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Power Performance of Small Polymer Electrolyte Fuel Cells under Various Humidification Conditions

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Abstract

To generate stable electricity with a polymer electrolyte fuel cell (PEFC), it is necessary to manage the cell's water content. We constructed a small PEFC with an active area of 4 cm^2, applicable to power portable electronics devices, and then investigated its power performance under various humidification conditions. By controlling the temperature of the PEFC, the humidifiers and the piping, and the hydrogen and air flow rates, we examined the power performance and cell resistance as functions of cell temperature, humidification temperature, and flow rates. We thus clarified optimum humidification conditions for maximum power performance and discovered the relationship between excess air ratio and maximum power.

1 Introduction

In a polymer electrolyte fuel cell (PEFC), hydrogen is supplied to the anode, and oxygen to the cathode. Chemical reactions generate electricity and produce water on the cathode side. Now, because the solid polymer electrolyte membrane between the PEFC electrodes can conduct protons only in the presence of water, almost all PEFCs supply water to the membrane by humidifying their gas feed stream. However, when this feed gas becomes supersaturated and product water accumulates in the PEFC, water flooding occurs in the gas diffusion layer, the catalyst layer, and the gas channel, all resulting in decreased PEFC performance. Such flooding is especially likely in a small PEFC, applicable for powering a portable electronics device, because of its narrow gas channel and lower gas flow rates. Therefore, it is necessary to manage the water content inside the small PEFC to generate stable electricity. Several studies have reported product water under higher humidification conditions in larger PEFCs with active areas of 6 to 104 cm^2, including Konomi & Nakamura [1], Konomi et al. [2], Lu et al. [3], and Yoshikawa et al. [4,5]. However there have been no full reports evaluating power performance and cell resistance of small PEFCs, with active areas of 4 cm^2 or less, under various humidification conditions. In this study, we first constructed a small PEFC with an active area of 4 cm^2. We then systematically examined its power performance and cell resistance as functions of cell temperature, humidification temperature, and hydrogen and air flow rates.

2 Experiment

Fig.1 shows our small PEFC, comprising a solid polymer electrolyte membrane (made of Nafion 112, with a thickness of 54 μm), electrodes with gas diffusion layers (carbon paper, with a thickness of 0.37 mm, loaded with 1.0 mg/cm^2 platinum), gaskets (silicon), separators (carbon with a gas-impermeable treatment, with a thickness of 4.5 mm) and end plates (aluminum alloy). The separator had a meander channel with a width of 2 mm and depth of 1 mm. Components on the anode side are the same as those on the cathode side.

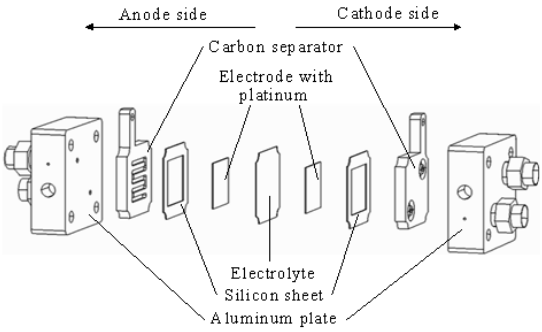

Figure 1: Experimental PEFC.

Fig. 2 shows our experimental apparatus. The hydrogen and air were regulated by mass flow controllers, and then were humidified in separate humidifiers before supplying them to the PEFC. We installed cartridge heaters into the end plates. We wrapped the humidifiers in rubber heaters. We then placed the PEFC, humidifiers, and piping in a thermostatic chamber to control their temperature. We connected the PEFC both to an electric load device (Model PLZ152 with a voltage resolution of 1 mV, Kikusui Electronics Corp.) to evaluate polarization and current transients, and to an ohm tester (Model 356E, Tsuruga Electric Corp.) to measure cell resistance at a frequency of 10 kHz.

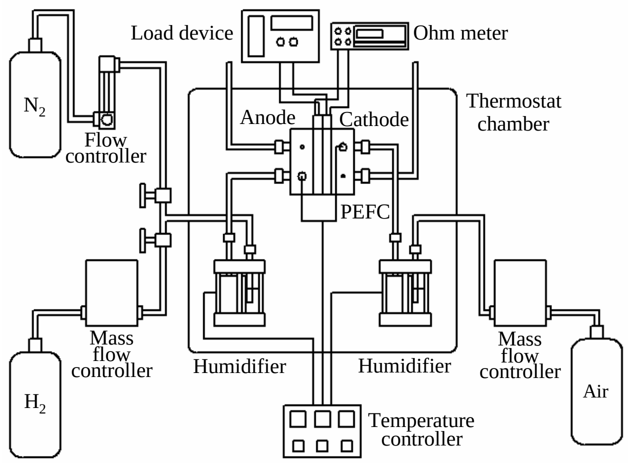

Figure 2: Experimental apparatus.

Table 1 shows our experimental conditions. We define the humidification temperature as the temperature both in water of humidifiers and in the thermostatic chamber. We define the hydrogen and air supply ratios as the proportion of the supply flow rate to the stoichiometric flow rate at 250 mA/cm^2 (hydrogen 7.0 cm^3/min [normal]; air 16.8 cm^3/min [normal]). In our experiment, before each measurement, we allowed the PEFC to stabilize at a current density of 2.5 mA/cm^2 for 1 hour. We then measured the cell voltage and resistance while increasing current density in increments of 5 mA/cm^2.

Table 1: Conditions.

PEFC	Temperature	60° C	80° C
Hydrogen	Humidification temperature	40, 50, 60° C	60, 70, 80° C
	Supply ratio	1.00	
Air	Humidification temperature	40, 50, 60° C	60, 70, 80° C
	Supply ratio	1.00, 1.25, 1.67, 2.50, 5.00, 10.00	

3 Results and Discussion

Fig. 3 shows the effect of humidification temperature on cell voltage, power density, and resistance, with air supply ratio of 1.25 and 5.00, at cell temperature of 60 °C. Looking first at an air supply ratio of 1.25, and with a current density of 60 mA/cm^2 or less, we see that both cell voltage and power density increased with increased humidification temperature. But when current density exceeds 65 mA/cm^2, both cell voltage and power density are higher at humidification temperature of 50 °C than at 40 °C and 60 °C. Cell voltage dropped extremely at 135 mA/cm^2 at a humidification temperature of 60 °C, but dropped at 230 mA/cm^2 at 40 °C and 50 °C. At lower current densities, cell resistance decreased with increased humidification temperature. But at higher current densities, cell resistance decreased at humidification temperatures of 40 °C and 50 °C, and was similar to that at 60 °C.

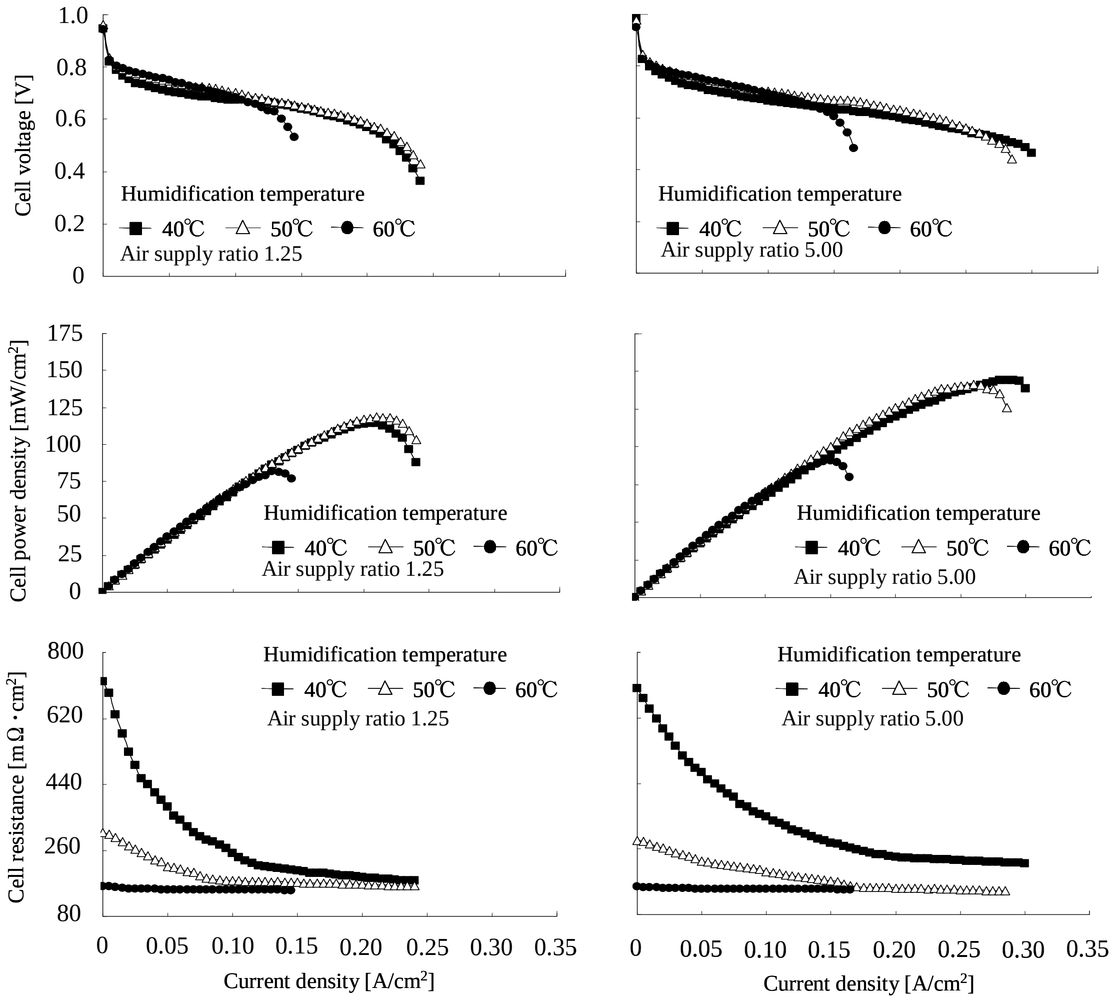

Figure 3: Effect of humidification temperature on cell voltage, power density, and resistance with air supply ratios of 1.25 and 5.00 at cell temperature of 60 °C.

Looking next at an air supply ratio of 5.00, with a current density of 50 mA/cm^2 or less, we see that both cell voltage and power density increased with increased humidification temperature. With current densities between 80 and 260 mA/cm^2, both cell voltage and power density are higher at a humidification temperature of 50 °C than at 40 °C and 60 °C. But when current density exceeds 260 mA/cm^2, both cell voltage and power density are higher at a humidification temperature of 40 °C than at 50 °C. While the cell voltage dropped extremely at 160 mA/cm^2 at a humidification temperature of 60 °C, it dropped at 285 mA/cm^2 at 50 °C, and 305 mA/cm^2 at 40 °C. At lower current densities, cell resistance also decreased with increased humidification temperature. At higher current densities, cell resistance at a humidification temperature of 50 °C fell to almost the same level as that of 60 °C, but cell resistance at 40 °C did not fall to that same 60 °C level. It seems that, at lower current densities, the solid polymer electrolyte membrane dries with a lower humidification temperature, resulting in decreased cell voltage. But as the current density increases, the moisture content on the solid polymer electrolyte membrane is maintained by the product water, so the cell voltage reduction rate decreases with a lower humidification temperature.

Similarly, it appears that at higher current densities water flooding occurs in the gas diffusion layer, or in the catalyst layer in the cathode side, with a higher humidification temperature. This water flooding inhibits reactions and the maximum power density decreases. It seems that, with a higher air supply ratio, it is easier for the product water to drain out, and there is less incidence of water flooding, resulting in increased cell voltage and power density.

Fig. 4 shows the effect of humidification temperature on cell voltage, power density, and resistance, with air supply ratio of 1.25 and 5.00, at cell temperature of 80 °C. Looking first at an air supply ratio of 1.25, with a current density of 105 mA/cm^2 or less, we see that both cell voltage and power density at a humidification temperature of 80 °C are higher than at 60 °C and 70 °C, but cell voltage and power density are similar at 60 °C and 70 °C. With current densities exceeding 110 mA/cm^2, both cell voltage and power density decreased with increased humidification temperature. While the cell voltage dropped extremely at 155 mA/cm^2 at a humidification temperature of 80 °C, it dropped at 230 mA/cm^2 at 70 °C, and 305 mA/cm^2 at 60 °C. At lower current densities, cell resistance decreased with increased humidification temperature. However, at higher current densities, cell resistance at 60 °C and 70 °C did not fall to the 80 °C level.

Looking next at an air supply ratio of 5.00, with a current density of 195 mA/cm^2 or less, we see both cell voltage and power density at a humidification temperature of 80 °C are higher than at 60 °C and 70 °C, and the differences of cell voltage and power density between 80 °C and 60 °C or 70 °C are larger with an air supply ratio of 5.00 than that with the previous air supply ratio of 1.25. Here, with this air supply ratio of 5.00, both cell voltage and power density at 60 °C are similar to those at 70 °C. With current densities exceeding 200 mA/cm^2, both cell voltage and power density decreased with increased humidification temperature. Cell voltage dropped extremely at 205 mA/cm^2 at a humidification temperature of 80 °C, but dropped at 305 mA/cm^2 at 70 °C and at 330 mA/cm^2 at 60 °C. At a humidification temperature of 60 °C, the maximum power density is slightly higher at this air supply ratio of 5.00 than that with the previous air supply ratio of 1.25. At higher current densities, cell resistance at 60 °C and 70 °C with an air supply ratio of 5.00 did not decrease to the level of 80 °C, and was always higher than that with an air supply ratio of 1.25. It seems that, at cell temperature of 80 °C, with decreased humidification temperature, at both lower and higher current densities, the solid polymer electrolyte membrane dries, resulting in no increase to cell voltage and power density.

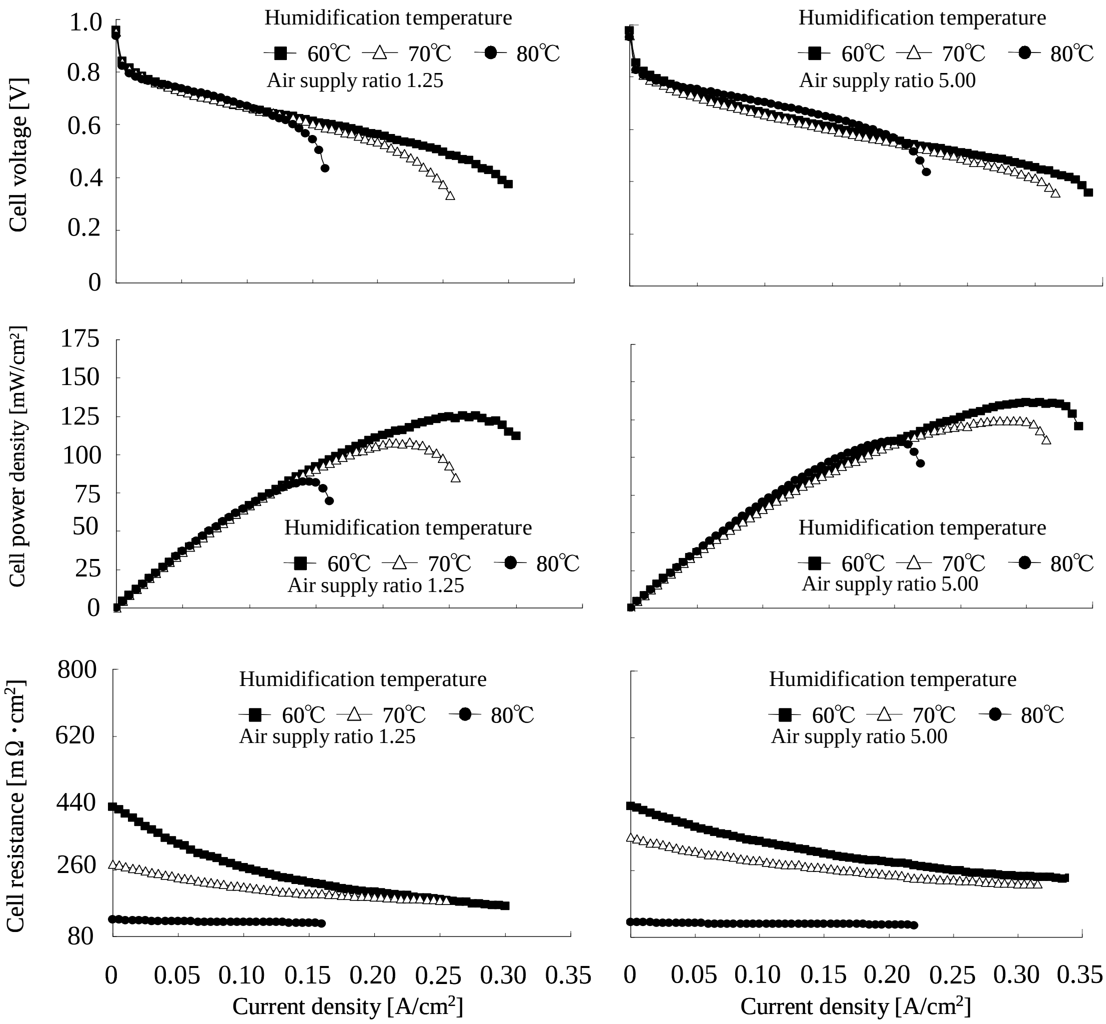

Figure 4: Effect of humidification temperature on cell voltage, power density, and resistance with air supply ratios of 1.25 and 5.00 at cell temperature of 80 °C.

Fig.5 shows the relationship between the excess air ratio and the maximum power density. At cell temperatures of 60 °C and 80 °C, when the humidification temperature increased, the maximum power density decreased. At most humidification temperatures, the maximum power density increased with increased excess air ratio. But at a cell temperature of 60 °C, when the excess air ratio exceeded 5.0, the maximum power density held nearly constant. And at a cell temperature of 80 °C, when the excess air ratio exceeded 2.5, the maximum power density again held nearly constant. Therefore, taking into account the air flow rate supplied in actual operation, the optimum excess air ratio are 5.0 and 2.5, at cell temperatures of 60 °C and 80 °C, respectively.

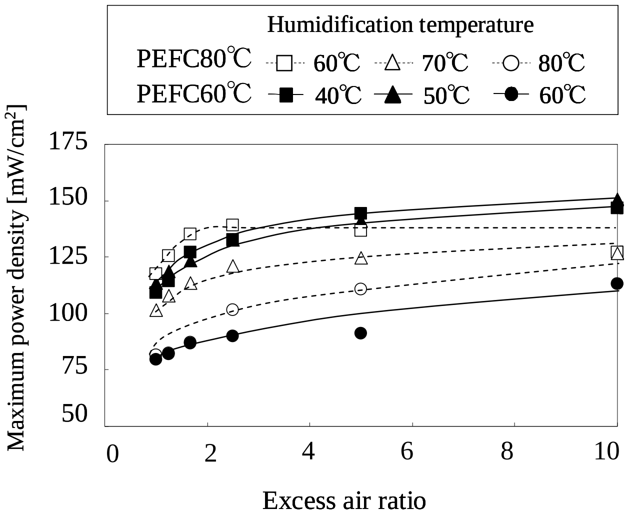

Figure 5: Maximum power density vs. excess air ratio.

4 Conclusion

Utilizing our small PEFC, we investigated its power performance under various humidification conditions. Our major results are as follows:

1. When the humidification temperature increased at lower current densities, or decreased at higher current densities, both cell voltage and power density increased.
2. Maximum power density decreased with increased humidification temperature.
3. Taking into account the air flow rate supplied in actual operation, the optimum excess air ratio is 5.0 at a cell temperature of 60 °C, and 2.5 at 80 °C.

Acknowledgments

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