< Technical Note >

VISUALIZATION OF THE INTERNAL WATER DISTRIBUTION AT PEMFC USING NEUTRON IMAGING TECHNOLOGY: FEASIBILITY TEST AT HANARO

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Neutron imaging technique was used to investigate the water distribution and movement in Polymer Electrolyte Membrane Fuel Cell (PEMFC) at HANARO, KAERI. The Feasibility tests were performed in the first and second exposure rooms at the neutron radiography facility (NRF) at HANARO in order to check the ability of each exposure room, respectively. The feasibility test apparatus was composed of water and pressurized air before making up the actual test apparatus. Due to the low neutron intensity in the second exposure room, the exposure time was too long to investigate the transient phenomena of PEMFC. Although the exposure time was improved to 0.1 sec in the first exposure room, it was difficult to discriminate detail water movement at the channel due to the high noise level. Therefore, the experimental setup must be optimized according to the test conditions. Water discharge characteristics were investigated under different flow field geometries by using feasibility test apparatus and the neutron imaging technique. The water discharge characteristics of a 3-parallel serpentine are superior to those of a 1-parallel serpentine, but water at Membrane Electrode Assembly (MEA) was not removed, regardless of the flow field type.

KEYWORDS : Neutron, Visualization, MEA, PEM Fuel Cell

1. INTRODUCTION

The polymer electrolyte membrane fuel cell (PEMFC) is one of the most promising candidates for automotive applications due to its high energy conversion efficiency and absence of chemical pollution. PEMFC usually uses hydrogen and oxygen as fuel in order to generate electricity, and heat and water are generated as byproducts during that procedure. These byproducts create several problems coupled with fluid flow, heat, and mass transfer processes. Moreover, water more seriously affects the efficiency of the PEMFC system since the proton conductivity of the membrane is highly influenced by the water content. If the water content at the membrane and channel is too low, the conductivity of proton is decreased and the efficiency is dropped. Conversely, too much water content causes flooding at the channel. The flooding impedes gas flow and also reduces the efficiency [1]. Therefore, it is necessary to visualize the channel and MEA of PEMFC to maintain the water content and distribution properly. Moreover, knowledge of the water movement and distribution in the channel and membrane of PEMFC is helpful to increase the efficiency [2,3]. However, since PEMFC is usually made of metallic parts, it is difficult to visualize it by ordinary methods, such as optical light.

The neutron imaging technique is one of the radiography methods which is a visualization technique that uses the attenuation of a radio ray at its transmission through the irradiated materials. X-ray, gamma-ray, and thermal neutrons can be used as a radio ray. A thermal neutron beam is the best choice to examine the inside of the PEMFC among these because the thermal neutron beam has unique characteristics for the attenuation coefficient compared with an X-ray and gamma-ray. Fig. 1 shows the mass attenuation coefficients of various elements for thermal neutrons and X-rays [4]. The mass attenuation coefficients of an X-ray increase monotonically with the atomic number. Thus, the X-ray imaging method does not supply sufficient contrast for light elements (for example, hydrogen and its compounds) when they are surrounded by heavy elements.

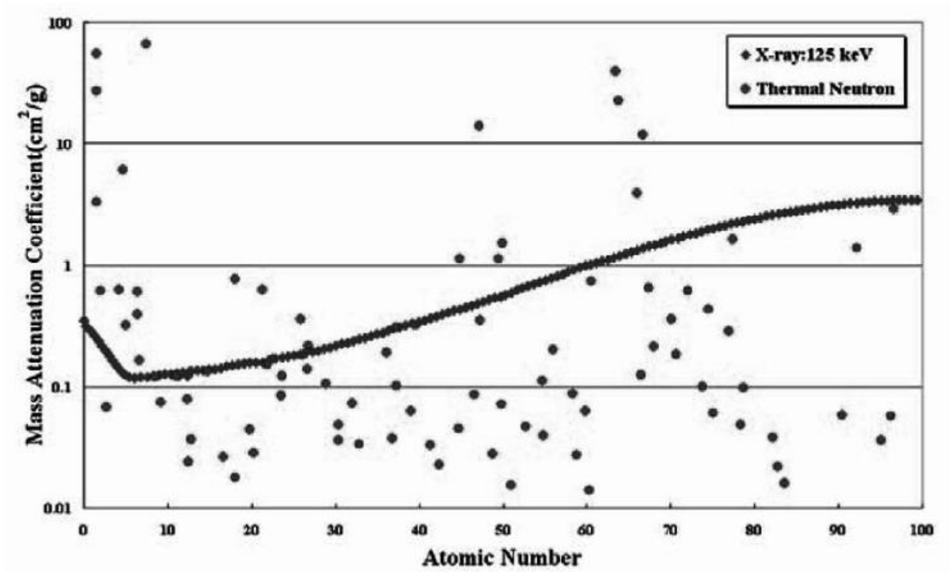

Fig. 1. Mass Attenuation Coefficient Among a Thermal Neutron and X-ray

On the other hand, the mass attenuation coefficient of thermal neutrons depends much on the nucleus. Thermal neutrons penetrate most of metals with particular ease, while they are strongly attenuated by such materials as hydrogen and water [5,6]. Most PEMFCs has a metallic coverage, made of aluminum, for example, and the water is generated during operation. Therefore, a thermal neutron is a powerful tool to visualize the water movement and distribution in PEMFC.

In this feasibility test, we checked the ability of the neutron radiography facility (NRF) at HANARO by using feasibility test apparatus. Then, the water discharge characteristics were investigated under different flow field geometries by using the neutron imaging technique.

2. EXPERIMENTAL SETUP AND NEUTRON IMAGE TECHNIQUE SYSTEM

In order to check the ability of the neutron radiography facility (NRF) at HANARO, the feasibility test apparatus was set up. The feasibility test apparatus consists of two parts: a water supply loop and pressurized air loop. Fig. 2 shows a schematic diagram of the feasibility test apparatus. Since the objective of this feasibility test was to identify the ability of the neutron imaging facility at HANARO, KAERI for the PEMFC research field, a real fuel cell test station was not needed. The distilled water and pressurized air was used in order to simulate an actual operating PEMFC. Because the water temperature during operation ranges from 60 to 80°C, a hot-plate was used to maintain a constant water temperature.

The water of the PEMFC is usually formed at the cathode. The water for the feasibility test is only supplied to the cathode by using a pressurized air and water tank. Since the PEMFC is opaque, it is difficult to know how much water exists at the cathode channel. The water is supplied about ten minutes into the cathode channel. The valve located at the outlet of the PEMFC is closed in order to entrap water in the cathode channel. The pressurized air is supplied for about 2 minutes, and then is stopped. Afterwards, the valve at the outlet of the PEMFC is opened. Finally the neutron images were taken supplying the pressurized air into cathode channel.

The two geometries sketched in Fig. 3 have been chosen to investigate the water discharge characteristics with an active area of 100 cm^2 single-cells. One illustration is a 1-parallel serpentine, and the other is a 3-parallel serpentine. In all experiments, the flow field used for anode and cathode are symmetric, disregarding their different demands for the sake of simplicity. The flow fields were directly machined into a carbon-graphite block. Both have a channel width and depth of $1\text{^}10^{-3}$ m, and the rib-to-channel ratio is 0.5. The GDL used at this study is Nafion-112.

All experiments described above were performed at the neutron radiography facility (NRF) at HANARO, KAERI. The NRF provides two measurement positions (first and second exposure rooms), with different neutron intensities (from 5×10^6 to 1×10^7 n/cm^2s) and collimation ratios (from 200 to 270). The thermal neutron intensity is the

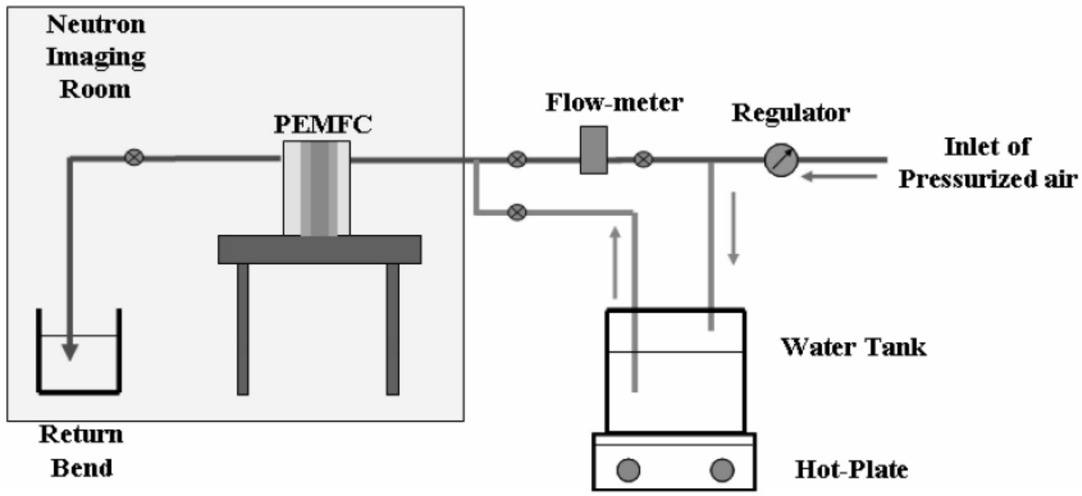

Fig. 2. Schematic Diagram of Test Apparatus

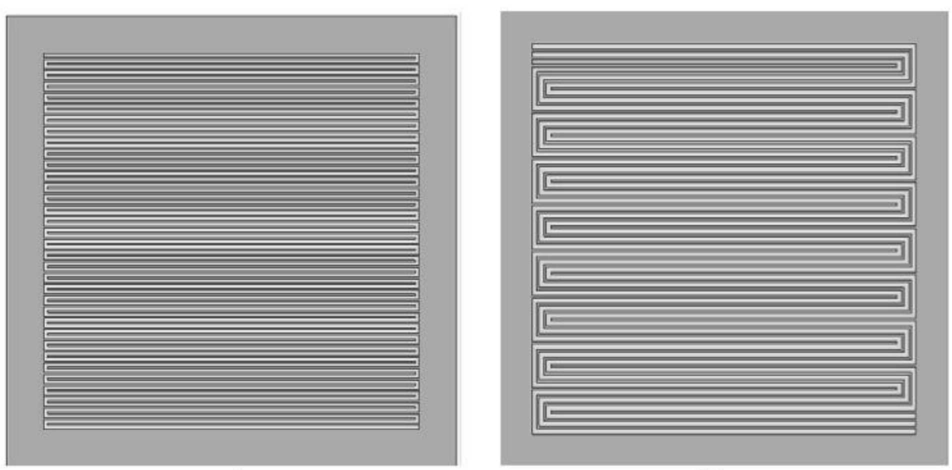

Fig. 3. Schematic Diagram of the Investigated Flow Field Geometries: a) Shows a Continuous Flow Field with a 1-Parallel Serpentine; b) Shows a Continuous Flow Field with a 3-Parallel Serpentine

highest at the front position towards the source (first exposure room), while the collimation ratio is best at the position with the greatest distance to the source (second exposure room). Therefore, a feasibility test was performed at each position in order to check the ability of the NRF, HANARO. The detecting system of this feasibility test consists of a neutron-sensitive scintillator fabricated by the Applied Scintillation Technologies and CCD camera with 1340×1300 pixels housed in a light tight box. The neutron beam is converted into light by the scintillator. The light is reflected by a mirror and then measured by the CCD camera with a f 1.4, 85 mm Nikon lens system. This design protects the camera against the neutron beam.

The neutron image of an operating PEMFC is the sum of the attenuations of non-changing parts and those of changing parts of the PEMFC with time. The non-changing parts of a PEMFC are composing materials, and the changing part is water distribution and movement. It is very difficult to discriminate the water distribution and movement with one image. Two kinds of neutron images (dry and wet) were taken, and the wet image was normalized by the dry image to see only the water effect.

3. RESULTS AND DISCUSSION

Fig. 4 is a dry neutron image of PEMFC developed at the second exposure room. The image is an averaged result of 100 images with exposure times of 20 sec. It is possible to see the components of PEMFC and part of the feasibility test apparatus, as shown in Fig.4. Since the exposure time is 20 sec, it is difficult to discriminate and determine the instant phenomena and the transition process of water distribution and movement at the PEMFC. From these results, the second exposure room of the NRF is not suitable for the instant phenomena of the PEMFC.

Fig. 5 is dry neutron images of the PEMFC taken at the first exposure room under various exposure times. Each image is an averaged result of 100 images with exposure times of 0.1 sec and 4 sec. The first exposure room has higher neutron intensity compared with the second exposure room, and the exposure time is improved from 20 sec to 0.1 sec. However, the neutron image taken at 0.1 sec uses very little of the dynamic range of the CCD camera. After normalizing the dry and wet images, too much noise remains. Due to the high noise level, the spatial resolution was lost, as shown in Fig. 6. The red color at Fig.6 means a high water fraction, and the black color stands for a low water fraction. Since the exposure time is short, it is possible to visualize the transient water movement and distribution in the channels of PEMFC. However, it is difficult to discriminate the detailed water behavior due to poor spatial resolution. Fig. 7 is a neutron image with an exposure time of 4 sec. The image quality of Fig. 7 is higher than that of Fig. 6, but since the exposure time is increased from 0.1 sec to 4 sec, the instant phenomena of the PEMFC were lost. Therefore, the temporal and spatial resolutions were optimized in order to investigate the PEMFC at the NRF, HANARO. Anyway, the NRF of HANARO is acceptable for the investigation of water movement and distribution at PEMFC.

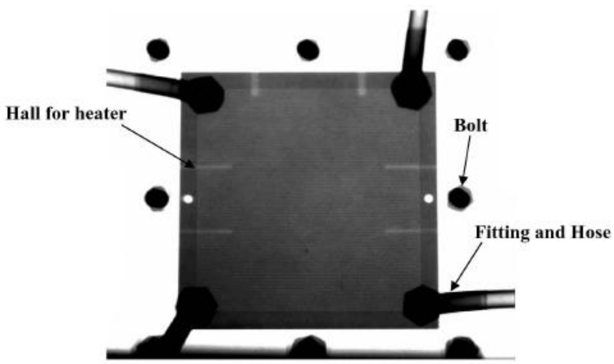

Fig. 4. Test Result at Second Exposure Room with 20 sec Exposure Time at 3-Parallel Serpentine

After checking the ability of the NRF, the water removal characteristics at PEMFC were investigated under a different flow field design at same flow-rate (200cc/min) by using the neutron imaging technique at the NRF, HANARO. The feasibility test was performed at first exposure room with a 4 sec exposure time. Figs. 8 and 9 are test results of different flow field geometries. Although the flow-rate is the same, the water discharge characteristics are different according to the flow field design. At the start position, each PEMFC has water in the channel, as shown

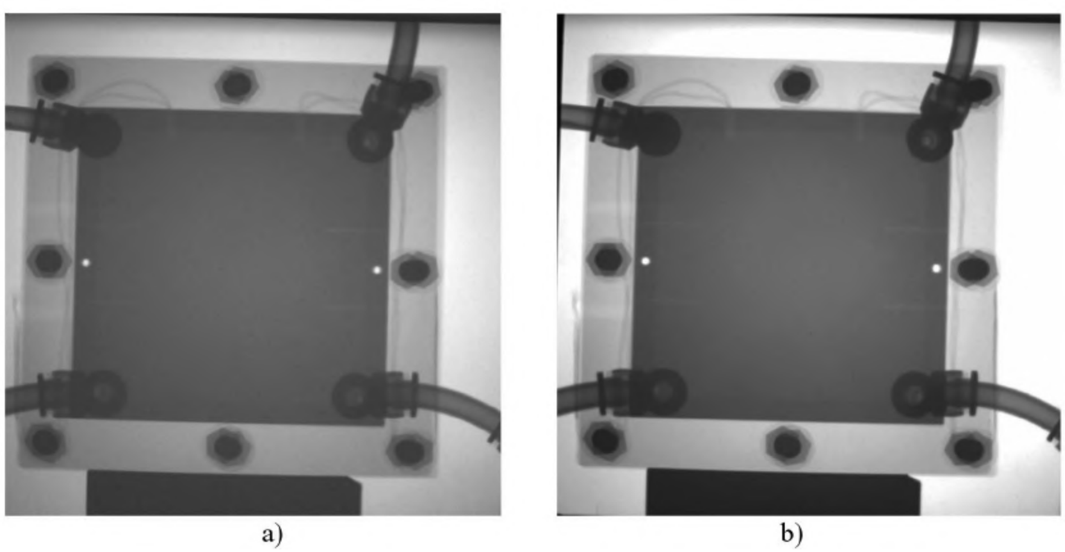

Fig. 5. Test Result at the First Exposure Room at the 3-Parallel Serpentine: a) 0.1 sec and b) 4 sec

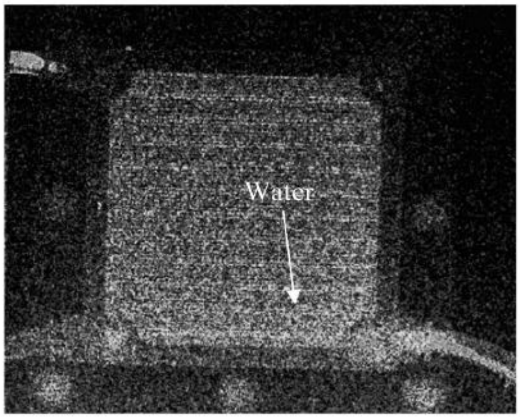

Fig. 6. Test Results at the First Exposure Room with 0.1 sec Exposure Time at the 3-Parallel Serpentine

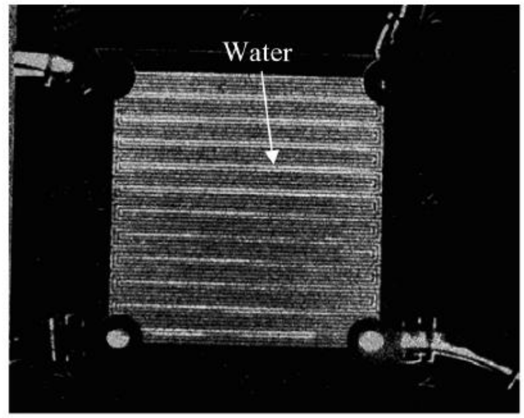

Fig. 7. Test Results at the First Exposure Room with 4 sec Exposure Time at the 3-Parallel Serpentine

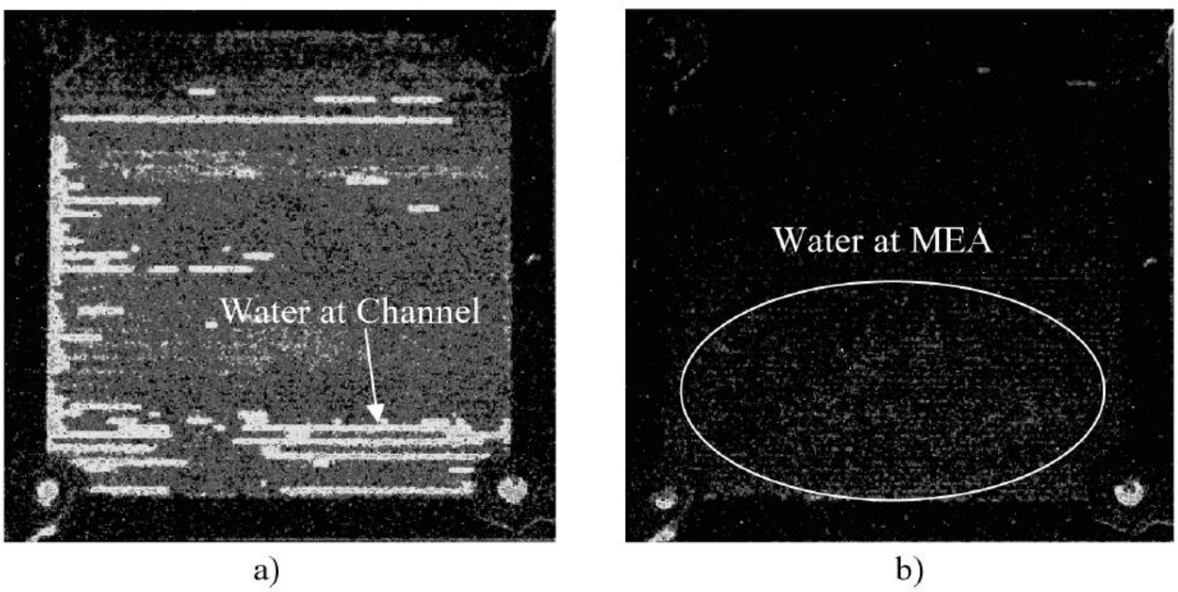

Fig. 8. Test Results at the 1-Parallel Serpentine Flow Field at 200 cc/min: a) Start and b) After 300 sec

at Figs. 8 and 9, but the discharge time is different: a) the 1-parallel serpentine is about 300 sec and b) the 3-parallel serpentine is about 160 sec. This result comes from the differential pressure between the inlet and outlet of each PEMFC. The total flow pass-length of the 1-parallel serpentine is 3 times that of the 3-parallel serpentine. The longer flow pass produces higher fractional loss and it is difficult to discharge the water at channel. Moreover, though the water at each channel was removed, the water at membrane electrode assembly (MEA) is not removed. This result shows the merit of the neutron imaging technique compared with other methods. Though the visualization method with a transparent window can discriminate the water movement and distribution in the channel of the PEMFC, it is impossible to see the MEA of the PEMFC. Since the auto-vehicle was run in sub-zero temperature conditions, the freezing of water at MEA means the damage of MEA. Therefore, the water at the PEMFC, regardless its position, must be removed as soon as possible. However, the water at MEA was not removed by using the pressurized air method during these feasibility tests, regardless of flow field geometries. In order to remove the water at the PEMFC, special treatment is needed at the PEMFC, for example heating, microchannel for water removal, and so on. The neutron imaging technique is a powerful tool to improve the water removal efficiency at the PEMFC.

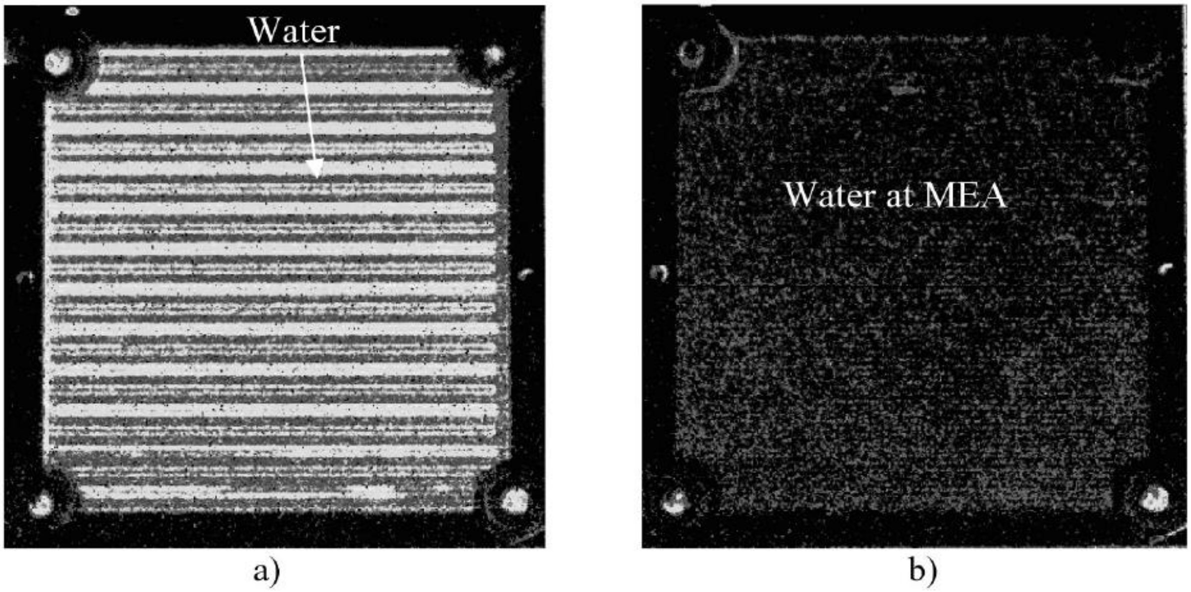

Fig. 9. Test Results at the 3-Parallel Serpentine Flow Field at 200 cc/min: a) Start and b) After 160 sec

4. CONCLUSIONS

In this study, the ability of the NRF, HANARO to conduct PEMFC research was checked. According to the measurement positions, the exposure time was changed from 20 sec to 0.1 sec. Due to high noise level at 0.1 sec, the detailed water movement and distribution of the channel was not discriminated, but the transient phenomena of the PEMFC could be visualized. As the exposure time was increased to 4 sec, the image quality was improved. Therefore, the experimental setup can be optimized according to test conditions. The investigation of different flow field geometries has unveiled that the water at a 3-parallel serpentine was removed more rapidly than that of a 1-parallel serpentine. The water at the MEA of both cases was not removed during the feasibility test. The neutron imaging technique was able to check water distribution, and that information is used for the schemes of water management. Finally, the efficiency of the PEMFC was improved.

REFERENCES

[1] W. Vielstich, A. Lamm, H. Gasteiger, *Handbook of Fuel Cells – Fundamentals*, Technology, Application, Wiley, New York, (2003).

[2] R. Satija, D.L. Jacobson, M. Arif, S.A. Werner, "In situ neutron imaging technique for evaluation of water management systems in operating PEM fuel cells", J. Power Sources, **129**, 238, (2004).

[3] R.J. Bellow, M.Y. Lim, M. Arif, A.K. Thompson, D. Jacobson, "Neutron imaging technique for in situ measurement of water transport gradients within in polymer electrolyte fuel cells", J. Electrochem. Soc., **146**, 1099, (1999).

[4] Von der Hardt, P., and Rottger, H., *Neutron Radiography Handbook*, Reidel, Dordrecht, Holland, (1981).

[5] H. Asano, N. Takenaka, T. Fujii, "Flow characteristics of gas-liquid two-phase flow in plate heat exchanger (Visualization and void fraction measurement by neutron imaging technique)", Exp. Therm. and Fluid Sci., **28**, 223, (2004).

[6] K. Mishima, T. Hibiki, "Quantitative limits of thermal and fluid phenomena measurements using the neutron attenuation characteristics of materials", Exp. Therm. and Fluid Sci., **12**, 461, (1996).