Separation analysis of electro-osmosis and diffusion of water in electrolyte membrane of PEMFC under low-humidity operation

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To alleviate performance degradation of proton exchange membrane fuel cell (PEMFC) due to membrane dehydration during low-humidity operation, it is essential to understand and control water transports such as electro-osmosis and back-diffusion through electrolyte membrane. In the previous studies, Zawodzinski et al. experimentally measured the diffusion coefficient of water in Nafion membrane using MRI [1], and determined the electro-osmotic drag coefficient based on a concentration cell technique [2]. Furthermore, Lu et al. measured the water and current distributions in a segmented fuel cell simultaneously, and first presented a new approach to estimate the net water crossover coefficient in electrolyte membrane [3]. However, the detailed transport mechanisms of electro-osmosis and back-diffusion in electrolyte membrane of operating PEMFCs have not yet been evaluated separately. In this study, the water vapor and current distributions on the anode side of an operating PEMFC are firstly measured using the visualization method proposed in our previous work [4], and the profile of the net water transport coefficient is numerically determined under low-humidity conditions. In addition, the electro-osmotic drag coefficient of Nafion membrane is also measured as a function of relative humidity (RH) based on hydrogen pumping method [5]. Thereby, the electro-osmosis and back-diffusion of water across the electrolyte membrane in the operating PEMFC can be separately analyzed.

In this experiment, the water vapor distribution in the anode channel of a transparent fuel cell is first visualized using humidity test paper (HTP), which is the measurement technique presented in our past work [4]. HTP is a test paper for detecting water vapor in the range of 20-90% RH, and makes it possible to quantitatively evaluate the water vapor concentration inside the operating fuel cell. The schematic diagram of the transparent cell used in this study is shown in Fig. 1. The active area of the MEA is 5.0 cm^2. To monitor the current distribution, the anode-side current collector is divided into 10 segments. By experimentally investigating both the water vapor and current profiles, the distribution of the net water transport coefficient, α, can be numerically determined.

Furthermore, the electro-osmotic drag coefficient, n_d, of Nafion-115 membrane is also measured based on hydrogen pumping method [5], and two transport mechanisms of electro-osmosis and back-diffusion through the electrolyte membrane of the operating PEMFC are quantitatively distinguished. Fig. 2 shows the experimental setup for measuring the electro-osmotic drag coefficient. Low humidified hydrogen and highly humidified nitrogen are supplied into the anode and cathode of the test cell, respectively. The amount of water transferred across the MEA due to the electro-osmosis and back-diffusion is monitored by four dew-point meters placed at the inlet and outlet of the test cell. Both anode and cathode electrodes of the test cell are electrically connected to the potentio-galvano stats, and the constant current can be arbitrarily applied between two electrodes. The electro-osmotic drag coefficient is calculated by the following equation

$$n_d = K_w \left(P_{w,ca} - P_{w,an} \right) A \cdot \frac{F}{I} \qquad (1)$$

where K_w is the water permeability, P_w the partial pressure of water vapor, A the electrode area, I the current applied by the potentio-galvano stats.

Fig. 3 presents the distributions of the detailed water transports through the electrolyte membrane in the operating PEMFC. These distinguished water fluxes were estimated from the experimental results. The positive net water flux indicates that water apparently migrates from the anode to cathode, and the negative net flux indicates from the cathode to anode. The electro-osmotic and back-diffusion fluxes are given in positive value. The operating temperature and current density are 70°C and 0.3 A/cm^2. The relative humidity at the anode and cathode inlets is 30% and 0%, respectively. When dry cathode gas is supplied to the cell, the electro-osmotic flow is larger than the back-diffusion in the upstream region. Even if the cathode inlet is drier than the anode inlet, the forward diffusion of water from the anode to cathode doesn't occur. On the other hand, in the downstream region, the back-diffusion of water is dominant due to the water production at the cathode side.

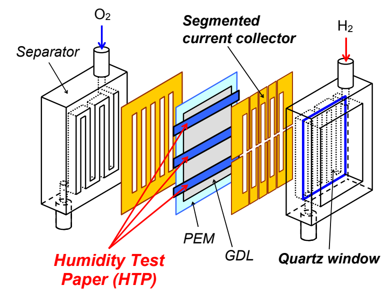

Fig. 1 Schematic diagram of the transparent fuel cell.

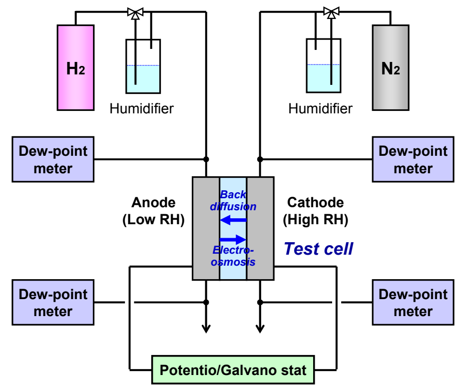

Fig. 2 Experimental setup for the measurement of the electro-osmotic drag coefficient.

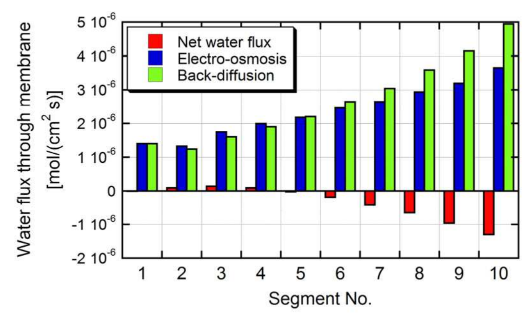

Fig. 3 Distributions of the detailed water transports through the membrane in the operating PEMFC.

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