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Short communication

Probing water distribution in compressed fuel-cell gas-diffusion layers using X-ray computed tomography

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ABSTRACT

X-ray computed tomography was used to investigate geometrical land and channel effects on spatial liquid-water distribution in gas-diffusion layers (GDLs) of polymer-electrolyte fuel cells under different levels of compression. At low compression, a uniform liquid-water front was observed due to water redistribution and uniform porosity; however, at high compression, the water predominantly advanced at locations under the channel for higher liquid pressures. At low compression, no apparent correlation between the spatial liquid water and porosity distributions was observed, whereas at high compression, a strong correlation was shown, indicating a potential for smart GDL architecture design with modulated porosity.

1. Introduction

Effective liquid-water management is essential for commercializing polymer-electrolyte fuel cells (PEFCs). At lower operating temperatures, there is a need to remove liquid water from the cathode electrode to ensure reactant (oxygen) transport [1–4]. To achieve maximum water permeation, it is necessary to optimize the gas-diffusion layers (GDLs), which are porous backing layers between the catalyst layer and flowfields. Although water transport in GDLs has been investigated with modeling [5–7] and experiments [8,9], there are still unresolved questions, especially under *in-operando* conditions wherein the GDLs are selectively compressed under flowfield lands but remain uncompressed under flowfield channels. Several studies have used X-ray computed tomography (XCT), which is a high-resolution, non-intrusive characterization technique that can visualize water distribution in GDLs and PEFCs [10–16]. Previous *in-situ* studies of water permeation through GDLs predominantly concentrated on uncompressed samples. Recently, the morphology of dry GDLs with land and gas-channel effects was characterized using XCT [17,18], but those studies did not investigate the water redistribution under different GDL compressions. Currently, there is a gap in understanding how flowfield compression effects liquid-water permeation and distribution inside the GDLs under the flowfield lands and channels.

Herein, we report spatially-resolved liquid-water distributions in GDLs at different levels of compression with land and channel effects using an *in-situ* and *ex-operando* experimental set-up and XCT. Liquid-water pathways for different compressions are correlated to local porosity distributions and the three-dimensional morphology of water clusters is quantified.

2. Experimental

Fig. 1a) and b) shows a schematic of the experimental setup and a photograph of the sample holder mounted on the stage. The experimental setup consists of an aluminum stage with a water column inside, a thin-walled, Kapton tube with cap, and a grooved 1 mm punch to represent the PEFC land/channel geometry. An ultra-fine pitch thread was used to fine-tune the compression of the GDL sample. SGL® 10 BA carbon paper was used with an average thickness of 400 μm, a reported uncompressed porosity of 0.88, and containing 5% PTFE treatment. Capillary pressure and water saturation were controlled hydrostatically using liquid-water column height.

The collection of tomographic data was performed at Beamline 8.3.2 at the Advanced Light Source (ALS). The source energy was 14 keV, the number of back-projections was 1025, and an exposure time of 500 ms, a 0.5 mm LuAG scintillator, 5× lenses, and a sCMOS (PCO.edge) camera with a 3.3 × 3.3 mm field of view produced an image with a resolution of 1.33 μm. Image reconstruction was done with commercial software Fiji and Octopus 8.5 [19]. The imaged data

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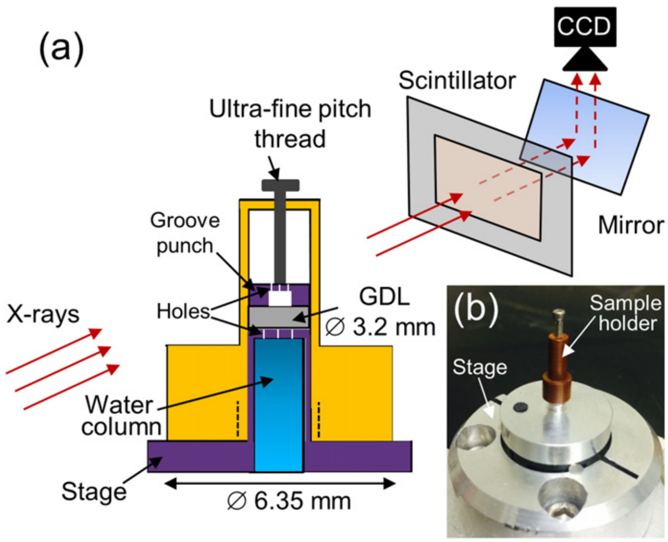

Fig. 1. Experimental set-up including a) the schematic of a sample holder and b) a photograph of the sample holder mounted stage.

was of a high quality and minimal filtering was necessary for accurate segmentation.

3. Results and discussion

3.1. Tomography of compressed GDLs with water intrusion

Fig. 2a), b) and c) shows spatially-resolved liquid-water distribution for a 2.4 mm field of view under locations of land and channel for GDL compressed thicknesses of 340, 260, and 210 μm, herein referred to as A, B, and C, respectively. The stress and compression of the samples are reported in Table 1. Imaging was done for increasing capillary pressure (liquid-column height) until water breakthrough was observed. The local porosity for each sample and the reconstructed and segmented tomographs at a centerline cross-section are shown as well, where reduced porosity under the lands is observed due to compression. Porosity and saturation were calculated as cross-section averages parallel to the channel and land directions (*i.e.*, in-plane direction). Liquid-saturation levels remain low as breakthrough is reached at low values, in agreement with *ex-situ* measured water-retention curves [20]. Higher saturation levels are observed for higher liquid-water pressures. The liquid-water saturation front is nonuniform, where variations in local liquid saturations can be as high as 0.45.

This liquid-water distribution heterogeneity is normalized by water retention curves, commonly used to characterize liquid-water saturation as a function of liquid pressure in the PEFC modeling community [4,20]. As Fig. 3a) shows, for all measured liquid pressures, the volume-averaged liquid-water saturation remains below 0.27. Under the channels the average saturation is higher for all three samples. This increase is particularly pronounced at higher capillary pressures. Such local heterogeneities in saturation imply that expressions which use the volume-averaged values (*e.g.*, effective diffusivities) [21,22] will predict incorrect values, as they do not capture land/channel effects as well as local water distributions, which has recently been discussed [15].

The average liquid-front position normalized by the GDL's compressed thickness is shown in Fig. 3b). The liquid front advances approximately linearly with liquid pressure, and the front position under the channel is further than for the whole sample, thus indicating preferential water pathways. The average front position is much smaller at breakthrough than the GDL thickness, showing that water fingering is occurring. For PEFCs, the average liquid-front position represents the

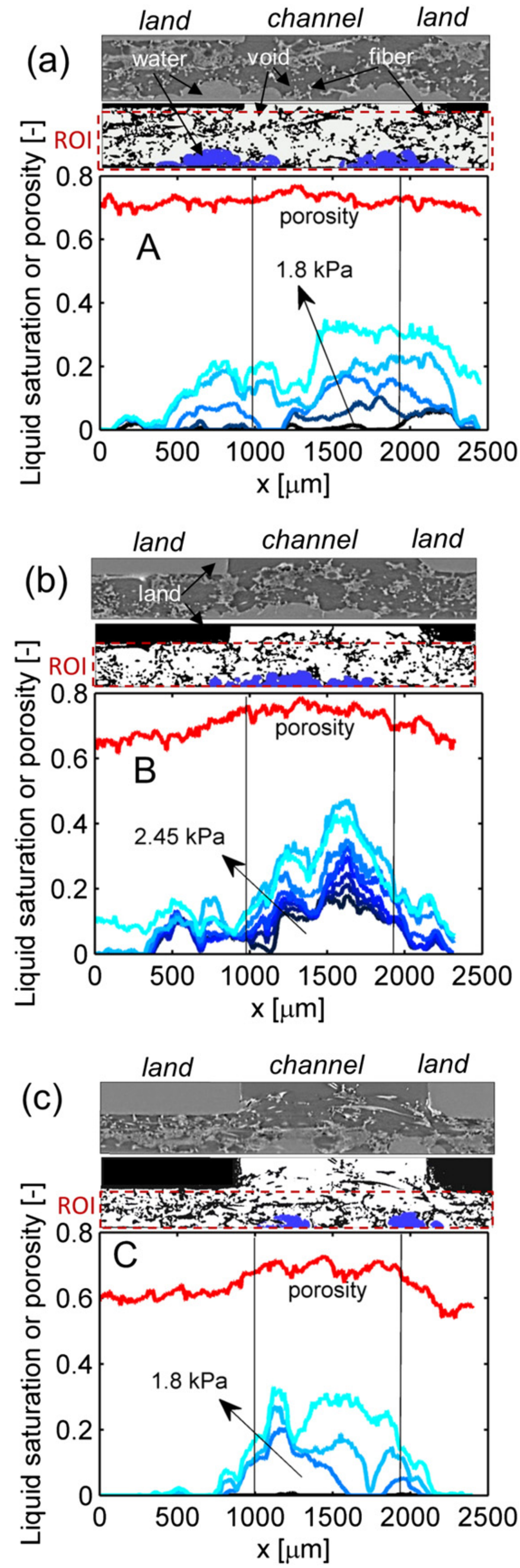

Fig. 2. Average liquid-water saturation and porosity as a function of position under lands and channel for GDLs under three levels of compression (see Table 1) with pressure ranges of a) 0.1 to 1.8 kPa, b) 0.3 to 2.45 kPa and c) 0.1 to 1.8 kPa. The reconstructed and segmented tomographs are located on top; the region of interest (ROI) used to compute the distributions is marked.