

Current distribution in a single cell of PEMFC

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Abstract

Understanding of current and temperature distributions along with the variation of gas composition in the cell of PEMFC is crucial for designing cell components such as the flow field plate and the membrane–electrode assembly. Current distribution in the single cell was experimentally measured by using a specially designed single cell which was composed of 81 compartments. Each compartment was electronically insulated from the neighboring compartments. Current distribution was measured by using Hall effect sensors that were connected to the corresponding compartments. The influences of flooding and stoichiometry variation of the feed gas were discussed in terms of the rate of electrochemical reaction, from the measured distributions of local currents in a segmented single cell.

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Keywords: Segment; Single cell; PEMFC; Current; Distribution; Electrochemical reaction

1. Introduction

The performance of a PEMFC is affected by many factors such as cell temperature, humidity level, partial pressures of feed gases, configuration of channels in the bipolar plate and the characteristics of the membrane–electrode assembly and so on [1–4]. In an attempt to understand the influences of these factors in PEMFC performance, current distributions in a single cell have been, in general, studied by numerical simulations. However, experimental evidence is required to substantiate the numerically calculated results and also to give a better understanding of the nature of the electrochemical reactions occurring inside the cell. Only few experimental studies have been reported [2,5–8] up to now, concerning the distribution of current within a single cell. These directly measured results provide important insights in designing the cell components, stack and the system of a PEMFC.

The objective of this work was to obtain a better understanding of the nature of the electrochemical reaction inside a single cell at various operating conditions. Current distribution in the single cell was experimentally recorded by using the specially segmented single cell. From the measured

distribution of local currents in the single cell under the various experimental conditions, the influence of flooding and stoichiometry variation of feed gas were discussed in terms of the electrochemical reaction.

2. Experimental

2.1. Membrane–electrode assembly fabrication

Before being used in manufacturing MEA, the polymer electrolyte membrane, Nafion 1135 (DuPont) was treated in various solutions to remove trace organic and inorganic contaminants and to change its form. The pretreatment procedure involved boiling the membrane in 3 wt.% aqueous H₂O₂ solution for 1 h, followed by boiling a fresh sample for 1 h in pure water. Then, the membrane was boiled for 24 h in 1 M H₂SO₄ solution to make the membrane in H⁺ form. After that, the membrane was boiled for 2 h in pure water to remove the remaining H₂SO₄ on the surface of the membrane, followed by drying the membrane at ambient temperature.

A 40 wt.% Pt/C (HiSPEC 4000 Fuel Cell Catalyst, Johnson Matthey) was used as an electrocatalyst on both the cathode and the anode. The electrocatalyst slurry mixed with 5 wt.% solubilized Nafion was made to increase the contact area between the membrane and the platinum clusters. The

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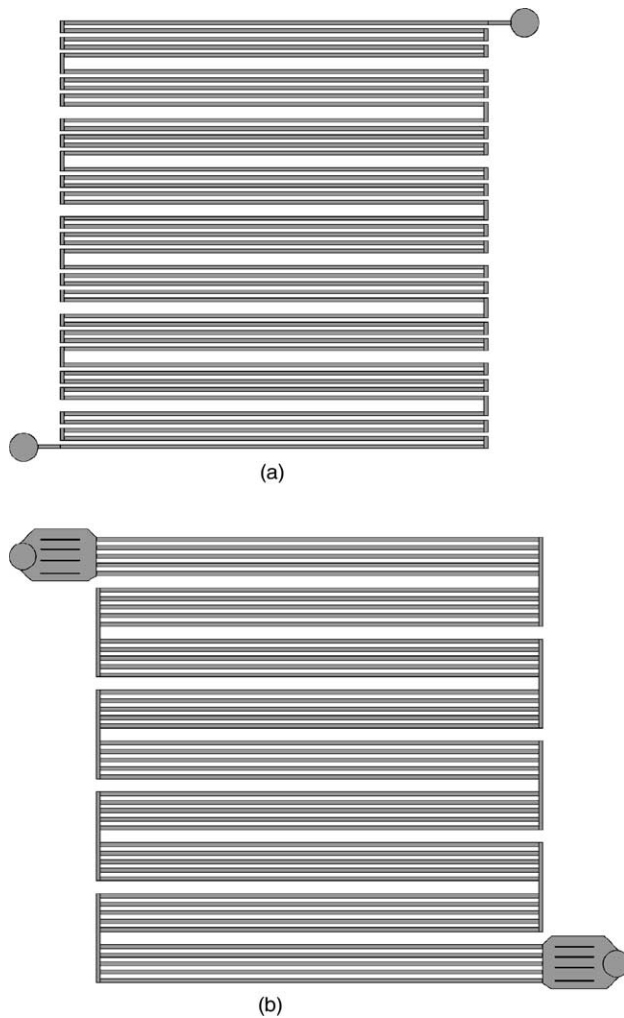


Fig. 1. Flow channel configurations of (a) anode and (b) cathode flow field plates.

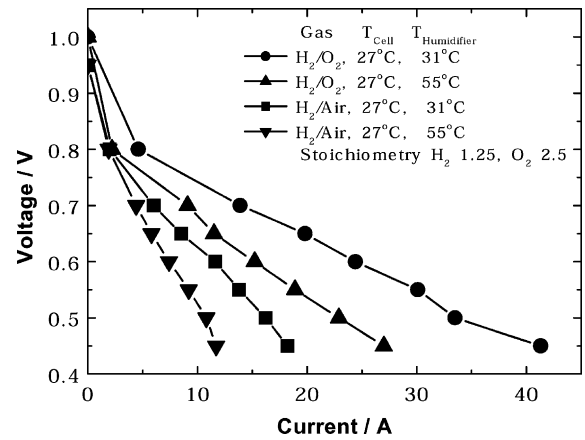


Fig. 2. Performance of segmented single cell operated at H₂/O₂ and H₂/air atmospheres under 100% relative humidity and partially flooding conditions.

Nafion and Pt/C slurry was prepared by first thoroughly mixing the Nafion solution and the Pt/C, using a magnetic stirrer. The ratio of supported Pt catalyst to Nafion was maintained at 3:1 (in weight of solids).

Catalytic layers were fabricated by spray-drying of catalyst-containing slurries onto the teflonized carbon cloth, used as a gas diffusion media backing. Prior to spraying, the carbon cloth backing was coated by PTFE emulsion to provide hydrophobic properties to the gas diffusion media (TGP-H-060, Toray). The slurry formulation was composed of electrocatalyst, Nafion ionomer and water. After the spraying, electrocatalyst-coated gas diffusion media were dried for 2 h in the vacuum oven at 80 °C. Then, dried electrocatalyst-coated diffusion media were hot-pressed on each side of the H⁺ type Nafion membrane of 90 μm thick for 210 s at 120 °C with a pressure of 50 atm.

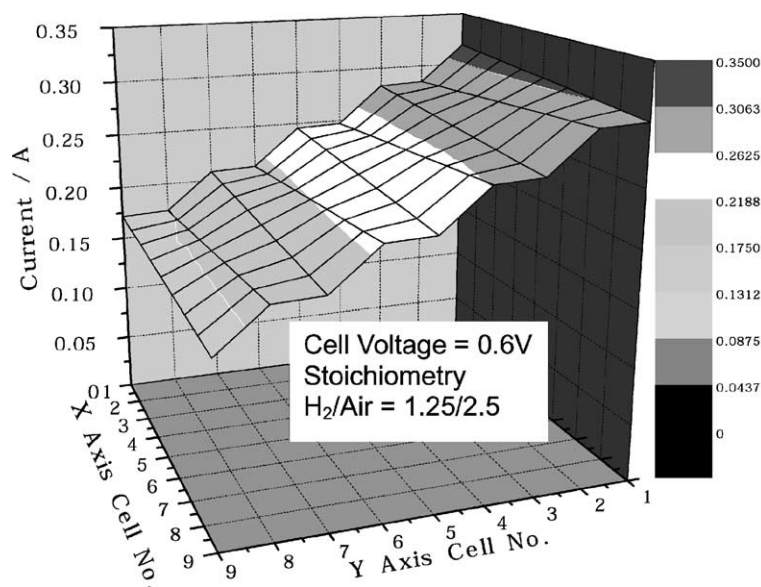


Fig. 3. Calculated distribution of current in a single cell at ambient cell temperature. Only stoichiometry variation in the cell was considered. Stoichiometry of H₂/O₂ gases were 1.25 and 2.5, respectively.

The Pt loading of 0.5 mg/cm^2 was maintained for both anode and cathode catalytic layers. Both the diffusion media and MEA were not segmented, according to the report of Nojonen et al. [2] that non-segmented diffusion media do not distort the current distribution significantly.

2.2. Segmented single cell

The segmented single cell was composed of two parts. One was a flow field plate to provide gas flow and the other was a current collecting plate. The flow field plate was segmented with 9×9 compartments and the compartments were electrically insulated from each other. Eighty-one

pieces of graphite blocks having a dimension of $9 \text{ mm} \times 9 \text{ mm}$ were inserted into the pre-formed bakelite frame. The graphite blocks were separated from each other by a distance of 3 mm. In order to fill the gaps between the inserted graphite blocks and the bakelite frame, the graphite inserted bakelite frame was soaked in bakelite resin for 3 days. The flow field plate was machined to give a flow field of serpentine type after complete setting of the soaked resin. Fig. 1(a) and (b) shows the flow channel configurations of anode and cathode flow field plates, respectively. The channels were 1 mm wide and deep, and the width of the rib was also 1 mm. The dimension of the active area was $105 \text{ mm} \times 105 \text{ mm}$.

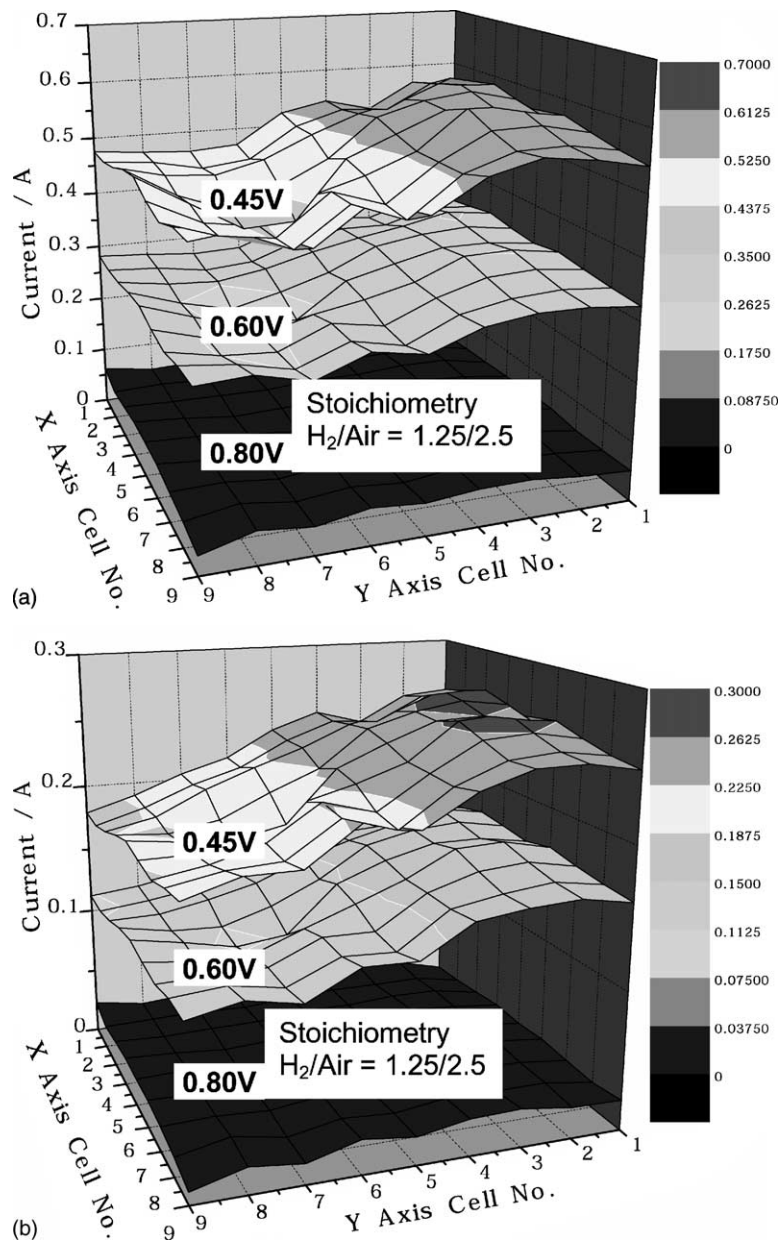


Fig. 4. Change in distribution of current in a single cell as a function of cell voltage, measured at cell temperature of 27°C and 100% relative humidity: (a) H_2/O_2 atmosphere; (b) H_2/air atmosphere. Stoichiometry of H_2/O_2 gases were 1.25 and 2.5, respectively.

The current collecting plate was made by a similar method to the flow field plate. In this case, copper blocks were used instead of graphite blocks. It was found that the current collecting plate should have sufficient thickness to prevent bending in a single cell, causing insufficient electrical contact near the center. After the assembly of the flow field plate and the current collecting plate, all the graphite blocks intimately contacted the corresponding copper blocks. Thus, local current, voltage and temperature could be measured at each compartment. The copper blocks of the current collecting plate were connected to the array of 81 pieces of current-measuring Hall effect sensors. Temperatures were measured at nine points along the path of the flow field.

2.3. Single cell operation

The segmented single cell was operated at 27 °C and ambient pressure of H₂/O₂ or H₂/air with the stoichiometry of 1.25/2.5. In the normal operating conditions, the relative humidity in the cell was maintained to 100% by keeping the humidifier temperature at 31 °C. A partially flooding condition was made by keeping the temperature of the humidifying unit at 55 °C. A complete flooding condition was prepared at the humidifier temperature of 65 °C. In this case, water flow at the gas outlet was observed. In all cases, the stoichiometry of hydrogen and oxygen were maintained at 1.25 and 2.5, respectively.

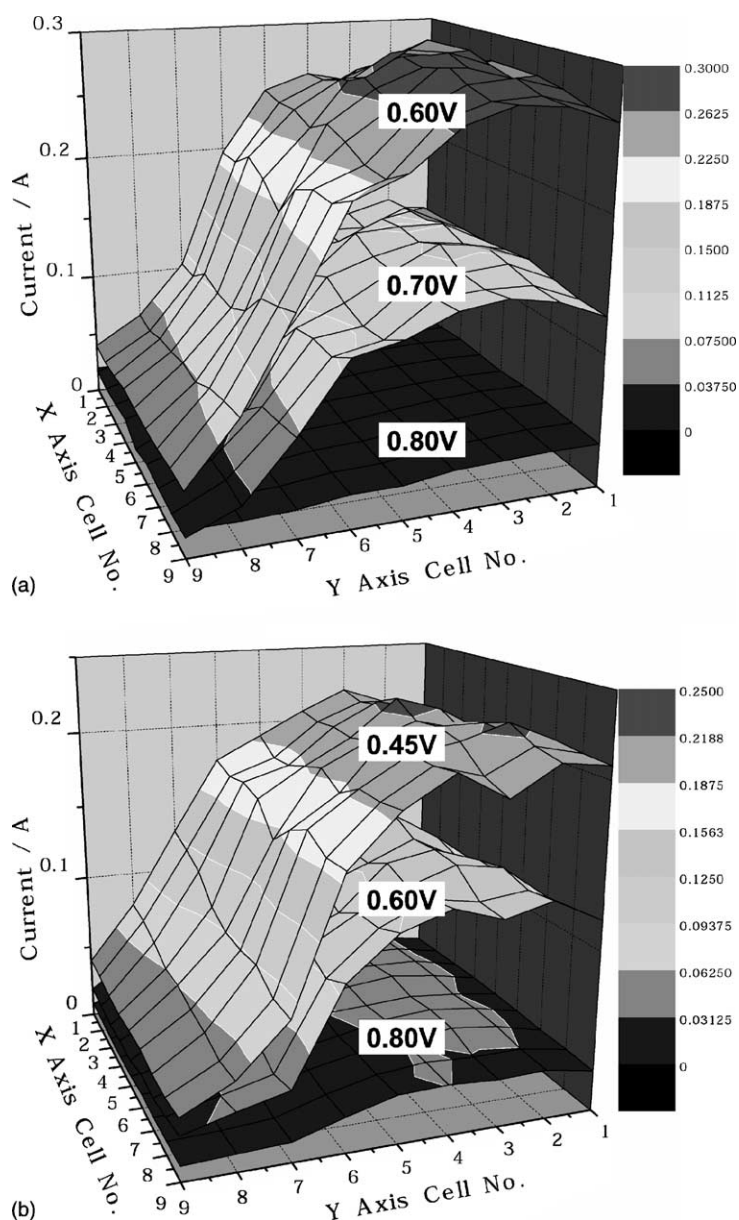


Fig. 5. Change in distribution of current in a single cell as a function of cell voltage, measured at cell temperature of 27 °C and partially flooded condition: (a) H₂/O₂ atmosphere; (b) H₂/air atmosphere. Stoichiometry of H₂/O₂ gases were 1.25 and 2.5, respectively.

Fig. 2 shows the performance of a segmented single cell operated at H_2/O_2 and H_2 /air atmosphere under 100% relative humidity and partially flooding conditions. In the case of operation under H_2/O_2 gas, gas diffusion seems not to occur. In the air condition, however, the current decreases, slightly non-linearly, with decreasing cell voltage in the lower voltage region, indicating the initiation of limited oxygen diffusion.

3. Results and discussion

In order to compare with the measured data, the distribution of local currents in a single cell at ambient cell temperature was calculated, considering the stoichiometry variation alone along the channel and is depicted in Fig. 3. The performance of a single cell at various stoichiometries was previously determined experimentally. The cell voltage and stoichiometry of the H_2 /air gases were assumed to be 0.6 V and 1.25/2.5, respectively. The calculated current level decreases monotonously along the channel of the flow field. The result indicates that the rate of electrochemical reaction occurring in the single cell is a strong function of stoichiometry or partial pressure of the feed gases flowing through the channels, as already reported by several authors [1,3].

The distribution of local currents in the segmented single cell was measured at various cell voltages. The cell was operated at a temperature of 27 °C and 100% relative humidity. The stoichiometries of the H_2/O_2 gases were 1.25 and 2.5, respectively. Fig. 4(a) and (b) demonstrates the results measured in H_2/O_2 and H_2 /air atmospheres, respectively. As the cell voltage decreases, the local current decreases more steeply, irrespective of the gas atmosphere. Comparing the current distribution measured in H_2/O_2 and H_2 /air atmospheres, the current in the H_2 /air atmospheres is

diminished more quickly as the feed air flows along the gas channel, especially at lower cell voltages.

Let us consider two aspects of water condensation and partial pressure variation of the feed gas. As the electrochemical reaction occurs, water is produced as a result of the electrochemical reaction and is gradually accumulated and condensed along the gas flowing channel. At the same time, partial pressure of the feed gas flowing through the channel decreases. At a given voltage, the quantity of water produced by the reaction in the H_2/O_2 atmosphere is larger than that in the H_2 /air atmosphere. Furthermore, the flow rate of feed gas in the H_2/O_2 atmosphere is much lower than that in the H_2 /air atmosphere. Therefore, flooding by the condensed water in the H_2/O_2 atmosphere is more pronounced, compared to the situation in the H_2 /air atmosphere. However, Fig. 4(a) and (b) shows opposite results to that expected. In this operating condition, flooding seems not to significantly affect the rate of the electrochemical reaction. Considering that the rate of the electrochemical reaction occurring in the single cell is a strong function of stoichiometry or the partial pressure of the feed gases flowing through the channels as shown in Fig. 3, the more steep reduction of current in the H_2 /air atmosphere as the feed air flows along the gas channel seems to be attributable to the more limited diffusion of oxygen atoms in air than in a pure oxygen atmosphere.

The influence of flooding in the distribution of local currents in the segmented single cell was measured at various cell voltages, and the results are plotted in Fig. 5(a) and (b). The cell was operated at cell and humidifier temperatures of 27 and 55 °C, respectively. The relative humidity was calculated to exceed 300%. The stoichiometry of the H_2/O_2 gases were 1.25 and 2.5, respectively. Fig. 5(a) and (b) shows the results measured in H_2/O_2 and H_2 /air

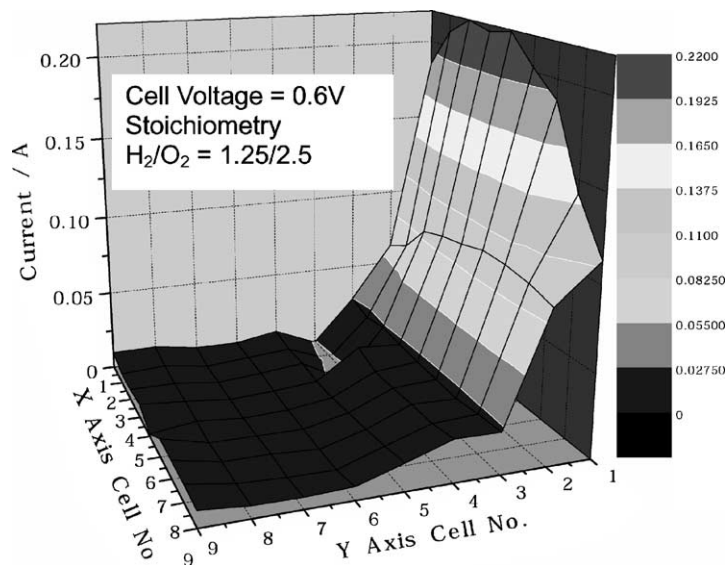


Fig. 6. Distribution of current in a single cell at cell temperature of 27 °C under the complete flooding condition. Stoichiometry of H_2/O_2 gases were 1.25 and 2.5, respectively.

atmospheres, respectively. The current decreases steeply at the outlet region of the cell, irrespective of the gas atmospheres and cell voltages. Comparing the current levels of the 100% relative humidity condition, even the highest current level is lower than that in the normal condition. This result seems to originate from the partial flooding at the inlet region and the reduced partial pressure of the feed gas by the increased partial pressure of water vapor.

The distribution of local current in the segmented single cell was measured under complete flooding condition and is

depicted in Fig. 6. The cell was operated at cell and humidifier temperatures of 27 and 65 °C, respectively, and the resulting relative humidity was calculated to exceed 600%. In this case, water flow at the gas outlet was observed. The stoichiometry of H₂/O₂ gases were 1.25 and 2.5, respectively. It seems that most part of the MEA is flooded with condensed water and only the region near the gas inlet is active. Comparing the results as shown in Figs. 4–6, the process of flooding and drying in a cell seems to be summarized as follows. The flooding process starts at the outlet region of a cell, then it

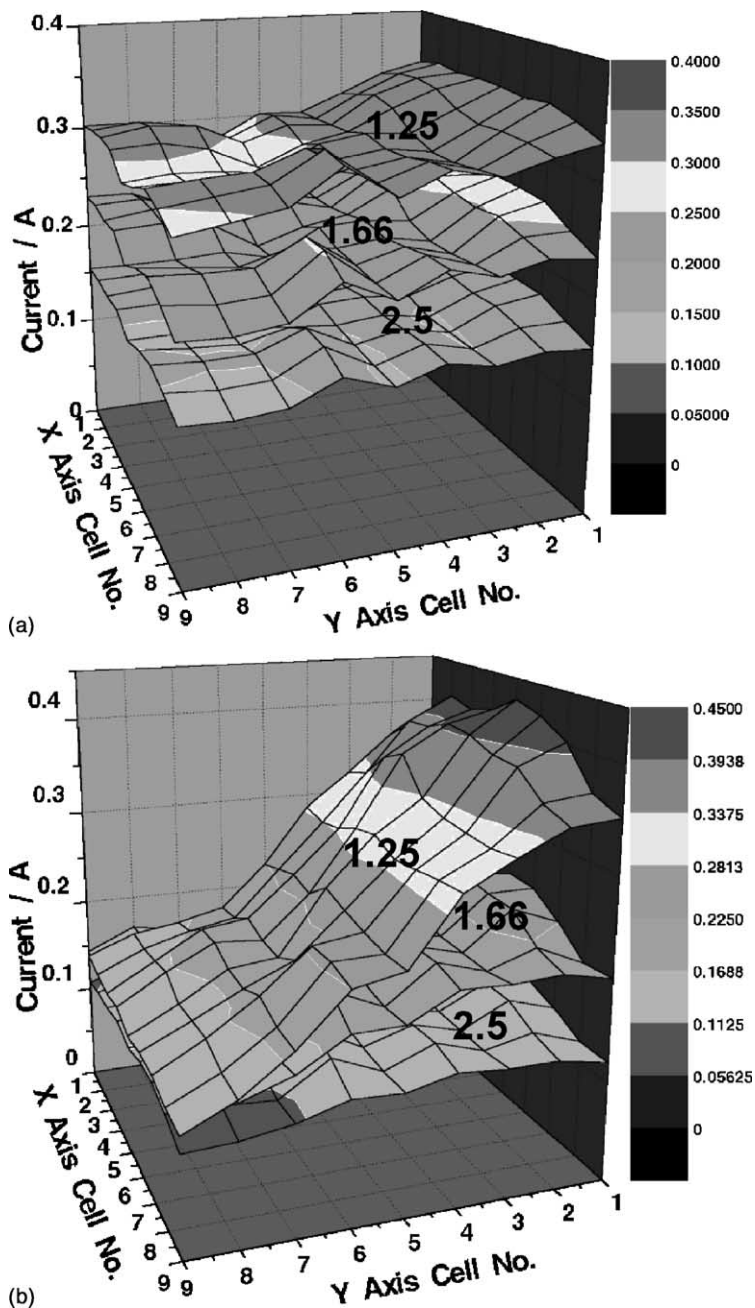


Fig. 7. Change in distribution of current in a single cell as a function of oxygen stoichiometry, measured at cell temperature of 27 °C and 100% relative humidity condition: (a) H₂/O₂ atmosphere; (b) H₂/air atmosphere. Stoichiometry of H₂ was 1.25 and current levels of H₂/O₂ and H₂/air conditions under the oxygen stoichiometry of 2.5 were 12 and 10 A, respectively.

propagates to the inlet area. The drying process of a cell seems to occur in the direction opposite to the flooding case.

The influence of oxygen stoichiometry on the distribution of local currents in the segmented single cell was measured at H_2/O_2 and H_2/air , and the results are plotted in Fig. 7(a) and (b), respectively. The current levels of H_2/O_2 and H_2/air conditions under the oxygen stoichiometry of 2.5 were 12 A and 10 A, respectively. As the stoichiometry of oxygen decreases, the resulting current of the H_2/air condition decreases more steeply along the gas flow channel compared to that of the H_2/O_2 condition. The result indicates that the nitrogen atmosphere in air retards the oxygen diffusion severely, especially at the lower stoichiometry condition. Higher porosity and thinner layers for both the catalytic and the diffusion media might help to mitigate the limited diffusion of oxygen in the air condition.

4. Concluding remarks

The influences of flooding and stoichiometry variation of feed gas on the performance of a single cell were experimentally measured and discussed by using a specially segmented single cell which was composed of 81 compartments.

The more steeper reduction of the current in the H_2/air condition than in the H_2/O_2 condition as the feed gas flowed along the cathode channel was attributed to the more limited diffusion of oxygen atoms in air than in a pure oxygen atmosphere.

From the results measured under the various humidity conditions, it was suggested that the flooding process begins at the gas outlet region of a cell, then it propagates to the inlet

area. The drying process of a cell seems to occur in the direction opposite to the flooding case.

The results measured under the various oxygen stoichiometry conditions indicated that the nitrogen atmosphere in air severely retards oxygen diffusion severely, especially in the lower stoichiometry condition.

Acknowledgements

This work was supported partly by Ministry of Science and Technology as a part of the “National Research Laboratory Program” and by Ministry of Commerce, Industry and Energy.

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