Effects of operating parameters on performance of a proton exchange membrane fuel cell

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Abstract

The performance of a proton exchange membrane fuel cell (PEMFC) under various operating conditions was investigated experimentally using dry and humidified hydrogen and oxygen as reactant and oxidant gases, respectively. Experiments have been carried out on a single PEM fuel cell with the active area of $5\,cm^2$. The results showed that the most important factor affecting the performance of PEMFC is the mass transport limitation including the transport of reactant and oxidant gases to active sites of catalyst layer, the transport of the proton from the anode side to the cathode side through the membrane, and the transport of produced water from the cathode side to the anode side by back diffusion mechanism. Operating parameters that examined in this paper i.e. temperatures, pressures, and humidity of reactant gases could decrease these limitations and improve the performance of the fuel cell. Based on these investigations, the optimum conditions are operation at higher pressure and elevated temperature with the humidified reactant gases. Furthermore, pressurized cathode side has better affected on the performance of the PEM fuel cell than pressurized anode side.
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Keywords: Operating parameters; Performance; PEMFC; MEA; Mass transport

1. Introduction

The performance of fuel cells is known to be influenced by different operating conditions such as temperature, pressure, and humidification of the reactant gases. Ferng et al. [1] have investigated analytically and experimentally the performance of proton exchange membrane (PEM) fuel cell. Their model has focused on the cathode compartment of PEMFC. Wang et al. [2] studied experimentally the effects of different operating parameter on the performance of PEMFC using pure hydrogen on the anode side and air on the cathode side. Hyun and Kim [3] studied experimentally the effect of external humidity on fuel cell performance. J.-J. Hwang and H.-S. Hwang [4] investigated a parametric study of a double-cell stack of PEMFC. Mugikura and Asano [5] have compared the performance of several types of fuel cells. Kazim et al. [6] investigated the parameter effects of cathode operating conditions on the performance of PEMFC using mathematical model. The experimental investigations presented in this paper focus on the performance of a PEMFC under various temperature and pressure conditions using dry and humidified hydrogen and oxygen as the fuel and reactant gases, respectively. Experiments have been carried out on a single PEM fuel cell to provide systematic experimental data that may be valuable for the fuel cell developers.

2. Experimental

2.1. Apparatus

A schematic drawing of the experimental apparatus employed in this study is shown in Fig. 1. Pure hydrogen and oxygen were served as the fuel and oxidant gases, respectively. H_2 and O_2 are fed at 150 and 200% the stoichiometric requirements at the maximum current density. Reactant humidification was achieved by temperature-controlled water bottles. The temperature of which was calibrated to yield the quoted relative humidity (RH) values

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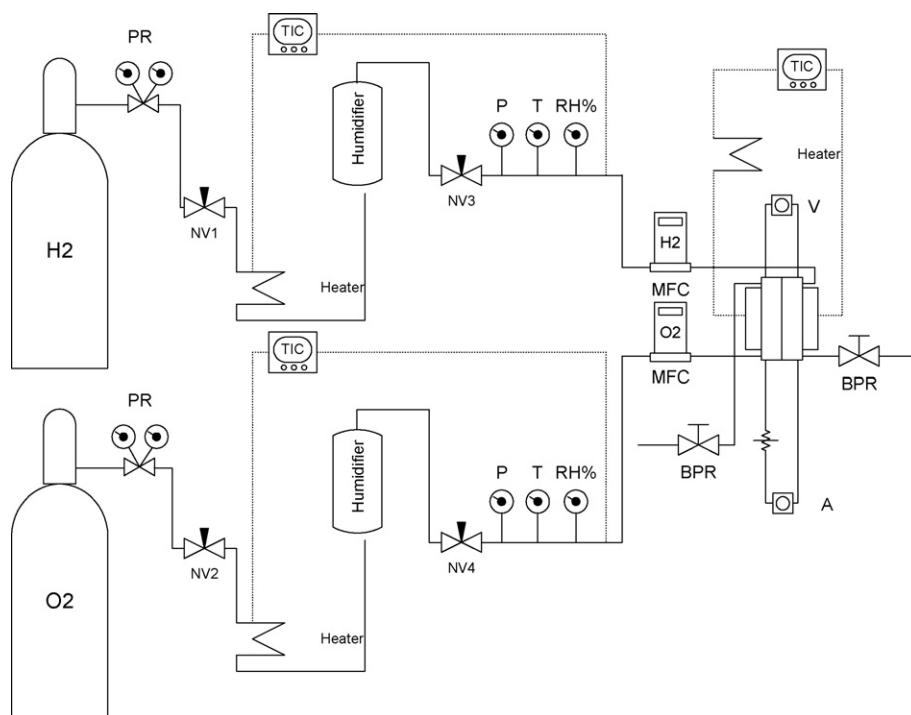
Fig. 1. Schematic representation of experimental apparatus.

and dew points. Fuel and oxidant gases flow rates are controlled using the mass flow controller (MFC, AALBORG, GFC171). The PEM fuel cell was pressurized by a backpressure regulator to given pressure conditions. A single PEM fuel cell (ElectroChem, FC05-01SP) with active surface area of 5 cm^2 was used for all experiments in this study. The temperature of this cell is controlled via a temperature controller (Barnant Company, 8900-15). The gas connection between the gas control system and the fuel cell inlets are well insulated to prevent the water vapor from cooling and condensing on the way to the fuel cell. The membrane electrode assembly (MEA) was prepared in-house by an identical procedure. Cell voltage and current were determined simultaneously using Multimeters at different loads. The polarization curves (voltage versus current density) of the PEMFC were obtained under different operating temperature and pressure conditions.

2.2. MEA fabrication

Before being used in manufacturing MEA, the polymer electrolyte membrane Nafion 117 (ElectroChem Inc., EC-NM-117) was cleaned and treated to ensure that the membrane is completely in the protonic form. The pretreatment procedure involved boiling it in 3 wt.% H_2O_2, for 60 min, followed by boiling for 60 min in deionised water (two times). The membrane boiled for 60 min in 0.5 M H_2SO_4 solution, followed by boiling for 60 min in deionised water (two times). An electrocatalyst (Pt/C 20%) was mechanically mixed for 30 min in isopropanol with loading of 0.4 mg cm^{-2}. Subsequently, PTFE emulsion solution (ElectroChem, EC-TFE 30) about 30 wt.% of the mixed was added to the mixture and stirred by ultrasound (Sounopuls, HD2200). This slurry was coated upon the toray car-

bon paper (ElectroChem, Teflon treated, EC-TP1-060) by using the spray apparatus, and dried for 24 h in air and then, for 60 min in an inert gas (nitrogen 99.99%) at 225 °C. Then, the dried electrodes were pressed by a rolling apparatus, and subjected to sintering for 30 min in an inert gas (nitrogen 99.99%) at 350 °C. Electrodes were impregnated by brushing a Nafion 5% solution (ElectroChem, EC-NS-05) with the loading of 2 mg cm^{-2} onto the electrocatalyst layer. The electrodes were dried in an oven for 60 min at 80 °C. These electrodes and the membrane were hot-pressed together at 140 °C for 3 min and 120 atm to complete MEA.

3. Results and discussion

3.1. Effect of cell operating temperatures

Study on the effect of the fuel cell operating temperature was carried out in humidified and dry inlet gases conditions. Fig. 2 shows voltages versus current densities for changing the fuel cell temperature for four levels from 50 to 80 °C with the externally humidified anode and cathode sides. Humidification temperatures were equal to the cell temperatures. Backpressures were constant in 2 atm. An increase in the cell voltage at the same current density is viewed in this figure, particularly under high current densities. In other words, the performance of the fuel cell is improved under elevated cell operating temperature in humidified inlet gases conditions. The increase of the fuel cell performance with the increase of the cell temperature can be explained by two reasons. First, in the high temperature the diffusivity increases and mass transport resistance decreases and second, the increase in ohmic-ion conductivity of Nafion membrane occurs in elevated temperature. Fig. 3 shows the effect of
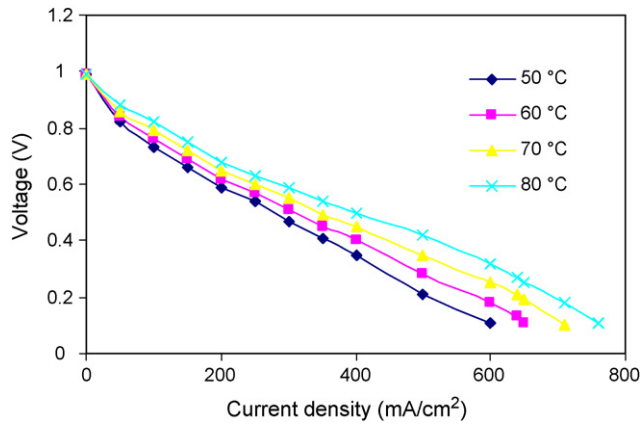
Fig. 2. Voltage vs. current density curves for different operating temperatures from 50 to 80 °C, backpressures are constant in 2 atm, humidified gases are used, and humidification temperatures are equal to the cell temperatures.

three levels of cell temperature from 50 to 70 °C on the fuel cell performance using dry hydrogen/oxygen as fuel/oxidant gases. Backpressures were constant in 2 atm. This figure displays an increase and a decrease in the fuel cell performance in high and low current densities, respectively with increasing the fuel cell operating temperature. In the low current density region, the water produced in the cathode is not sufficient to humidify the anode by back-diffusion mechanism, and higher operating temperature will give more sever membrane dry-out problem. In the high current density, water production rate in the cathode side increases and membrane hydration can be done by back-diffusion mechanism from the cathode to the anode.

3.2. Effect of operating pressures

The effects of fuel cell pressure on PEM fuel cell performance are shown in Figs. 4–6. Fig. 4 illustrates the effect of changing both the anode and the cathode sides operating pressure from 1 to 3 atm. The operating temperature of cell was fixed at 70 °C. Humidified hydrogen and oxygen were used ($T_{dp} = 70$ °C). The higher back-pressure of inlet gases enhances the cell performance. The open circuit voltage was elevated with the increase in the pressure, according to the Nernst equation. The improvement in the cell performance due to the increase of the operating
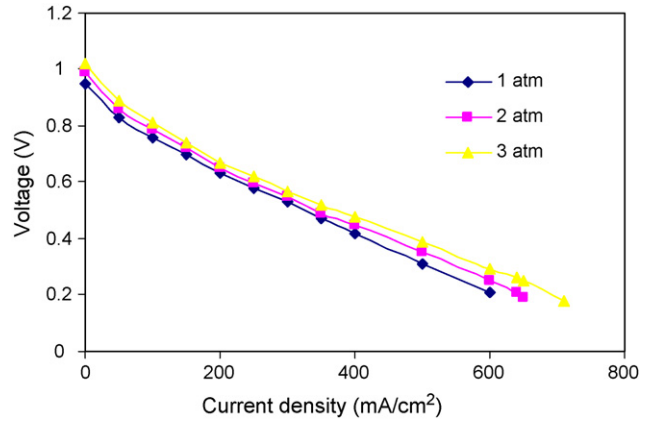

Fig. 4. Voltages vs. current density curves for different operating pressures of the anode and the cathode sides from 1 to 3 atm, humidified gases are used, and cell and humidification temperatures are same and equal to 70 °C.

Fig. 5. Voltages vs. current density curves for pressurized anode and pressurized cathode sides, humidified gases are used, and cell and humidification temperatures are same and equal to 70 °C (left is anode side and right is cathode side).

pressure can be explained by increasing the diffusivity of the reactant gases resulting in decreasing the mass transport resistance problem. The comparison of the effect of the operating pressure of the anode and the cathode sides on fuel cell polar-
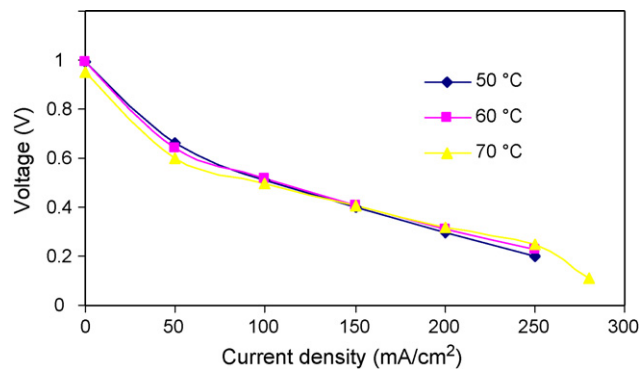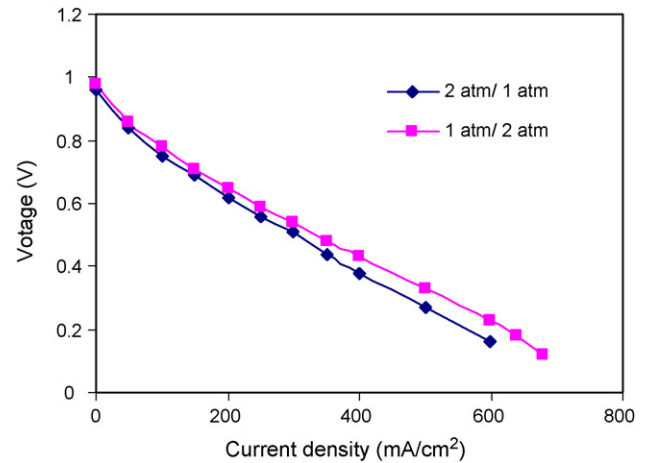

Fig. 3. Voltage vs. current density curves for different operating temperatures from 50 to 70 °C, backpressures are constant in 2 atm, and dry gases are used.
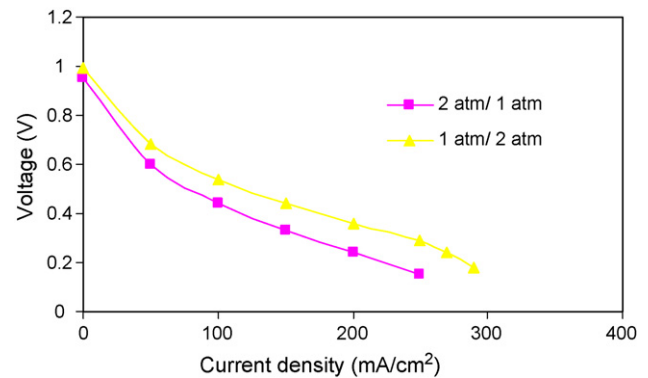

Fig. 6. Voltages vs. current density curves for pressurized anode and pressurized cathode sides, dry gases are used, and cell temperature is 70 °C (left is anode side and right is cathode side).
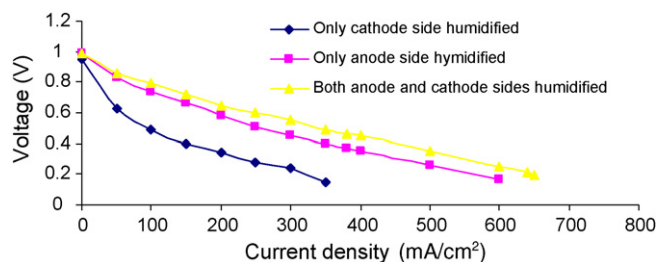
Fig. 7. Voltages vs. current density curves for different humidification of inlet gases, the temperature of cell and back-pressures are constant in 70 °C and 2 atm, respectively. The humidification temperatures are equal to the cell temperature, when humidified hydrogen and/or oxygen are used.

ization curves with dry and humidified gases are presented in Figs. 5 and 6, respectively. It is observed that the effect of the pressurized cathode side on the cell performance is better than for the pressurized anode side. An appreciable improvement in the fuel cell performance due to pressurized cathode side rather than pressurized anode side is viewed, when dry inlet gases are used. This is especially true in the high current density region. This phenomenon could be explained by water transport across the membrane from the cathode side to the anode side by the back-diffusion mechanism which enhances the hydration level of the membrane. At the higher current densities, water generation rate is high and the pressure gradient across the membrane from the cathode side to the anode side, when humidified gases are used, prevents the water holdup problem in the cathode side. Also, pressurized cathode side improves oxygen reduction reaction by an increase in its partial pressure.

3.3. Humidification effects

The effects of humidification of inlet gases on the fuel cell performance have been shown in Fig. 7 that include the humidification of only the cathode (the anode is dry), only the anode (the cathode is dry), and both the anode and the cathode (for comparison). The temperature of cell and the back-pressures are constant in 70 °C and 2 atm, respectively. The humidification temperatures are equal to the cell temperature, when humidified

hydrogen and/or oxygen are used. It is observed that the performance of the cell, not only greatly depends on the humidification of the gases, but the anode humidification has also considerable effect on the fuel cell performance, especially at the lower current densities. This behavior may be explained by the lower ionic conductivity of Nafion membrane in dry condition. The proton must be transferred from the anode side through the membrane to the cathode side and humidified anode side can enhance this operation.

4. Conclusions

In this work, we prepared in-house a PEMFC membrane electrode assembly with an active area of 5 cm^2 by an identified method, and then we investigated the effects of the operating parameters on its performance. The experiments showed that the most important factor affecting the performance of PEMFC is the mass transport limitation including the transport of reactant and oxidant gases to active sites of catalyst layer, the transport of the proton from the anode side to the cathode side through the membrane, and the transport of produced water from the cathode side to the anode side by back diffusion mechanism. Operating parameters that were examined in this paper i.e. temperatures, pressures, and humidity of reactant gases could decrease these limitations and improve the performance of the fuel cell. Based on these investigations, the optimum conditions are operation at higher pressure and elevated temperature with humidified reactant gases. Furthermore, pressurized cathode side has better effect on the performance of PEM fuel cell than pressurized anode side.

References

[1] Y.M. Ferng, Y.C. Tzang, B.S. Pei, C.C. Sun, A. Su, Int. J. Hydrogen Energy 29 (2004) 381–391.
[2] L. Wang, A. Husar, T. Zhou, H. Liu, Int. J. Hydrogen Energy 28 (2003) 1263–1272.
[3] D. Hyun, J. Kim, J. Power Sources 126 (2004) 98–103.
[4] J.-J. Hwang, H.-S. Hwang, J. Power Sources 104 (2002) 24–32.
[5] Y. Mugikura, K. Asano, Electr. Eng. Jpn. 138 (2002) 24–33.
[6] A. Kazim, P. Forges, H.T. Liu, Int. J. Energy Res. 27 (2003) 401–414.