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Short communication

Effect of a GDL based on carbon paper or carbon cloth on PEM fuel cell performance

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A B S T R A C T

A commercially available GDL based on carbon paper or carbon cloth as a macroporous substrate was characterized by various physical and electrochemical measurements: mercury porosimetry, surface morphology analysis, contact angle measurement, water permeation measurement, polarization techniques, and ac-impedance spectroscopy. SGL 10BB based on carbon paper demonstrated dual pore size distribution and high water flow resistance owing to less permeable macroporous substrate, and more hydrophobic and compact microporous layer, as compared to ELAT-LT-1400 W based on carbon cloth. The membrane-electrode-assembly fabricated using SGL 10BB showed an improved fuel cell performance when air was used as an oxidant. The ac-impedance response indicated that a microporous layer which has high volume of micropores and more hydrophobic property allows oxygen to readily diffuse towards the catalyst layer due to effective water removal from the catalyst layer to the gas flow channel.

1. Introduction

A gas diffusion layer (GDL) is embedded between the catalyst layer and the gas flow channel in proton exchange membrane (PEM) fuel cells. The GDL mainly functions as (i) a gas diffuser, (ii) a current collector, and (iii) a physical support, thus determining the catalyst utilization and the overall performance. It also permits gas-phase water to reach the membrane and liquid-phase water to come out of the catalyst layer. A GDL is wet-proofed to prevent water flooding and enhance reactants transport to the catalytic active sites [1–3].

A GDL typically consists of a macroporous substrate and a microporous layer (MPL) of carbon black. Woven carbon cloth or non-woven carbon paper is widely used as a macroporous substrate due to its high gas permeability and electronic conductivity [2]. An MPL reduces ohmic resistance between the catalyst layer and the macroporous substrate, provides non-permeable support during catalyst deposition, and manages liquid water flow [4,5].

The effect of a single-layer GDL (e.g., carbon paper and carbon cloth) on the fuel cell performance has been studied by several researchers, who demonstrated that carbon cloth led higher performance, primarily due to higher porosity and less water saturation [6–8]. Also, extensive work has been performed to examine how the MPL properties such as (i) carbon powder type [4,9], (ii) carbon loading (or MPL thickness) [4,10–13], and (iii) hydrophobic agent concentration [14–16] control water management in PEM fuel cells. However, the effect of the macroporous substrate in a GDL on pore characteristics for the reactant and the product transport has not been addressed in literature extensively. The objective of this work is to characterize physical properties of a commercially available GDL prepared with carbon paper or carbon cloth and examine how the GDL properties affect water management and oxygen flow during PEM fuel cell operation.

2. Experimental

2.1. Physical characterization of gas diffusion layer

Porous structures of the GDLs were analyzed by using a mercury porosimeter (Micromeritics Autopore 9500). In order to perform analysis, small pieces of a GDL were weighed and loaded onto a penetrometer which consists of a sample cup integrated with a metal-clad and glass capillary stem, followed by outgassing from a GDL in a vacuum. Then the penetrometer was automatically filled with mercury. Pore size distribution (PSD) curve was determined from the mercury intrusion data, i.e., the volume of mercury penetrating the pores versus the applied pressure p. Under the assumption that all pores are cylindrical, the pore diameter d_p was calculated from the value of p using a well-known capillary law [17]:

$$d_p = \frac{4\gamma \cos\theta}{p} \quad (1)$$

where γ and θ denote the surface tension of mercury and the contact angle of mercury with the sample, respectively.

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Water transport characteristics through the GDL were determined using the laboratory-fabricated water permeation cell, as shown in Fig. 1. A GDL sample with a diameter of 5 cm was placed into the water permeation cell. Water was slowly added to the inner cylinder in the cell until the hydrostatic head (i.e., water height from the GDL) reaches 102 cm (≈10 kPa) with the valve closed. When the value was open and the water started to flow, the amount of water passing through the GDL was recorded with time. The water at the outer cylinder was circulated at 20 °C using the water bath.

Surface morphology of a GDL was examined using scanning electron microscope (Hitachi). Hydrophobic nature of an MPL was characterized by surface contact angle measurement using a contact angle standard goniometer (Ramé–Hart Instrument).

2.2. Preparation of membrane-electrode assembly

The cathode catalyst ink was prepared by ultrasonically blending Pt/C powder (45 wt.% Pt, Tanaka) with Nafion solution (5 wt.% Nafion, Alfa Aesar), deionized water and methyl alcohol for 2 h. The catalyst ink was sprayed onto one side of the Nafion 112 membrane until a total Pt loading of 0.4 mg cm^{-2} was achieved. A commercially available catalyzed GDL (20 wt.% Pt/C, 0.5 mg cm^{-2} Pt, E-TEK) was used as the anode for all fuel cell tests. The Nafion-coated anode (1.2 mg cm^{-2}) was hot-pressed to the uncatalyzed side of the membrane at 140 °C and at 15 atm for 90 s. Finally, the GDL of interest was placed on the cathode catalyst layer.

2.3. Electrochemical measurements

Electrochemical experiments were carried out in a single cell with serpentine flow channels. Pure hydrogen gas humidified at 77 °C and air humidified at 75 °C were supplied to the anode and cathode compartments. All the measurements were performed at 75 °C and at ambient pressure. Polarization technique was conducted with a fully automated test station (Fuel Cell Technologies Inc.) using a 30 mV potential step and a 5 min dwell time. The stoichiometry of hydrogen and air was 2.0 and the geometric area of the MEA used was 25 cm^2. The electrochemical impedance measurement was performed by applying an ac-amplitude of 10 mV over the frequency range from 10 mHz to 10 kHz.

3. Results and discussion

Table 1 lists the physical characteristics for four commercially available GDLs: SGL 10CA (carbon paper loaded with 10 wt.% PTFE, SGL Carbon), Carbon Cloth A (carbon cloth loaded with 10 wt.% PTFE, E-TEK), SGL 10BB (carbon paper loaded with 5 wt.% PTFE and the MPL, SGL Carbon) and ELAT-LT-1400 W (carbon cloth loaded with no PTFE and the MPL, E-TEK). All pore characteristics were estimated from the analyses of mercury intrusion data. The average pore diameter $d_{p,ave}$ was determined using the Carman–Kozeny theory [18]:

Table 1
Physical characteristics for commercially available GDLs.

Property	SGL 10CA	Carbon Cloth A	SGL 10BB	ELAT-LT-1400 W
Total thickness δ_t (μm)	380	360	420	380
Total pore volume V_t (cm^3 g^{-1})	3.5	2.3	2.3	1.6
Median pore diameter $d_{p,med}$ (μm)	52.1	71.2	37.7	7.8
Average pore diameter $d_{p,ave}$ (μm)	6.8	5.9	0.5	0.3
Characteristic length l_{ch} (μm)	77.4	194.6	45.3	34.9

$$d_{p,ave} = \frac{4V_t}{A_t} \quad (2)$$

where V_t and A_t denote the total pore volume and the total pore surface area in a GDL. As summarized in Table 1, the median pore diameter $d_{p,med}$ and the characteristics length l_{ch} which represents the largest drainable pore size for Carbon Cloth A is larger than those for SGL 10CA, while SGL 10CA demonstrates higher value of $d_{p,ave}$. It is typically attributed to their different porous structures between non-woven carbon paper and woven carbon cloth shown in Fig. 2(a) and (b) [2]. For a dual-layer GDL, as presented in Fig. 2(c) and (d), MPLs are densely coated on the different substrates and surface morphology for both MPLs is quite similar. However, SGL 10BB is ca. 4.8 times higher than ELAT-LT-1400 W in terms of $d_{p,med}$, although $d_{p,ave}$ for SGL 10BB is slightly higher. The results indicate there exists different pore geometry coupled with macroporous substrate between SGL 10BB and ELAT-LT-1400 W.

Fig. 3 shows the PSD curves (dV/dlogd_p) for SGL 10CA, Carbon Cloth A, SGL 10BB, and ELAT-LT-1400 W. As seen in Fig. 3, most of pores in SGL 10CA are observed between 20 and 100 μm, indicating that carbon fibers randomly arrayed result in single PSD. However, Carbon Cloth A exhibits dual PSD in the 2–50 μm and 100–300 μm ranges, which results from the void volume between individual carbon fibers and between carbon yarns (bundles of carbon fibers). It is also observed that there is no significant difference between two single-layer GDLs at smaller pores ($d_p < 2$ μm). Comparing the PSD data for dual-layer GDLs, it is obvious that in the case of SGL 10BB, the pore size ranges between 0.01 and 0.1 μm in the MPL and from 6 to 300 μm in the carbon paper. In contrast, the PSD for ELAT-LT-1400 W is highly uniform over the whole pore sizes. Furthermore, higher volume of pores ranging from 0.1 and 10 μm is observed for ELAT-LT-1400 W. This indicates that the MPL in ELAT-LT-1400 W is significantly entrenched into carbon cloth, reducing large pores ($d_p > 6$ μm) during the MPL deposition. Fig. 3 also illustrates differential pore volume (dV/dd_p) against pore size for SGL 10BB and ELAT-LT-1400 W (see the inset). SGL 10BB contains more micropores ranging from 0.01 to 0.1 μm, when compared to ELAT-LT-1400 W. Hence, the mercury intrusion porosimetry in this study specifies that a single-layer GDL based on carbon cloth has larger characteristic length and pore volume at $d_{p,ave} > 150$ μm due to its woven structure, as compared to that based on carbon paper, which makes carbon particles readily introduced into the pores between carbon yarns during the MPL deposition [19].

In PEM fuel cell, the liquid water produced and condensed at the cathode catalyst layer flows through the GDL, depending on pore geometry as well as hydrophobicity in the GDL [20,21]. For a dual-layer GDL, liquid water transport is not strongly affected

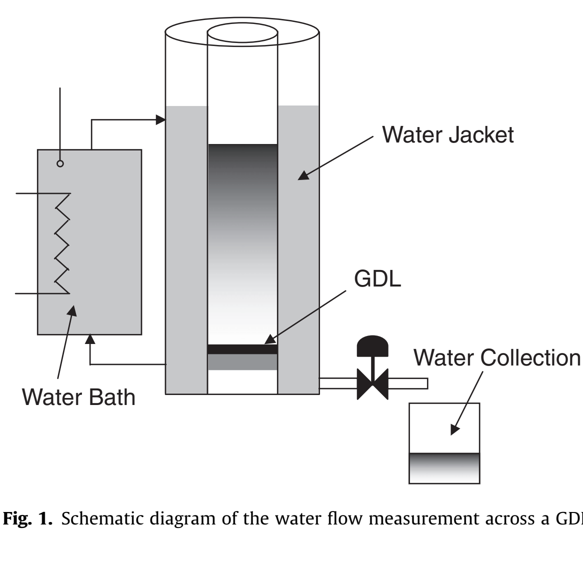

Fig. 1. Schematic diagram of the water flow measurement across a GDL.