Research on performance optimization method of proton exchange membrane fuel cell for vehicle

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Abstract. In recent years, with the extensive use of fossil fuels, the global environment has deteriorated sharply, and human beings are facing the problem of energy conversion. Due to the high calorific value, light weight, abundant reserves, and pollution-free combustion of hydrogen energy, many countries hope to use hydrogen energy as a new sustainable energy instead of fossil energy. Through the introduction of proton exchange membrane fuel cells in class and literature research, it is found that proton exchange membrane fuel cell is a very representative energy technology with high efficiency, low noise, and cleanness in several new energy sources. Especially after the two goals of carbon neutralization and carbon peak are proposed, hydrogen energy has received high attention from basic research and industrial application. To further optimize the performance of proton exchange membrane fuel cells, this paper analyzes the flow field structure and energy management strategy of proton exchange membrane fuel cells for vehicles and makes a systematic summary on the basis of previous studies.

Keywords: proton exchange membrane fuel cell, flow field, energy management strategy.

1. Introduction

With the massive burning of fossil fuels and the increase in carbon dioxide emissions, the global greenhouse effect is worsening. Under such circumstances, many countries are vigorously developing hydrogen energy, hoping to realize the transformation from a high carbon society to a low carbon society by utilizing the characteristics of high calorific value, lightweight, abundant reserves, and pollution-free combustion of hydrogen energy. As the world's largest carbon emitter, China is considering using hydrogen energy to mitigate carbon emissions and achieve carbon neutrality while promoting the high-quality economic development of the country. In China, vehicle exhaust emissions are one of the important causes of environmental pollution. Reducing vehicle exhaust emissions will make a great contribution to alleviating the global greenhouse effect.

Compared with traditional gasoline diesel engines, hydrogen proton exchange membrane fuel cell (PEMFC)has the characteristics of high efficiency, low noise, and clean technology, and is the most suitable for vehicle PEMFC. PEMFC consists of four parts: external circuit, anode, cathode, and electrolyte. The cathode and anode usually need to contain a certain amount of the catalyst to accelerate the electrochemical reaction, the hydrogen fuel feed hole to the anode, under the action of catalyst loses electrons into hydrogen ions and electrons, electrons from the anode, via an external circuit to the cathode, hydrogen ions through to proton exchange membrane to the cathode, oxygen in the cathode electron, And react with hydrogen ions to form water.

However, the performance of PEMFC is largely restricted by its structure and control strategy in the application, for example, the service life decreases rapidly and the temperature increases sharply in the case of high power rapid discharge. Therefore, this paper will discuss the design and development stage and practical application stage of PEMFC, respectively, to improve the practical performance of PEMFC from the aspects of PEMFC structure and PEMFC management strategy.

In the process of PEMFC design, it is necessary to optimize the structure of the PEMFC to improve the performance of the cell. The bipolar plate is the key component of the PEMFC structure. Its flow channel structure determines the important performance of PEMFC, such as hydrothermal management, mass transport, and current density distribution. In this paper, the optimization methods of the current flow channel structure of PEMFC are summarized. For the research on bipolar plates, D 'Adamo and Borghi (2021) conducted a multidimensional CFD study on the traditional and conical channel distributors through numerical analysis of the limited area of the serpentine gas distributor and the scale-less analysis, The combined effects of pressure loss, catalyst layer utilization, a flow state of anisotropic diffusion medium and convective/diffusion equilibrium were evaluated. Based on the simulation results, it was concluded that channel coning is a very effective method to improve the power density of PEMFC [1,2]. Abraham B and Murugavel K, (2021) conducted a numerical simulation of proton exchange membrane fuel cells by using the computational fluid dynamics (CFD) model in ANSYS FLUENT software. Based on Taguchi's method, The porosity of the gas diffusion layer and catalyst layer in a single cell was optimized, and its performance was compared with that of the cell with uniform porosity in each pore layer. The results showed that the performance of the cell was improved by 12.5% by optimizing the porosity [3].

The study of the PEMFC operation stage should be combined with its structural optimization and developed in parallel. The main application scenarios of PEMFC are hydrogen energy vehicles. Compared with traditional gasoline-electric vehicles, hydrogen energy vehicles have the advantages of strong endurance, short hydrogenation time, small safety risks, and high energy conversion rate. And its main energy source is a proton exchange membrane fuel cell. Proton exchange membrane fuel cell due to insufficient dynamic response ability will lead to the decline of vehicle performance, and the rapid discharge of the battery will reduce the energy utilization efficiency and its service life [4]. Therefore, at present, most PEMFC vehicles use the auxiliary energy storage system as the auxiliary power source and work together with PEMFC to form a hybrid drive system to jointly drive the vehicle. Therefore, for multiple power sources of PEMFC, a reasonable and efficient energy management strategy must be adopted for power distribution. To improve the vehicle economy and PEMFC operating efficiency, proton exchange membrane fuel cell performance gives full play. Ma et al. (2021) divided the energy control strategies of PEMFC vehicles into three categories. Based on rule type, dynamic optimization type, and intelligent type, it is proposed that offline control or network control can be carried out based on intelligent optimization strategy [5]. Hames Y et al. (2018) proposed four strategies to make up for the shortage of proton exchange membrane fuel cells by using high-power density lithium batteries and ultracapacitors simultaneously, but without considering the complexity of the system and the requirements for automotive computing performance [6].

In this paper, by analyzing the predecessors to study and numerical simulation of different types of double plate structures concluded the performance impact of the different flow paths, thus further improving the structure of the PEMFC, before the relevant systems and control, the paper summarized the research and its horizontal contrast prospects the proton exchange membrane fuel cell possible future development direction.

2. Flow field optimization analysis of vehicle proton exchange membrane fuel cell

Proton exchange membrane fuel cell (PEMFC) is highly efficient energy equipment used in new energy vehicles. Its biggest advantage is that the discharge of product water does no harm to the environment [7]. The bipolar plate is a key part of PEMFC. The flow field structure determines the hydrothermal management, electrochemical reaction intensity, gas distribution uniformity, and current density distribution of PEMFC. Whether its layout is reasonable directly affects the comprehensive performance of proton exchange membrane fuel cell. An Improper layout may cause a local hot spot/waterflooding phenomenon in PEMFC. Thus, the battery performance is reduced [8]. Figure 1 is the schematic diagram of proton exchange membrane fuel cell and bipolar plate.

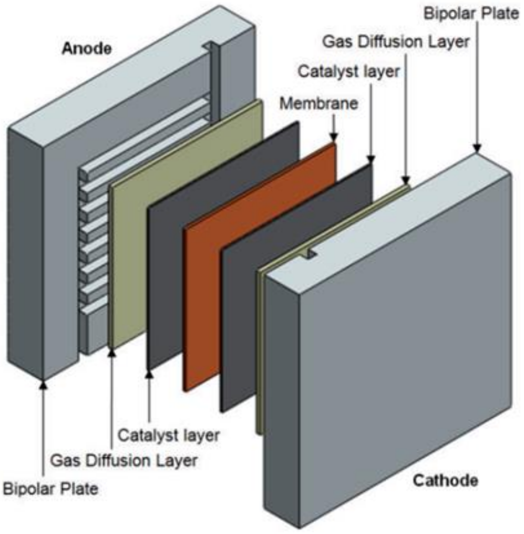


Figure 1. Schematic diagram of proton exchange membrane fuel cell and bipolar plate.

Proton exchange membrane flow field is divided into conventional flow field and new flow field [9], both of which have different characteristics in performance, manufacturing difficulty, water removal capacity, and other indicators.

2.1. Conventional flow field

2.1.1. Parallel flow field.

The Parallel flow field is one of the most basic flow field structures. The linear parallel flow field and wave parallel flow field are formed according to the difference in fluid movement path. If the flow field is sliced and differentiated, the motion range of gas is also differentiated into the shape of the flow channel section, which has a great influence on the performance of PEMFC [10]. Figure 2 is comparison of maximum power density and pressure drop curves of flow fields with different cross-section shapes.

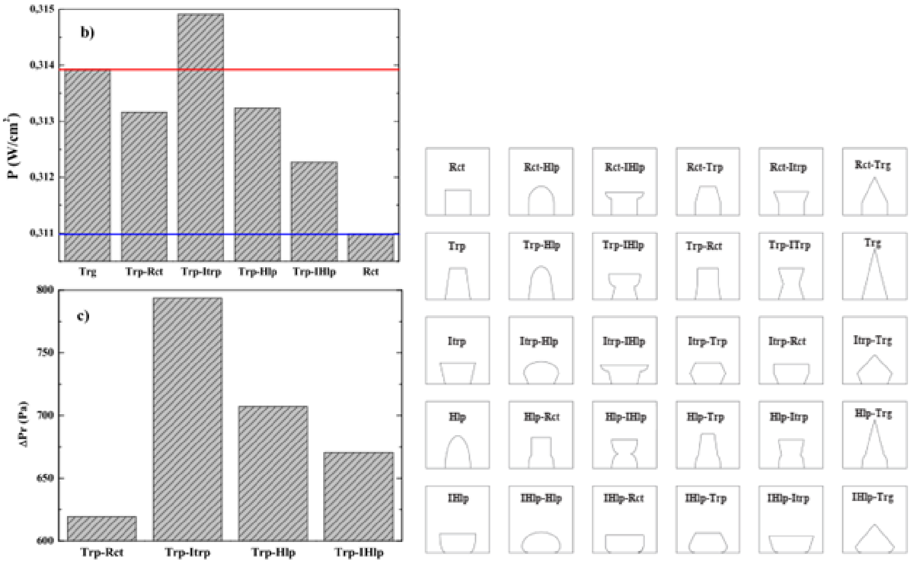


Figure 2. Comparison of maximum power density and pressure drop curves of flow fields with different cross-section shapes.

Mohammedi et al. used a three-dimensional CFD model to study the influence of section shape on the power density, pressure drop, and local transport phenomena of a single straight channel. The model used 30 channel cross-section shapes with the same area, including 5 regular channel forms and 25 new channel forms.

Experiments and numerical results show that the model has good consistency. In medium and high current density, channel cross-section shape has a significant influence on power density. Bottom trapezoidal and top inverted trapezoidal (TRP-ITRP) channel cross-section configurations perform best. However, the channel section structure with inverted semi-elliptic bottom and inverted trapezoid top have the worst performance. The triangular channel section shows the maximum pressure drop, the Rectangular channel cross-sections show minimum pressure drop. If the channel cross-section structure is not properly selected, the power density loss can reach 4.65%.

2.1.2. Rib interventional flow channel.

In the conventional flow field, adding the rib structure is also conducive to improving the comprehensive performance of PEMFC. Gao Qiang et al. conducted a simulation study on the ribbed flow field with COMSOL Multiphysics software, and the results showed that the wedge-shaped rib in the flow channel has an obstruction effect on the horizontal flow of reaction gas in the gas channel. Rib disturbance is advantageous to the oxygen of the air to the diffusion-reaction area, and the wedge ribs have a certain Angle, the reaction gas after contact with the wedge finned produces a velocity vector perpendicular to the direction of flow, the diffusion of gas in diffusion plays a certain role in promoting, improve the uniformity of the gas distribution, enhance gas convection, enhance mass transfer performance of the flow channel.

2.1.3. Serpentine flow field.

Compared with the parallel channel, the snake channel has better reactant gas distribution and higher maximum current density and is one of the most common flow field structures. Compared with a single serpentine channel structure, the pressure drop of the inlet and outlet of the multi-serpentine channel is smaller and the reactant gas distribution is more uniform under the same area. Therefore, the multi-serpentine flow channel structure is more suitable for the actual design of PEMFC. Yang Wang et al. studied the arrangement of series obstacles and the variation of height parameters as geometric variables. In order to further analyze from the physical field, 3d numerical simulation was used to study the improvement effect of obstacles on PEMFC performance. It is shown that the presence of obstacles can enhance the migration of reactant gas to the gas diffusion layer (GDL) and increase current density compared with conventional channels. Maximum current density can be obtained by placing obstacles at the rear of the channel (global obstacles), while maximum reactant gas uniformity can be obtained by placing obstacles at the GDL interface (total obstacles). Shi Lei et al. conducted numerical simulation and computational research on flow and mass transfer processes in PEMFC with different flow passage sizes (width-depth), gas diffusion layer (GDL) porosity, inlet velocity, and temperature by using COMSOL Multiphysics, a direct coupling analysis software for multi-physical fields [11]. The results of simulation analysis show that the optimal width-depth combination of an 8-channel composite serpentine flow channel is 1.2mm-0.8mm. The optimized combination of inlet velocity -- GDL porosity -- temperature is 0.5m/s-0.5-353.15K.

2.1.4. Finger flow field.

Different from the common parallel flow field structure, plug type refers to the flow of import and export is closed at the end of the channel, under the drive of the pressure difference depends on forced convection and diffusion to the function of the catalyst layer, at the same time, due to the sheer force produced by forced air can also take away most of the water retention in the diffusion layer, reduce the chances of the phenomenon of water [12]. A. KAZIM et al. analyzed the advantages of interfingered flow field by establishing A mathematical model in 1999, and the results showed that the limiting current density of proton exchange membrane fuel cell using interfingered current field was about 3 times that of the conventional current field [13]. The results also show the maximum power density of PEM. The mass transfer of reactants to the catalyst layer is increased and the performance of the proton exchange membrane fuel cell is improved. Hadi Heidary numerically and experimentally studied the effects of channel blockage on velocity contour, reactant distribution on catalyst layer, local current density, polarization curve, and power density curve of traditional finger plug proton exchange membrane fuel cell [14]. Clogging increases the pressure drop along the flow channel and also balances the factory pumping power that drives the flow field working fluid. Therefore, the effect of indentation on pressure drop and pumping power was also measured. The results show that blocking channels increases the limiting current density by 9% and the maximum net power (pumping power minus generated power) by 22% at 1.5 SLPM. Figure 3 is schematic diagram of structures with and without blocking.

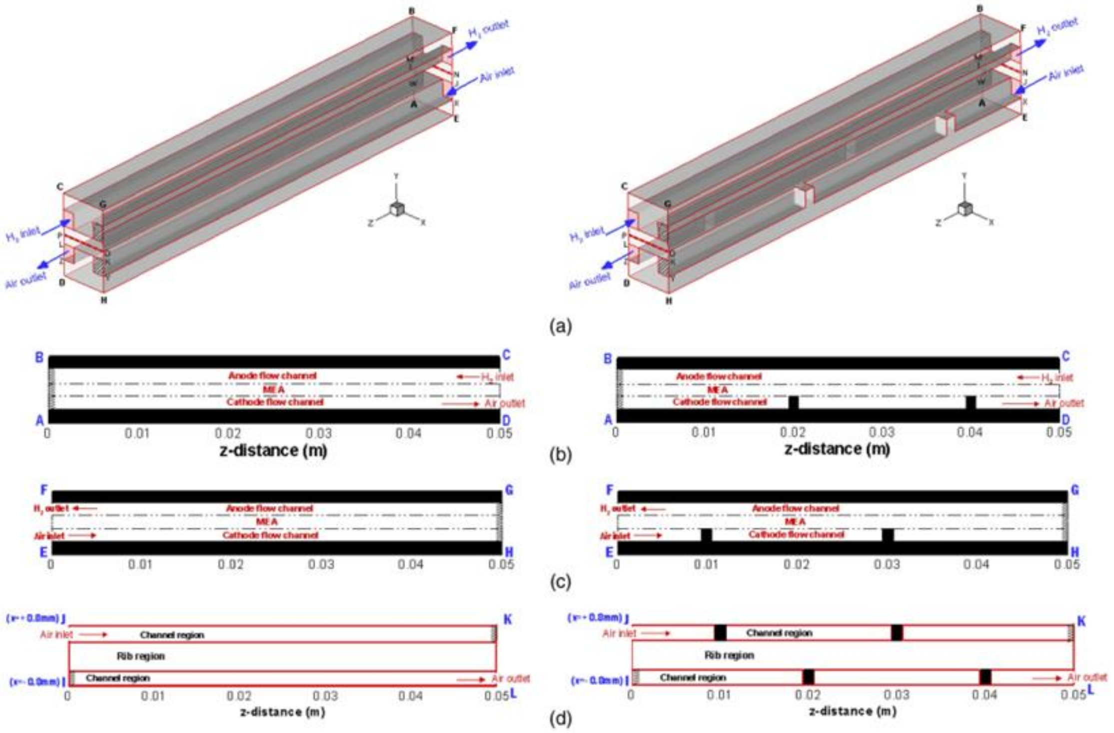


Figure 3. Schematic diagram of structures with and without blocking [12]

2.2. New flow field

The existing new flow fields, including the bionic flow field, three-dimensional flow field, and metal foam flow field, are discussed. The bionic flow field is based on natural biological channel geometry, such as the leaf vein system, in which nutrients flow through the parent channel and are distributed to smaller sub-channels. Due to the natural evolution of these flow networks, the distribution of nutrients is maximized with the minimum pressure drop, naturally forming a better degree of gas uniformity. These design theories based on fractal design, genetic algorithms, and other design theories attract more and more researchers to engage in research [15].

2.2.1. Bionic flow field.

To investigate the effects of different flow field designs, researchers have begun to study the effects of naturally stimulated bionic flow fields, such as veins and the human pulmonary vascular system, on the performance of PEM proton exchange membrane fuel cells. Nutrients distributed in branching systems have an optimal arrangement that is efficient in each part. The main reasons for choosing these designs were the uniform distribution of reactants and better water management. Srinivasa Reddy Badduri et al. experimentally explored the performance of PEMFC with three flow field structures, namely triple snake flow field, lung flow field, and blade flow field, under different working conditions, and analyzed the influence of operating parameters such as reactants' backpressure, operating temperature and relative humidity in biological channel design on the performance of PEMFC [16]. Part of the research results is shown in the figure. The results show that among the three flow field shapes considered (three-snake flow field, lung flow field, and blade flow field), there is a double blade flow field. Figure 4 is schematic diagram of flow field structure of three shapes. Figure 4 is Schematic diagram of flow field structure of three shapes.

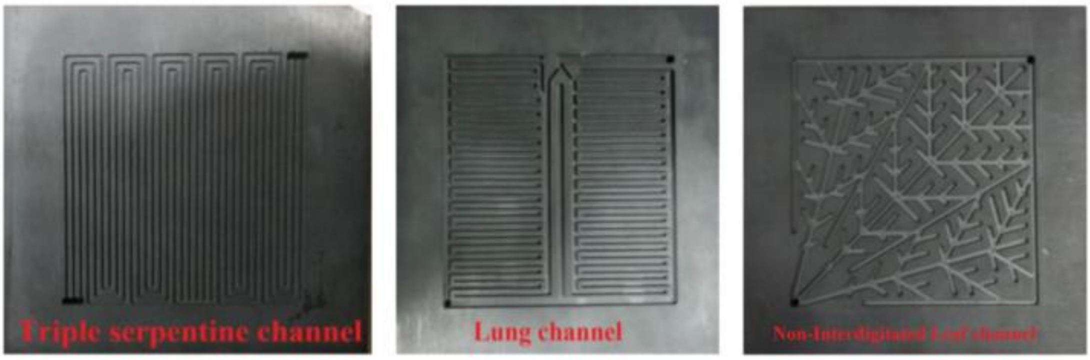


Figure 4. Schematic diagram of flow field structure of three shapes [16].

The performance of the plating cell is better than the other two flow field shapes. The power density of the proton exchange membrane fuel cell with the cross-finger-blade channel design is 6.72% higher than that of the proton exchange membrane fuel cell with the non-cross-finger-blade channel design. It can be seen that the flow field design based on bionics has a great positive effect on improving the performance of PEMFC.

2.2.2. three-dimensional flow field.

Figure 5 is voltage-current density-energy density curves of three flow channel structures at 0.3Mpa, and three models used by Jun Shen [17]. Figure 6 is EMTC curves of different flow channels. Compared with the traditional two-dimensional flow field, the three-dimensional flow field has been proved in many studies to improve the performance of proton exchange membrane fuel cells and greatly enhance the transport of reactants. Jun Shen et al. studied the transport distribution characteristics of reactants and water in proton exchange membrane fuel cells through a parallel two-dimensional flow field, simplified three-dimensional flow field, and tilted three-dimensional flow field, and proposed efficiency evaluation criteria to evaluate the superiority of flow channel design [17]. The results show that the three-dimensional flow field has the advantages of strong mass transferability, uniform water distribution, and strong water removal ability, which is superior to the parallel two-dimensional flow field. Xi Chen et al. established a three-dimensional multiphase model of a proton exchange membrane fuel cell with a three-dimensional wave channel and applied CFD method to optimize the geometric structure of the three-dimensional wave channel [18]. The results show that the three-dimensional wave channel is better than the DC channel in promoting the reactant gas migration, removing liquid water in the microporous layer and avoiding the concentration of thermal stress in the film. There are not only structural innovations but also the establishment of evaluation indexes for guiding flow field design. Yonghua Cai proposed a new three-dimensional cathode flow field with a main channel, sub-channel, and transition zone, and proposed evaluation criteria for guiding flow field design [19]. The experimental results show that PEC and EMTC can be used to evaluate the performance of PEMFC, thus guiding the flow field design of PEMFC. The higher PEC and EMTC values are, the better PEMFC performance is.

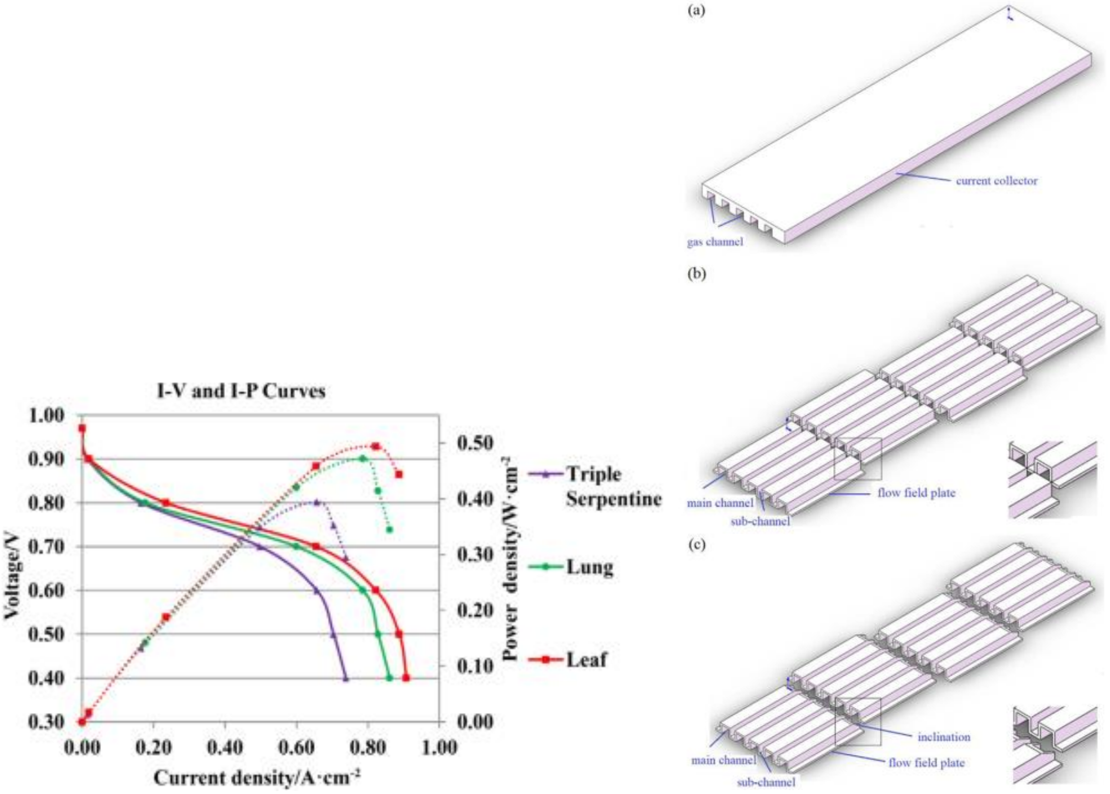


Figure 5. Voltage-current density-energy density curves of three flow channel structures at 0.3Mpa, and three models used by Jun Shen

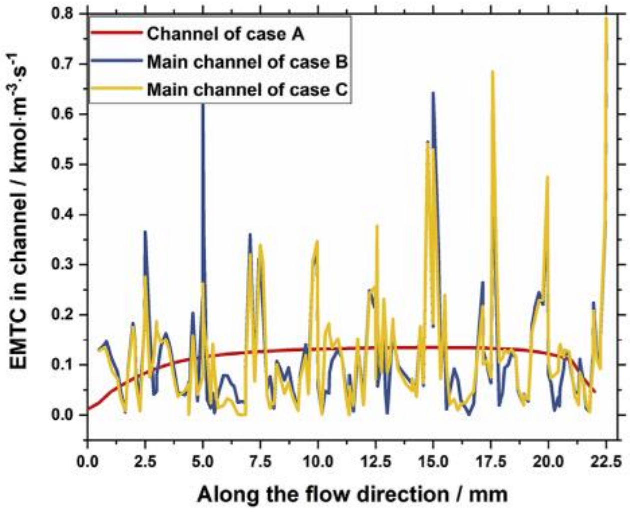


Figure 6. EMTC curves of different flow channels

2.2.3. Metal foam flow field.

Porous metal is a kind of material with both structure and function. Thanks to its advantages of low density, high porosity and controllable permeability, porous metal also has good heat dissipation performance, so it is very important for the uniform distribution of temperature and the discharge of water and heat from battery products. Mengshan Suo et al. conducted a numerical study on the effect of the metal foam flow field on oxygen transport in PEM proton exchange membrane fuel cell under zero humidity by using a three-dimensional LBM model [20]. To focus on the hole. Figure 7 is typical cell structure reconstruction metal foam.

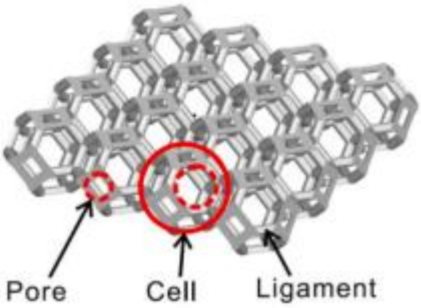
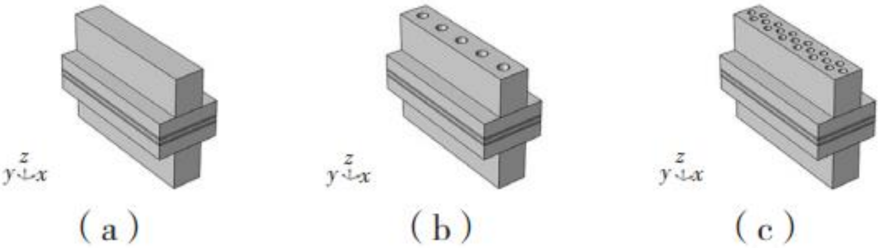


Figure 7. Typical cell structure reconstruction metal foam.

Water vapor condensation and liquid transport are ignored in the simulation due to the influence of structural parameters such as porosity, pore density, and compression ratio. It was found that compared with the channel rib flow field, the metal foam flow field lengthened the gas retention time, enhanced the convection, and increased the transport area between the flow field and GDL. Therefore, the mass transfer rate of oxygen to CL was improved and oxygen distribution was improved. The thick ligaments in the low porosity foamed metal are conducive to convection and inhibit diffusion, and the decrease of the porosity of foamed metal increases the mass transfer rate. Metal foam is characterized by small interstice and large contact areas, as well as easy corrosion and difficult maintenance.

2.3. Efficiency analysis of existing flow field structure

Figure 8 is the three flow channel model structures. In command to discover the control of run means arrangement on PEMFC, a model was accepted. Assume that model (1) battery operation is steady-state; (2) Power unit is laminar run; (3) The domestic temperature of the power unit is continuous, and there is no temperature move and warm interchange with the surroundings; (4) Liquid live in the power unit in the type of vapour; (5) The uncertain fumes is think to be an principal gas. A is the DC channel without holes, B and C are the one-line flow channel with holes, and the single-matching-row cross run means with cavity respectively. By set up (a), (b), and (c) three different run means to work out the link to between the electric-powered meadow, attention field, and speed field of the power unit, the control of run means with cavity on substance move and run tightness delivery on the catalytic covering was planned.



(a) (b) (c)

Figure 8. Three flow channel model structures.

The above corporal model was answered by COMSOL Multiphysics and check with the test data of the isothermal model put forward by Ubong. The experimental data were compared with the simulation [21].

The substance move in the room run means and catalytic covering and its control on the speed of compound response were analyzed. When the small hole is added, the current density is larger under the same battery voltage, which is because the material transfer and seepage velocity in the battery is improved, the mass fraction of the material is increased, and the compound response speed is increased. The presentation of the room with run channel arrangement B and C is obviously better than that of the first flow means A, and the flow channel with double row interlaced holes is the best. In the case of a-kind flow channel,expected to the reality of a ridge, the opening between the center flow tightness and the two borders is big, and the chemical reaction is mainly concentrated on the two sides. In the b-formed run means, although there is still a crest, the small cylinder in the flow means changes the speed delivery in the run channel, creation the flow tightness drop along the flow way [22]. On the basis of single-row and double-row interlaced channels, the number and distribution of holes were added to obtain the current density distribution. Because the space between the holes is too near, consequence in less fumes in piece of the area, resulting in the flow delivery in the catalytic covering is different from the nearby current region.

The consequences indicate that the run means with cavities is better to flow channel A in fumes permeability,room force, and power unit production presentation [23]. Therefore, it is established that raise the small cavities in the flow means can not only raise the substance move interior the power unit but also lessen the run tightness dissimilarity on the catalytic covering.

In command to discover the control of the trapezoidal dc means on the presentation of the proton interchange layer petrol room, a three-solid, multiphase arithmetical model of PEMFC was accepted by pretending the run,warm move, lot transfer, and electrochemical response of proton interchange layer petrol room. It mainly contains lot preservation equating, impetus conservation equating, strength conservation equating, part conservation equating, ask for conservation equating, and fluid liquid establishment and convey equating.

Assumptions: In command to set up the arithmetical model, the following presumptions are mainly produced:

1) The gas mixture in PEMFC is ideal gas;
2) The gas flow in PEMFC is laminar and incompressible;
3) The spreading layer and the catalytic covering are uniform and isotropic;
4) The influence of gravity is ignored.

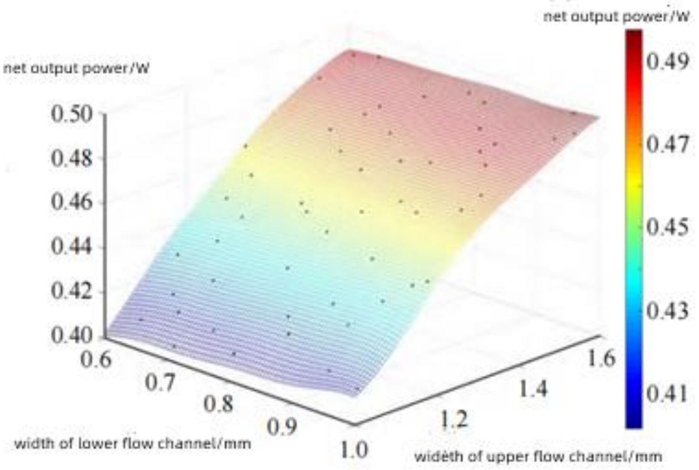


Figure 9. The surface of output power.

The limited amount manner based on the uncomplicated algorithm was used to answer the force and speed link to equating under non-isothermal, multiphase, and continuous-country state. In command to enhance the meeting of answers and firmness, using the multigrid series of events manner of F cycle. The Biconjugate Slope make stable manner(BCGSTAB) is request to the firm-stage and layer-stage possible equating. The above solution methods were adopted for subsequent simulation optimization. When the inflexible manage voltage is 0.5 V, the flow tightness under a different numeral of grating is got. Figure 9 is the surface of output power.

According to the produce answer covering, the run means arrangement corresponding to the greatest mesh production control got by the genetic algorithm is the spacious and brief trapezoidal structure [22].

The topmost lowest part width of the bottom model is 1mm, the subordinate bottom breadth is 1mm, the run means tallness is 1mm, and the crest width is 1mm. After optimization, the topmost and bottom width of the trapezoidal run corridor is 0.99927mm, the subordinate and lowest part breadth is 1.59998mm, the flow passage tallness is 0.76951mm, and the crest width is 0.40023mm. By contrast the presentation of the optimal model with that of the fundamental model, it is established that the mesh production control of the optimal model raised by 20.90%.

3. Proton exchange membrane fuel cell system for vehicle

3.1 Brief Introduction of Vehicle Proton Exchange Membrane Fuel Cell System

To compensate for the low power density of proton exchange membrane fuel cells for hydrogen fuel vehicles, lithium batteries and supercapacitors are usually used as auxiliary energy sources. In the application of proton exchange membrane fuel cell vehicles, there are three types of common energy systems, namely, proton exchange membrane fuel cell + power battery, proton exchange membrane fuel cell + supercapacitor, and proton exchange membrane fuel cell + power battery + supercapacitor

3.2 energy systems

3.2.1. Proton exchange membrane fuel cell + power battery.

According to the proton exchange membrane fuel cell, three topologies are generated by different connection modes between the power supply and drive motor. The advantages and disadvantages of different connection methods can be seen in the table. Because the power battery has the characteristics of long energy storage time and large energy storage, the proton exchange membrane fuel cell + power battery system is the most widely used structure of hydrogen energy vehicle energy system. But power batteries need to be started and stopped to meet the changing power of the vehicle. And compared with the supercapacitor, the power battery can only achieve the cycle of the supercapacitor in the case of deep discharge, so the life is low. Compared with the supercapacitor which only carries out physical storage, the electrochemical reaction inside the power battery will produce adverse side reactions to a certain extent, leading to the attenuation of the battery life.

3.2.2. Proton exchange membrane fuel cell + supercapacitor.

According to the different connection modes of proton exchange membrane fuel cell, supercapacitor and drive motor, its topology can be divided into three kinds. The specific comparison is shown in the table below. The supercapacitor has the characteristics of strong instantaneous charge and discharge capacity and long service life, so it is also regarded as a possible energy storage mechanism for future hydrogen fuel vehicles. Supercapacitors can supplement vehicle power in a short time by mixing with proton exchange membrane fuel cells [24]. Compared with the power battery, its cold start performance, acceleration performance, and regenerative braking performance have been greatly improved. It also makes the system have a longer life cycle and higher charge and discharge frequency. Because the internal reaction is a physical reaction, the safety factor of the supercapacitor is high, and the internal resistance is relatively small compared with the traditional power battery. However, this also makes the energy stored in the supercapacitor very unstable, easy to lead to capacitor instantaneous discharge current greatly control more complex.

3.2.3. Proton exchange membrane fuel cell + power battery + supercapacitor.

The circuit structure of proton exchange membrane fuel cell + power battery + supercapacitor can be mainly divided into two types of connections, and the specific analysis is shown in the following table. Due to the good acceleration performance of the vehicle needs the support of high power density and high energy density, and considering the complementary relationship between the power battery and the supercapacitor, the power battery, and the supercapacitor are applied to the proton exchange membrane fuel cell system at the same time. Proton exchange membrane fuel cell + power battery + supercapacitor can meet the power and efficiency requirements of vehicle start and stop, idle speed, and braking feedback to the greatest extent. In this mode, the electric energy moves into three energy sources. This electric energy enters the inverter through the DC bus and is converted into AC voltage to drive the AC motor.

4. Energy management strategy analysis of vehicle proton exchange membrane fuel cell

4.1 rule-based energy management strategy.

4.1.1. Control mode control.

This paper compares five EMS that can be implemented in the FCHV monitoring system. According to the priority of fuel economy or SOC balance, and due to the nonlinear relationship between ΔSOC and FCHV fuel economy, increasing the change of SOC will reduce the fuel economy of vehicles in the driving cycle [25]. The optimization strategy has advantages in the changes of equivalent energy consumption, energy efficiency, and charging state (SOC). Optimized fuzzy logic control (FLC) and optimized operation mode control (OMC) can be considered the most suitable control strategies. (In this paper, FLC and OMC are considered by GA optimization strategy [26]. The multi-objective optimization is selected and the parameters of the control strategy are adjusted by the new fitness function according to the performance test results.)

4.1.2. State machine control.

This energy distribution strategy is mainly used in the combination of batteries with supercapacitors or proton exchange membrane fuel cells. In order to solve the problem of power allocation, a method based on finite state machine is proposed. The power capacity of the battery and supercapacitor is regarded as an important parameter in the management strategy, and the maximum net power is obtained by the optimal oxygen excess ratio control [27]. Compared with the traditional feedforward control, the controller has the characteristics of high response speed, small overshoot and small steady-state error. (Advantages: The power capacity and charge state of energy equipment are fully considered in the state of machine control.)

4.1.3. Fuzzy control. Based on wavelet and fuzzy logic:

(This study focuses on battery + supercapacitor power system (UC)) Advanced energy management strategy is very necessary for allocating the power demand of the vehicle in a way suitable for vehicle power supply to improve the fuel economy and durability of the hybrid powertrain components while maximizing the performance [28]. This study proposes an energy management strategy combining wavelet and fuzzy logic for existing hybrid electric vehicle systems. Wavelet transform has a strong ability to analyze the signals composed of instantaneous changes, which can quickly analyze the power demand of hybrid electric vehicles (HEV). It can ensure the power demand to improve the fuel economy and durability of the hybrid syste m components and also ensure the maximization of the performance of proton exchange membrane fuel cells. In addition, fuzzy logic has a very suitable structure for hybrid system control.

Optimized frequency decoupling EMS: a frequency decoupling EMS optimized by fuzzy control method to extend the life of proton exchange membrane fuel cell and improve the fuel economy of FCHEV [29]. In this EMS, proton exchange membrane fuel cells, batteries and supercapacitors are used to provide the low-frequency, medium-frequency, and high-frequency components of the required power, respectively, to ensure that proton exchange membrane fuel cells can provide the low-frequency of the required power to extend their life, and at the same time ensure the rapid response of power demand and maintain the SOC of the battery/supercapacitor within the predetermined range.

4.2 Energy Management Strategy Based on Optimization.

4.2.1. Particle swarm optimization.

(The biggest advantage is robustness, but the degree of conservatism may be higher.) Robust optimized energy management system (EMS) to ensure optimal and robust performance under uncertain parameters [30]. The RO-based algorithm includes the uncertainty of cost function and constraint set, to protect the system performance from feasibility and optimality problems.

4.2.2. Equivalent Hydrogen Consumption Minimization Strategy (ECMS).

ECMS control can be considered the most suitable control strategy for high-power hybrid electric vehicles [31]. ECMS achieves the lowest hydrogen consumption and equivalent hydrogen mass consumption of powertrain, thereby reducing the amount of hydrogen stored in electric vehicles and the related weight. In addition, the implementation is simple, the universality is strong, and the complexity of control is low so the calculation time is small.

4.2.3. Dynamic programming algorithm (DP).

A multi-objective optimization EMS design is designed, and the energy management algorithm of the proton exchange membrane fuel cell/lithium battery hybrid system is designed by using the soft operation strategy [32]. Based on the optimization results of the DP algorithm, the soft operation strategy is defined to focus on fuel economy, system durability, and lithium battery size adaptation. This is a soft operation strategy designed by a real-time multi-objective control algorithm. It has good dynamic performance, optimizes the life cycle cost, and achieves a good balance between fuel economy and system durability. The disadvantage is that the calculation is too large.

4.2.4. Pontryagin Minimum Principle (PMP).

An energy management strategy based on Pontryagin minimum principle (PMP) and a rule-based energy management strategy is established [33]. To prolong the service life of the batteries, a rule-based energy management strategy is established with SOC as the main reference. Secondly, a comprehensive objective function is established to determine the basic variables of the hybrid system, which are the control variable Pbatt and the state variable SOC. On this basis, the energy management controller based on Pontryagin minimum principle is successfully designed. This controller has better real-time performance and can give full play to the performance advantages of proton exchange membrane fuel cells. By adjusting the energy distribution ratio of each power unit, the economy and fuel efficiency of the vehicle can be improved, and the emission can be reduced to achieve the goal of environmental protection.

The main development direction of energy management strategy in the future is real-time computing and high economy. The improved rule-based control strategies, such as the optimized thermostat control strategy and the optimized operating mode control strategy, have advantages in equivalent energy consumption, state of charge (SOC) change and energy utilization efficiency. The management strategy based on optimization is mainly based on multi-objective dynamic programming algorithm and PMP algorithm, which has advantages in real-time dynamic calculation and enhancing battery adaptability [34]. The dynamic combination of rule-based and optimization-based management strategies, supplemented by information platforms such as Internet intelligent transportation, can construct a new energy management strategy that meets the requirements of real-time, stable calculation, and high vehicle economy.

5. Conclusions

With the gradual implementation of the national energy strategy, the proton exchange membrane fuel cell will gradually become a substitute for the existing battery products such as lithium batteries. For the flow field structure in the bipolar plate, the future trend will be to comprehensively consider the use conditions, design and optimize the structure of the inlet, outlet, internal flow field structure, the combined degree with the gas diffusion layer, current density, energy density, and other factors.

It is not limited to the single conventional flow field structure and the new flow field structure and should be used flexibly, which also puts forward higher requirements for the manufacturing level. The laser additive manufacturing method proposed by Pengyi Huang provides us with the imagination space for the manufacturing of complex flow channels.

In the future, the main development direction of energy management strategy is real-time and low cost. The optimized rule-based control strategy, such as the optimized fuzzy strategy and the optimized operating mode control, has advantages in terms of equivalent energy consumption, energy efficiency, and charge state (SOC) change. The management strategy based on optimization is mainly based on a multi-objective dynamic programming algorithm and PMP algorithm. The dynamic combination of rule-based and optimization-based management strategies, supplemented by information platforms such as Internet intelligent transportation, can construct a new energy management strategy that meets the requirements of real-time, stable calculation, and high vehicle economy.

In this paper, the structure of hydrogen energy proton exchange membrane fuel cell is summarized and the current structure-based research is briefly summarized. Several optimized flow channel structure models are summarized, and the use scenarios of hydrogen energy proton exchange membrane fuel cells are summarized based on the current situation and future imagination. Considering the development of artificial intelligence and future traffic, a new energy management strategy based on learning (intelligence) is formed by effectively combining artificial intelligence learning, neural network, intelligent road traffic, and other technologies, which can provide a feasible optimization scheme for proton exchange membrane fuel cell vehicles with both control effect, real-time performance and high economy.

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