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Numerical Studies on PEM Fuel Cell with Different Landing to Channel Width of Flow Channel

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Abstract

Proton Exchange Membrane Fuel Cell (PEMFC) is a promising power generating device with high efficiency, zero emissions and working at atmospheric temperature and pressure. The performance of the fuel cell is highly influenced by the operating parameters like temperature, pressure, humidity and mass flow rates of reactant gases; and the design parameters like flow channel designs and dimensions, rib size, channel length, thickness and porosity of GDL, membrane type etc. In this paper, the effects of different Landing to Channel (LxC) width of flow channel were studied numerically. The full three-dimensional models of a proton exchange membrane fuel cell have been developed with a constant channel length of 20 mm and with different Landing to Channel width (LxC) in mm of 0.5x0.5, 1x1, 1.5x1.5, 2x2. While operating the fuel cell at different voltages, the current density values were obtained and the polarization and power density curves were drawn. From the results, it was found that the PEMFC with landing to channel width of 0.5x0.5 mm has generated a high current density and high power density compared to other three designs. Also it was found that the smaller width of landing and channels are required for high current density and power density outputs of the PEMFC due to the better water management.

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Keywords: PEMFC; performance; Landing to Channel width; three-dimensional models; power density

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1. Introduction

The environmental pollution of the world is increasing day by day due to the use of fossil fuels by the automobiles and some power generating systems. So there is a necessity to find out the alternate power sources. The fuel cells are one of the high efficient power generating sources with zero/very low emissions.Fuel cell is an electrochemical device which converts chemical energy of fuel into electricity, heat and water. Due to the exothermic reactions, heat is generated from the fuel cell. Based on the operating temperature, fuel cells are classified into low, medium and high temperature fuel cells. Compared to all other fuel cells, the Proton Exchange Membrane fuel cells (PEMFC) are having high efficiency and working at atmospheric temperature and pressure. The Hydrogen Oxidation Reaction (HOR) is carried out in the anode side and Oxygen Reduction Reaction (ORR) is carried out in cathode side as follows in the proton exchange membrane fuel cell.

$$\text{Anode side: } H_2 \rightarrow 2H^+ + 2e^- \quad (1)$$

$$\text{Cathode side: } 2H^+ + 2e^- + \tfrac{1}{2}O_2 \rightarrow H_2O \quad (2)$$

$$\text{Overall reaction: } H_2 + \tfrac{1}{2}O_2 \rightarrow H_2O + \text{Electricity} + \text{Heat} \quad (3)$$

Nomenclature

Symbols

e^-	Electrons
H^+	Protons
H_2	Hydrogen
H_2O	Water
I	Current density (mA/cm^2)
O_2	Oxygen
P	Power density (mW/cm^2)
V	Cell potential (V)

Abbreviations

GDL	Gas Diffusion Layer
LxC	Landing to Channel width
MEA	Membrane Electrode Assembly
PEMFC	Proton Exchange Membrane Fuel Cell

The PEMFCs are currently under rapid development and promise to become an economically viable commercial power source in many areas, especially for transportation, stationary, portable and automobile applications, because of their high power density at low operating temperatures and zero emissions [1]. In this effort, many critical issues of PEMFC technology need to be addressed. One of the key issues is the performance enhancement of fuel cell by studying the influence of various operating and design parameters. Badreddine Larbi et al. [2] studied the effect of porosity and pressure and they concluded that higher backing layer porosity is required for better performance. A simple analytical model of a high temperature PEM fuel cell was developed, which is a valuable tool for the processing of experimental data [3]. Wei-Mon Yan et al. [4] studied the effect of flow channel designs on performance of PEMFC and concluded that the interdigitated flow field having 1.4 times better power output than the conventional flow field design. Dyi-Huey Chang et al. [5] studied the effect of flow channel depth and flow rates on performance of miniature PEMFC. They concluded that optimum flow rate was essential for shallow channel depth to maintain sufficient pressure to force reactant into channel and also to have proper water balance. Shimpalee et al. [6] investigated the effect of number of gas paths on a 200 cm^2 serpentine flow field design. They concluded that the 13-channel flow field design gives the best performance for a single cell PEMFC. However, for making a PEMFC stack, the 26-channel flow-field design may be the optimal choice due to more uniform current density distribution on the flow field channel and a lower pressure drop. Also the effect of flow channel dimensions and rib widths for performance studies on PEMFC were studied [7]. Atul Kumar et al. [8] optimized the flow channel dimensions and shape in the flow field of end plates in a single pass serpentine flow field design. The triangular and hemispherical shaped cross section resulted in 9% excess hydrogen consumption in anode side, thus it can influence the enhanced performance of the PEM fuel cell. Lin Wang et al. [9] concluded that effect of humidification temperatures is not significant at higher current densities. Also when humidification temperatures are less than cell temperature, the PEMFC performance deteriorates. The liquid water transport within the Gas Diffusion Layer (GDL) and liquid water removal from the surface of the GDL play a crucial role in determining the performance of cell [10]. P.Karthikeyan et al.[11] optimized the ten operating and design parameters of PEMFC using L27 orthogonal array with three levels by Taguchi method.

1.1 Water management issue

In addition to the effect of flow field design and operating parameters, the performance of the PEM fuel cells is highly affected by the water management problem. Enough water-vapor must be available to maintain high electrolyte ionic-conductivity for ensuring suitable performance. The excessive water present in the liquid phase, blocks the pores in the catalyst and GDLs, which hinders the transport of hydrogen and oxygen to the catalyst. The lower level of water also reduces the performance of the fuel cell. So proper balancing of the water in the membrane is playing a vital role. P.Karthikeyan et al. investigated the water impact on performance of PEMFC with porous flow channels [12]. They concluded that the porous flow channels had 48% more power output than non porous flow channels due to water accumulation in non porous flow channels. M.Muthukumar et al.[13] investigated the effect of two, three and four pass serpentine flow field design and concluded that the PEMFC with three pass serpentine channel has produced the high performance. V.Lakshminarayanan et al.[14] numerically investigated the effect of six cross sections of single flow channel of PEMFC. Thus, proper water management is absolutely essential for enhanced fuel cell performance. Also, water and thermal management issues were severely affected by proper selection of design and operating parameters. So, it is clear that there is an exigent need of analyzing the simultaneous effect of operating and design parameters. In this paper, the PEMFC with four different Landing to Channel width were analyzed to study the effect of design parameters on the performance of PEM fuel cell.

2. Modeling of PEMFC

The full three dimensional models of PEM fuel cell with four different Landing to Channel width (LxC) were created and analyzed using commercial finite element software (COMSOL Multiphysics 4.3b) as shown in Fig.1. A fuel cell with single straight flow channel of length 20 mm with rectangular cross-section was considered.

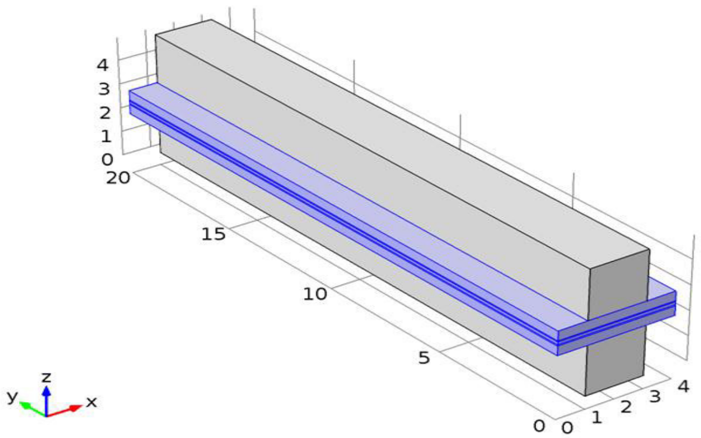

Fig.1 The full model of PEM fuel cell with single channel

The landing area of the PEMFC is used for conducting the electrons that generated during Hydrogen Oxidation Reaction (HOR), from anode side to the cathode side via external circuit. The channel area is used for flowing and distributing of reactant gases on anode and cathode sides. The PEM fuel cell was consisting of seven layers. The seven layers under consideration were electrolyte membrane, anode and cathode catalyst layers, anode and cathode Das Diffusion Layers (GDL), anode and cathode flow channels. The membrane coated with catalyst layer on its both sides is forming Membrane Electrode Assembly (MEA) which is the heart of fuel cell. Model creation started with the "PEMFC adding domains". By using "advanced description domains", the required geometries were generated with respect to the relevant geometry parameters (Length, height, width, etc.). The Cartesian coordinates were used to describe the entire geometry in the required coordinate position. Finally model had been created by retrieving the data from design parameters table in the software.

2.1 Assumptions in modeling

The model is assumed as three-dimensional and steady, the inlet gases as ideal gases, the system as an isothermal, the flow as laminar, the fluid as incompressible, the thermo physical properties as constant and the porous GDL, the two catalyst layers and the membrane as an isotropic. The corresponding modules necessary for the analysis were selected in the software. Free and subsurface flow module, current distribution module and species transport module were included in the analysis. The flow module involves the flow of the species according to given boundary conditions like pressure, velocity etc. The species transport module deals with the chemical reactions taking place for the given diffusivity matrix. Current distribution module determines the amount of current density generated corresponding to reaction taking place. Thus, a coupled analysis of all these three modules were performed in the software and the power density was deduced from the polarization curve.The simulation has been solved by simultaneous equations like conservation of mass, momentum, energy, species, Butler–volmer equation, Joule heating reaction and Nernst equation to obtain reaction kinetics of PEM fuel cell namely mass fraction of O_2 and H_2O, pressure and current flux density distribution on flow channel.

2.2 PEMFC dimensions and operating parameters

The length of the channel was considered as 20 mm for all four designs. The Landing to Channel (LxC) width were taken as 0.5x0.5, 1x1, 1.5x1.5, 2x2 mm and the corresponding height of the channels were taken as 0.5, 1, 1.5, 2 mm respectively. The front view of the fuel cells with various Landing and Channel dimensions were shown in Fig.2.

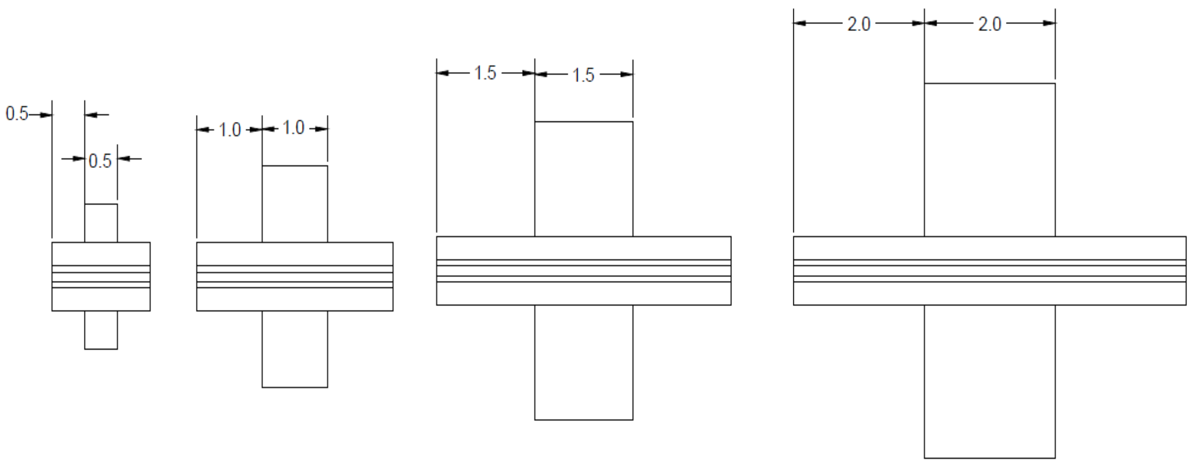

Fig.2. Front view of PEMFC with four different Landing to Channel width (All dimensions are in mm)

The membrane thickness of 0.1 mm, porous electrode thickness of 0.05 mm, GDL porosity of 0.4, GDL permeability of 1.18e-11 m^2, membrane conductivity of 9.825 S/m, GDL electric conductivity of 222 S/m. Hydrogen molar mass 0.002 kg/mol, water molar mass of 0.018 kg/mol, Oxygen molar mass of 0.032 kg/mol were taken for all the cases. The inlet mass fraction of H_2, O_2 and H_2O were considered as 0.743, 0.228 and 0.023 respectively. The PEMFCs were operated at a temperature and pressure of 50°C and 1.5 bar respectively.

3. Results and Discussions:

The four models of PEM fuel cell with seven layers namely membrane, anode and cathode catalyst layers, anode and cathode GDL, anode and cathode flow channels were operated at the same operating conditions of 50°C temperature and 1.5 bar pressure. The current density (*I*) is the current generated per unit active area, i.e. the ratio between the current that can be drawn from the cell corresponding to the particular voltage and the unit active area of the fuel cell. The power density (*P*) is the ratio between the power generated from the cell corresponding to the particular voltage and the unit active area of fuel cell. The polarization curve is the curve drawn between the current density and the voltage, whereas the power density curve is the curve drawn between current density and the power density.These polarizationcurves and power density curves are used to find the efficiency of the fuel cell system.

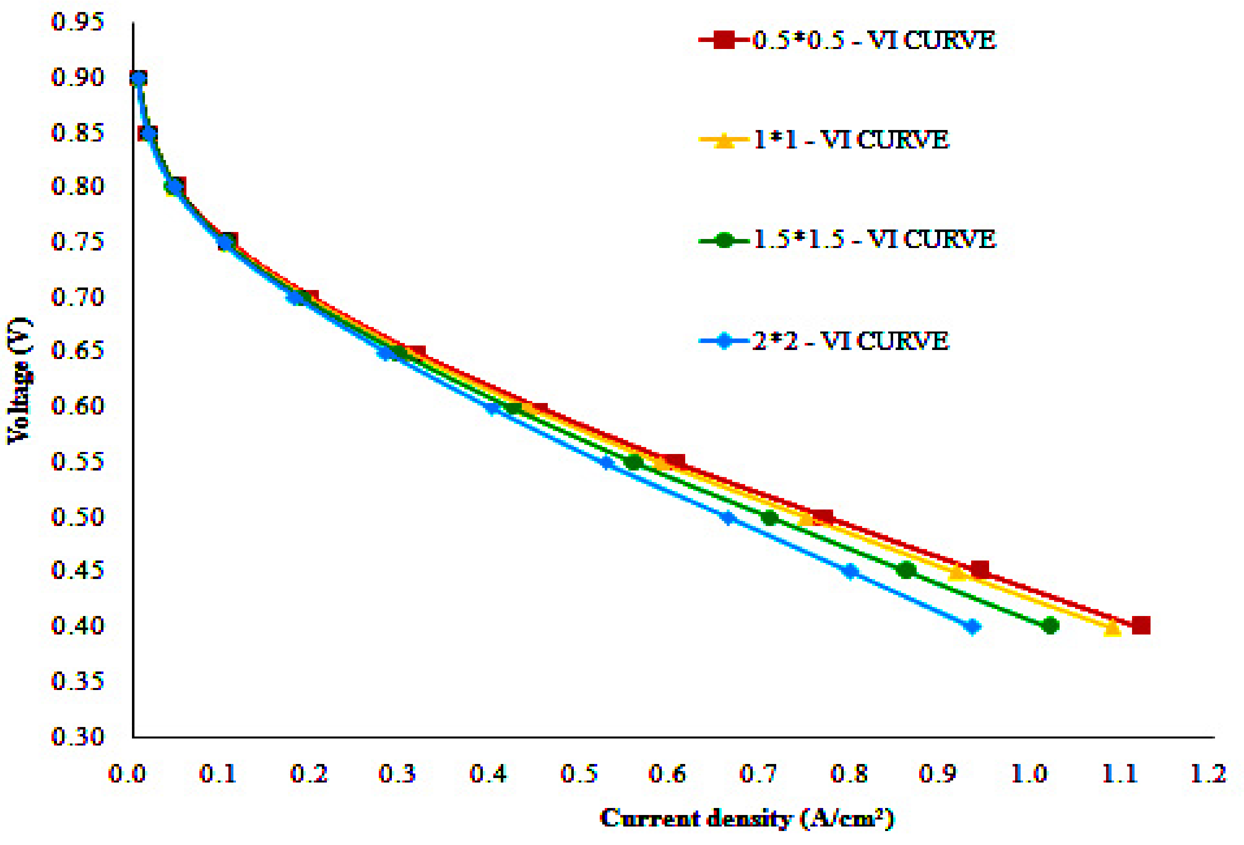

Fig.3 Polarization curves of all the designs

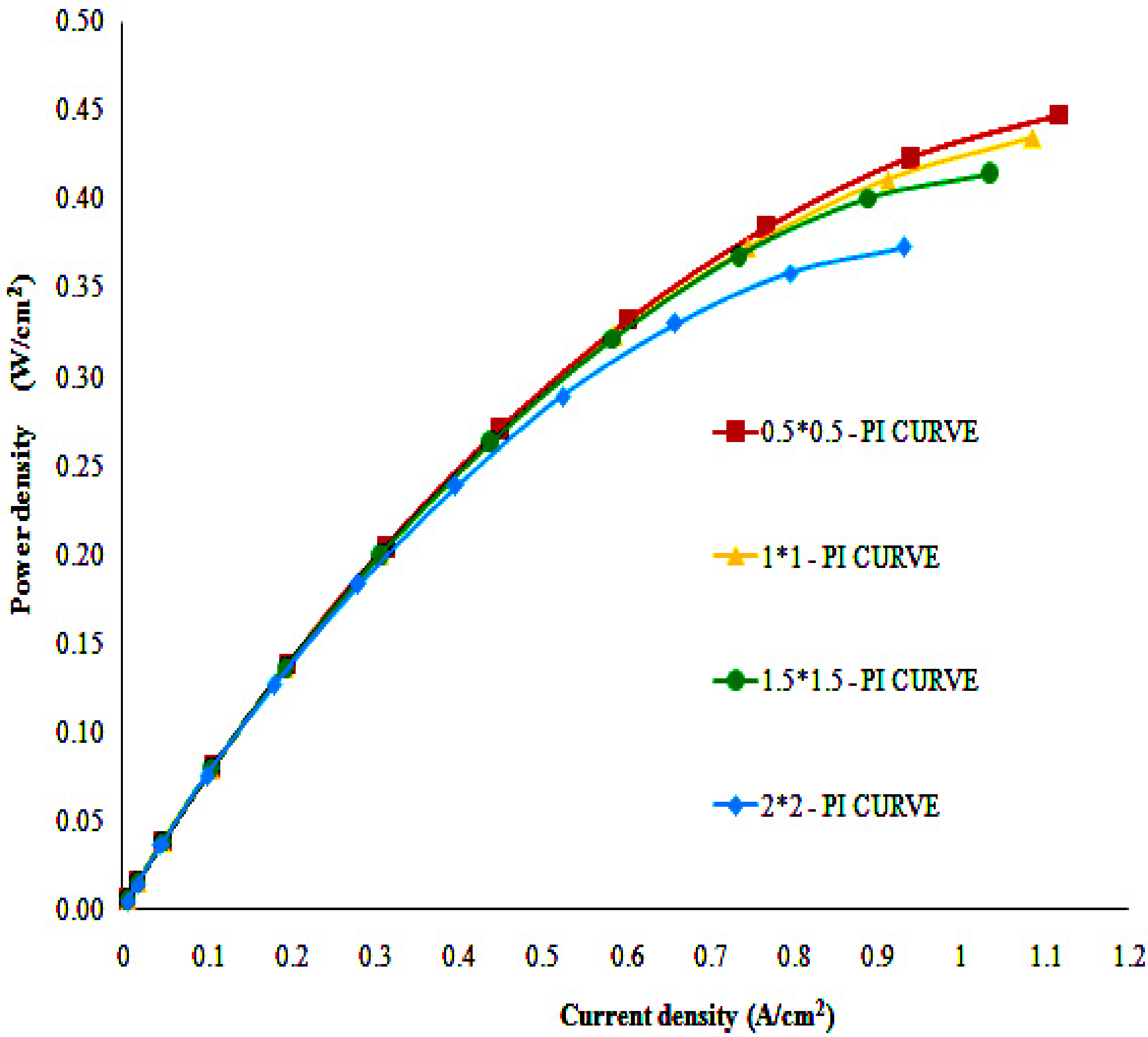

Fig.4 Power density curves of all the designs

Initially the PEMFC with landing to channel width of 0.5x0.5 mm was taken and analyzed at the above said operating conditions. The maximum power density of 0.4473 W/cm^2 was obtained corresponding to the cell potential of 0.4 V at a temperature 40°C. The corresponding peak current density was 1.1183 A/cm^2. Next the PEMFC with landing to channel width of 1x1 mm was taken. The maximum power density of 0.4347 W/cm^2 was obtained corresponding to the cell potential of 0.4 V at a temperature 40ºC. The corresponding peak current density was 1.0866 A/cm^2. Next the PEMFC with landing to channel width of 1.5x1.5 mm was taken. The maximum power density of 0.4146 W/cm^2 was obtained corresponding to the cell potential of 0.4 V at a temperature 40ºC. The corresponding peak current density was 1.0365 A/cm^2. Finally the PEMFC with landing to channel width of 2x2 mm was taken. The maximum power density of 0.3741 W/cm^2 was obtained corresponding to the cell potential of 0.4 V at a temperature 40ºC. The corresponding peak current density was 0.9327 A/cm^2. The polarization curves for all four designs were illustrated in Fig.3 in which the current density values *(I)* were taken in x-axis and the cell voltage values (V) were taken in y-axis.

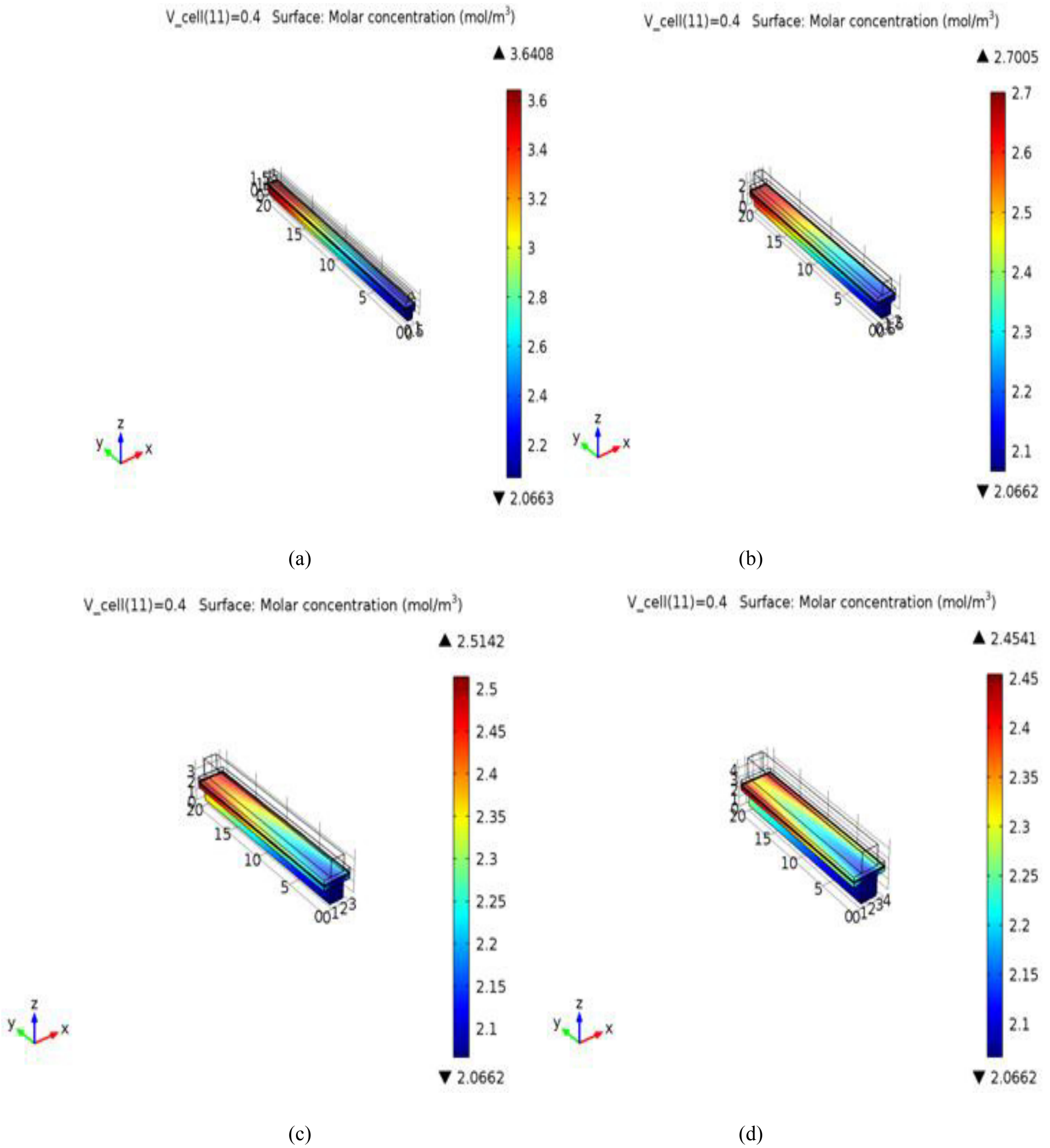

Fig.5 Cathode oxygen concentrations of (a) 0.5x0.5, (b) 1x1, (c) 1.5x1.5, (d) 2x2

From the polarization curves, it was found that the PEMFC with 0.5 x 0.5 mm design has produced the maximum current density compared to other three designs at the cell potential of 0.4 V. The power density curves for various designs of PEMFC were illustrated in Fig.4 in which the current density values (*I*) were taken in x-axis and the power density (*P*) values were taken in y-axis. From the power density curves, it was found that the PEMFC with 0.5x0.5 mm design produced maximum power density. In all three designs, the peak values of current density and power density were obtained corresponding to the cell potential of 0.4 V.The ribs are used for transmitting current and the channels are used for distributing the oxygen and hydrogen in the fuel cell. So their dimensions are influencing the performance of fuel cell. The oxygen concentrations at the cathode side of the channel for all the designs were shown in Fig.5. While comparing the cathode oxygen concentration of all the designs in Fig.5, the PEMFC with 0.5x0.5 was having higher value of 3.6408 mol/m^3 whereas PEMFC with 1x1, 1.5x1.5 and 2x2 mm designs were having the values of 2.7005, 2.5142 and 2.4541 mol/m^3 respectively. Also anode hydrogen concentration and anode water concentration values of 0.5x0.5 design were high. This shows that the electrochemical reactions and current passing through the external circuit were high and losses due to other parameters were less in the particular design. Therefore the power density obtained was more in the 0.5x0.5 mm design.

4. Conclusion

Thefull three dimensional models of proton exchange membrane fuel cell with four different Landing to Channel width werenumerically analyzed using commercial available software package to find out the effect of Landing to Channel width on the performance of PEMFC. The landing width and the channel width of 0.5x0.5, 1x1, 1.5x1.5 and 2x2 mm were considered for this analysis. Except the channel depth, landing and channel width, all other design parameters and the operating parameters were kept constant for all the designs. From the current density values obtained corresponding to the cell potential from the analysis, the polarization curves and power density curves were drawn for all the designs. From the results, it can be concluded that the PEMFC with landing to channel width of 0.5 x 0.5 mm has produced the better performance with peak power density of 0.4473 W/cm^2 and peak current density of 1.1183 A/cm^2 compared to other three designs. Even though the active area of other designs were more, the efficiency of the systems were less. Due to the better water management, the performance of the 0.5x0.5 mm design is better than other design.Also it was found that the peak power density values of all four designs were obtained corresponding to the cell voltage of 0.4 V. In future the study can be extended to reveal the combined effect of operating and design parameters on the performance of PEMFC.

References

[1] Ibrahim Dincer, Hydrogen and Fuel Cell Technologies for Sustainable Future, Jordan Journal of Mechanical and Industrial Engineering, 2008, pp. 1-14.

[2] Badreddine Larbi, WaelAlimi, Effect of porosity and pressure on the PEM fuel cell performance, J. Hydrogen Energy, 38 (2013) pp.8542-8549.

[3] O.Sharmardina, A.Chertovich, A simple model of a high temperature PEM fuel cell, J. Hydrogen Energy, (2009) pp.1-9.

[4] Wei-Mon Yan, Chi-Yen Chen, Sheng-Chin Mei, Chyi-Yeou Soong, Falin Chen, Effects of operating conditions on cell performance of PEM fuel cells with conventional or interdigitated flow field, J. Power Sources, 162 (2006) pp. 1157-1164.

[5] Dyi-Huey Chang, Jung-Chung Hung, Effects of Channel Depths and Anode Flow Rates on the Performance of Miniature Proton Exchange Membrane Fuel Cells, J. Applied Science and Engineering, (2012) pp. 273-280.

[6] Shimpalee. S, Greenway. S, Van Zee. J.W, The impact of channel path length on PEMFC flow field design, J. Power Sources, 160 (2006) pp.398-406.

[7] Shimpalee. S, Numerical studies on rib & channel dimension of flow field on PEMFC performance, J. Hydrogen Energy, 32 (2007) pp. 842-856.

[8] Atul Kumar, Ramana Reddy. G, Effect of flow channel dimensions and shape in the flow field distributor on the performance of polymer electrolyte membrane fuel cells, J. Power Sources, 113(2003) pp.11-18.

[9] Lin Wang, Attila Husar, Tianhong Zhou, Hongtan Liu, A parametric study of PEM fuel cell performances, J. Hydrogen Energy, 28 (2003) pp. 1263-1272.

[10] M.Coppo, N.P.Siegel, M.R. von Spakovsky, On the Influence of Temperature on PEM fuel cell operation, J. Power Sources, 159

(2006) 560-569.

[11] P.Karthikeyan, M.Muthukumar, Optimization of Operating and Design Parameters on the Proton Exchange Membrane Fuel Cell by using Taguchi Method, J. Procedia Engineering, 64 (2013) 409-418.

[12] Karthikeyan.P, Calvin L.H, Lipscomb.G, Neelakrishnan.S, Abby.J.G, Anand.R, Experimental Investigation of the Water Impact on Performance ofProton Exchange Membrane Fuel Cells (PEMFC) with Porous and Non-Porous Flow channels. Proceedings of the ASME 2012 International Mechanical Engineering Congress & Exposition, Houston, Texas, USA. 2012.

[13] M.Muthukumar, P.Karthikeyan, V.Lakshminarayanan, Performance studies on PEM Fuel Cell with 2, 3 and 4 Pass Serpentine Flow field Designs. Applied Mechanics and Materials, 592-594 (2014) pp. 1728-1732.

[14] V.Lakshminarayanan, P.Karthikeyan, M.Muthukumar, Numerical Investigation of Performance studies on single pass PEM fuel cell with various flow channel designs. Applied Mechanics and Materials, 592-594 (2014) pp. 1672-1676.