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Effect of Multi-pass Serpentine Flow Field Designs on the Performance of Proton Exchange Membrane Fuel Cell

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Abstract

The fuel cells are one of the alternate sources that can produce the power with zero emissions without affecting environment. The performance of PEM Fuel Cell (PEMFC) is highly influenced by the operating and design parameters. In this paper, the complete 3D models of PEMFC with multi-pass serpentine flow field designs having three, six and nine passes were analysed using COMSOL Multiphysics software package. The cross-section of the channel and the operating parameters were considered as same for all three designs. From the polarization and performance curves drawn using the numerical results, the peak power density and peak current density values of each design were compared. The PEMFC with six pass serpentine flow field has produced more power density compared to three and nine pass serpentine flow field designs at the cell potential of 0.4 V. Due to the better water management in the PEMFC with 6 pass serpentine flow field design, the higher power output is obtained in it.

Keywords**:** zero emissions; performance; PEMFC; multi-pass serpentine; power density

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1. Introduction

Due to the increase in number of fossil fuel based power generation systems, the environmental pollution and depletion of fossil fuel resource are being unavoidable at present. The automakers and industrial developers are investigating many possible solutions to bring out new methods of improving engine efficiency and to reduce environmental pollutants that come from the engine exhaust in both stationary and transportation applications. In the last decade, the fuel cells appear to be one of the most suitable alternatives for the generation of clean energy, and PEM fuel cell seems to be one of the most reliable ones. Compared with other type of fuel cell, PEMFC has easy implementation, longer lifetime, low operating conditions, high power density and fast start-ups. The PEM fuel cells are working by direct conversion of chemical energy of reaction between hydrogen and oxygen into electricity. The electrochemical reactions at anode and cathode sides of PEM fuel cell are given below.

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

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

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

The serpentine flow channel layout can give good cell performance compared to other designs, due to the balanced water removal and limited pressure drop. So the PEMFC with serpentine channel was considered in this study. The performance of PEMFC can be improved by changing the geometric parameters of the flow fields.

1.1 Effects of design parameters on the performance of PEMFC

A 2D model has been created and analysed by varying the channel dimensions and porosity. The channel with the larger height and gas diffusion layer with smaller porosity will also help in improving the fuel efficiency [1]. The fuel cell performance has been analysed by comparing the water management flow field (WMFF) against the control cathode flow field by Danial G. Strickland [2]. They concluded that the integrated wicks increase the power from 0.41 to 0.68 W/cm^2, at very low air stoichiometry. Atul Kumar et al. [3] optimized the flow channel dimensions and the shape in the flow field of end plates in a single pass serpentine flow field design. In PEMFC with serpentine gas flow channels, the longer the straight channel sections provide larger gas pressure between adjacent channels that increase the under rib width convection and the fuel cell performance [4]. The performance of the PEMFC can be increased upto 41% by inserting the wire coil in the oxygen supply channel, when compared to the conventional straight flow channel [5]. 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. The performance of PEM fuel cell with two, three and four pass serpentine flow field designs were numerically studied and concluded that PEMFC with three pass serpentine channel produced high power density than other two designs [7]. Dyi-Huey Chang et al. [8] 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.

1.2 Effects of operating parameters on the performance of PEMFC

Badreddine Larbi et al. [9] 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 [10]. The influence of operating and design parameters were studied and ranked by P.Karthikeyan et al. [11]. They considered ten operating and design parameters; and optimized the values. The PEM fuel cell with serpentine flow channel produces more power output compared to other flow channels like parallel, Interdigitated, pin type and cascade type channels, due to better water management in it. So the PEMFC with serpentine flow channel design was considered in this analysis.

Nomenclature

Symbols

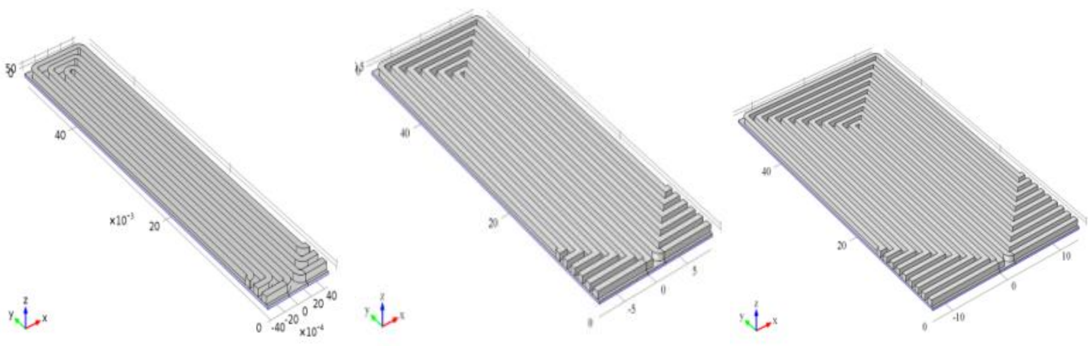
e^-	Electrons
H^+	Protons
H_2	Hydrogen
H_2O	Water
I	Current density (A/cm^2)
O_2	Oxygen
P	Power density (W/cm^2)
V	Cell potential (V)

Abbreviations

GDL	Gas Diffusion Layer
MEA	Membrane Electrode Assembly
PEMFC	Proton Exchange Membrane Fuel Cell

2. Modeling of PEM Fuel Cell

The 3D models of PEM fuel cell with three, six and nine passes were created, meshed and analysed using COMSOL Multiphysics software package. The channel width of 0.8 mm, rib width of 0.7 mm, plate width of 50 mm, GDL height of 0.3 mm and membrane thickness of 0.1 mm were taken for all the models. The model creation started with the “PEMFC adding domains”. The assumptions made while modelling the PEMFC were steady, laminar and incompressible flow with isothermal, homogeneous material properties, adoption of Darcy’s law with negligence of gravitational field effect and contact resistance. The models were finely meshed by using “mesh creation domain” with tetra-hectral meshing. The three serpentine flow field designs with 3, 6 and 9 passes were shown in Fig.1.



(a) (b) (c)

Fig.1. Serpentine flow field design with (a) 3 pass, (b) 6 pass, (c) 9 pass

3. Results and Discussion

The PEM fuel cell models with three, six and nine passes serpentine flow field were analysed numerically with the operating temperature of 323 K and the operating pressure of 1.5 bar. The open circuit voltage was kept as 1.23 V and the current density values were obtained for various cell potentials. The current density is the amount of current produced per active area of the cell and the power density is the amount of power produced per active area of the cell. The PEMFC with three pass serpentine flow channel has produced the current density of 1.1238 A/cm^2 and peak power density of 0.4495 W/cm^2 corresponding to the cell potential of 0.4 V. The PEMFC with six pass serpentine flow channel has produced the current density of 1.1902 A/cm^2 and peak power density of 0.4761 W/cm^2 corresponding to the cell potential of 0.4 V. The PEMFC with nine pass serpentine flow channel has produced the current density of 1.1798 A/cm^2 and peak power density of 0.4719 W/cm^2

corresponding to the cell potential of 0.4 V. The polarization curves and power density curves for all the designs were shown in Fig. 2-3 respectively.

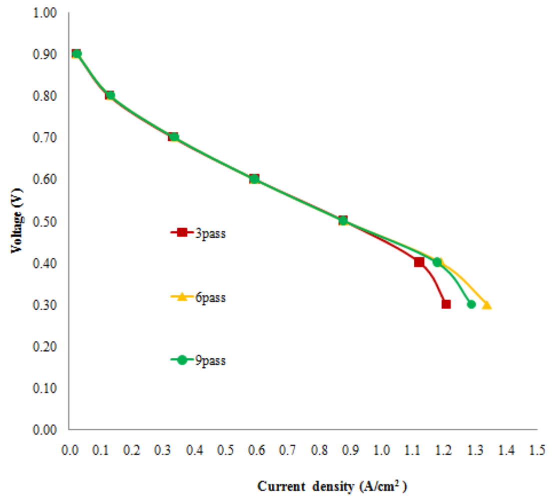


Fig. 2. Polarization curves

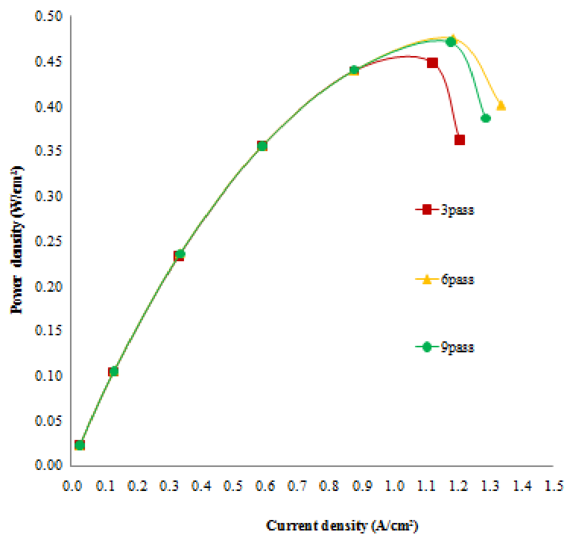
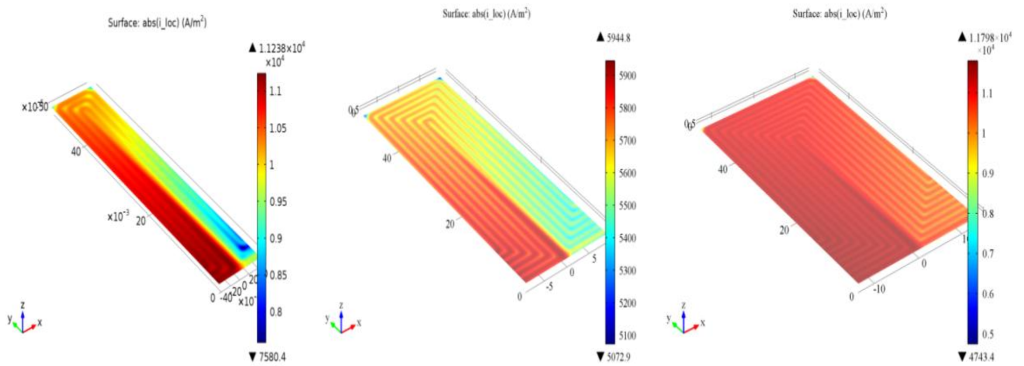


Fig. 3. Power density curves

From the power density curves, it was found that the PEM fuel cell with six pass serpentine flow channel was generating more power density than other two designs. The current density distributions of the different multi-pass serpentine flow channels of PEMFC were shown in Fig.4. While comparing the current density plots of all the designs, the current density generation was uniform throughout the active area of the PEMFC with 9 pass serpentine flow channel. In PEMFC with 3 pass and 6 pass channels, the current generation was not uniform.



(a) (b) (c)

Fig. 4. Current density plots for (a) 3 pass, (b) 6 pass, (c) 9 pass

4. Conclusion

The three dimensional model of serpentine flow field having 3 pass, 6 pass and 9 pass along with Gas Diffusion Layers, Catalyst Layers and membrane were analysed by keeping the same size of rib and channel width. The current density values corresponding to different cell potential were obtained and the polarization curves and power density curves were drawn. it was found that the maximum power density were obtained as 0.4495, 0.4761 and 0.4719 W/cm^2 for 3 pass, 6 pass and 9 pass designs respectively, when the fuel cell models were operated at the cell potential of 0.4 V. From the above results, it is concluded that the six pass serpentine flow channel yielded more power output compared to other two types. It is also concluded that while operating the fuel cell at the cell potential of 0.4 V, the maximum power outputs were obtained in all the designs. As the number passes were increased, the corresponding electrochemical reactions and the rate of water generation were also increased. The excess water generated in cathode side is to be removed properly; otherwise they stay on cathode side of fuel cell and block the flow of oxygen. This reduces the electrochemical reactions and overall power output of the fuel cell system in 9 pass serpentine flow channel design. Due to this, the performance of the 9 pass flow field design is low compared to 6 pass flow field. In future the operating parameters of the fuel cell like temperature, pressure etc. can also be varied and their effects can be studied in detail.

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