Liquid Water Storage and Removal from Polymer Electrolyte Fuel Cells

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Introduction

The residual water content stored in fuel cell media under steady or time-varying operation is of great interest, because it can play a critical role in the operating performance, pressure loss, degradation via ionic contaminants or mechanical damage, and time to start and degradation from a frozen condition. Liquid water storage and distribution in the diffusion media of polymer electrolyte fuel cells (PEFCs) is not solely a function of the diffusion media properties, however, and although the diffusion media plays a strong role in water removal, the interface between the land and diffusion media also has an important influence on the water storage and removal rate under steady and transient operation. In these studies, the relationship between the diffusion media, channel geometry, land area, and interfacial forces on the water storage in the fuel cell are being investigated. Non-intrusive water visualization within a full-sized fuel cell is not possible without neutron radiography. It produces excellent resolution and remains non-intrusive. This is helpful in performance tests and model validation efforts.

Experimental Setup

The tests in this study were done in the Neutron Beam Laboratory at the Penn State Radiation Science and Engineering Center using the Breazeale Nuclear Reactor to provide the thermal neutron beam. The water in the fuel cell attenuates the neutron beam and a CCD camera is used to capture both steady state images and transient videos. Custom software developed by Penn State quantifies the liquid water in the cell and produces water mass versus cell location images. The water in the channels and in the diffusion media under the channels is also differentiated from the water under the landings of the flow field using a masking technique.

On of the many fuel cells used is shown in Figure 1. On the left side, a black and white neutron image of an operating, 50cm^2 active area fuel cell is shown. On the right side, the active area of the fuel cell (area in which electrochemical reaction takes place) is magnified, and the image has been falsely colored to identify liquid water storage locations. Through extensive experimental study, we have found that a complex interaction exists between the fuel cell media, geometry, interfaces, and surface properties that controls the liquid water stored in the diffusion media. The greatly complicates matters compared to traditional theory, which only considered the material properties of the diffusion media to dominate multi-phase flow in these media. This work has therefore opened up a new area of study in fuel cell science, trying to define this complex relationship.

Testing for these studies has involved small and full size stack cells, at ambient, heated, and even frozen conditions. Figure 2 shows a 7 channel parallel fuel cell that has been frozen to -10^{o}C after shutdown.

Results

Surface Treatment

Space limitations preclude the complete discussion of the results of the channel geometry, frozen cell, neutron tomography, and DM studies. In this brief report, the effect of channel wall surface treatment is discussed. Figure 3 is a preliminary result comparing a gold-coated hydrophilic wall fuel cell at 10A, 80^{o}C, with 100/100 humidity inlets, with the same fuel cell having one half of the wall surfaces coated with a hydrophobic wall treatment. The landing area was not altered for testing, only the channel walls were treated to provide a hydrophobic surface that is very different than the normal hydrophilic surface of the gold plating used. Clearly, there is a significant difference generated by the hydrophobic surface treatment, but this interfacial effect is not included in any published multi-phase models.

Channel/Land Geometry

Other results illustrate the large influence that the channel/land geometry and diffusion media type have on water storage. Figure 4 shows the area water density measured in the fuel cell under the lands and in/under the channels measured for two different channel/land geometries. In these cases tested with a hydrophobic diffusion media, there is more water stored under the lands than in/under the channels. This is a result of the relatively low temperature and flow

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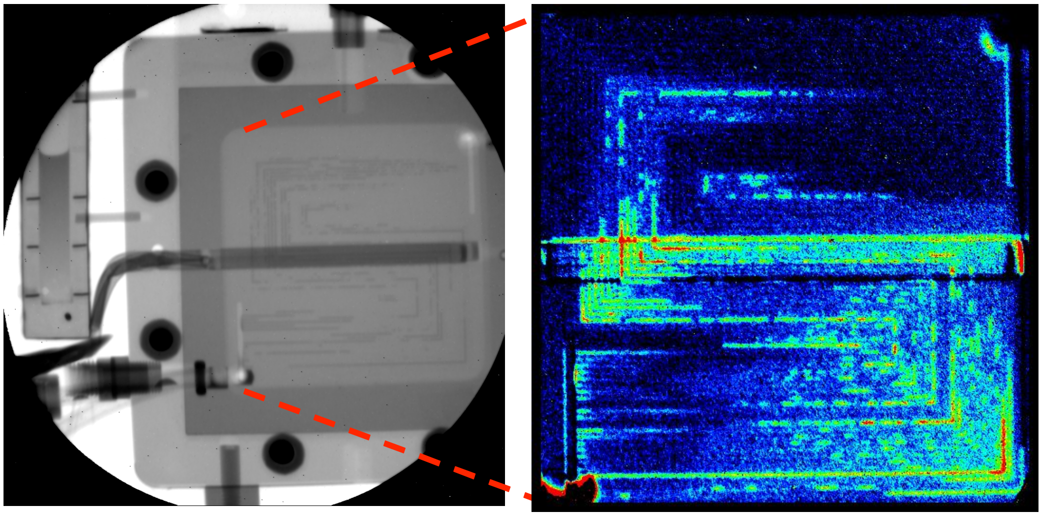

FIGURE 1: Raw neutron image and processed false color image of a 50 cm^2 fuel cell used in this study

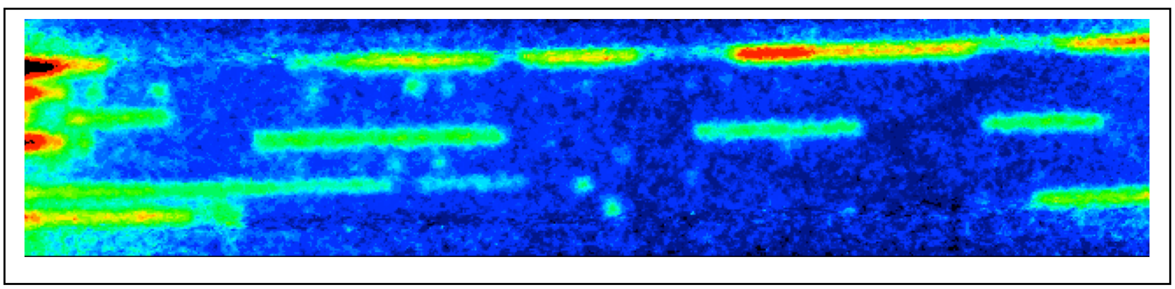

FIGURE 2. False color neutron image of a fuel cell frozen to -10°C, showing distribution of ice formations in a parallel flow channel fuel cell (Red is high ice thickness, blue is low ice thickness).

blockage affect of the land, although the imbalance between the land versus channel water content in the diffusion media appears to also be a function of the in-plane liquid permeability of the diffusion media.

For the woven cloth diffusion media tested, there is a reduced difference between channel and land water content, and the channel to land liquid water ratio is nearly 50:50 for a wide range of operating conditions. For paper DM, however, there is a greater difference between channel and land DM saturation in steady state. Also from Figure 4, it can be seen that the fuel cell with the largest channel to land ratio has the lowest water for a given condition. This condition was observed in all comparison cases, and is a result of the noted excessive liquid buildup under the land for the paper diffusion media. In general, to minimize liquid water storage in the diffusion media, a large channel to land ratio should be used with a DM with high in-plane liquid permeability.

Conclusions

Neutron radiography is an excellent non-intrusive technique to visualize the water distribution in a PEFC. There are several ongoing projects at the RSEC that investigate the liquid water storage and distribution in a PEFC. Several new physical phenomena have been revealed that are not currently considered in state-of-the-art computational models of PEFCs. In particular, the strong role of interfacial contact area and surface energy has been shown, that will continue to lead us toward a cell design with optimized water management.

Publications

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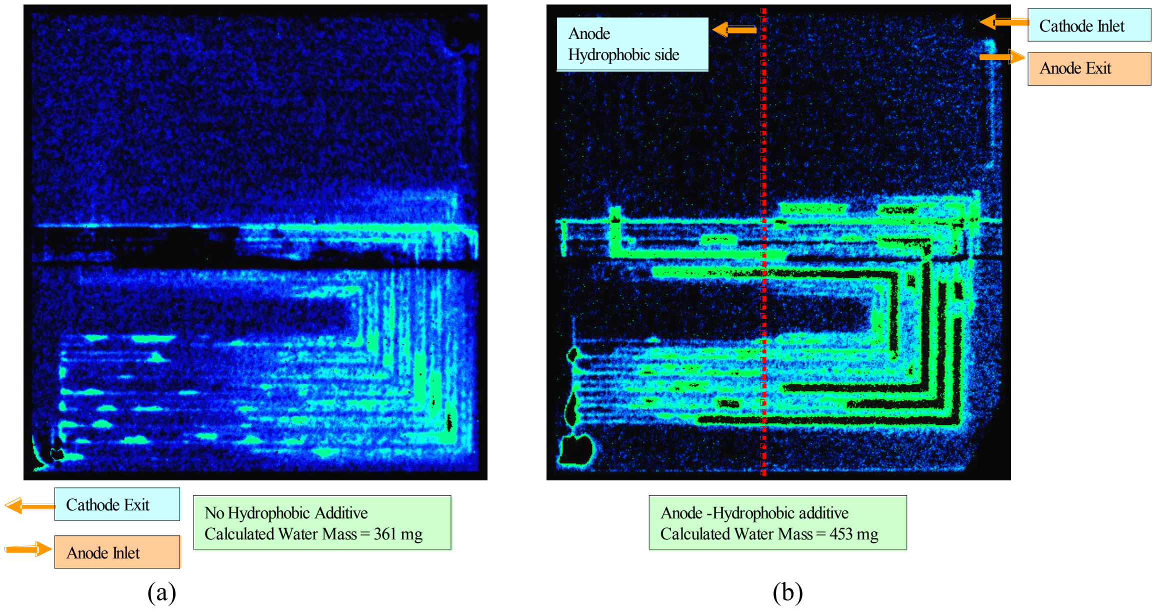

FIGURE 3. Comparison of fuel cell with a) hydrophilic gold channel walls with b) one half hydrophobic anode side walls. All other walls are still gold coated without hydrophobic additive.

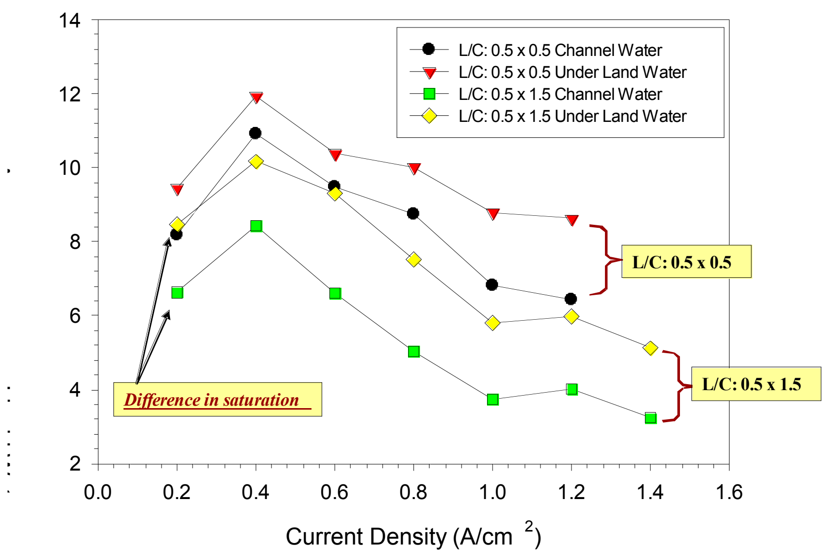

FIGURE 4. Area water density measured in the fuel cell under the lands and in/under the channels measured for two different channel/land geometries.

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