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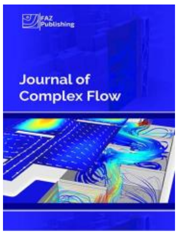

Measurement of Heat Flow for Contact Resistance and Thermal Conductivity in Fuel Cell Material

M.K.O. Alsayed[1,*] B. Manshoor[2], H. Salleh[3]

[1]Faculty of Technical Engineering, Bright Star University of Technology, Marsa Bregha, LIBYA
[2]Flow Analysis, Simulation, and Turbulence Research Group (FASTREG),
Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, MALAYSIA
[3]Combustion Research Group (CRG), Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia, MALAYSIA

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Abstract: The thermal conductivity of the component membrane electrode assembly (MEA) and GDL must be estimated in order to better understand the heat transfer processes in the proton exchange membrane fuel cells. Also, to produce the efficient thermal and water management for accurate determination thermal. This is one of the factors affecting the durability of a fuel cell and need to get a solution to minimize costs and optimize the use of electrodes and cells. In this study methodology, it is to estimate the through-plane thermal conductivity of dry Nafion and thermal contact resistance in order of different temperature and pressure. The prediction through-plane thermal technique can be employed using test rig measurement, with slight modification, to estimate through-plane thermal conductivity. Other than that, it is to study the thermal properties and predict the temperature distribution at the test rig during run the experiment. The thermal conductivity of dry Nafion across the specimen with the different temperature is being compared with benchmark result. To validate the result, the Fourier's law equation has been chosen in this study case with involving the average value of temperature parameter 30°C until 90°C. The parameter temperature at 90°C, thermal conductivity is obtained $0.198\mathrm{Wm}^{-1}\mathrm{K}^{-1}$ due to the graph of thermal conductivity versus different temperature. Whilst the parameter pressure at 1.2Mpa the thermal conductivity was found $0.471\mathrm{Wm}^{-1}\mathrm{K}^{-1}$. From the resulting graph, it can be concluding that the increasing the temperature thermal conductivity of the dry Nafion will be decrease. Also, the thermal conductivity of the dry Nafion decrease when the compression pressure was applied. At the point, it can be summed up as well as dry Nafion is the best material for the application in fuel cell to avoid waste heat generation and temperature distribution that can affect drying and degradation phenomenon in the fuel cell.

Keywords: Fuel cell, Gas diffusion layer, Thermal conductivity

1. Introduction

Internal temperature distribution in a polymer electrolyte fuel cell (PEFC) is critical for efficient water and thermal management. In a fuel cell, local variation in temperature can be attributed to the waste heat generation, which includes the irreversible heat of electrochemical reaction, losses due to over potential at each electrode and joule heating in all components. The temperature distribution can affect the drying or flooding and degradation phenomenon in the fuel cell which deteriorates its performance.

Analytical model is conferred that only heat transfer is steady- state, one- dimensional in the through plane direction in gas diffusion layer. With the equation that have been given by Grasof and Peclet numbers showed that natural convection and convective heat transfer are negligible [1, 2]. It is compared to the conduction in the gas diffusion layer. Then it also neglects the radiative heat transfer under 100 K. The thermal resistance, $R_{t,cond}$ for conduction in plane wall is considered below equation:

$$R_{t,cond} = \frac{\Delta T}{q} = \frac{L}{kA} \qquad (1)$$

where ΔT is the difference in temperature across the wall, q is the heat flux, L is the length of the plane wall, k is the thermal conductivity of the wall, and A is the cross sectional area of the wall.

The temperature on the through-plane thermal conductivity of the gas diffusion layer with the presence of PTFE it's found that thermal conductivities decrease with increasing the temperature. Then the thermal contact resistance of the gas diffusion layer shown increasing the temperature it will causes the thermal conductivity decrease [3]. The temperature distribution has a strong impact on the cell performance. It influences the at water distribution by means of condensation and effects the multicomponent gas diffusion transport characteristics through thermos-capillary forces and thermal

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**Corresponding author: muneer@bsu.edu.ly*

buoyancy. Hence, the thermal and water management issue are strongly coupled and they have a direct impact on cell performance [4, 5]. Three dimensional CFD code [6-8] have used to investigate the coupled cooling process involved in fluid flow and heat transfer between the solid plate and the coolant flow. It has been investigated six different cooling modes in analysis and have arrived at the conclusion that serpentine type flow mode is better than the parallel type mode

Actually, the thermal conductivity of gas diffusion layers is much lower than in-plane thermal conductivity. For example, at 35ºC, in-plane thermal conductivity of 10 AA was drawn to be 12.5 $\mathrm{Wm^{-1}K^{-1}}$ [9] while the through-plane thermal conductivity with the same material and temperature was shown the measure as 0.55 $\mathrm{Wm^{-1}K^{-1}}$ at 2 bars. It can be concluding that compression pressure gives a positive effect to the thermal conductivity. Seeing that, the addition of PTFE is decrease on the through-plane conductivity of the gas diffusion layer when the heat transfer from fiber to fiber is flow in the through-plane direction. It can be observed that thermal conductivity of the gas diffusion layers is much more decrease after PTFE treatment.

If the PTFE is not added in the gas diffusion layer, the thermal conductivity will become highest with the range 50%. In addition, it higher than PTFE treated gas diffusion layers. However, after adding the percentage of the PTFE which is 5, 10, 20 and 30 % to the gas diffusion layers, there is incomparably difference in the through-plane thermal conductivity [10-12]. Hence, the objectives of this study is to determine the measurement the thermal conductivity and thermal contact resistance of membrane by through-plane direction. Other than that, it is to improve the performance and durability in fuel cell material.

2. Experimental Works

For the experimental works, selection of material is mainly based on the thermal conductivity measurement casing, thermocouple, heater and also the cooling water for cold plate. A few materials will be considering and it will narrow down to a single selected based on their ability of work, material function, availability in market and suitability.

Conductivity is important because it is the only way that heat can pass through opaque solids. If one end is heated, the heat will be passed through to the other end and it causes molecule movement. The faster molecules which are the higher temperature vibrate against slowing movement cool molecules causing them to heat up and energy is transferred to the slower molecules from the faster ones which cause conduction to take place. Heat always moves from hot region to cooler region. The proportionally constant is called the thermal conductivity of the materials.

2.1 Test Rigs Set Up

Fig. 1 shows an insulated long circular cross section of standard material with known thermal conductivity is uniformly compressed between two backing plates while Fig. 2 shows the location of specimen between the two cylindrical aluminum bronze during the experimental works. Both backing plates are maintained at a different constant temperature, thus acting as a heat source and sink, to generate the heat flow. Thermocouple arrays are inserted in the cylindrical standard material above and below the test sample. The test sample with unknown thermal conductivity is placed between the two standard material cylinder rods. The compression pressure is precisely controlled and measured with a load cell.

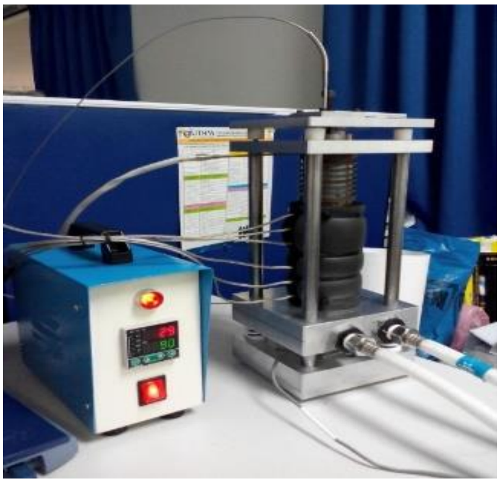

Fig. 1 – Experimental set up

Fig. 2 – Specimen placed between two cylindrical aluminum bronze

The full schematic diagram for the test rig was shown as in Fig. 3. The diagram clearly shows the location for the specimen and the location of the thermocouples used to measure thermal conductivity and thermal contact resistance of thin films.

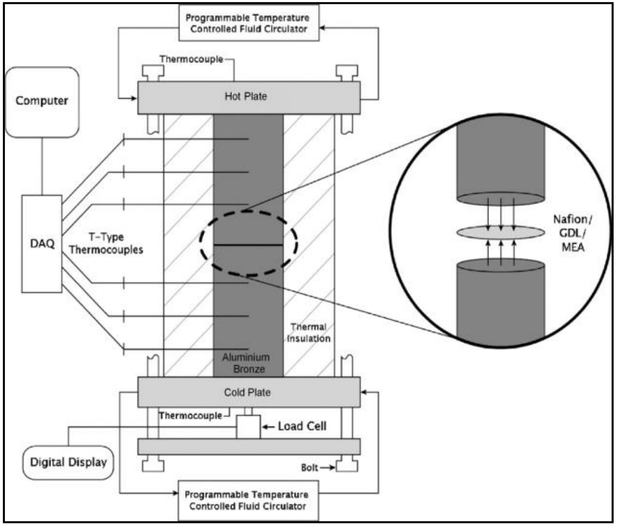

Fig. 3 - Schematic diagram of the test rig set up

2.2 Experimental Setting

Fig. 3 shows graph of temperature versus thermal probe location at steady state temperature profile. It shows that the temperature drops from high level to the low level. Since the heat flux is proportional to the temperature difference, the through-plane thermal resistance across the dry Nafion can be determining using Fourier's law in the axial direction [13, 14].

In this experiment, the temperature at each location in the upper and lower thermocouple arrays was measured and be averaged 30 minutes for the analysis. The experiment also will be specified condition for 3 to 4 hours to ensure a true steady state condition and it will be assumed to be reached when the temperature fluctuation in the point 0.5°C. The experiment was carried out by selecting the suitable material which are the aluminum bronze and the dry Nafion membrane. It was placed between two cylindrical pieces of aluminum bronze. The three high precision thermocouples per array were fixed equidistantly in the upper and lower pieces of aluminum bronze. The temperature of upper and lower compression plates was monitored by thermocouple. Then the compression pressure was measured using a load cell and it will be placed between the two bottom plates. The experiment will only start recorded when the heat at the hot plate reach steady state that is around 80ºC to 90ºC.

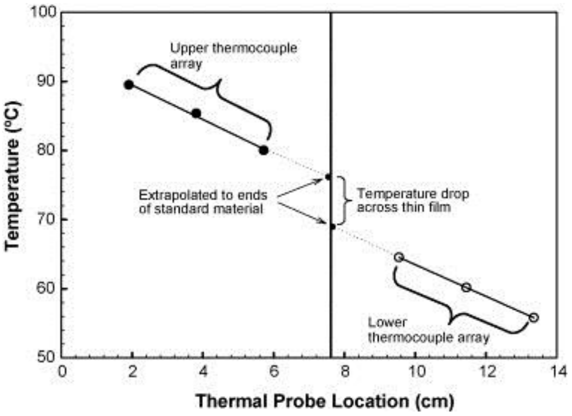

Fig. 3 – Steady state temperature profile at thermal probe location [15]

Upon the different temperature, ΔT determining the thermal conductivity of the membrane. Also, the percentage of range for thermal conductivity against time of the membrane can be determined through this experiment. The result of the experiment will then compare with published data.

3. Data Validation

An analysis of the experimental results due to the level of reliability of thermal conductivity of membrane in the fuel cell materials will discussed in this section.

From graph gained from the experiment shows the steady state temperature profile at thermal probe location with the thickness of the dry Nafion is 0.000183m. In the comparison from the benchmark it is shown the indicated from the others benchmark using the steady state method with the higher temperature when run the experiment. It also gives a little similar graphical of thermal conductivity against temperature. Fig. 4 shows the benchmark from other researcher used in this study.

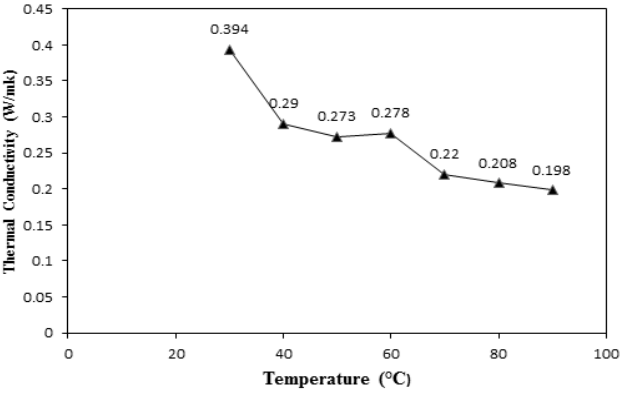

Fig. 4 – Graph of thermal conductivity versus temperature

4. Result and Discussion

For the first experiment set the heater temperature controller until 30ºC. During the experimentation, the entire system must be monitored at a specified condition for 3 to 4 hour to ensure a true steady state. The data will be collected at channel 1 until channel 6 displayed at computer after 30 minutes. The experiment will be repeated with different temperature. From the experimental results, it showed that thermal conductivity of Nafion at 30°C is 0.394 $\mathrm{Wm^{-1}K^{-1}}$ and at 90°C the thermal has been found 0.194 $\mathrm{Wm^{-1}K^{-1}}$. As conclusion, it decreases with increasing temperature, where the test temperature is defined as the average across the test specimen. This is because the collision probability of phonons increases at high temperature due to an increase in the number of participating phonons. In this experiment, Nafion is the insulating material for crystalline which is proportional to the mean free path.

For the second experiment, the temperature of upper hot plate and lower cold plate will be compression under pressure. Then, a load cell will be used and was placed to measure the compression pressure between the two bottom plates. The digital displayed will be connected with the load cell to apply the load. The experiment will be repeated at different pressure. Fig. 5 showed the graph of thermal conductivity dry Nafion against compression pressure. It can be seen the reduction of thermal conductivity of the dry Nafion when the pressure is applied to the specimen.

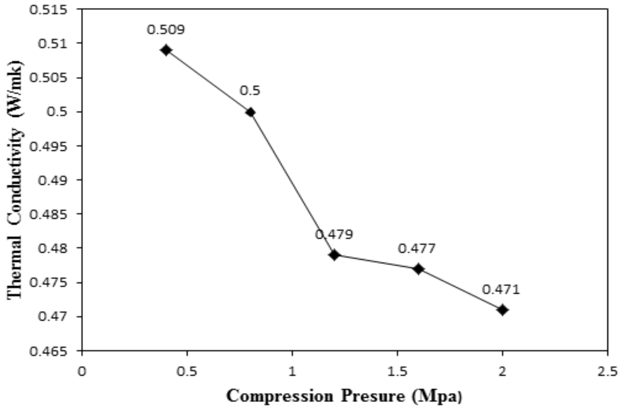

Fig. 5 – Graph of thermal conductivity versus compression pressure

For the load 0.4 Mpa the thermal conductivity is 0.509 $\mathrm{Wm^{-1}K^{-1}}$ and at the highest load 2.0Mpa the thermal conductivity was been drawn 0.471 $\mathrm{Wm^{-1}K^{-1}}$. It can be concluding that compression pressure are also the main affect to the dry Nafion which can affects the transport properties, temperature and water management. Also it can be related the concept of thermal contact resistance which is when two surfaces are pressed against each other, the peaks form good material contact but the valleys form voids filled air in most cases. As a result, an interface contains numerous air gaps of varying sizes that acts as insulation because of the low thermal conductivity of air. Thus, an interface offers some resistance to heat transfer.

5. Conclusion and Recommendation

In this study it can be concluded that the objective is achieved by successfully, from the level of reliability for thermal conductivity of dry Nafion still have a range for improvement. The decision was made up upon determining the thermal conductivity for dry Nafion to test the level of reliability of the thermal conductivity measurement. This can be concluding that at temperature 90°C still able to depicted accurate and reliable result for the thermal conductivity dry Nafion. Although, there is still a small range between the theoretical value and experimental value, but the best part of the test rig is it able to present almost different thermal conductivity value against temperature. Furthermore, the thermal conductivity of the test rig seen to have an improvement and manage to reduce the percentage of error between theory value and experimental value.

For the future study, some improvements are suggested due to lack of certain data and results in this study. Main improvements that can be considered are in term of test rig modification. It is recommended equipping the test rig with a temperature controller and water pump. A controller of heater temperature allows the user run experiment on the material in any specification temperature, while water pump can ensure the water flow in the cold plate constantly. Besides that, an effective design of the main heater and cooling water pump for the test rig should be recommendation. The concentration of the heat generated by the heater at the hot plate and the concentration of the cold flow at the cold plate also should be study to search for the best way in order to gather the concentration of heat.

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