Minireview Article
Design and study of wave flow field bipolar plates for proton exchange membrane fuel cells

ABSTRACT

Proton exchange membrane fuel cell (PEMFC) is an efficient energy conversion device that converts hydrogen and oxygen directly into electricity through a chemical reaction. In PEMFC, the bipolar plate plays a crucial role, responsible for the collection and transfer of current and the distribution of reactant gases. The wave flow channel bipolar plate is a new design designed to improve the performance of the battery, including enhancing the mass transfer efficiency and reducing the pressure drop. This paper analyzes the advantages and disadvantages of other flow channels, and uses computational fluid dynamics (CFD) simulation to evaluate the influence of wave flow field design on the internal fluid dynamics of the fuel cell. It is observed that the wave flow field can effectively increase the length of the flow path and improve the distribution of reactant gas by comparing the traditional flow path with the wavy flow path.

Keywords:fuel cell, Hydrogen,Wavy runner, Bipolar plate

Introduction

1. RESEARCH STATUS OF PEMFC REACTION FLOW FIELD

The common types of PEMFC bipolar plate reaction flow field mainly include parallel flow field, serpentine flow field, interfinger flow field and point flow field. In addition to optimizing these traditional flow fields, researchers at home and abroad have also developed some new flow fields, such as three-dimensional daily flow field and bionic flow field.

In recent years, researchers at home and abroad have carried out a series of studies on the common bipolar plate reaction flow field. Timurkutluk et al. [1] numerically studied the influence of different channel depths on convergence/divergence in a parallel flow field model. The results show that convergent parallel flow field is superior to conventional parallel flow field and divergent parallel flow field. The optimized convergent parallel flow field improves the uniformity of cathode oxygen concentration distribution, and the battery power density is 16% higher than that of conventional parallel flow field.

Mohammad[2]et al. studied and analyzed the transport characteristics of traditional, convergent and divergent serpentine flow fields of PEM fuel cells through numerical studies. The results show that compared with the traditional and divergent serpentine flow fields, the improved convergent serpentine flow field has better current density, oxygen concentration and pressure distribution uniformity, but the channel pressure of the convergent flow field is 6.25 times higher than that of the traditional serpentine flow field, thus reducing the water content in the catalyst layer.

Heidary[3] established a three-dimensional numerical model of DC channel PEMFC with convex structure to study the influence of the number and height of convex on PEMFC. The results show that the net output power of PEMFC in the case of complete blockage is still higher than that in the case of partial blockage, and the net power of PEMFC can be increased by 30% by using five completely blocked bosses in the 5cm long cathode side channel.

Ghanbarian et al. [4] studied the influence of boss shape and arrangement on the performance of parallel flow field fuel cells through numerical simulation. The results show that the trapezoidal boss has the most significant effect on PEMFC, and the net power of the fuel cell can be increased by 26.75% when the boss height is 90% and the zigzagged arrangement is adopted.

Kumar[5]conducted experimental studies on the snake and conical runner, and the results showed that the conical runner could change the flow rate of reaction gas towards GDL and increase the concentration of reaction gas at CL. Compared with the traditional snake runner, the maximum power density of the conical runner increased by 17%.

Perng[6] et al. studied the influence of baffle Angle and baffle height on PEMFC performance by adding ladder baffle in DC channel. The results show that the performance of PEMFC with trapezoidal baffle channel is better than that without baffle channel. When the baffle Angle is 60 ° and the height is 1.125 mm, the net power of the battery is increased by about 90%.

Liu et al. [7] designed an improved parallel flow field with differentiator structure to improve the uniformity of reactant distribution in the parallel flow field, and compared it with the snake flow field through numerical simulation. The results show that this structure can improve the uniformity of reactant distribution in the parallel flow field, and the output power density of the battery increases with the decrease of the size of the differentiator.

Fan[8] et al. studied the effects of multi-plate structure channels and integrated structure channels on the performance of fuel cells by numerical simulation. The results showed that compared with the traditional DC channel, the new channel can make more oxygen flow to the cathode catalytic layer, and the proton exchange membrane fuel cells with an Angle of 30 ° , a width of 0.5mm, and a spacing of 6.0mm have the best performance.

Selvaraj et al. [9] studied the effects of ridge width/channel width (L/C) on four proton exchange membrane fuel cells with different flow fields by numerical simulation, and the results showed that: when L/C was 2/2, the performance of the four flow field forms of fuel cells was optimal.

Huang et al. [10] studied the effects of traditional serpentine flow field and new bionic flow field on the performance of PEMFC through numerical simulation and experimental research. The results show that compared with CSFF, NBFF can significantly improve the droplet dynamic transport characteristics, and the liquid water removal rate is increased by 36.3%.

Lim[11] et al. studied PEMFC 3D model with modified parallel flow field mode. The results show that the improved parallel flow field has more uniform distribution of hydrogen, oxygen, liquid water and current density than the traditional parallel flow field, thus improving the performance of PEMFC.

Chen et al. [12] developed a two-dimensional, two-phase, non-isothermal steady-state model to study the effects of baffle height and position on mass transfer and performance of oriented channel fuel cells. The simulation results show that the uniform distribution of baffles in the flow channel can not only enhance the transport of reactants, but also help to expel more liquid water, so as to obtain higher net power. Although the use of large baffles in the upstream section of the runner can better improve performance, there will also be more water accumulation. An increase in the height of the baffle increases the transport of the reactants, expelling more liquid water, while increasing the current density output.

Abdulla et al. [13] conducted a detailed performance analysis on the enhanced cross-flow shunt serpentine flow field layout of square PEMFC, and the results showed that the serpentine flow field layout in this way was superior to the five-channel serpentine flow field, and the performance was optimal when the rib width ratio was 1/1. The best working conditions are: stoichiometric ratio of 1.5/3, working temperature of 70℃, working pressure of 200kPa, anode and cathode humidification rate of 50%/10%.

Ghasabehi[14] studied the influence of conical parallel flow field on PEMFC performance, and carried out optimization design studies on GDL porosity, anode and cathode stoichiometric ratio, working pressure and working temperature. The results show that the limiting current density of the conical parallel flow field is 41% higher than that of the conventional parallel flow field. The optimization results show that the ideal porosity of GDL is 0.68, the working pressure is 1atm, the stoichiometric ratio of anode and cathode is 2.62/3, and the working temperature is 323K.

Ozdemir et al. [15]studied the influence of channel width to rib width ratio (C/R) of a single serpentine flow channel by numerical simulation. The results show that when the C/R operating voltage is 2 at 0.6V, the serpentine flow field has a maximum power density of 1.0896W/cm2, which is 13.5% higher than that when the C/R is 0.5.

Rahmani et al. [16]used a three-dimensional two-phase PEMFC numerical model to study the effects of wavelength and amplitude of wave channel (FIG. 1) on battery performance, mass and heat transfer. The results show that the waveform channel can effectively improve the uniformity of temperature and reaction gas distribution inside the cell, and the increase of wavelength or amplitude is beneficial to improve the performance of PEMFC. The output power of the wave channel with amplitude of 0.5nn and wavelength of 2mm is 20% higher than that of the DC channel.

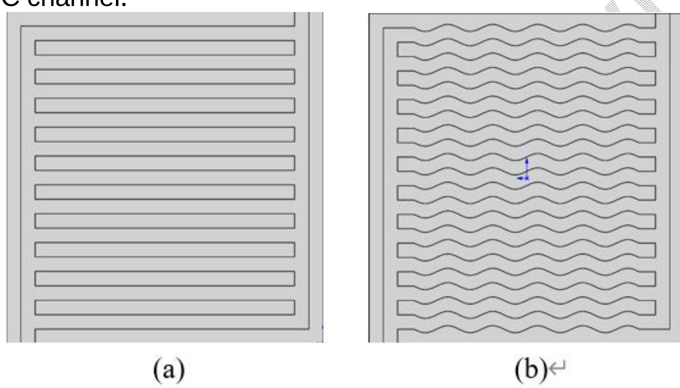

Fig. 1 Wave channel and straight channel

Chen Xi [17] et al. 's numerical simulation method on the effect of wave length and amplitude on the performance and mass transfer of PEMFC. The results show that the wavy flow field can effectively promote the oxygen transmission and accelerate the liquid water removal compared with the parallel flow field. The wave length and amplitude are 4mm and 0.8mm, respectively, and the maximum power of the wave field is increased by 30.7% compared with the parallel flow field.

Chen Jiahao [18] et al. used numerical simulation to study the influence of the number of flow channels on the serpentine flow field PEMFC. The results show that with the increase of the number of serpentine channels, the inlet and outlet pressure drop of the flow field will decrease, the flow velocity of the reaction gas will increase, the concentration of oxygen will increase, and the drainage capacity of the flow field will increase, which will lead to the improvement of the battery performance.

Ye Zhijie et al. [19] studied the influence of variable diameter snake structure bipolar plate runner on PEMFC through numerical simulation, and the results showed that: Variable diameter snake runner increased the liquid water removal rate of the runner and improved the performance of the snake runner.

Wang Longfei[20] et al., based on Fluent, established numerical models of the composite serpentine flow field and the new type of flow field for analysis and research. The results show that the new type of flow field has better reactant distribution and drainage performance than the composite serpentine flow field, so that the performance of the new type of flow field PEMFC is higher than that of the composite serpentine flow field.

Zhang Ning et al. [21] studied the influence of graded flow field (cathode, anode, anode and cathode) on PEMFC through numerical simulation. The results show that in the high current density region, the gradually deformed flow field can effectively improve the voltage loss caused by concentration polarization, and thus improve the performance of the battery. The performance of the cathode flow field is much better than that of the anode flow field.
Sun Feng [22] et al. added baffles in the DC passage and conducted an optimization design study on the baffle spacing and height, and obtained the optimal arrangement scheme of baffles: the number is 5, the spacing is 0.9mm, the spacing difference is 0.4mm, the blocking rate is 75%, and the blocking rate difference is 2.5%. The peak power of this scheme can be increased by 4.96% compared with that without baffles.
For the new reaction flow field, domestic and foreign scholars have done a series of studies. He[23] et al. studied the effect of three-dimensional flow field of trapezoidal baffle with different inclination angles on PEMFC performance through experiments, and compared it with parallel flow field. The results show that the three-dimensional flow field can significantly improve the performance of proton exchange membrane fuel cells at high current density. The flow field with large inclination Angle is suitable for the application scenario of low water content, and the flow field with small inclination Angle is more suitable for the case of high water content.
Based on the structural design of spiral flow field, Tamerabe et al. [24] studied the influence of rib width, spiral turns and inlet and outlet direction of spiral flow field on PEMFC. The results show that the smaller the rib width, the larger the contact area between the flow channel and GDL, and the more uniform the reactant distribution; The uniformity of reactant distribution can be improved with the increase of spiral turns. The reaction gas is passed from the outside to improve the current density distribution and thus improve the performance of the fuel cell.
Wan, Yang[25][26] et al. optimized the structural parameters (obstacle height and width) of M-channel through numerical simulation, and the results showed that: The mass and heat transfer performance of M-channel is better than that of wavy channel. The performance of fuel cell increases first and then decreases with the increase of obstacle height (decrease of obstacle width). When the obstacle height H is 0.15mm, the fuel cell has the best performance.
Son[27] et al. studied the influence of the number of turns of the serpentine structure on the flow field of metal foam, and the results showed that: The serpentine structure leads to the pressure difference between the regions in the flow field, which strengthens the convective flow in GDL, and thus improves the performance of the metal foam flow field. However, the increase in the number of turns of the serpentine structure will increase the extra power loss. When the number of turns of the serpentine structure is 2, the net power output of the metal foam flow field is the highest.
Ebrahim[28] studied the influence of metal foam flow field on PEMFC based on numerical simulation. The results show that compared with the traditional parallel flow field, the metal foam flow field can enhance the gas transmission and improve the current density distribution. Moreover, due to the high permeability of the metal foam, the pressure drop of the flow field is very small, and the internal temperature of the fuel cell is lower and the temperature distribution is more uniform, resulting in better performance output of PEMFC.
Ghadhban et al. [29] studied the effects of vein and tree-shaped flow field on PEMFC performance, and the results showed that the flow field with vein form had the best performance, which was 5.12% higher than that with single snake design and 3.75% higher than that with tree-shaped flow field design.
Li Zijun et al. [30] studied the influence of three-dimensional waveform flow channel on fuel cell performance and mass transfer through numerical simulation and experimental verification. The results showed that three-dimensional waveform flow channel could improve the forced convection effect of reaction gas, and the peak power density of waveform flow channel was increased by 10.16% compared with DC channel.

Chen Tao [31] et al. designed a new bionic structure flow field plate based on the plant vein structure and optimized the design through numerical simulation. The results show that the performance of the new bionic structure PEMFC is better than that of the traditional parallel structure. The change of branch position and the increase of the number of branches can improve the performance of PEMFC. The ohmic heat generated by the optimized structure is 19.4% less than that of the parallel structure.
Chu Xu et al. [32] studied the influence of baffle arrangement and baffle shape (rectangle, trapezoid, semicircle) on the performance of DC channel PEMFC through numerical simulation. The results show that the performance of PEMFC with baffle row (from low to high) is the best, and the performance is improved by 14.3% compared with that of unbaffle channel. The performance of ladder baffle PEMFC is better than that of rectangle and semi-circle.
Lian Yutao et al. [33] studied the influence of the number and shape of channels on the radial flow field PEMFC performance of circular bipolar plates based on numerical analysis. The results show that increasing the number of channels is conducive to improving the transport capacity of reactants and improving the performance of fuel cells. The rectangle channel shape with aspect ratio of 1.5/1.75 is the best shape.
Zhao Yonghao et al. [34] designed a flow channel structure with double reinforcement mass transfer to study the effects of both lateral and longitudinal reinforcement flow channel structures on the transport and performance of reactants. The results show that the structure can improve the performance of PEMFC by increasing the flow rate of reactive gas and strengthening the transmission of reactive gas. Under the optimal structure parameters, the output performance of PEMFC can be increased by 28.7%.
Shang Xian-Shang et al. [35] studied the influence of block shape and number on the performance of serpentine flow channels, and the results showed that, under uniform arrangement, square block had the most obvious improvement on the performance of the battery. When the operating voltage was 0.5V, the current density of PEMFC could be increased by 21%, but it would cause a large voltage drop. In the non-uniform arrangement, the optimal block distribution design can improve the output performance by 4%.
An Zhiguo et al. [36] studied the influence of the stepped flow channel model on the mass transfer and performance of PEMFC through numerical simulation. The conclusions are as follows: Compared with the conventional DC channel, the stepped structure can effectively improve the uniformity of oxygen distribution and water distribution inside the battery, and the maximum power density can be increased by 13.58%, but the pressure drop will increase resulting in additional power loss.
Wu Shengwei et al. [37] studied the influence of the expansion area in the flow channel on PEMFC through numerical simulation. The results show that the performance of the new extended flow channel PEMFC is better than that of the traditional DC channel, and the optimal extended length is 2mm. At high current density, the extended flow channel increases the uniformity of oxygen distribution at the interface between the catalytic layer and the membrane, improves the removal efficiency of liquid water in the flow channel, and increases the number of extended areas in the flow channel, which is conducive to the improvement of fuel cell performance.
Wang Ke et al.[38] conducted a numerical simulation study on the bionic runner with neuron structure, and the results showed that the increase in the number of branches of the runner was beneficial to improving the uniformity of oxygen distribution and drainage efficiency, thus improving the performance of the bionic runner PEMFC.
Xia Lei et al. [39] optimized the design of the trapezoidal DC channel proton exchange membrane fuel cell by genetic algorithm, and obtained the optimal structural parameters of the trapezoidal DC channel: upper base width, lower base width, channel height and ridge width ranging from 0.99927mm-1.59998mm-0.76951mm-0.40023mm. The net output power of the optimal model is increased by 20.90% at 0.5V.

Su Dandan [40] et al. added a trapezoidal baffle in the DC channel to optimize the design of the trapezoidal baffle Angle and study the influence of the trapezoidal baffle Angle on the transmission characteristics of the reaction gas. The results show that the oxygen concentration in porous media and the performance of fuel cell can be improved by increasing the front and back inclination angles and the number of baffles.
Meng Qingran et al. [41] studied the influence of flow field groove shape on PEMFC performance based on simulation analysis. The results show that when the number of rectangular grooves is 5, the performance of PEMFC is the best. The improvement of performance of PEMFC by grooves is wavy, rectangular and triangular from high to low.
Wang Zeying[42] et al. simulated and analyzed the flow field of the bionic structure (ginkgo biloba leaf vein) through numerical simulation, and the results showed that: The peak power density of PEMFC in the bionic flow field is increased by 28.85% compared with that in the horizontal flow field. The main reason is that the bionic flow field has higher gas pressure, resulting in more uniform distribution of the reacter and current density in the bionic flow field than that in the parallel flow field. However, the peak power density of the bionic flow field is decreased by 4.36% compared with the five-snake flow field.
This paper summarizes the research on flow field design by researchers in related fields at home and abroad, which mainly focuses on two aspects: One is to improve the design of traditional parallel flow field and serpentine flow field by adding convex and baffle; On the other hand, it is to design new flow fields, such as 3D flow field and bionic flow field. As an improved flow field of parallel flow field, wave flow field inherits the advantages of parallel flow field while retaining the disadvantages of parallel flow field, which is prone to problems such as "flooding" and "air shortage". Some scholars hope to improve wave flow field by changing wave flow field structure, such as reducing wave period and increasing wave flow field. However, there are relatively few studies on the influence of subchannel structure on wave flow field PEMFC.

2. RESEARCH STATUS OF COOLING FLOW FIELD OF PEMFC

Rahgoshay et al. [43] studied the influence of traditional serpentine and parallel cooling plate flow fields on fuel cell performance through numerical simulation. The results show that under the same operating conditions, the maximum temperature ratio between parallel and serpentine flow fields is 1.0028, but for uniform temperature index, the serpentine cooling flow field is 24% better than the parallel model, and compared with the parallel flow field, changing the heat transfer rate can effectively improve the PEMFC performance of the serpentine cooling flow field.
Li et al. [44]studied and analyzed the cooling plate of the new flow path design with non-uniform cross section through numerical simulation. The results show that compared with the traditional DC channel, the new channel with non-uniform cross section has lower maximum temperature and temperature difference.
Arash[45] et al. established a numerical model to study the effects of coolant flow rate and reaction gas inlet and outlet manifold on temperature distribution in bipolar plates. The results show that the higher the coolant flow rate, the more uniform the temperature distribution, and the lower the flow rate, the lower the pressure drop and power loss. The inlet and outlet manifold of the reaction gas has a certain influence on the temperature distribution in the bipolar plate.
Ebrahim et al. [46] studied fluid flow and heat transfer in a zigzag flow channel (FIG. 2) through numerical simulation. The results show that the maximum surface temperature, surface temperature difference and uniformity index of the zigzag channel decrease by 5%, 23% and 8%, respectively, compared with that of the parallel channel. The cooling performance of the zigzag channel is significantly improved when the flow rate of the coolant is higher and the heat flux applied to the surface of the cooling plate is higher.

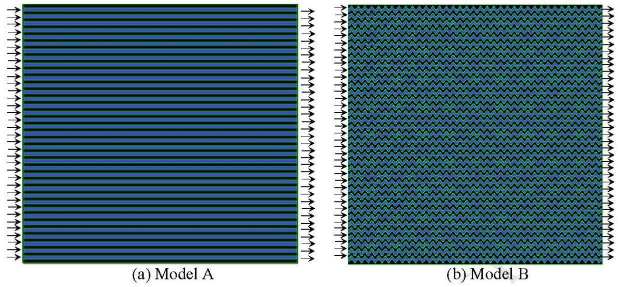

Fig. 2 Parallel and serrated flow channels

Mehdi et al. [47] studied the effect of porosity and pore size of metal foam flow field on the performance of cooling system. The results show that the decrease of pore size and porosity and the increase of Reynolds number can improve the uniformity of temperature distribution, but lead to the increase of pressure drop.

Based on the serpentine flow field design, Acar et al. [48] studied the influence of the flow channel/rib width ratio (C/R) on the cooling flow field performance and inlet and outlet pressure drop. The results show that when C/R increases from 0.33 to 3.0, the average temperature, temperature uniformity index, temperature difference and pressure drop decrease by 5%, 40%, 37% and 79%, respectively. When C/R is 3.0, the temperature distribution uniformity is better and the pressure drop is the lowest.

Seyed[49] et al. established a numerical simulation model of PEMFC with serpentine cooling channel to study the influence of serpentine flow field structure on internal temperature distribution and performance of fuel cells. The results show that the four-stage serpentine flow field has a lower temperature range and better temperature uniformity than other flow field structures, and has better cooling performance.

In this paper, it is summarized that scholars in related fields have not only studied the cooling performance of traditional parallel flow field and serpentine flow field, but also designed some new flow fields, such as sawtooth flow field and metal foam flow field, etc., while there are relatively few studies on the cooling performance of wave flow field.

3. CONCLUSIONS

The application of bipolar plates in proton exchange membrane fuel cells is reviewed in this paper. The study found that the wave flow field design significantly improved the performance of PEMFC, including improved power density and energy conversion efficiency, while reducing the pressure drop of the system. These improvements are mainly due to the enhanced mass transport and mixing of reactant gases by the wave flow field, as well as improved thermal management inside the battery. Therefore, the wave flow field bipolar plate design provides a promising direction for the development of PEMFC, especially in the pursuit of high performance and high efficiency applications. Future work could further explore optimal parameters for wave flow field design and how they perform under different operating conditions to enable commercialization and scale application of PEMFC technology.

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