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# The through-plane thermal conductivity and the contact resistance of the components of the membrane electrode assembly and gas diffusion layer in proton exchange membrane fuel cells

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## HIGHLIGHTS

- The thermal conductivity of the membrane was comparable in both directions.
- The through-plane thermal conductivity of the membrane decreases with temperature.
- The through-plane thermal conductivity of the GDL decreases with temperature.
- The through-plane thermal conductivity of the GDL increases with compression.
- The thermal conductivity of the catalyst was comparable in both directions.

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## ABSTRACT

The thermal conductivity of the components of the membrane electrode assembly (MEA) and GDL must be accurately estimated in order to better understand the heat transfer processes in the proton exchange membrane (PEM) fuel cells. In this study, an experimental investigation has been performed to measure the through-plane thermal conductivity and the contact resistance for a number of gas diffusion layer (GDL) materials. The sensitivity of these quantities to the temperature, PTFE content and micro porous layer (MPL) coating has been undertaken. In addition, the through-plane thermal conductivity of the membrane has been measured and reported as a function of temperature and water content. Further, the through-plane thermal conductivity of the catalyst layer has been determined as a function of temperature and platinum loading. It has been found that the through-plane thermal conductivity of the components of the MEA decreases when the temperature increases, and the through-plane thermal conductivity of the GDL is significantly lower than its in-plane thermal conductivity.

## 1. Introduction

The thermal conductivity of the components of the membrane electrode assembly (MEA) and GDL must be accurately estimated in both directions, namely in-plane and through-plane directions, in order to better understand the heat transfer processes in proton exchange membrane (PEM) fuel cells [1–3]. Many researchers use a steady state method to measure the thermal conductivity of gas diffusion layers (GDLs) in the through-plane directions [4,5]. In particular, Vie et al. [6] were the first research group who attempted to measure the thermal conductivity of the fuel cell components. In their paper, many thermocouples have been inserted in the fuel cell and the temperature gradient is measured at different locations. The thermocouples were inserted between the gas diffusion layers, the catalyst layers and the membrane. The thermal conductivity of the E-Tek ELAT GDL and the catalyst layer was about $0.2 \pm 0.1$ W m$^{-1}$ K$^{-1}$. However, these measurements were not accurate due to the high uncertainty on the locations of the thermocouples and due to the fact that the thermocouples blocked some of the active area of the fuel cell. Khandelwal and Mench [7] measured the through-plane thermal conductivity of Toray and SIGRACET® carbon papers under 20 bar compression pressure. Ramousse et al. [8] estimated the thermal conductivity of a typical GDL to be lower than the thermal conductivity of pure carbon samples but they did not take into account the effect of the compaction pressure on the thickness of the sample. Nitta et al. [9] measured the thermal conductivity of SGL 10BA GDL and the thermal contact resistance between the GDL and the graphite rods. It was found that the values of the GDL thermal

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conductivity obtained were almost 4 times larger than those found in the literature and it depends on the compression pressure on the sample. They reported the measured through-plane thermal conductivity of the GDL to be about 1.8 ± 0.11 W m$^{-1}$ K$^{-1}$. Karimi et al. [10] determined the through-plane thermal conductivity of SpectraCarb GDL experimentally. The contact resistance between the GDL and the aluminium apparatus surface was studied as a function of compression and PTFE content. The results showed that as the compression load increases, the thermal conductivity of the GDL increases. The obtained through-plane thermal conductivity of the GDL was 0.36 and 0.7 W m$^{-1}$ K$^{-1}$under a compression load 0.7 and 13.8 bar, respectively. Burheim et al. [11] reported that the through-plane thermal conductivity of dry GDLs and GDLs that contain water. The liquid water was sucked for about 30 s and the volume fraction of the water was calculated by comparing the weight of the dry and wet GDLs. Their results showed that the through-plane thermal conductivity of the GDL increases with the presence of liquid water and it is 0.15 and 1.6 W m$^{-1}$ K$^{-1}$ for the dry and wet GDL, respectively.

In this paper, an experimental setup, based on the steady-state method, is developed to measure the through-plane thermal conductivity of the components in the membrane electrode assembly (MEA) and GDL at different operating temperatures. The thermal conductivities of the GDLs are investigated as a function of the PTFE loading, temperature and compression pressure. In addition, for the present study to be comprehensive, the through-plane thermal conductivities of Nafion® membranes and catalyst layers are measured and reported as a function of the temperature.

## 2. Materials and procedures

### 2.1. Test apparatus

An experimental apparatus has been developed to measure the thermal conductivity of the various components of the MEA and GDL under steady state conditions. Therefore, the formula employed to estimate the thermal conductivity is the Fourier law [12]:

$$q_S = k_S A_S \frac{\Delta T}{L_S} \tag{1}$$

where $A_S$ is the cross-sectional area of the sample, $L_S$ is the length of the sample, $k_S$ is the thermal conductivity of the sample, and $\Delta T$ is the temperature drop across the sample.

The test apparatus is shown in Fig. 1. It consists of, from top to bottom, (i) a dial gauge indicator to measure the reduction in the thickness of the sample under compression, (ii) a load cell which records the compression pressure on the sample, (iii) the upper steel flux metre, which contains 3 thermocouples, (iv) the tested sample, and (v) the lower steel flux meter which also contains 3 thermocouples whose temperature gradient is maintained low and constant using a cooling system, see Section 2.3 for more details.

### 2.2. Materials

The through-plane thermal conductivity of the GDL is determined for five different SGL samples (10AA, 10BA, 10CA, 10DA, 10EA) whose PTFE loading are 0, 5, 10, 20 and 30%, respectively. In addition, the effect of the micro porous layer (MPL) coating on the through-plane thermal conductivity has been investigated for two different samples, namely 10BC and 10BE, and the thermal conductivity of them has been compared with that of their base substrate, namely 10BA. These GDL samples, which were provided by the SGL Technologies Gm bH, Germany, are listed in Table 1.

The through-plane thermal conductivity of a 115 Nafion® 115 membrane (Du Pont, USA), which is about 127 μm thick, is also measured and reported. Furthermore, the through-plane thermal conductivity of the catalyst is evaluated with three different platinum (Pt) loadings, namely 0.2, 0.4 and 0.6 mg cm$^{-2}$ in order to investigate the effect of this loading on the through-plane thermal conductivity of the catalyst layer.

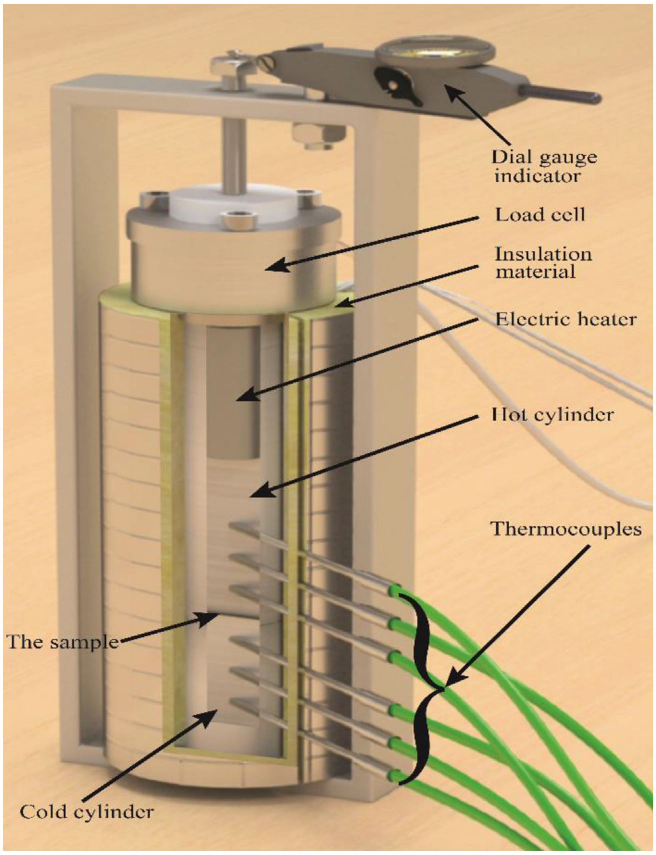

**Fig. 1.** Configuration of the experimental set-up to measure the through-plane thermal conductivity of the MEA components.

### 2.3. Experimental conditions

All measurements were performed under vacuum conditions in order to eliminate the heat transfer by convection. Moreover, the fixtures and the samples were well insulated by using Rockwool insulation to minimise the heat loss in the radial direction and mitigate heat transfer by radiation. The effect of the temperature on the through-plane thermal conductivity of all the components in the MEA and GDL was investigated in the temperature range 35–80 °C, which is the most likely operating temperature range of PEM fuel cells [13]. In addition, the effect of the compression pressure was investigated for the compression range 1–20 bar, in which the normally-used compressive pressure on PEM fuel cells

**Table 1**
Manufacturers' specifications for the tested GDLs.

| GDL | Thickness (μm) | PTFE loading (wt. %) |
|---|---|---|
| 10AA | 390 | 0 |
| 10BA | 400 | 5 |
| 10CA | 400 | 10 |
| 10DA | 400 | 20 |
| 10EA | 374 | 30 |
| 10BC | 415 | 23[a] |
| 10BE | 367 | 50[a] |

[a] PTFE loading in the MPL (wt. %).