Journal of Power Sources 292 (2015) 39–48

Contents lists available at ScienceDirect

Journal of Power Sources

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

Double-layer gas diffusion media for improved water management in polymer electrolyte membrane fuel cells

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HIGHLIGHTS

- New double-layer GDM with graded PTFE loading is demonstrated for PEMFCs.
- Double-layer GDM shows improved water management even under flooding conditions.
- Numerical model for saturation level in double-layer GDM is developed.
- Numerical predictions are validated by experimental measurements.
- Adding GDM layers with graded hydrophobicity can improve water management in PEMFCs.

ARTICLE INFO

Article history:
Received 7 April 2015
Accepted 11 May 2015
Available online 19 May 2015

Keywords:
Polymer electrolyte membrane fuel cell
Water management
Gas diffusion media
Gas diffusion layer
PTFE loading
Flooding

ABSTRACT

Water management is an important consideration to improve the performance of polymer electrolyte membrane fuel cells (PEMFCs). Reactant gases are supplied to the catalyst layer through gas diffusion media (GDM) in PEMFCs. Under high current draw conditions, the GDM can flood with liquid water which is detrimental to fuel cell operation. In this paper, we investigate the effectiveness of a double-layer GDM with different polytetrafluoroethylene (PTFE) loadings to mitigate saturation with liquid water under flooding conditions. We developed a numerical model to predict the saturation field in the double-layer GDM, and showed that the overall saturation level is decreased when the layer with higher PTFE loading is placed adjacent to the catalyst layer. It was found that the interface between the two GDM layers plays a significant role in regulating the saturation level by lowering the driving saturation level for water transport inside the GDM. The numerical predictions of the model were validated by conducting experiments with the double-layer GDM which showed a higher limiting current density and more stable performance, thereby confirming that the new GDM architecture can improve water management in PEMFCs.

1. Introduction

The polymer electrolyte membrane fuel cell (PEMFC) is one of the most promising replacements for fossil-fuel combustion engines for automotive applications because it is highly efficient, produces zero emissions, and can start up and shut down quickly due to its relatively low operating temperature (70 °C) [1]. Despite major advances in PEMFC technology over the past two decades, several issues continue to challenge PEMFC performance and durability. One of these issues is water management. In order to perform effectively, the polymer electrolyte membrane needs to be well hydrated for good proton conductivity. This implies that the fuel cell must operate at a high humidity level. However, excessive humidity can lead to condensation of liquid water within the porous gas diffusion media (GDM), especially under high current conditions, a situation known as flooding. Flooding is extremely detrimental to performance as the saturated GDM blocks reactant gas access to the catalyst layer [2]. Therefore, it is critical to design GDMs that are less susceptible to flooding even under conditions of high humidity.

Water transport in porous media has held long-standing interest in groundwater modeling and petroleum research. More recently, these ideas have also been applied to PEMFCs to identify porous diffusion media with optimal two-phase transport properties [3,4]. Many research groups have attempted to experimentally

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http://dx.doi.org/10.1016/j.jpowsour.2015.05.028
0378-7753/

characterize water transport inside the porous GDM to better understand and control their transport properties [5–7]. Others have employed numerical models to gain insight into two-phase flow behavior in porous media to provide guidance for improved fuel cell design [8–10].

The properties of the porous medium such as porosity, thickness, and contact angle play an important role in determining the transport of liquid water. In PEMFCs, PTFE-treated carbon paper or cloth with a typical porosity of 80% is commonly used as the GDM. The carbon fiber provides hydrophilic pathways to wick away liquid water generated at the catalyst layer to the flow field channels, whereas the hydrophobic PTFE-treated pores remain open to serve as transport pathways for the reactant gases. Hydrophilicity and hydrophobicity are often manipulated to improve water transport within the GDM in PEMFCs. For example, a highly hydrophobic micro porous layer (MPL) sandwiched between the catalyst layer and the GDM can facilitate better water transport [11,12]. The MPL combined with the GDM together constitute the gas diffusion layer (GDL) of the PEMFC.

It was shown by Ref. [13] that the use of a double-layer MPL can improve water management. However, their experimental results did not shed light on how exactly their novel MPL design contributed to improved water transport. Many numerical models and simulations have been developed to explore and improve water management. It was suggested in Ref. [14] that a graded porosity distribution in the GDM could benefit water removal. Similarly, a general idea to optimize water transport by controlling the thickness of the MPL and PTFE loading in the GDM was reported by Refs. [15,16]. It was also shown by Ref. [17] that a variation in the in-plane hydrophobicity in the flow direction can aid water management inside the channel. Although modeling work to date has shown promise for optimizing GDL design by controlling the key transport properties, the predictions of these numerical models are not usually substantiated by experimental data.

The effect of adding an MPL on fuel cell performance was studied by Ref. [18] using a numerical model. They concluded that the highly hydrophobic MPL increased the backward flux of water through the membrane toward the anode and thus reduced the flux of water from the membrane to the cathode. Moreover, the bilayer structure further reduced the saturation level at the cathode catalyst layer/MPL interface. Both of these effects combined to reduce the flooding at the cathode side.

In this paper, we report results from a numerical model in which the through-plane hydrophobicity of the GDM is controlled by using a double-layer GDM architecture with different PTFE loadings to optimize the transport of liquid water and reactant gas. We also employ an MPL at the interface between the catalyst layer and the inner GDM layer. The MPL restricts liquid water transport from the membrane to the cathode side, while the novel double-layer GDM with different hydrophobicities facilitates the water removal and reduces water accumulation inside the cathode GDL. The numerical predictions of the model were validated by experiments in which GDM with different PTFE loadings were prepared and tested in a fuel cell under flooding conditions. The numerical model was then employed to explain the experimental results. The combined experimental and numerical efforts have provided us with a better understanding of water transport as a function of the double-layer GDM design.

2. Experiments

2.1. Materials for double-layer GDM

The central component of the PEMFC is the catalyst-coated membrane (CCM), also known as the membrane electrode assembly (MEA). The MEA is sandwiched between GDMs and the layers are hot-pressed together. In the current work, a CCM from IonPower (NR-212, active area = 25 cm^2) was used for all the MEAs tested. A single layer GDM (TGP-H-060) was used on the anode side for all cases because the anode is less prone to flooding under normal operating conditions. The anode GDM had a thickness of 190 μm and a PTFE loading of 20%. For the cathode, we employed a novel double-layer GDM with different PTFE loadings as shown in Fig. 1. The cathode GDM consisted of two thinner carbon papers (TGP-H-030) each with a thickness of 110 μm, for a total thickness of 220 μm.

For comparison, a baseline fuel cell with a single layer GDM on the cathode side was also tested; for the baseline case, the cathode GDM was identical to the anode GDM. To match the total 20% PTFE loading of the baseline case, the individual layers in the double-layer cathode GDM had PTFE loadings of 10% and 30%. The slightly higher thickness of the double-layer cathode GDM compared to the baseline case was found to have a negligible effect on performance. This was confirmed by testing a double-layer cathode GDM wherein each layer had the same PTFE loading of 20%. In addition, another case with a single layer cathode GDM with 30% PTFE loading was also tested to determine whether just a single layer with a uniform higher PTFE loading is responsible for the improved performance instead of the double-layer configuration with different PTFE loadings. All of the cases tested are listed in Table 1. It should be noted that an MPL consisting of 20wt% PTFE and 80wt% carbon powder was sprayed on to the carbon paper GDM to form the GDL as shown in Fig. 1. The GDL was sintered at 280 °C for 30 min, and then at 350 °C for 30 min in an oven under nitrogen. The thickness of the MPL was around 50 μm.

2.2. Experimental procedure

The following procedure was used to evaluate the effectiveness of the double-layer GDM. First, each fuel cell, employing serpentine flow fields with air and hydrogen running in parallel, was conditioned under a constant current density of 0.5 A cm^{-2} for 3 h with the humidifier and fuel cell temperatures both set to 80 °C to fully hydrate the membrane. Next, the current density was increased to 1.7 A cm^{-2} with H_2/air stoichiometries of 3.0/2.4 and the cell temperature was reduced by 1 °C every 45 min while holding the humidifier at 80 °C. The cell voltage was continuously recorded during this test. The reduction in cell temperature causes the supply gas streams to become supersaturated and promotes flooding behavior. The cell's performance is adversely affected by the increasing saturation level until the cell finally produces no voltage due to complete flooding. The recorded voltage vs. time was

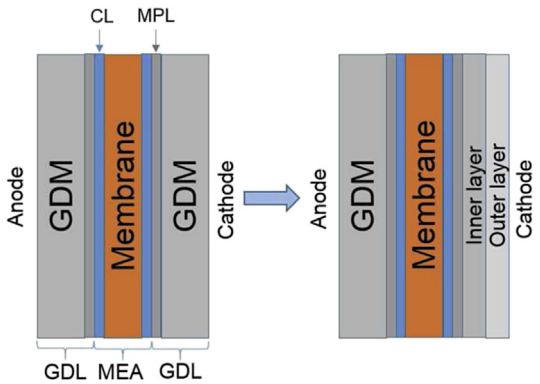

Fig. 1. Traditional configuration of a PEMFC (left), and double-layer cathode GDM configuration (right).