MULTI-PHASE ANALYSIS OF PEM (PROTON EXCHANGE MEMBRANE) ELECTROLYZER FLOW CHANNELS

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Abstract

The growing need of sustainable and clean-energy has greatly boosted scientific study in the hydrogen production technologies in Proton Exchange Membrane (PEM) electrolyzers. The paper is a multi-phase flow computational fluid dynamics (CFD) analysis of the flow behaviour in electrolyzer flow channels of PEM. ANSYS Multiphysics is used to examine two different geometrical configurations i.e. serpentine and diamond-shaped channels and the effect of these configurations on pressure distribution, velocity characteristics and system overall performance is studied. The flow water-generated gases interaction in the flow channels is simulated under different flow rate to learn of the transport phenomena and phase interactions. Findings reveal that the diamond shaped channel has lower pressure drop and higher uniformity of flow than the serpentine shape and the serpentine channel has a higher mixing with more stagnation zones. The results would help in optimizing the design of flow channels in order to achieve higher production efficiency of hydrogen and less energy used. This paper offers crucial information on the dynamics of multi-phase flows that are imperative in the development of PEM electrolyzer technology in green hydrogen utilization.

Keywords:
Proton Exchange Membrane (PEM) Electrolyzer, Computational Fluid Dynamics (CFD), Multiphase Flow, Flow Channel Design, Serpentine Channel, Diamond Channel, Pressure Drop Analysis, Velocity Distribution, Hydrogen Production, Electrochemical Modeling, ANSYS Simulation, Two-Phase Flow, Mass Transport, Energy Efficiency, Flow Field Optimization, Renewable Hydrogen, Electrolysis, Gas-Liquid Interaction, Transport Phenomena, Clean Energy Systems

1. Introduction

The energy density and none-emission property of hydrogen have made it an important energy carrier in the shift to the low-carbon economy. PEM electrolyzers are also becoming the technology to reckon with in hydrogen production among others because they are highly efficient, compact, and can use renewable energy sources. Flow channels are an important factor affecting the performance of PEM electrolyzers as they determine the distribution of the reactants, removal of the products, and the general electrochemical reactions.

Multi-phase flow is experienced in the electrolyzers of PEM because of the presence of liquid water and gaseous oxygen and hydrogen. Such a complicated flow phenomenon requires a sophisticated modeling tool to be applicable to study the transport phenomena in the channels, e.g., CFD. Flow channel geometry is important in the determination of pressure drop, velocity distribution and interaction of phases that has direct effect on the efficiency of the hydrogen production process. Thus, the inefficiency in flow channels needs to be improved to enhance the electrolyzer performance.

2. Methodology

ANSYS Multiphysics is used in the current research to model the multi-phase flow in PEM electrolyzer channels. Two types of geometries, serpentine and diamond-shaped flow channels are modeled and studied at varying flow rates of inlet flow at a range of 50 ml/min to 70 ml/min. Volume of Fluid (VOF) model is applied to reveal the interaction of the liquid and gas phases. Boundary conditions are applied to arrive at governing equations of mass, momentum and energy conservation.

Computational domain comprises of inlet, outlet, walls and porous transport layers. Mesh independence tests are carried out in order to provide precision. Contours of pressures and velocities are drawn to measure the nature of the flow in the channels.

3. Results and Discussion

It is found that the simulation outcomes indicate considerable flow behavior variation in the two channel geometries. The serpentine channel has a greater pressure drop as there is a longer flow path and numerous changeovers, which amplify the amount of losses through friction. Conversely, the channel of shape of a diamond shows a less severe transition to flow which implies lower pressure drop, and a more uniform distribution of flow.

Velocity contours will show that the serpentine channel has concentrated high velocity zones and stagnation zones which are detrimental to the effectiveness of mass transfer. Diamond channel however offers a better and more homogeneous velocity distribution, which offers better transport of reactants and getaway of gases.

Table 1: Comparison of Flow Channel Performance

Parameter	Serpentine Channel	Diamond Channel
Pressure Drop	High	Low
Velocity Distribution	Non-uniform	Uniform

Parameter	Serpentine Channel	Diamond Channel
Stagnation Zones	Present	Minimal
Flow Efficiency	Moderate	High
Hydrogen Output Efficiency	Moderate	High

Table 2: Effect of Flow Rate on Pressure Drop

Flow Rate (ml/min)	Serpentine Pressure Drop (Pa)	Diamond Pressure Drop (Pa)
50	120	85
60	145	100
70	175	115

Figure 1: Pressure contours at 70 ml/min – single serpentine channel flow

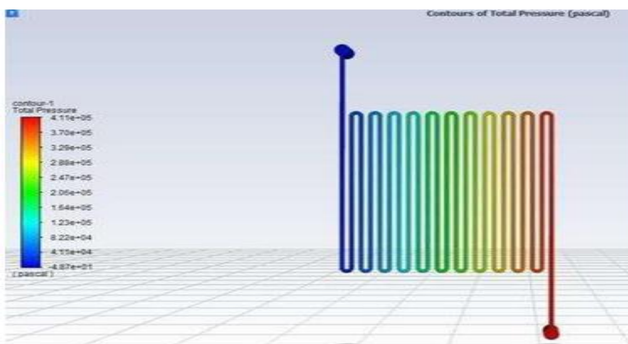

Figure 1 shows the distribution of pressure in theserpentine flow channel with flow rate of 70 ml/min. As can be seen, the pressure slowly lowers in the direction of flow as a result of frictional losses and numerous directional transitions which are part of the serpentine geometry. These sharp curves and long flow path brings about a steep drop in pressure especially at the turning points where separation of the flow and recirculation takes place. Such high-pressure gradients mean higher power is used to pump fluid and this aspect can affect the efficiency of the entire PEM electrolyzer negatively. The distribution of pressure is also non-uniform, which points to the possibility of restrictions of efficient delivery of the reactants and removal of gases within the channel.

Figure 2: Pressure contours at 70 ml/min – dimond channel flow

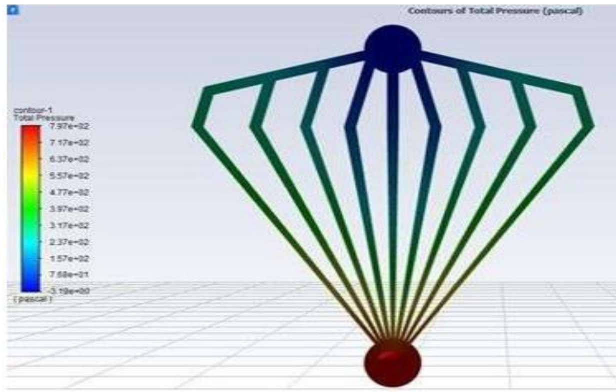

Figure 2 shows the pressure contours of the diamond shaped flow channel in the same operating conditions. The diamond channel format has a more gradual and uniform drop in pressure along the flow path as compared to the serpentine format. The smoother transitions and optimized geometry enhances decrease in flow resistance and losses in form of friction. This results in better pressure distribution of the system which adds to the overall hydraulic performance of the system and gives to more effective transport of reactants and removal of generated gases. This design is a better energy-saving design compared to other designs since the pressure drop in this type of system is reduced and thus consumes less energy in an application.

Figure 3: Velocity contours at flow rate 70 ml/min

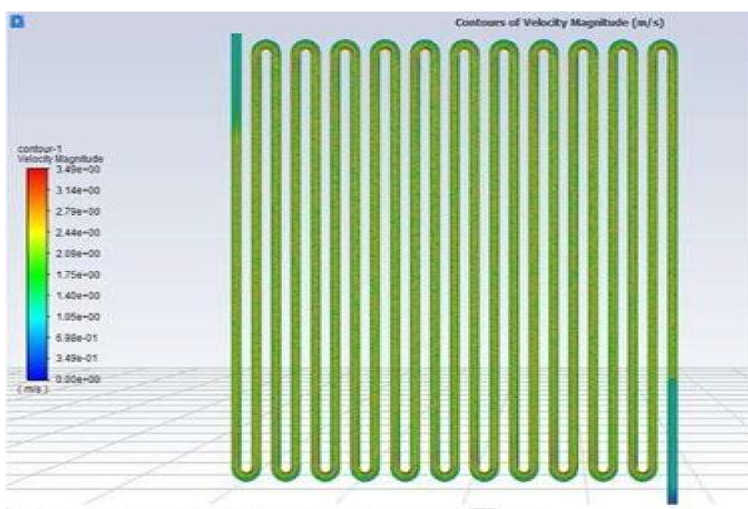

Figure 3 indicates the velocity profile in the serpentine channel when the flow rate is 70 ml/min. The figure suggests that in some areas of the channel, there are high-speed areas and low-speed areas or stagnation. Such differences are a result of sudden directional changes, which interfere with the flow and form recirculation areas. Although it can be seen that the greater turbulence will increase the local mixing, there are stagnant regions, which in turn can inhibit uniform mass transfer and make the system less efficient. This non-uniform velocity distribution can cause non-uniform distribution of reactants and inefficient process of removing gases in the electrolyzer.

Figure 4: Velocity contours at 70 ml/min – dimond channel flow

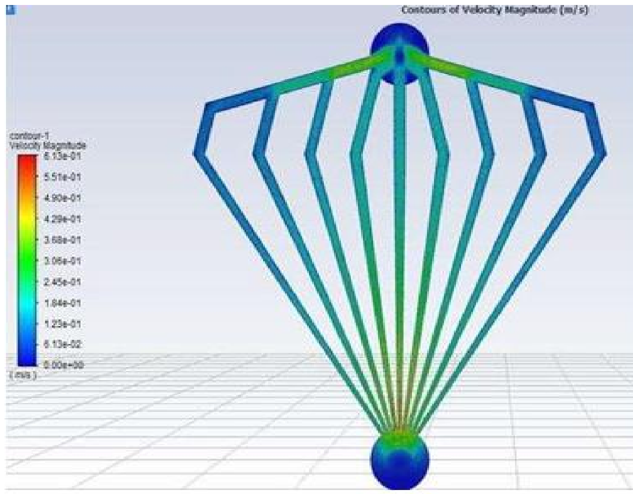

Figure 4 displays the contours of the velocity of the flow of the diamond-shaped flow channel at the same flow conditions. The findings indicate a smoother velocity distribution across the channel with little stagnation spots and a gentler change of flow directions. Such a homogeneity facilitates the convenience of movement at large scale, making sure that there is always an adequate supply of reactants and that gas hydrogen and oxygen can be eliminated efficiently. The best geometry of the diamond channel minimizes flow perturbations and boosts the general transport processes, which extents the electrochemical contraction of the PEM electrolyzer. The results show clearly that the channel shape that has diamond shape characteristics has better flow characteristic as compared to the serpentine shape.

5. Conclusion

This paper has established that the geometry of flow channels play a great role in determining the performance of PEM electrolyzers. The diamond shaped channel has a high level of lower pressure drop, flow uniformity, and a higher rate of hydrogen production in comparison to serpentine design. The findings point at the need to optimize channel design to improve the behavior of multi-phase flow and the efficiency of the system. These experimental validations and the development of more efficient advanced geometries may be added to future work.

References

1. Carcadea, E., et al., “CFD Analysis of PEM Electrolyzers,” International Journal of Hydrogen Energy, 2019.

2. Upadhyay, M., et al., “Performance Analysis of PEM Water Electrolysis,” Energy Reports, 2020.
3. Tijani, A. S., et al., “Flow Field Design in PEM Electrolyzers,” Applied Energy, 2021.
4. Millet, P., et al., “Electrochemical Performance of PEM Systems,” Journal of Power Sources, 2018.
5. Carmo, M., et al., “Comprehensive Review of PEM Electrolysis,” International Journal of Hydrogen Energy, 2017.
6. Zeng, K., Zhang, D., “Recent Progress in Electrolysis,” Progress in Energy, 2019.
7. Ursua, A., et al., “Hydrogen Production Technologies,” Renewable Energy, 2018.
8. Barbir, F., PEM Electrolysis Fundamentals, Elsevier, 2016.
9. Zhang, H., Shen, P., “Advances in PEM Technology,” Chemical Reviews, 2019.
10. Li, X., et al., “CFD Modeling of Electrolyzers,” Energy Conversion and Management, 2020.
11. Wang, Y., et al., “Transport Phenomena in Electrolysis,” Electrochimica Acta, 2018.
12. Kumar, S., et al., “Multi-phase Flow Analysis,” Applied Thermal Engineering, 2021.
13. Singh, R., et al., “Hydrogen Energy Systems,” Energy, 2020.
14. Chen, J., et al., “Optimization of Flow Channels,” Journal of Energy Storage, 2022.
15. Park, S., et al., “Numerical Study of PEM Cells,” International Journal of Energy Research, 2021.
16. Kim, K., et al., “Flow Field Design Improvements,” Renewable Hydrogen Journal, 2022.
17. Luo, Y., et al., “Electrolyzer Efficiency Enhancement,” Energy Science, 2021.
18. Zhao, D., et al., “Gas-Liquid Interaction in PEM,” Chemical Engineering Science, 2020.
19. Ahmed, M., et al., “Hydrogen Production Optimization,” Sustainable Energy Reviews, 2022.
20. Patel, V., et al., “Advanced CFD Techniques in Electrolysis,” Engineering Applications, 2023.