Temperature characteristics of 5KW air cooled proton exchange membrane fuel cell

Shimei Sun[1, a *], Xinyu Zhang[2,b] andLei Feng[3,c]

1Jilin Jianzhu University, Changchun,China

2 Jilin Jianzhu University, Changchun,China

3 Jilin Normal University, Changchun,China

[a]sunshir@163.com, [b]278338162@qq.com, [c]1009562702@qq.com

* please mark the corresponding author with an asterisk

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Abstract. The thesis studies the temperature characteristics of 5kW air natural convectional type proton exchange membrane fuel cell. The three-dimensional mathematical model of the proton exchange membrane fuel cell system is established. Using COMSOL software multiphysics simulation modeling, from the aspect of air natural convection, heat and mass transfer coupling, with natural air cooling characteristics, it gets the numerical solution. The solution is that the battery temperature rises rapidly when the pressure drops. It will reduce the battery performance. Therefore, it is necessary to reasonably control the pressure of air cooling type battery and the temperature range. It has important significance to proton exchange membrane fuel cell efficient thermal management system .

Introduction

Proton exchange membrane fuel cell, as a new type of energy saving energy, is widely used in various fields. Proton exchange membrane fuel cell can be started quickly, and can be operated at room temperature and atmospheric pressure, and the power density is high. At the same time, it can be used as a portable power source for power from 1W to 100W. When the proton exchange membrane fuel cell works, the energy conversion efficiency can reach 40% ~ 60%, and a large amount of heat is accompanied. In order to stabilize the high efficiency and stability of the proton exchange membrane fuel cell, the temperature of the internal electrochemical reaction should be maintained at 95 ~ 70$^{\circ}C$, and can be stable at around 80$^{\circ}C$. According to the cooling ways, proton exchange membrane fuel cell can be divided into two types which are air cooling and circulating water cooling. Besides the common advantages of water cooling, air cooling has the advantages of simple structure, low energy consumption and low working temperature. In the research and application of the power supply of small power equipment, it has a good market prospect.

This paper studies 3D numerical simulation on air natural convection type 5kW proton exchange membrane fuel cell. In order to improve the air natural convection type proton exchange membrane fuel cell's performance and to understand internal coupling phenomenon, a three-dimensional mathematical model is established. Based on the finite element method and partial differential equation method, it solves the model and gets the effect distribution characteristics of natural convection of air on the battery temperature.

Working principle 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.

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. 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:

$$2H_2 \rightarrow 4H^+ + 4e^- \tag{1}$$

Cathode:

$$O_2 + 4e^- + 4H^+ \rightarrow 2H_2O \tag{2}$$

Total response:

$$2H_2 + O_2 \rightarrow 2H_2O \tag{3}$$

Air-cooled proton exchange membrane fuel cell

Air natural convection type proton exchange membrane fuel cell (PEMFC) is a new structural fuel cell for miniaturization requires without air compressor and humidifier. It can effectively reduce the volume of the battery. There are many factors that affect the overall performance of the air natural convection type proton exchange membrane fuel cell, which is closely related to the characteristics of flow, heat transfer and mass transfer in the cell. Therefore, to research numerical simulation of the internal transmission phenomenon and to analysis the influencing factors of air natural convection type proton exchange membrane fuel cell performance is important to improve the performance of the battery.

Aimed to the air natural cooling of proton exchange membrane fuel cell temperature performance, a 3D numerical simulation is established to calculate the key parameters in the internal battery. The lack of natural convection of air flow rate is the main reason of causing concentration polarization. Therefore, reasonable design should be helpful to optimize the heat transfer, mass transfer and flow performance of gas, so as to improve the performance of the battery.

Mathematical model

To analysis of the characteristics of the internal temperature distribution characteristics of the battery and to ensure that the battery in a reasonable operating temperature range can achieve purpose of optimizing the battery structure and improving the performance of the battery. To establish the fuel cell mathematical model with mathematical simulation, combined with the characteristics of air natural convection type proton exchange membrane fuel cell, a three-dimensional mathematical model is established, including fluid dynamics and heat and mass transfer conservation equations, electrode kinetics and so on.

Model hypothesis

Before the mathematical model is established, the following basic hypothesis is needed: (1) The internal membrane electrode of proton exchange membrane fuel cell has good humidification. Battery temperature distribution is constant. Battery operates under stable conditions; (2) The reaction gas is ideal gas completely saturated by water. Fluid flow is laminar flow; (3) The reaction gas will not penetrate proton exchange membrane; (4) The water in proton exchange membrane is in the form of soluble, in the electrode is in the form of gas. Liquid water exists in the form of droplets, and can be taken away by the gas flow. There is no affection on the gas in the channel; (5) Diffusion layer, Catalytic layer resistivity and Porosity are Identity each other; (6) The catalyst layer described by the clustering model. Catalyst layer intima phase, solid phase composition and pore have constant ratio. The size of aggregate block and pore is uniform; (7) The gravity effect is negligible.

Continuity equation

Assuming that the gas is in the condition of a continuous medium and low velocity flow, the mass conservation equation is:

$$\nabla g i_1 = Q_1 , \; i_1 = -s_1 \nabla f_1 \tag{4}$$

$$\nabla g i_s = Q_s , \; i_s = -s_s \nabla f_s \tag{5}$$

$$f_1 = phil , \; f_s = phis \tag{6}$$

In the formula: i for the electric current, Q for the heat generated by the battery; s_1 、 s_s for the electrolyte conductivity and the electric conductivity of the electrodes; $phil$ 、 $phis$ for the electrolyte potential and potential; f_s for grounding potential.

Electrochemical polarization (Butler-Volmer) formula

$$i_o = i_1 = nFk_c c_o^* = i_2 = nFk_a c_R^* \tag{7}$$

In the formula: i_1 、 i_2 for the positive and reverse reaction current density of the cathode reaction respectively; k_c 、 k_a for the positive and negative reaction rate constant; c_o^* 、 c_R^* for the concentration of the oxidation state and the reduced state at the electrode surface. When the electrode reaction is in equilibrium, that is $i_1 = i_2$,the external current and the over potential are zero.

$$i_{loc} = i_o \left(\exp\left(\frac{a_a Fh}{R\mathrm{T}} \right) - \exp\left(\frac{-a_c Fh}{R\mathrm{T}} \right) \right) \tag{8}$$

In the formula: i_{loc} for the exchange current density; and a_a 、 a_c for the anode conversion coefficient and the cathode transfer coefficient.

Law of conservation of energy

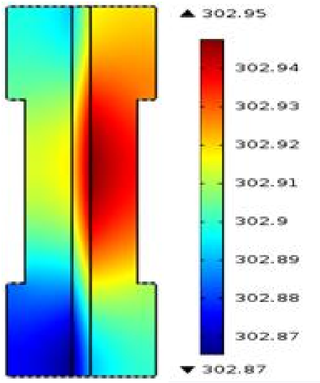
From the first law of thermodynamics, considering the influence of the porosity of porous media, the energy conservation equation can be obtained from the unit control body is as following:

$$r c_p m g \nabla \mathrm{T} = \nabla g (k \nabla \mathrm{T}) + Q \tag{9}$$

In the formula: c_p for the constant pressure specific heat; T for temperature; k for the effective coefficient of heat transfer of fluid; Q for fluid energy source; On the left, the first is not in steady state; On the right, the second is energy source term.The effective heat transfer coefficient can be calculated according to the heat transfer coefficient and the porosity of the porous media. The energy term of the fluid is caused by an irreversible energy loss of the electrochemical reaction.

Simulation results and analysis

In the 3D model from the angle of mass, heat and momentum transfer of considering temperature, the transmission and transformation of water pressure and established 5kW air cooling proton exchange membrane fuel cell mathematical model of heat and mass transfer. The characteristics of the temperature of proton exchange membrane fuel cell by air natural convection are preliminarily established.



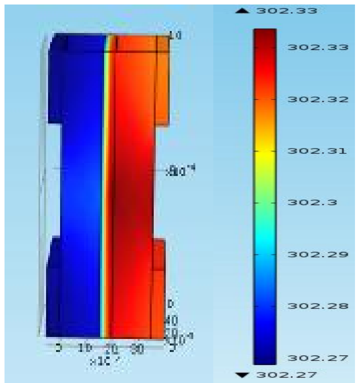
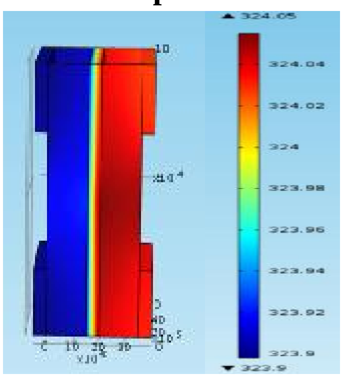


Figure 1. The working voltage of 0.8 V, 5 kw of proton exchange membrane fuel cell temperature is 302.87 K ~ 302.95 K.	Figure 2. The working voltage of 0.8 V, air cooling type 5 kw of proton exchange membrane fuel cell temperature is 302.27 K ~ 302.33 K.

From two groups working temperature contrast diagram, obvious can see join as natural cooling the air temperature is lower than the proton exchange membrane fuel cell under normal working temperature. Reasonable cooling of cooling air was added into the battery to the battery thermal management plays an important role. Temperature distribution and the coupling relationship between the electrochemical reaction characteristics. Temperature and electrochemical properties are inseparable. Temperature is too low, can reduce the activity of catalyst, electrochemical polarization increases.

At the same time, led to the decrease of the cell temperature difference between internal and surrounding environment, it is difficult to keep the cathode natural convection, so that the cathode flow channel air flow is insufficient, lead to the reaction layer of oxygen consumption can not get timely supplement, oxygen partial pressure drop battery performance degradation reaction layer, low temperature can result in electrode materials of resistance increase electrochemical characteristics will also decline. But the temperature is too high and will cause the evaporation of water, causing membrane water shortage, cell electrochemical performance will decline, even unable to work.

Voltage to the temperature of the air cooling type of proton exchange membrane fuel cell.



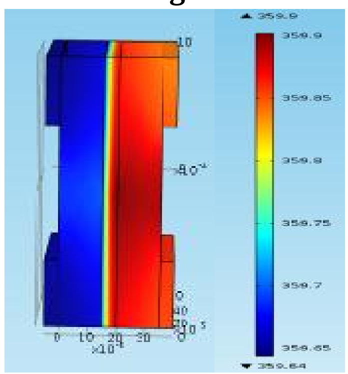


Figure 3 shows the working voltage is 0.6V, the air cooling type 5KW proton exchange membrane fuel cell temperature is 323.90K~324.05K.	Figure 4 shows the working voltage is 0.4V, the air cooling type 5KW proton exchange membrane fuel cell temperature is 359.64K~359.90K.

In the selected two working pressure is 0.6V and 0.4V ,5kW air cooling proton exchange membrane fuel cell temperature maps can be seen when the battery remaining voltage less, the battery temperature is higher and higher, battery release more heat, faced with condition of cell necrosis.

The reason is that with the loss of the battery voltage, battery temperature rising rapidly, when the temperature rise to about 80$^{\circ}C$ ~ 90 $^{\circ}C$, this is because a lower activity of catalysts at low temperature, battery exists obvious activation polarization, and because the proton exchange membrane fuel cell have lower water vapor partial pressure activity in the smaller and proton exchange membrane fuel cell ohmic resistance is bigger. Temperature will reduce the ohm impedance of the proton exchange membrane fuel cell, at the same time reduce activation polarization potential, and thus improve the performance of the battery. At different operating temperatures, however, this improvement is limited by the water vapor pressure of the proton exchange membrane. When the temperature is too high, can make the membrane dehydration, cause membrane performance becomes poor, causing the deterioration of the battery performance, therefore only improve current density increases the amount of water produced by electrochemical reaction to maintain the balance of water. Need as much as possible, ensure that the temperature of the battery on the transverse are distributed temperature difference should not exceed 10$^{\circ}C$, had better not more than 5$^{\circ}C$. Because of uneven local temperature will result in uneven distribution of current density and not making the protons in non-uniform membrane fuel cell moisture, easy to cause the proton exchange membrane fuel cell performance degradation. At the same time, the activity of the electrode is different under different temperature, the activity of the electrode over potential of good or bad depends on the electrode.. Proton exchange membrane fuel mass transfer in fuel cells is also affected by the battery temperature. High battery temperature can increase the evaporation of water in the cathode, which can reduce the partial pressure of oxygen. Moreover, by electroosmosis effect to water will be as the battery cathode increases with the rising of temperature. Therefore, reasonable temperature for the battery thermal balance is very important.

Summary

By numerical simulation method, establish the three-dimensional air natural convection type 5kW proton exchange membrane fuel cell temperature characteristics, it is concluded that if the appropriate to join the cooling system of proton exchange membrane fuel cell, reduce the battery temperature rise caused by the increase of heat; at the same time to the variation of temperature and pressure control of air cooling type battery, in pressure drop when the battery temperature rises rapidly, which will reduce the battery performance. For air cooling type of proton exchange membrane fuel cell temperature control problems, fully improve the battery thermal management requirements, meet the requirements of the stability and dynamics of the system.

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