, depending on this water flow rate and heat transfer conditions used for cooling, a certain level of temperature increase and pressure change takes place inside the cell. [20]

Continuity Eq;

$$\frac{\partial}{\partial t}(\rho) + \nabla \cdot (\rho u) = 0 \tag{6}$$

Momentum Eq:

$$\rho\frac{\partial u}{\partial t} + \rho(u.\nabla)u = -\nabla p - \nabla \cdot \left[\left(\rho C_d(1-C_d)\right)u_{\text{slip}}\,u_{\text{slip}}\right] + \nabla \cdot \left(\mu(\nabla u + (\nabla u)^T)\right) + \rho g + F_{\text{drag}} \tag{7}$$

Mixture Velocity Eq;

$$u = \frac{\phi_c\rho_c u_c + \phi_d\rho_d u_d}{\rho} \tag{8}$$

Mass friction Eq;

$$C_d = \frac{\rho_d\phi_d}{\rho} \tag{9}$$

Transport Eq;

$$\frac{\partial(\phi_d\rho_d)}{\partial t} + \nabla \cdot (\phi_d\rho_d u_d) = -m_{dc} \tag{10}$$

Energy Eq;

$$\nabla \cdot \left(\left(\rho_d C_{p,d}\right)\phi_d u_d T + \left(\rho_c C_{p,c}\right)\phi_c u_c T\right) = k(\nabla^2 T) \tag{11}$$

Table 4.Hydogen Flux versus Number of Channel

Number of Channel	Hydogen Flux (kg/m2s)
10	34x10-5
15	24,1x10-5
23	12,5x10-5

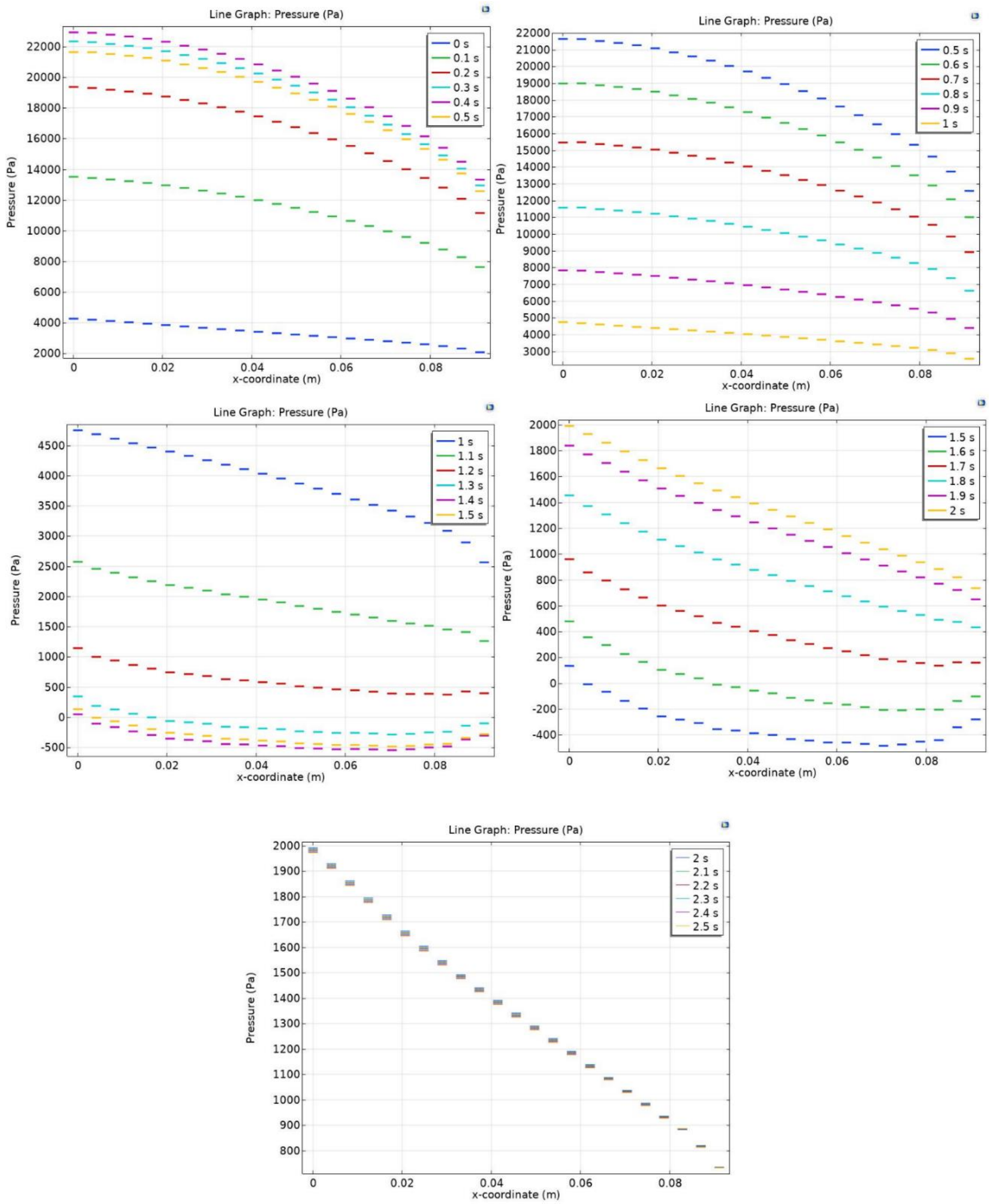

Figure 8. Pressure values in the duct closest to the inlet in the range of 0-2.5 seconds at 0.1 second intervals

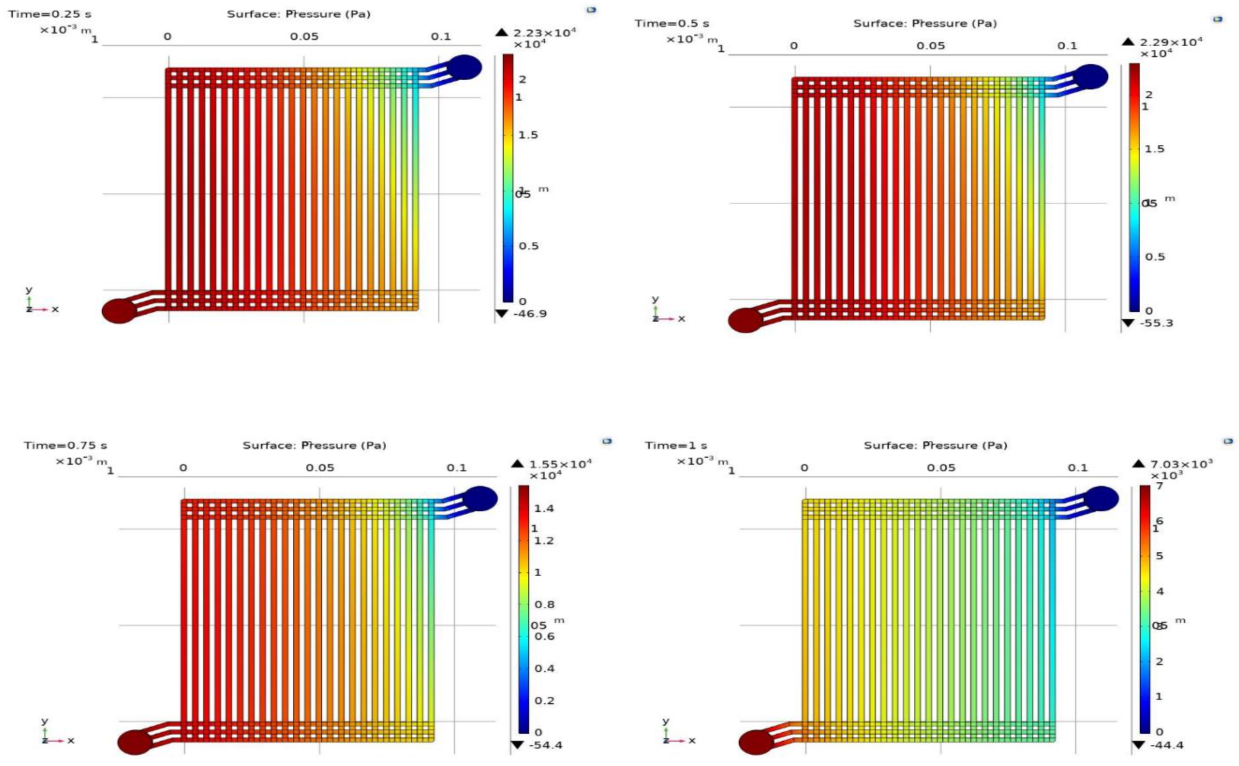

Figure 9. Pressure distributions in the PEM cell surface between 0-1 s at 0.25 second interval

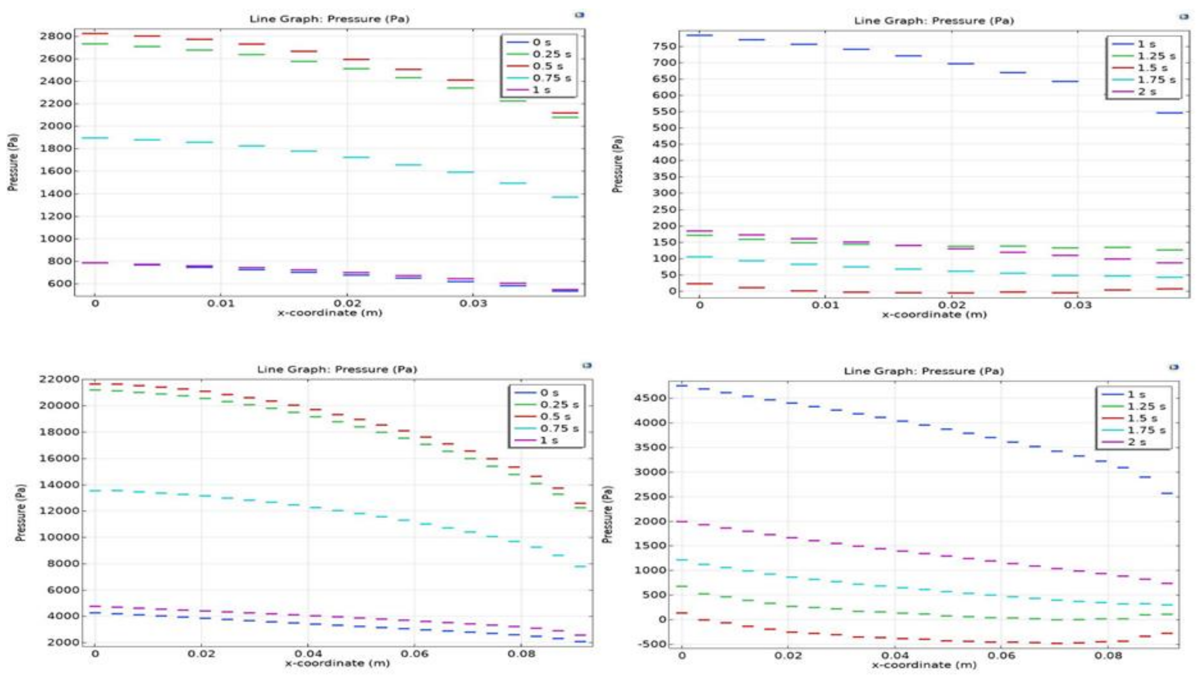

Figure 10. Pressure distributions of the 10-channel PEM cell and the 23-channel PEM cell in the range of 0-2 seconds at 0.25 second intervals

3. RESULTS AND DISCUSSIONS

In this study, 3-dimensional, two-phase (hydrogen and water) computational fluid dynamics (CFD) analysis was performed in a polymer electrolysis membrane cell (PEM). When Figure 8. is examined, it can be seen that the pressure values occurring in the channel closest to the inlet in the range of 0-2.5 seconds at 0.1 second intervals. When the pressure values are read one by one from the solution, it is seen that it increases up to 0.4 seconds and shows the highest value at this point. From the starting point to 0.4 seconds, the pressure value increased by 438%. Then the pressure drops to 99.79% for up to 1.4 seconds and becomes almost zero. In the last table of the figure, almost all pressure values now appear equal after 2 Seconds. This shows that an equilibrium cannot be achieved in the pressure distribution up to 1.4 seconds within the channels and after 2 seconds a pressure balance occurs within the electrolysis channels.

When Figure 9 is examined, the pressure distributions formed in the PEM cell in the interval of 0-1 sec at 0.25 second intervals are seen along the xy axis. Here, the pressure first increases and then decreases with the start of the electrolysis process.

Figure 10 shows the pressure distributions of the 10-channel PEM cell and the 23-channel PEM cell. From the figure presures can be seen in the range of 0-2 seconds at 0.25 second intervals. Here, in the first line, the pressures of the PEM cell consisting of 10 electrolysis channels are seen in the channels between 0-2 seconds, in the 0.25 second time interval, on the Cut Line 3d axis.

In the 2nd line of the figure, the intra-channel pressures of the 23-channel PEM cell are seen in the Cut Line 3d axis between 0-2 seconds in the 0.25 second time interval.

In the 23-channel PEM cell, the pressure in the electrolysis channel closest to the inlet is 21645 Pa in 0.5 seconds, while the pressure in the electrolysis channel closest to the inlet of the 10-channel PEM cell is 2825 Pa in 0.5 seconds. At the same water inlet flow rate, the first channel pressure in the 23-channel cell is 666% higher than in the 10-channel cell. Regardless of the number of channels, the pressure balance in the channel takes place after 1.4 seconds.

When Table 4 is examined, it is seen that the hydrogen production per unit area per unit second decreases as the number of channels increases at a constant inlet flow rate. The reason for this is that the amount of water entering the channel decreases inversely proportional to the number of channels, and therefore the potential for electrolysis of the water decreases.

Although the increase in the number of channels reduces the unit hydrogen production, it reduces the pressure fluctuation in the manifold and the channel. This shows that in terms of efficiency, undesirable pressure fluctuations in the cell can be prevented by using the number of channels.

4.CONCLUSIONS

The pressure increases rapidly for up to 0.4 seconds, then decreases rapidly and then becomes softer. In particular, after 2 seconds, a pressure equilibrium can be mentioned in the PEM cell for up to 30 seconds. The pressure, which rises suddenly up to 0.4, drops to almost zero when it comes to 1.5 seconds. There is an undesirable severe pressure fluctuation in the cell in the range of 0-1.5.

As the number of electrolysis channels increases, the pressure in the middle of the channels close to the channel water inlet also increases. The pressure in the middle of the first electrolysis channel of the 23-channel PEM cell is more than 6.5 times greater than the pressure in the middle of the first electrolysis channel of the 10-channel PEM cell.

The intracellular pressure, which reaches the maximum pressure in 0.4 seconds and makes big fluctuations before the 2nd second, the number of channels can be regulated and made smoother. This is very important for cell design and efficiency.

In an electrolysis cell with a constant water flow inlet, the number of channels and the unit gas production amount and pressure distribution can be regulated. With the data of this study, design and efficiency studies of PEM cells with this type of structure can be done.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Baran TAŞĞIN: Conceptualization, performed the experiments and analyse the results.

Mustafa İLBAŞ: Review the manuscript and project administration.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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