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Investigation of Water Transport Dynamics in Polymer Electrolyte Membrane Fuel Cells Based on a Gas Diffusion Media Layers

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***Abstract*—**In this investigation, synchrotron X-ray imaging is used to study water transport inside polymer electrolyte membrane fuel cells. Two measurement techniques are used, namely in-situ radiography and quasi-in-situ tomography combining together in order to reveal the relationship between the structures of the microporous layers (MPLs) and the gas diffusion layers (GDLs), the operation temperature and the water flow. The developed cell is equipped with a thick GDL and a high back pressure MPL. It is found that these modifications strongly influence the overall water transport in the whole adjacent GDM.

***Keywords*—**Polymer electrolyte membrane fuel cell, microporous layer, water transport, radiography, tomography.

I. Introduction

RENEWABLE energy systems such as fuel cells and electric motors are considered to offer alternatives to the traditional engines powered by fossil fuels in both mobile and stationary applications [1]-[13]. For transportation, and especially in the automotive sector, polymer electrolyte membrane fuel cells (PEMFC) are considered the most convenient fuel cell type.

In the PEMFC, good water management is important to prevent two undesirable operation cases: extravagant drying of the membrane and flooding of the diffusion media [1], [5], [14]-[26]. In the first situation, the membrane shrinks and loses its proton conductivity, which decreases fuel cell efficiency. In the second situation, liquid water in the cell materials blocks gas flow to the catalyst layers. As a result, the catalyst layers are undersupplied with gas and the cell performance drops. Hence, a well-balanced water management is a substantial condition for optimization the power output and long term stability.

A better efficiency can be achieved by a good water transport optimization in the gas diffusion and the MPLs. Such conditions include temperatures below 60 °C as well as high currents that both give rise to elevated water contents [24], [27]-[36].

Multi imaging techniques and modeling were used in renewable energy and PEMFC research to provide a good understanding of the physical phenomena related to the fuel cell performance. Imaging techniques have various objectives in the field of energy related materials like characterization of the dynamic behavior under varied operating conditions as well as structural properties of these materials. X-ray and neutron technologies allow visualizing water distributions under operating conditions and to quantify the water content [24], [32], [37]-[48]

In this study, a modified Freudenberg GDM material with thick GDL and high back pressure MPL is subjected to synchrotron X-ray imaging to investigate the dynamic liquid water transport behavior. The material is compared to the reference material at two different temperatures.

II. Experiments

The experiments were carried out using two PEMFC with active areas of 5.4 cm^2 and flow fields that contain seven parallel vertical channels. The modified cell has a membrane electrode assembly (MEA), which consists of a catalyst-coated membrane (CCM) equipped with a GDL from Freudenberg company based on a H2315 fiber substrate, while the second cell has a reference MEA consisting of a CCM equipped with a H1410 I4 C10 GDL. The modified GDM has an uncompressed thickness of 231 µm and includes developed GDM with a thick GDL and high back pressure MPL. At the experiment, fuel cell operation was fixed at a current density of 1 A/cm² at stoichiometric ratios of 5 at both sides. The temperatures of 40 °C and 55 °C were used for the compression.

The investigation was with synchrotron X-ray of a region in the middle of the vertical cell extension and in an area of ~10% of the total area [49]. Fig. 1 shows the investigation method parts.

III. Results

At 40 °C, the voltage for the reference cell was 500 mV, whereas the cell with the modified material achieved 560 mV with otherwise identical operation parameters. While during the second operating temperature which is 55 °C the voltage of the reference cell was 525 mV and for the modified cell it was 557 mV. In the present case, the thick GDL and the MPL having high back pressure might play a major role in the water

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distribution: They facilitate accumulation of liquid water. The emerging product water then moves from side to side through the GDL into the channel, from where the water is removed continuously by the gas stream.

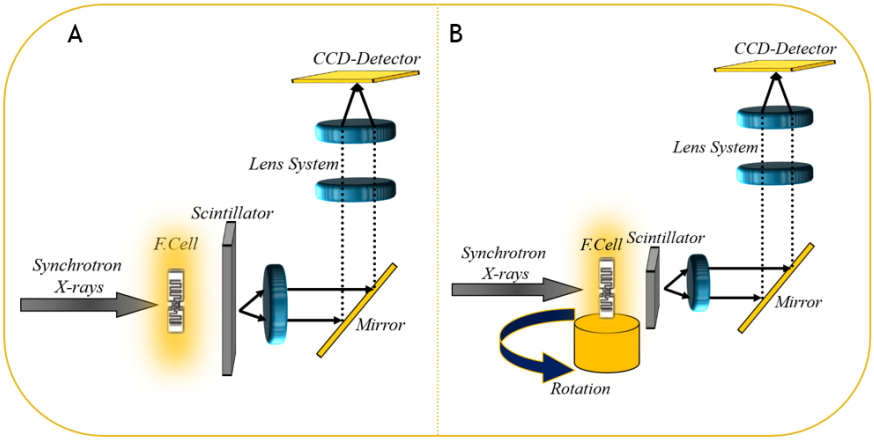

Fig. 1 Scheme of the synchrotron radiography setup (A), scheme of the synchrotron tomography setup (B)

The tomographic image data of the dry and operated state have been matched in order to extract the water distribution. Fig. 2 shows the result of the matching between the operated and the dry status for the reference cell which is the water distribution in the cell in the anode (A and C) and cathode (B and D) at 40 °C (A and B) and (C and D) 55 °C.

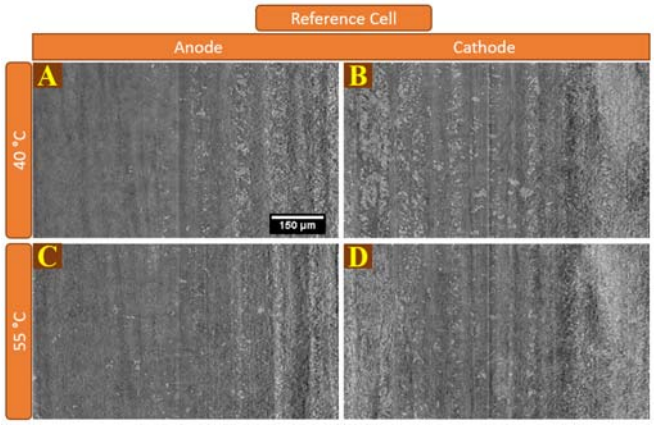

Fig. 2 The water distribution in the cell in the anode (A and C) and cathode (B and D) at 40 °C (A and B) and (C and D) 55 °C

Fig. 3 shows the water distribution in the modified cell with thick GDL and high back pressure MPL. It is found that the water amount is decreased with temperature rising. More water amount can be found in the cathode side at both operating temperatures.

From the radiographic data it was seen that the cell with the modification has less water amount than the reference cell during the both operating temperature. Fig. 4 shows the water activity map. The activity map focuses on the areas with strong fluctuations of x-ray attenuation, which especially applies to the droplets. The activity $A_t(x, y)$ at a given pixel position (x, y) is defined as:

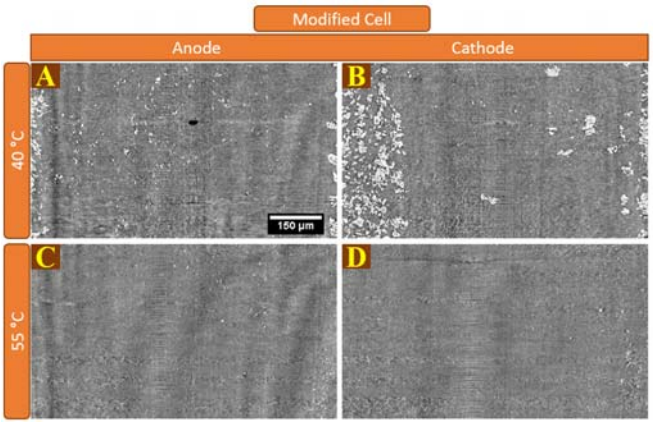

Fig. 3 The water distribution in the cell in the anode (A and C) and cathode (B and D) at 40 °C (A and B) and (C and D) 55 °C

$$A_t = \frac{1}{t*N} \sum_{k=2}^{N} | d_k(x,y) - d_{k-1}(x,y)|,$$

where N is the total number of images, d the local water depth and t the exposure time of each image.

Figs. 5 (A)-(D) show cross section of the water saturation in the reference and modified material in the channel and rib regions, separately on anode and cathode side at the two operation temperatures, 40 and 55 °C. Figs. 6 (A) and (B) show the water saturation of the reference cell at the channels and ribs of the anode and cathode sides separately. The water saturation of the anode GDL at the channels at 40 °C is slightly more than at 55 °C (about 5%), while the water saturation of the anode GDL beneath the ribs is approximately the same. The water saturation at the cathode channels is similar for channel and rib regions at both operating temperatures, while the water saturation of the cathode beneath the ribs at 40 °C is slightly more (about 4%) than at 55 °C.

In case of the thick GDL and high back pressure MPL material water saturation at anode side in the channel region at

40 °C is about 5% higher than at 55 °C, and in the rib region is higher by 10% during the 40 °C than 55 °C. Water saturation on the cathode beneath the channels is slightly higher at 40 °C than at 55 °C, see Fig. 6 (B).

IV. Discussion

The real water rate is the same for both operation temperatures, but for the GDM, the water is transported differently from the GDL through the channel out of the cell. The cell shows less water amount in the anode and cathode regions comparing with the reference cell that it has a high amount of the water.

Thick GDL with High Back Pressure MPL at 40 °C

The water amount at the cathode is less as in the reference material. Furthermore, close to the membrane less water is found (about 10% beneath the ribs and about 15% beneath the channels) compared to the reference material.

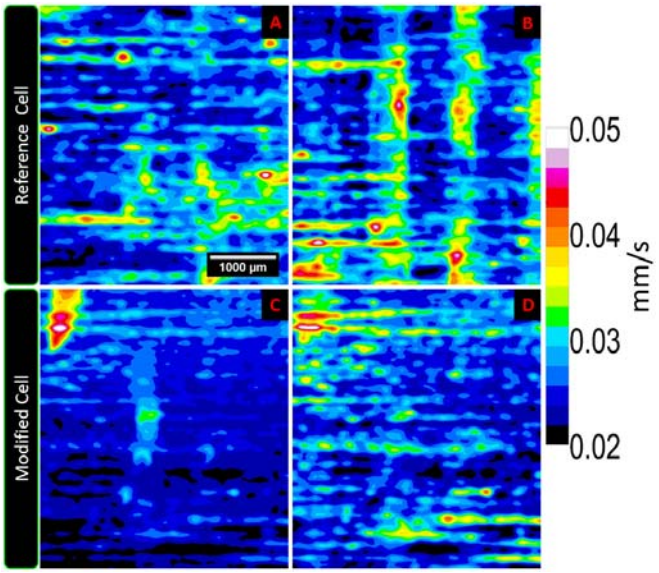

Fig. 4 The water activity map for the reference cell (A and B) and for the modified cell (C and D) during 40 and 55 °C respectively

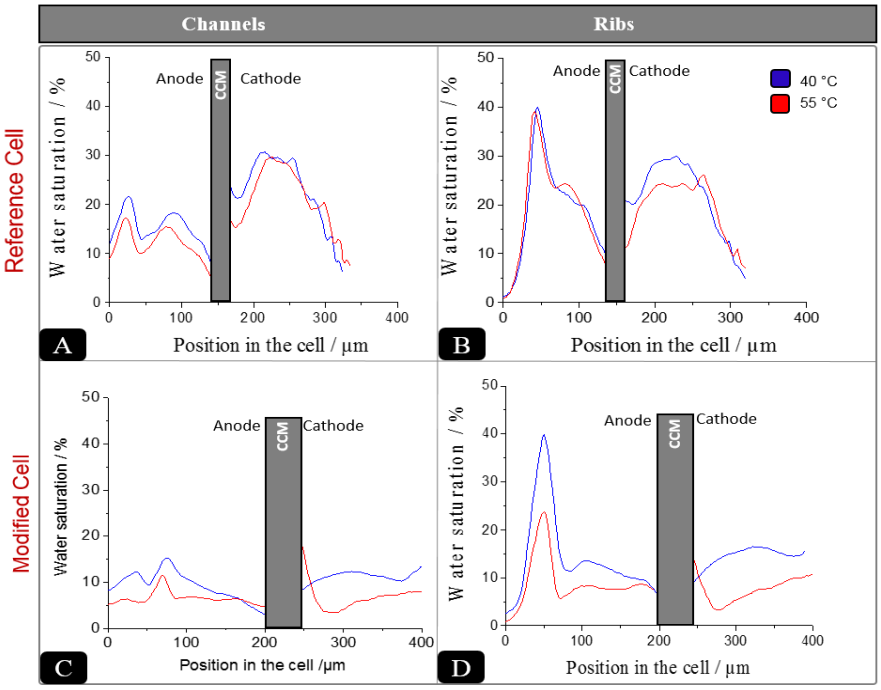

Fig. 5 Water saturation for channels and ribs of the anode and cathode in the GDL with reference MPL (A), thick GDL with MPL having high back pressure (B) at the two operation temperature of 40 and 55 °C

The modified cell seems to decrease water condensation and accumulation close to the membrane that may contribute to effect membrane humidification. It could be assumed that water diffusion through the thicker areas of the modified GDM is varied compared to a standard GDM with a more or less constant thickness. These thick areas lead the water to move far to the membrane at certain spots and could be the reason for different water supply of the membrane.

Thick GDL with High Back Pressure MPL at 55 °C

At 55 °C the modified GDM material is again the best performer with a higher voltage (about 6%) than for the reference material. The water amount for the cathode rib is less by about 5% than the water amount in the cathode channels. It was found less liquid water (about 15%) than the reference cell at 40 and 55 °C.

V. Conclusions

This work illustrates a study related to the PEMFCs focusing on the liquid water transport through the GDM system. Previous work has shown a strong influence of unintentionally caused cracks in the micro-porous layer and perforations of the gas diffusion media. It could be pretended that this effect can be exploited with a tailored GDM material containing a thick GDL and high back pressure MPL. This study shows that the cell with a modification in the GDM can affect the water transport ways in the cell, which was not observed in the reference cell. In this way, the modifications geometry can use to optimize the overall performance of fuel cells in general.

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