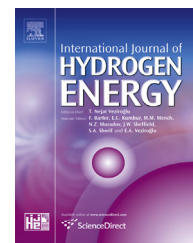


Available online at www.sciencedirect.com

ScienceDirect

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

Optimum design of polymer electrolyte membrane fuel cell with graded porosity gas diffusion layer

Y. Zhang¹, A. Verma, R. Pitchumani*

Advanced Materials and Technologies Laboratory, Department of Mechanical Engineering, Virginia Tech, Blacksburg, VA 24061, United States

ARTICLE INFO

Article history:

Received 23 November 2015

Received in revised form

10 February 2016

Accepted 13 February 2016

Available online xxx

Keywords:

Proton exchange membrane (PEM)
fuel cell

Graded porosity electrode

Current density distribution

Optimization

Membrane durability

Fuel cell reliability

ABSTRACT

Variation in the local current density along a polymer electrolyte membrane (PEM) fuel cell often causes sharp temperature and stress gradients that affect the membrane durability and service life of fuel cells. Towards minimizing the variation in local current density, and potentially improving fuel cell reliability, this paper explores the use of functionally graded porosity in the gas diffusion electrode layers along the flow direction. A computational model for fuel cell is used together with a numerical optimization method to determine the optimum porosity distribution along the length of the channel, with the objective of maximizing power density while limiting the current density variation. The optimum porosity distribution and the corresponding local current density distribution are compared and discussed in detail for different operating conditions. Experimental studies are conducted to measure the local current density distribution in a fuel cell with a segmented current collector and to evaluate the effects of graded porosity distribution in the gas diffusion layer. It is shown that use of an optimally graded porosity distribution improves the uniformity in current density along the length of the channel by up to a factor of 10, while maximizing the power density.

Copyright © 2016, Hydrogen Energy Publications, LLC. Published by Elsevier Ltd. All rights reserved.

Introduction

Proton exchange membrane (PEM) fuel cells are considered a viable alternative energy source for mobile and stationary applications owing to their high power density, simple design and pollution free operation. However, widespread commercialization of PEM fuel cells is primarily challenged by their low reliability in service, caused by membrane electrode assembly (MEA) degradation and failure. During the operation of a PEM fuel cell, significant variation in local current density

could exist along the length of the channel due to the reduced reactant concentrations, leading to sharp temperature and stress gradients. The temperature and stress gradients affect water management and may lead to localized hot spots and pin-holes, causing membrane degradation and failure in some cases [1–6]. Since MEA degradation dramatically affects the performance and the life of fuel cells, it is important to mitigate the variation of the local current density to ensure the operation reliability of fuel cells.

Several studies have been reported in the literature to determine the current density distribution in fuel cells using in

* Corresponding author. Tel.: +1 540 231 1776.

E-mail address: pitchu@vt.edu (R. Pitchumani).

¹ Now with General Motors Company, Pontiac, MI, United States.

<http://dx.doi.org/10.1016/j.ijhydene.2016.02.077>

0360-3199/ Copyright © 2016, Hydrogen Energy Publications, LLC. Published by Elsevier Ltd. All rights reserved.

situ experimental techniques and numerical simulations. Stumper et al. [7] discussed three different techniques for investigating current density distribution and their relative benefits. For the partial membrane electrode assembly (MEA) approach either segments of MEA were masked or several MEAs with partially catalyzed active area were tested to determine localized current density. In the second method, several electrically isolated subcells were placed at various locations along the flow channel and were controlled by a separate load. In the third method, a passive graphite resistor network was placed between the flow field plate and the current collector plate to test potential drop across the resistors to obtain the local current density distribution. Mench et al. [8] built segmented flow plates for both anode and cathode sides, which were fabricated by embedding gold plated stainless steel ribs in a polycarbonate block, acting as segmented current collectors. A similar approach was used in Ref. [9], where a measuring gasket was specifically designed and inserted between the flow field plate and the gas diffusion layer to measure the local current by the current collecting strips in the gasket. Natarajan et al. [10] investigated the local current density distributions using segmented current collectors and gas diffusion layers. The printed circuit board technology, adopted from Refs. [11,12], was used to create a segmented current collector and flow field. The segmented current collector approach was also used in air-breathing PEM fuel cell to study the transient and steady state current density distributions in Refs. [13] and [14].

Another method to test the local current density distribution is to measure the electromagnetic field throughout the cell [15,16]. Freunberger et al. [17] used a number of very thin wires placed in parallel with the channels and solved a Laplace equation to convert this measurement into the current density in sections parallel to the flow channels. Wang and Liu [18] measured the current density under the channel and shoulder, separately, by loading only the specific areas with catalyst. Gerteisen et al. [19] studied the effects of operating conditions on current density distribution and high frequency resistance in a segmented PEM fuel cell. Luo and Liu [20] used partially catalyzed membrane electrode assemblies to investigate the difference in current density at inlet channel, land and the outlet channel. Besides experimental work, numerical simulation studies are also reported [1,21–24] on investigating the local current density distribution under different design factors including material properties, geometry parameters and operating conditions.

The previous studies show that the local current density is not uniform inside the cell and decrease due to the consumption of the reactant gases along the length of the channel. The current density distribution can be manipulated by modifying component material properties such as the porosity of gas diffusion layers (GDLs). The purpose of the gas diffusion layers, made of porous media, in a fuel cell is to effectively distribute the reactant gases into the catalyst layers for electrochemical reactions, and to allow for electronic conduction simultaneously. During the operation of the cell, reactant species concentrations decrease along the channel owing to reactant consumption, which leads to a non-uniform species distribution and, in turn, non-uniform current density distribution. Gurau et al. [25] developed a

one-dimensional half-cell model to investigate the influence of the effective porosity of GDL on the cell performance, considering that the pores maybe partially filled with liquid water and thus changing the local porosity. A similar model was employed in Ref. [26], and the non-uniform porosity along the thickness of the cell was investigated by four different continuous functions of position to study its effect on the cell performance including the oxygen mass fraction distribution, current density distribution and membrane phase potential distribution. Yan et al. [27] studied the effect of flow distributor and diffusion layer geometries and morphologies on the species transport phenomena suggesting that increase in porosity and water content leads to better performance. The influence of uniform and gradient porosity across the thickness of the GDL on liquid water transport was analyzed in Ref. [28]. Min et al. [29] performed a parameter sensitivity analysis in the numerical modeling of PEM fuel cell, including the effect of different porosity values on the cell performance. Tang et al. [30] investigated the effects of porosity-graded microporous layers (MPL), by printing MPLs with different content of NH_4Cl pore-former and the porosity of the graded MPL decreased from the inner layer to outer. It was found that the fuel cells with graded MPL had better performance owing to better water and gas transportation. Schweiss et al. [31] doped MPLs of GDLs with multi walled carbon nanotubes, leading to improved conductivity and increase in larger mean pore diameter, and thus an improvement in mass transport. It is envisioned that increasing the porosity will result in more reactant gases being transported to catalyst sites for electrochemical reactions. Therefore, tailoring the gas diffusion layer to have a gradually increasing porosity along the channel will provide for a more uniform distribution of the reactant gases into the catalyst layer, thus achieving a more uniform current density distribution along the length of the channel and forms the scope of current study.

This paper proposes an approach to reduce the local current density variation by using functionally graded porosity in the gas diffusion layer along the gas channel, with the goal of determining the optimum porosity distribution of the gas diffusion layer so as to achieve a desired uniformity in current density while maximizing the power density. By tailoring the porosity variation in the GDLs such that the porosity increases gradually along the flow length, the availability of the reactants at the catalyst sites can be controlled so as to yield uniformity of the electrochemical reaction and, in turn, the local current density. To this end, a two-dimensional numerical model is developed to describe the transport and electrochemical phenomena inside a conventional PEM fuel cell. The porosity distribution is parameterized using a power law functional form or piecewise continuous variation, such that the porosity increases monotonically along the length of the channel. Systematic parametric studies are conducted to obtain the optimum porosity and current density distributions for different operating conditions. The optimum results from the simulations, in turn, is used to fabricate GDLs with the graded porosity distribution which are tested in a fuel cell test station to investigate the improvement in the local current density distribution. The computational and experimental studies are used to demonstrate effectiveness of the method

Download English Version:

<https://daneshyari.com/en/article/7710740>

Download Persian Version:

<https://daneshyari.com/article/7710740>

[Daneshyari.com](https://daneshyari.com)