THE EFFECT OF OPERATION AND DESIGN PARAMETERS ON THE PERFORMANCE OF PEMFC

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UDC: 621.5

INTRODUCTION

The proton exchange membrane fuel cell (PEMFC) is considered to be a promising power source, especially for transportation and stationary cogeneration applications due to its high efficiency, low operating temperature, high power density, low emission, low noise .In the last decade a great number of researches have been conducted to improve the performance of the PEMFC.

The performance of a PEMFC is affected by many factors such as cell operation temperature, operation pressures, relative humidity, and mass flow rate of feed gases, channel geometries in current collector plate and the characteristics of the membrane. To understand the influences of these factors in PEMFC performance, current distributions in a single cell have been, in general, studied by numerical simulations. In literature, several modelling and experimental work has been investigated in order to understand the effect of these parameters to the fuel cell performance.

He et al. developed a two-dimensional, two-phase, multi-component transport model to investigate the effects of the gas and liquid water hydrodynamics, membrane thickness on the performance of an air cathode of a PEM fuel cell employing an interdigitated gas distributor. [1]

Yann et al. studied the influences of various operating conditions including cathode inlet gas flow rate, cathode inlet humidification temperature and cell temperature on the performance of PEM fuel cells with conventional flow field and interdigitated flow field Experimental results showed that the cell performance is enhanced with increases in cathode inlet gas flow rate, cathode humidification temperature and cell temperature. [2]

Guvenlioglu et al. developed a detailed steady-state, isothermal, two-dimensional model of a proton exchange membrane fuel cell a finite element method was used to solve this multi-component transport model in membrane. The model-predicted fuel cell performance curves were compared with published experimental results. The effects of channel width and bipolar plate shoulder dimensions, porosity, and the relative humidity of the inlet streams on the fuel cell performance were evaluated. It was found that smaller width channels and bipolar plate shoulders were required for high current density operations. [3]

Husar et al. studied experimentally the effects of different operating parameters on the performance of proton exchange membrane fuel cell using pure hydrogen on the anode side and air on the cathode side. Experiments with different fuel cell operating temperatures, different cathode and anode humidification temperatures, different operating pressures, and

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various combinations of these parameters have been carried out. The experimental results were presented in the form of polarization curves. Based on this study it was found that the performance of the fuel cell increases with the increase of pressure due to the increase of the exchange current density and the reactant gas partial pressures. [4]

Passos et al. studied Nafion membranes with the aim at characterizing the effects of the Nafion content, the catalyst loading in the electrode and also of the membrane thickness and gases pressures. They presented a decrease of the membrane thickness favours the fuel cell performance at all ranges of current densities. At high current densities the best fuel cell performance was found for the electrode with 0.35 mg Nafion cm−2. [5]

1. MODEL DESCRIPTION

A complete single cell PEMFC (figure 1) assembly divided into cathode current collector plate, gas diffusion layers , catalyst layers and anode current collector plate, gas diffusion layers , catalyst layers and membrane were constructed in Gambit2.4.6 and proper boundary conditions were introduced. The computational full model of a single fuel cell would require very large computing resources and long times. So the model is therefore limited to one straight flow channel with the active layer (figure 2). Boundary conditions are set as follows: constant mass flow rate at the channel inlet and constant pressure condition at the channel outlet.

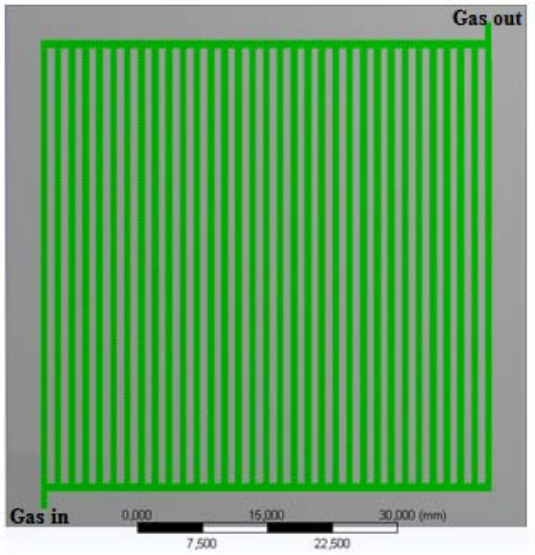

Figure 1 *Current collector plate withstraight channel*

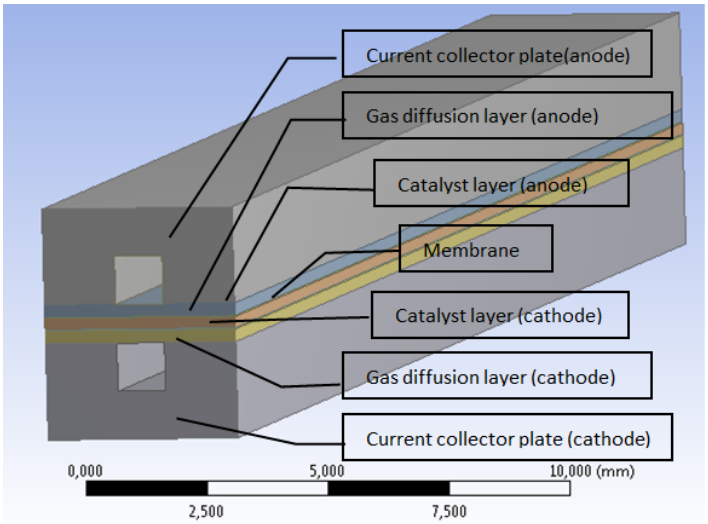

Figure 2 *Schematic view of components of a PEMFC*

2. NUMERIC MODELLING

The below all governing equations and appropriate boundary conditions were solved by using the capabilities of FLUENT 14.0 that employs a finite volume method.

The governing equations for numerical simulation are:

- Conservation of mass,
- Momentum transport,
- Species transport,
- Energy equations.

Conservation of mass equation:

$$\nabla.(\rho\vec{u}) = S_m. \tag{1}$$

The source terms are;

$$S_m = S_{H_2} + S_{wv_p} + S_{wl_p} + S_{awv_a}, \tag{2}$$

$$S_m = S_{O_2} + S_{wv_p} + S_{wl_p} + S_{awv_a}, \tag{3}$$

$$S_{H_2} = -\frac{M_{H_2} A_{an} i}{2F}, \tag{4}$$

$$S_{O_2} = -\frac{M_{O_2} A_{an} i}{4F}. \tag{5}$$

The water vapour at anode and cathode sides is:

$$S_{awv_a} = -\frac{M_{H_2O} A_{an} \alpha i}{F}, \tag{6}$$

$$S_{wv_g} = \frac{(1+2\alpha)M_{H_2O}A_{cv}I}{2F}. \quad (7)$$

The change of phases between water vapour and liquid water depends on partial pressure and is defined as:

$$S_{wl_p} = -S_{wv_p} \quad (8)$$

$$= -\frac{M_{H_2O}\Sigma_{n\,of\,v}\frac{mass_{n\,of\,v}}{M_{n\,of\,v}}\left[\frac{P^{sat}-P_{wv}}{p}\right]_c V}{\left(1-\frac{P^{sat}}{p}\right)} \quad (9)$$

Momentum transport equation:

$$\nabla.(\rho\vec{u}\vec{u}) = -\nabla P + \nabla.(\mu\nabla\vec{u}) + S_{p,i} \quad (10)$$

Where $S_{p,i}$ is the sink source term for porous media in x, y and z-directions:

$$S_{p,i} = -\left(\sum_{j=1}^{3}\frac{1}{\beta_{ij}}\mu u_j\right) \quad (11)$$

Here β is the permeability.

Species transport equation:

$$\nabla.(\rho m_n\vec{u}) = \nabla.(J_n) + S_n, \quad (12)$$

Here 'n' denotes for H_2, O_2 water vapour and liquid water. The source terms are the same as those of the conservation of mass equation. The diffusion mass flux (J) of species n in n-direction is:

$$J_{\xi n} = -\rho D_{n,m}\frac{\partial m_{W,n}}{\partial \xi} \quad (13)$$

Where *n* is the dummy variable for direction *x*, *y* or *z*.

Energy equation:

$$\nabla.(\rho\vec{u}h) = \nabla.(k\nabla T) + S_h \quad (14)$$

The source term *h S* can be obtained by energy losses and heat source by phase change. The heat source from the electrochemical reaction:

$$S_{he} = h_{rxn}\left[\frac{IA_{cv}}{2F}\right] - IV_{cell}A_{cv}, \quad (15)$$

The local current density of the cell is calculated from the open circuit voltage ( ) and the losses;

$$I = \frac{\sigma_m}{t}[V_{oc} - V_{cell} - \eta], \quad (16)$$

Where t is the membrane thickness and is the membrane conductivity and defined as:

$$\sigma_m = \left(0.514 \frac{M_{m,dry}}{\rho_{m,dry}} C_{H^+} - 0.326\right) . exp\left(1268 \left(\frac{1}{T_0} - \frac{1}{T}\right)\right) \quad (17)$$

3. MODEL ASSUMPTIONS

The present model assumes:

- Ideal gas mixtures,
- Steady-state conditions,
- The flow is laminar,
- System is isothermal,

Isotropic and homogenous electrodes, catalyst layer and membrane.

4. ANALYSIS OF MODEL

In this study, the model presented is a three-dimensional, isothermal, single-phase, steady-state model that resolves coupled transport processes in membrane, catalyst layers, gas diffusion layers and reactant flow channels of a PEM fuel cell. The computational domain (Figure 3) is divided into 94080 cells. Boundary conditions are set as follows: constant mass flow rate at the channel inlet and constant pressure condition at the channel outlet. At the below, geometrical, physical and electrochemical parameters used in study are given in Table 1 and Table 2.

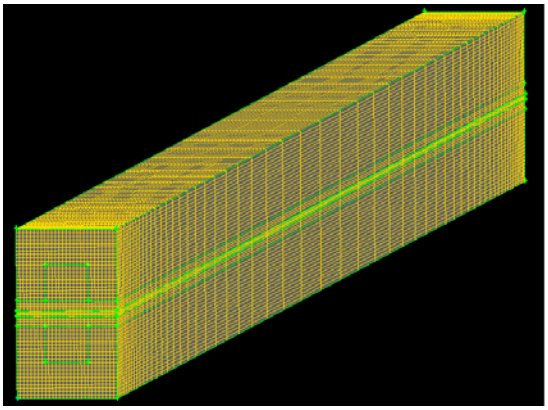

Figure 3 *Fuel cell geometry and computational domain*

Table 1 *Geometrical Parameters*

Parameters	**Value(mm)**
Channel depth	1
Channel width	0.8,1 and 1.2
Channel length	125
Gas diffusion layer thickness	0.27
Catalyst layer thickness	0.02
Membrane thickness	0.127 and 0.051

Table 2 *Physical and Electrochemical Parameters*

Parameters	Value
Gas diffusion layer porosity	0.5
Gas diffusion layer viscose resistance	1e+12 1/m²
Catalyst layer porosity	0.5
Catalyst layer viscose resistance	1e+12 1/m²
Catalyst layer surface /volume ratio	200000 1/m
Reference H_2 diffusion	3e-05 m²/s
Reference O_2 diffusion	3e-05 m²/s
Reference H_2O diffusion	3e-05 m²/s
Anode reference exchange current density	7500 A/ m²
Cathode reference exchange current density	20 A/ m²
Electrolyte area	0.003 m²
Open circuit voltage	0.95 V
Operation pressure	1atm and 2atm
Operation temperature	323K,333K,343K
Cathode mass flow rate	5.0e-6 kg/s
Anode mass flow rate	6.0e-7 kg/s

5. RESULTS AND DISCUSSION

Results are divided into two parts: First, the results observed for operating parameters and the results based on design parameters.

5. 1 *Operation Parameters*

Effect of operation temperature on fuel cell performance

Increasing operation temperature is helpful to enhance electrochemical reaction rate and ionic transport in PEMFC, and the cell performance. However, operation temperature should not be higher than 363 K, or PEMFC may be damaged due to overheating. From the results shown in Figure 4, it is observed that, as the cell temperature increased from 323 K to 343 K, current density increases and the cell performance is enhanced.(channel width is 0.8 mm, pressure is 1 atm and membrane is Nafion 115).

Effect of operation pressure on fuel cell performance

The effects of operation pressure on fuel cell performance are considered for 1atm and 2atm. As can be seen in Figure 5, the current density increases while moving from operation pressure of 1atm to pressure of 2atm. It can be said that operation pressure plays a more important role in fuel cell performance.(channel width is 0.8 mm and membrane is Nafion 115)

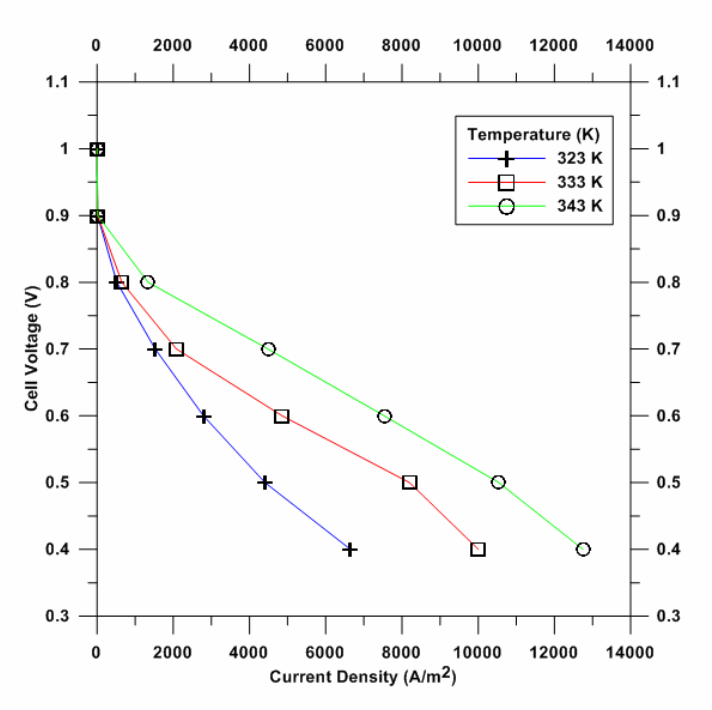

Figure 4 *Operation temperature effect on cell polarization curve*

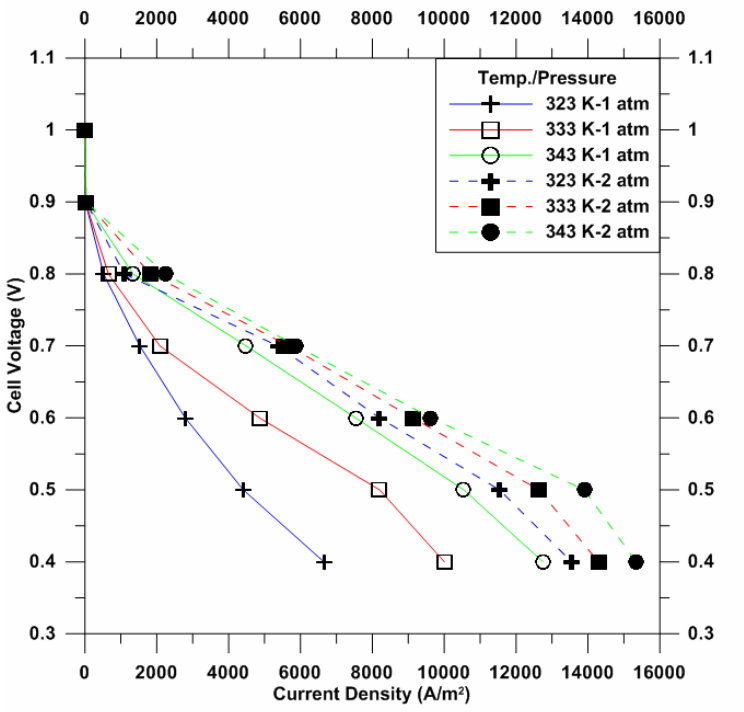

Figure 5 *Operation pressure effect on cell polarization curve*

5. 2 *Design Parameters*

Effect of channel width on fuel cell performance

Analysis of the channel width, in the range of 0.8–1.2 mm, on the fuel cell performance is shown in Figure 6. Operation temperature and pressure are set to be at 333 K and 2 atm. Nafion 115 membrane is used. The effect of channel width on the fuel cell performance becomes more important at high current density applications. It can be seen from Figure 6 that increasing the channel width while the cell width remains constant decreases the current density.

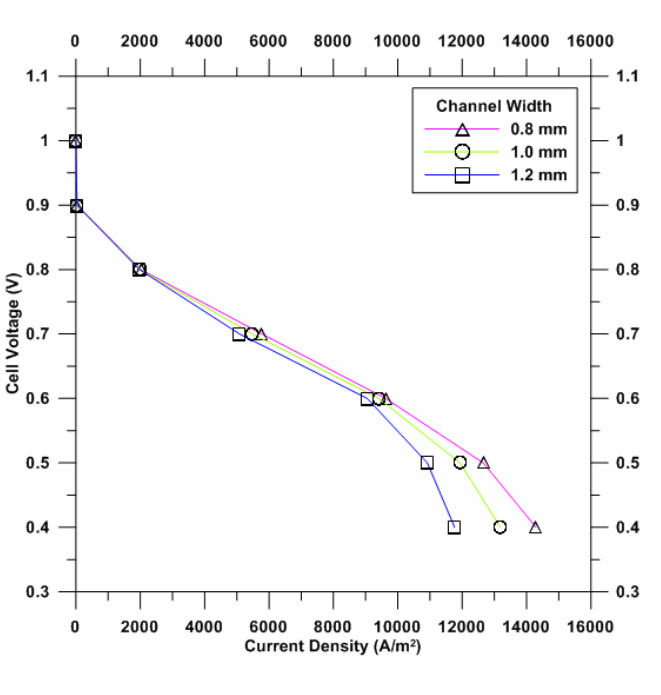

Figure 6 *Channel width effect on cell polarization curve*

Effect of membrane thickness on fuel cell performance

In Figure 7, we investigate the effects of membrane thickness on the current density. As we know, ion conductivity resistance decreases as the membrane thickness decreases and it has no effect on the cell open circuit potential. Operation temperature and pressure are set to be at 333 K and 2 atm. The membrane thickness decreases from 0.127 mm (Nafion 115) to 0.051 mm (Nafion 212). It can be seen from Figure 7 that fuel cell current density clearly increases as decreasing membrane thickness.

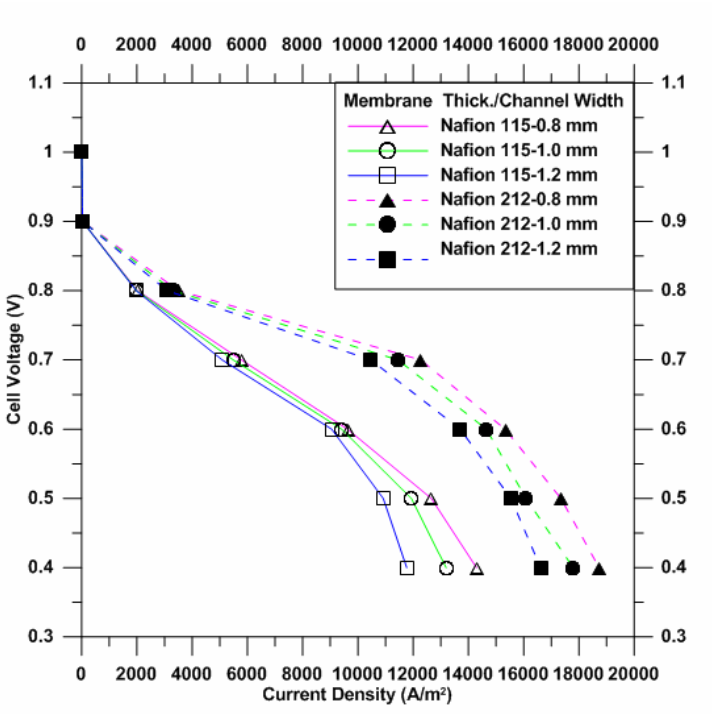

Figure 7 *Membrane thickness effect on cell polarization curve*

6. CONCLUSIONS

Using a single-phase, steady-state, three-dimensional flow simulation of PEM fuel cell, the following conclusion was obtained:

1) Operation temperature is helpful to enhance fuel cell performance. But should not be higher than 363 K, due to overheating of PEMFC.

2) It is found that smaller sized channels (narrow channel width) are required to obtain higher current densities.

3) The membrane thickness has important effect on the polarization curve of the fuel cell. Operation of fuel cell has improved with decreasing its thickness.

7. REFERENCES

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