Ex Situ Characterization Method for Flooding in Gas Diffusion Layers and Membrane Electrode Assemblies With a Hydrophilic Gas Diffusion Layer

Proper water management is required for the operation of polymer electrolyte fuel cells (PEFCs), in order to maintain the critical balance between adequate membrane hydration and prevention of water flooding in the catalyst layer. In PEFCs, the membrane electrode assembly (MEA) is sandwiched between two gas diffusion layers (GDLs). In addition, a microporous layer (MPL) is generally applied to the GDL substrates for better water removal from the cathode catalyst layer. This paper is the first to report on an ex situ characterization method for water flooding in GDLs. As the humidity of O₂ gas on the substrate side of the GDL was increased in incremental steps, O₂ gas began to diffuse into the MPL side of the GDL. When the O₂ relative humidity exceeded the dew point, water flooding was observed on the surface of the MPL and the O₂ concentration dropped sharply because the O₂ diffusion was suppressed by the produced liquid water. When comparing to the estimated mass transfer loss based on the actual polarization curves of an MEA using the GDL, it was found that the decrease in the O₂ concentration on the MPL side of the GDL can be used as an index of water flooding in the PEFC.

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1 Introduction

Intensive research and development activities have been carried out over the last few decades to improve the performance of PEFCs [1–3], promising technology for electric vehicles, and other applications because of their high-energy efficiency, low operating temperature, and zero emissions. Water flooding in the catalyst layer has a significant impact on PEFC performance. When a sufficient amount of product water is not removed from the cathode catalyst layer, excess water will accumulate and hinder the transportation of oxygen by covering up the reaction sites on the catalyst, causing the cathode to flood and a significant drop in performance, particularly at high current densities. In order to elucidate the mechanism of water flooding, various imaging techniques [4–7] have been employed for monitoring water distribution in the cell, and several physical indicators [8–11], such as gas flow resistance, the cell resistance, and pressure drop in the cell during the PEFC operation, have been reported. GDLs are critical components in PEFCs. When identical catalyst-coated membranes are used, the performance of MEAs is largely dependent on the properties of GDLs used. Some of the most significant properties of GDLs are thickness, contact angle, porosity (pore size distribution), electrical and thermal conductivity, gas and liquid permeability, and mechanical properties [12]. However, relatively little correlation has been established between ex situ characterization results and in situ PEFC performance including water flooding. This paper is the first to report on an ex situ characterization method for flooding in GDLs. This method is expected to expedite the development of GDLs which can improve water transport and mitigate cathode flooding.

2 Method and Materials

2.1 Flooding Evaluation. In this paper, a moisture vapor diffusion permeameter (MVDP, Seika Corporation, Tokyo, Japan) was employed in order to evaluate water flooding in the GDL. According to the manufacturer, the MVDP is designed to measure the gas diffusivity and transmission coefficients. The flow layout in the MVDP is shown in Fig. 1. Water vapor can be supplied at any humidity level to each side of the temperature-adjusted sample chamber by using bubblers and mass flow controllers. Both sides of the sample are monitored by pressure difference meters, which feedback a signal to the auto pressure controller. The key for evaluating gas diffusion is the precise control of gas flow and pressure. The accuracy of measurement and control is shown in Table 1. As indicated in Fig. 2, when gas 1 and gas 2 flow through the channels at equal pressure and separated by a GDL sample, gas 1 flows into the dryer region, due to the concentration gradient. Concentration of gas 1 diffused into gas 2 can be measured accurately in the MVDP. The actual measuring procedures are as follows. A cooling metal block was set in a measuring chamber in the MVDP, and then a GDL sample (27 × 11 mm) was placed on the block as shown in Fig. 3. At first, oxygen and nitrogen gases (80 °C, 0% RH) were fed separately for about 300 s onto each side of the sample, which separates the measuring chamber. The surface temperature of the MPL side of the GDL was maintained at 60 °C by a cooling metal block that is in contact with the sample. The humidity of O₂ was increased in incremental steps from 0% RH to 24, 43, and 57% RH, holding the relative humidity constant for 240–300 s at each step. As the humidity in the O₂ side increases, the O₂ concentration in the N₂ side decreases and flooding is observed when the O₂ relative humidity exceeds 43% RH (dew point). The condensed water hampers the oxygen permeation into the N₂ side as shown in Fig. 4. The more the condensed water at the interface between the MPL surface and the metal block, the larger the decrease in O₂ concentration in the N₂ side. The decrease in the oxygen concentration in the N₂ side, therefore, can

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