

State-of-the-art Bipolar Plate Flow Field Structures for Proton Exchange Membrane Fuel Cell

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Abstract. Recently, proton exchange membrane fuel cell (PEMFC) has been gaining attention as an environmentally friendly solution for powering renewable energy vehicles. PEMFC is composed of several key components, one of which is the bipolar plate (BPP). The BPP is a crucial component that performs several functions in the PEMFC, including: supporting the membrane electrode assembly (MEA), providing fluid channels for H_2 , O_2 , and coolant, isolating H_2 and O_2 to prevent direct contact, collecting electrons, and transporting heat. Additionally, BPP are often made of corrosion-resistant materials, such as stainless steel, to improve the durability and longevity of the PEMFC. With the increasing demand for renewable energy vehicles, research and development in the BPP is becoming more important to make PEMFC more efficient and cost-effective. The performance of the BPP will be significantly impacted by the design of the flow field (FF) structure of the bipolar plate and the various operating circumstances of the PEMFC. Combined with the design patents and related literature based on the BPP's FF in recent years, several traditional FF and new FF structure schemes are summarized, and the related research results of FCs based on different FF structure schemes are summarized.

Keywords: Proton exchange membrane fuel cell, bipolar plate, design principle, flow field.

1. Introduction

Traditional power plants may be replaced in the future by more beneficial and environmentally friendly new energy power plants due to the growing scarcity of traditional fossil fuel energy supply and the worsening environmental issues. In 2021, global sales of new fuel-efficient vehicles have reached 9.77 million, or 15.2% of total auto market share, an increase of 89.7% from the previous year. In the same year, sales volume of the hydrogen fuel cell (FC) vehicles in major countries in the world was about 16 thousand, an increase of sixty-eight percent year-on-year. And in 2021, China had sold about 3.31 million new energy passenger vehicles and holding a fifty-three percent share of the worldwide market, which means that the biggest energy vehicle market around the world has become China, who had surpassed Europe by 2021 [1]. In the first half of 2022, sales of hydrogen FC vehicles in China will reach 1,031, a year-on-year increase of 59.6% [2]. As one of the representatives of the rise of new energy vehicles, hydrogen FC vapor may be a viable new energy power device.

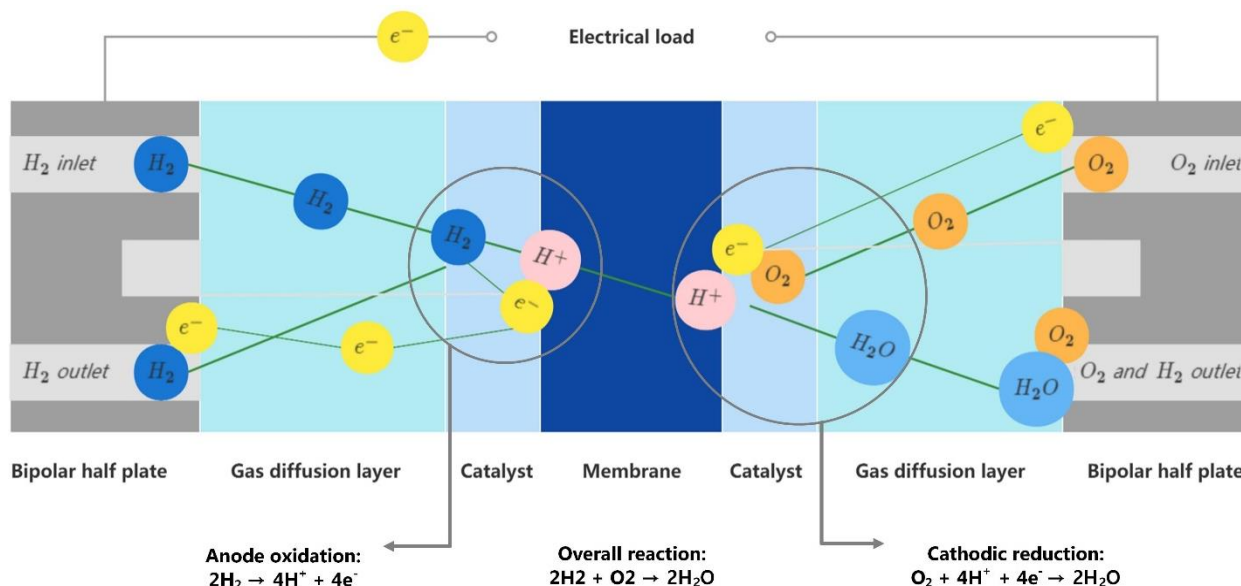


Figure 1. Principal model of PEMFC

Incorporating hydrogen as the primary energy source and utilizing either oxygen from the air or a distinct source as the oxidant, the PEMFC operates effectively, and these FC, referred to as H_2 fuel cells, play a crucial role in powering vehicles that run on hydrogen fuel.

The PEMFC is the nucleus of FC vehicles and a device which directly converts chemical energy into electrical energy. In the PEMFC, the smallest element of the unit that completes the electrochemical reaction is termed a single cell, which comprises of an anode plate (AP), a MEA and a cathode plate (CP), as illustrated in Fig. 1 displayed.

The operating voltage of a single PEMFC cell is typically between 0.6V and 0.85V, which is not high enough to power a vehicle. To overcome this limitation, multiple PEMFC's cells are connected in series to increase the overall output voltage. This allows the PEMFC to produce the higher voltage required to power the motors and other systems in a vehicle. Additionally, connecting multiple cells in series also increases the overall power output of the PEMFC, making it more capable of powering a vehicle's propulsion system. Overall, by connecting multiple PEMFC cells in series, it is possible to create a PEMFC stack that can provide the high voltage and power required for vehicle applications. The integrated components formed by repeated stacking of single cells are called FC stacks, and the operating temperature of on-board FCs is generally between 333K and 373K.

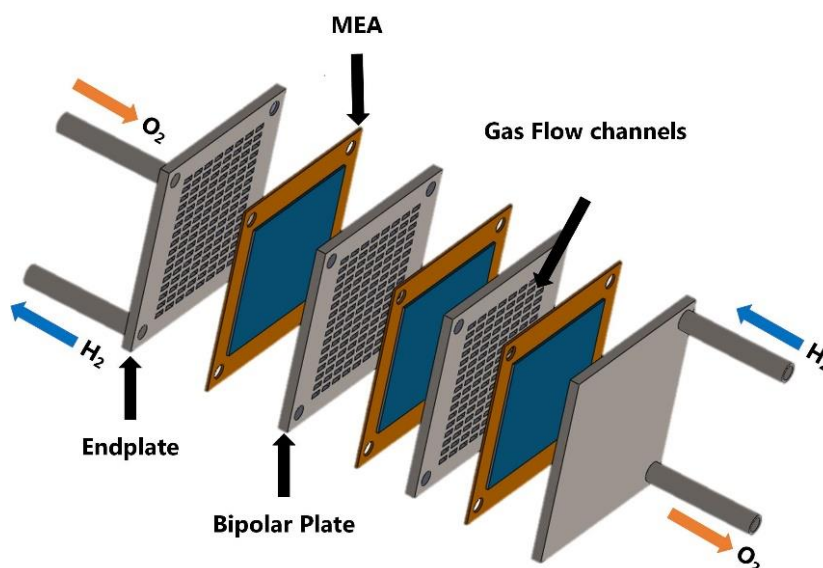


Figure 2. Schematic diagram of PEMFC structure

Fig. 2 shows the location of the BPP in a PEMFC. The BPP of the PEMFC is one of the core components of the PEMFC, which is welded by the AP and CP of adjacent single cells. Its main function is to support the MEA, provide fluid flow channels, collect electrons, conduct heat, etc. Conventional FC BPPs can be separated into four functional areas: pipeline area, allocation area, flow area, and sealing area. The FF structure of the BPP will greatly affect the capability of the PEMFC. Diverse FF structure designs impact the reaction gas transit and chemical reaction rate in the FF of the PEMFC, thereby changing the MEA layer conductivity of the PEMFC, relative humidity, current density distribution cause different effects. At present, the flow fields (FF) of PEMFC BPPs can be separated into traditional flow fields and novel flow fields. Traditional flow fields in PEMFC are the various configurations that is used to distribute the gases throughout the cell. The three main types of flow fields are the parallel flow field (PFF), serpentine flow field (SFF) and interdigitated flow field (IFF), and new FF majorly include waveform FF (WFF), bionic FF (BFF), helical FF (HFF) and three-dimensional FF (3D-FF). Another important factor affecting the FF functionality of a FC BPP is the choice of material for its fabrication. Different materials will affect the design and processing of BPP runners to a certain extent.

This paper will focus on the design of various FC's BPP FF structures, as well as the influence of the geometric parameters of each flow channel and corresponding working conditions on the design and treatment of BPP FF and the performance of the FC, and the present state of the FC on the geometrical characteristics of each runner and associated operating conditions. Impact of BPP design flaws and directions for future optimization.

2. Traditional Bipolar Plate Flow Field Structure Scheme

2.1. Parallel Flow Field

The PFF is a major flow channel for the BPP. According on whether the cross-section of the flow channel fluctuates throughout the flow channel, PFF can be separated into parallel flow channels with equal cross-section and parallel flow channels with non-equal cross-section. Of these, the performance of a PEMFC using parallel flow channels with equal cross-sections is for the most part determined by the geometrical shape of the cross-section and the amount of PFF's flow channels. As shown in Fig. 3, Khazaei et al. [3] evaluated the overall property of PEMFC with three geometric forms of the flow channel such as rectangle, triangle, and ellipse according to the cross-section of the flow channel. The findings demonstrate that that the rectangular flow channel can allow the reactant gas to permeate the PEMFC's gas diffusion layer (GDL) more thoroughly, hence accelerating the chemical reaction on the surface of the catalytic layer (CL) and enhancing the FC's performance. At the same time, the PEMFC's efficiency correlates to rectangular, elliptical, and triangular shapes as the number of flow channels rises by 1 to 4 or 8.

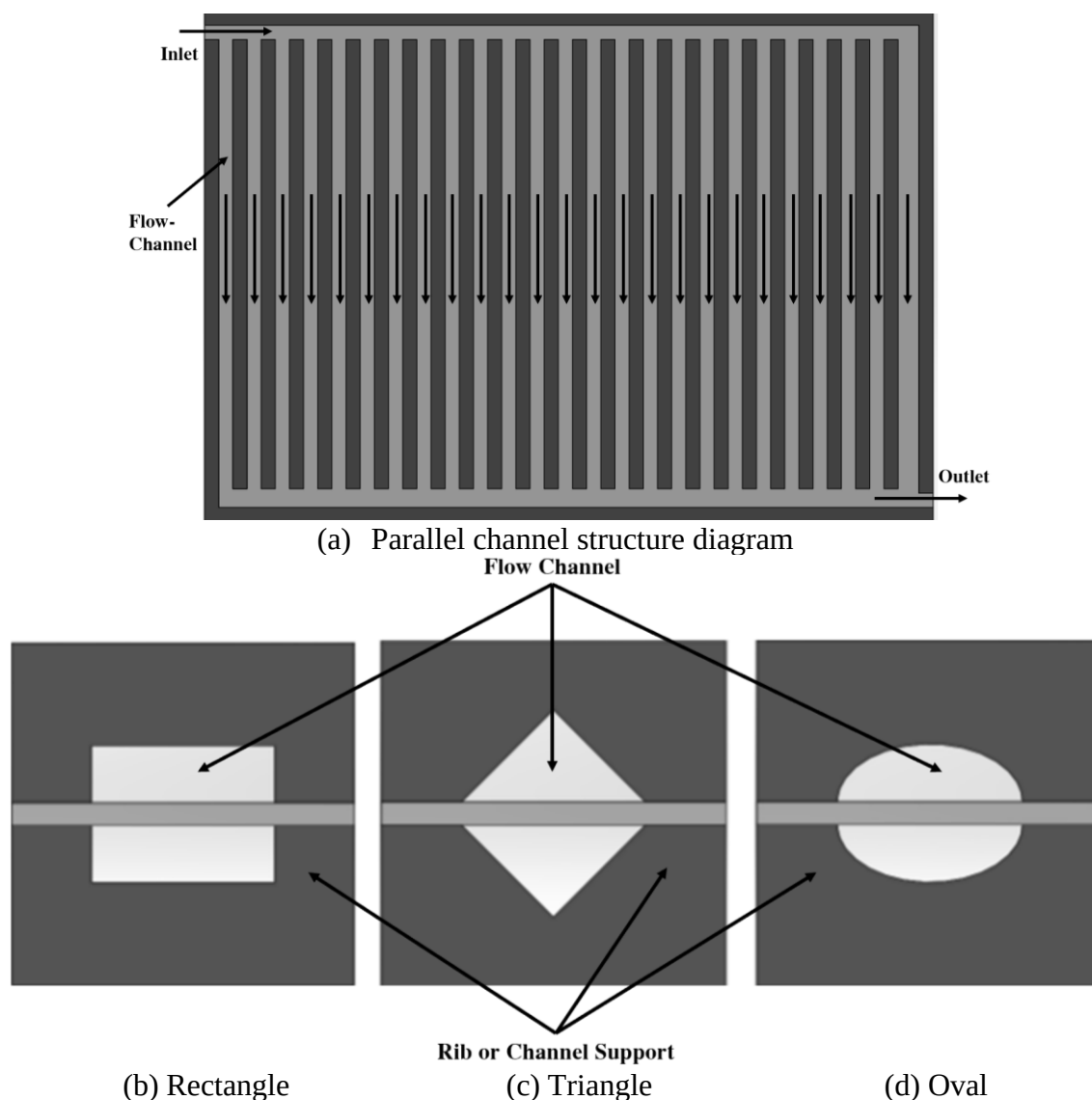


Figure 3. Equal cross-section parallel flow channel (a) the overall structure, (b) rectangle cross-sectional form (c) triangle cross-sectional form, (d) oval cross-sectional form.

The PEMFC, which utilizes parallel flow channels with non-equal cross-sections, experiences a significant impact on its characteristics due to the alteration in the CSA of the flow channel along its direction of flow, as the distribution of the cross-sectional dimensions greatly influences the performance of the FC. Tianya Li et al. [4] examined the FF structure of the FC mold using cathode flow channel illustrated in Fig. 4 as a square variable cross-section flow channel, and the findings revealed that utilizing a square variable cross-section cathode flow channel has superior water management. Therefore, it can increase the property of the FC in a high-humidity working environment, and can make the allocation of the reaction components and the current density more average, thus the function of the PEMFC will be enhanced. Fig. 5 depicts the stepped variable cross-section flow channel proposed by Chen Xi et al. [5], utilizing computational fluid dynamics to examine the parallel flow channels of the PEMFC BPP with 0 to 8 steps, and explore the influence of the number of steps on the function of the PEMFC. The findings of the study demonstrate that the stepped flow field (FF) design may have several advantages over traditional FF designs. With its capability to decrease the cross-sectional area (CSA) of the flow channel, the stepped FF design not only elevates the velocity of the gaseous flow but also leads to an enhancement in the transfer of gases from the flow channel to the GDL and CL, a vital aspect for the optimal functioning of the PEMFC, thus holds a key benefit. Another advantage of the stepped FF design is that it can enhance diffusion of the gases throughout the cell. The improved diffusion can help remove the reaction-generated

liquid water, which is a common issue in PEMFCs. With the potential to enhance the performance of PEMFCs by reducing the risk of water spraying from the cathode, which can cause damage to the cell and impede its performance, the stepped flow field design not only augment the mass transfer rate of reactants to the CL, resulting in an improvement in the cell's performance but also improve the performance of PEMFCs by reducing the CSA of the flow channel, augmenting the velocity of the gas flow, and enhancing the diffusion of gases throughout the cell, leading to an increase in power output and improved efficiency. Furthermore, it has been observed that the best condition of the PEMFC is achieved when there are 8 steps in the stepped FF and a step length of 6.4 mm, indicating that as the number of steps in the stepped FF increases, the property of the related FC also increases.

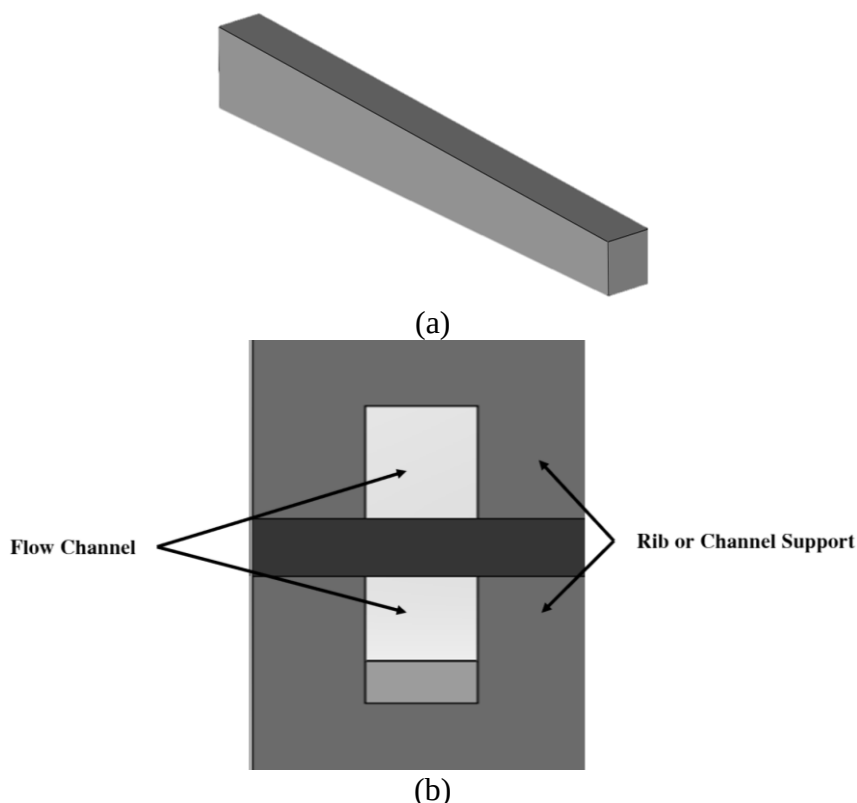


Figure 4. Schematic diagram of the structure of the deformed cross-section flow channel (a) flow channel shape (b) cathode variable square cross-section flow channel

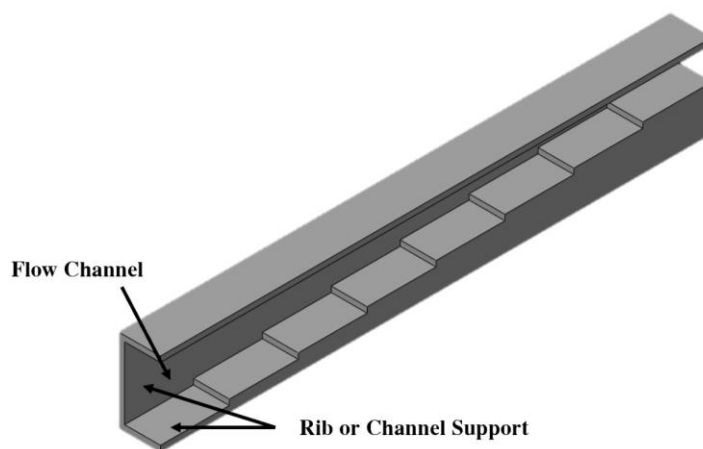


Figure 5. Cross-section of stepped flow channel

Through the research given by Tianya Li, Chen Xi et al. The works in [4, 5] on BPP FCs with non-equal cross-section parallel channels, it is not difficult to find that when the channel depth of the PEMFC property FF changes monotonously along the channel direction, inlet, and outlet dimensions. The smaller the ratio, the more obvious the performance improvement of the same type of PEMFC.

However, parallel runners also have significant disadvantages. Because the PEMFC structure is smooth and easy to process, the residence time of the gas in the runner cannot be guaranteed, making the gas utilization rate relatively low.

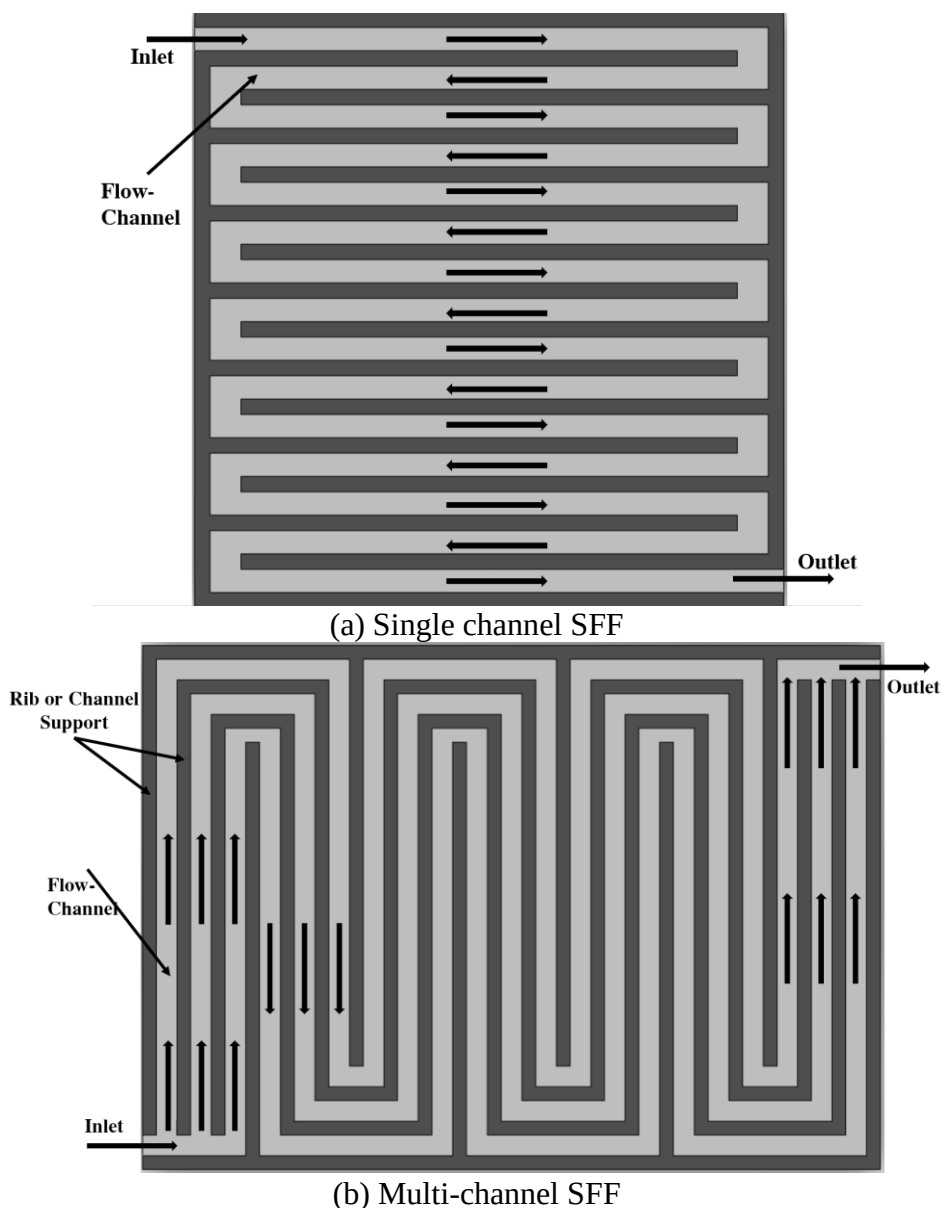


Figure 6. SFF (a) Single channel (b) multi-channel

2.2. Serpentine Channel Flow Field

As illustrated in Fig. 6, the SFF is one of the BPP flow channels typically employed in the PEMFC, and its effect on the property of the PEMFC is largely influenced by the amount of SFF and the depth of the single flow channel. Gundlapalli et al. [6] performed computational fluid dynamics (CFD) flow simulations to examine vanadium redox FCs' performance by employing the single- and three-channel SFF. The PEMFC with this configuration has improved electrochemical performance. In addition, under the concept of guaranteeing the strong construction of the bipolar plate, properly raising the channel depth and the overall size of the BPP may raise the pressure in the channel to an acceptable level limit. Chowdhury et al. [7] investigated the impact of the variations of channel depth on the PEMFC property based on graphite single-channel SFF bipolar plates fabricated using CNC machine tools. In the research, Chowdhury et al. [7] defined the FF whose channel depth grows linearly along the flow direction as a divergent FF, and the FF whose channel depth reduces linearly along the flow direction as a convergent FF. Effects of deep, divergent, and convergent FF on the

PEMFC performance. The findings indicate that as the depth of the SFF becomes narrower, the gas diffusion effect increases, resulting in a PEMFC with improved current density and FC performance. At the same time, the concentration of reactants in the converging runner is higher, which strengthens the diffusion effect of the reactants in the CL, thereby enhancing the chemical reaction and making the function and current density of the PEMFC using the converging FF. Compared with the divergent FF, the convergent FF also offers greater drainage capacity under low temperature circumstances. Whether it is a divergent FF or a convergent FF, the smaller the depth gradient of the flow channel from the inlet to the outlet is, the better the FC capability is the performance of the PEMFC using the convergent FF is obviously better than that of the PEMFC using a constant depth FF. There is a depth gradient that allows optimum PEMFC performance in a convergent FF.

Through the research conducted by Gundlapalli, Chowdhury et al. [6, 7] on the serpentine runner, it can be found that the depth of the serpentine flow channel is an important factor affecting its corresponding the PEMFC, and its depth gradient has a positive correlation with the capability of the PEMFC. Obviously, given the same size bipolar plates, a FC with serpentine flow channels will provide reactants a longer reaction time than a FC with parallel flow channels. But the SFF also has obvious disadvantages, especially for the single-channel SFF, the narrow channel is easy to cause gas blockage and affect the chemical reaction, the multi-channel SFF can overcome this shortcoming to a certain extent, but its FC performance is not as good as that of a single-channel FF FC.

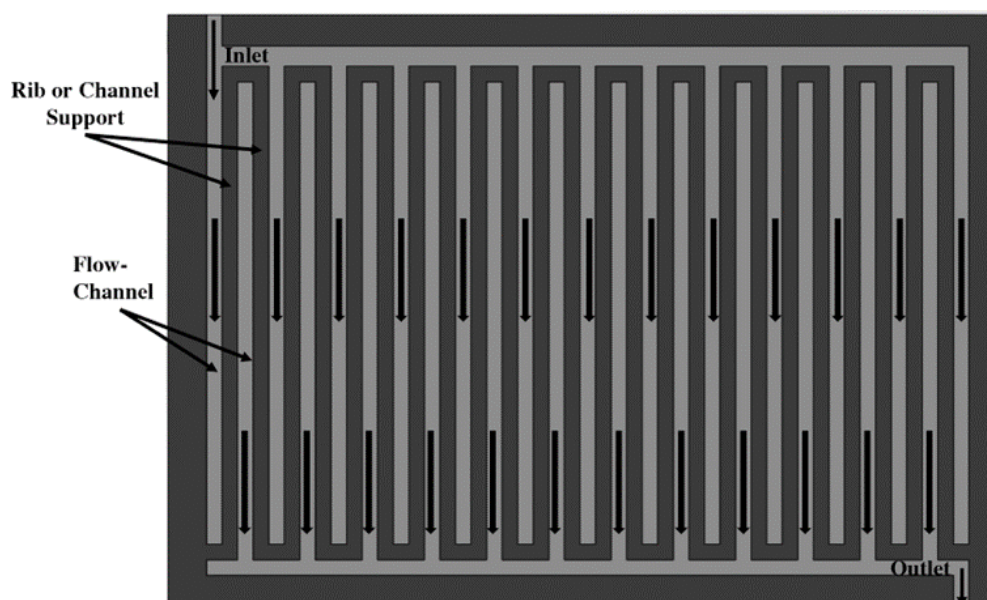


Figure 7. Interdigitated Flow Field

2.3. Interdigitated Flow Field

As illustrated in Fig. 7, it is a structure scheme of a pluggable BPP FF. Obviously, the gas intake and exit of the plug-in FF are not directly linked, and the gas entering the runner is forced to disperse to the peripheral flow channel and the reaction CL, therefore enhancing the power density by boosting the gas utilization rate.

Lin Wang and his team [8], by conducting experiments through the use of a three-dimensional PEMFC mathematical model, examined the impact of the interlayer flow field on the performance of PEMFCs under varying conditions of operating temperatures, gas humidities, pressures, and reactant gas flow rates and found that while the performance of the PEMFC improves with the rise in temperature when the working conditions of the PEMFC reach a specific level of humidity, it exhibits an inverse correlation with the temperature when the humidity of the working environment of the PEMFC is low. Therefore, the humidification of the AP and CP has a large impact on the PEMFC employing the cross-channel FF. In the meantime, the performance of PEMFC improves as the working pressure increases.

The study conducted by Xuyang Z and colleagues [9] aimed to investigate and analyze the performance and electrochemical reactivity of FCs with cross-finger flow channels of various exit channel widths. By utilizing a combination of polarization curves, electrochemical impedance spectroscopy (EIS), and cyclic voltammetry on a proton exchange membrane FC with a membrane electrode area of 4300 square millimeters (mm^2), the researchers were able to conduct a thorough analysis and gain a comprehensive understanding of the electrochemical behavior of these FCs.

Subsequently, the results reveal that FCs with narrower FF exit channels consistently perform better in terms of power density; they also have lower charge transfer resistance but higher ohmic resistance, which may be due to their greater ability to remove water and their reduced ability to hydrate their membranes as a result of the humidified inlet gas; finally, narrower FF exits also increase the overall electrochemical reactivity of the FC bipolar.

Nathaniel J et al. [10] constructed a PEMFC with a SFF, set the channel width and channel to evaluated the PEMFC capability under varied channel lengths via trials, and analyzed the experimental data using variance analysis. A comprehensive examination of the influence of pivotal factors was conducted through statistical analysis, and the findings revealed a tendency for the ratio of length to width of the BPP flow channel within the PEMFC to exhibit an inverse relationship with the efficiency and output of the PEMFC. Specifically, as the aspect ratio decreases, the performance and yield of the PEMFC increases.

Through the rigorous and in-depth investigations undertaken by esteemed researchers such as Lin Wang, Xuyang Z, Nathaniel J, and their peers in the academic community [8-10], it has been firmly established that the effectiveness and efficiency of PEMFC utilizing a cross-finger type runner FF is intimately linked to the operating parameters of the PEMFC, as well as the proportion of the runner and other architectural features. The complex interaction among these factors plays a critical role in determining the overall performance of these FCs.

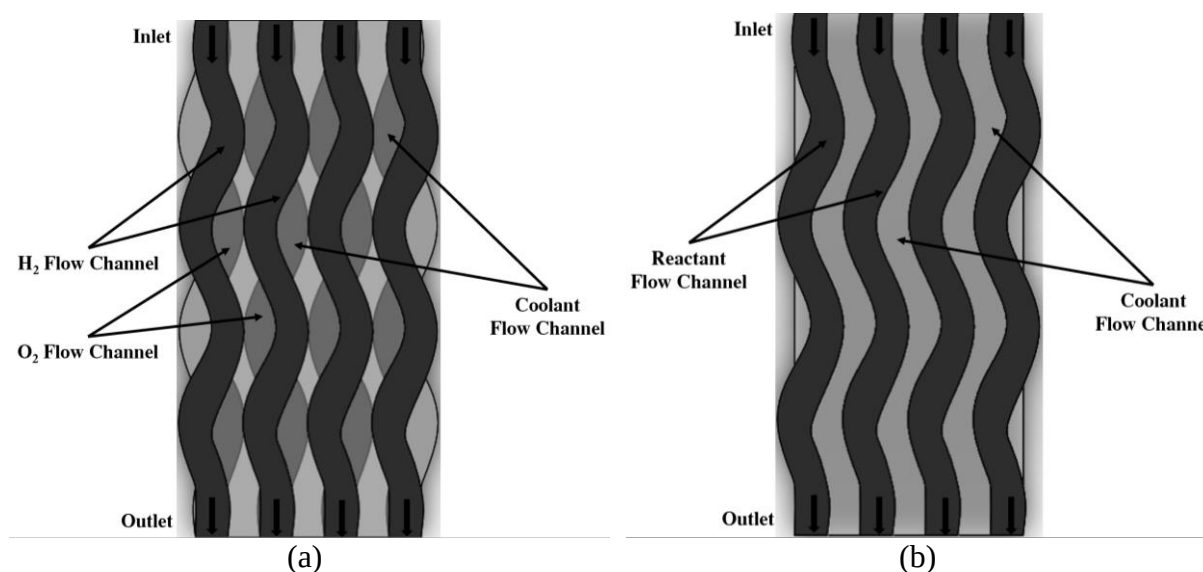


Figure 8. WFF (a) staggered wavy flow field (SWFF), (b) parallel wavy flow field (PWFF)

3. New Flow Field Structure Scheme

3.1. Waveform Flow Field

As shown in Fig. 8, it is a channel whose CSA does not vary along the flow direction, but its overall channel route is S-shaped. the waveforms on the cathode side and the anode side are opposite, as illustrated in Fig. 8(a) (a). The identical waveform on the CP side and the AP side is a PPWFF, as illustrated in Fig. 8(b).

In the relatively typical PFF and SFF, the cathode FF generally exhibits the feature of uneven distribution of reaction gas concentration and cathode overflow. Yong Z et al. [11] developed the

PEMFC's BPP model with a wavy FF in the coolant flow channel, which was simulated by 3D multiphase CFD, examined the addition of water as the coolant. The findings of the influence of cooling FF on FC capability indicated that the peak current density of the PEMFC BPP with cooling runner was 14.9 percent higher than that of the BPP with the same structure but without cooling FF. Meanwhile, As the current density of the PEMFC increases, it is observed that the power density of the PEMFC also increases in a corresponding manner. Furthermore, it has been observed that the power density of the PEMFC that utilizes a cooling flow field is greater than that of the PEMFC which does not have a cooling flow field. Additionally, it has been determined that the maximum power density of the PEMFC that utilizes a cooling flow field is also superior to the maximum power density of the PEMFC that does not have a cooling flow field. Complementarily, Yong Z et al. [11] compared the heat transfer characteristics and temperature allocation of bipolar plates under different coolant flow rates, and the investigation discovered that there exists a flow rate of the coolant in the FC that results in a temperature distribution that is relatively homogenous. When the flow rate of the coolant is inversely proportional to the thermal dissipation capability of the PEMFC, the optimal flow rate can be attained. Nevertheless, once the flow rate exceeds a particular threshold, the influence of the flow rate on the temperature distribution within the PEMFC will become insignificant.

Yong Z et al. [11] also compared the PFF, the offset wavelength field with different dimensions and numbers of cathode side channels, and the PFF. The design demonstrates that by increasing the number of flow channels on the cathode side of the BPP of the PEMFC while simultaneously reducing the dimensions of the FF channels on the cathode side, not only can the pressure drop of the runners be increased, and the discrepancy in liquid water concentration be reduced, but it also leads to an enhancement in the gas flow rate and concentration in the flow channels on the cathode side of the BPP, while decreasing the concentration of liquid water which in turn accelerates the chemical reaction, thereby improving the electrochemical reaction rate, and increasing the uniformity of gas distribution in the CL of the PEMFC through the enhancement of the number of flow channels and reduction of the size of each individual runner. Additionally, compared to the SWFF, the adoption of a WFF will boost the PEMFC's net output power density. The PEMFC's improvement in net output power density is superior to that of the PWFF.

A 315 cm² car FC was constructed by Cong Yin et al. [12]. The SWFF is used, and the bipolar plates are made of metal. In order to investigate the operating circumstances of the BPP and the relative flow direction of the liquid phase, a 3D two-phase non-isothermal model is created. The findings demonstrate that the PEMFC's capability is somewhat influenced by the various outlet pressures of the bipolar plates, including the back pressure and operating temperature. Volumetric flow of the reactive gas causes liquid water to build up in the porous material. On the anode and cathode sides, the regions with a high liquid water concentration, however, do not cross across. The water saturation area extends when the local relative humidity changes with an increase in flow channel back pressure in the proton exchange membrane, but the uniformity of water content in the membrane is not affected. It and temperature are inversely connected. At the same time, the reaction consumption rate mostly affects the H₂ concentration, whereas an increase in runner back pressure raises the O₂ concentration. The FC's overall performance has increased. The fluid interchange between the coolant layers will be improved by the anti-phase wave FF, increasing the PEMFC bipolar plate's ability to dissipate heat.

The capability of FCs utilizing wave FF is also influenced by junction characteristics such as wave curvature, periodic channel wavelength, channel, and rib width [12]. Consequently, a crucial area of research for the future will continue to be the creation of wave and FF structures.

3.2. Bio-inspired Flow Field

It is often challenging to have appropriate reaction gas distribution and BPP drainage capability because of the classic FC BPP FF structure's relatively large distance between the intake and exit.

As seen in Fig. 9, Jinhua Dong et al. [11] proposed a split-new BFF structure based on Murray's law design to address the issue. The team also ran numerical simulations to contrast the DC FF with

the BFF sans Murray's law design to see which was better at boosting FC capability. The findings showed that the new structure was superior at high current densities. The findings demonstrate that the BFF's FC performance is significantly higher than its conventional FF counterpart at high current densities, and that the BFF with Murray's law design enhances FC performance more than the BFF without Murray's law design. Additionally, because the BFF configuration is employed, an enhancement in the molar concentration and homogeneity of oxygen in the runner is ensured, and as per Murray's design, it has been observed that the molar concentration of oxygen in the BFF surpasses that in a BFF which does not incorporate Murray's design. The molar concentration of O_2 is greater in the BFF created using Murray's law than it is in the BFF created without Murray's law, and the BFF performs to have more advantages than the normal one. It also has superior water management skills. Moreover, the BFF is greater than water management.

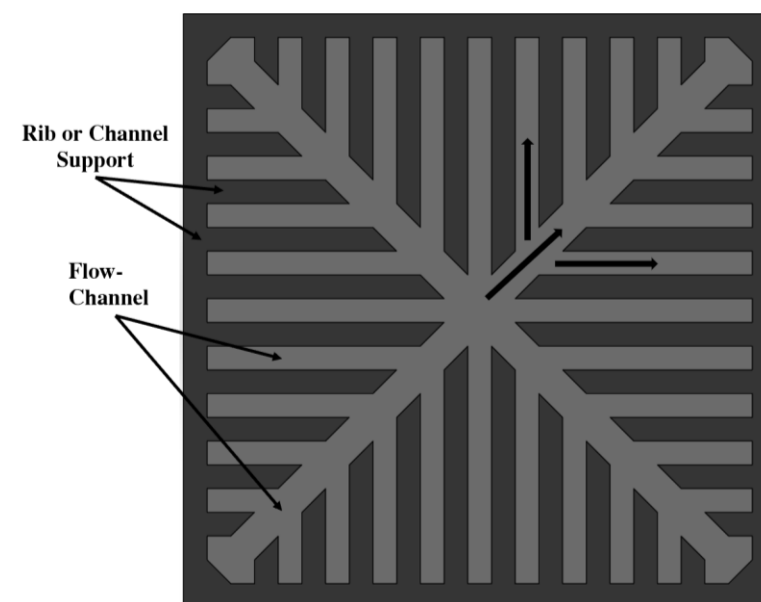


Figure 9. The structure of the four-leaf clover BFF

A FC's BFF structure based on plant leaves and human lung branches was proposed by Srinivasa Reddy Badduri et al. [14] and compared experimentally to the three-flow SFF. The results show that the PEMFC capability is influenced by the flow channel back pressure, FC operating temperature, and relative humidity (RH), with the PEMFC performance steadily improving as the PEMFC operating temperature rises. Performance-wise, the BPP's FC with vein-like bionic flow channels outperforms the other two FF designs. Additionally, compared to non-interdigitated finger-vein-like bionic flow channels, FCs developed with interdigitated finger-vein-like bionic flow channels have a greater power density. The PEMFC with runner architecture has a 6.72 percent higher power density. In comparison to FCs with non-interdigitated biomimetic flow channel designs, the resulting net power density is greater. The resulting net power density is 5.58 percent more than that of FCs made using biomimetic flow channels that are not cross-lobed.

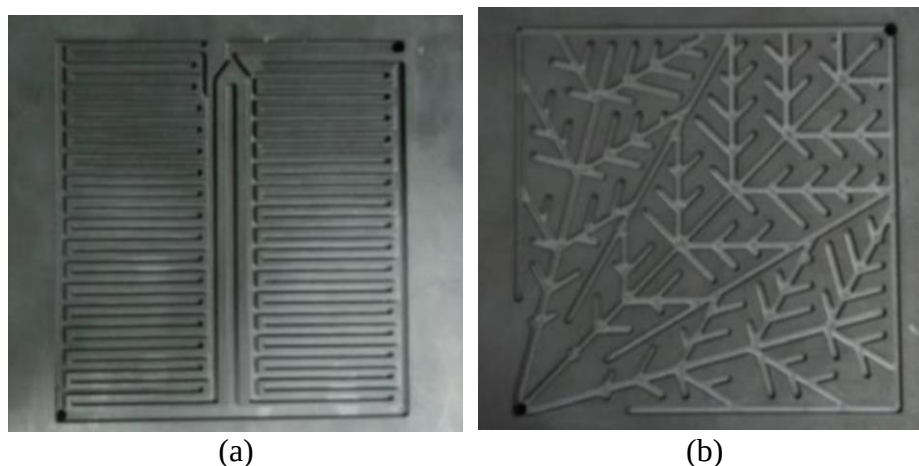


Figure 10. Structural diagram of bionic flow channel (a) lung-shaped in [14], (b) leaf vein-shaped in [14]

While reactive gas allocation and water management capabilities have been improved by research on the PEMFC model with BFF by Jinhua Dong, Srinivasa Reddy Badduri et al. [13, 14], its capability is mostly impacted by back pressure and relative humidity. Through Jinhua Dong, Srinivasa Reddy Badduri, and other researchers' investigations on the PEMFC model with a BFF. Back pressure and relative humidity have the most effects on how well it performs, while also enhancing reactive gas distribution and water management skills.

3.3. Circular Flow Field

A circular radial FF was created by Wanchao Zhu et al. [15] that used the parallel channel's features for flow allocation and the serpentine channel's drainage capacity, as shown in Fig. 11, and established the radial FF of different structures. The pressure drop and drainage capacity of the new FF were examined using the mathematical model and compared to the traditional FF. The research outcome shows that, although the structured circular radial flow field may not exhibit the same level of efficiency in terms of current density and maximum power density as the multi-flow SFF, it does boast a significant advantage in terms of maintaining the pressure drop within the flow channel within an acceptable range, thereby reducing the energy dissipation that may occur as a result of excessive pressure drop. To analyze and evaluate the pressure drop and draining capability of the new flow field in comparison to the traditional flow field, a mathematical model was employed, and it has been observed that the width of the channel and the rib that partitions the channels play a crucial role in determining the performance of the radial flow field, which is evident by the fact that, conversely, the depth of the flow channel has a relatively minimal impact on the performance of PEMFCs when utilizing a radial flow field's bipolar plate. It is well-established that the width of the channel and rib in a radial FF can have a substantial impact on the distribution of gases, as well as the pressure drop across the FF. A narrower channel width can lead to higher gas velocities and improved mass transfer, while a wider rib can help reduce the pressure drop. However, the depth of the flow channel is less critical, as it primarily affects the volumetric and gravimetric power density of the PEMFC, but it has minimal impact on the overall performance. This is because the depth of the channel primarily affects the amount of space available for the gases to flow, rather than the distribution or pressure drop. In conclusion, while the width of the channel and rib in a radial FF can significantly impact the function of the PEMFC, the depth of the flow channel has a relatively minimal effect on the PEMFC performance when using a radial FF's BPP. To enhance the flow's current and power densities, the CSA of the flow channel should be as small as feasible.

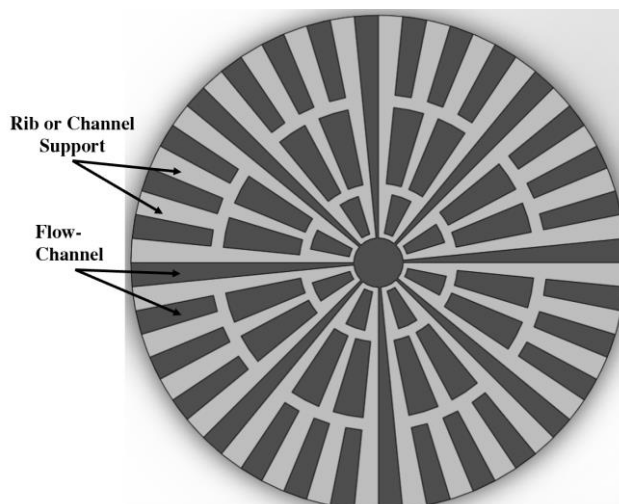


Figure 11. FF structure diagram of circular radial channel

In conventional FF, pressure loss along the way and local pressure loss usually lead to a large drop in the power of the PEMFC. Yuanhong Li et al. [16] designed a circular radial spiral groove as shown in Fig. 12 to solve this problem. FF to reduce pressure loss and increase the power of PEMFC, and through numerical simulation, compare with traditional FF in terms of electrochemical capability, cathode water concentration allocation and pressure drop. The simulation findings demonstrate that the electrochemical performance of the PFF and the radial spiral groove FF are almost identical. At the same time, the radial spiral groove FF's pressure drop is relatively small, and its average water concentration is lower than that of the conventional runner. There is adequate drainage in the FF.

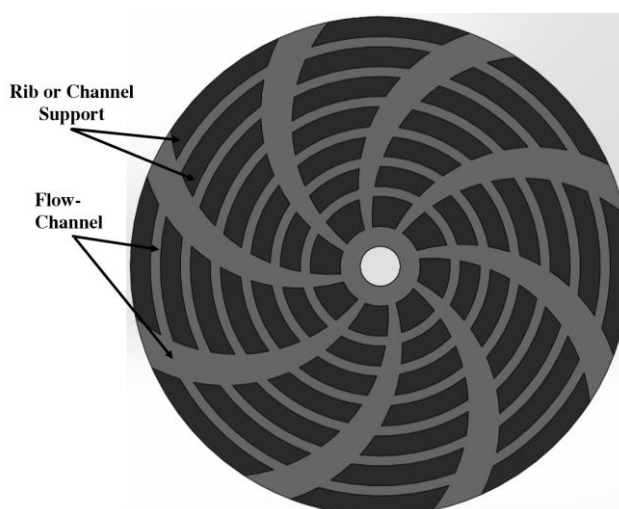


Figure 12. FF structure diagram of circular radial channel

3.4. 3D Flow Field

To augment the cathode-side drainage capacity of the BPP and enhance the delivery of reactant gas to the porous electrode, Xuan. L. and his colleagues [15] introduced a pioneering three-dimensional bionic cathode FF that drew inspiration from the form of minuscule intestinal villi, and in order to examine the impact of this BFF on the electrochemical capabilities and mass transfer performance of the FC, the researchers also constructed a computational model.

4. Summary

This study includes research results based on BPP FF structures and analyses the possibilities of centralised design for BPP FF structures for the FC proton over the last few years. Table 1 illustrates the influence of the different performance parameters of bipolar plates and CF. It is not difficult to

determine that for ordinary BPP FFs, the geometric parameter design of the cross-section is the primary element impacting the FC performance, notably the modification of the flow channel depth is the major influencing factor. Advances in FC technology have opened a variety of industrial potential for PEMFC in the future, and the bionic models cited in the new FF are a major component in FC performance. In summary, as a final observation, it can be deduced that the design of the internal FF structure of the bipolar plate, which is an essential element of the FC core, has a considerable influence on the performance of the proton exchange membrane FC, as it plays a crucial role in the overall functioning of the FC. The FF structure of the BPP must take into consideration several critical variables, including the cost of materials, the complexity of the production process and the practicality of PEMFC's BPP. Future research into FC will continue to concentrate on further characterizing the design parameters of the FF structure and the influence of the operating environment on the PFMEC, as well as finding a balance between the capabilities of the BPP and the cost of fabrication.

Table 1. Comparison between Different Flow Field Configurations

Bipolar plate type	Main Structural Parameters Affecting Fuel Cell Performance	Operating Conditions Affecting Fuel Cell Performance
Parallel flow field	- Flow channel shape - Runner divergence - Number of runners	Reaction gas flow rates
Serpentine flow field	- Number of runners - Runner depth - Runner divergence	- Reaction gas flow rate - Operating temperature
Cross-finger flow field	- Flow field exit size - Runner aspect ratio	- Operating temperature - Gas humidity - Working pressure
Waveform flow field	- Waveform curvature - Channel length - Rib width	- Flow channel back pressure - Operating temperature with or without cooling field
Bionic flow field	Bionic object	- Operating temperature - Relative humidity - Flow channel back pressure
Circular flow field	- Radial flow field form - Flow channel width - Rib width	—
3D flow field	Bionic object	—

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