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Various Flow-Field Designs for Enhancing Fuel the Cell Performance of Proton Exchange Membrane Fuel Cells

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Abstract. The flow-field design is an essential key in the operation of fuel cells, it conducts main functions such as contributing reactants to the membrane electrolyte assembly (MEA) over gas diffusion layers, conductive part, clamping MEA as well as water management & thermal management and so on. As a result, it is necessary to optimize the flow-field design of fuel cells in order to enhance fuel cell operation characteristics. This paper shows numerical analyses of fuel cell characteristics based on 4 configurations of flow-field in order to find out the best design for enhancing fuel cell performance. The results showed that the different design of flow-field for the anode side and the cathode side can contribute to enhancing fuel cell operation characteristics due to their difference in water formation and discharge. Indeed, the fuel cell configuration with the serpentine flow field in anode side and the pin flow field in the cathode side is the best design because it leads to reducing the water flooding in the cathode side and drying in the anode side. The maximum power density of configuration 1-4 is 0.515, 0.528, 0.585, respectively. It means an improvement of 13.6% percentage can be observed. The research results of this research are the foundation of optimizing the design of the flow-field design.

1. Introduction

In recent several decades, proton exchange membrane fuel cell (PEMFC) has been developed to consider as one of the best solutions to cope with the depletion of energy resources and air pollution due to its fewer emissions and high efficiency compared to the traditional energy sources [1]. A fuel cell working as a battery transfers chemical energy into electrical energy; however, it is continually fed with fuel and thus it can solve the restriction of battery-related to the low energy storage.

As clearly shown in figure 1, a PEMFC includes some main parts: a polymer electrolyte membrane in the centre of the fuel cell, an anode and a cathode, catalyst layers, gas diffusion layers and bipolar plates containing the flow-fields. In the operation of PEMFC, hydrogen enters the fuel cell at the anode side, and thus it is oxidized into two protons and electrons. This is an electrochemical reaction process, and only ions can pass through the membrane but the electrons cannot due to the special design of electrolyte. In the case of the cathode side, oxygen enters the fuel cell and reacts with the hydrogen ions and the electrons to produce water. Otherwise, the free electrons pass through a connected wire from the anode to the cathode generating the electric current.

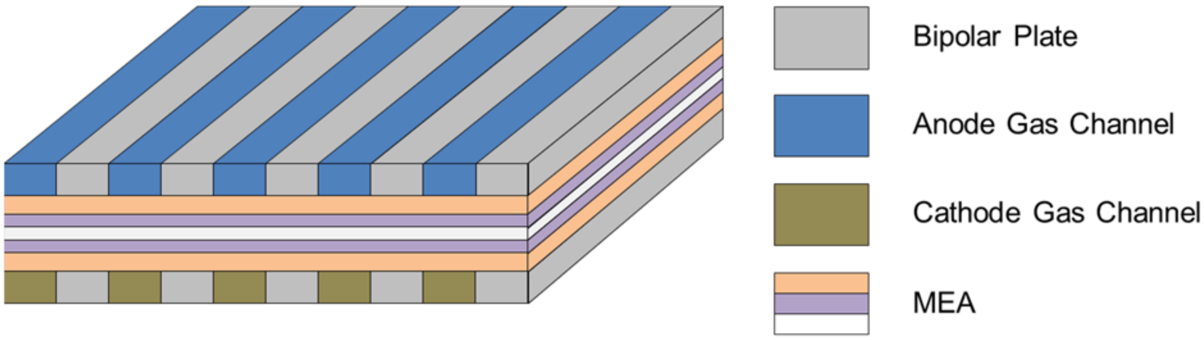

Figure 1. Schematic of a computational domain for PEMFC simulation.

In the fuel cell operation, the flow-field design leads to hydrogen and oxygen through gas diffusion layers to the MEA due to its special design. In addition, it also plays an important role in the water & thermal management; consequently, the flow-field pattern selection is very important due to the affection of its shape, size and pattern on the fuel cell operation characteristics. Many previous studies have focused on developing the novel flow-field design to improve fuel cell performance by both numerical simulation and experiment. D.H. Jeon et. al performed computational fluid dynamics (CFD) simulations based on 4 configurations of single, double, cyclic and symmetric channel patterns to compare their effect on the fuel cell performance. This research showed that the flow-field of the double channel has a higher performance of about 3% and the most uniform current density distribution compared to the other configurations with high inlet humidity. However, corresponding to the low inlet humidity, the difference in performance and current density distribution among four configurations is trivial [1]. In another similar research topic [2], the configurations of single serpentine, parallel, interdigitated and pin flow-field were performed to evaluate the electrochemical reaction behaviours, water formation as well as water discharge of the reference fuel cell. This research showed that corresponding to the same identical operating conditions, the single serpentine flow-field design shows better characteristics compared to those of the interdigitated flow-field. In addition, the worst mass transfer characteristics can be observed in case of the pin and the single parallel flow-field show due to their membrane flooding and drying phenomena.

As mentioned in many previous studies [3-8], the serpentine flow-field is the good design and has been considered in worldwide applications because this design contributes to the equal distribution of supply gases as well as formed water. The design of serpentine is also complicated with many types of design conducted by scientists. A serpentine flow field added sub-channels (SFSC) can improve fuel cell performance as the results shown in [8]. Indeed, an enhancement performance of approximately 18% in comparison with the conventional serpentine flow-field (CSFF) design can be observed by using SFSC design. Furthermore, when flexible applying SFSC for the cathode side and CSFF for the anode side, the fuel cell performance can be enhanced up to 24% because this design overcomes the water flooding in the cathode side and drying in the anode side as shown in [7].

The results in [7] suggested that the flow-field should be designed differently between the anode and cathode side since water is formed in the cathode side and transferred to the anode side. From the ideas of previous results, this research aims to find out the best configuration for the anode and the cathode side. As a result, we performed four configurations based on serpentine flow-field (CF1), parallel flow-field (CF2), interdigitated flow-field (CF3) and pin flow-field (CF4),. The numerical configurations are as follows: Configuration 1 in which CF1 is used at both the anode and the cathode, configuration 2 in which a CF1 and a CF2 are used at the anode and the cathode, respectively, configuration 3 in which a CF1 and a CF3 are respectively used at the anode and the cathode, and configuration 4 in which a CF1 and a CF4 are used at the anode and the cathode, respectively. Figure 2 shows the assembly of 4 configurations using for the simulation process in this research.

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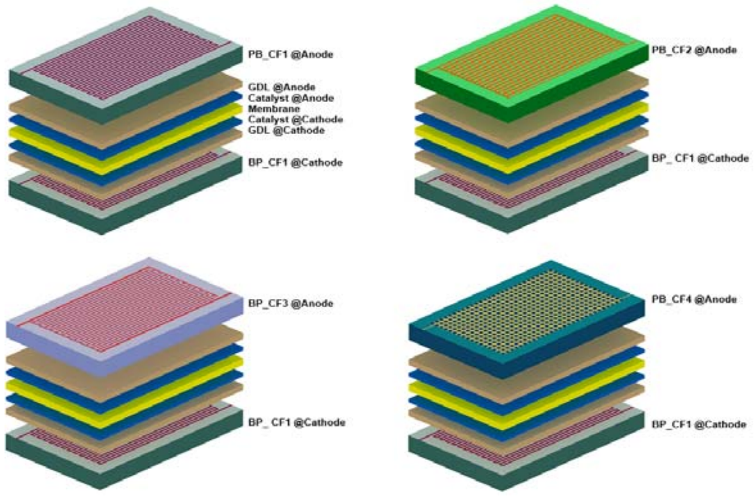

Figure 2. Schematics of the computational domains: (a) configuration 1, (b) configuration 2, (c) Configuration 3 and (d) configuration 42. Testing equipment, experiment setup and test procedure.

2. Model development

In this study, the numerical work is based on a steady-state, multi-phase phenomena, and three-dimensional mass transfer model, including heat transfer aspects of a PEM fuel-cell fuel cell. The Version 14.5 ANSYS program was used to simulate the fuel cell simulation. Figure 2 illustrates based on the computational domain listed in figure 1. The Bipolar palates used in this simulation are based on the serpentine (SPP), the parallel (PRP), the interdigitated (IDP) and the pin flow field (PIP) of the BP as depicted in figure 2. The equations used in this work, conservation of mass, Navier-Stokes equations, species transport equations, energy equation, and water phase change mode, and so on. Table 1 shows the parameters of the test fuel cell used in this research.

Table 1. Properties and Paramenters in this Numerical.

Parameters	**Value**	**Unit**
Porosity after compressed	70	%
GDL thermal conductivity	0.31	W/m·K
MEA thickness	100	μm
Membrane thermal conductivity	0.15	W/m·K
Dry membrane density	2.0	g/cm^3
Dry membrane equivalent weight	1050	g/mol
Cathode exchange current density	0.05	A/cm^2
Cathode transfer coefficient	0.5	
Anode exchange current density	0.2	A/cm^2

3. Results and Discussion

The polarization and power density curves corresponding with 4 configurations of the fuel cell are shown in figure 3.

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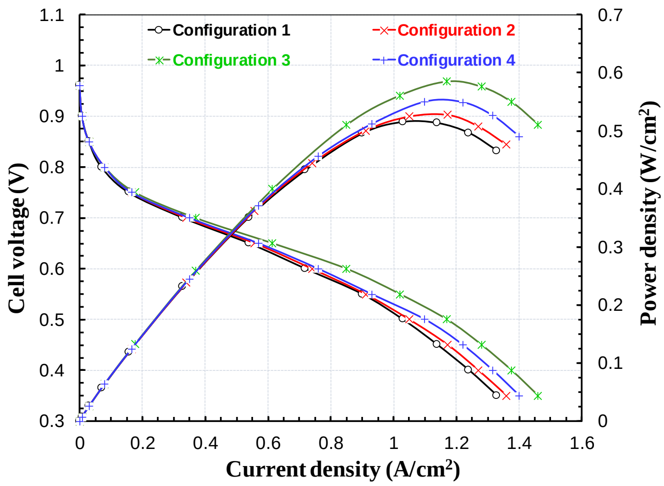

Figure 3. The polarization and power density curves of four different flow field patterns.

Figure 3 represents the average polarization and power density curves at the membrane electrolyte surface of configurations 1-4 corresponding the maximum values of power densities are 0.515 (W/cm^2), 0.525 (W/cm^2),0.55 (W/cm^2), 0.585 (W/cm^2), respectively. Generally, the power densities among four configurations are different from each other when compared with the same current density point. Indeed, the power density of configuration 1 retrofitted SPP flow-field for both the anode and the cathode side is lower than other configurations, it suggested that the fuel cell performance can be enhanced by flexible applying the different flow-field for the anode and the cathode bipolar plate. The reason for this phenomenon is the difference in the reaction process in two sides. At the membrane cathode surface, oxygen is reduced and forms water as a product. Afterwards, water moves along the gas channels as well as in the direction perpendicular to the anode side by the electro-osmotic drag. Increasing current density results in an increase of water formation in the cathode side since back diffusion is not enough to build up for the electro-osmotic drag in drying at the anode side, and thus the anode drying shows faster progress than the moving water velocity. As a result, the water flooding can be observed in the cathode side, meanwhile, the membrane drying may happen in the anode side. The serpentine flow-field is the good design for equally leading the supplied gases throughout the catalyst and also supports for the water discharge in both the anode and the cathode side. This can cause the membrane drying in another side which reduces the fuel cell performance. The PRP, IDP and PIP configuration can solve the problem because they show a lower water discharge process than SPP design as mentioned in [2]. Therefore, the fuel cell performances of configurations 2-3 are higher than those of configuration 1 as shown in figure 3.

4. Conclusions

This research shows the numerical optimization of flow field pattern based on the various configuration of flow-field of SPP, PRP, IDP and PIP using ANSYS software. The results show that with the same active area and operating conditions are identical, the configuration strictly affects the fuel cell performance. In addition, due to the difference in the operating characteristics between the anode and the cathode side, the flow-field of the anode and the cathode side should be designed differently in order to reduce the anode drying in the anode side and the water flowing in the cathode side.

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