



AN EFFECT OF STRAIGHT AND SERPENTINE FLOW FIELD DESIGN ON PROTON EXCHANGE MEMBRANE FUEL CELL

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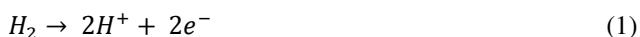
ABSTRACT

Proton exchange membrane fuel cell (PEMFC) is energy conversion device especially in future use in stationary and vehicular applications. PEMFC's provide high efficiency and power density with null emission, low operating temperature, quickly start and long life. One aspect that is crucial to optimizing the performance of PEM fuel cells understands is the physics in the flow field and how changes in flow field geometry affect the performance. Hence, in the present study, a model of PEM fuel cell was simulated to understand the effect of straight and serpentine flow field on performance of fuel cell and to predict the effects of changes in the flow field geometry. Commercial Computational Fluid Dynamics (CFD) software was used to extend a numerical three dimensional model of a single PEM fuel cell. Numerical model assumed as a steady state, including Navier-Stokes equations, phase equilibrium, governing electrochemical equations and energy equation. These equations resolved in order to get flow channel and gas diffusion media characteristics, the local current density on the membrane surface, velocity along flow channel and the temperature of the entire control volume. The results show that the local velocity distributions become more uniform for straight flow field designs compare to the serpentine flow field designs. The simulation work here also gives a good agreement with the experimental results and gave a high confidence for the results in order to determine the effectiveness of the flow field design in PEMFC.

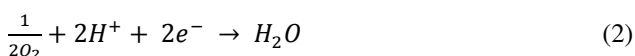
Keywords: PEM fuel cell, CFD, serpentine flow.

INTRODUCTION

One of the most important aspects in developing fuel cell design is modelling concept that calculation which make it possibility investigate complex geometries and various circumstances by spending less time and effort from attempt investigation. Basic operation of a fuel cell is characterized as gas-mixture transport and species transformation by electrochemical reactions. Hydrogen from anode flow channel is transported through the Gas Diffusion Layer (GDL) toward the Membrane Electrode Assembly (MEA) surface. In Catalyst Layer (CL), hydrogen molecules will dissociated to proton and electrons. This reaction of hydrogen Catalyst Layer can be written as;



Water that fertilizes MEA hydrates the proton and electro osmosis and diffusion transport water in MEA. Air mixture in cathode channel transports through the GDL toward the MEA where the reaction occur between Oxygen and proton. This reaction will produce water.



The oxygen accept electron from one electrode and hydrogen will supply the electron to another electrode. This flow can generate power electric motor of an automobile or other electrical device. This system save the environment cause water is the only waste product of the PEM fuel cell system.

FUEL CELL MODELS

Flow channel design is important characteristic in water management of PEMFC's in order to increase performance. In this study, the numerical work base on three dimensional models, in order to make the numerical simulation manageable, several assumptions was made, which are:

- 1) The cells were operating under steady-state condition.
- 2) The temperatures of cell are uniform and fix.

Figure-1 illustrates a schematic of PEMFC's the typical design use for testing. The main part in PEMFC's consist three main parts, which are an anode, a cathode, and polymer electrolyte membrane. There has three distinct regions at an anode and a cathode, the region consist of the gas channel, the gas diffusion channel and the catalyst layer.

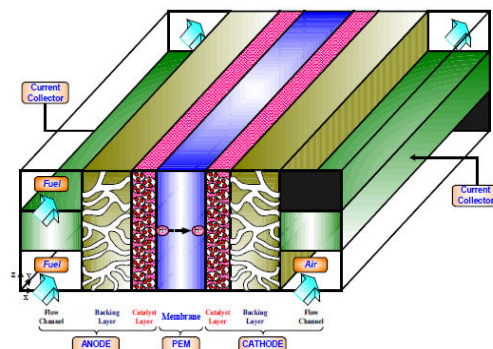


Figure-1. Three dimensional schematic diagram of a PEM fuel cell [1].



In order to improve the PEM fuel cell performance, many research have studied the problem of water management inside PEM fuel cell for both condition steady state and transient operation discuss in [2, 3]. However, their flow-field effect in the performance is absent from literature. To optimize the flow-field design, studies of flow patterns will give an idea to fix it. Depending on the optimum temperature changes in system from electrochemical reaction, water phase change and cooling or heating in system.

METHODOLOGY

As shown in Figure-1, the PEM fuel cell and its various components contain of the anode gas channel, gas-diffusion anode, anode catalyst layer, membrane, cathode catalyst layer, gas diffusion cathode, and cathode flow channel. Humidified air is fed into the cathode channel, whereas hydrogen is supplied to the anode channel. For this study, the authors were concentrating on the flow channel that used to flow an oxygen and hydrogen through the PEM fuel cell. Figure- shows the view of gas flow channel in this research. There are divided into two part flows which are an anode side flow channel and a cathode side flow channel. Both channels have same parameter which is 0.3mm for the dimension channel.

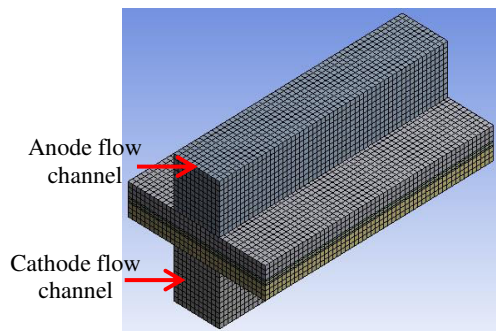


Figure-2. 3-D computational of PEMFC flow channel.

Based on Error! Reference source not found., it shows the main component in this system at an anode component and cathode component t and each component have Catalyst layer and gas diffusion layer. At the middle part is membrane as the main part in these systems which are hydrogen separate with electron and start transfer to catalyst layer at the cathode part.

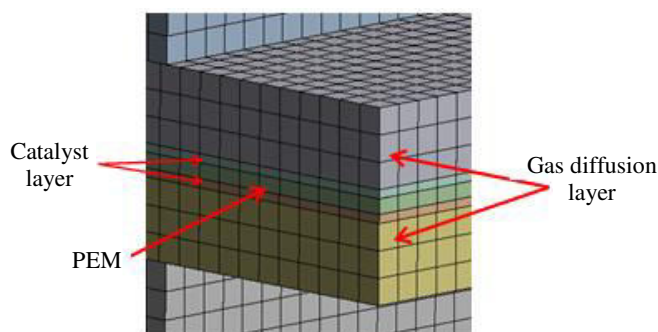


Figure-3. Computational domain of PEMFC.

The boundary conditions used are summarized in Table-1. The modeling is done with the available condition in research by Hashemi etc. [4] and Al. Baghdadi [5]. The simulation parameter that used in this study also referred to research that had been done by Islam [6], which is used an Ansys DM version 15.1 as their modeler. Ansys meshing set up as default, size function and smoothing as fixed and medium with slow transition. Fluent 3-D single precision with solver type as pressure based.

Model flow is turbulent because the Reynolds number more than 4000 with fluid Hydrogen and Oxygen while at wall solid set up as Aluminum with constant temperature. However, we assume it laminar cause of the channel is very small. By using the turbulent model, the accuracy of performance will decrease. Scheme for solution method is SIMPLE method with spatial discretization Green-gauss node based; standard pressure and solution initialization is hybrid with 150 iterations.

Table-1. Geometry and operational parameter.

Parameter	Symbol	Value
Cell length	L_{cell}	5 mm
Cell width	W_{cell}	5 mm
Gas Channel width	W	0.3 mm
Gas Channel height	H	0.3 mm
Gas diffusion layer thickness (GDL)	δ_{GDL}	0.26 mm
Wet membrane thickness (PTFE)	δ_{mem}	0.05 mm
Catalyst layer thickness (CL)	δ_{CL}	0.0287 mm
Anode and cathode pressure	P_a and P_c	1e5 Pa
Initial temperature both inlet	K	353.15
Porosity of :		
GDL	-	0.8
CL	-	0.6
Membrane	-	0.4
Operating pressure	P_a	101325
Mass flow rate:		
Anode	kg/s	6.0e-7
Cathode		5.0e-6

RESULTS AND DISCUSSIONS

The simulation work had been done for two cases of flow which are serpentine flow and straight flow. The results that were come out from this research are the distribution of velocity profile for both cases.

Error! Reference source not found. and Error! Reference source not found. shows the distribution of component of the flow velocity in the serpentine gas flow channel and straight gas flow channel under operating conditions at inlet anode mass flow rate 6.0e-7 kg/s with supply hydrogen gas at 0.1 m/s and species transport for Hydrogen is 0.8. At the inlet cathode side, set up for mass



flow rate is 5.0×10^{-6} kg/s with Oxygen flow through with species transport 0.2. For both gas flow channel set up temperature is 353.15 K. Both figures below show the different between two cases design of gas channel.

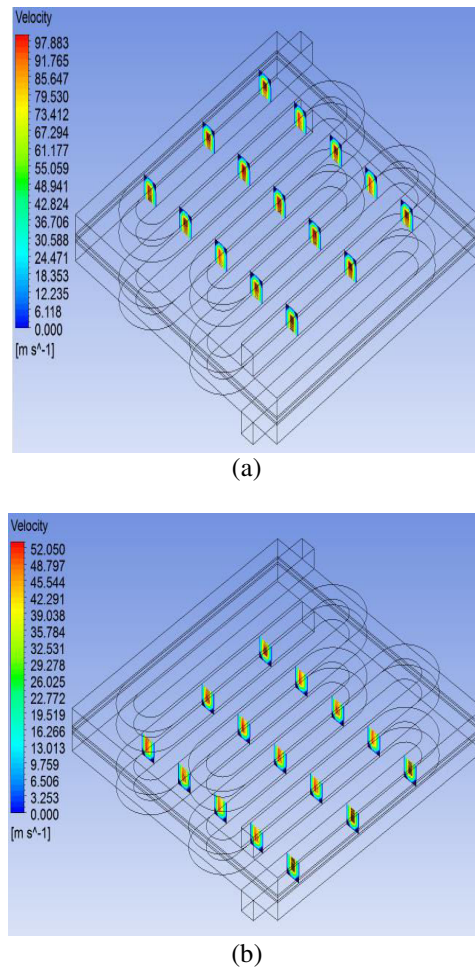


Figure-4. Serpentine laminar flow velocity (a) anode channel and (b) cathode channel.

In the straight flow fields, the velocity vectors were higher in those channels near the outlet and lower in the inlet channels. In straight flow field, the velocity vectors were not uniform along the channels which indicated that the mass flow rate was uneven along the channels. Like the straight flow field, the velocity vectors in the serpentine design also decreased throughout the channel. The velocity was lower at the edges than at the center, but unlike the serpentine flows, the velocity vectors were more uniform and decreased steadily ensuring better mass flow rates. The wider channel width, the greater the velocity and the narrower the channel width, the lower the velocity. Base on the figure above, the velocity was more uniform in the serpentine design than the straight design.

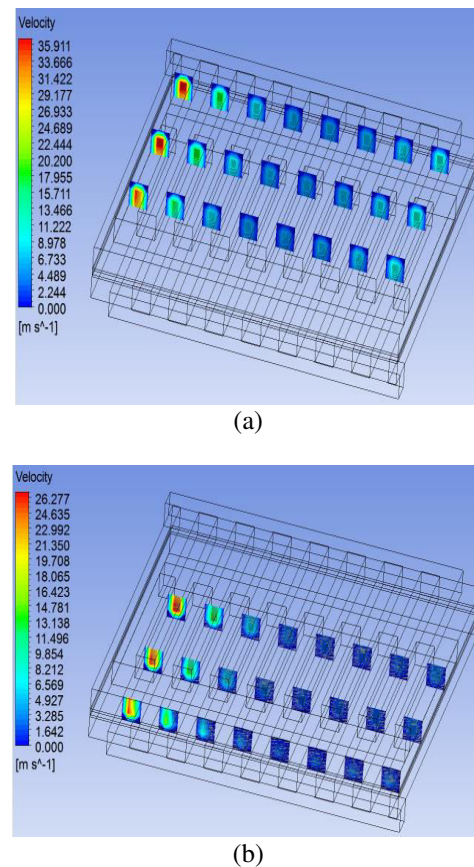


Figure-5. Straight laminar flow velocity (a) anode channel and (b) cathode channel.

Figure-6 shows the graph of local velocity contour on the gas flow channel in plane yz-axis direction for two different flow-field designs, which are serpentine flow channel and straight flow channel. Both channel flow in steady-states condition. From the figure, the velocity distribution of serpentine flow-field is more uniform than straight flow-field.

For the serpentine flow-field, the maximum local velocity of 97.883 m/s and 52.050 m/s at both an anode and a cathode flow channel. Meanwhile, the minimum local velocity for serpentine flow-field for an anode is 6.118 m/s and at cathode channel are 3.253 m/s. In case for straight flow-field in Error! Reference source not found., the highest local current density is 35.911 m/s at an anode flow channel, while at the cathode flow channel shows 26.277 m/s as the highest velocity flow through in channel. while, the minimum local velocity at an anode flow is 2.244 m/s and 1.642 m/s at cathode flow. All this case operates in 353.15 K temperature.

The result shows the velocity flow smooth, but at the middle velocity start going down, at this point as shown in Figure-6, pressure drop higher. The shape of both gas flow channel also disturbs flow smoothly. This is shown that the different flow design for gas flow channel in PEMFC give affect in performance flow.

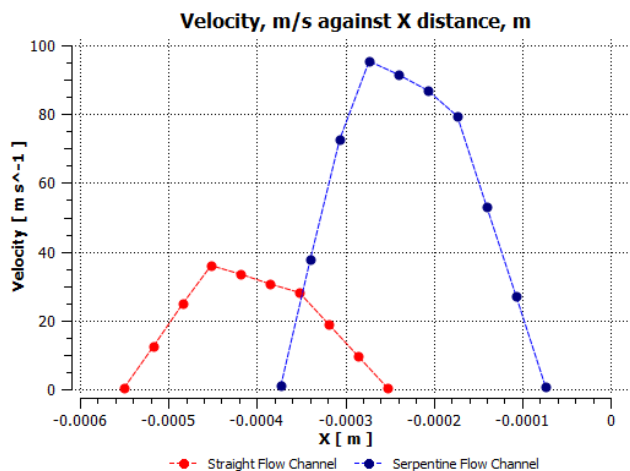


Figure-6. Graph velocity m/s against distance Z, m for both channels.

CONCLUSIONS

As performed in this paper, the simulation of two flow-field design configuration and effect between two designs on PEM fuel cell performance were presented. The local velocity for serpentine gas flow channel and straight gas flow channel were analyzed. In conclusion, the changing flow-field design or pattern of PEM fuel cell can affect the local velocity and other characteristic that need to analyze to improve its performance. The serpentine flow-field gives more uniform local velocity compare with straight flow-field, this occur cause of shape of gas channel for serpentine is direct from inlet to outlet, compare to straight gas flow channel, the gas fed from inlet and gas distribute by channel and it maybe not constant when it distribute.

ANCKNOWLEDGEMENT

Partial support was provided by MOHE (Ministry of Higher Education, MALAYSIA) and Universiti Tun Hussein Onn Malaysia (UTHM) under the Fundamental Research Grants Scheme (FRGS), vote 1466.

REFERENCES

- [1] Um S. and Wang C.Y. 2000. Three dimensional analysis of transport and reaction in proton exchange membrane fuel cells. ASME-Publications-HTD. 366: 19-26.
- [2] Glandt J., Shimpalee S., Lee W. K., and Van Zee J. W. 2002. Modeling the effect of flow field design on PEM fuel cell performance. Catalyst, 2(H2), H2.
- [3] Jeon D. H., Greenway S., Shimpalee S. and Van Zee J. W. 2008. The effect of serpentine flow-field designs on PEM fuel cell performance. International Journal of Hydrogen Energy. 33(3): 1052-1066.
- [4] Hashemi F., Rowshanzamir S. and Rezakazemi M. 2012. CFD simulation of PEM fuel cell performance: Effect of straight and serpentine flow fields. Mathematical and Computer Modelling. 55(3-4): 1540–1557.
- [5] Al-Baghdadi M. A. S. 2014. Analysis of transport phenomena and electrochemical reactions in a micro PEM fuel cell with serpentine gas flow channels. Journal homepage: [www. IJEE. IEEFoundation.org](http://www.IJEE.IEEFoundation.org). 5(2): 139-154.