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Rapid response control of humidity for a polymer electrolyte membrane fuel cell test system

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ABSTRACT

Rapid humidity regulation is key to maintaining good fuel cell performance, so the design of a suitable humidification system and control strategy is important for the polymer electrolyte membrane fuel cell test system. In this study, a humidification system with dry and wet gas mixing is proposed, and PID control is used to track a predetermined relative humidity set point. The results show that the humidity can be quickly and precisely controlled and adjusted by dry and wet gas distribution control, and that the change in wet gas inlet flow is consistent with the actual change in relative humidity.

Keywords: fuel cell, humidification system, humidity regulation, control strategy

NONMENCLATURE

1. INTRODUCTION

Proton exchange membrane fuel cells (PEMFC) are an important type of technology to efficiently utilize hydrogen energy[1]. The fuel cell test system, as an essential equipment in the process of fuel cell common technology research, stack design and development, verification and iterative optimization, and commercial product performance testing and evaluation, plays a huge role in promoting the development of fuel cells.

The humidification module is an important auxiliary system that affects the performance and durability of the fuel cell system. In order to improve the proton conductivity of the cell proton exchange membrane, the membrane needs to maintain a sufficient level of hydration to conduct protons efficiently. Low or no wetting operations can accelerate the membrane degradation process. However, too much water may in turn impede the transport of reactants and affect the system output performance. Therefore, the humidity of air and hydrogen should be precisely controlled before entering the fuel cell stack, and the design of a suitable humidification system and control strategy is important for the widespread use of fuel cells.[2-3]

To date, the main humidification methods used in fuel cell systems are membrane humidification, gas bubble humidification, and spray humidification. Dry gas humidification in membrane humidifiers uses wet gas or liquid water for humidification. It uses a membrane to separate the wet side from the dry side. The water vapour diffuses through the membrane into the dry gas to complete the humidification. In a bubbling humidifier, the reaction gas stream enters a vessel filled with hot water via a distribution tube. The gas is dispersed into many small bubbles, which then exit the water to complete the humidification. A spray humidifier is a humidification device in which water in liquid or vapour form is injected directly into the fuel cell inlet, with liquid water being used more often as the injection of vapour requires heating to generate steam[4]. Membrane humidification is typically used for portable or vehicle-mounted applications, helping to reduce the weight and space of the system. For high power fuel cell test systems, where space is not strictly limited but there is a higher power requirement for humidification, gas bubble or spray humidification is more appropriate. Bubble humidifiers are well suited to power plants or test systems, providing sufficient humidification even under emergency shutdown operating conditions, but with significant humidification

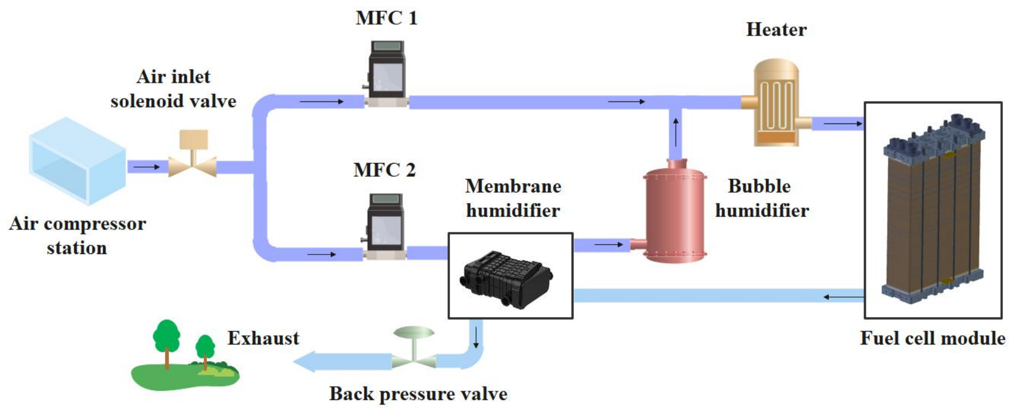

Fig. 1 Sketch of a dry and wet air mixing humidification system

hysteresis when system conditions change[5]. The disadvantage of humidifying the reactant by spraying is that when a higher amount of water is injected, water droplets may enter the single cell directly and eventually settle on the gas diffusion layer (GDL), thus impeding the transport of the reactant gas and affecting the output performance of the fuel cell. The humidifier in this study therefore uses a combination module of a bulb humidifier and a membrane humidifier.

For high-power test systems, the following main problems currently exist: 1) The achievable humidity range is limited; 2) the amount of water transported exceeds that required for normal operation; 3) High energy requirements for water circulation and high energy requirements for water heating and cooling; 4) Humidity response is slow to respond to changes in the required set point. If the target humidity control is carried out by adjusting the humidifier operating temperature, there will be a large hysteresis in the temperature control response, which cannot meet the rapid response requirements of humidification[6-7].

In response to the slow response of the current humidification system, this paper proposes a dry and wet gas mixing humidification system and uses PID control to track the predetermined relative humidity set point, discussing the proportional change of the air inlet dry and wet gas and the feasibility of the method.

2. MATERIAL AND METHODS

2.1 System layout

This study presents a novel air humidification module system that allows rapid regulation of the relative humidity of the inlet gas to the power stack by proportional adjustment of the wet and dry gases. As shown in Figure 1, the air humidification system, whose piping is shown in blue, consists of an air compressor station, an inlet solenoid valve, a mass flow controller, a bubble humidifier, a membrane humidifier, a heater and a back pressure valve. The ambient air is compressed at the compressor station and then enters the test system. The incoming air is first divided into two air streams, a dry air stream and a wet air stream, with the incoming air volume controlled by the MFC. The wet gas stream is first humidified by a membrane humidifier, then by a bubble humidifier for deep humidification, where the outlet humidity can be above 80%. The humidified gas and the dry gas then enter a heater for heating and mixing to meet the humidification requirements of the fuel cell, where the heater temperature is equal to the operating temperature of the stack. After the mixed gas has passed through the electric stack, the resulting tail gas flows through the membrane humidifier for the comprehensive use of heat and water and gas and is then directly discharged into the atmosphere, where the inlet pressure of the electric stack can be regulated by the back pressure valve of the tail gas.

2.2 Empirical model

The relationship between the outlet gas relative humidity(RH) and the inlet gas flow rate can be obtained through a joint experimental test of the bubble humidifier and membrane humidification gas, as shown in Figure 2. The outlet relative humidity of the humidification system decreases with the increase of the inlet gas flow rate, but the outlet relative humidity is maintained above 85%. When the bubble humidifier temperature, heater temperature and stack module operating temperature remain consistent, the fuel cell inlet gas humidity RH can be expressed as：

$$RH=\frac{Qd}{Qw+Qd}RH_{hum} \quad (1)$$

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where *Qd* is the dry gas, *Qw* is the wet gas and RH_{hum} is the relative humidity of the wet gas after it has passed through the humidifiers.

Equation (1) shows that, ideally, the target humidity of the stack inlet can be controlled by adjusting the ratio of the inlet dry and wet gas inlet, provided that the total amount of inlet gas remains unchanged, and since the gas flow rate can be adjusted quickly, this method enables fast response control of humidity.

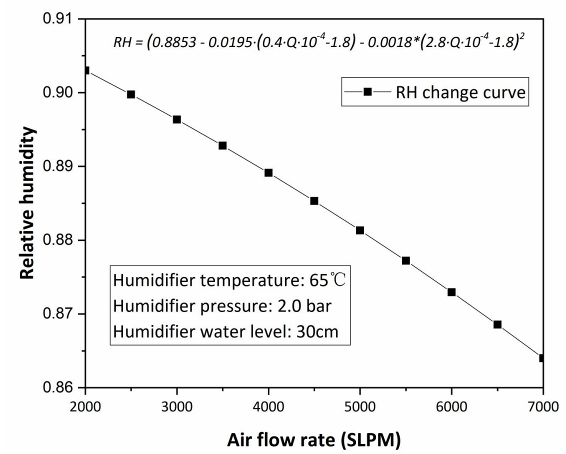

Fig. 2 The relationship between the outlet gas relative humidity(RH) and the inlet gas flow rate.

2.3 Humidity control

In this study we have chosen the mass flow rate of air （Q) through the humidifier as the manipulation variable and the relative humidity of the mixed stream at the outlet as the control variable. The total gas flow rate and relative humidity required at different fuel cell operating points are also specified in order to control the relative humidity and the mass flow rate of the gas at the desired level. A proportional-integral derivative (PID) controller is used for feedback control of the humidity of the humidification system. The feedback adjustment process for humidity is shown in Figure 3. First the RH at the humidifier outlet and at the stack inlet is measured using humidity sensors 1-3. Then the deviation of the RH at the stack inlet from the set point is calculated. Finally the deviation of the RH value is passed on to the controller as an error value e for a suitable control action, which in turn determines the inlet flow of wet and dry air. At the same time the controller can also operate the bubble humidifier for water replenishment according to the RH1 and RH2 at the humidifier outlet.

3. RESULTS AND DISCUSSION

In this study, a humidity operating spectrum was selected and tracked based on actual fuel cell operating requirements. A variation in humidity from 20%-80% over a range of 2 cycles was simulated and provides information on the controller's response to a sharp change in RH set point, where the total inlet air flow is fixed at 7000 SLPM.

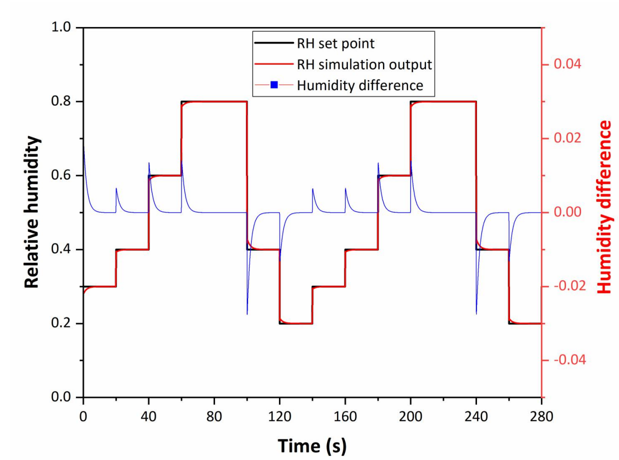

Fig. 4 RH tracking of humidity operating spectrum and deviation

Figure 4 shows the ability of the system controller to track the RH set-point when the fuel cell inlet RH is required. The graph shows that the RH output as a whole is tracked with a high degree of accuracy and without any oscillations. This control method achieves fast and accurate control of the fuel cell inlet humidity. It can also be seen that the deviation between the RH set-point and the output is small and that the peaks in deviation are caused by a mismatch between the RH set-point and the measurement. When the RH needs to be changed, the deviation increases accordingly, and at

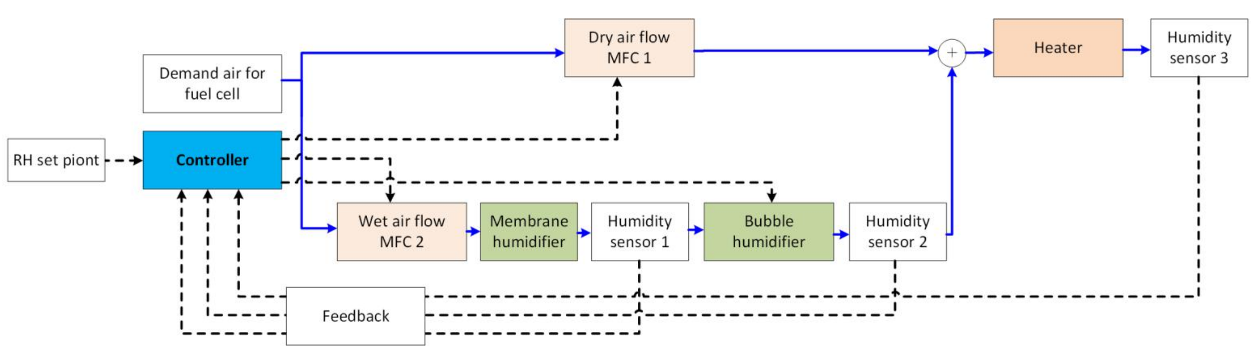

Fig. 3. Schematic of the closed loop control

the same time the larger the RH change, the larger the deviation peak. As RH gradually reaches a steady state value, they decrease and converge to 0.

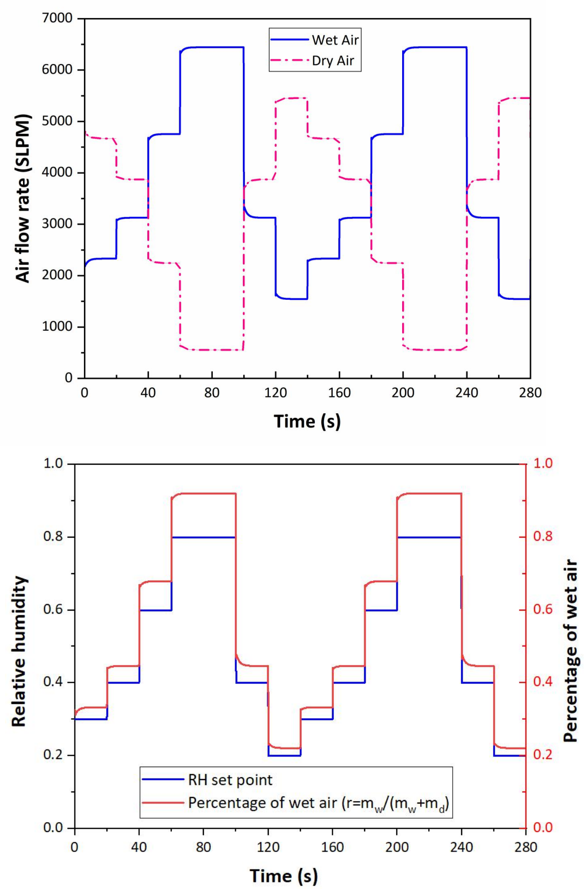

Fig. 5 The change curve of the flow rates of wet and dry air in the humidification system and their ratios

Figure 5 shows the flow rates of wet and dry air in the humidification system and their ratios in order to achieve the desired RH set point in Figure 4. As can be seen from the graph, the trend of the moisture change is essentially the same as the change in RH, with some small fluctuations in the flow rate as RH changes. Thus it can be demonstrated that the wet and dry gas mixing method can achieve rapid adjustment of the fuel cell inlet gas humidity. It is also noted that the percentage of wet air flow is somewhat higher compared to the RH target setting, this is because according to the experimental results in Figure 2, the RH of the outlet gas is lower than 100% after the wet air flow passes through the humidifier, therefore in order to achieve the RH target value, the percentage of wet air in the air intake has to be higher than the RH setting overall.

4. CONCLUSIONS

In this study, a humidification system with a mixture of dry and wet gas is proposed and a PID control method is applied to track a predetermined relative humidity set point. The conclusions are as follows.

(1) The system can use fuel cell exhaust gas to preheat and humidify the inlet air, reducing external energy consumption and improving the system energy utilization.

(2) The use of mixed wet and dry gas humidification regulation enables fast and accurate control of fuel cell inlet gas humidity. the RH output as a whole is tracked with a high degree of accuracy and without any oscillations.

(3) The trend of the wet gas inlet flow changes in general in line with the changes in RH, and the inlet percentage of the wet gas flow is high compared to the RH target setting.

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