Commentary

Bipolar plate flow field structure research status and trends for hydrogen fuel cell vehicles

ABSTRACT

The bipolar plate is the fundamental structural element of the hydrogen fuel cell, and its flow field design has a significant impact on the performance of the fuel cell. The hydrogen fuel cell is employed as an important energy supply source for vehicle power.The classification and operation of hydrogen fuel cells, as well as the benefits and drawbacks of conventional flow fields, are discussed in this paper and contrasted with the state of bipolar plate flow field research in recent years.Comprehensive analysis is done on the optimization of the fuel cell bipolar plate flow field based on the conventional flow field.All are favorable to enhancing fuel cells' ability to generate electricity and aid in the progressive development of a full set of structural design guidelines.

Keywords: bipolar plate flow field, hydrogen fuel cell, vehicle power

1 INTRODUCTION

The subject of new energy and emission reduction has drawn considerable attention from nations all over the world as the world transitions to an energy consumption pattern altered by the post-epidemic period. China has proposed a new objective of "dual carbon" as a means of adapting to the global energy change. Due to its benefits of abundant reserves, little emissions, and excellent efficiency, hydrogen has come to the attention of more and more researchers. Because of its great conversion efficiency and lack of any chemical reactions via burning, the hydrogen fuel cell stands out among other hydrogen energy equipment as a power generation device.

Transportation, portable electricity, aerospace, and stationary cogeneration power plants can all use hydrogen fuel cells. According to varied operating temperatures, hydrogen fuel cells can be classified as low temperature region fuel cells, medium temperature region fuel cells, and high temperature region fuel cells. The typical operating temperature range of fuel cells, including polymer fuel cells, phosphoric acid fuel cells, and similar devices, in the low temperature zone is 60℃to 250℃. Such as the solid oxide fuel cell in the medium temperature state, the operating temperature range of the fuel cell in the region of medium temperature is

400℃to 700℃. Molten carbonate fuel cells, for example, have an operating temperature range between 600℃and 1000℃in the high temperature area.

One of the many different types of fuel cells is the proton exchange membrane fuel cell, which is a power source and power generation device that can function well in the low temperature area. There has been active promotion of the automotive industry. When hydrogen (fuel) enters the cathode of a proton exchange membrane fuel cell, which are split into two hydrogen ions H^+, with the external circuit load serving as the conduit for the electrons' entry into the anode. Only the oxygen atom O_2 of the anode can cross the proton exchange membrane of the ion and get two electrons in the external circuit, resulting in the formation of water molecules on the catalytic layer's surface. Figure 1 illustrates the fundamental operation of a proton exchange membrane fuel cell. The chemical reaction expression is as follows(1);(2)(3):

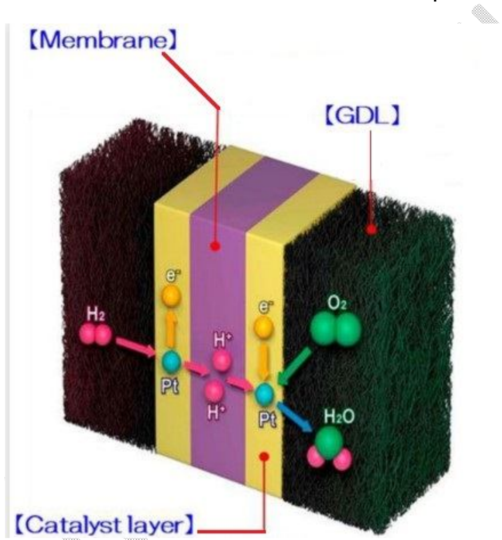

Fig. 1 Basic schematic diagram of proton exchange membrane fuel cell

Anode: $H_2 \rightarrow 2H^+ + 2e^-$ (1)

Cathode: $1/2O_2 + 2H^+ + 2e^- \rightarrow H_2O$ (2)

overall response: $H_2 + 1/2O_2 \rightarrow H_2O$+Electricity + heat (under the action of catalyst) (3)

The bipolar plate typically serves as the principal structural component of the hydrogen fuel cell, supporting the entire fuel cell membrane electrode, moving and directing the reaction gas, gathering and conducting current and heat, and discharging liquid water. Therefore, a key strategy in the development of hydrogen fuel cells for vehicle power is the structural optimization of bipolar plates.

2. THE CURRENT STATE OF RESEARCH AND THE BENEFITS AND DRAWBACKS OF CONVENTIONAL FLOW FIELD STRUCTURES

According to the flow field form, research on the bipolar plate's flow field design can be categorized into parallel flow fields, interdigital flow fields, serpentine flow fields, etc. To carry out structural design and optimization, install baffles. In order to enhance the distribution of reactants and raise the battery's power density, multiple types of flow fields' diverse properties are also combined to create a mixed flow field.

Figure 2 (a) Parallel flow field (b) Alternating finger flow field (c) Serpentine flow field

The structural design of the parallel flow field in the typical flow field is quite simple. As shown in Fig. 2, and frequently consists of many parallel straight tubes (a). There is a slight pressure decrease as a result of each flow channel's intake to output distance being less than that of other traditional flow fields. This will lead to an uneven distribution of reaction gas among different flow routes. It is challenging to quickly purge and remove the reaction product water from the flow channel due to the parallel flow field's simultaneous increase in flow velocity with flow channel width and gradual decrease in flow velocity. This causes liquid water to build up and reduce reaction efficiency and working time.

The pressure drop in the flow field will rise as a result of the numerous blocked flow channels, creating the flow field. As shown in Figure 2, the reaction gas flows through the serpentine flow field's single meandering flow channel from the intake to the flow field structure before exiting at the outlet (c). Only one serpentine flow channel is used by the serpentine flow field, which results in a high flow velocity and outstanding drainage performance in the flow channel, which can swiftly remove any collected liquid water. However, the pressure loss will considerably increase as the flow field's surface area increases; The entire flow field will completely fail if there is a blockage in the serpentine flow channel at any point.

3. THE STATE OF OPTIMAL FLOW FIELD RESEARCH DOMESTICALLY AND INTERNATIONALLY

The majority of academics focus on creating new flow field structures through structural optimization or recombination based on serpentine, interdigital, and parallel flow fields.

The influence of altering the cross-sectional area of the flow channel on the performance of the bipolar plate flow field, including the performance of the fuel cell's power generation, the uniformity of the reaction gas distribution, the performance of water removal, etc., was designed and analyzed by Chen Yao [1]using the method of numerical simulation on the basis of creating a parallel flow field. The disruption of the gas in the flow channel is encouraged by modelling the impact of various gradients on the parallel flow field. The outcomes demonstrate that the stepped parallel flow field's power density, which reaches 21.5%, is more efficient than the original traditional parallel flow field. The stepped flow field can also speed up the discharge of liquid water, reduce flooding, and improve the homogeneity of gas concentration and current density distribution.

To investigate the impact of serpentine flow field structure on battery performance, Jeon et al. [2] created four different types of serpentine flow fields in various widths. The study's findings demonstrate that the multi-serpentine construction has a shorter channel length, a more uniform distribution of characteristics like current density and water vapor, and superior overall battery performance. However, in the four serpentine flow field structures, the current density distribution is not uniform, and the flow velocity varies at the corner of the flow channel. Four different ridge widths were employed in a single serpentine flow field by Zhang et al. [3] to evaluate the impact of ridge width on battery performance. The findings demonstrate that decreasing ridge width and increasing inlet flow invariably improve battery performance. Different combinations of ridge width and reactant flow rate at various cell voltages can get the cell to the point of maximum net power density when pumping power is taken into account.

The current density of the fuel cell has been successfully increased by including a boss structure in the flow channel. Employing both numerical and experimental techniques, Ebrahimzadeh et al. [4] investigated the impact of bosses in a two-way serpentine flow field on PEMFC efficiency.The bosses with dimensions of 1.5mm high x 3.6mm wide had the biggest impact on the voltage drop and current density of the PEMFC, according to their initial numerical simulations of the height and width of the bosses. The boss's layout and shape were then examined. The findings indicate that at a voltage of 0.6 V, the current density of the fuel cell with a triangle boss is more than 50% higher than that without one.

Figure 3 illustrates the two-dimensional, two-phase, non-isostatic model Chen et al. [5]created to examine the impact of baffle height and position on the mass transport and functionality of fuel cells with parallel flow fields. Baffles that are evenly spaced across the flow channel will not only improve reactant transport but also aid in the discharge of more liquid water; conversely, increasing the baffle height will speed up reactant transport but make it more difficult to discharge liquid water; reverse the baffle's direction It will result in a decrease in the amount of reactant transport and make liquid water discharge more challenging.

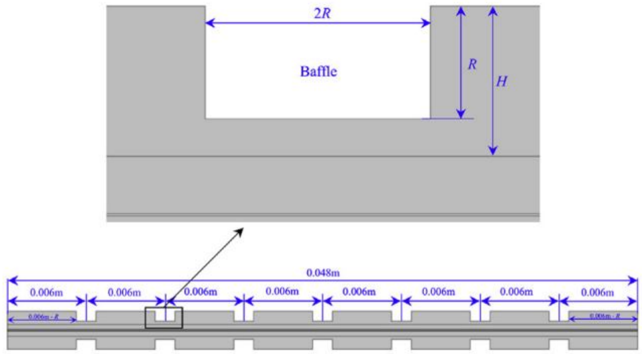

Figure 3 Model of the two-dimensional PEMFC by Chen

On a two-dimensional, two-phase, non-isosteady state model, Guo et al. [6]investigated the impact of baffle height and position on mass transfer, performance, and power loss.The findings demonstrate that the baffle in the gas flow channel may improve not only the transport of reactants but also the liquid water discharge, and that the improvement effect grows with baffle height. Baffles placed upstream of the flow channel will also improve PEMFC performance. Additionally, Guo et al. [7]developed a mathematical model for a two-dimensional, two-phase anisostatic fuel cell and examined how the design of the baffles inside the flow channel affected the fuel cell's ability to transfer mass and lose energy. They created baffle flow channels that were rectangular, trapezoidal, wavy, semicircular, and triangular, respectively. The growth rate of net power is the highest (20.21%), and the results show that the rectangular baffle flow channel is more favorable for improving reactant transfer and battery performance. They also created a sleek design for the rectangular baffle's windward and leeward sides at the same time.

The extension of the leeward side can reduce or even completely eliminate eddy currents, which directly lowers the power loss of gas transmission and pumping. The particular structural design lowers the resistance to gas flow. Both the net power of the PEMFC and the transmission power are increased. It is clear that structurally optimizing the baffle's size, height, and location inside the flow channel can significantly enhance the fuel cell's performance. By modifying the flow field's structure and incorporating bionic design principles into the bipolar plate's flow field design.Figure 4 depicts the cross-section of the improved parallel flow field, which was developed by Tomoo Yoshizumi et al. [8]based on the MIRAI's first-generation 3D flow field. The findings indicate that the modified variable diameter flow channel, which is on par with the 3D flow channel of the first generation of MIRAI, increases the oxygen content in the GDL by 130% when compared to the regular flow channel. Increased from 2.8Kw/Kg to 5.4Kw/Kg in mass power density. The performance, stability, and lifespan of the power generation have been much enhanced compared to the previous generation of fuel cell stacks, and the cost has also decreased.

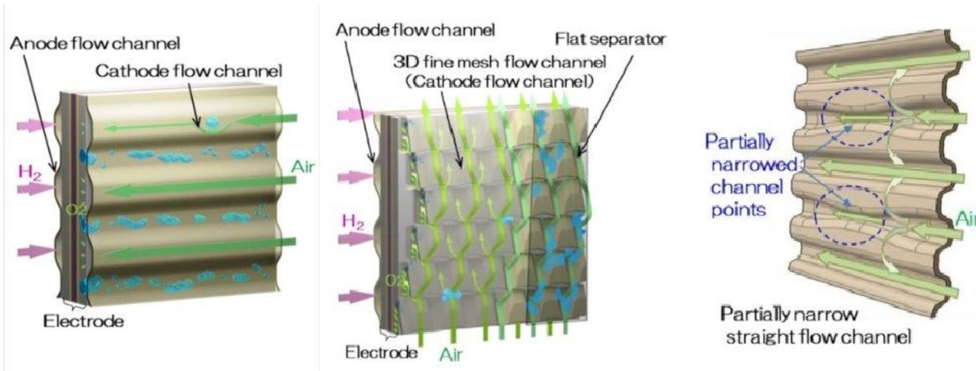

Figure 4 shows the Toyota Mirai's flow field architecture

The bionic flow field is generated from the conventional flow field. The bionic flow field can significantly lessen the pressure loss when compared to the conventional flow field. A. Iranzo, C.H. Arredondo, A.M. Kannan, el,al.[9] research the differences in the design of various bionic flow fields based on organic and inorganic structures are discussed, and the findings demonstrate that the biomimetic flow field has greater cell voltage and more effective water management than the conventional flow field. Additionally, the pressure drop of the blade-type and lung-lobe-type flow fields (26~27Pa) is smaller than that of the conventional flow field (38~41Pa), which lowers the pumping power and benefits the fuel cell's electrochemical reaction. Although bipolar plate flow field design has used this biomimetic design extensively and it has been successful thus far, it is generally thought that biomimetic design has not yet realized its full potential.

4.CONCLUSION

With the constant advancement of technology, hydrogen fuel cell vehicles, a subset of new energy vehicles, will progressively take over as the primary source of electricity for commercial vehicles or passenger vehicles. The development of the flow field structure of bipolar plates has significantly aided in the mass production and gradual commercialization of hydrogen fuel cell vehicles in recent years. Numerous experts have worked hard to optimize and reorganize the flow field structure based on the conventional bipolar plate flow field structure. The study's findings indicate that including a boss structure in the hydrogen fuel cell bipolar plate's flow field structure can enhance reactant movement within the fuel cell and encourage liquid water discharge.

The development of bionic flow fields based on biology and nature will also see more applications in the future. Since no comprehensive collection of standard templates for designing bipolar plates has yet been created by research, a set of standard design criteria is gradually being established in order to serve as a reference point for future structural design. standards for design parameters. This not only controls the design of the bipolar plate structure, but also acts as a guide for subsequent iterations of the design.

According to a large number of research reports, the ideal design of the bipolar plate structure is generally based on the traditional flow field form, optimizing the shortcomings of the traditional flow field, and enhancing the bipolar plate's ability to generate power, transfer mass and heat efficiently, and remove water. Enhancing competencies. The enhancement of the total power density of the single cell and the stack is significantly impacted by the optimization of the bipolar plate structure. It also significantly lowers the cost of the fuel cell stack, hastening the commercialization of hydrogen fuel cell vehicles. To examine the bipolar plate flow field structure for the improvement of fuel cell power generation efficiency, however, there is still much work to be done.

REFERENCES

[1]Xi Chen,Yao Chen,Qian Liu,el.al.Performance study on a stepped flow filed design for bipolar plate in PEMFC.Energy reports,2021:336-347.

[2]Jeon D H, Greenway S, Shimpalee S, et al. The effect of serpentine flow-field designs on PEM fuel cell performance[J]. International journal of hydrogen energy, 2008, 33(3): 1052-1066.

[3]Zhang X, Higier A, Zhang X, et al. Experimental studies of effect of land width in PEM fuel cells with serpentine flow field and carbon cloth[J]. Energies, 2019, 12(3): 471.

[4]Ebrahimzadeh A A,Khazaee I , Fasihfar A . Experimental and numerical investigation of obstacle effect on the performance of PEM fuel cell[J]. International Journal of Heat and Mass Transfer, 2019, 141:891-904.

[5]Chen H, Guo H, Ye F, et al. A numerical study of baffle height and location effects on mass transfer of proton exchange membrane fuel cells with orientated-type flow channels[J]. International Journal of Hydrogen Energy, 2021, 46(10): 7528-7545.

[6]GUO H, CHEN H, et al. Baffle shape effects on mass transfer and power loss of proton exchange membrane fuel cells with different baffled flow channels[J]. International journal of energy research,2019,43(7):2737-2755.

[7]Chen H , Guo H , Ye F , et al. A numerical study of baffle height and location effects on mass transfer of proton exchange membrane fuel cells with orientated-type flow channels[J]. International Journal of Hydrogen Energy, 2021,46(10):7528-7545.

[8]Yoshizumi, T., Kubo, H., and Okumura, M. Development of High-Performance FC Stack for the New MIRAI,SAE Technical Paper 2021-01-0740, 2021.

[9] A. Iranzo, C.H. Arredondo, A.M. Kannan, et,al. Biomimetic flow fields for proton exchange membrane fuel cells A review of design[J],2019.