Characterization of Permeability Changes and Hydrophobic Nature of GDL, and Correlation with PEMFC Performance

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Introduction

Polymer Electrolyte Membrane Fuel Cells (PEMFC) use gas diffusion layer (GDL) to distribute reactants to anode and cathode in areas that are orthogonal to the bulk flow but parallel to the membrane. Such distribution is necessary because most flow field designs use ribs that separate the flow channels to provide electrical contact between the current collectors and electrodes. GDL is normally under compressive stress, which influences permeability and resistivity. The hydrophobic/hydrophilic pore structure characteristics of GDL influence fuel cell performance by affecting the degree of hydration of the membrane, formation of liquid water, and water transport across the membrane. The objectives of this study are to measure fundamental properties including permeability, resistivity, and hydrophobic/hydrophilic characteristics of GDL and characterize the performance of GDL in a PEMFC.

Experimental

Permeability: Permeability was measured using the fully automated PMI Capillary Flow Porometer (1). Compressive stress was applied on the sample. Pressure drop across the sample and gas flow rate through the sample were measured while the sample was under the desired compressive stress. The instrument yielded accurate and repeatable results. Permeability was computed using Darcy's law from the flow rate, pressure drop and sample dimensions. Measurements were repeated for several compressive stresses up to about 300 psi.

Hydrophobic and hydrophilic pore structure: The pore structures were determined by mercury and water intrusion porosimetry (2). Mercury cannot enter pores spontaneously because it is non-wetting for all pores. Application of pressure forces mercury into pores. Pore diameter, D is given by the intrusion pressure, p.

$$D = - 4 \gamma \cos \theta / p \qquad\qquad\qquad [1]$$

Where γ is the surface tension and θ is the contact angle of the intrusion liquid. The pore volume is given by intrusion volume. Thus, volume and diameter of both hydrophobic and hydrophilic pores are obtained by the mercury intrusion technique. From the measured pore volume, V and diameter, D, the pore volume distribution over diameter is computed in terms of the distribution function, F.

$$F = - (dV / d \log D) \qquad\qquad\qquad [2]$$

When water is used as the intrusion liquid, it fills the hydrophilic pores spontaneously, but requires pressure to be forced into hydrophobic pores. Consequently, water intrusion pressure yields diameter of hydrophobic pores, and volume of intruded water yields volume of hydrophobic pores. The relations given above are used to compute the pore structure of hydrophobic pores using θ as

the contact angle of water with hydrophobic pores. The measurements were made using the PMI Mercury/Water Intrusion Porosimeter.

Resistivity measurement: The resistivity of GDL was measured under compression. The GDL sample and a gasket were placed together inside a fuel cell and then, the fuel cell was assembled by applying clamping torque. For the measurement of resistance, a potentiostat was employed. At a fixed compression pressure, the voltage was measured when the current was applied to the cell with a potentiostat. The resistance was calculated from the voltage and current relation (i.e., Ohmic Law). This measurement was repeated for several compressive stresses up to about 300 psi.

Cell Performance tests: Before the cell performance tests, the internal compression pressure was measured. The compression pressure inside cell is function of thickness difference between a gasket and a GDL. The procedures of measuring the internal compression pressure were explained in the reference (3). The cell performance tests for various compression pressures and inlet humidity conditions are in progress. Tests will be conducted at the anode dry (i.e., the cathode humidification temperature changes when the dry hydrogen is supplied at the anode side), cathode dry (i.e., the anode humidification temperature changes when the dry air is supplied at the cathode), and both humidity conditions at fixed compression pressure. These data will show the effects of the permeability and resistivity on the cell performance. In the experiment, the cell temperature and back pressure are maintained at 70 ^{o}C and 101 kPa, respectively.

Results and Discussions

Effect of Compressive stress on Permeability of GDL: The thickness of GDL can change depending on the thickness of the gasket and the degree to which the gasket is compressed as the cells are clamped together. Compression not only reduces thickness, but also decreases porosity and increases gas phase mass transfer resistance. In this investigation, two GDLs were examined for the measurement of permeability. The results in Figure 1 demonstrate the strong effects of compressive stress on permeability of GDL A and GDL B.
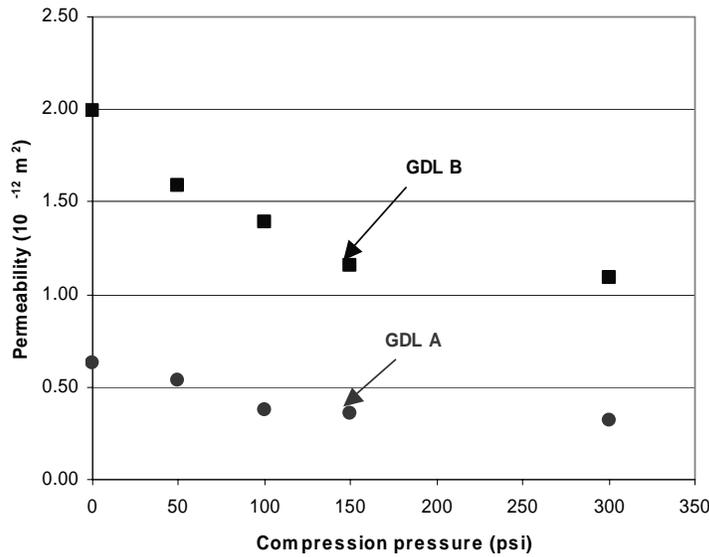

Figure. 1. Permeability changes for various compression pressures

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Dependence of permeability on compressive stress is similar in both materials. The permeability decreases at a decreasing rate and approaches a constant value. Such behavior is normally observed in porous materials (4). The permeability of GDL A is much lower than that of GDL B. In the absence of compressive stress, permeability of GDL A is only about 25 % of that of GDL B. Under pressure, permeability of GDL A is about 50 % of that of GDL B. Thus, permeability of the two GDLs becomes close under pressure.

Effect of Compressive Stress on Resistivity of GDL: Compression may increase the overall electron conductivity of the GDL, improve the contact resistance in the cell, and hence, minimize some of the electrical resistance losses inside the cell. Figure 2 shows the influence of compressive stress on resistivity. As expected the resistivity does decrease appreciably with increase in compressive stress. GDL B shows higher resistivity than GDL A. Resistivity of GDL A is about 65 % of that of GDL B. When the compressive stress increases, the ratio of the resistivities does not change appreciably although the permeability of the two GDLs becomes closer.
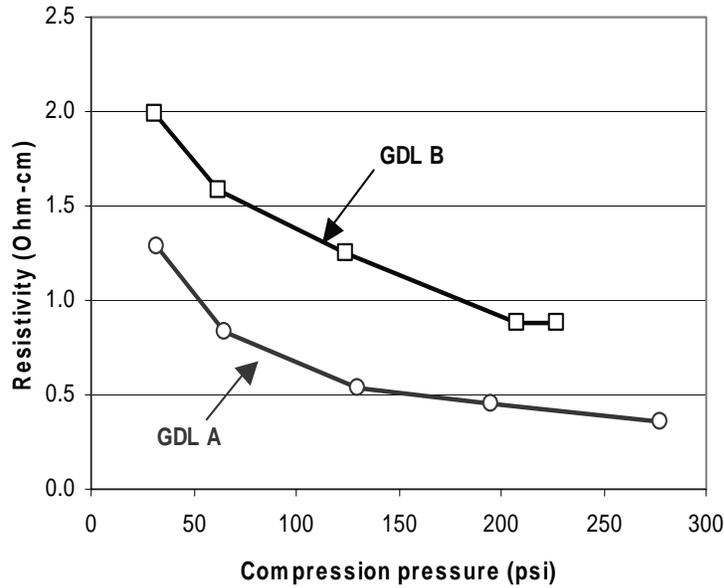

Figure. 2. Resistivity changes for various compression pressures

Hydrophobic and Hydrophilic Pore Structure: Figure 3 shows the variation of pore volume distribution function with pore diameter of GDL A. As suggested by Equation 2, the area under the distribution function in any pore diameter range is the volume of pores in that range. The distribution due to mercury intrusion gives pore volume distribution of hydrophobic and hydrophilic pores, where as the distribution due to water intrusion gives the volume distribution of only the hydrophobic pores. The difference represents the distribution of hydrophilic pores. The results summarized in Table 1 show that the hydrophobic pores and hydrophilic pores are present in equal parts and the mean pore diameter (volume based) of hydrophilic pores is a little less than that of hydrophobic pores.
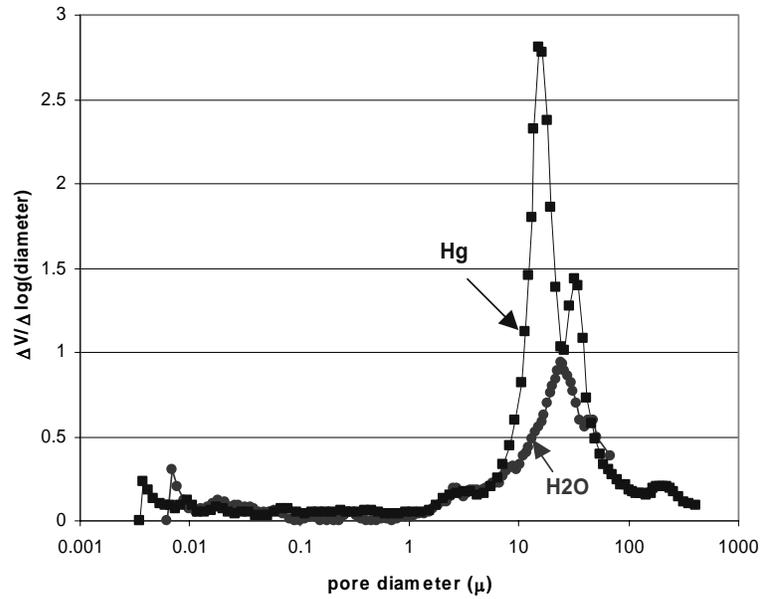
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Figure 3. Pore size distribution for GDL A

Table 1 Characteristics of pores

Characteristics	Total pores	Hydrophobic pores	Hydrophilic pores
Pore volume, cc/g	1.55	0.78	0.77
Pore volume, %	100	50.3	49.7
Mean pore diameter			
(Based on volume), μm	16.3	17.1	< 16.3

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