

## V.G.2 Neutron Imaging Study of the Water Transport in Operating Fuel Cells

Muhammad Arif (Primary Contact),  
David L. Jacobson, Daniel S. Hussey  
National Institute of Standards and Technology  
100 Bureau Drive  
Gaithersburg, MD 20899  
Phone: (301) 975-6303; Fax: (301) 926-1604  
E-mail: arif@nist.gov

DOE Technology Development Manager:  
Nancy L. Garland  
Phone: (202) 586-5673; Fax: (202) 586-9811  
E-mail: Nancy.Garland@ee.doe.gov

Start Date: FY 2003  
Projected End Date: Project continuation and  
direction determined annually by DOE

### Objectives

- Provide neutron imaging-based research and testing infrastructure to enable the fuel cell industry to design, test, and optimize prototype to commercial grade fuel cells.
- Provide a secure facility for proprietary research by industry. Make open research data available for beneficial use by the general fuel cell community.
- Continually improve and develop methods and technology to accommodate rapidly changing industry/academia needs.

### Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section (3.4.4.2) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- (A) Durability
- (D) Air, Thermal and Water Management

### Technical Targets

- Instrument: Development and operation of fuel cell neutron imaging testing facility.
- Research: *In-situ* nondestructive study of real time dynamic water transport in operating PEM fuel cells.
- Data Analysis: Develop accurate data interpretation and quantitative image processing.

### Accomplishments

- Discovered that there is competition between water transport mechanisms which can result in more water in the anode than cathode gas diffusion media.
- Measured the total water content of a cell and demonstrated that the effects of local heating and evaporation can lead to decreased cell water content at high cell temperature and current density.
- Demonstrated triangular cross-sectional flow channels improve both water removal and gas flow and enhance cell performance.

### Introduction

At the National Institute of Standards and Technology (NIST), we maintain the premier fuel cell neutron imaging facility in the world and continually seek to improve its capabilities. This facility provides researchers a very powerful and effective tool to visualize and quantify water transport inside operating fuel cells. Imaging the water dynamics of a proton exchange membrane fuel cell (PEMFC) is carried out in real time with the required spatial resolution needed for fuel cells that are being developed today. From these images, with freely available NIST developed image analysis routines, PEMFC industry personnel and researchers can obtain *in-situ*, nondestructive quantitative measurements of the water content of an operating PEMFC. Neutron imaging is the only *in-situ* method for visualizing the water distribution in a “real world” PEMFC. Unlike x-rays, whose interaction with materials increases with the number density of electrons, neutrons interact via the nuclear force, which varies somewhat randomly across the periodic table, and is isotopically sensitive. For instance, a neutron’s interaction with hydrogen is approximately 100 times greater than that with aluminum, and 10 times greater than that with deuterium. It is this sensitivity to hydrogen (and insensitivity to many other materials) that is exploited in neutron imaging studies of water transport in operating fuel cells.

### Approach

The typical scales of interest in a PEMFC are: channels approximately 1 mm wide and 1 mm deep, the gas diffusion media (GDM) is 0.1-0.3 mm thick, the membrane is 0.01-0.05 mm thick, and the active area is 50-500 cm<sup>2</sup>. Thus, to study *in-situ*, nondestructive water/hydrogen transport in PEM fuel cells while in operation and hydrogen transport/distribution in hydrogen storage media, we will develop new facilities

and improve existing capability for obtaining high spatial and temporal resolution neutron imaging. Employing the mathematical models of neutron scattering, we will develop a software suite that enables users to obtain quantitative measurements of the water content in an operating PEMFC. Due to the complexity of PEMFCs and the large number of open questions regarding water transport in PEMFCs, we will develop partnerships with industry and academia to train them in the use of the facility, collaborate with them on research projects, and seek their feedback to pursue future technical breakthroughs.

## Results

We achieved our FY 2006 milestone by completing the design, fabrication and installation of a new NIST neutron imaging facility (NNIF) at the NIST Center for Neutron Research in February 2006 (see Figure 1). The NNIF has joined the NIST Center for Neutron Research proposal system, making public access to the facility more transparent. This new facility has a large floor plan (more than 150 sq. ft.) allowing for innovative fuel cell experiments, as well as state-of-the-art fuel cell infrastructure. General users of the NNIF have access to a maximum hydrogen flow rate of 18.8 slpm and a fuel cell control test stand that has a 1.5 kW boost power supply, making the NNIF the world's premier facility for *in-situ* imaging of PEMFCs. At the new NNIF, in collaboration with our industrial, national laboratory and academic partners, we have carried out several non-proprietary experiments exploring the water transport mechanisms in the GDM of PEMFCs, as well as in the gas flow channels.

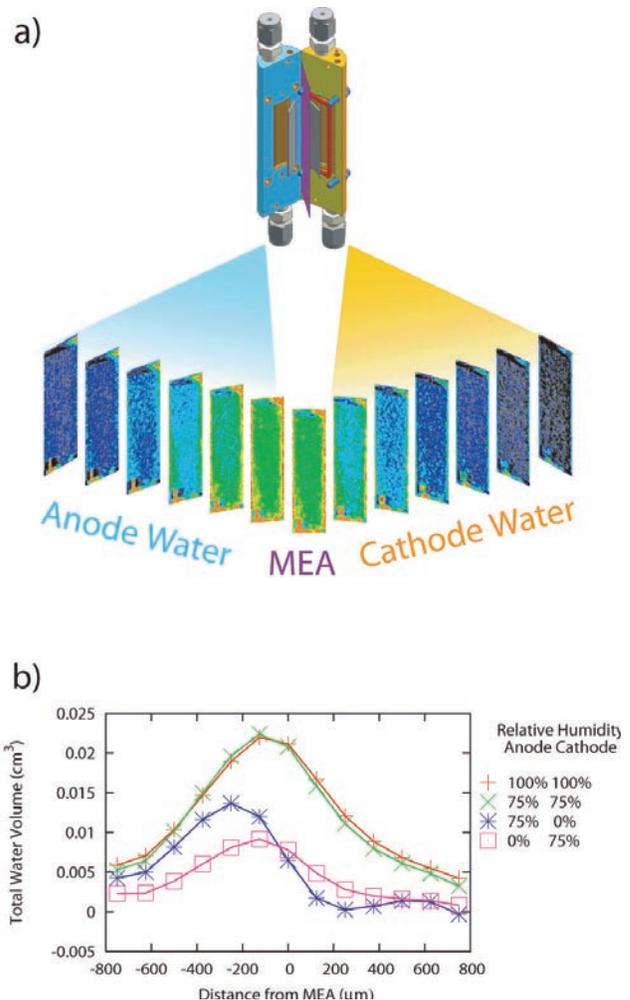
We have acquired the first *in-situ* tomographic images (3-D) of an operating fuel cell (see Figure 2), resulting in two significant findings. First, the water distribution peaks in the anode gas diffusion medium,



**FIGURE 1.** Photograph of the new NIST neutron imaging facility at the NIST Center for Neutron Research. This facility has greatly enhanced imaging and analysis capability enabling innovative fuel cell experiments and simplifying setup of routine hardware.

suggesting that operating parameters, or material choices need to be optimized to move the water distribution peak to the cathode. Second, the water distribution shape indicates that the dominant water transport mechanism in the diffusion medium is evaporation, with capillary pressure playing little to no role. We are conducting a set of follow-on experiments to confirm this hypothesis. Determining the dominant transport mechanism will have a great impact on refining fuel cell models.

We have measured the change in total water content for different fuel cell temperatures at several steady-state current densities. At high temperatures and current density, the membrane can become dehydrated, indicating that local heating improves evaporation. Future work will further elucidate the relationship



**FIGURE 2.** a) Images of the water distribution obtained from tomographic measurement of the test cell. The slice widths are 0.125 mm thick, yielding seven slices in each of the anode and cathode GDM, and one slice averaging the entire MEA. b) The total water in the soft goods for four different cases. The shape of the water distribution indicates that the primary water transport mechanism is evaporation. In addition, the peak of the water distribution is clearly in the anode of the cell.

between local heating, evaporation, and convection in order to pinpoint the water transport mechanisms in the gas diffusion medium.

We have demonstrated that a triangular cross-sectional channel geometry improves fuel cell performance through passively increasing the water removal rate of product water in the cathode channels. Neutron imaging confirmed that the triangular cross-section traps water at the vertex of the channel/GDM interface, keeping the gas flow channel clear of water slugs. The water removal of uncoated triangular channels surpassed that of poly-tetrafluoroethylene (PTFE) coated rectangular channels. The cell performance was increased, and the total water content of the cell was reduced, indicating that the triangular geometry improved water removal through a passive mechanism.

We have measured the hydration of the membrane in an operating cell without interference from the gas diffusion media or channel water. By measuring the water content of the portions of the membrane under the sealing gasket of the cell (outside of the active area), we can make inferences as to the hydration state of the membrane. Future work will help validate the technique so that it can be incorporated as a standard analysis tool.

## Conclusions

1. 3-D imaging indicates that the primary water transport mechanism in the GDM may be evaporation rather than capillary action.
2. Flow channels with triangular cross-section have been demonstrated to be more efficient in transporting water than conventional rectangular cross-sections, resulting in better fuel cell performance.
3. The relationship between hydration level, current density, and temperature has been characterized. The highest water content is not always observed at the greatest current density because of the competition between water generation and local heating.

## Future Directions

- Enhance the facility for fuel cell study at low temperatures (down to -40°C).
- Focus more on commercial size fuel cells and MEA robustness and efficiency studies.
- Develop and employ detectors with increasing higher spatial (eventual goal of 5 micrometer or better) and temporal resolution.
- Accelerate technology transfer to industry.

## FY 2006 Publications/Presentations

1. M.A. Hickner, N.P. Siegel, K.S. Chen, D.N., McBrayer, D.S. Hussey, D.L. Jacobson, M. Arif, "Real-time imaging of

liquid water in an operating proton exchange membrane fuel cell," *Journal of the Electrochemical Society* vol.153, no.5 p. A902-8 (2006).

2. D.J. Ludlow, C.M. Calebrese, S. Yu, C. Dannehy, D.S. Hussey, D.L. Jacobson, M. Arif, M.K. Jensen, G.A. Eisman, "PEM fuel cell membrane hydration measurement by neutron imaging", *Journal of Power Sources* (accepted).
3. T. Trabold, J. Owejan, D. Jacobson, M. Arif and P. Huffman, "In-Situ Investigation of Water Transport in an Operating PEM Fuel Cell Using Neutron Radiography: Part 1 - Experimental Method and Serpentine Flow Field Results", *International Journal of Heat and Mass Transfer* (accepted).
4. J. Owejan, T. Trabold, D. Jacobson, D. Baker, D. S. Hussey, M. Arif, "In-Situ Investigation of Water Transport in an Operating PEM Fuel Cell Using Neutron Radiography: Part 2 - Transient Water Accumulation in an Interdigitated Cathode Flow Field", *International Journal of Heat and Mass Transfer* (accepted).
5. Siegmund, O.H.W. , Vallerga, J.V., Martin,A., Feller, W.B., Arif, M., Hussey, D.S., Jacobson, D.L., "A high spatial resolution event counting neutron detector using microchannel plates and cross delay line readout", to be submitted to *Nuclear Instruments and Methods, Section A*.
6. D.S. Hussey, J.P. Owejan, D.L. Jacobson, T. A. Trabold, J. Gagliardo, M. Arif, "Tomographic imaging of an operating proton exchange membrane fuel cell", (in preparation).

## Presentations

1. D.L. Jacobson, B. Du, D.S. Hussey, M. Arif, "Tuning hydrogen content for improved PEMFC water management: A neutron radiography study", Second International Conference on Green and Sustainable Chemistry and the Ninth Annual Green Chemistry Engineering Conference, Washington, D.C., June 24, 2005.
2. D.L. Jacobson, D.S. Hussey, M. Arif, "Neutron Imaging for Fuel Cells and Hydrogen Storage", Gordon Conference on Hydrogen-Metal Systems, Waterville, ME, July 14, 2005.
3. D.L. Jacobson, D.S. Hussey, M. Arif, "Neutron Imaging at NIST: An in situ method for visualizing and quantifying water dynamics in low temperature PEM fuel cells", Fuel Cell Seminar, Palm Springs, CA, November 17, 2005.
4. D.L. Jacobson, D.S. Hussey, M. Arif, "NIST Neutron Imaging Facility for Fuel Cell Imaging", International Conference on Neutron Scattering, Sydney, Australia, November 28, 2005.
5. D.S. Hussey, J.P. Owejan, D.L. Jacobson, J. Gagliardo, T.A. Trabold, M. Arif, "Three Dimensional analysis of a Proton Exchange Membrane Fuel Cells with Neutron Tomography", International Conference on Neutron Scattering, Sydney, Australia, November 28, 2005.
6. D.S. Hussey, J.P. Owejan, D.L. Jacobson, J. Gagliardo, T.A. Trabold, M. Arif, "In situ Fuel Cell tomography at the new NIST Neutron Imaging Facility", American Conference on Neutron Scattering, St. Charles, IL, June 20, 2006.