International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 0995

ANALYSIS OF OPTIMAL HUMIDIFICATION CHARACTERISTICS ABOUT PEMFC

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ABSTRACT

Based on the one-dimensional water transfer model and the lumped parameter model of fuel cell, the relationship between the steady-state output voltage of the fuel cell and the one-dimensional steady-state distribution of multi-state water is constructed in this paper. The optimal humidification strategy of the fuel cell is proposed, which guides the control of the relative humidity of the fuel cell anode and the relative humidity of the cathode and avoids the flooding and dehydration phenomenon inside the fuel cell and realizes the maximize output voltage of the fuel cell.

Keywords: Fuel cell, Humidification, Strategy

NONMENCLATURE

Abbreviations	
PEM	Proton Exchange Membrane
PEMFC	Proton Exchange Membrane Fuel Cell
GC	Gas Channel
GDL	Gas Diffusion Layer
CL	Catalyst Layer
Symbols	
C	Material concentration (mol/m^3)
D	Gas diffusion constant (m^2/s)
F	Faradic constant (96485 C/mol)
H	Thickness (m) or Height (m)
i	Current density (A/m^2)
I	Current (A)
L	Length (m) or Thickness (m)
M	Molecular molar mass (g/mol)
R	Resistance (Ω) or Gas constant (J/(kg·K))
V	Voltage (V)

1. INTRODUCTION

With the increasing of environment pressure, proton exchange membrane fuel cell (PEMFC) is considered as

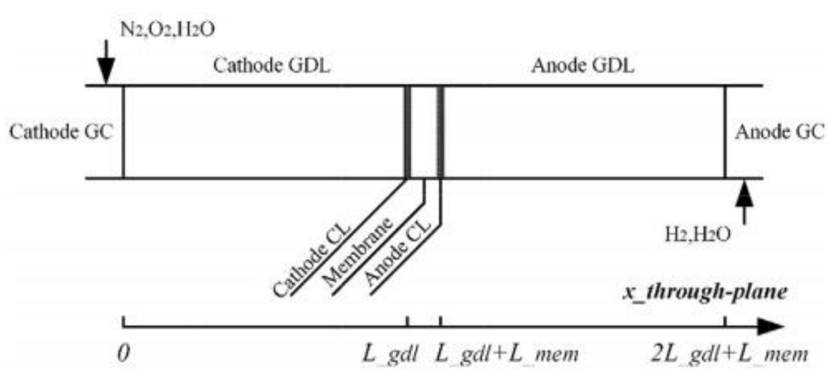

Fig 1 Schematic diagram of the one-dimensional model domains.

the ideal power source for vehicles. Many researches are focus on improving the performance of PEMFC. CY,Wang et al. [1] studied the effect of the hydrophobicity of GDL on power performance. L,Wang et al. [2] studied the effect of operating temperature, anode/cathode humidification temperature, and operating pressure on FC's power performance. Jung S. Yi et al. [3] studied the effect of convective flow by differential pressure in the membrane and the effect of humidification designs on the performance of a PEM fuel cell. As we all know, the most important thing about fuel cells is water management issues. Both dehydration and flooding can adversely affect the performance of fuel cells. At a constant current, the water content in the membrane is mainly affected by the relative humidity of the cathode and anode inlets. So, it is particular important to control the relative humidity of the cathode and anode to maximize the output voltage of the fuel cell. Based on the mechanism model of one-dimensional water transfer, this paper establishes the relationship between the monolithic output voltage and the relative humidity of the cathode and anode and gives the optimal humidification map to guide the humidification of the fuel cell.

2. ONE-DIMENSIONAL WATER TRANSFER MODEL

The water management problem of fuel cells is the key to solving fuel cell performance improvement and durability optimization. To describe the distribution of water content along the proton conduction direction, a mechanism model of one-dimensional water transfer is established. The fuel cell can be divided into 7 regions according to the component distribution along the proton conduction direction, namely cathode GC, cathode GDL, cathode CL, PEM, anode CL, anode GDL, anode GC, as shown in Fig 1 shown. In the pores of the gas diffusion layer, the liquid water is driven by the capillary force. The water transfer in the proton exchange membrane takes into account the two mechanisms of concentration diffusion and electromigration. The water transfer process between gas channel and gas diffusion layer is dominated by the mass transfer of gaseous water. The water transfer process of the catalyst layer is the most complicated. In order to simplify the model, only the formation and mutual conversion mechanism of the three states in the catalyst layer are considered. JM, Hu et al. [4] have explained the specific formula of the one-dimensional water transfer model in detail, which will not be repeated here.

3. MONOLITHIC VOLTAGE MODEL

The single-cell output voltage is related to the single-cell Nernst voltage and the voltage drop. The single-cell voltage drop is mainly composed of three parts: polarization voltage drop, ohmic voltage drop and concentration voltage drop. The formula is as follows:

$$V_{cell} = V_{Nernst} - V_{ohm\_loss} - V_{Tafel\_loss} - V_{mass\_loss} \qquad \text{Equation 1}$$

where V_{Nernst} is single Nernst voltage, V_{ohm_loss} is ohmic voltage drop, V_{Tafel_loss} is polarization voltage drop, V_{mass_loss} is concentration voltage drop.

3.1 Ohmic Voltage Drop Model

Based on Ohm's Law, the model of ohmic voltage drop can be obtained.

$$V_{ohm\_loss} = i_{fc} \bullet R_{dc} \qquad \text{Equation 2}$$

where R_{dc} is DC impedance which has the relationship with the ohmic resistance of proton exchange membrane and cathode catalyst layer.

3.2 Polarization Voltage Drop Model

The polarization loss voltage drop here is also the charge transfer overpotential, which is theoretically determined by the exchange current density. The polarization loss voltage drop model in this paper is required to describe the effect of liquid water saturation of the cathode catalyst layer on the polarization loss voltage drop. The accumulation of liquid water in the cathode catalyst layer results in a decrease in the effective reaction area, and an increase in the current density of the actual reaction increases the polarization loss.

$$V_{Tafel\_loss} = \frac{RT_{fc}}{\alpha_c F} \ln\left(\frac{s_{stop}}{s_{stop} - s_{ccl}} \bullet \frac{i_{fc}}{ai_0^{ref}} \right) \qquad \text{Equation 3}$$

where s_{ccl} is cathode catalyst layer liquid water saturation, which can be obtained from one-dimensional water transfer model. s_{stop} is liquid water saturation when the fuel cell is stopped due to flooding. ai_0^{ref} is exchange current density.

3.3 Concentration Voltage Drop Model

The concentration loss voltage drop is also the concentration overpotential, determined by the concentration of the reactant gas on the surface of the electrode. For fuel cells, the voltage drop due to concentration loss is determined by the oxygen concentration of the catalyst layer.

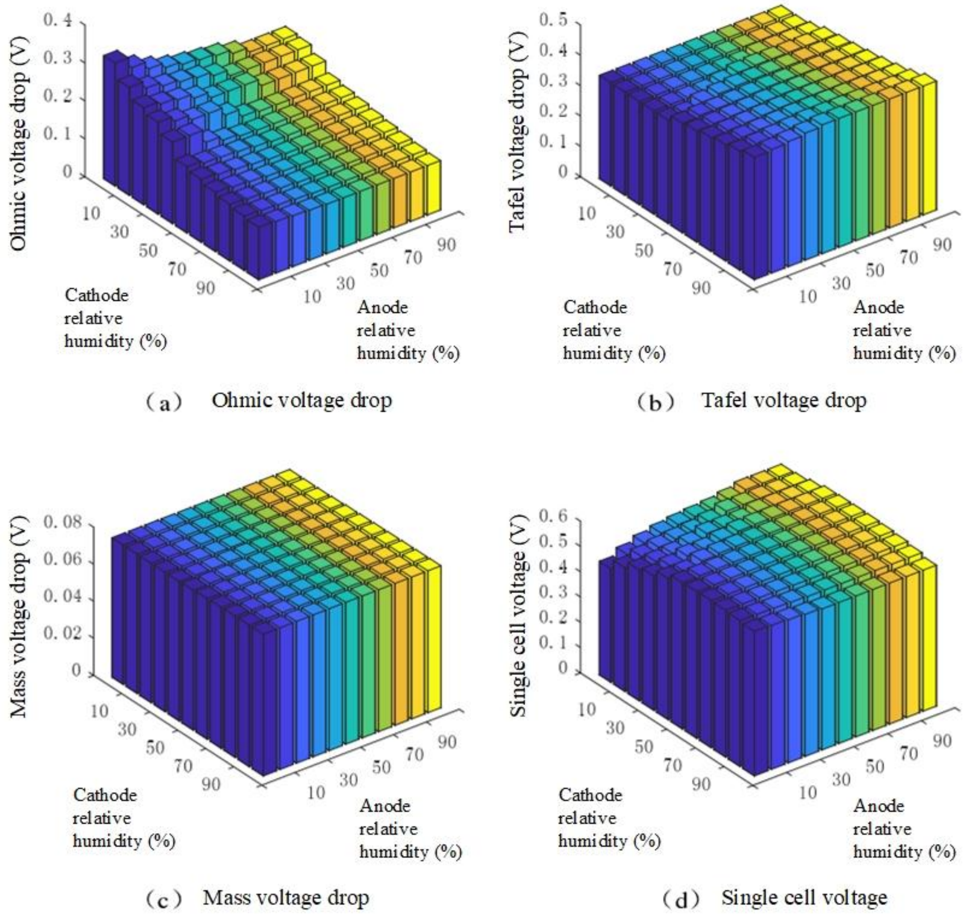

Fig 2 Voltage drop and monolithic output voltage distribution in the humidification condition – current density is 1000mA/cm^2

$$\begin{cases} V_{mass\_loss} = \dfrac{RT_{fc}}{\alpha_c F} \ln\left(\dfrac{C_{O_2}^{ref}}{C_{O_2,ccl}}\right) \\ C_{O_2,channel} = \dfrac{1}{V_{g,out}}\left(V_{g,in} C_{O_2,\text{supply}} - \dfrac{i_{fc}}{4F}\dfrac{L_{ch}}{H_{ch}}\right) \\ C_{O_2,ccl} = C_{O_2,channel} - \dfrac{i_{fc}}{4F}\dfrac{1}{h_{O_2}} - \dfrac{i_{fc}}{4F}\dfrac{L_{gdl}}{D_{O_2}\varepsilon_{gdl}^{1.5}} \end{cases} \quad \text{Equation 4}$$

where $C_{O2,ccl}$ is oxygen concentration in the cathode catalyst layer, $C_{O2,supply}$ is oxygen concentration at the cathode inlet, $C_{O2,channel}$ is oxygen concentration in the cathode channel, D_{O2} is oxygen diffusion coefficient.

The distribution results of the multi-state water are input into the voltage drop model to obtain an ohmic voltage drop, a polarization loss voltage drop, a concentration loss voltage drop, and a monolithic output voltage in different humidification modes (Fig). As can be seen from the figure, when relative humidity of the cathode and anode is low, the ohmic voltage drop is high, because the proton exchange membrane is dry, and the dc resistance is large. When relative humidity of the inlet increases, the proton exchange membrane becomes wet, dc resistance decreases, and the ohmic voltage drop decreases. It is fit for common sense. When the inlet humidity of the anode is higher than 50%, liquid water appears in the fuel cell, the reaction area decreases, and the exchange current density increases, which lead to the polarization voltage drop starts to increase. The

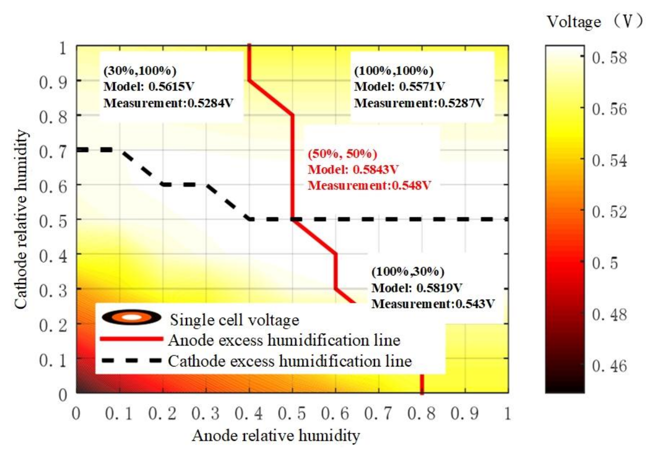

Fig 3 The single output voltage in the whole humidification plane

concentration voltage drop varies little because oxygen is sufficient.

The optimization of humidification parameters for the purpose of maximizing the output voltage of the fuel cell needs to consider the comprehensive influence of water at different locations and different states on three voltage drops. The distribution of ohmic voltage drop, polarization loss voltage drop, concentration loss voltage drop and monolithic output voltage in the whole humidification condition plane can be obtained based on the multi-state water one-dimensional steady-state distribution numerical solution method and monolithic voltage model.

4. ANALYSIS OF THE WHOLE HUMIDIFICATION PLANE

For the simulation, its operating temperature is 70℃. At the beginning, the fuel cell system is supplied with hydrogen at 0% relative humidity for a stoichiometry value of 1.5 as well as air at 0% relative humidity for a stoichiometry value of 2. The anode humidity is fixed to a specific value and the cathode relative humidity is increased gradually. The average single cell voltage needs to be recorded with cathode humidity rising, then increase the anode relative humidity and repeat the previous steps. Finally, the single output voltage in the whole humidification plane can be obtained.

Under the condition that the relative humidity of the anode is fixed, the output curve of the fuel cell monolithic output with the relative humidity of the cathode basically shows a trend of increasing first and then decreasing, basically in the case of medium cathode relative humidity, the output voltage reaches its maximum value. Fig 3 shows the distribution of the fuel cell monolithic output voltage over the entire range of gas supply humidification. The color is deep and shallow, representing the monolithic output voltage of the fuel cell from low to high. The ideal inlet humidity is the cathode and anode inlet humidity corresponding to the maximum output voltage. Fig 2 shows the optimal cathode and anode inlet humidity at current density from 100mA/cm2 to 1000mA/cm2 for each current density. With the increase of current density, the maximum output voltage corresponding to each current density decreases monotonically, and the corresponding anode humidity also decreases continuously. The red line in Fig 2 is the optimal humidification path. When humidifying the fuel cell stack, the inlet humidity should be as close to the red line as possible to obtain the maximum output voltage which means the performance of the stack is best without flooding and membrane dehydration.

The model-based fuel cell supply humidification parameter optimization method is ultimately to give a MAP optimized for humidification parameters as shown in Fig 2.

5. CONCLUSION

In this paper, the maximum output voltage of fuel cell is the target, and the one-dimensional steady-state distribution of multi-state water is combined with the voltage model. A model-based optimization method of intake humidification parameters is proposed. The core of the method is to give a humidification parameter optimization MAP that can be used to guide the optimization of intake humidification parameters. Meanwhile, in order to obtain the maximum output voltage, the working point of the humidification parameter should be as close to or on the humidification optimization path as possible as the humidification capacity allows. On the one hand, the humidification parameter optimization MAP and the model-based humidification parameter optimization method proposed in this paper can avoid the working conditions of poor humidification; on the other hand, they also point out the direction for the current humidification optimization. Optimization MAP of humidification parameters is of great significance to realize real-time optimization control of humidity.

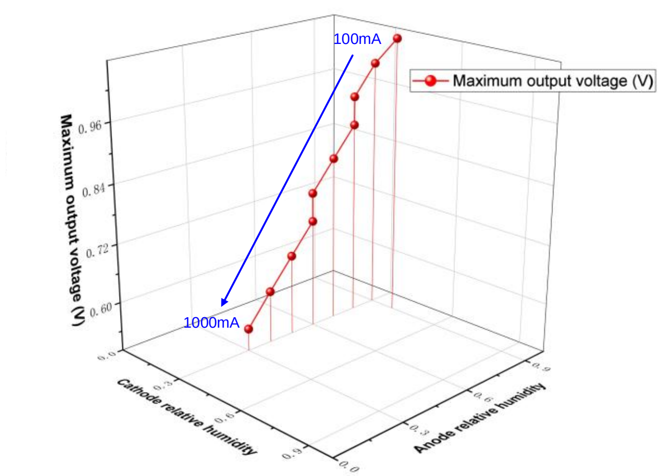

Fig 2 Maximum output voltage at different current density from 100mA/cm^2 to 1000mA/cm^2

ACKNOWLEDGEMENT

This work is supported by National Natural Science Foundation of China (Nos. 51576113 and U1564209), Beijing Municipal Science & Technology Commission (No. Z181100004518004 and D171100007517002).

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