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This document appeared in

Detlef Stolten, Thomas Grube (Eds.):
18th World Hydrogen Energy Conference 2010 - WHEC 2010
Parallel Sessions Book 1: Fuel Cell Basics / Fuel Infrastructures
Proceedings of the WHEC, May 16.-21. 2010, Essen
Schriften des Forschungszentrums Jülich / Energy & Environment, Vol. 78-1
Institute of Energy Research - Fuel Cells (IEF-3)
Forschungszentrum Jülich GmbH, Zentralbibliothek, Verlag, 2010
ISBN: 978-3-89336-651-4

Evaluation of Power Performance of Small Free-Breathing Polymer Electrolyte Fuel Cells

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Abstract

Utilizing commercially-available parts, we constructed a small free-breathing polymer electrolyte fuel cell, with an active area of 4 cm^2 and hole openings in the separator on the cathode side. We then systematically investigated power performance and cell resistance as functions of cell temperature, hydrogen flow rate and cell tilt angle. We thus clarified the power performance at each temperature, hydrogen flow rate and cell tilt angle, and found the optimum operating conditions for higher power performance to current density.

1 Introduction

When used to power portable electronics devices, polymer electrolyte fuel cells need to be small and simple, with minimal auxiliary devices. There are great hopes that portable electronics devices will be powered by free-breathing polymer electrolyte fuel cells (hereafter "free-breathing fuel cells") needing no auxiliary air circulation devices. The cathode side of these free-breathing fuel cells takes oxygen directly from the surrounding air, using natural convection. Several studies have reported performance evaluations of larger free-breathing fuel cells, with active areas of 6 to 18 cm^2, including Hottinen et al. [1,2], Schmitz et al. [3] and Park et al. [4]. Neponen et al. [5] measured current distribution of free-breathing fuel cell, with an active area of 25 cm^2. However, there have been no full reports evaluating the performance of small free-breathing fuel cells, with active areas of 4 cm^2 or less, applicable to power portable electronics devices. In this study, we investigated the power performance of a small free-breathing fuel cell, without humidifiers on the anode side and without air circulation devices on the cathode side. For the purpose of this study, utilizing commercially-available parts, we constructed a small free-breathing fuel cell with an active area of 4 cm^2 and hole openings in the separator on the cathode side. By controlling our cell temperature and hydrogen flow rate, we examined power performance and cell resistance as functions of cell temperature, hydrogen flow rate and cell tilt angle.

2 Experiment

Figure 1 shows single free-breathing fuel cell with an active area of 4 cm^2. The solid polymer electrolyte membrane was Nafion 112, with a thickness of 54 μm, made by DuPont. The electrodes with gas diffusion layers were carbon paper with a thickness of 0.37 mm, loaded with 1.0 mg/cm^2 platinum, made by Chemix Co., Ltd. The separators, with a thickness of 4.5 mm, were made of carbon with a gas-impermeable treatment, again by Chemix Co., Ltd. The separator on the anode side had a meander channel with a width of 2 mm and a depth of 1 mm. The separator on the cathode side had nine hole openings of 2.8 mm diameter. The end plates were made of aluminum. We drilled holes of 1 mm and 6 mm diameter, to install a K-type sheathed thermocouple and a cartridge heater, respectively.

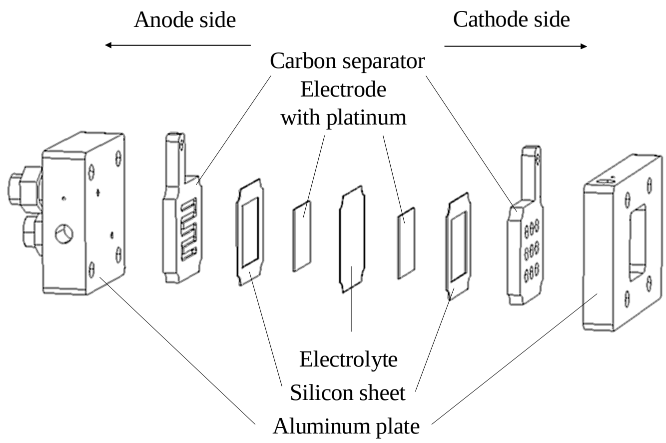

Figure 1: Experimental free-breathing fuel cell.

Figure 2 shows our experimental apparatus. The hydrogen was regulated by a mass flow controller, and then supplied to our free-breathing fuel cell, without humidification. However, only when we were breaking in our cell, we humidified the hydrogen using a humidifier at ambient temperature, before supplying it to our fuel cell. We mounted our fuel cell on a tilt jig, so that we could rotate its center plane between perpendicular to the ground and horizontal. We installed cartridge heaters into the end plates. We connected our fuel cell both to an electric load device (Model PLZ70UA, Kikusui Electronics Corp.) to evaluate cell performance, by measuring polarization and current transients, and to an ohm tester (Model 356E, Tsuruga Electric Corp.) to measure internal resistance of our cell, at a frequency of 10 kHz.

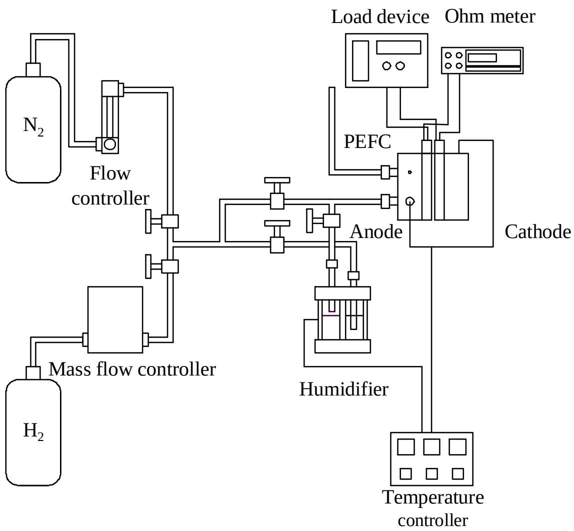

Figure 2: Experimental apparatus.

In our experiments, we set the cell temperature successively at ambient temperature, 30, 40 and 60 °C. We defined the hydrogen supply ratio 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]). We set this hydrogen supply ratio successively at 1 and 2. Before each measurement, we supplied unhumidified hydrogen of 18.6 cm^3/min [normal] to our cell at ambient temperature, until cell resistance reached 300 mΩ. Then, to break in the cell, we allowed the cell to stabilize at a current density of 2.5 mA/cm^2 for 30 minutes, while supplying the fixed hydrogen with humidification at ambient temperature and setting at the fixed cell temperature. After this break-in, we measured the cell voltage and resistance, while increasing current density in increments of 5 mA/cm^2. Here we averaged two measurements, one immediately after establishing each current density, and one 3 minutes later, for our cell voltage and resistance data. We ran our experiments at an ambient temperature of 22 to 26 °C, and a relative humidity of 35 to 70%.

3 Results and Discussion

Figure 3 shows the effect of cell temperature on cell voltage, power density and resistance, with a hydrogen supply ratio of 1, and with the cell center plane perpendicularly to the ground (i.e. a cell tilt angle of 0°). We see that, at a lower current density, both cell voltage and power density decreased, and cell resistance increased, with increased cell temperature. But at a higher current density, the cell voltage reduction rate at higher cell temperature is less than that at lower cell temperature, and cell resistance has a minimum effect on the cell temperature. The maximum power density also increased with increased cell temperature. It appears that, at a lower current density, the solid polymer electrolyte membrane dries as the cell temperature becomes higher, resulting in an increased resistance to proton conduction, thus reduced cell voltage. On the other hand, it seems that, at a higher current density, the moisture content of the solid polymer electrolyte membrane was maintained by the product water, so the cell voltage reduction rate decreased with higher cell temperature.

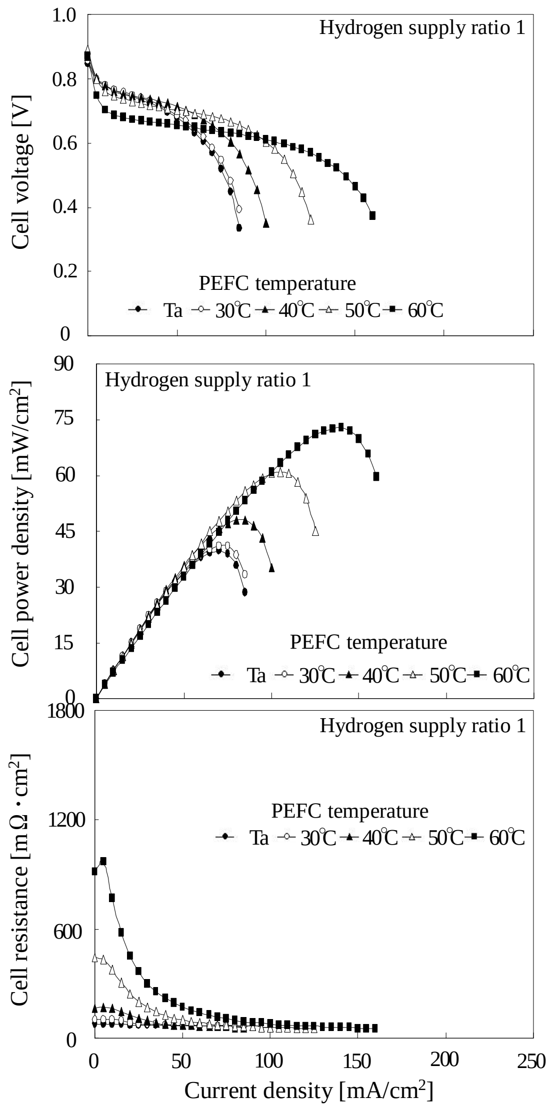

Figure 3: Effect of cell temperature on cell voltage, power density and resistance with hydrogen supply ratio of 1 and cell tilt angle of 0°.

Figure 4 shows the effect of cell temperature on cell voltage, power density and resistance, this time with a hydrogen supply ratio of 2, and again with the cell center plane perpendicularly to the ground (cell tilt angle of 0°). The trend in temperature dependence on cell voltage, power density and resistance vs. current density with this hydrogen supply ratio of 2 is almost the same as that with the previous hydrogen supply ratio of 1. Specifically, at the ambient temperature and a cell temperature of 30 °C, cell voltage, power density and cell resistance with this hydrogen supply ratio of 2, is almost the same as that with the previous hydrogen supply ratio of 1. However, at cell temperatures of 40 °C and above, cell voltage and power density with this hydrogen supply ratio of 2 is lower than that with a hydrogen supply ratio of 1, but the cell resistance with this hydrogen supply ratio of 2 is higher than that with a hydrogen supply ratio of 1. It seems that, with increased hydrogen flow rate and a higher cell temperature, the solid polymer electrolyte membrane becomes drier, decreasing cell voltage.

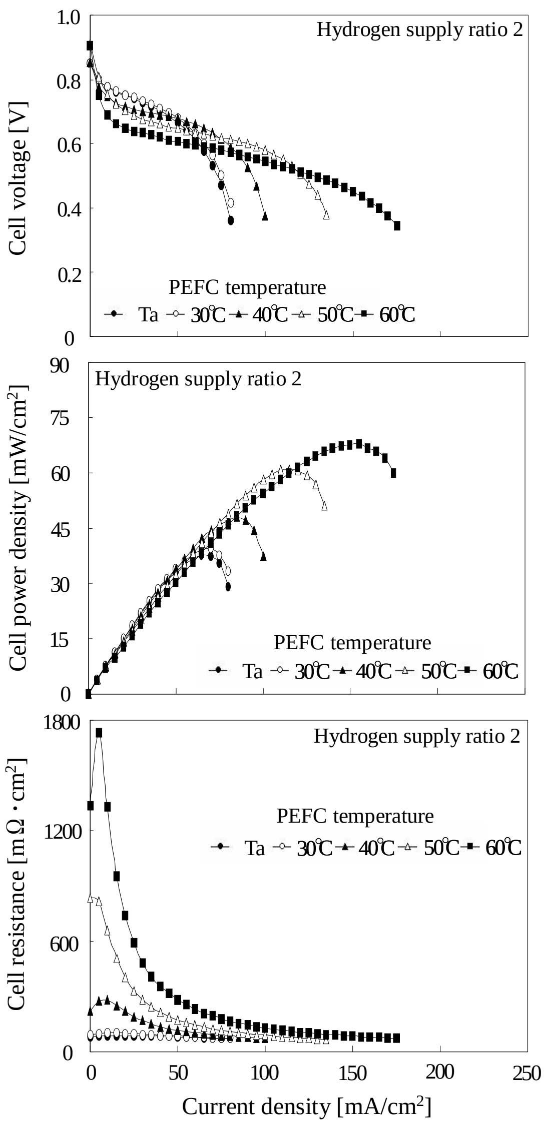

Figure 4: Effect of cell temperature on cell voltage, power density and resistance with hydrogen supply ratio of 2 and cell tilt angle of 0°.

Figure 5 shows the effect of cell tilt angle on cell voltage, power density and resistance, with a hydrogen supply ratio of 1, at ambient temperature. Positive tilt angle represents the cathode inclining upward from the cell center plane perpendicularly to the ground, negative tilt angle represents the cathode declining downward. Both, positive and negative cell tilt angles, have a minimum effect on the cell voltage, power density and resistance. It appears that sufficient air is supplied by natural convection from hole openings in separator to the cathode, even when tilting the cell upwards or downwards.

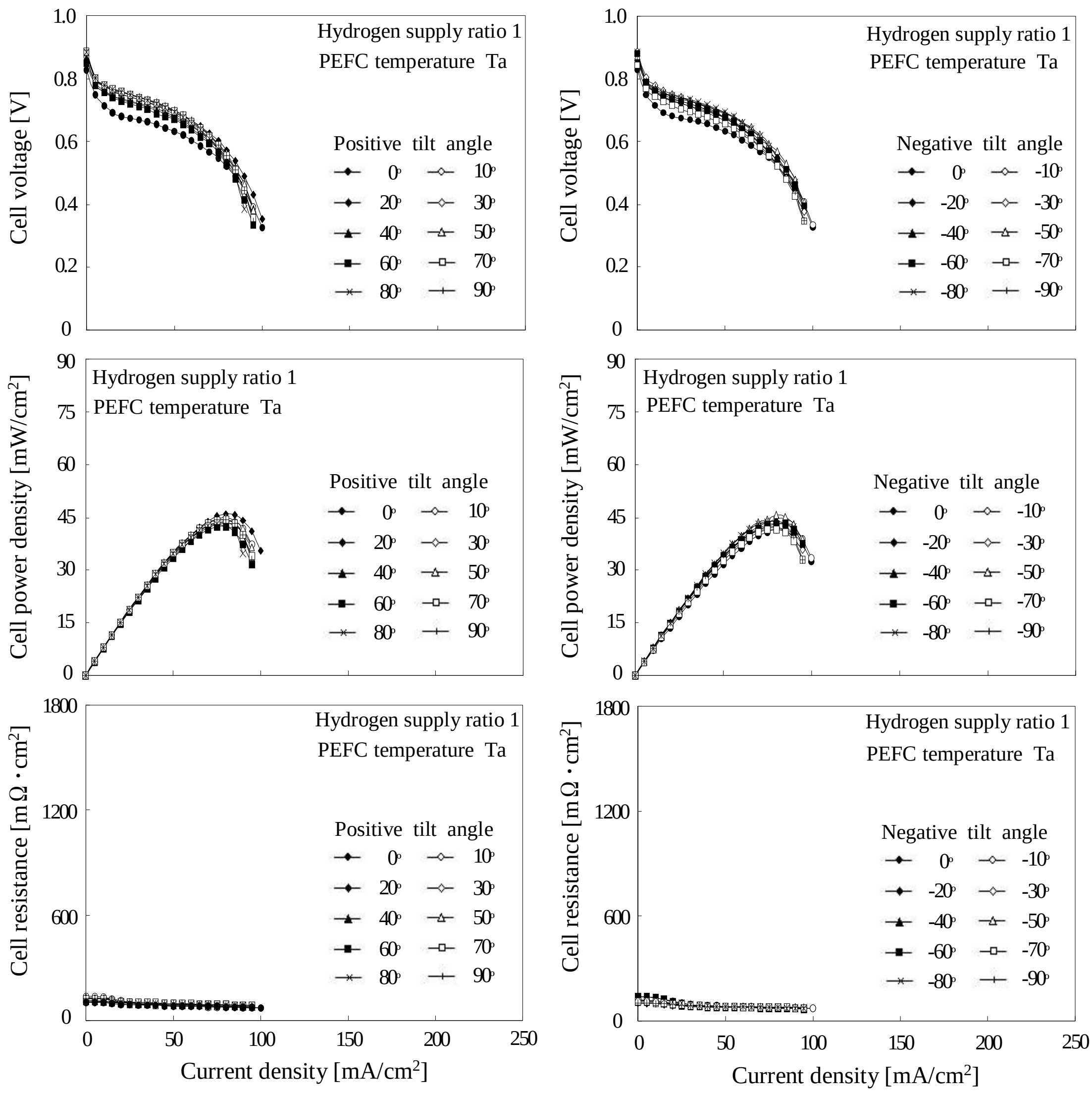

Figure 5: Effect of cell tilt angle on cell voltage, power density and resistance, with a hydrogen supply ratio of 1, at ambient temperature.

4 Conclusion

We constructed a small, free-breathing fuel cell, with an active area of 4 cm^2, and hole openings in separator on the cathode side. We investigated the power performance and cell resistance of this fuel cell, as functions of cell temperature, hydrogen flow rate and cell tilt angle. Our major results follow:

1. At a lower current density, both cell voltage and power density decreased with increased cell temperature. But at a higher current density, the cell voltage reduction rate decreased, and the maximum power density increased, with increased cell temperature.
2. At a higher cell temperature, both cell voltage and power density decreased with increased hydrogen flow rate.

3. Tilting the cell upward or downward has a minimum effect on both cell voltage and power density.

In our future work, we will examine the effect on power performance of the size of the holes in the separator on the cathode side.

Acknowledgements

We would like to thank Chemix Co., Ltd. for their help in producing our small free-breathing fuel cell.

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