INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 39 (2014) 9409–9419

Available online at www.sciencedirect.com

ScienceDirect

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

Liquid water breakthrough pressure through gas diffusion layer of proton exchange membrane fuel cell

*Mehdi Mortazavi**, *Kazuya Tajiri*

Mechanical Engineering—Engineering Mechanics, Michigan Technological University, 1400 Townsend Drive, Houghton, MI 49931, USA

ARTICLE INFO

Article history:
Received 15 January 2014
Received in revised form
27 March 2014
Accepted 29 March 2014
Available online 5 May 2014

Keywords:
PEM fuel cell
Gas diffusion layer (GDL)
Breakthrough pressure
Water transport

ABSTRACT

The dynamic behavior of liquid water transport through the gas diffusion layer (GDL) of the proton exchange membrane fuel cell is studied with an ex-situ approach. The liquid water breakthrough pressure is measured in the region between the capillary fingering and the stable displacement on the drainage phase diagram. The variables studied are GDL thickness, PTFE/Nafion content within the GDL, GDL compression, the inclusion of a microporous layer (MPL), and different water flow rates through the GDL. The liquid water breakthrough pressure is observed to increase with GDL thickness, GDL compression, and inclusion of the MPL. Furthermore, it has been observed that applying some amount of PTFE to an untreated GDL increases the breakthrough pressure but increasing the amount of PTFE content within the GDL shows minimal impact on the breakthrough pressure. For instance, the mean breakthrough pressures that have been measured for TGP-060 and for untreated (0 wt.% PTFE), 10 wt.% PTFE, and 27 wt.% PTFE were 3589 Pa, 5108 Pa, and 5284 Pa, respectively.

Introduction

Proton exchange membrane (PEM) fuel cells have gained much attention over the last few decades as a promising power source for automotive, portable, and stationary applications [1]. As a PEM fuel cell operates, hydrogen is oxidized in the anode and oxygen is reduced in the cathode to produce electricity, the intended product, with water and heat as byproducts. While some amount of the produced water can enhance the performance of the cell by hydrating its membrane, an excess amount of liquid water can threaten a continuous performance of the cell by filling the open pores of the gas diffusion layer (GDL). The GDL serves different roles in a PEM fuel cell. It enhances electrical contacts between the catalyst layer and the bipolar plate, supports the thin and fragile electrolyte membrane from mechanical damage, diffuses reactants over the catalyst layer, and facilitates water transport from the catalyst layer to the gas channel. Saturation of the GDL pores with liquid water is referred to as GDL flooding. GDL flooding blocks the transport of the reactants to the catalyst layer and lowers the performance of the cell by causing reactant starvation. The accumulation of excess water within the gas channel can also deteriorate the

* *Corresponding author.*
E-mail addresses: mortazav@mtu.edu (M. Mortazavi), ktajiri@mtu.edu (K. Tajiri).
http://dx.doi.org/10.1016/j.ijhydene.2014.03.238

performance of the cell by narrowing the flow cross-sectional area within the flow channel. This phenomenon is referred to as gas channel flooding and similar to GDL flooding, it can substantially deteriorate the performance of the cell. A steady performance of the cell relies on an appropriate balance between the water produced and water removed from the catalyst layer. This can be achieved by acquiring an accurate insight into the water transport phenomena across the electrode and GDL. Some studies reviewed water transport in PEM fuel cell and its balance within the membrane [2,3]. Water transport on the surface of the GDL has been previously studied by many researchers, including Mortazavi and Tajiri [4]. The current work focuses on the liquid water transport through the porous GDL.

Water transport through the porous media in fuel cells has been studied in some works. Different models have been proposed to describe the microscale liquid water transport through the GDL and micro-porous layer (MPL). Nam and Kaviany [5] studied the distribution of condensed water within the GDL and suggested that the liquid water transports from the catalyst layer to the gas channel in a branching-type geometry. According to their model, water transports through the GDL via capillary motion in a large main stream that is extended from the catalyst layer to the gas channel. The main water path is fed by smaller streams of liquid water that transport condensed micro-droplets to macro-droplets. This model has been confirmed by Pasaogullari and Wang [6] when they took a one-dimensional analytical solution of water transport phenomena within the GDL. Park et al. [7] argued that liquid shear force and water evaporation are the dominant driving forces that transport liquid water within the GDL. Litster et al. [8] suggested that the water transport through the GDL occurs by fingering and channeling. According to their hypothesis, water recedes when a dead end occurs and flows into adjacent breakthrough channels.

Similar to the GDL, water transport through the MPL has been speculated with a wide variety of hypotheses. While some studies conclude that coating a GDL with an MPL facilitates water transport from the catalyst layer to the GDL because of the pore size gradient [5,9,10], a completely opposite conclusion can also be found in literature [7]. Similarly, while some studies report that the cathode MPL enhances the back diffusion of water from the cathode to anode [11–13], others argue that the MPL has no particular impact on the back diffusion of water [14–17]. Lu et al. [18] studied liquid water transport through GDLs with and without MPL. They injected liquid water to the surface of the GDLs (MPL side for GDLs with MPL) and visualized water breakthrough from the surface of the GDLs. It has been reported that the water saturation of GDLs with MPL was lower than the water saturation of GDLs without MPL. Furthermore, they reported that for GDLs without MPL, water breakthrough locations changed dynamically but for GDLs with MPL, the breakthrough locations did not change over time. They suggested that MPL has two roles in water transport through the GDL. First, it limits the number of water entry locations into the GDL and second, it stabilized the water path through the GDL.

These controversial hypotheses emphasize the need for further studies of water transport through the GDL and MPL. A correct understanding about the liquid water transport mechanism through these components can lead to proper water removal from inside the cell. It should be added that the unique wettability and microstructural properties of each layer adds to the complication of this study.

As a common practice, GDLs are usually treated with a hydrophobic agent such as polytetrafluoroethylene (PTFE). The hydrophobic nature of the PTFE particles facilitates water removal from the GDL to the gas channel [19]. It also keeps liquid water from reentering the GDL after being expelled [8,20]. Furthermore, it has been reported that adding PTFE to GDL enhances both the gas and water transport for a cell working under flooding conditions while an excessive amount of PTFE content can lead to serious flooding in the catalyst layer [11].

Water transport through the porous structure of GDL and MPL can be studied by different approaches such as measuring the liquid water breakthrough pressure and/or visualization techniques. Bazylak comprehensively reviewed different methods of visualizing liquid water transport in PEM fuel cell components [2]. The breakthrough pressure is defined as the pressure at which liquid water passes through the porous media and emerges from the surface. The liquid water breakthrough pressure through the GDL has been measured in some studies [18,21–23]. Tamayol and Bahrami [21] measured the breakthrough pressure of 5 wt.% treated Toray carbon papers, TGP-030, TGP-060, and TGP-090. For TGP-060, they also measured the breakthrough pressure for untreated and 20 wt.% PTFE content. It has been reported that the breakthrough pressure increases with GDL thickness and PTFE content. Liu and Pan [22] analyzed water saturation inside the GDL by combining the images of water droplets on the surface of the GDL with the breakthrough pressures.

In this work, liquid water transport through the porous structure of the GDL is experimentally studied by measuring the liquid water breakthrough pressure. The liquid water breakthrough pressure is measured for different GDL thicknesses and different PTFE contents within the GDL. The effect of GDL thickness on liquid water transport through the GDL is also studied by reconstructing the pore-network of the GDL based on the GDL microstructural properties. Moreover, the effect of MPL and GDL compression on liquid water breakthrough pressure is investigated.

Experimental setup

Water breakthrough experiment

Liquid water breakthrough pressures through the GDL samples were measured with an ex-situ setup. Fig. 1 shows the schematic and the picture of the experimental setup. Water was injected to the surface of the GDL through a 250 μm diameter (Upchurch-U111) stainless steel capillary. A 1/16 inch (1.58 mm OD) FEP tube connected the stainless steel capillary to the female slip luer of the syringe in the syringe pump. The stainless steel capillary had an external diameter of 3.1 mm. The capillary was inserted into the test section via a through-all hole that was machined on one of the polycarbonate plates. The test section, made of two polycarbonate plates, held the GDL samples that were cut into pieces of