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Liquid water preferential accumulation in channels of PEM fuel cells with multiple serpentine flow fields

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ABSTRACT

This work presents an experimental investigation on the preferential accumulation of liquid water in the channels of a multiple serpentine PEMFC with 50 cm^2 active area. Neutron imaging was used for visualizing the liquid water distribution during the cell operation for a wide range of operating conditions. Liquid water accumulation in the cathode channels was observed for most of the operating conditions, with a preferential accumulation in certain channels of the flow field. A statistical analysis was performed in order to determine the main characteristics of this accumulation (i.e. channel number and degree of accumulation). As cathode channels were positioned in vertical direction, it was found that gravity effects had an important influence in the accumulation, as well as the relative position of the channel with respect to the inlet and outlet locations. The gas flow direction had also a major impact on the water accumulation within the channels, with significantly more water accumulated in channels with upwards gas flow.

Introduction

The flow field design of a PEM Fuel Cell has a major influence in reactants distribution, water management, parasitic losses, and consequently in the cell performance and overall system performance [1,2]. The design of optimised flow field designs has therefore attracted very much interest and research efforts, where not only experimentation with prototypes but also numerical models such as 3D CFD simulations [3,4] and analytical models [5,6] are commonly used.

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. In addition to performance parameters, an

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appropriate water balance in the cell is also critical for durability issues [7,8].

Comprehensive reviews are available for determining the main effects of the flow field design on the cell performance, as in the work of Li and Sabir [1], or Li et al. [2]. The advantages and disadvantages of each design on the different phenomena (reactants distribution, water removal, pressure drop) is presented, although for each cell or stack, and even for each operating condition, the final design must always be a trade-off between the design parameters.

One of the main difficulties when assessing the flow field design in PEM fuel cells is the knowledge or prediction of the gas–liquid two-phase flow that is developed in the channels. Anderson et al. [9] presented a review of two-phase flow in the flow channels, featuring both experimental (in-situ and ex-situ) and modelling/CFD techniques, where the overall conclusions state that specific studies are required for providing an understanding of the hydrodynamics, and in particular for flow channels, where work must continue in ex situ approaches, in situ testing, and also numerical simulations. Hydrodynamics of two-phase flow in gas flow channels such as flow patterns, pressure drops, flow maldistribution, etc., are recognised to represent specific areas that need to be better understood. As an example, Lu et al. [10] investigated the two-phase flow in PEMFC cathode parallel channels over a wide range of superficial air velocity (air stoichiometry) and superficial water velocity in, where flow patterns and flow regime maps are provided.

For the investigation and design of liquid water in fuel cells it is obviously of high interest to enable the visualization of the liquid water distributions within the cell. 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 [11–13]. This technique was used by Owejan et al. [14] 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. [15] 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.

In this work, 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 flow field channels were investigated, particularly focusing on the preferential accumulation of liquid water in certain channels, identifying the main causes of the preferential accumulation so that improved designs can be achieved.

Experimental

Cell description

The cell used in the experiment was a 50 cm^2 active area cell from ElectroChem Inc., with metallic Bipolar Plates (five-channel serpentine flow field, Fig. 1). The general flow field layout is cross-flow, with horizontal channels in the anode and vertical channels in the cathode. A representation of the gas serpentine-type path is included in Fig. 1 for the cathode side, where the gas inlet is located in the top-right corner and the gas outlet in the low-left corner. There are 9 vertical paths through the plate (alternating downwards-upwards). Each of the main paths is composed out of 5 parallel channels, and thus a total of 45 channels are machined in the 50 cm^2 flow field. Each set of 5 parallel channels will be called “block” in the following sections. Channel width is 0.71 mm and rib width is 0.86 mm. Channel depth is 1.1 mm. Each set of ten channels (5 downwards and 5 upwards) is connected to a common manifold, with 5 incoming channels and five outgoing channels, where the manifold has a depth of 1.7 mm and a width of 1.5 mm.

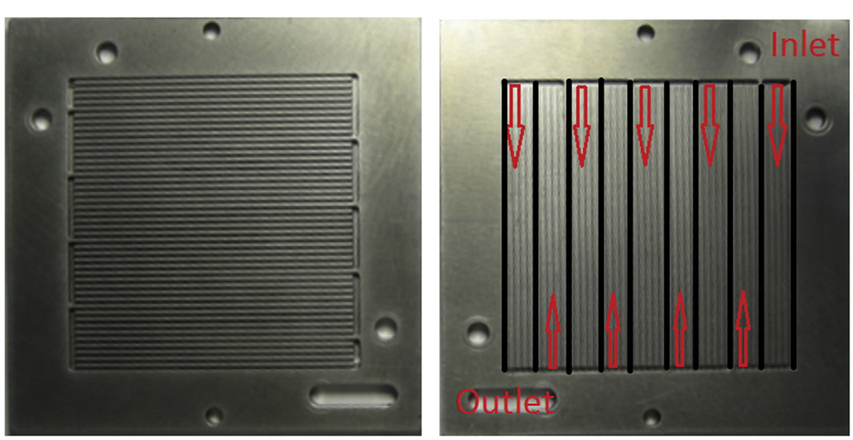

Fig. 1 – Bipolar Plates used in the 50 cm^2 fuel cell, showing the serpentine flow field in cross-flow configuration: horizontal channels in the anode side (left), vertical channels in the cathode sides (right). A schematic of the gas serpentine path is included for the cathode side.