Effective Diffusivity Measurement of Partially-Saturated Diffusion Media

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Optimal water management in proton-exchange-membrane fuel cells (PEMFCs) is critical to enable high power and efficient energy conversion. The proton-exchange membrane (Nafion®) needs to remain hydrated for high proton conductivity, while flooding of the cathode porous media, e.g., catalyst layer (CL), microporous layer (MPL), and gas-diffusion layer (GDL), hinders the gaseous reactant transport and thereby limits cell performance (1). Thus, fundamental understanding of the reactant transport through these porous media in the presence of water is essential for performance optimization and material design.

The effective diffusivity of a porous medium is generally related to the porosity and tortuosity,

$$\frac{\langle D \rangle}{D} = \frac{\varepsilon}{\tau} = f(\varepsilon)g(S) \tag{1}$$

where $\langle D \rangle$ is the effective diffusivity, D is the bulk diffusivity, ε is the porosity, and τ is the tortuosity. Water-filled pores hinder gaseous reactant flows, resulting in increased tortuosity. Thus, the effective diffusivity can also be expressed by normalized functions of porosity and liquid saturation, i.e., $f(\varepsilon)$ and $g(S)$, respectively, where S is the liquid saturation (ratio of water-filled volume to the total pore volume). Those relations have been theoretically studied (2, 3), but need to be validated experimentally or improved based on the experimental results. In this study, the effective diffusivities of unsaturated and partially-saturated fuel-cell porous media are experimentally examined using an ex-situ electrochemical limiting-current method for typical fuel-cell diffusion media including different PTFE loadings.

Experimental

The effective diffusivity was measured using the limiting current in an electrochemical hydrogen-pump cell (4). The cell consisted of a membrane-electrode assembly (MEA), GDLs/MPL, and flow channels. The MEA (Ion Power, Inc.) was a NR212® membrane with a Pt/C catalyst loading of 0.4 mg Pt/cm^2 on both sides. The MEA was sandwiched with the dry GDL (SGL10AA in the reference/counter electrode) and dry or partially-saturated tested GDL (in the working electrode), e.g., SGL Sigracet 10, Toray-TGP-120, and Freudenberg H2315. In the reference electrode, 4% H$_2$ in Ar gas was used, while in the working electrode, 1000 ppm H$_2$ in Ar gas was supplied. Such a diluted H$_2$ gas was used to ensure that the limiting current was limited by the H$_2$ diffusion through porous media in the working electrode. The effective surface area was 3.74 mm^2.

Results

The measured effective diffusivities of the partially-saturated GDL are shown in Figure 1(a). For GDLs without PTFE $g(S)$ can be fit to a power law. PTFE treatment favorably changes the liquid distribution for improved gas-transport pathways, especially at low saturations, and a new correlation is proposed using a cumulative log-normal distribution function.

The measured effective diffusivities of a combined GDL and MPL are shown in Figure 1(b). Comparing with GDL alone, the MPL does not seem to have a significant impact on the effective diffusivity. This is perhaps caused by the dominant transport resistance being related to the relatively large thickness and increased tortuosity change by the water-filling pores of the GDL, as well as perhaps the presence of cracks in the MPL.

This work provides insights for fuel-cell models and transport phenomena, which can lead to the optimal GDL/MPL material design and cell operation.
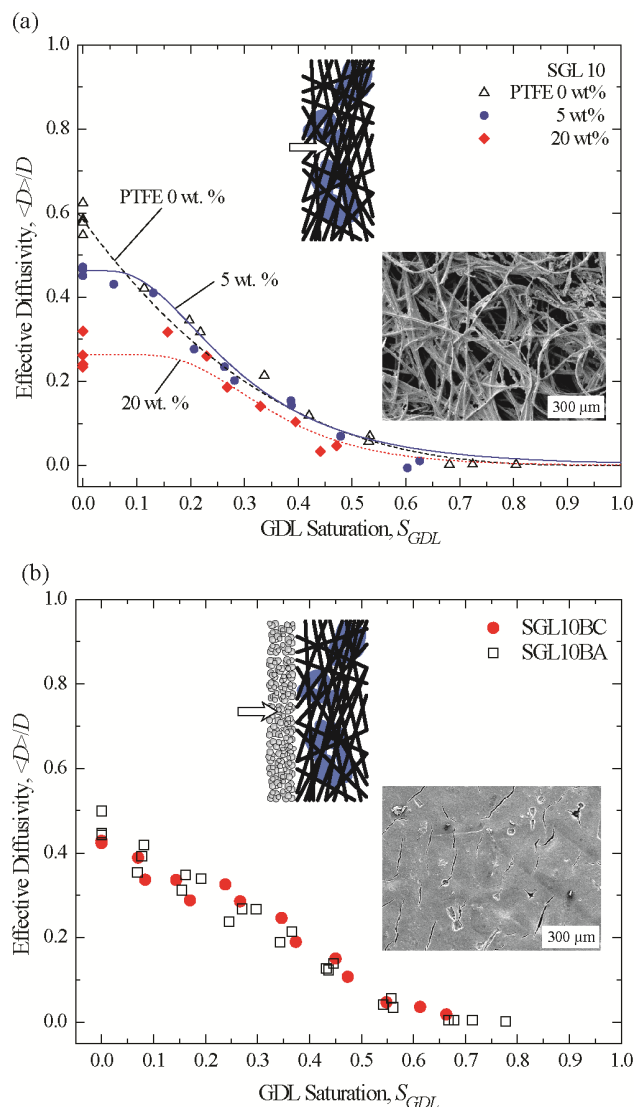

Figure 1. Effective diffusivities of partially-saturated (a) SGL10 series, and (b) SGL10BA and 10BC.

References

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