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Effects of difference flow channel designs on Proton Exchange Membrane Fuel Cell using 3-D Model

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Abstract

This research was studied to design of flow field on Proton Exchange Membrane Fuel Cell for distributions in reaction gas. The design of flow field was studied the effects of channel configurations of flow field plates on the performance of a PEMFC. Effects of widths, length and curve channel of a flow field plate were studied in an effort to optimize the dimensions of channel. It was assumed that the development of these design techniques with CFD will require. This study used three-dimensional computational fluid dynamics (CFD) model was investigated the effects of serpentine flow channel designs on the performance of proton exchange membrane fuel cells. This model was validated by the experiments. The numerical results were provided understanding the effect of flow field pattern design on performance of the fuel cell. This led us to a better design of gas flow field, which improves the gas distribution and water management. This research will investigate the relationship between channel length, channel curvature and characteristics of flow field with pressure drop, velocity distribution by using numerical model. The experiments will performed to verify the numerical predictions on polarization curve and power curve. The output from this research will enlight our on fundamental knowledge, which can be applied on design and operate the fuel cell.

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Keyword : Numerical Model; Flow Field; PEMFC; CFD

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1. Introduction

Proton exchange membrane fuel cells (PEMFCs) transform the chemical energy into electricity. Hence, it was an environment friendly energy source. Its performance and efficiency still needed to be improved, and the issues of cost, reliability and safety are needed to be considered to realize the fuel cell

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commerciality. In order to enhance its performance and reliability, it is necessary to learn more about the mechanism that causes the performance loss, such as, non-uniform concentration, current density distributions, high ionic resistance due to dry membrane, or high diffusive resistance due to the flooding on the cathode. The flow field and water/thermal management of fuel cell need optimal design to achieve high performance and reliability. The numerical modeling and dedicated experimental technique development are currently the effective tools to improve the optimal design of fuel cell system. Most of these models compute the flow field along a single channel to study the reaction species and current density distributions. Mazumder and Cole (2003) and Su et al. (2005) presented three-dimensional models based on computational fluid dynamics approach. Beming et al. (2002) and Wang and Lu (2004) and Hu et al. (2004) have used self-developed PEMFC numerical base on of the SIMPLE algorithm. Their three-dimensional models account for the effect of the complex geometry, specifically interdigitated flow field. They allow a parametric study for a realistic flow field, concentration and current distributions. The simulation results are well compared with the experimental data of polarization curve. However, the influence of flow field design upon concentration and current density distributions were less discussed. Mench et al. (2003) proved that the effects of cathode stoichiometry variation and transient flooding on local current density affect the current distribution on serpentine flow field. The efforts on fuel cell modeling and experimental measurement technique are valuable for fuel cell developers, which can optimize fuel cell designs and operations. Even though intensive studies have been carried on the affect of gas dynamics in flow field on fuel cell performance, the data of flow path configuration still needed to investigates. This research will focus on the gas dynamic within the channel length and channel curvature for design flow field. The numerical results will provide understanding the effect of these parameters. The results will investigate the relationship between channel length and channel curvature with pressure drop and velocity distribution by using numerical model. The experiments will be set up to compare the numerical predictions on polarization curve and power curve. This information will be implied as a guideline for design an appropriate flow field for PEMFC.

2. Methodology

2.1 Fundamental of PEMFC

Single PEMFC components includes of flow field plates, gas diffusion, catalyst layer, membrane, shown in Fig. 1. Fuel cells are energy source from electrochemical in cell. The reactions are from hydrogen gas flow pass the catalyst layer in Anode, it is Oxidation reaction and show in equation (1). Hydrogen ion from the reaction flow pass Electrolyte to Cathode and the reaction in the catalyst layer are Reduction, The Oxygen is reactance in the reaction and show in equation (2). The products from the reaction are water and electrons. The current in the Cathode and Anode from electron flow pass between two sides.

Oxidation process : $H_2 \longrightarrow 2H^+ + 2e^-$ (1)
Reduction process : $O_2 + 4e^- + 4H^+ \longrightarrow 2H_2O$ (2)

Electrical energy is obtained from a fuel cell only when a reasonable current is drawn, but the actual cell potential is decreased from its equilibrium potential because of irreversible losses as shown in Fig. 2. Several sources contribute to irreversible losses in a practical fuel cell. The losses, which are often called polarization, overpotential, or overvoltage, originate primarily from three sources: activation polarization, ohmic polarization, and concentration polarization. These losses result in a cell voltage for a fuel cell that is less than its ideal potential.

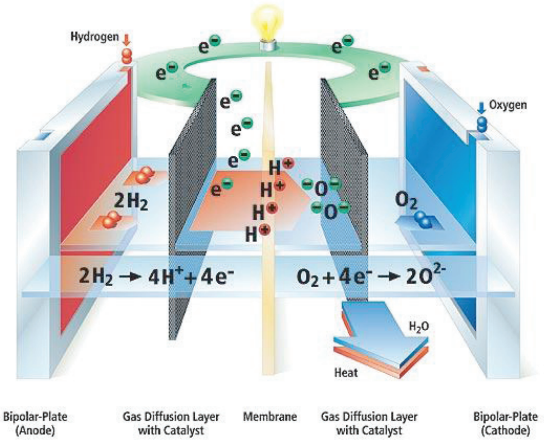


Fig. 1. Schematic diagram of PEMFC: http://www.princeton.edu/.../ Hydrogen/fuelcells.html.

2.2 Numerical modeling

In this study, a 3-D numerical model is presented to analysis flow field of proton exchange membrane fuel cells. The model is based on the solution of the conservation equations of mass and momentum using the CFD. Tables 1 and 2 illustrate the dimensions of PEMFC and the boundary conditions used in the numerical simulation.

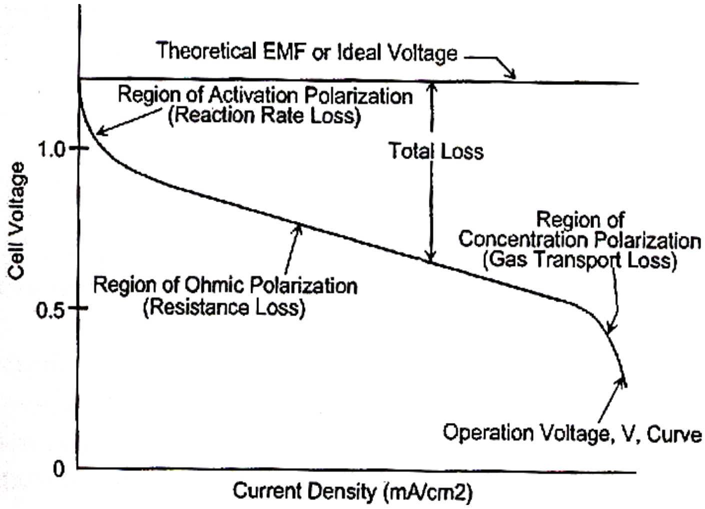


Fig. 2. Ideal and actual fuel cell voltage and current.

Table 1. Main Dimensions for the numerical model.

Characteristics	Sizing
Channel Area (cm^2)	10×10
Channel width (mm)	1
Channel depth (mm)	1
Rib width (mm)	1

Table 2. Boundary Conditions.

Boundary conditions	Value
Gas fuel inlet (cm^3/min)	200-500
Operating pressure (atm)	1
Temperature (K)	323

The main assumptions of the modeling are:

1. Steady state
2. Laminar flow
3. Gases are treated as ideal gas
4. Isothermal

These conservation equations used in flow field model are follows;
Mass conservation

$$\nabla(\rho U) = 0 \tag{3}$$

Momentum conservation

$$\begin{aligned} \nabla \cdot (\rho U u) &= -\frac{\partial P}{\partial x} + \nabla(\mu \nabla u) \\ \nabla \cdot (\rho U v) &= -\frac{\partial P}{\partial y} + \nabla(\mu \nabla v) \\ \nabla \cdot (\rho U w) &= -\frac{\partial P}{\partial z} + \nabla(\mu \nabla w) \end{aligned} \tag{4}$$

2.3 3-D model of channel length, channel curvature and characteristics of flow field

The full domain flow field is shown in Fig. 3. It describes a detailed three-dimensional model of transport phenomena within the gas channel. The dimensions of the computational domains have 6 elements in the x-direction, 71 elements in the y-direction, 6 elements in the z-direction, for a total of about 2,556 elements.

Channel length and channel curvature of flow field is developed from the result of multi-serpentine flow fields. The channel curvature has 4 cases which shown in Fig. 4. and channel length has 6 cases studied. The channel length has varied 1 to 6 channels on multi serpentine flow field. Number of channel has independent of channel length, which increases number of channel get channel length is shorter. Characteristics of depth channel are change 0.8, 1 and 1.2 mm.

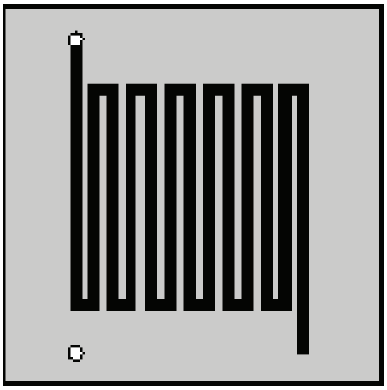


Fig. 3. One Channel of Serpentine Flow Field.

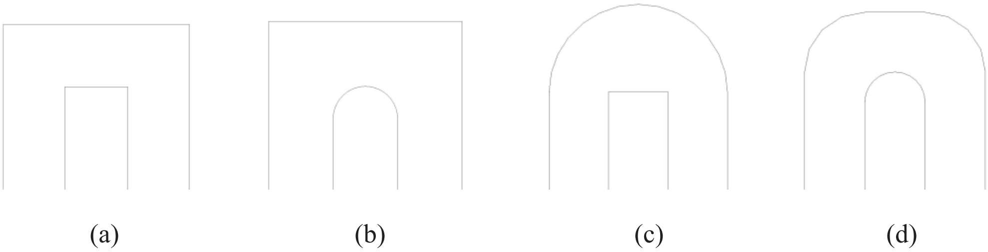


Fig. 4. Channel curvatures (a) sharp curve (b) Radius in Curve (c) Radius out Curve (d) Smooth Curve.

2.4 Experimental details

An experimental system is setup to measure the current/ voltage polarization curves. Graphite plate is used as a current collector. Other materials used in the single cell are O-BASF 12E-W MEA, reaction area 100 cm^2 and brass current collector. The dimensions of components and operating conditions are consistent with the numerical model.

3. Result and discussion

3.1 The effect of channel curvature on flow field

The results of flow and pressure drop are effect of curvature are shown in Figs. 5-8.

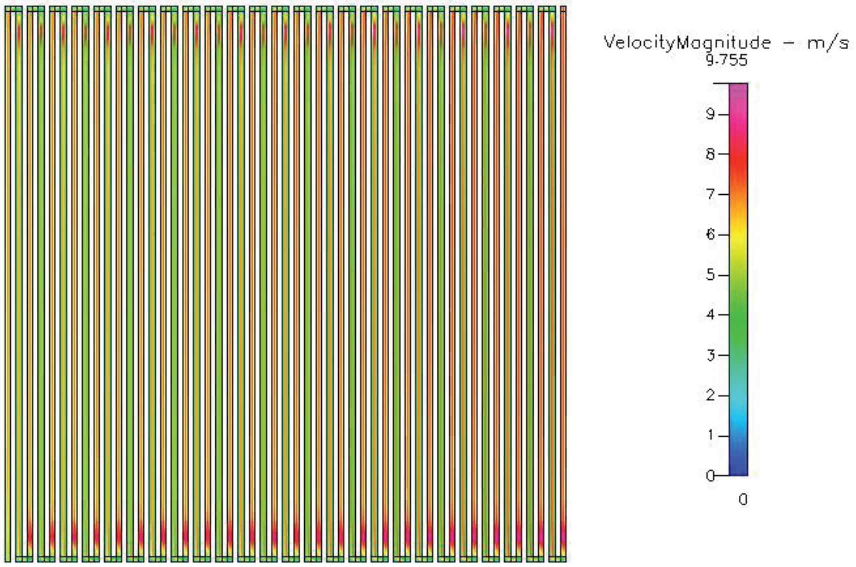
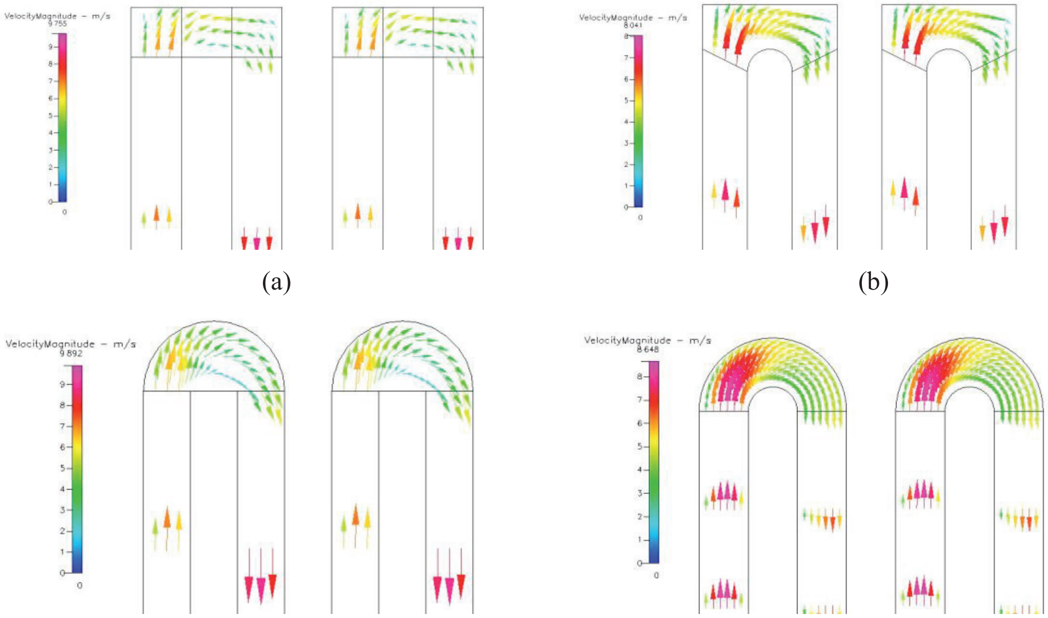


Fig. 5. Velocity of flow field at 300 cm3/min of Sharp Curve.



(a) (b)

(c) (d)

Fig. 6. Characteristic of flow at 300 cm^3/min (a) sharp curve (b) Radius in Curve (c) Radius out Curve (d) Smooth Curve.

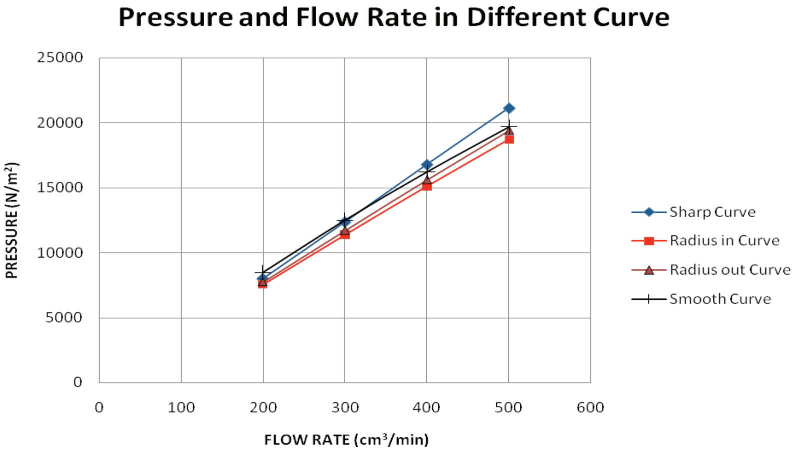


Fig. 7. Pressure in different curve.

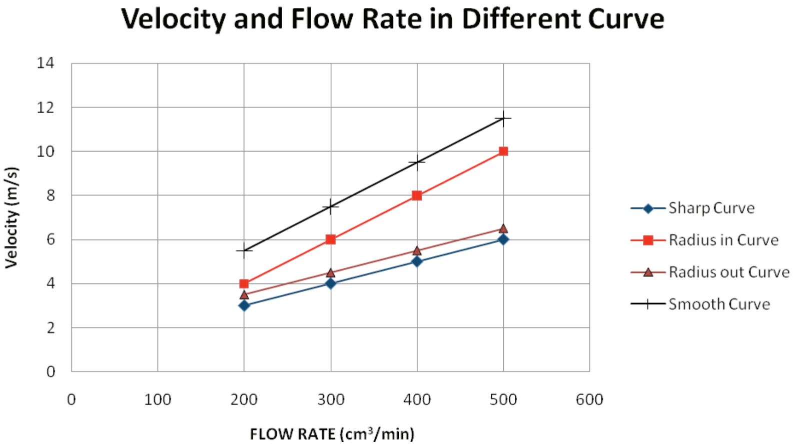
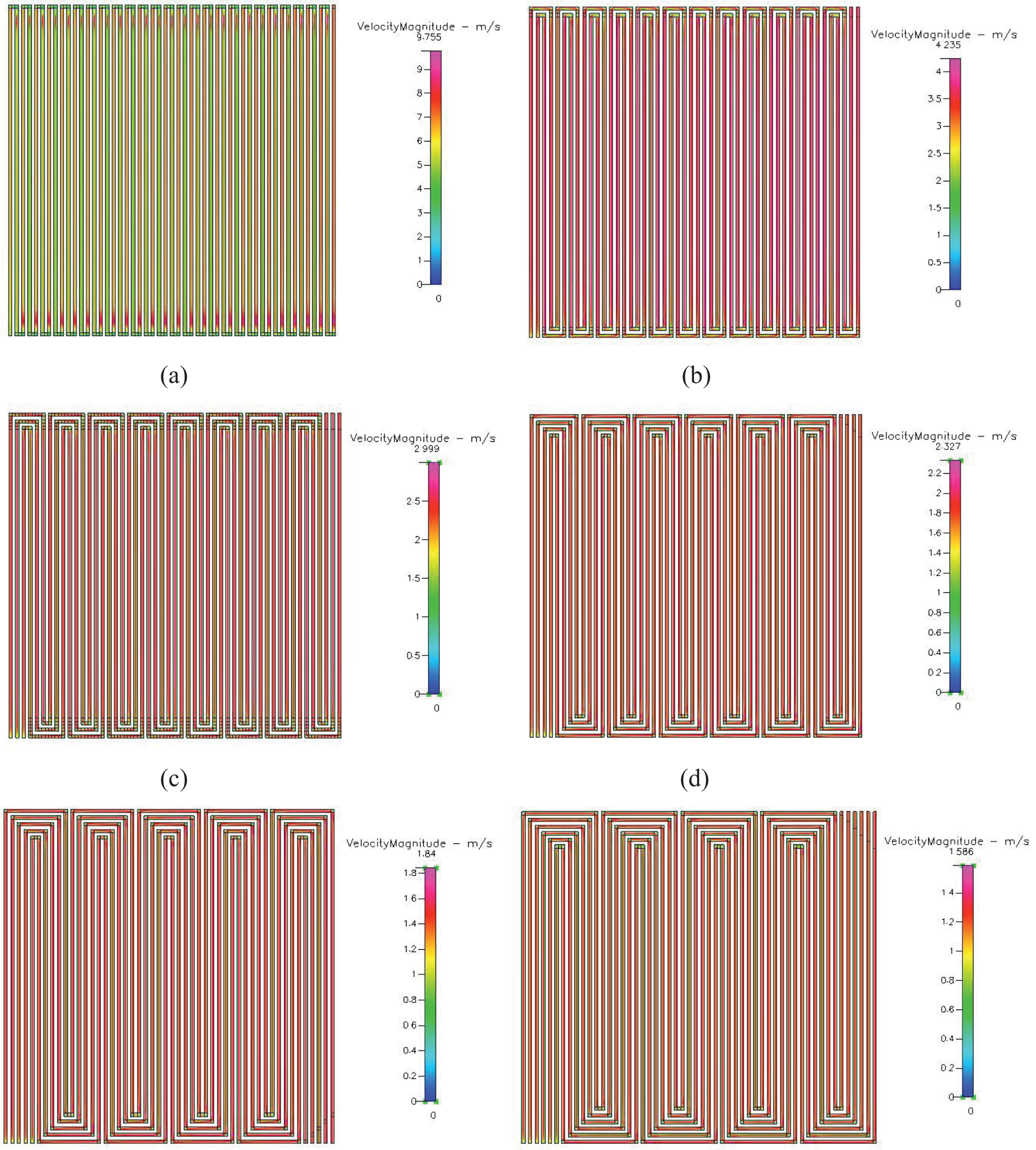


Fig. 8. Velocity in different curve.

Figures 6(a) and (b) display non-uniform velocity distribution on sharp curve and radius in curve. High gas distribution appears at upper curve and low gas distribution at bottom curve, its have avoid area at bottom center. Figure 6(c) shows uniform velocity distribution on outer filter. High gas distribution and smooth flow appears at upper curve and low gas distribution still occurs at bottom curve, its have avoid area at center bottom curve. Figure 6(d) provides uniform velocity distribution and gas distributes overall through the turn. The result of different curve that the sharp curve is also confirm the best configuration because it has non-uniform flow distribution and high pressure drop for the high electro chemical reaction in MEAs and water management. The pressure drop and velocity in different curve at all flow rates are shown in figs. 7. and 8. The sharp curve is highest pressure drop but it has lowest velocity and smooth curve is high velocity.

3.2 The effect of channel length on flow field

The results of flow and pressure drop are effect of length show in Figs. 9.-11.



(a) (b)

(c) (d)

(e) (f)

Fig. 9. Velocity of flow field at 300 cm^3/min (a) 1 channel (b) 2 channels (c) 3 channels (d) 4 channels (e) 5 channels (f) 6 channels

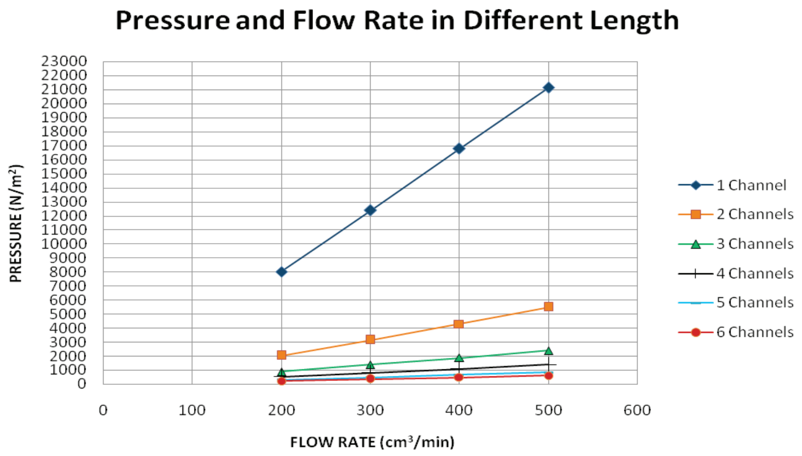


Fig. 10. Pressure in different length.

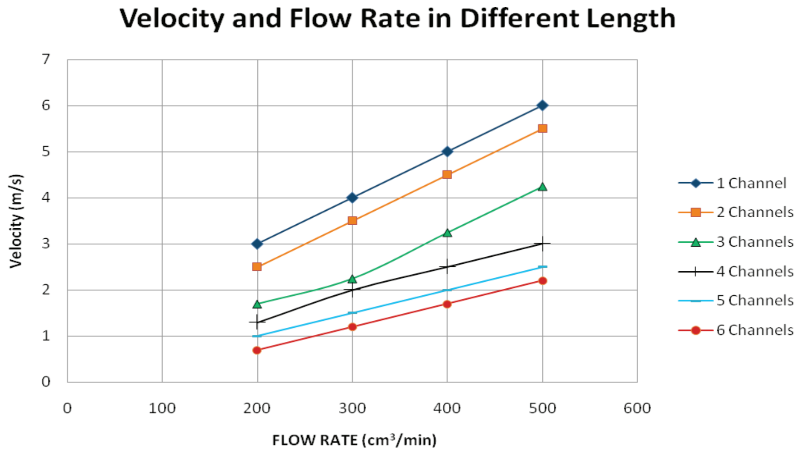
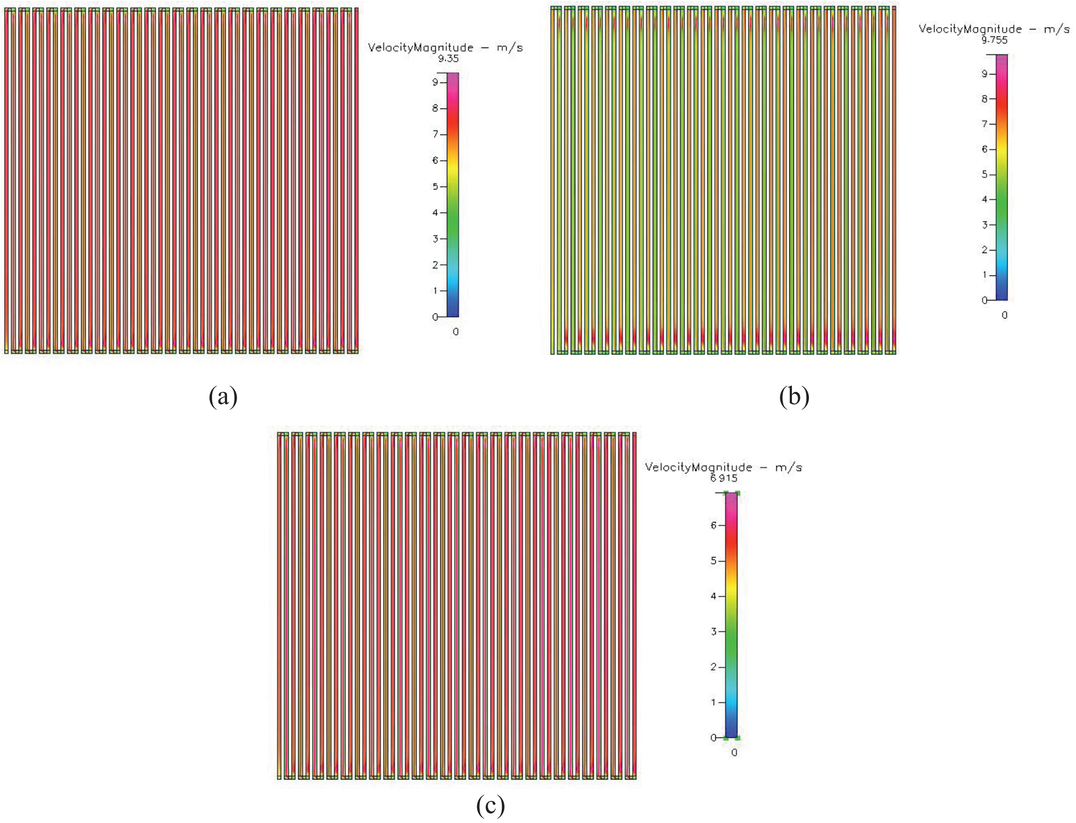


Fig. 11. Velocity in different length.

The velocities and pressure drop distribution in 1, 2, 3, 4, 5 and 6 serpentine channels at 300 cm^3/min. Figure 9 is shown 1 channel has average velocity approximate 4 m/s and pressure drop is 12,380 N/m^2. Gas distribution has uniform in serpentine pattern. Lower velocities distribution appears at channel curvatures and high velocities distribution at downstream of channel. The pressure drop has decreases along length channel. In 2 , 3, 4, 5 and 6 channels have a velocity approximate 3.5, 2.25, 2, 1.5 and 1.2 m/s, and pressure drop is 3,138, 1,385, 798.5, 489.4 and 359.5 N/m^2, respectively. The pressure drop and velocity in different length channels at all flow rates are shown in Figs. 10. and 11. The 1 channel has highest pressure drop and velocity and 4, 5 and 6 channels have nearest pressure drop.

3.3 The effect of channel depth on flow field



(a) (b)

(c)

Fig. 12. Velocity of flow field at 300 cm3/min (a) 0.8 mm. (b) 1.0 mm. (c) 1.2 mm.

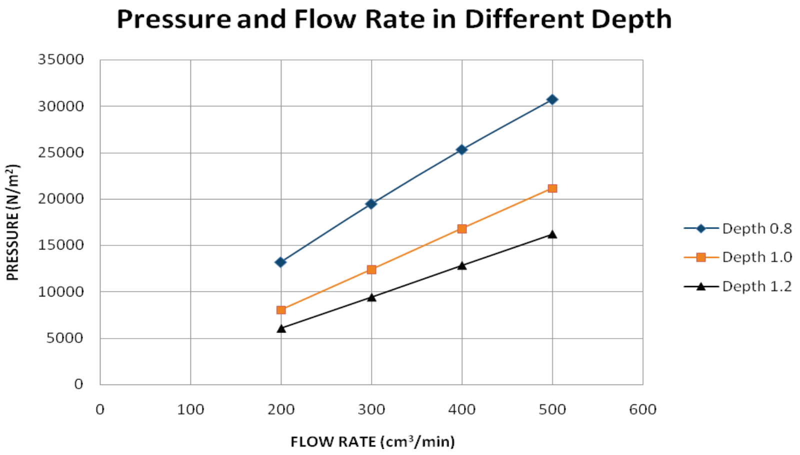


Fig. 13. Pressure in different depth.

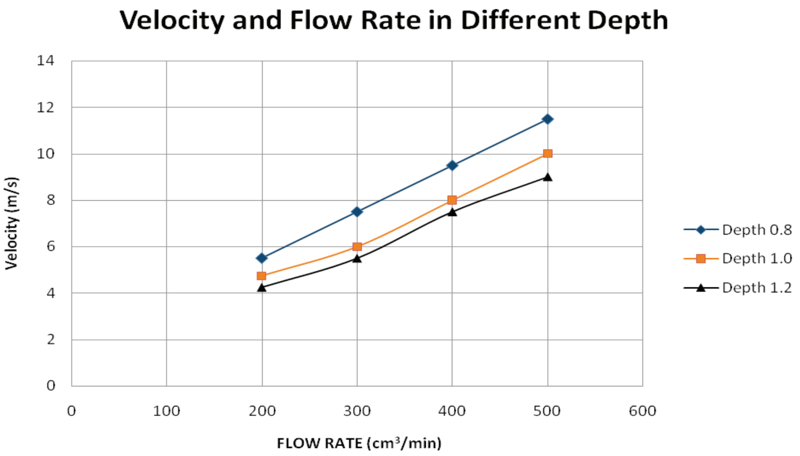


Fig. 14. Velocity in different depth.

Figure 12 displays velocity of 3 depths channel at 300 cm^3/min. In 0.8 depth channel has velocity approximate 7.5 m/s and pressure drop is 19,470 N/m^2. In 1.0 and 1.2 depth channel have velocities approximate 6 and 5.5 m/s and pressure drop is 12,380 and 9,410 N/m^2, respectively. The pressure drop and velocity in different depth channels at all flow rates are show in figs. 13. and 14.

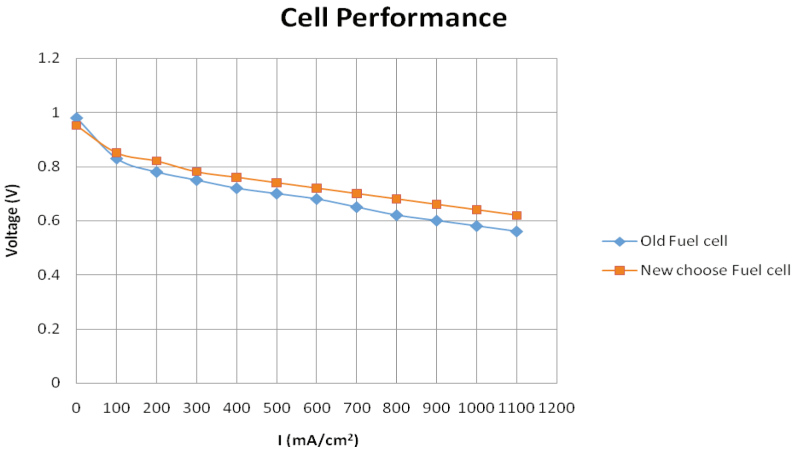


Fig. 15. Comparisons between the old fuel cell and the new choose fuel cell.

The performance of fuel cell predict from I-V curve. Fig. 15 shows the experiment test between old fuel test and new choose fuel cell, the old fuel cell is 4 channels, smooth curve and depth 1 mm.. The new choose is 6 channels, sharp curve and depth 1 mm.. The new fuel cell has better performance than old fuel cell about 25%.

4. Conclusion

A 3-D numerical modeling to predict velocities distribution and pressure drop is presented in this research. The influence of channel length, channel curvature and channel depth is investigated. The best channel curvature from gas distribution is sharp curve and 6 channels serpentine because it has secondary flow and higher area of gas flow, high velocity and pressure drop when compare with channel length. From that result, the fuel cell with our flow field provides better performance. At the outlet, there is the distribution of gas regularly which releases the water from fuel cell. From the experiment results on 4 channels smooth curve and 6 channels sharp curve, there are found that the fuel cell has the density of electric power about 900 and 1,200 mA/cm^2 at 0.6 V, respectively. Flow field has 6 channel is 25% better than 4 channels. The study still continued in order to improve the fundamental knowledge on other geometric parameters. This information will be implied as a guideline for design an appropriate flow field for PEMFC.

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