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Study of The Effect of Channel Width on Micro Fuel Cell Performance Using 3D Modeling

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Abstract: Proton exchange membrane fuel cells (PEMFCs) are very promising for both mobile and mid-power stationary applications. One of the key components of fuel cells is the flow field plate through which hydrogen fuel will reach the anode and oxygen reach the cathode. Another function of the flow field plate is the electron collection. Traditionally flow field plates are made of graphite which makes them good for current collection. The dimensions of the flow channel play an important role in fuel cell performance. Here we build a three dimensional model for a fuel cell in using COMSOL Multiphysics. The performance of the cell is studied under varying channel widths.

Keywords: PEM Fuel cell, 3-D modeling, Gas Diffusion layer, Membrane Electrode Assembly.

1. Introduction

Fuel cells [1] are emerging as the power sources of the future. PEM fuel cell [2] are the most popular type of fuel cells which use hydrogen as the fuel. The necessary improvements for fuel cell operation [3] and performance demands better design and optimization. These issues can be addressed easily if mathematical models[7][9][10] are available. Traditionally the flow field plates are made of graphite and the current collection is carried out from the flow field plates. But in literature, many authors [4][5][6] have reported building micro fuel cells, where the flow field plates are also made of silicon. The channel width plays an important role in the performance of micro fuel cells. Here the channel width is varied from 0.5 mm to 1.5 mm and the performance variation is studied.

2. Governing equations for the fuel cell model

Mass conservation or continuity equation tells that the change of mass in a unit volume must be equal to the sum of all species entering or exiting the volume in a given time period. This law applies to the flow field plates, GDL and the catalyst layer. Momentum conservation relates net rate of change of momentum per unit volume due to convection, pressure, viscous friction and pore structure. This law applies to the flow field plates, GDL and the catalyst layer.

Species conservation relates the net rate of species mass change due to convection, diffusion and electrochemical reaction. The most commonly used one is the Stefan-Maxwell diffusion equation.

Charge conservation corresponds to the continuity of current in a conducting material. This is applied to the GDL, catalyst layer and the membrane.

3. The model

A 3 dimensional model [8] of a PEM fuel cell is implemented using COMSOL Multiphysics. The present model is established based on the following assumptions:

- Flow is laminar everywhere due to small gas pressure gradient.
- Reactant gases behave as the ideal gas mixture.
- The electrodes and membrane are made of homogeneous materials.
- The temperature distribution across the cell is uniform.
- Water exists only in the gas phase in the fuel cell.
- The polymer electrolyte membrane is impermeable to reactant gases.
- Protons can only transport through the electrolyte, and electrons through the solid phase.
- Three species including oxygen, water and nitrogen are considered on the cathode side while only hydrogen and water are considered on the anode side.
- The fuel cell is operating at the steady state.

The following are the operating conditions of the model.

- Cell length (L) 1mm
- Channel height 0.001m
- GDL width 0.3 mm

- Porous electrode thickness 0.5 mm
- Membrane thickness 0.05 mm
- GDL Porosity 0.4
- GDL electric conductivity 1000 S/m
- Inlet H_2 mass fraction (anode) 0.743
- Inlet H_2O mass fraction (cathode) 0.023
- Inlet oxygen mass fraction (cathode) 0.228
- Anode inlet flow velocity 0.2m/s
- Cathode inlet flow velocity 0.5m/s
- Anode viscosity 1.19 E-5 Pa.s
- Cathode viscosity 2.46 E -5 Pa.s
- Permeability (porous electrode) 2.36 E -12 m^2
- Membrane conductivity 10 S/m

. Figure 1 shows the structure of the model developed in Comsol Multiphysics. The top part is the anode side while bottom part corresponds to the cathode.Figure 2 shows the top view of the model.

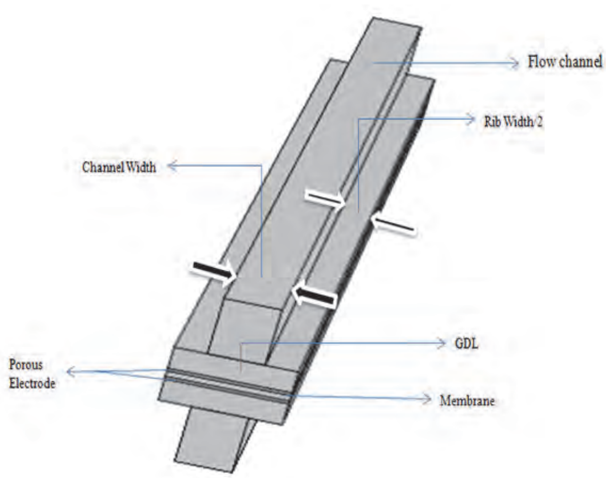

Figure 1. The schematic of PEM fuel cell model

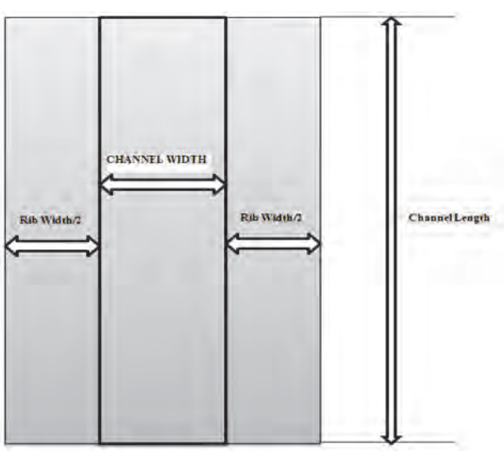

Figure.2 Top view of the schematic of PEM fuel cell model

4. Effect of channel width

Effect of channel width on the performance of the cell is studied by varying the width of the channel and keeping channel width to rib ratio constant at 1. All other parameters of the cell are kept constant. As seen from the Figure 3, the performance of the cell degraded as the width of the channel is increased from 0.5 mm to 2 mm. The probable reason for this stems from oxygen concentration distribution in the cell for various channel widths as oxygen concentration is directly related to local current density inside the cell at higher current densities.

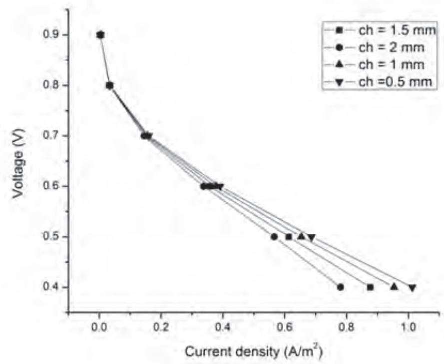

Figure 3. Polarization curves for different channel widths with channel width to rib width ratio is one

Figure 4 shows oxygen mole fraction on the surface of cathode catalyst layer along the length of the channel. These line graphs are taken at the center of the length of the cell. From these profiles it appears to contradict the assumption mentioned above as the oxygen fraction is highest for the channel width of 2 mm and lowest for the channel width of 0.5 mm. But the situation becomes clearer when we look at Figure 5. It shows oxygen mole fraction plotted in the direction perpendicular to the channel on the catalyst surface. Gaussian distribution of the species is observed with the peak in the middle of the channel. It includes the effect of the rib where the catalyst underneath the rib is hidden. From Figure 5, it is clear that oxygen mole fraction is increased under the rib as the width of the channel is decreased. This is due the higher pressure drops created along the length of the channel at smaller widths of the channel. This scenario is clear from the Figure 6 which shows the pressure of the mixture along the length of the channel. Higher pressure drop forces more oxygen molecules inside the rib thereby increasing their concentration.

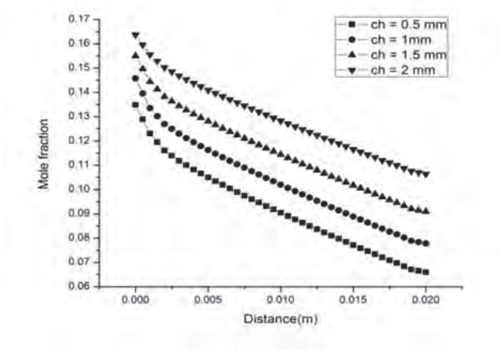

Figure 4. Oxygen mole fraction along the length of the channel for different channel widths at cell potential of 0.4v

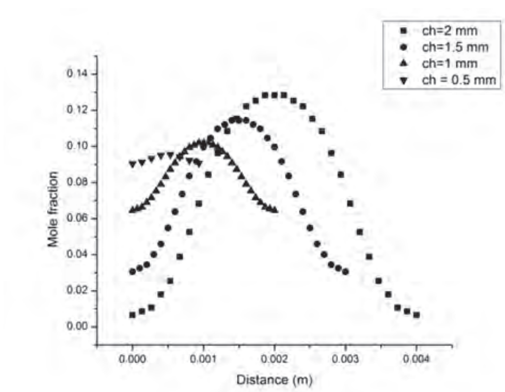

Figure 5. Oxygen concentration profiles across the length of the channel for different channel widths at cell potential of 0.4 v

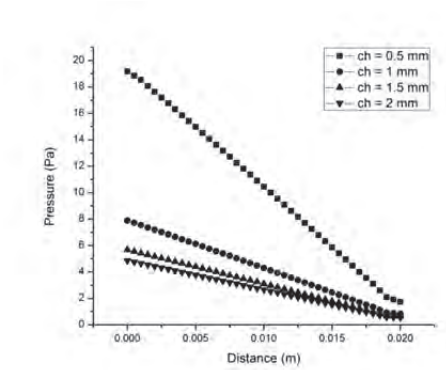

Figure 6. Pressure variation along the length of the channel for different channel widths for the case in figure 5

5. Conclusion

A 3-dimensional model for PEM fuel cell is validated under the experimentally feasible assumptions. The effect of channel width on the fuel cell performance is studied by considering various channel widths employing different distributions and dimensions. The performance of the cell is degraded as the width of the channel is increased from 0.5 mm to 2 mm and the reasons for performance drop is analysed.

6. References

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