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Experimental Study on the Mutual Humidification System of PEM fuel cell and AEM fuel cell

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ABSTRACT

A method of mutual humidification strategy is explored in this study making the best use of water production characteristics of proton exchange membrane fuel cell (PEMFC) and anion exchange membrane fuel cell (AEMFC). And the results show that in the relatively dry outside humidification condition, the performance of PEMFC can be elevated in various extends. Technically, in the various extents of load, the performance changes show stable and consistent trend. With the electrochemical test measures, the principles of mutual humidification are investigated.

Keywords: self-humidification, PEMFC, AEMFC

1. INTRODUCTION

Consuming the oxygen and hydrogen, the PEMFC and AEMFC enjoy the advantages of high efficiency, environment friendly characteristic and wide application object therefor more attention is paid to them [1,2].

The PEMFC and AEMFC have many similarities and obvious differences. The structures of them can be alike as the sandwich construction containing the end plate (EP), bi-polar plate (BPP) and membrane electrode assembly (MEA) [3,4]. And the differences lie in the MEA and the mechanism of reaction process. Firstly PEMFC adopts the proton exchange membrane and electrolyte for proton transportation, while they are anion exchange membrane and alkaline electrolyte in AEMFC. Secondly thanks to the distinct cores of two kinds of fuel cell, the electrochemical process in the catalyst layer and the mass transport inside the membrane are different as a result, where the water is produced in the cathode of PEMFC and in anode of AEMFC [5,6].

From the aspect of water management of fuel cell, it is a double-edged sword in PEMFC, for the good side, it can wet the membrane decreasing the Ohm resistance and diffuse to the anode assisting the hydration of ion [7]. For the bad side the overwhelming water causing flooding could hinder the mass transfer of oxygen [8]. Under low humidification, the water diffusion by the concentration difference in the anode and cathode may also cripple the movement of proton ion [9,10]. And for the AEMFC, it is still vital for the water is a necessary reactant in the cathode [11,12].

Technically, the humidity control matters both in the academic perspective and engineering application [13]. Some scholars put emphasis on the self-humidification manners and endeavor from the membrane [14], gas circulation [15] and composition of cell [16].

Thanks to the characteristic of water production of AEMFC, where the water is produced in the anode side, the drawback of lacking water under low outside humidification condition can be reduced by the parallel connection measures making full use of the water production characteristics no matter what PEMFC or AEMFC. The counter flow measure ensures the relatively dry inlet gas of anode (hydrogen) passes through AEMFC firstly carrying the water produced and forming the moist airflow to the PEMFC. Vice versa, the oxygen goes through the PEMFC and then the gas gets wetted. So the main function for mutual humidification fuel cell system by parallel connection is to humidify the anode inlet gas by the water from AEMFC, offsetting the water transport from cathode to anode in PEMFC and therefore improve performance as showed in the fig 1.

In this work, the experiment of mutual humidification system by parallel connection is conducted under the dry inlet gas condition of 20%

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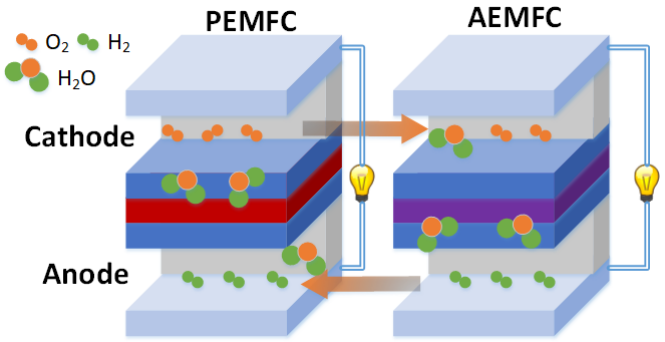

Fig 1 Principle of fuel cell reaction and mutual humidification system by parallel connection

outside relative humidity and practicability is confirmed. Besides the electrochemical impedance spectrum (EIS) is studied to investigate the principles of mutual humidification system.

2. EXPERIMENT

2.1 AEMFC preparation

Fumapem-FAA-3-50, a commercial alkaline membrane produced by Fuma-tech GmbH Company, is used to fabricate the AEMFC's MEA. The AEMFC in this paper is single cell adopting homemade CCM to fabricate MEA with active area of 25 cm^2. The catalyst ink including 60% Pt/C, electrolyte ionomer of FAA-3-SOLUT-10 and Isopropyl alcohol, all of which are in proportionate ration, will be under supersonic bath for 50 minutes with temperature under 30 degrees Celsius. In the manufacturing process, air-spraying method is used to place the configured ink onto the film of membrane to form CCM at the loading with platinum of 0.5 mg cm^{-2}, which then is put into 1m KOH for 24 h to exchange bromine ions.

2.2 PEMFC preparation

The PEMFC is equipped with commercial MEA from Wuhan WUT New Energy Co., Ltd and tested for mutual humidification after activation. The specific parameter are as follows:

Table 1. Parameters of PEMFC

Parameter	Type	Features
Membrane	Private	15 μm
GDL	Toray-060-MPL	240 μm
Catalyst layer	Pt/C	An:0.1 mg cm^{-2} Ca:0.4 mg cm^{-2}
Active area	/	25*25 mm^2

2.3 Binding strategies and preparation

To realize the function of mutual humidification by parallel connection, it is vital to make sure that air tightness, the system temperature and the insulation of two cells. The connection method between two cells is by the way of epoxy resin applied on their respective inlet and outlet integrating two single cells into one, while the other parts stay unbothered. The measure above can insulate the two cells too, forming a transparent gap between.

Here are the parameters of experiment:

Table 2. Parameters of experiment

Parameter	value	Unit
Temperature	60	℃
Flow filed	Serpentine	/
Relative humidity	20	%

3. RESULTS AND DISCUSSION

Fig 2 (a) shows in the small load of PEMFC, 0.8 A cm^{-2} set, the performance rises at a voltage range of 0.01 V or power range of 0.05 W, 1.54% in all. Correspondingly

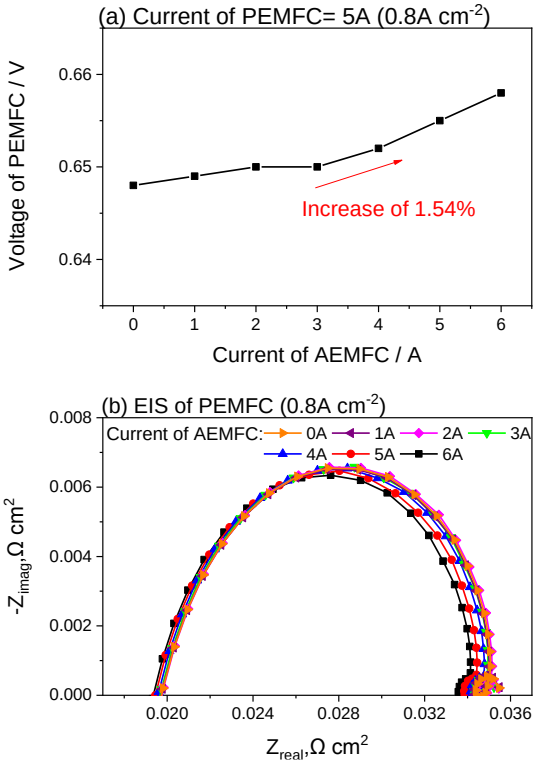

Fig 2 Performance curve (a) and EIS cureves (b) of PEMFC at 0.8 A cm^{-2}.

the EIS curves (b) show the trend of reduction in Ohm resistance in a tiny range. The PEMFC is in small load of less water demand, less water production and less water transmission in the membrane. And the gas inlet of 20% relative humidity can satisfy the most water in need,

where weakness to enhance performance lies in the Ohm resistance of the membrane. Owing to the dry condition, the functional group of membrane is hard to work. In the anode, water needed for the hydration of hydrogen ion is not that eager for the load is small. In such a situation, the membrane not sufficiently hydrated is relieved by the AEMFC humidification function. Therefor the higher ohm resistance in such a dry condition is alleviated by the mutual humidification system.

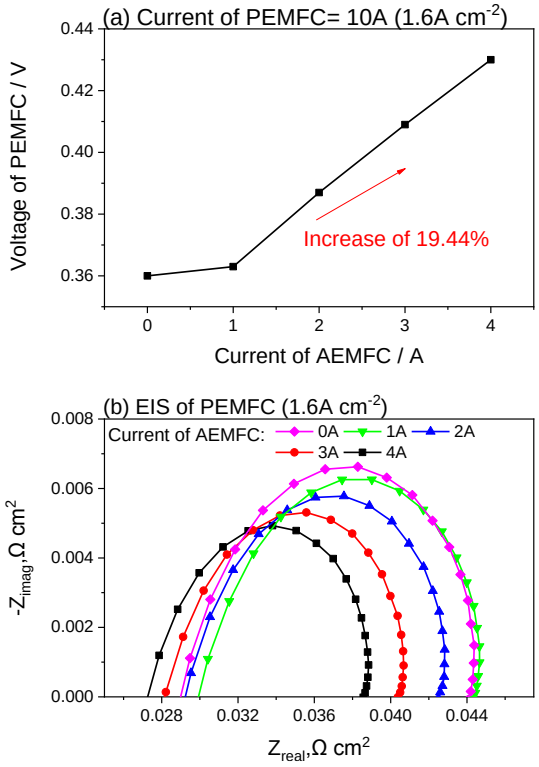

Fig 3 Performance curve (a) and EIS cureves (b) of PEMFC at 1.6 A cm^{-2}.

Fig 3 (b) shows at the middle load of 1.6 A cm^{-2}, the performance of PEMFC shows the better off tendency too, reaching the rate of 0.07 V or 0.7 W in power, 19.44% in all. Besides as the current of AEMFC increases, the performance increase of PEMFC never stops showing strong upward trend. Combing with the EIS test (b), the reason of this can be explained by the favorable change of cathode polarization resistance and the decreasing Ohm loss. Since the load burden increases, for one aspect the water produced in cathode is more than that in 0.8 A cm^{-2} load which can help humidify the membrane. For another aspect more water is needed in the cathode of PEMFC to form triphasic sites. A more moist flow from AEMFC outlet can satisfy the water required in anode and relieve the liquid diffusion from cathode.

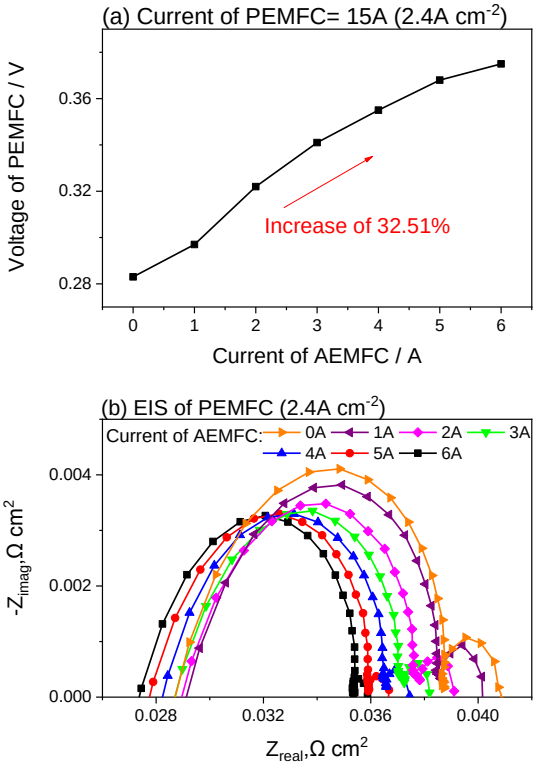

Fig 4 Performance curve (a) and EIS cureves (b) of PEMFC at 2.4 A cm^{-2}.

Fig 4 (a) shows when the load is set as 2.4 A cm^{-2}, the mutual humidification system shows great advantage in humidifying effect and the output of PEMFC is going to increase in a relatively big scale about 0.09 V or 1.4 W in power, 32.51% in total. Due to the tough condition of dry inlet gas and the heavy load, in the EIS curves (b), the concentration resistance part is emerged and weakening gradually, meantime the polarization loss and Ohm loss are relived as AEMFC's load stepping up. In this circumstance the PEMFC nearly works at its extremity when the oxidant is in lack for the triphasic sites is not enough and water produced by the AEMFC increases the water content in anode side of PEMFC. So more water in cathode of PEMFC stays rather than diffused to anode promoting the formation of triphasic sites.

4. CONCLUSION

In this study, a mutual humidification strategy is investigated. Working in the harsh condition of dry inlet gas, the system can offer the performance promotion of 1.54% in 0.8 A cm^{-2}, 19.44% in 1.6 A cm^{-2} and 32.51% in 2.4 A cm^{-2}. From the EIS test, it is easy to conclude that the water produced by AEMFC in the upstream can humidified the membrane of PEMFC, thereby alleviating

the Ohm resistance under these three cases. In the bigger load of 2.4 A cm^{-2}, the elevation is affected by the polarization resistance and concentration loss meantime. The fuel deficient phenomenon doesn't show up in the 2.4 A cm^{-2} case, but conclusively there must exits an optimization between the effect of mutual humidification and fuel usage.

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