Removal of product water is a problem in polymer electrolyte fuel cells (PEFCs) that operate at less than 100°C. As water vapor pressure increases along gas flow in a cell, the difficulty of removing product water also increases in downstream of the flow. This problem is negligible in case of small-area electrode, but it becomes serious in large-area electrode. The means we have taken to solve this problem is to make intentionally temperature difference between gas inlet and outlet in the cell. This method effectively prevented the large-area electrode of 600cm² and 2000cm² from the condensation of water vapor in the cell. We have added a theoretical explanation for the effect of the temperature difference method.

INTRODUCTION

Since PEFCs are usually operated at lower temperature than the boiling point of water, the issue of water management is very important in stable operation. Condensed water in electrodes hinders gas diffusion, and stuffed water in gas grooves causes ill distribution of gas. There are two approaches to remove water efficiently. One is to remove condensed water by capillary force using some hydrophilic materials. Another way is to prevent water vapor from condensing by adjusting cell temperature. We have examined the latter method, which makes intentionally temperature difference between gas inlet and outlet in the cell.

EXPERIMENTAL

In order to make intended temperature difference, the structure of cooling water flow path in a separator was designed as shown in Figure 1. Cell temperature was changed by controlling temperature and flow rate of cooling water passing through the grooves which made a right angle with gas passages. A 6-cell stack with 600cm² electrodes, as shown in Figure 2, and a 2-cell stack with 2000cm² electrodes were used in the
experiment. Both anode and cathode catalyst layers contained 2.6 mg/cm² of Pt black. The anode feed gas was pure H₂, and the cathode feed gas was air. Operating conditions are shown in Table 1.

RESULTS

Figure 3 shows the effect of cell temperature at gas inlet (Tᵢ) on cell voltage in 600cm² electrode cells operated at 0.2MPa abs. Cell temperature difference between gas inlet and outlet (∆T) was fixed at 7°C. Each cell voltage was corrected into the deviation from maximum cell voltage in the figure. The cells gave stable voltage in the range of 66 to 68°C (Tᵢ) except for No.2 and No.4 cells.

Figure 4 shows the effect of ∆T on cell voltage at constant Tᵢ (66°C). High cell voltage was obtained in the 5 to 7°C of ∆T except for No.4 cell. Different behavior of No.2 and No.4 cells is considered to be due to ill distribution of gas. These experimental results give that the optimum temperature in 600cm² cells is Tᵢ=66 to 68°C and ∆T=5 to 7°C.

Figure 5 and 6 show the case of 2000cm² electrode cells. Maximum cell voltage was obtained at Tᵢ=69°C and ∆T=3 to 5°C. Since the 2000cm², 2-cell stack was operated at low pressure (0.1MPa abs), the effect of temperature difference is less remarkable than that in the 600cm² stack.

MODEL DEVELOPMENT

Model Description

A theoretical model has been developed to calculate Tᵢ and ∆T for various operating conditions. The schematic view of the model is shown in Figure 7. In this model, the contribution of anode on water removal was represented by a parameter α that is the ratio of product water removed through cathode to total removed water. The ratio α was determined experimentally. The anode polarizations is ignored because pure H₂ is used for anode feed gas. Assuming that the partial pressure of water vapor at cathode reaction site is equal to the saturated water vapor pressure at the cell temperature, the pressure difference of water vapor between the reaction site and the gas passage, Δp(x), can be expressed as:

\[
Δp(x) = P_w(T(x)) \cdot \left[ \frac{V_w(x)}{V_w(x) + V_A(x)} \right]
\]

where x is the distance from the gas inlet (0≤x≤L), P_w is the saturated pressure of water vapor, T is the cell temperature, P is the total pressure, V_w is the flow rate of water vapor in air, V_A is the flow rate of dry air. V_W and V_A are the functions of x, and can be expressed as:
\[ V_w(x) = V_{wo} + \frac{\alpha}{2F} \int_0^x i(t)dt \]  
\[ V_{\lambda}(x) = V_{\lambda 0} - \frac{1}{4F} \int_0^x i(t)dt \]  

where \( V_{wo} \) and \( V_{\lambda 0} \) are the flow rate of water vapor and air at inlet, \( \alpha \) is the ratio of product water removed through cathode. \( \Delta p(x) \) in equation [1] can be written as:

\[ \Delta p(x) = \Delta p_0 \left( \frac{T(x)}{T_0} \right) \left( \frac{P}{P_0} \right) \left( \frac{i(x)}{i_0} \right) \]  

where temperature \( T_0 \), pressure \( P_0 \), and current density \( i_0 \) are selected value as standard conditions of calculation. \( \Delta p_0 \) is the calculated pressure difference of water vapor from \( T_0 \), \( P_0 \), \( i_0 \), and the thickness of cathode. Equation [4] implies variation of diffusion coefficient by temperature and pressure.

Calculation of Optimum Temperature Distribution

The temperature distribution \( T(x) \) can be obtained by solving equation [1] to [4]. \( T_i \) and \( \Delta T \) is given by \( T_i = T(0) \) and \( \Delta T = T(L) - T(0) \). Figure 8 shows the contour of computed \( T_i \) as a function of dew point of air and total pressure at 0.4A/cm². \( \Delta T \) can be also calculated as shown in Figure 9. The computed temperatures corresponding to the operating conditions in Table 1 are \( T_i = 65.9°C \) / \( \Delta T = 7.2°C \) (600cm²), \( T_i = 68.5°C \) / \( \Delta T = 2.8°C \) (2000cm²), which agree with the experimental results in Figure 2 to 5.

Optimum temperature distribution can be obtained from these figures. High pressure or low temperature requires large \( \Delta T \). High utilization of air or high current density also needs to enlarge \( \Delta T \) from equation [1] to [4].

CONCLUSIONS

A temperature difference method operated effectively to remove product water from cathode in the experiments of 600 and 2000cm² electrode cells. The optimum cell temperature and temperature difference can be calculated from water vapor pressure in inlet air, total pressure, and current density. The computed optimum operating temperature shows good agreement with the experimental results.
Table 1 Operating Conditions

| Parameter            | 600cm² | 2000cm² |
|----------------------|--------|---------|
| Current Density      | 0.4A/cm² | 0.4A/cm² |
| Pressure             | 0.2MPa  | 0.1MPa  |
| Air Utilization      | 25%     | 25%     |
| H₂ Utilization       | 72%     | 36%     |
| Dew Point of Air     | 57°C    | 65°C    |

Fig. 1 Schematic Illustration of Cooling Water Flow

Fig. 2 6-Cell Stack with 600cm² Electrode
Fig. 3  Cell Voltage vs. Cell Temperature at Gas Inlet (600cm²)

Fig. 4  Cell Voltage vs. Cell Temperature Difference between Gas Inlet and Outlet (600cm²)

Fig. 5  Cell Voltage vs. Cell Temperature at Gas Inlet (2000cm²)

Fig. 6  Cell Voltage vs. Cell Temperature Difference between Gas Inlet and Outlet (2000cm²)
Fig. 7 Schematic View of Model

Fig. 8 Calculated Contour of Inlet Cell Temperature $T_i$ at 0.4A/cm²  

Fig. 9 Calculated Contour of Temperature Difference between Gas Inlet and Outlet $\Delta T$ at 0.4A/cm²