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A new model for thermal contact resistance between fuel cell gas diffusion layers and bipolar plates

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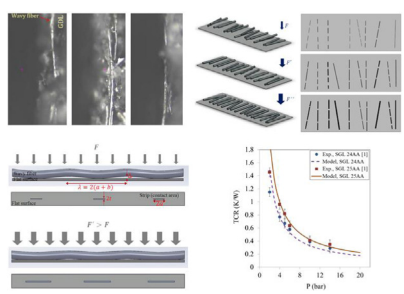
HIGHLIGHTS

- Optical images show that GDL fibers are wavy and not straight.
- Thermal contact resistance (TCR) decreases with fiber wavelength.
- TCR increases with curvature, diameter and amplitude of fiber and GDL porosity.
- TCR does not change with fiber length.
- TCR variations with geometric parameters are higher at lower compression.

GRAPHICAL ABSTRACT



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ABSTRACT

A new analytical model is developed to predict the thermal contact resistance (TCR) between fibrous porous media such as gas diffusion layers (GDLs) of polymer electrolyte membrane fuel cells (PEMFCs) and flat surfaces (bipolar plates). This robust model accounts for the salient geometrical parameters of GDLs, mechanical deformation, and thermophysical properties of the contacting bodies. The model is successfully validated against experimental data, and is used to perform in a comprehensive parametric study to investigate the effects of fiber parameters such as waviness and GDL properties on the TCR. Fiber waviness, diameter and surface curvature, as well as GDL porosity, are found to have a strong influence on TCR whereas fiber length does not affect the TCR when the porosity is kept constant. Such findings provide useful guidance for design and manufacturing of more effective GDLs for PEMFC heat management.

The analytic model can be readily implemented in simulation and modeling of PEMFCs, and can be extended with minor modifications to other fibrous porous media such as fibrous catalysts, insulating media and sintered metals.

1. Introduction

Durability, reliability and stability of polymer electrolyte membrane fuel cells (PEMFCs) are strongly dependent on heat and associated water management. It has been recently shown [1,2] that the contact resistance between the PEMFC components may be higher than their bulk resistances. However, contact resistance has typically either been roughly estimated or simply overlooked in performance model analyses [3,4]. This is mainly due to the technical barriers and challenges in measuring and predicting contact resistance, especially over a range of compression, see e.g. Refs. [5–12].

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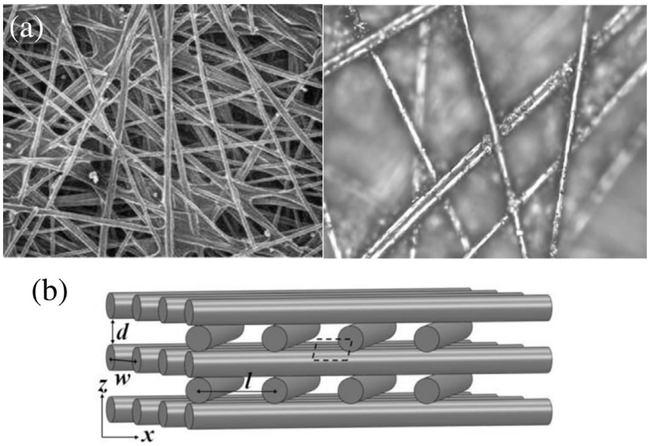

Fig. 1. (a) GDL surface images (Sigracet GDLs) and (b) Proposed geometrical modeling for a GDL.

Among the interfacial resistances in PEMFCs, the contact resistance between gas diffusion layer (GDL) and neighboring bipolar plate (BPP) is of special interest due to the rib/channel structure of the BPP compressing the adjacent GDL. The complexity of the GDL micro-structure and its surface morphology have lead most researchers to adopt numerical [13,14] and experimental [15–21] methods rather than analytic models. In our previous works (Sadeghifar et al. [1,2,5]), the thermal contact resistances (TCR) of different GDLs with metallic surfaces and also with graphite BPP were measured. The results showed that the contact resistance can be as high as the GDL bulk resistance, even for thick GDLs with thermal conductivities as low as 0.2 W m^{-1} K^{-1}. A few numerical studies have also been performed to estimate the GDL-BPP contact resistance. Using ANSYS Fluent, Nitta et al. [16] numerically estimated the contact resistance between a GDL and a graphite plate, but reported, inconsistently with contact mechanics considerations and available experimental observations, that the GDL thermal conductivity is independent of compression.

The objective of this study is to develop a mechanistic analytic model for predicting the thermal contact resistance between a GDL—a fibrous porous material—and a flat surface, e.g. a graphite or metallic BPP. The present model is built using: i) GDL and BPP salient geometric parameters, such as waviness, diameter, distribution and orientation of fibers, GDL porosity; ii) applied load, mechanical deformation, Hertzian theory; iii) thermophysical properties of both contacting bodies, i.e., fibrous porous medium and flat plate, properties such as thermal conductivities and effective Young's modulus; and iv) heat conduction in GDL fibres (spreading/constriction resistances).

2. Model development

The real area between the two contacting bodies is the key parameter in determining both electrical and thermal contact resistance. The contact area can be determined using geometrical and mechanical modeling. The TCR at the interface between a fibrous porous medium and a solid flat plate can be obtained using an appropriate thermal model that includes heat transfer in both contacting bodies through the contacting areas. This section provides an overview of different elements of the model.

2.1. Geometrical model

Based on images of different GDLs, the fibers are assumed to have a circular cross-section, as was the case in our previous works [1,8], see Fig. 1. In almost all previous GDL geometric models, the fibers are assumed to be straight, i.e. cylindrical. When modeling interfacial phenomena, which are highly dependent on surface topography and morphology, more realistic assumptions are required. Our analysis of GDL images reveals that fibers are in fact wavy, as can be seen in Fig. 2. Consequently, fibers are considered as wavy cylinders, with a sinusoidal profile in this study, see Fig. 3. The waviness of the fibers is measured optically using a mechanical tester microscope (NANOVEA). This instrument allows micro-scale imaging/filming while scanning the sample in different directions. The statistical data for fiber waviness and amplitude are presented in Fig. 4(a) and (b) for Sigracet (SGL) GDLs. The wavelength (λ) and amplitude (Δ) data fall in the ranges 50–1900 µm and 2-5d_f for the Sigracet samples. For most engineering applications, however, using the average values of fiber amplitude and wavelength may lead to sufficient accuracy.

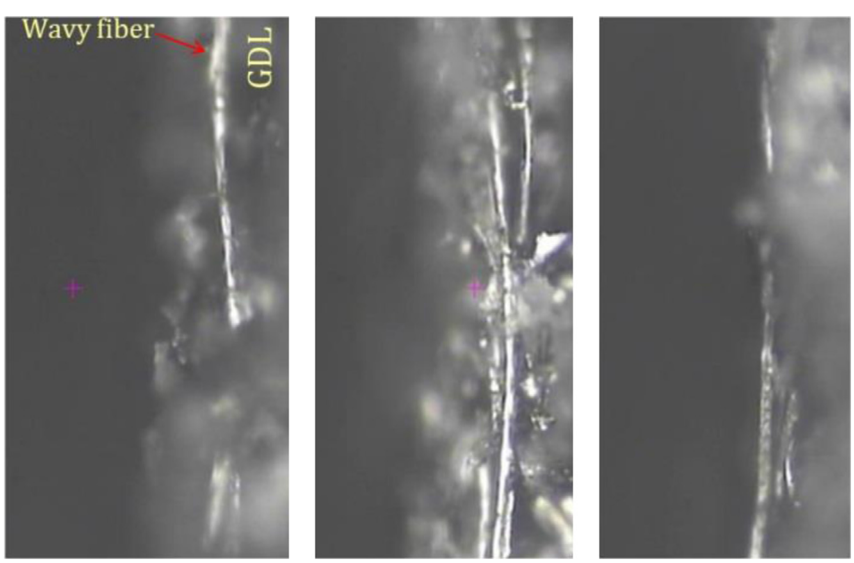

Fig. 2. GDL images showing waviness of the fibers.