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Passive Proton Exchange Membrane Fuel Cell Temperature Characteristic

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Abstract. In this paper, we study the air natural cooling passive proton exchange membrane fuel cell. By controlling the temperature within a reasonable working temperature range, we try to ensure the battery in its best performance in the working condition. Through the establishment of three-dimensional model and the numerical simulation of internal heat transfer as well as mass transfer process in the passive proton exchange membrane fuel cell, we conclude that the temperature change of the environment has a great influence on that in the passive proton exchange membrane fuel cell. Exploring the method of natural cooling heat dissipation is meaningful to the efficient thermal management of the passive proton exchange membrane fuel cell system.

Keywords: Air natural cooling, Passive proton exchange membrane fuel cell, Temperature, Efficient thermal management.

1. Introduction

Along with the increasingly serious environmental and resource problems, we pay more attention to the sustainable development of energy application, and require the energy to be more efficient, clean and cheap. Passive proton exchange membrane fuel cell has the advantages of clean, high energy conversion efficiency, also, it functions well in the normal temperature. It is usually used in the absence of active cooling equipment or air transport, especially, when the battery is installed in printed circuit board (PCB), its application is more extensive. Therefore, whether from the perspective of clean fuel, or simplify the structure of the battery, reduce cost and increase the reliability, passive proton exchange membrane fuel cell has a big advantage to research [1].

In fuel cells, the distribution of temperature has an important influence over the water management and heat and mass transfer. Exploring internal heat transfer law is an important way to improve the performance of the battery, which is getting more attention. For PEMFC, the running temperature is an important parameter to the battery, it not only has a great influence on the performance of the battery, but also a certain guiding significance for the water and thermal management of battery.

Nowadays, studies which focus on the natural convection and mixed convection heat transfer temperature in the passive proton exchange membrane fuel cell is less, by using Comsol Multiphysics software, this paper establishes three-dimensional numerical simulation to analyze the distribution of temperature field in PEMFC under the condition of heat convection.

1.1. The Working Principles of Proton Exchange Membrane Fuel Cell

In the proton exchange membrane fuel cell, it occurs the redox reaction which the fuel and oxidant take place on both sides of the proton exchange membrane. It is a kind of energy conversion device that turns chemical energy which is neutralized by the fuel and the oxidant directly into electrical energy according to the electrochemical principle [2].

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After hydrogen reaching to the anode through the air guide plate or pipe, in the role of the anode catalyst, the hydrogen molecular is electrolyzed into hydrogen ions (protons) with positive electricity and electrons with negative electricity [3]. Hydrogen ions reach to the cathode through the electrolyte (proton exchange membrane), while electrons reach there through the external circuit. Electrons form the current in the external circuit which can output power to the load through the connection. In the other side of the cell, the oxygen reaches the cathode through the pipeline or the air guide plate. In the role of the cathode catalyst, oxygen ions, hydrogen ions and electrons react into water and release heat at the same time. The chemical reaction equations are as following:

Anode reaction: $H_2 \rightarrow 2H^+ + 2e^-$ (1)

Cathode reaction: $0.5O_2 + 2H^+ + 2e^- \rightarrow H_2O + Q$ (2)

The total reaction: $H_2 + 0.5O_2 \rightarrow H_2O + E + Q$ (3)

1.2. Passive and Active PEMFC

Active fuel cell need pump, fan and other auxiliary equipment to transport fuel and oxidant to battery. Passive fuel cells do not rely on such auxiliary equipments mainly on the free diffusion of the battery. Compared with active fuel cell, the extra accessory equipment in the Passive fuel cells, such as pump, fan and sensors will no doubt take up larger space, thus to increase the complexity of the whole battery system, at the same time, these accessories will consume a certain amount of energy, and reduces the efficiency of the overall battery system.

In the passive PEMFC, neither the oxygen feeding in cathode nor the hydrogen feeding in anode rely on circulating pump, and since the anode is equipped with hydrogen storage box cavity, the supply of hydrogen depends completely on the process that hydrogen molecules reach electrode from the hydrogen cavity by means of free diffusion; and the supply of oxygen depends completely on concentration and air convection diffusion [4]. Therefore, by removing the battery auxiliary equipment such as pump, heating humidifying device, passive PEMFC reduces the energy consumption, simplifies the structure of fuel cell system, thus the weight and volume of the battery system can meet the requirements of portable power supply easily.

1.3. The Working Principle of Air Natural Convection of Cathode Side in PEMFC

The mass transfer in cathode is caused by natural convection in the air, which is a result of the density gradient. Air density gradient was caused by temperature difference and the gradient of the chemical reaction on the surface of the cathode. Cathode gas density is a function of several parameters such as temperature, relative humidity, and pressure. Compared with the surrounding environment, cathode surface is hotter and more humid and less oxygen, which leaves the low gas density near the surface, then it will drive a buoyancy lift, and diffuse heat and water vapor into the surrounding environment through the natural convection. the buoyancy lift is $F = g\left(\rho - \rho_{amb}\right)$. Where: g, ρ, ρ_{amb}, respectively represents the acceleration of gravity, air density in cathode , air density in the surrounding environment. Buoyancy lift is balanced by viscosity, when it exceeds a critical dimensionless Grashof number, the fresh oxygen transfer to the cathode by natural convection. As a result, the cathode side of the natural convection is a complex coupling of heat and mass transfer occurring on the surface of the fuel cell and gas interface.

2. The Battery Design

In this paper, we study a small (less than 500 w) power battery, its anode side is made of Copper, the cathode side is made of alloy Steel (Steel AISI 4340). Both of anode and cathode adopt parallel current collector, which size is 20 mm × 20 mm × 0.0335 mm; Cathode is equipped by collecting plate in hole shape with four Φ 8 mm of for air breathing hole arranged in sequence, which size is 20 mm × 20 mm × 0.8 mm, the thickness of the membrane is 0.02 mm, besides, the design of cathode and anode for syncretic structure, the anode and cathode current collector plate have the same size, which are directly exposed in the air.

The purpose of the design on both sides of passive air fuel cell is to ensure that the ambient temperature and load current (determined by the current density and heat conditions) can be controlled within a reasonable range. In the design, the size of orifice plate in cathode is usually bigger than that in anode, which aims at transporting electrode reactant more effectively to the electrode. Compared to the current collector

The hole is smaller in size, so it is necessary to maintain its structural rigidity and conductivity. At the same time, the reaction between the big holes will produce higher partial Ohmic heat loss in diffusion layer. Battery installed in printed circuit board (PCB), which use copper film current collector. PCB has lower coefficient of thermal conductivity, so all the heat generated by the cathode dissipates in the form of convection cooling and surface radiation cover. As a passive proton exchange membrane fuel cell plate, printed circuit board (PCB) integrates the collector and serial, which greatly optimizes the structure of the battery. In addition, it has the advantages of high strength, light weight, low cost, mature technology and can be easily processed and implemented to achieve conduction and insulation.

3. Mathematical Models

3.1. Model Assumptions

Before establishing the mathematical model, we need the basic assumptions as following: (1) The internal membrane electrode of proton exchange membrane fuel cell has good humidification. The battery's temperature distribution is uniform and constant. The battery operates under stable conditions; (2) Reaction gas is an ideal gas which is fully saturated by water. The fluid flow is laminar flow; (3) The reaction gas will not penetrate the proton exchange membrane; (4)The water in the proton exchange membrane is present in the form of dissolving. It is the gaseous state in the electrode. The liquid water inside the flow channel exists in the form of droplets and can be taken away by the gas flow, but it does not affect the gas in the flow channel; (5) The diffusion layer, the conductivity of the catalyst layer and the porosity are all uniformed and isotropic; (6) The catalyst layer is described by the crowding index model. The component ratio among the film phase, the solid phase and the pore in the catalyst layer is constant. The size of the crowding layer and pore is uniform; (7) The gravity effect is neglected.

3.2. The Mathematical Model Description of the Electrode

(1)The catalyst layer is described by the crowding index model. The concentration of hydrogen and oxygen dissolved in the surface of crowding index is described by the Henry's law; (2) The charge transport current density is described by Using Butler-Volmer electrodynamics expression. The catalyst layer can be regarded as the boundary of the charge transfer; (3) The diffusion layer and the catalyst layer both can be regarded as porous media model. The flow of gas in porous media can be described by the Darcy's law. The mechanical parameters of the gas flow rate, pressure and others can be obtained in the diffusion layer and catalyst layer by the Darcy's law; (4) The diffusion and convection of the cathode and the anode are apiece described by a multi-component diffusion equation of Mexwell-Stefan.

4. The Results and Analysis of the Numerical Simulation

Besides water and electronic, the final products of reactions in proton exchange membrane fuel cell include heat. The heat generated in PEMFC mainly consists of two parts: one part is the Joule heat caused by battery ohm internal resistance; the other part is the heat of reaction caused by chemical oxidation [5]. In order to ensure the fuel cell function within the best working temperature range, it is necessary to be cooled. In this paper, by using the theory of two phase flow in porous media, we set up the passive three-dimensional mathematical model of proton exchange membrane fuel cell and analyze the proton transportation in porous media, electrochemical engineering and natural air cooling process. With the aid of numerical simulation, we theoretically analyze the process of mass transfer, heat transfer and electrochemical reaction inside the battery, and then providing scientific theoretical guidance to optimize the structure of the battery and operating conditions, therefore to ensure that the battery thermal management system can run efficiently [6].

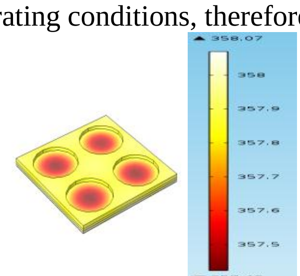

Fig. 1: The air natural convection

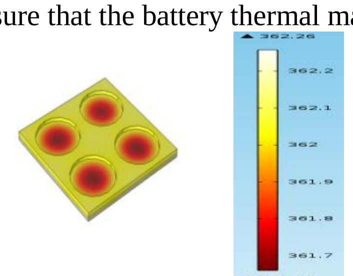

Fig. 2: Battery temperature

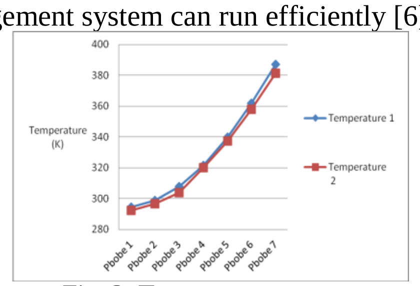

Fig. 3: Temperature contrast

As can be seen from the Fig. 1-Fig. 3, after adding the air natural convection to battery, we find the temperature was apparently lower than that without adding any cooling process. Reasonable temperature can improve the "flooded" problem in cathode side, speed up the rate of diffusion of water in the proton exchange membrane, increase the proton conduction velocity in the film and reduce the ohmic resistance of the battery electrolyte, thereby strengthening discharge performance of passive proton exchange membrane fuel cell and improving power density as well as the conversion efficiency between chemical energy and electrical energy. Therefore, we can take effective cooling way to achieve the ideal performance of battery.

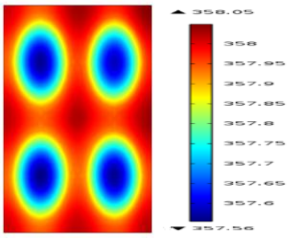

Fig. 4: The temperature of inner membrane

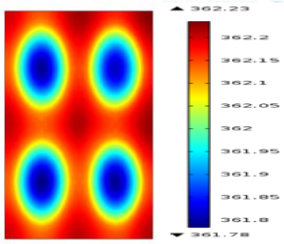

Fig. 5: The temperature of inner membrane

As can be seen from the Fig. 4 is that the temperature distribution of inner membrane with air natural convection, the temperature is 357.56. ~ 358.05K, the difference is 0.49K, Fig. 5 is that the temperature distribution of inner membrane without air natural convection, the temperature is 361.78 ~ 362.23K, the difference is 0.45K.Four rounded areas represent the temperature of the cathode size, the temperature inside circle is lower than that of the outer boundary, because the position in the center of the circle is largely exposed to air and its surface is smoother; besides, due to the circular irregularity, the heat transfer outside the circle border is poorer. In passive proton exchange membrane fuel cell, the free diffusion way in cathode side makes the membrane which locates near the cathode has better heat dissipation performance. When considering radiation and natural convection at the same time, the temperature gradually decreased from the catalytic layer to the proton exchange membrane area and gas diffusion layer.

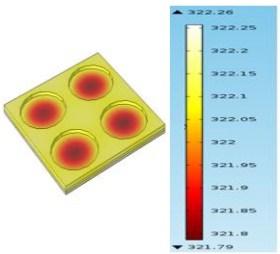

Fig. 6: Outside temperature is 273K

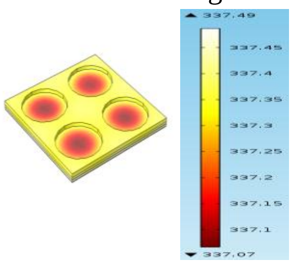

Fig. 7: Outside temperature is 293K

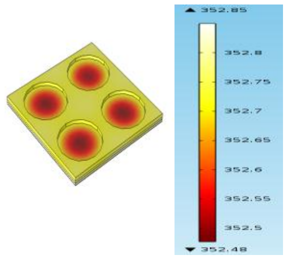

Fig. 8: Outside temperature is 313K

As can be seen from the Fig. 6 is that under the air natural cooling of PEMFC, the surrounding temperature is 273K, the temperature inside the battery is 321.79 ~ 322.26K. Fig. 7 is that under the air natural cooling of PEMFC, the surrounding temperature is 293K, the temperature inside the battery is 337.07 ~ 347.49K. Fig. 8 is that under the air natural cooling of PEMFC, the surrounding temperature is 313K, the temperature inside the battery is 352.48 ~ 352.85K. The reason is that with the increase of ambient temperature, the catalytic activity of catalysts which locate in the catalytic layer of both cathode and anode side will also increase, and the increment will also speed up the electrochemical reaction velocity, in addition, the rise in the temperature of the battery will partly increase the reaction diffusion rate of hydrogen and oxygen, therefore accelerate the electrochemical reaction rate. Simultaneously, because of the rise of the external environment temperature, it transfers less heat with the battery, hence the battery temperature will increase.

5. Conclusions

Since people has a weak understanding of how the battery internal heat and mass transfer influence its performance, as long as the disadvantages of the long-term period of the experiment and the expensive material goods, so numerical simulations about internal heat and mass transfer of the passive proton exchange membrane fuel cell have important theoretical significance and engineering application value. This paper mainly studies on how parameters influence the performance of the battery under the condition of air natural cooling. The rise of battery temperature is helpful to improve the performance of the battery, however, when temperature exceeds the appropriate working temperature range, the battery will suffer damage.

With the increase of discharge time, the amount of hydrogen which infiltrate into the cathode will increase gradually, under the function of the cathode oxygen, more hydrogen will join in the chemical reaction, thus produce a lot of heat, the accumulated heat will rise the battery temperature gradually. As the electrochemical reaction goes, heat diffuses into the ambient environment under the condition of natural convection. Changes of environmental temperature have great influence on the battery temperature ,so we need to control factors of ambient temperature, cooling the battery to its best working temperature range and to achieve the best performance.

6. Acknowledgements

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7. References

[1] Kamaruzzaman Sopian, Wan Ramli `JVan Daud. Challenges and Future Developments in Proton Exchange Membrane Fuel Cells. *Renewable Energy* ,2006.

[2] Xiaochen Yu, Biao Zhou. Water and thermal management for Ballard PEM fuel cell stack. *Journal of Power Sources*, 2005.

[3] Yahia Lasbet, Bruno Auvity. A chao"ic heat-exchanger for PEMFC cooling applications. *Journal of Power Sources*, 2005.

[4] DJILALI N, LU D M. Influence of hea: transfer on gas and water transport fuel cells. *Inter J Therm Sci*, 2002.

[5] FulIer T F, Newman J. Water and thermal management in solid polymer electrolyte fuel cells. *J Electrochem Soc*, 1993.

[6] Eikerliug M., Kharkats Y., Komyshev A.A., et al, Phenomenological theory of electroosmotic effect and water management in polymer electrolyte proton-conducting membranes [J]. *Electrochemical Society*, 1998.