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Bipolar Plate Flow Field Structure Research Status and Trends for Hydrogen Fuel Cell Vehicles

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Commentary

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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 [1]. Due to its benefits of abundant reserves, little emissions, and excellent efficiency, hydrogen has come to the attention of more and more researchers [2].

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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.

Fig. 1 depicts the global sales volume of hydrogen fuel cell vehicles from 2015 to 2021 based on information from Jato Dynamics, a British auto research firm [3]. Fuel cell car sales grew year over year, reaching 15,500 units globally sold of hydrogen fuel cell vehicles in 2021, an increase of 84% from the previous year. Just two models—the Hyundai NEXO and the Toyota MIRAI—account for 98 percent of all sales of hydrogen fuel cell vehicles in 2017. The low sales numbers have been attributed to the high cost of these hydrogen fuel cell vehicles as well as the weak hydrogen infrastructure. Additionally, while there are currently only a few options for hydrogen fuel cell vehicle models, there will be a wide range of options available in the future as fuel cells become the primary power source for these vehicles [4-6].

Transportation, portable electricity, aerospace, and stationary cogeneration power plants can all use hydrogen fuel cells [7]. According to varied operating temperatures, hydrogen fuel cells can be classified as low temperature region fuel cells,

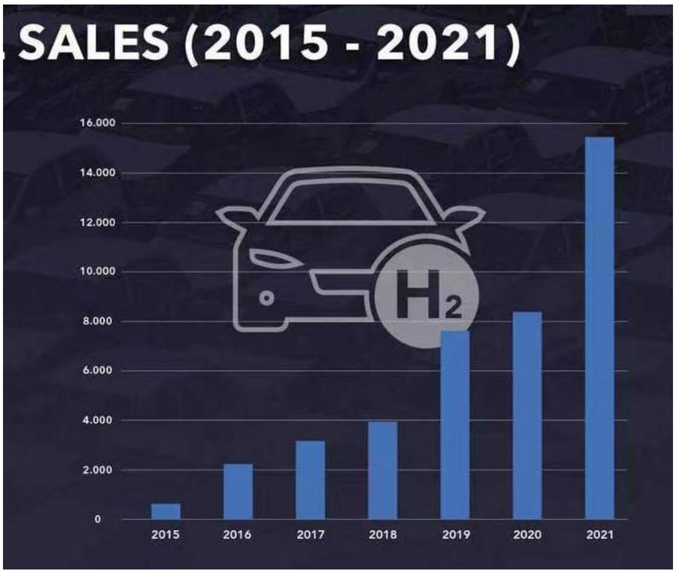

Fig. 1. Shows car sales for hydrogen fuel cells from 2015 to 2021

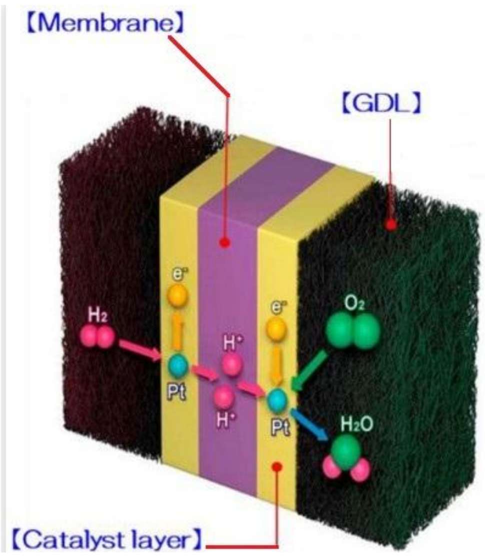

Fig. 2. Basic schematic diagram of proton exchange membrane fuel cell [25]

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°C to 250°C. 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°C to 700°C. Molten carbonate fuel cells, for example, have an operating temperature range between 600°C and 1000°C in the high temperature area [8].

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. We can see this in Fig. 2.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. Fig. 2 illustrates the fundamental operation of a proton exchange membrane fuel cell. The chemical reaction expression is as follows (1);(2)(3):

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. RESEARCH STATUS OF COMMON FLOW FIELD STRUCTURE

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 [9]. 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.

The structural design of the parallel flow field in the typical flow field is quite simple. The pace of processing and forming is quick, and opening the mold is easy. As shown in Fig. 3, 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.

Fig. 3 illustrates the non-current flow field structure of the interdigital flow field (b). In order to increase the forced convection between the reaction gas and the porous electrode in the flow channel and achieve high power generation performance, Fig. 3 (b) shows that there are numerous blocked and dead flow channels in multiple flow channels. The multiple blocked flow channels that make up the flow field will cause the pressure drop in the flow field to increase. However, the presence of several blocked flow channels will worsen the flow field's pressure drop and raise the flow field's pump power, both of which would worsen the power generation performance.

As shown in Fig. 3, 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). One of the important concerns to enhance the performance of PEMFC, including voltage drop, condensate discharge, cell voltage maximization, and uniformity of current density, is the geometric characterisation of the serpentine flow field. 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; [10]. The entire flow field will completely fail if there is a blockage in the serpentine flow channel at any point.

(A) (B) (C)

Fig. 3. (a) Parallel flow field (b) interdigital flow field (c) Serpentine flow field

3. RESEARCH STATUS OF FLOW FIELD STRUCTURE AFTER OPTIMIZATION BASED ON COMMON FLOW FIELD

The majority of academics focus on creating new flow field structures through structural optimization or recombination based on serpentine, interdigital, and parallel flow fields [11-17].

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 [18] 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 [19] 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 [20] 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 [21] 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.

Fig. 4 illustrates the two-dimensional, two-phase, non-isostatic model Chen [22] created to examine the impact of baffle height and position on the mass transport and functionality of fuel cells with parallel flow fields. Changing the values for 2R and H in Fig. 2 alters the baffle's position and height from Fig. 4. According to the study, a baffle that is evenly dispersed along a flow path can improve both the transit of reactants and the discharge of liquid water. Reactant transport speeds will increase and liquid water discharge will become more challenging when baffle height is decreased. Reducing the amount of reactants carried and making liquid water removal more challenging are two effects of moving the baffle rearward.

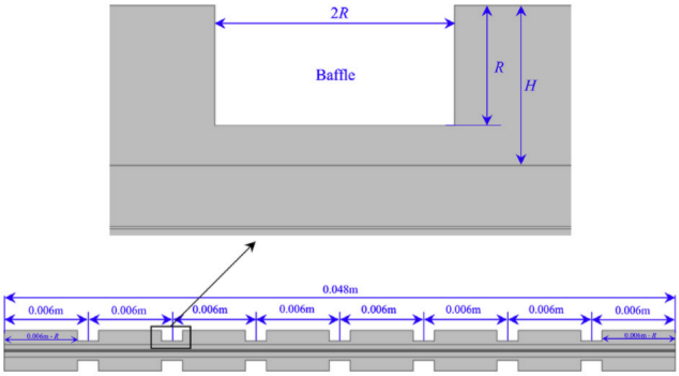

Fig. 4. Model of the two-dimensional PEMFC by Chen [22]

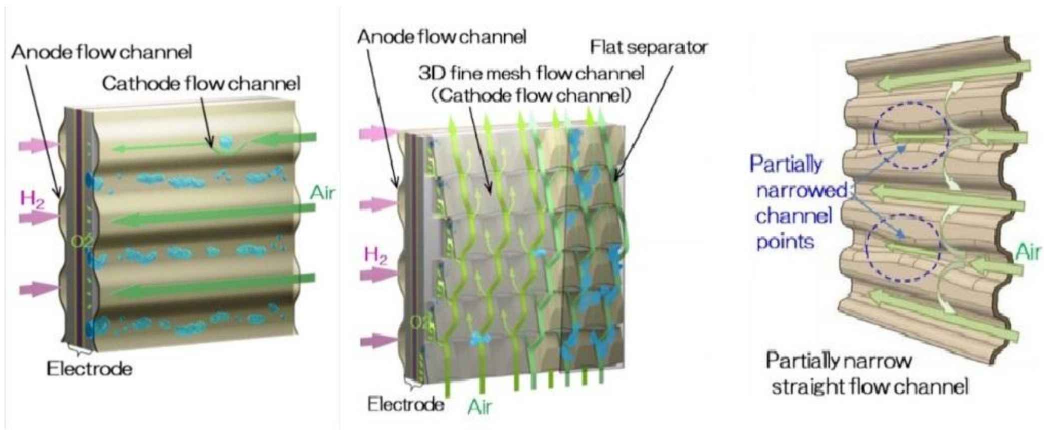

Fig. 5. Shows the Toyota Mirai's flow field architecture [25]

On a two-dimensional, two-phase, non-isosteady state model, Guo [23] 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 [24] 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. This is so that convection between the air and the diffusion layer can be stronger due to the rectangular boss.

By modifying the flow field's structure and incorporating bionic design principles into the bipolar plate's flow field design. Fig. 5 depicts the cross-section of the improved parallel flow field, which was developed by Tomoo Yoshizumi [25] based on the MIRAI's first-generation 3D flow field. The cathode plate is enhanced to a 3D flow field based on a parallel flow field in Fig. 4. As a result of this enhancement, air is distributed more effectively, entering the diffusion layer more quickly and reacting with hydrogen. However, the

3D flow field's increased weight results in higher costs and lower energy densities. Toyota thereby created a novel parallel flow field with variable cross section. The air will speed up as it travels through the confined area of the flow section symbolized by the basket in Fig. 5, creating a convective effect that will quickly discharge the product water. 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.

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. Currently, the flow field of bionic research is still in the early stages of rapid development. Numerous studies [26-32] indicate that the flow field of bionics has enormous development potential and the potential to simultaneously increase fuel cell power density and decrease pressure drop. As a result, the fuel cell power density has a significant overall effect of ascent and accelerates the flow field distribution form for the change of the flow field. A. Iranzo, C.H. Arredondo, A.M. Kannan [33] 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 [34]. 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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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