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Water build-up and evolution during the start-up of a PEMFC: Visualization by means of Neutron Imaging

Alfredo Iranzo [a,*], *Antonio Salva* [a], *Pierre Boillat* [b,c], *Johannes Biesdorf* [b], *Elvira Tapia* [a], *Felipe Rosa* [d]

[a] AICIA-School of Engineering, Thermal Engineering Group, Camino de los Descubrimientos s/n, 41092 Sevilla, Spain
[b] Electrochemistry Laboratory (LEC), Paul Scherrer Institut (PSI), CH-5232 Villigen, Switzerland
[c] Neutron Imaging and Activation Group (NIAG), Paul Scherrer Institut (PSI), CH-5232 Villigen, Switzerland
[d] Thermal Engineering Group, Energy Engineering Department, School of Engineering, University of Sevilla, Camino de los Descubrimientos s/n, 41092 Sevilla, Spain

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ABSTRACT

A commercial 50 cm^2 PEM fuel cell with serpentine flow fields was operated at 2.0 bar (a) and 60 °C with different relative humidity (RH) values for the inlet reactants (a matrix of 3 RH for anode and 3 RH for cathode). Between each test the cell was decompressed and liquid water was thus flushed out. The liquid water build-up and the time evolution during each experiment were recorded by means of Neutron Imaging. A qualitative and quantitative analysis of the results is presented in this work. It was observed that the dynamics of water build-up comprises three main stages, where the major difference is the liquid water accumulation rate. The onset location for the water appearance in the flow field channels was found to be determined by the flow field design, gravity and gas flow direction along the serpentine path. The time evolution of the water progressive accumulation along the flow field channels and cell active area is discussed.

Introduction

Water management in PEM fuel cells (PEMFCs) has a major influence in the cell and stack performance [1–3] and also in the durability of the cell components [4,5]. As water is being produced in the cathode side of the cell during operation, especially at high current densities, the channels in the cathode side are receiving high amounts of liquid water and therefore the water removal capability of the cathode side is a critical parameter for ensuring a correct operation. Liquid water can even block some of the channels, particularly in parallel flow fields, preventing reactants from uniformly reaching the electrode and thus increasing mass transport losses. Effective water removal from gas channels is therefore of major interest for enhancing the performance of fuel cells.

* *Corresponding author*. Fax: +34 954 463153.
E-mail address: airanzo@us.es (A. Iranzo).
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In addition to performance parameters, an appropriate water balance in the cell is also critical for durability issues [4,5].

For the investigation and design of liquid water in fuel cells it is obviously of high interest to enable the *in situ* visualization of the liquid water distributions within the cell during operation. Among the different instruments for experimental research of liquid water in fuel cells, Neutron Imaging represents an important technique as it allows the visualisation and quantification of local water content within the cell during operation (steady-state and transient conditions) [6–9]. This technique was used by Owejan et al. [10] to obtain two-dimensional distributions of liquid water in operating 50 cm^2 fuel cells, where variations of flow field channel and diffusion media properties were made to assess the effects on the overall volume and spatial distribution of the accumulated water. In another work, Owejan et al. [11] describe the design of an in-situ test apparatus that enables investigation of two-phase channel flow within PEMFCs, including the flow of water within the bipolar plate channels. In all these works, non-uniform liquid water contents in the flow field channels are clearly observed, that may strongly influence the final operation and performance of the cell. Two-phase flow phenomena in flow field channels is therefore of high interest for the better understanding and design of flow field designs. Iranzo et al. [12,13] used neutron radiographs obtained for a 50 cm^2 fuel cell to analyse how different operating conditions such as anode or cathode relative humidity, cathode stoichiometry, or current density, influences the cell liquid water content and distribution, where the effect of cathode oxidant (air/O_2) was also analysed [14]. The results were also used for supporting validation of a 1D model [15] and a 3D CFD (Computational Fluid Dynamics) model [16].

However, as stated by Banerjee and Kandlikar [3], most of the two-phase flow studies found in the literature focus on the steady state behaviour of water in the PEMFCs, whereas relatively few works addresses the transient behaviour of the water build-up and evolution. One of the existing works related to the visualization of the liquid water formation and transport in PEMFCs was presented by Spernjak et al. [17]. An operational 10 cm^2 transparent single-serpentine PEMFC was investigated by direct visualization in order to assess liquid water formation and transport, where different Gas Diffusion Layers (GDLs) were examined over a range of operating conditions. The transients were generated by setting a step changes in the current drawn, and time evolution of the water distribution and cell current density are discussed. The authors also extended the analysis to different flow field designs by simultaneous neutron and optical imaging [18] in 25 cm^2 PEMFCs. They investigated parallel, serpentine, and interdigitated flow fields, and parallel and interdigitated cells were found to feature significantly higher water contents than the serpentine flow field. The water content dynamics of the cell for a step-change in the current drawn were also investigated in detail. In all cases the images obtained were in the through-plane direction (so that the membrane in-plane active area was observed). The transient water accumulation in interdigitated flow-fields was also investigated by Owejan et al. [19] by means of Neutron Imaging.

X-ray radiography was used by Hinebaugh et al. [20] to analyse the time evolution of liquid water in a 5 cm^2 PEM fuel cell, operating at conditions critical for water management. They used the X-ray beam along the plane of the fuel cell, and images obtained were therefore corresponding to the through-plane distribution of liquid water in the porous materials. It was clearly observed that liquid water first appeared near the cathode catalyst layer, and then travelled laterally within the porous gas diffusion layer. This is in agreement with the time profiles presented by Iranzo et al. [21] and obtained by Neutron Imaging for a "1D" fuel cell.

Image acquisition using a CCD camera with transparent flow field channels were used by López et al. [22] for water management studies with two different single cells of 49 cm^2 (serpentine-parallel and cascade-type). Pressure drop in both hydrogen and oxygen gas flow paths were measured simultaneously. It was observed that when using the cascade-type flow-field geometry, liquid water dis not flood the gas flow channels. Time fluctuations in the pressure drop of the gas flow clearly indicated transient processes inherent to water formation and management of the cell.

Other relevant works are the ones by Hickner et al. [23], who carried out Neutron Imaging experiments to measure the water content of an operating 50 cm^2 PEMFC under varying conditions of current density and temperature, and found that changes in water content lag changes in current density by at least 100 s, both when the current density was increased and decreased. Siegel et al. [24] used the same technique to analyse the accumulation of liquid water within the cell structure of a 53 cm^2 PEMFC with a dead-end anode configuration. It was observed that even for dry hydrogen supply, accumulation of liquid water in the anode gas distribution channels was occurring in most tested conditions, followed by a significant voltage drop. Transients were observed as the cell operation was in dead-end. Satija et al. [25] used Neutron Imaging to create a real-time radiography dataset consisting of 1000 images at 2-s intervals, where water production, transport, and removal throughout the cell were shown. This dataset was also analysed to quantify and calculate the amount of water present in the cell at any time.

The objective of the work presented in this article is to further investigate the water build up and evolution during the start-up of a PEM fuel cell, for a set of different anode and cathode relative humidity conditions. The additional insight gained into the liquid water dynamics during cell transients can contribute to a better understanding and optimized design of cell components and operating conditions, which should result in an optimized performance of the cell dynamics in applications such as automotive fuel cells dealing with driving cycles. There are very few works available in the literature investigating the transient evolution of liquid water and the related dynamics of the cell using visualization techniques, so this work intends to provide further findings for technical cells (50 cm^2 in the present case).

An extensive experimental campaign was carried out using neutron radiography for a 50 cm^2 PEM fuel cell with a multiple serpentine flow field. The liquid water patterns in the cell including flow field channels were investigated during the transient build-up of liquid water. The dynamics of the water evolution and cell quantitative water balance during the transients has been determined.

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