Journal of Power Sources 320 (2016) 222–230

Contents lists available at ScienceDirect

Journal of Power Sources

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

Measurement of effective bulk and contact resistance of gas diffusion layer under inhomogeneous compression – Part II: Thermal conductivity

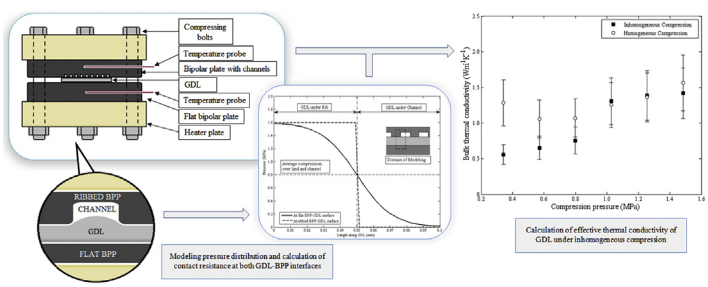
Prabudhya Roy Chowdhury [1], Ajit Vikram [2], Ryan K. Phillips, Mina Hoorfar*

University of British Columbia, School of Engineering, Kelowna, BC, Canada

HIGHLIGHTS

- Thermal contact resistances at the GDL-Bipolar Plate (BPP) interface is measured.
- Bulk thermal conductivity of GDL is measured under inhomogeneous compression.
- Non-linear pressure distribution at the GDL-BPP interface is obtained numerically.
- Effective bulk thermal conductivity increases with increasing the pressure.
- Contact resistance has the major contribution in the overall thermal resistance.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 21 February 2016
Received in revised form
19 April 2016
Accepted 22 April 2016
Available online 29 April 2016

Keywords:
Fuel cell
Gas diffusion layer
Inhomogeneous compression
Thermal contact resistance
Bulk thermal conductivity

ABSTRACT

The gas diffusion layer (GDL) is a thin porous layer sandwiched between a bipolar plate (BPP) and a catalyst coated membrane in a fuel cell. Besides providing passage for water and gas transport from and to the catalyst layer, it is responsible for electron and heat transfer from and to the BPP. In this paper, a method has been developed to measure the GDL bulk thermal conductivity and the contact resistance at the GDL/BPP interface under inhomogeneous compression occurring in an actual fuel cell assembly. Toray carbon paper GDL TGP-H-060 was tested under a range of compression pressure of 0.34 to 1.71 MPa. The results showed that the thermal contact resistance decreases non-linearly (from 3.8×10^{-4} to 1.17×10^{-4} $Km^2 W^{-1}$) with increasing pressure due to increase in microscopic contact area between the GDL and BPP; while the effective bulk thermal conductivity increases (from 0.56 to 1.42 $Wm^{-1} K^{-1}$) with increasing the compression pressure. The thermal contact resistance was found to be greater (by a factor of 1.6–2.8) than the effective bulk thermal resistance for all compression pressure ranges applied here. This measurement technique can be used to identify optimum GDL based on minimum bulk and contact resistances measured under inhomogeneous compression.

© 2016 Elsevier B.V. All rights reserved.

1. Introduction

Gas diffusion layers (GDL) in proton exchange membrane fuel cells (PEMFC) play an important role in transporting different

* Corresponding author. School of Engineering, University of British Columbia, 3333 University Way, USA.

E-mail address: mina.hoorfar@ubc.ca (M. Hoorfar).

[1] Present address: Indian Institute of Technology, Kharagpur, India.

[2] Present address: Indian Institute of Technology, Kanpur, India.

http://dx.doi.org/10.1016/j.jpowsour.2016.04.112
0378-7753/© 2016 Elsevier B.V. All rights reserved.

species from the bipolar plates (containing channels for flowing reactants) to the catalyst layers (where reactions occur) and transferring the byproducts (water and heat) from the catalyst layer to the bipolar plates (BPP). Due to its complex porous structure, the transport properties of the GDL (e.g., porosity [1–6], diffusivity [7–9], permeability [9–12], electrical [13–16], and thermal [17–25] conductivity) were widely studied in the past decades. The accurate measurement of these properties in an actual fuel cell assembly is significantly important for identifying an optimum GDL for different operating conditions. Among different properties, the measurement of the thermal and electrical conductivity of the GDL could be more challenging as it requires techniques that can separate the bulk resistance of the GDL from the resistances at the interface of the GDL and BPP, which also depend on different factors such as the structure of the BPP and compression pressure. This study focuses on the measurement of the thermal properties of the GDL (both the bulk and contact resistances). In essence, the GDL is responsible for managing the waste heat generated due to reaction, and hence an accurate measurement of the thermal conductivity and contact resistances associated with this layer is of prime importance for a number of reasons: the PEMFC is sensitive to excessive heat and can be damaged at high temperatures [26]. Hence, the GDL needs to remove the waste heat effectively from the cell to prevent high temperatures and large temperature gradients across the reaction site and the flow plate. Efficient thermal management also enhances water management in the GDL [27,28], improving transport of the reactant gas to the membrane. Finally, accurate modeling of the temperature profile of the membrane electrode assembly (MEA) requires knowledge of the resistances associated with each component, including the GDL.

The thermal conductivity and contact resistances associated with the GDL have been investigated with certain accuracies by several groups in the past decade [17–25,29–32]. A detailed review of the various methods developed for the measurement of the thermal resistances associated with the GDL has been presented by Arvay et al. [26]. As a first group who studied the *in-situ* temperature gradient in the membrane electrode assembly (MEA) in a fuel cell, Vie and Kjelstrup [17] used small diameter thermocouples to estimate the thermal conductivity of each component in the MEA (including the GDL, membrane, and catalyst layer). In essence, they sandwiched the thermocouples between the GDL and the membrane. The thermocouples had a thickness comparable to the thickness of the GDL and membrane, resulting in a significant contact pressure around the probes affecting the accuracy of the thermal conductivity measurements. Khandelwal and Mench [18] used a steady-state heat flux method to find the thermal conductivity of different components (including dry Nafion®, various GDLs and catalyst layers) and the thermal contact resistance between the GDL and a metal plate as a function of temperature and compression pressure. In their setup, the GDL was sandwiched between two metal plates of known conductivity and a known heat flux was passed through the system. Two types of GDLs were tested: SIGRACET® (with and without PTFE loading) and Toray carbon paper (no PTFE). For the temperature range of 27–73 °C, the measured thermal conductivity values of the Toray paper were in the range of 1.24 ± 0.19 Wm^{-1} K^{-1} to 1.80 ± 0.27 Wm^{-1} K^{-1}; whereas SIGRACET papers with and without PTFE loading showed the thermal conductivity values of 0.22 ± 0.04 Wm^{-1} K^{-1} and 0.48 ± 0.09 Wm^{-1} K^{-1}, respectively. For each GDL type, samples with two different thicknesses were tested to separate the bulk and contact resistances by assuming similar thermal resistivity for two different GDL thicknesses. However, this assumption may not be valid as the GDL fabrication process may lead to different fiber orientation with the change in the specimen thickness, resulting in different bulk properties for the two thicknesses of samples used. The same method of unidirectional steady -heat flux was used by Ramousse et al. [22] for the measurement of the thermal conductivity of GDLs made of carbon felts. Instead of using different thicknesses of specimens, they stacked different numbers of GDLs between the hot and cold plates. As a result, they obtained a line for the measured resistance as a function of the number of GDLs stacked. The slope and the intercept of this line present the bulk conductivity of the sample and the contact resistance between the GDL and the plates, respectively. Nitta et al. [19] studied the effect of compression on the GDL deformation resulting in a stress-strain curve for the GDL under homogenous compression (applied using two flat plates sandwiching the GDL). Then, they used the stacking method to obtain the thermal conductivity of the GDL as a function of compression pressure (varied from 0 to 5.5 MPa). Combining the two results, they obtained the thermal conductivity of the GDL and the contact resistance as a function of GDL deformation (thickness). They showed that the bulk thermal conductivity of the GDL is independent of compression pressure, while the thermal contact resistance decreases non-linearly with compression pressure. Using this method, they estimated conductivity of a Toray TGP-H-060 GDL as 1.18 ± 0.11 Wm^{-1} K^{-1}. Following the same approach, other groups [21,29] have estimated the thermal conductivity of a variety of porous structures (with different PTFE loadings) as a function of compression pressure.

Radhakrishnan et al. [30] used a guarded hot plate method (a unidirectional steady-state heat flux method) to measure the thermal conductivity of Toray papers at compression pressures of 0.04–1.5 MPa. The conductivity was investigated over a range of temperatures from 25 to 75 °C. The thermal conductivity of the sample was found to decrease with increasing temperature. In their study, they also proposed a new fractal model to predict the effective thermal conductivity of the GDL without using any empirical constant. The predications of the model showed great agreement with the experimental measurements. Sadeghi et al. [32] also used the constant heat flux method to estimate the bulk thermal and thermal contact resistances for Toray TGP-H-060 and TGP-H-120 carbon papers. They found that the thermal contact resistance (compared to the bulk thermal resistance) is the dominant component of the overall resistance. In another part of their study, Sadeghi et al. [31] repeated the experiments with a cyclic loading to estimate the effect of hysteresis on the GDL. They found a significant effect of hysteresis on both bulk and contact resistances (up to 34% between loading and unloading). The changes in both resistances were insignificant after 5 cycles. Zamel et al. [23] used the method of monotonous heating to investigate the in-plane thermal diffusivity of carbon paper (Toray TGH-H-120) over a temperature range of −20 to 120 °C. They found that the in-plane thermal conductivity decreases with an increase in temperature. They also investigated the effect of Teflon loadings (0–50 wt. %) on the thermal conductivity values. For instance, they found that the in-plane conductivity of the GDL at 70 °C varies from 12.5 ± 0.9 to 10.6 ± 0.7 Wm^{-1} K^{-1} for the PTFE loadings of 0 and 5 wt. %, respectively. Higher PTFE loadings than 5 wt. % did not present a major effect on thermal conductivity. In another study, Zamel et al. [24] measured the through-plane thermal conductivity of TGP-H-120 GDL using the thermal capacitance (slug calorimeter) method (ASTM standard E2584-07). Unlike the in-plane thermal conductivity, the through plane conductivity was found to increase as the temperature was increased. This finding suggests that the thermal conductivity of the GDL is direction dependent. Based on the heterogeneous porosity profile of the GDL, Yablecki and Bazylak [25] developed an analytical model to determine the effective through-plane thermal conductivity of the GDL under compression. Their model includes two main components: the physical model of the GDL considering compressed fibers (facilitated through

Download English Version:

https://daneshyari.com/en/article/1286056

Download Persian Version:

https://daneshyari.com/article/1286056

Daneshyari.com