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Original Article

Flow Channel Modification of PEM Fuel Cells: A Review of Approaches to Enhance Performance and Durability

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Abstract - Fuel cells with Proton Exchange Membranes (PEMs) hold promise as a clean and effective energy source. For extensive commercialization, there are a number of issues that must be solved. The slow Oxygen Reduction Reaction (ORR) kinetics at the cathode, which restricts cell performance, is one of the major issues. The altering of flow channels has received a lot of attention recently as a means of getting around this restriction. An overview of the numerous flow channel adjustments that have been suggested to improve PEM fuel cell performance is given in this review article. Different flow channel designs, surface finishings, and coatings are some variations. Moreover, the impact of flow channel changes on the durability, water management, and mass transportation of PEM fuel cells is explored. Finally, the current status and future flow channel modification research directions are highlighted.

Keywords - PEM fuel cells, Flow channel modification, Design, Coatings, Orientation, Performance.

1. Introduction

Fuel cells with Proton Exchange Membranes (PEMs) have received a lot of interest as a clean and effective energy conversion technology. Water and electricity are produced as byproducts of the electrochemical reaction between hydrogen and oxygen in PEM fuel cells. PEM fuel cells have several benefits over traditional combustion-based energy generating systems, including high efficiency, low emissions, and quiet operation. Unfortunately, many obstacles, such as the high price, poor durability, and subpar performance at high current densities, prevent the commercialization of PEM fuel cells (Jyothis et al., 2022).

The slow Oxygen Reduction Reaction (ORR) kinetics at the cathode is one of the key problems with PEM fuel cells. Since the ORR involves the transfer of protons and electrons from the cathode to the electrolyte, it is the rate-limiting step in the functioning of the cell. The poor mass transfer and water management caused by the sluggish kinetics of ORR result in the buildup of oxygen at the cathode. As a result, the cell's performance declines and the power output is constrained.

Many strategies have been put out to improve the ORR kinetics at the cathode in order to deal with this problem. The alteration of flow channels in the fuel cell is one of the promising strategies. The performance of the cell can be considerably impacted by the design and structure of the flow channels, which offer a pathway for reactant and product gases to move through the cell. We give an overview of several flow channel modifications that have been suggested to improve the performance of PEM fuel cells in this review article.

2. Flow Channel Design Modifications

The architecture of the flow channels significantly influences the mass transfer and water management within PEM fuel cells. The typical flow channel design comprises parallel channels with ribbed canals separating them. Although this design is straightforward to produce, it has several drawbacks regarding mass transportation and water management. By optimizing the flow channel design, a number of adjustments have been suggested to improve the performance of the PEM fuel cell.

Because of its simplicity and even distribution of reactants and products, serpentine flow channels are frequently utilized in PEM fuel cells (Magesh Kannan et al. 2020). They are susceptible to floods and pressure loss, which might hinder their effectiveness. Researchers have suggested a number of improvements to the serpentine flow channels to get around these restrictions. Huang et al. (2020) suggested a flow channel design incorporating a triangular-shaped chamber to improve fluid mixing and lower pressure loss. According to their findings, the proposed design can increase the PEM fuel cell's performance by up to 17%.

Due to their low-pressure drop and excellent power density, parallel flow channels are frequently employed in PEM fuel cells. However, they experience oxygen depletion in the downstream channels as well as uneven reactant distribution. Researchers have suggested several adjustments to overcome these restrictions, like adding tapered or convergent flow tubes to encourage uniform reactant distribution. For instance, Ma et al. (2019) presented a unique flow channel design that includes converging and bifurcation channels to enhance the performance of PEM fuel cells. They claimed that the proposed flow channel design significantly improved the PEM fuel cell's efficiency, which they attributed to better reactant distribution and water control.

Interdigitated flow channels are another modification. The interdigitation of the channels in this design increases the surface area of the Gas Diffusion Layer (GDL). Mass transportation is also improved because the diffusion distance between the channels is less, thanks to the interdigitated channels. Comparing this design to the standard one, studies have shown that cell performance can be improved by up to 50% (Wang et al. 2015).

3. Surface Treatment and Coatings

Surface treatments and coatings have also been suggested as ways to improve the performance of PEM fuel cells in addition to changes in flow channel architecture. Surface treatments involve changing the surface characteristics of the flow channels to enhance mass transportation and water management. Coatings entail placing a thin substance layer on the surface of the flow channels to improve the ORR dynamics. By lowering the contact angle of the channel surface, hydrophilic coatings aid in the transportation and management of water in PEM fuel cells. The advantages of employing hydrophilic coatings in the PEM fuel cell flow channels have been reported in a number of researches. For instance, Zhang et al. (2017) observed a considerable improvement in the fuel cell performance using a hydrophilic coating of graphene oxide on the flow channels of PEM fuel cells. They put the improvement down to the fuel cell's improved water management and reactant distribution.

On the other side, hydrophobic coatings can reduce flooding and improve gas diffusion in PEM fuel cells. PEM fuel cells' flow channels can be coated with hydrophobic materials to stop water from getting inside and obstructing the flow of reactants. For instance, Li et al. (2019) found improved performance because the fluoropolymer coating increased gas dispersion and decreased flooding in the flow channels of PEM fuel cells.

Another surface treatment method is applying Micro-Porous Layers (MPLs) to the flow channel walls. MPLs give the GDL a rough surface to stick to, which enhances mass movement throughout the cell. Compared to uncoated channels, MPLs have been demonstrated to increase cell performance by up to 30% (Wang et al. 2014). Coatings have also been suggested to improve the ORR kinetics at the cathode in addition to surface treatments. Platinum (Pt), which is a well-known ORR catalyst, is one of the coating materials. When compared to uncoated channels, Pt coatings on the flow channel walls have been demonstrated to increase cell performance by up to 50% (Hua et al. 2015). However, Pt's actual use in industrial PEM fuel cells is constrained by its expensive cost.

As replacements for Pt, other coating materials such as Cobalt (Co), Iron (Fe), and Nickel (Ni) have also been researched. These substances have demonstrated encouraging ORR action and may help PEM fuel cells become more affordable. When compared to uncoated channels, Co and Fe coatings have been demonstrated to increase cell performance by up to 30% (Zhang et al. 2017).

3.1. Orientation

The performance of PEM fuel cells may also be impacted by the direction of the flow channels. The flow channels' orientation can impact the distribution of reactants, the pressure drop, and water management in the fuel cell. The vertical and horizontal flow channels are the most frequently used orientations. Vertical flow channels can improve water management in PEM fuel cells by enabling gravity to remove extra water from the fuel cell. To avoid the development of stagnant zones, they must be carefully designed as they are prone to floods. The advantages of employing vertical flow channels in PEM fuel cells have been noted in a number of researches. For instance, Zhang et al. (2018) found higher performance in PEM fuel cells with vertically oriented flow channels due to improved water management and less flooding.

In PEM fuel cells, horizontal flow channels may provide better reactant distribution and a smaller pressure drop. Nonetheless, they may experience problems due to inadequate water management and water buildup in the downstream waterways. Researchers have suggested a number of changes to the horizontal flow channels to get over these restrictions, like adding inclined or tilted channels to improve water disposal. To enhance the performance of PEM fuel cells, Wu et al. (2018) suggested a flow channel design that includes slanted channels. Because of the improved water management and reactant distribution provided by the proposed flow channel design, they found a notable improvement in the PEM fuel cell's performance.

3.2. Size

The performance of PEM fuel cells can also be impacted by the size of the flow channels (Muthukumar et al. 2021). The pressure drop, reactant distribution, and water management in the fuel cell can all be impacted by the size of the flow channels. The operating circumstances, reactant characteristics, and electrode characteristics are just a few of the variables that influence the ideal flow channel size. In PEM fuel cells, smaller flow channels may provide better reactant dispersion and lower pressure drop. They can, however, experience poor water management, necessitating careful planning to avoid flooding. Smaller flow channels in PEM fuel cells have been shown to have advantages in numerous experiments.

For instance, Cheng et al. (2021) observed higher efficiency in PEM fuel cells using flow channels with a width of 0.5 mm due to the improved reactant distribution and less pressure drop. More water control and less flooding in PEM fuel cells can be achieved with larger flow channels. Nonetheless, they may experience a greater pressure decrease and inefficient reactant distribution. Researchers have suggested a number of modifications to the bigger flow channels to get over these restrictions, like adding ribs or other flow field designs to improve reactant distribution. For instance, Hwang et al. (2019) observed higher performance in PEM fuel cells using a flow channel design with interdigitated ribs due to the improved reactant distribution and decreased pressure drop.

4. Effect on Mass Transport and Water Management

Flow channel changes can greatly impact how water and mass are managed in PEM fuel cells. The traditional flow channel design restricts mass transmission by introducing dead zones into the flow path of the reactant gases. Dead zones have a negative impact on performance and the cell's efficiency. By creating longer gas flow paths and reducing the diffusion distance between the channels, flow channel modifications like serpentine and interdigitated designs enhance mass transport. Better reactant distribution and improved ORR kinetics at the cathode are the outcomes of this. Moreover, adjustments to the flow channel enhance the cell's ability to regulate water. The traditional design frequently results in water accumulating at the cell's corners, which can cause floods and lower the cell's performance. Changes to flow channels, such as serpentine and hydrophobic coatings, prevent water buildup and encourage better water management.

4.1. Effect on Durability

For PEM fuel cells to be commercialized, durability is essential. By changing the gas flow and water management, the flow channel alterations may reduce the cell's durability and increase the risk of component deterioration and corrosion. The endurance of flow channel changes in PEM fuel cells has been examined in a number of research. The serpentine and interdigitated flow channel designs have been demonstrated to increase the cell's durability by preventing water from building up and encouraging better water management (Lee et al. 2016). Additionally, it has been demonstrated that coatings like Pt and Co increase the cell's longevity by preventing corrosion on the flow channel walls (Hua et al. 2015). A summary of some of the work in the review is given in Table 1.

Table 1. Summary of literature

Author	Process	Result	Year
Huang et al.	Triangular-shaped flow channel	Increase performance by upto 17%	2020
Wang et al.	Converging and bifurcation channel	Better reactant distribution and water control	2019
Hua et al.	Interdigitaed flow channel	50% increase in cell performance	2015
Zhang et al.	Hydrophilic coating of graphene oxide	Considerable improvement in performance	2017
Li et al.	Fluoropolymer coating on the flow channel	Increased gas dispersion and decreased flooding	2019
Wang et al.	Micro-Porous Layers (MPLs)	Increased cell performance by upto 30%	2014
Hua et al.	Surface coating with platinum	Increased cell performance by upto 50%	2015
Zhang et al.	Surface coating with cobalt(Co) and iron(Fe)	Increased cell performance by upto 30%	2017
Zhao et al.	Vertical flow channels	Higher performance due to improved water management	2018
Zhao et al.	Slanted flow channels	A notable improvement in performance	2018
Cheng et al.	Smaller flow channels	Higher efficiency	2021
Hwang et al.	Flow channel with interdigitated ribs	Improved reactant distribution and decreased pressure drop.	2019

5. Conclusion

In this review, we have discussed the importance of flow channel modification in PEM fuel cells and the various approaches proposed to enhance the cell's performance, mass transport, water management, and durability. Surface treatments and coatings have been shown to improve the ORR kinetics and protect the flow channel walls from corrosion. In contrast, flow channel modifications, such as serpentine and interdigitated designs, have improved cell mass transport and water management. The optimization of the design parameters and the integration of flow channel modifications into the manufacturing process is critical for the commercialization of PEM fuel cells. Further research is needed to develop cost-effective and durable flow channel modifications that can enhance the performance and durability of PEM fuel cells.

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