Nuclear Instruments and Methods in Physics Research A 600 (2009) 325–327

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Experimental approaches for distribution and behavior of water in PEMFC under flow direction and differential pressure using neutron imaging technique

TaeJoo Kim [a,b], JongRok Kim [a], CheulMuu Sim [b], SeungWook Lee [b], Massound Kaviany [c], SangYoung Son [d], MooHwan Kim [a,*]

[a] POSTECH, San31 Hyojadong, Pohang, Kyungbuk 790-784, Korea
[b] KAERI, 150 Deokjin-dong, Yuseong-gu, Daejeon 305-353, Korea
[c] University of Michigan, Ann Arbor, MI 48109-2125, USA
[d] University of Cincinnati, Cincinnati, Ohio, USA

ARTICLE INFO

Available online 30 November 2008

Keywords:
PEMFC
Water management
Neutron imaging technique
Visualization

ABSTRACT

In this investigation, we prepared a 3-parallel serpentine single PEMFC which has an active area of 25 cm^2 and a flow channel cross section of 1×1 mm. Distribution and transport of water in an operating PEMFC were observed by varying the flow directions (co-current and counter-current) in each channel and the differential pressures (100, 200, 300 kPa) applied between the anode and cathode channels. This investigation was performed at the neutron imaging facility at the NIST of which the collimation ratio and neutron fluence rate are 600, 7.2×10^6 n/s/cm^2, respectively. Neutron image was continuously recorded by an amorphous silicon flat panel detector every 1 s during the operation of the fuel cell. It has been observed that the differential pressure affects the total amount of water produced while the flow direction affects the spatial distribution of water when the neutron images were analyzed for several different operating conditions. More specifically, the amount of water production in the fuel cell increased as the partial pressure increases at a given current density and the water production was more uniform for the counter current than the co-current case. It is shown that the neutron imaging technique is a powerful tool to visualize the PEMFC. The information on the water distribution and behavior at an operating PEMFC helps improve the efficiency of PEMFC.

1. Introduction

As the number of power generators using fossil fuel energy increases in all applications, the necessity for alternatives to the internal-combustion engine have become even more obvious. With regards to automakers and industrial developers for stationary and transportation applications, PEMFC is now widely seen as a possibility [1]. Understanding liquid water content and its distribution within an operating PEMFC is critical to designing high-performance systems and formulating rational models for simulating PEMFC behavior. In the design and optimization of PEMFC, it is important to quantify the water content in an operating fuel cell in order to gain an insight into the dominant phenomena or processes that influence liquid water transport and removal. Improving PEMFC performance can be done in many ways [2,3]. Many researchers have studied the problem of water management inside the PEMFC for both steady state and transient operations. However, the effects of the flow direction and differential pressure on its performance are lacking in the literature. This work is concerned with a measurement of the liquid water behavior in an operating PEMFC under different flow directions and differential pressures between the cathode and anode by neutron imaging technique.

2. Experimental setup

All the experiments were conducted at Beam Tube 2 (BT-2) of Center for Neutron Research (NCNR), a research center of the National Institute of Standards and Technology (NIST) which has been moved from the old NCNR facility at the BT-6 [4]. The new imaging instrument and setup used in this experiment is similar to the previous one [4] but a flat panel amorphous silicon detector with 127 μm pixel and a 1 Hz imaging acquisition rate was utilized for these experiments instead of a charge-coupled device (CCD) camera with scintillator. The neutron

*Corresponding author. Tel.: +82 54 279 2165; fax: +82 54 279 3199.
E-mail address: mhkim@postech.ac.kr (M. Kim).

0168-9002/$ - see front matter
doi:10.1016/j.nima.2008.11.083

fluence rate and L/D ration of BT-2 are $7.2\times10^6\,n/s/cm^2$ and 600, respectively.

The raw neutron image data was analyzed using IDL programming language. At first, we acquired two separate sets of data: "dry" images, and "wet" images. The dry images mean the neutron image of a non-operating fuel cell and we used an average image of 1,000 ea in order to attain good statistics during the normalization process. The wet images were obtained under each normal fuel cell operation by maintaining a constant current. Applying Beer's law, the total water thickness was obtained from the natural log of the ratio of the wet to dry intensities. In these images, all the cell features except for the water content were subtracted and not visible in the resulting image. This type of data analysis is referred to as a "dry reference" in the present work. The neutron imaging procedure, and data reduction procedure were executed as presented in [4–6].

A 25 cm^2 fuel cell was built as a graphite 3-parellel serpentine type (both anode and cathode) with aluminum end plates as shown in Fig. 1. The channel depth, width, and rib width were all 1 mm. The MEA (membrane–electrode-assembly) was built with a Gore™ 5510 membrane. The fuel cell was controlled by a fuel cell test station which provides an accurate flow of humidified hydrogen and air as well as dry nitrogen and pure/nitrogen mixed oxygen. The cell was heated to a temperature of 70 °C by an inserted heater.

The effect of the flow direction and differential pressure between the cathode and anode were investigated in this study. The cell was operated at different current densities from 0.1 to 1.3 A/cm^2. The fuel cell was purged with dry nitrogen for 10 min before every different pressure and flow direction condition in order to remove traces from previous tests. Neutron imaging was initiated at least 3 min after a new condition was established. Table 1 shows the experimental conditions.

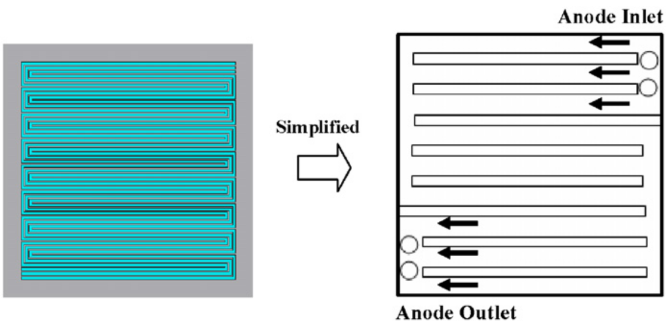

Fig. 1. Schematic diagram of investigated flow field geometry.

Table 1
Experimental conditions.

Flow direction	Differential pressure
Co-current Counter-current	Cathode (100, 200, 300 kPa), Anode (100 kPa)

Co-current: flow direction of anode and cathode is same.
Counter-current: flow direction of anode and cathode is opposite.

3. Results and discussion

The images displayed in Fig. 2 were recorded during a polarization curve measurement. The polarization curve was obtained by a stepwise increase (0.1 A/cm^2) of the current density from 0.1 up to 1.3 A/cm^2 and a subsequent decrease. At a current density of 0.1 A/cm^2 small slugs start to form from the middle of a fuel cell. With an increasing current density, the amount of liquid increases and at 1.2 A/cm^2, larger clusters of the liquid are present. Obviously, the removal of the liquid is inhibited

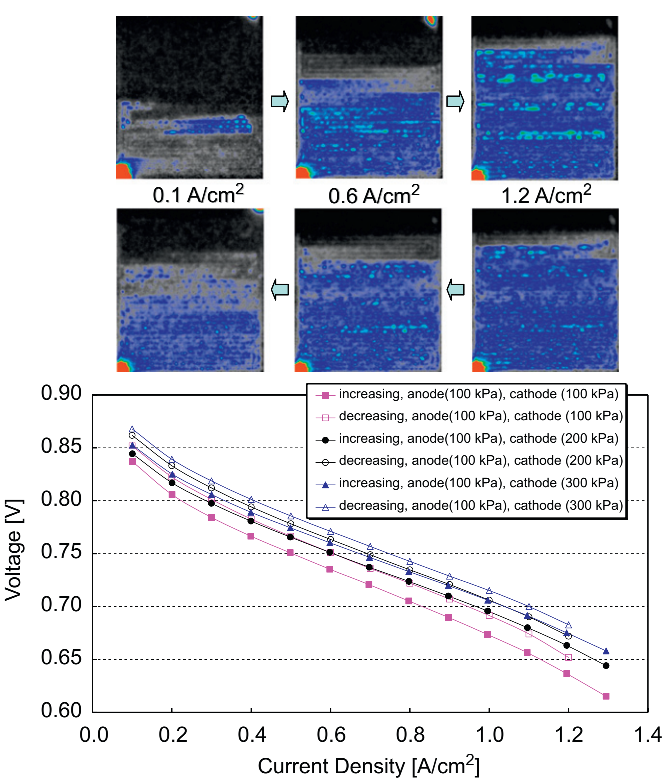

Fig. 2. Neutron images with anode 100 kPa and cathode 100 kPa at co-current flow (above) and corresponding polarization curve showing a hysteresis in liquid content (below). The arrows between the neutron images indicate whether they were measured during the ramping up or down of the current density.

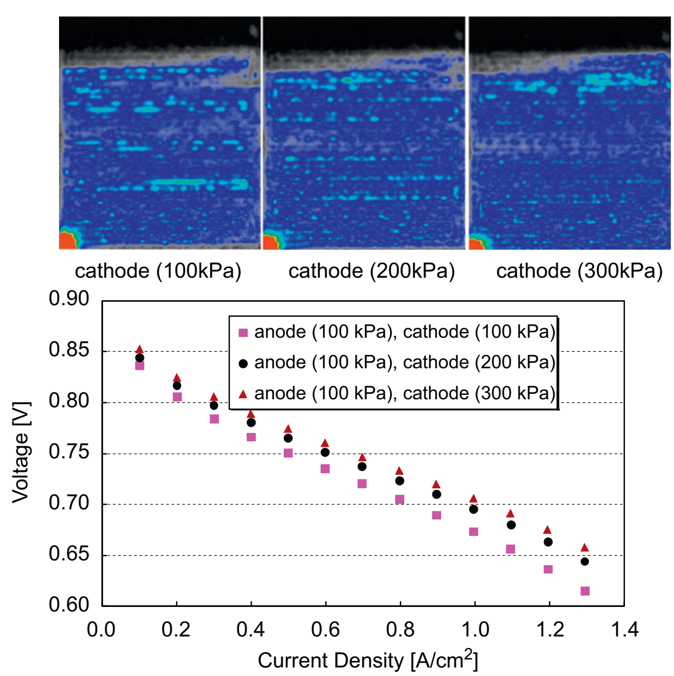

Fig. 3. Neutron Images for each different pressure at 1.3 A/cm^2 with the co-current flow (above) and the corresponding polarization curve (below).

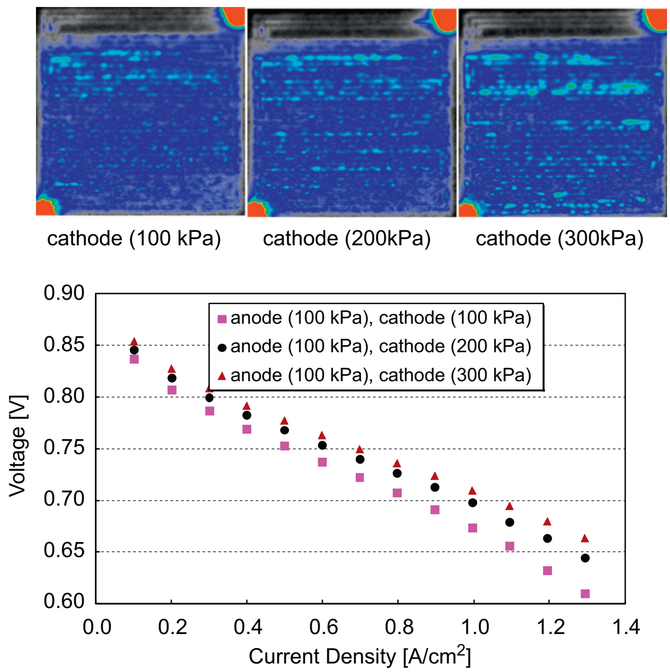

Fig. 4. Neutron Images at 1.3 A/cm^2 (above) and polarization curve according to the differential pressure at counter-current flow (below).

by the presence of larger clusters. Interestingly, the electrochemical performance is improved during the decreasing current procedure, which might be attributed to a reduced surface coverage of the cathode with OH adsorbates and/or a reduced ohmic resistance [7]. Fundamental investigations are needed to understand the observed dependency of the liquid removal on the water cluster size in more detail.

Although there are a number of parameters, which might influence the liquid accumulation and performance of PEMFC, the flow direction and the differential pressure between the cathode and anode are among them. Figs. 3 and 4 show the results from the differential pressure between cathode and anode. The electrochemical performance was improved with increasing differential pressure regardless of the flow direction, and improvement ratio was decreased at the higher pressures. It means there must be an optimal condition for a performance.

However, when comparing the neutron images for the co-current and counter-current flow cases, the water distribution and accumulation are different. These results are shown well in Fig. 5. Although the performance is similar under different flow directions, the water accumulation positions are different at each current density. In particular neutron images for the co-current case show that the fuel cell uses relatively limited area than the counter current case especially at low current density.

4. Conclusion

A series of measurements has been conducted to investigate the effect of the flow direction and the differential pressure between the anode and cathode using the neutron imaging technique. The water distribution and behavior was observed to coincide with the cell performance represented by the polarization curve for each operating conditions. It has been demonstrated that the performance was noticeably affected by the differential pressure whereas it was barely influenced by the flow direction. However, it was shown that there were significant differences in

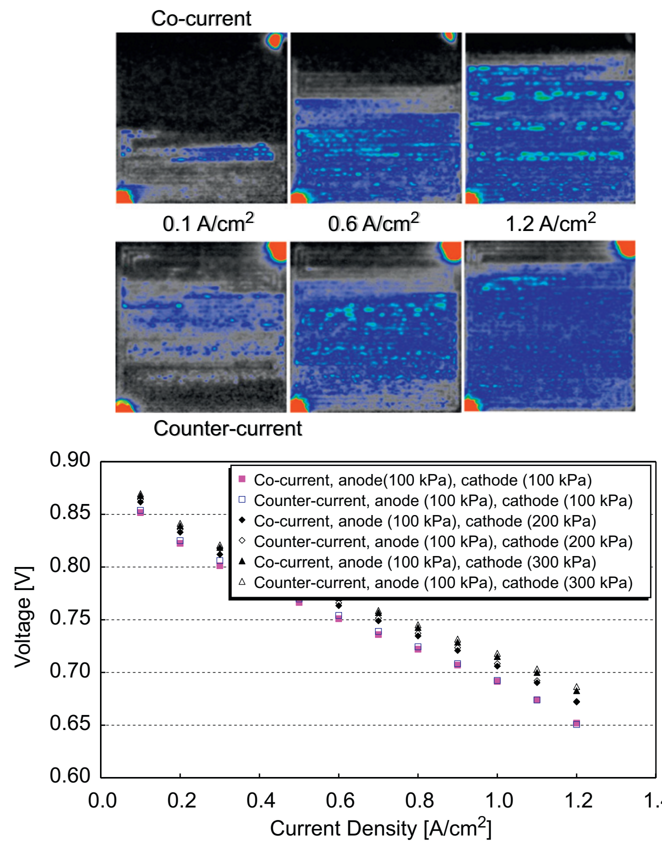

Fig. 5. Neutron images with anode 100 kPa and cathode 100 kPa (above) and polarization curves according to the differential pressures (below). The cell performance was almost identical for different flow directions while the water distribution in the cell is quite different. The trend about the water distribution depending on the flow directions is valid for all the other pressure conditions although not shown here.

the water formation and behavior due to the flow direction. It would be interesting to study the fundamentals of these phenomena based on the measurements presented in this work. It was also shown that neutron imaging technique is a powerful tool to visualize the PEMFC. The information of the water distribution and behavior of an operating PEMFC will help improve the efficiency of PEMFC.

Acknowledgments

The authors would like to thank Dr. Daniel Hussey and the NIST Ionizing Radiation Division for the contribution in the experiment. This study was supported by KAERI and the Korea Foundation for International Cooperation of Science and Technology (KICOS) through a grant provided by the Korean Ministry of Science & Technology (MOST) in M60602000005-06E0200-00410.

References

[1] S. Shimpalee, J.W. Van Zee, Int. J. Hydrogen Energy 32 (2007) 842.
[2] C.Y. Wang, X. Li, J. Power Sources 142 (2004) 134.
[3] J. Baschuk, X. Li, J. Power Sources 142 (2004) 134.
[4] R. Satija, D.L. Jacobson, M. Arif, S.A. Werner, J. Power Sources 129 (2004) 238.
[5] M.A. Hickner, N.P. Siegel, J. Electrochem. Soc. 153 (5) (2006).
[6] D.J. Ludlowa, C.M. Calebrese, S.H. Yu, C.S. Dannehy, D.L. Jacobson, D.S. Hussey, M. Arif, M.K. Jensen, G.A. Eisman, J. Power Sources 162 (2006) 271.
[7] D. Kramer, E. Lehmann, Nucl. Instr. and Meth. Phys. Res. Sec. A (2005) 52.