Performance of HT-PEMFC Based on Improved Baffle Structure

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Abstract: This study combines the three-dimensional model of the high-temperature proton exchange membrane fuel cell(HT-PEMFC) with theoretical analysis, by optimizing the structure of the fuel cell, adding a semicircular baffle in the gas channel and implementing novelly arranged obstacles to improve the PEMFC performance. The effects of velocity distribution, interface reactant concentration and pressure drop on performance are studied. The results show that adding obstacles in the gas channel will produce vertical velocity and can improve output performance, especially in the case of high current density and higher baffle radius. The superiority of the optimized structure in mass transfer capacity is proved, and a mechanism explanation is given for the improvement of performance.

Key words: high-temperature proton exchange membrane fuel cell (HT-PEMFC); baffle; mass transfer; field synergy; net power

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0 Introduction

Proton exchange membrane fuel cell (PEMFC) has the advantages of high energy conversion efficiency, low emissions, and high stability. It is considered to be one of the most suitable alternatives to traditional energy conversion systems, like internal combustion engines[1-2]. At present, PEMFC has been widely and successfully applied to many fields, such as automobiles, communications, and submarines[3]. PEMFC can be divided into two categories via different operating temperature ranges, i.e., the high temperature PEMFC (HT-PEMFC) and the low temperature PEMFC (LT-PEMFC). HT-PEMFC has an operating temperature range of 100—200 ℃, and the working temperature of LT-PEMFC is about 60—80 ℃[4]. Generally, since LT-PEMFC works at lower temperatures, a more complex water management system is required to maintain Nafion membrane performance, and pure hydrogen (99.99%) is used for fuel treatment to prevent CO poisoning of platinum catalysts[5-6]. Since HT-PEMFC operates at a temperature above 100 ℃ and uses polybenzimidazole (PBI) membrane, it can evaporate the liquid water produced by the cathode, thereby simplifying the water management system, and the PBI membrane has a better effect on CO poisoning tolerance, which can simplify the fuel treatment system[7]. In addition, the increase of temperature will increase the rate of electrochemical reaction. The consumption of hydrogen will be reduced, and the waste heat can be better recycled[8]. Therefore, the HT-PEMFC technology can reduce operation and equipment costs, moving closer to commercialization[9].

PEMFC is mainly composed of a proton exchange membrane (PEM), a catalytic layer, a diffusion layer, a bipolar plate and a flow channel. The hydrogen and oxygen (or air) are sent into the fuel cell by the anode/cathode flow channels, and then pass through the gas diffusion layer (GDL) to the catalyst layer (CL) for electrochemical reaction. Under the action of the anode catalyst, a hydrogen molecule is oxidized into two protons and two elec-

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trons are released. The electrons generated by the electrode reaction reach the cathode through the external circuit, and the protons reach the cathode through the electrolyte membrane. The electrons react to generate water and heat, and the generated water is discharged with the reaction tail gas.

Among them, the chemical reaction of PEMFC can be described as:

$$\text{Anode: } H_2 \rightarrow 2H^+ + 2e$$

$$\text{cathode: } \frac{1}{2}O_2 + 2H^+ + 2e \rightarrow H_2O + \text{Heat}$$

$$\text{Total: } H_2 + \frac{1}{2}O_2 \rightarrow H_2O + \text{electrolic} + \text{Heat}$$

During the operation of the fuel cell, there will be a significant voltage drop compared with the ideal voltage output, which should be reduced as much as possible. The irreversibility of the electrochemical reaction of the fuel cell is the main cause of the voltage drop. The voltage drop includes activation overpotential, ohmic overpotential and concentration overpotential. The activation overpotential and ohmic overpotential are related to physical properties and initial working conditions, while the concentration overpotential is determined by the structure and reaction process of the fuel cell. The enhanced mass transfer effect brought by the excellent structure will provide enough reaction gas for CL, which means lower concentration overpotential and better performance. In addition, enhancing the mass transfer process is also important for the long-term, efficient and stable operation of PEMFC. Jiao et al.[10] numerically studied the influence of flow channel geometry and CO poisoning on the performance of HT-PEMFC batteries. Their research results show that when pure hydrogen is fueled, the interdigital channel produces the highest power output compared with the serpentine and parallel channels. Singdeo et al.[11] applied a new serpentine geometry to the HT-PEMFC channel to improve the distribution and performance of reactants in the fuel cell. Numerical simulation results show that under the same voltage, compared with the common serpentine geometry (uniformity coefficient of 0.96), the new serpentine geometry can achieve better current density distribution (uniformity coefficient of 0.998) and higher average current density (increased by about 22%). In all channel structure design studies, in addition to different flow channel topology types, arranging baffles or ribs along the channel is considered to be another effective design to improve the performance of LT-PEMFC. There has been little research on HT-PEMFC.

Shen et al.[12] compared the performance of four LT-PEMFCs with different blocking baffles with a conventional single serpentine flow field. According to the principle of field synergy, it is verified that as the number of baffles increases, the average synergy angle between the gas velocity and concentration gradient at the cathode decreases, and the effective mass transfer coefficient is improved, thereby enhancing the performance of PEMFC. Jang et al.[13] studied the influence of the number of baffles on the transportation phenomenon of LT-PEMFC by numerical simulation. The results showed that with the increase in the number of baffles, the increase in current density at low voltage decreased. Therefore, there is an appropriate number of baffles corresponding to the highest net output power. Heidary et al.[14] studied the effect of partial or full blockage on the performance of LT-PEMFC, and the results showed that, despite the higher pressure drop, complete blockage forced more reactants into CL compared with partial blockage, promoted the supply of reactive gas, and improved the net electric power. Their follow-up study on the baffle position showed that the performance of staggered blockage in parallel flow channels is better than that of continuous blockage of baffles[15]. The numerical results of Perng et al.[16] show that the larger angle and height of the trapezoidal baffle provide more reactants for CL than the traditional flow channel, which can significantly enhance the blocking effect, thereby improving the performance of LT-PEMFC. When the trapezoidal baffle angle of LT-PEMFC is 60°, the maximum battery net power output at a battery voltage of 0.6 V is about 90% higher than that of PEMFC with a traditional flow channel (without baffle). The wave-shaped flow channel is also regarded as a flow channel with a continuous baffle. Kuo et al.[17] used a 3D calculation model to compare the LT-PEMFC with a traditional straight gas flow channel or a new wave-shaped gas flow channel. The results show that com-

pared with straight air channels, wave-shaped channels provide better convective heat transfer performance, higher air velocity, and more uniform temperature distribution. As a result, the efficiency of the catalytic reaction is greatly improved. The improved catalytic reaction is beneficial to increasing the battery voltage and improve the power density, especially in the case of high inlet temperature and current density.

There is nearly no written works considered the impact of the baffles in the channel of HT-PEMFC. In addition, the pressure loss caused by this baffle will result in additional power consumption for transporting the reactants. It is necessary to compare the actual increase in the net power output by the HT-PEMFC considering the pressure drop of the channel. In this paper, the numerical results of the straight channel HT-PEMFC are compared with the polarization performance obtained by experiments in the literature. The results show that the computational fluid dynamics (CFD) results agree well with the experimental measurement data and the model is credible. The purpose of this paper is to propose an innovative internal cross-shaped semicircular baffle channel via comprehensive numerical analysis on HT-PEMFC, and qualitatively study the different barriers in the bipolar plate channel in consideration of the net power output. To investigate the effect of plate layout on the comprehensive performance of HT-PEMFC, the parametric scanning method is used to quantitatively study the radius of the HT-PEMFC semicircular baffle under the highest performance conditions. Finally, a comprehensive analysis of the performance of different runners is carried out.

1 Design Description

The basic model of single channel PEMFC is based on the structure of parallel straight channel PEMFC. Since parallel straight channel PEMFCs are geometrically arranged periodically, the repeating units are shown in the red dotted line in Fig.1. Therefore, we select the periodic repetitive part of the fuel cell for numerical calculation, and the calculation domain is shown in the red dotted line in Fig.1.

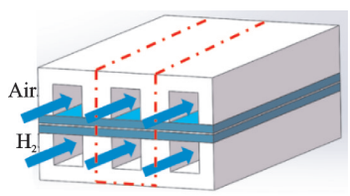

Fig.1 Position of single channel PEMFC in flow field

The addition of baffles can effectively enhance the transport of reactive gas to the diffusion layer and improve the performance, but at the same time, it increases the pressure drop, resulting in the increase of power consumption of the auxiliary system. Therefore, we redesigned the traditional semicircular baffle channel. On the one hand, the semicircular baffle was cut to reduce the pressure drop in the flow process; on the other hand, the semicircular baffle was staggered in the flow direction to reduce the uneven distribution. It is expected to improve the performance and reduce the pressure drop of the PEMFC channel. The relative position of baffles in a single channel fuel cell is shown in Fig.2. The height changes with the radius, and the radius (r) is defined as a variable geometric parameter.

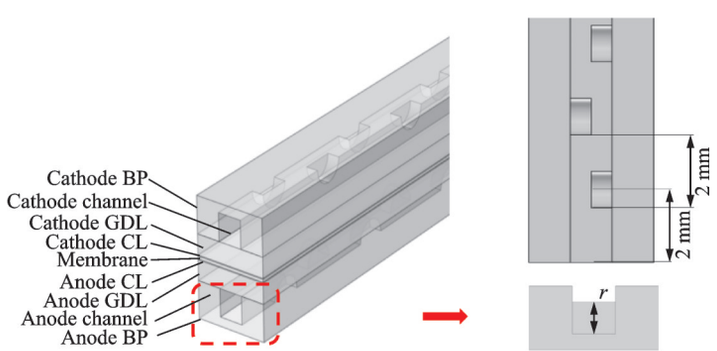

Fig.2 Geometric diagram of PEMFC with staggered semicircular baffle channel

In this paper, the semicircular baffle channel and staggered semicircular baffle channel are numerically simulated, and the performance of the three channels is analyzed by comparing with that of the straight channel, as shown in Fig.3.

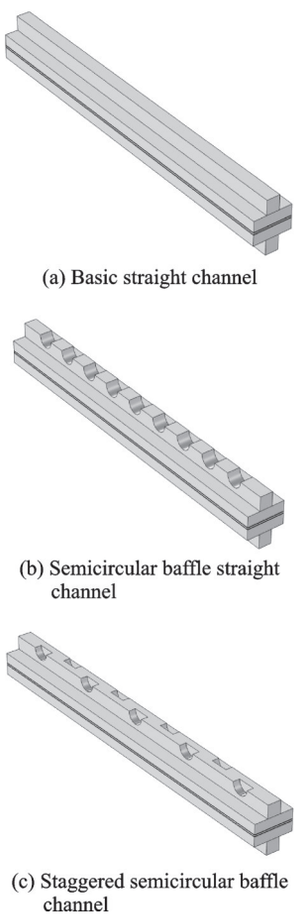

Fig.3 Computational domain of PEMFCs with different channels

2 Model Development

PEMFC model is complex. It is a multi-process and highly nonlinear energy conversion system with strong coupling. Various factors are interrelated and influence each other. Therefore, it is necessary to establish a specific and detailed mathematical model to describe the working process of HT-PEMFC.

The basic mathematical models used in the simulation of HT-PEMFC are described, including the basic hydrodynamic model and the electrochemical model. The established three-dimensional, single-phase, isothermal and steady-state HT-PEMFC models provide a theoretical basis for future simulation. In order to control the factors affecting the performance of PEMFC, the numerical examples in this paper are simulated under the same membrane electrode assembly (MEA) conditions. In addition, in the study of the influence of different baffle radii on the performance, the radius is set as 0.3, 0.4, 0.5, and 0.6 mm, respectively.

To simplify the model, the main assumptions of the HT-PMEFC model are as follows:

(1) The fluid is regraded as the single-phase, laminar, and stable flow;

(2) Isothermal conditions are adopted;

(3) The reaction gas is the ideal gas;

(4) The membrane only conducts protons, but does not allow the reaction gas to pass through;

(5) The GDL, Cl, and PEM layers are homogeneous and isotropic

(6) The contact resistance between layers is negligible.

2.1 Governing equations

The transport processes in different layers of a fuel cell are governed by partial differential equations as follows

$$\nabla\cdot(\varepsilon\rho\boldsymbol{u})=S_{\mathrm{m}} \tag{1}$$

where ε, $\boldsymbol{u}$, S_{m}, and ρ are the porosity, the velocity vector, the mass source term, the density of the fluid mixture, respectively.

$$\rho\boldsymbol{u}\nabla(\boldsymbol{u})=\nabla\left\{-pI+\mu[\nabla\boldsymbol{u}+(\nabla\boldsymbol{u})^{\mathrm{T}}]\right\}+S_u \tag{2}$$

where S_u is the momentum source term, $\boldsymbol{I}$ the identity matrix, p the pressure, and μ the viscosity.

$$\nabla\left\{-\rho\omega_i\sum_{j=1}^{N}D_{ij}\left[\frac{M}{M_j}\left(\nabla\omega_j+\omega_j\frac{\nabla M}{M}\right)+(x_i-w_j)\frac{\nabla P}{P}\right]+\omega_i\rho\boldsymbol{u}\right\}=S_k \tag{3}$$

where D_{ij} is the binary diffusion coefficient, x the mole fraction, w the mass fraction, M the molar mass, S_k the component source item, and the subscript k the type of component.

Charge conservation equations are

$$\nabla\cdot\left(-\sigma_{\mathrm{s,eff}}\nabla\boldsymbol{\Phi}_{\mathrm{s}}\right)=S_{\mathrm{s}} \tag{4}$$

$$\nabla\cdot\left(-\sigma_{\mathrm{e,eff}}\nabla\boldsymbol{\Phi}_{\mathrm{e}}\right)=S_{\mathrm{e}} \tag{5}$$

where $\sigma_{\mathrm{s,eff}}$, $\sigma_{\mathrm{e,eff}}$ are the conductivities of the solid

and membrane phases, respectively; $\boldsymbol{\Phi}_s$, $\boldsymbol{\Phi}_e$ the potentials of the solid phase and the membrane phase, respectively; and S_s, S_e the source terms of the electron current and proton current, respectively.

In the simulation, the Bulter-Volmer equation is mainly used to describe the electrochemical reaction process of cathode and anode of PEMFC, which mainly occurs in the catalytic layer of PEMFC. Eq.(6) represent current density on both electrodes.

Bulter-Volmer equations are

$$j_a = a i_{0,a}^{\mathrm{ref}} \left(\frac{Y_{\mathrm{H_2}}}{Y_{\mathrm{H_2}}^{\mathrm{ref}}} \right)^{0.5} \left[\exp\left(\alpha_a^a F / RT \right) \eta_a - \exp\left(-\alpha_c^a F / RT \right) \eta_a \right] \tag{6}$$

$$j_c = a i_{0,c}^{\mathrm{ref}} \left(\frac{Y_{\mathrm{O_2}}}{Y_{\mathrm{O_2}}^{\mathrm{ref}}} \right) \left[\exp\left(\alpha_a^c F / RT \right) \eta_c - \exp\left(-\alpha_c^c F / RT \right) \eta_c \right] \tag{7}$$

2.2 Boundary conditions

In the numerical simulation, the inlet velocity of reactant entering the channel is determined by

$$u_{\mathrm{in},a} = \frac{\xi_a \dfrac{I}{2F} A_{\mathrm{mem}} M_{\mathrm{H_2}}}{\rho_{\mathrm{H_2}} A_a} \tag{8}$$

$$u_{\mathrm{in},c} = \frac{\xi_c \dfrac{I}{4F} A_{\mathrm{mem}} M_{\mathrm{O_2}}}{\rho_{\mathrm{O_2}} A_c} \tag{9}$$

The geometric parameters and operating parameters of the calculation domain are shown in Table 1.

Table 1 Geometric and operational parameters

Parameter	Value
Channel length / m	0.02
Channel width / m	7.5×10^{-4}
Channel height / m	7.5×10^{-4}
Rib width / m	0.001 5
GDL thickness / m	550×10^{-6}
CL thickness / m	25×10^{-6}
Membrane thickness / m	75×10^{-6}
GDL porosity	0.5
Electrode porosity	0.3
GDL conductivity/(S•m^{-1})	687.5
Proton conductivity of electrolyte/(S•m^{-1})	10
GDL permeability	1.18×10^{-11}
Mass fraction of inlet hydrogen	0.99
Quality fraction of imported water	0.002
Mass fraction of imported oxygen	0.208
Air stoichiometry	5.2
Hydrogen stoichiometry	1.3
Operating pressure/ Pa	120×10^{3}
Operating temperature /K	433
Battery voltage/ V	0.6
Anode reference exchange Current density/(A•m^{-2})	1×10^{5}
Cathode reference exchange current density/(A•m^{-2})	1
Oxygen reference concentration/(mol•m^{-3})	40.88
Hydrogen reference concentration/(mol•m^{-3})	40.88
Reference diffusivity of H_2 in H_2O/(m^2•s^{-1})	9.15×10^{-5} (307.1 K)
Reference diffusivity of O_2 in H_2O/(m^2•s^{-1})	2.82×10^{-5} (308.1 K)
Reference diffusion rate of O_2 in N_2/(m^2•s^{-1})	2.2×10^{-5} (293.2 K)
Reference diffusivity of H_2O in N_2/(m^2•s^{-1})	2.56×10^{-5} (307.5 K)
Faraday constant/(C•mol^{-1})	96 487

Boundary conditions have a great influence on the correct simulation results. For the gas inlet boundary, the mass fraction of each component, the inlet mass flow rate and the inlet temperature are given. At the gas outlet boundary, the pressure at the outlet is given. The polarization curve is obtained by calculating the output current with the given output voltage at both ends of PEMFC. On the cathode side, the upper surface potential of the bipolar plate is equal to the fuel cell voltage; while on the anode side, the lower surface potential of the bipolar plate is set to 0. The boundary condition of the inner wall of the flow field is no sliding boundary, and the rest of the contact boundary is set as symmetrical, continuous insulating boundary conditions. On the external surfaces of bipolar plates, the temperature is assigned as the operating temperature of HT-PEMFC in the CFD simulations, as shown in Fig.4.

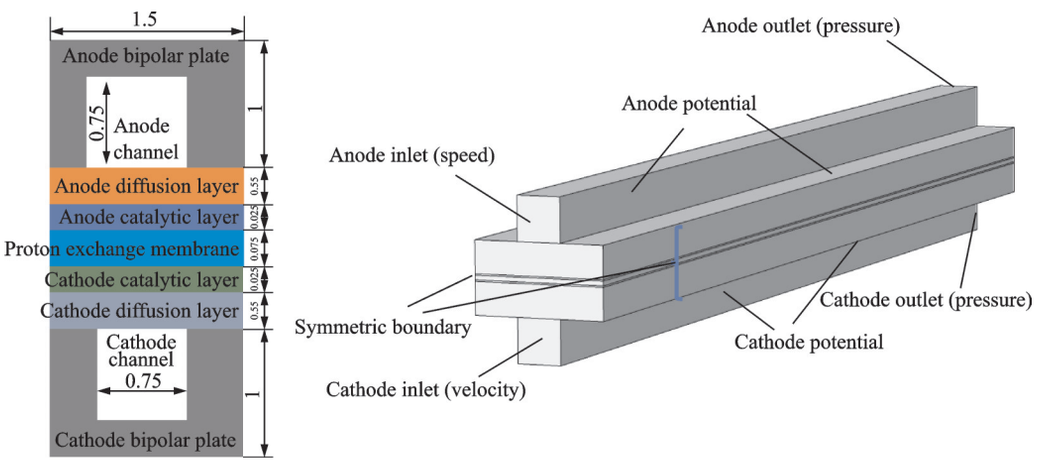

Fig.4 Basic dimensions and boundary types of the model (unit: mm)

The calculation of initial value will affect the convergence and the simulation, as well as calculation time. Although the operating conditions of different simulations will be different, it does not affect the simulation results, but increases the convergence speed of the model and reduces the calculation time.

2.3 Model validation

The number of grids has a significant influence on the simulation accuracy. Theoretically, more dense grids can obtain more accurate values, but more grids will increase the calculation time, even leading to memory overflow. Therefore, it is essential to select the appropriate number of grids. Using the parametric scanning method, the number of grids is increased in turn, and then the local current density of 0.4 V voltage is compared. The results are shown in Fig.5. It can be seen from Fig.5 that with the increasing number of grids, the current density gradually approaches a stable value of 1.017 A/cm^2, and basically does not change. Considering the accuracy and computing time, 71 245 grids will be used in the single cell model.

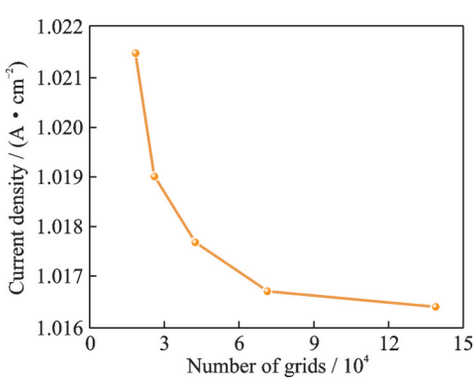

Fig.5 Grid independence verification diagram.

The above fuel cell model was solved using COMSOL Multiphysics 5.5, a commercial software based on finite element. These mutually coupled control equations are solved iteratively in separate solvers. For the diffusion layer, CL and membrane, their thickness is small and different, so the

grid is densified to varying degrees, thereby improving the accuracy of calculation. The simulation takes about 2.5 h to run on an Intel i5 9400F with 16.0 GB RAM, 2.9 GHz workstation. In order to ensure the accuracy of the numerical model, the polarization curve of the straight channel PEMFC obtained through simulation was compared with the experimental data[18], as shown in Fig. 6. It can be seen that the simulation results are in good agreement with the experimental data. At high current density, the difference is within 5.48%. Therefore, the model has been verified to be reliable.

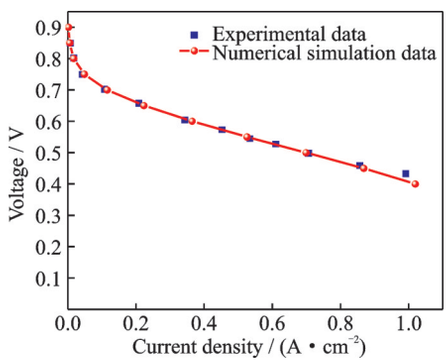

Fig.6 Comparison of simulation and experimental polarization curves of a straight-channel PEMFC

3 Results and Discussion

Under the same operating conditions, the effects of different baffle types (staggered semi-circular baffles, semi-circular baffles and contrasted with direct flow channels) and baffle radii have been used to study the mass transfer characteristics and electrochemical performance of high-temperature PEM fuel cells under the same operating conditions. First, the performance of the internally staggered semicircular baffle, semicircular baffle channel (basic baffle height is set to 0.5 mm) and the performance of the HT-PEMFC of the flow channel are discussed. Then, based on the obtained optimal baffle type, the performance of the HT-PEMFC with different radii is studied under the restriction of the channel height. The radius of the baffle is 0.3, 0.4, 0.5, and 0.6 mm. The relationship between baffle radius and its performance is analyzed. Then, based on the velocity field and the concentration distribution of reactants, the mechanism of mass transfer enhancement and the relationship with performance enhancement are discussed. Finally, the optimal flow channel structure under the design conditions of this paper is obtained.

3.1 Effect of baffle arrangement on performance

According to the CFD simulation results, the performance of HT-PEMFC with continuous semicircular baffles and staggered semicircular baffles added to the bipolar plate channel was compared with the channel without baffles. Fig. 7 shows the polarization curves and power curves of the HT-PEMFC in three types of bipolar plate channels. The addition of staggered semicircular baffles and continuous semicircular baffles makes the battery performance better than straight channels without baffles. In addition, continuous semicircular baffles can produce higher power density than staggered baffles. This is because the continuous semicircular baffle blocks the reaction fluid strongly and induces more reaction gas to the catalytic layer, which is conducive to enhance the electrochemical reaction.

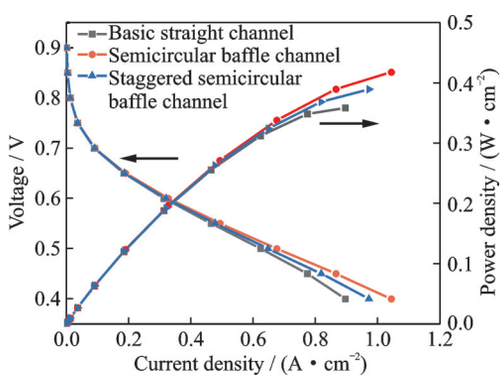

Fig.7 Polarization curve and power curve of three flow channels

It can be seen from Fig.8 that the molar concentration of oxygen in the flow direction of the three channels decreases continuously, and the curve is basically linear, which conforms to the law of conservation of mass. The mole concentration of oxygen at the interface of GDL-CL increases significantly in the baffled channel compared with that in the basic straight channel. In addition, the oxygen concentration of the baffle channel fluctuates periodically in the flow direction, and the oxygen concentra-

tion of the baffle channel is higher than that of the straight channel in the whole flow process. On the one hand, it indicates that the baffle disturbs the oxygen flow in the channel. On the other hand, it also indicates that the addition of the baffle enhances the oxygen transmission. It shows that this disturbance is conducive to the transport process of the reaction gas to the catalytic layer, or the addition of the new baffle designed in this chapter can effectively improve the reactant concentration at the GDL-CL interface.

However, considering the actual operation of the system, the net power of the system must be compared to evaluate the pros and cons of the HT-PEMFC channel structure. In Table 2, the three channel structure HT-PEMFC and performance-related values are listed. The simulation conditions are: the single cell voltage is 0.4 V, r=0.5 mm and N=9. From Table 2, it can be found that compared with the basic straight channel, the semicircular baffle channel increases the current density only by 16.52%, but increases the pressure drop by 8.84 times. The staggered semicircular baffle channel increases the current density by 8.59%, which only increases the pressure drop by 2.63 times. Therefore, from the point of view of the net system power, installing the staggered semicircular baffle in the channel suits better to practical operation needs than the continuous semicircular baffle. It is also a solution for improving the performance of HT-PEMFC.

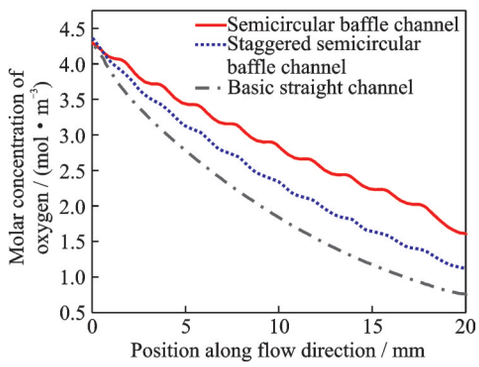

Fig.8 Oxygen molar concentration in three flow channels along the flow direction in GDL-CL plane

Table 2 Performance comparison of PEMFC in three channels (V_{cell} = 0.4 V, r = 0.5 mm, N= 9)

Type	Current density / (A•cm^{-2})	Pressure drop/Pa
Basic straight channel	0.896	16
Semicircular baffle channel	1.044	168
Staggered semicircular baffle channel	0.973	47

3.2 Influence of baffle size on performance

The influence of different baffle radius on the performance of HT-PEMFC is studied. In order to further explore the performance of the new baffle in different scenarios, the performance of the new baffle channel under different radii conditions is analyzed.

Based on the optimized staggered semicircular baffle structure in Section 3.1, the influence of baffle radius on the performance of HT-PEMFC is studied and compared with that of the straight channel. The baffle arrangement at the bottom of the flow channel are shown in Fig.9. The radii of semicircular baffles are selected as 0.3, 0.4, 0.5, and 0.6 mm, respectively. Similarly, the net power of the HT-PEMFC is determined, considering the pressure drop of the channel.

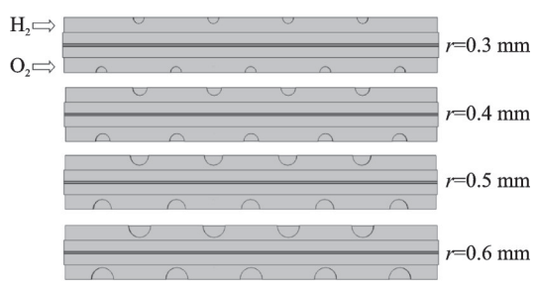

Fig.9 Schematic diagram of different baffle radii in the bipolar plate channel

Fig.10 is the polarization curve of the HT-PEMFC corresponding to different baffle radii under the same operating conditions, revealing the influence of the bottom baffle on the performance of HT-PEMFC. As shown in Fig.10, at a lower working voltage, as the radius of the baffle increases, the performance of the HT-PEMFC improves accord-

ingly. At a higher working voltage, the corresponding law of performance and the number of baffles is not in a clearly positive relationship. This is because more baffles enhance the clogging effect and induce more reactive gas to be supplied to the MEA. In addition, when the radius of the bottom baffle is 0.6 mm, HT-PEMFC has the optimal performance because it has the strongest blocking effect on the reaction gas.

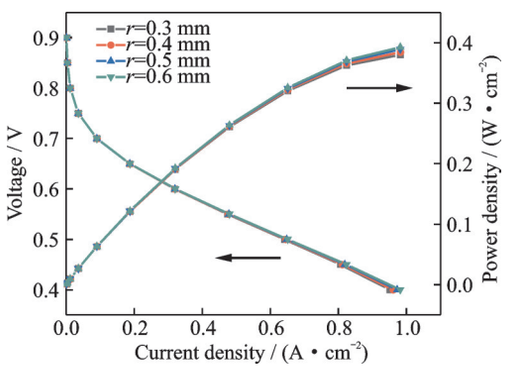

Fig.10 Polarization curve and power curve of HT-PEMFCs with different baffle radii

However, the installation of baffles increases the pressure drop, which requires more work to transport the reactants across the obstacles. In this paper, Fig.11 was plotted to show the pressure drop through the cathode bipolar plate channel with different baffle radii. The pressure drop between the inlet and outlet of the bipolar plate channel is $\Delta P = P_{\text{inlet}} - P_{\text{outlet}}$, where P_{inlet} and P_{outlet} are the average surface pressures of the inlet and the outlet.

The increase in the radius of the bottom baffle significantly increases the pressure drop through the bipolar plate channel. Therefore, although the more the bottom baffles, the higher the battery power density, a great pressure drop occurs, thereby reducing the actual battery power output (W_{net}) of the HT-PEMFC, which can be expressed by

$$W_{\text{net}} = W_{\text{FC}} - W_{\text{P}} \tag{10}$$

$$W_{\text{P}} = \Delta P \times A_{\text{ch}} \times u_{\text{in}} \tag{11}$$

where W_{FC} is the battery output power, W_{P} the pumping power of the auxiliary system that transports the reactants, A_{ch} the entrance area of the bipolar plate channel, and u_{in} the average import speed. In order to obtain the maximum net power of HT-PEMFC, Fig.12 is plotted to show the power output and net power output of HT-PEMFC. As the number of bottom baffles increases, battery power output increases accordingly. However, as shown in Fig.12, the maximum net power output of the battery appears when r=0.6 mm. Therefore, under the design conditions in this paper, the highest net power of HT-PEMFC is 0.389 3 W/cm^2 when the baffle radius is 0.6 mm.

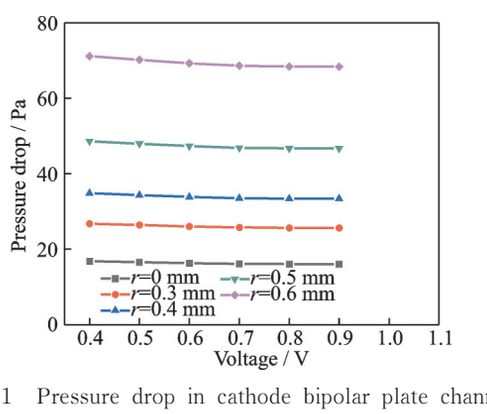

Fig.11 Pressure drop in cathode bipolar plate channel with different baffle radii

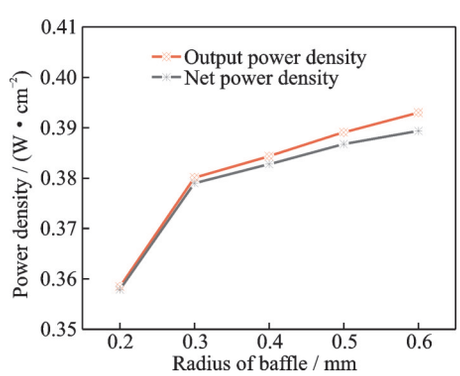

Fig.12 Comparison of output power and net power of HT-PEMFC bipolar plate channel cells with different bottom baffle radii

3.3 Comprehensive analysis of structural performance of different channels

Generally speaking, the blocking effect caused by the higher baffle height will lead to obvious flow resistance and higher auxiliary system power consumption, which will reduce the system efficiency. Figs.13, 14 show the current density and pressure drop of three channels of HT-PEMFC with different baffle radii. From the trend of baffle channel and foundation straight channel in Figs.13, 14, it can be

seen that baffle channel increases the performance output of fuel cell in various degrees, and leads to obvious pressure drop. The difference between the two baffle channels is that the staggered semicircular baffle channel can achieve performance growth with a slight increase in pressure drop, while the traditional semicircular channel needs a high pressure drop to achieve performance growth. For the two baffles, the PEMFC of the staggered semicircular baffle channel has more obvious advantages in improving the performance output and controlling the increase of pressure drop, which is conducive to the efficiency and stability of the system. In addition, with the increase of baffle radius, the performance of staggered semicircular baffle channel increases significantly at the cost of a smaller pressure drop. Although the current density of the conventional baffle channel HT-PEMFC has been greatly improved, the pressure drop of the conventional baffle channel increases much faster, which will significantly increase the power consumption of the auxiliary system, especially when the height is close to the height of the channel. Therefore, considering the performance output of fuel cell and the stability of the system, staggered semicircular baffle channel has a significant advantage.

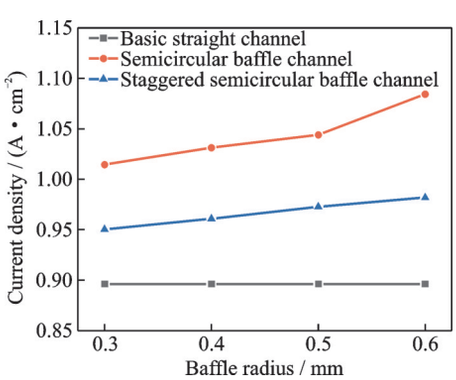

Fig.13 Influence of baffle radius on current density (V_{cell} = 0.4 V, r = 0.5 mm, N = 9)

The current density is a direct reflection of the battery performance. In this paper, the current density distribution contour of three HT-PEMFC in the middle plane is captured (Fig.15). It can be seen from Fig.15 that as the reactants are gradually consumed in the flow direction, the current density gradually decreases, and the current density in the flow channel is higher than that under the rib. Compared with the basic straight channel, the baffle channel has a higher current density, and a better distribution uniformity. Uneven distribution will lead to high local current density, which easily causes the damage of membrane electrode and shortens the battery life, thus further testifying the priority of baffle channel.

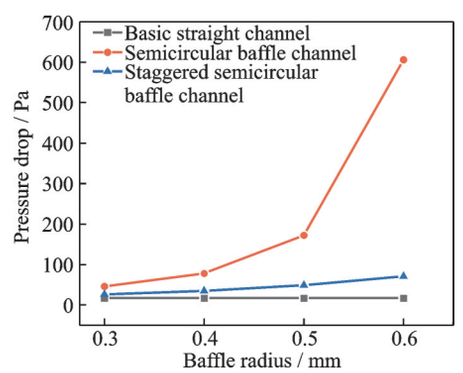

Fig.14 Influence of baffle radius on cathode pressure drop (V_{cell} = 0.4 V, r = 0.5 mm, N = 9)

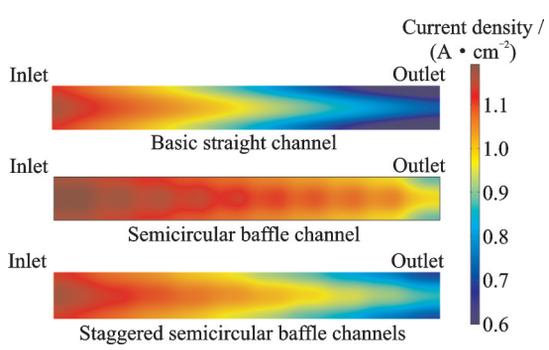

Fig.15 Distribution of current density at the middle plane of membrane (V_{cell} = 0.4 V, r = 0.6 mm, N = 9)

Due to the limitation of reaction kinetics, the oxygen reduction rate of cathode is much lower than the hydrogen oxidation rate of anode. The former is usually one millionth of the latter, so the reaction rate of cathode limits the efficiency of the whole battery. Secondly, when hydrogen and pure oxygen are used, the efficiency of PEMFC is very high. However, the commercialization of fuel cell needs to operate in the air under an ambient pressure. When the air is used, the performance of PEMFC is obviously

degraded due to the decrease of partial pressure. Finally, the poor mass transfer effect of cathode is also an important reason for the poorer performance. The worse mass transfer effect of oxygen in the gas diffusion layer and catalytic layer may double the voltage loss.

In order to further explore the mechanism of baffle channel in improving the cell performance, the velocity vector diagrams of three HT-PEMFC cathode gas channels are shown in Fig.16. Without the blocking of baffles, the main flow direction has no obvious disturbance along the flow direction. In the two baffle channels, due to the blockage of the baffle, the fluid is forced to pass the bottom of the baffle, and the cross-sectional area in the flow direction decreases, which leads to the increase of flow velocity. In addition, due to a certain inclination angle of the semicircular baffle, the fluid is forced to change its direction, resulting in an obvious vertical velocity component, which is the same as the concentration gradient direction. According to the principle of vector diffusion, the effective enhancement of mass transfer can be achieved. These two reasons together increase the reactant concentration of the catalytic layer, and then promote the electrochemical reaction, thereby improving the performance of the fuel cell.

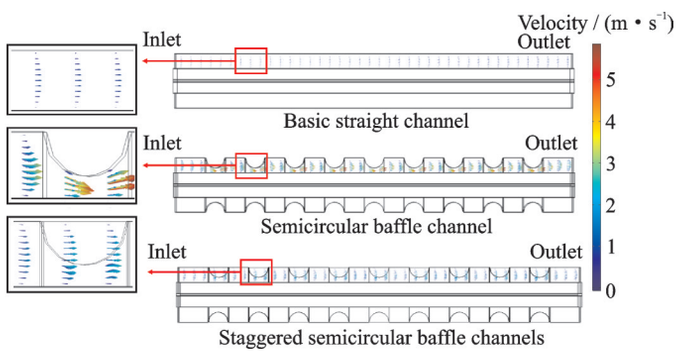

Fig.16 Velocity vector in cathode gas channel (V_{cell} = 0.4 V, r = 0.5 mm, N = 9)

4 Conclusions

A new type of staggered semicircular baffle channel is designed for HT-PEMFC. The performance of HT-PEMFC with different channel types and baffle radii is studied by the three-dimensional numerical simulation. The results are compared with those of HT-PEMFC with the basic straight channel and the conventional semicircular baffle channel. The mechanism of mass transfer enhancement in the proposed channel is studied considering the distribution of voltage drop and current density. The following conclusions can be drawn.

(1) The performance of baffle channel fuel cell is better than that of straight channel without baffle. In addition, the interleaved semicircular baffle channel proposed in this paper is more suitable for the practical use than the traditional semi-circular baffle channel, and can improve the performance of HT-PEMFC more efficiently.

(2) The net power of HT-PEMFC increases with the increase of baffle radius. Under the design conditions, the highest net power density of 0.389 3 W/cm^2 is obtained when the baffle radius is 0.6 mm.

(3) Due to the periodic staggered semicircular baffle, the strong blocking effect leads to the introduction of convective mass transfer, which is conducive to improving the local flow direction and velocity. As a result, the reaction gas delivery in GDL is significantly improved.

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基于挡板结构改进的HT-PEMFC性能分析

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摘要：本研究将高温质子交换膜燃料电池(High-temperature proton exchange membrane fuel cell, HT-PEMFC)的三维模型与理论分析相结合，主要通过优化燃料电池的结构、在气体通道中增加半圆形挡板和设置新的挡板来提高PEMFC的性能。研究了反应速度分布、界面反应物浓度和压力降对性能的影响。结果表明，在气路中添加障碍物可以产生垂直速度，提高燃料电池输出性能，特别是在高电流密度和高折流板半径的情况下。本文证明了优化后的结构在传质能力方面的优越性，并解释了性能提高的原因。

关键词：高温质子交换膜燃料电池；挡板；传质；场协同；净功率