Neutron radiography and tomography on operating PEM fuel cells

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Water management is a key issue in the development of low temperature polymer electrolyte membrane fuel cells (PEMFCs). Water is produced in the fuel cell reaction, the conversion of hydrogen and oxygen to electrical energy; thereby, water plays an important role: On the one hand a certain humidity inside the reaction layers and the membrane has to be maintained because only the wet membrane is proton conductive [1-3]. On the other hand the formation of excess liquid water strongly hinders the gas flow and has to be prevented. Thus visualisation of the water distribution in an operating fuel cell is of major interest in fuel cell development.

Conventional imaging methods based on magnetic resonance imaging or X-ray imaging are not suitable for this task, since the results from both methods are strongly influenced by the metallic components of the cells that make imaging practically impossible [4]. While X-rays, for example, are shielded by metals, neutrons can penetrate most of them very easily. Thus neutron imaging is a unique tool for the detection of hydrogen containing components covered by metallic parts [5, 6]. In the last years neutron radiography has been successfully applied for investigations of liquid water evolution and transport in low temperature PEM fuel cells [7-12]. However, all studies were focused on 2D radiography while a 3D tomographic imaging was only applied for investigations of very small fuel cells (1-2 cm^2 active area) due to the long measurement time for tomographic imaging: Typically 300 to 600 single radiograms at different viewing angles have to be performed in order to reconstruct a 3D image with sufficient level of detail. The overall measurement time is typically more than several hours compared to about 10-60 s for a single radiogram of sufficient quality.

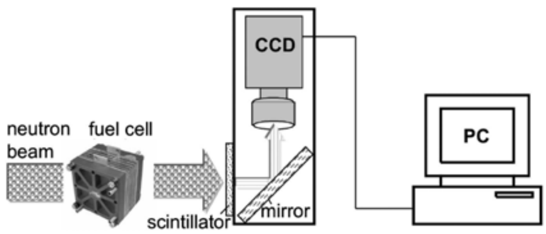

Fig. 1: Schematic drawing of the experimental setup. An almost parallel neutron beam is transmitted through an operating fuel cell to a scintillator screen. The absorbed neutrons produce light spots which are reflected by a mirror detected by a CCD camera.

In order to overcome the limits of 2D-radiography a new method has been developed that allows for a tomographic investigation of fuel cell stacks, i.e. the water distribution is visualised three dimensionally. By switching off the cell and stopping the gas flows the actual water distribution in the flow field channels can be “frozen” for a few hours [13]. Within this time a neutron tomography was performed. The measured three dimensional distribution of liquid water in the flow field channels represents the water distribution at the moment where the gas flows have been stopped. This technique was applied to single-stack fuel cells as well as stacks with up to 5 cells and dimensions up to about 14x14x10 cm^3.

Experimental setup

Serpentine flow fields with 1 mm wide ribs and channels were used. They were machined in separate blank graphite composite plates with five and 11 channels on the anode respectively cathode. The active area of the cells is about 100 cm^2. Cooling flow fields were applied to either electrode to ensure a proper tempering of the cell. Gore Primea membrane electrode assemblies (57-series) with a thickness of 19 µm were applied. SGL 10 BB material was used as gas diffusion layer (GDL). The cathodic gas stream was humidified at a dew point of 25 °C. The fuel cells were operated at typical parameter settings: u_C= 25 - 50 %, u_A=80 - 90 %, T = 55 °C, i_0 = 300-500 mA/cm^2,with u_C and u_A the utilization ratios of the cathodic and anodic gas stream, T the temperature of the thermostat and i_0 the current density; the respective values are mentioned in the text.

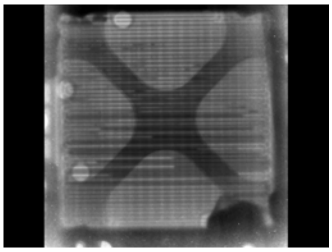

Fig. 2: Radiographic image of a fuel cell. The black horizontal lines are due to the high attenuation of liquid water indicating filled flow field channels.

The neutron tomography measurements were established at the CONRAD/V7 facility of the Hahn-Meitner Institute Berlin (BER II research reactor). A schematic drawing of the setup and a typical radiographic projection are given in Figures 1 and 2. For each tomography 600 single projections were taken with an exposure time of 30 s per projection, i.e. the overall measurement time was about 5 h. The achieved spatial resolution was about 300 µm.

Experimental results

Figure 3 shows photography of a fuel cell stack (left) and a tomographic image of a three-fold stack (right) that was measured by applying the new method. The tomogram shows the liquid water distribution inside the fuel cell while all other fuel cell components like end plate and flow fields are turned transparent. This image demonstrates the suitability of the method. If the water had moved while performing the tomography the measurement would have been useless.

As an example of the applicability of the method in fuel cell development, the so called “end-cell problem” in a five-fold fuel cell stack was investigated, i.e. the influence of the end plates on the cell performance was analysed. The water distribution among anodes and cathodes of the five cells was quantified and compared to the cell voltage. An overview is given in Figure 4. On the cathode side of the first cell and on the anodic flow field of the last cell comparable large water amounts can be seen. Due to the increased water content the average cell voltage is decreased in these two cells. In the inner cells, the amount of liquid water is lower and the performance is significantly higher. The gas flows are not hindered, while the membrane humidification is sufficient at the same time.

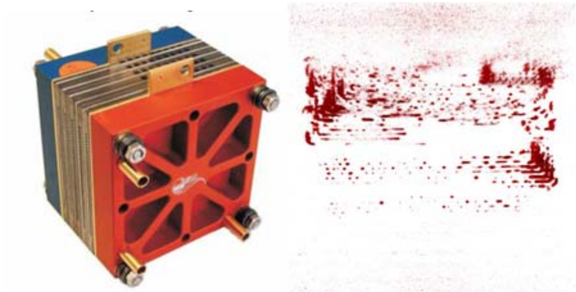

Fig. 3: Left, Photography of a PEM fuel cell stack (right) with dimensions of 14x14x10 cm^3 and a tomographic image of a comparable three fold fuel cell stack (right). All components except the liquid water are turned transparent. This way the three-dimensional distribution of the liquid water can be analysed.

The “end cell problem” can be explained by thermal effects that lead to an enhanced condensation of liquid water and cause deviations in the gas flow and pressure of the outermost cells. This causes a performance loss for these cells. It has been found that this effect is not as pronounced in three-fold stacks compared to fivefold ones but might play an even more important role in longer stacks.

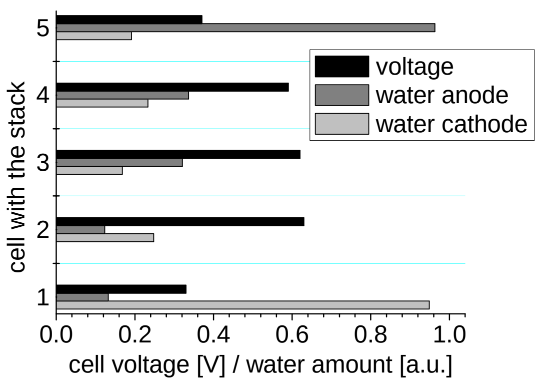

Fig. 4: Water distribution on anodes and cathodes within a 5-fold fuel cell stack compared to the cell voltage. The strong decrease in the cell voltage at the outer cell is due to the flooding of the flow field channels [13].

We presented quasi-in situ neutron tomography investigations of fuel cell stacks. Water accumulations in the separate cells of the stack were analysed and quantified. Furthermore a separation into anodic and cathodic contributions was possible. In future neutron tomography could greatly enhance the possibilities of neutron imaging in fuel cell research.

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