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EFFECTS OF FLOW-FIELD DESIGN ON THE PERFORMANCE CHARACTERISTIC OF PROTON EXCHANGE MEMBRANE FUEL CELLS

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Abstract:

Flow-field design of the bipolar plate plays an important role in the operation of proton exchange membrane fuel cells (PEMFC), it contributes reactants through gas diffusion layers (GDL) to the membrane electrolyte assembly (MEA), current collection, providing structural support to the MEA, water management & thermal management and so on. As a result, the flow-field design entails the design of the flow fields on both surfaces of the plate with optimum design parameters to assume responsibility for the stability and high performance of fuel cell. In this paper, numerical analysis-based design of the bipolar plate is investigated to enhance the performance of PEM fuel cell through a comparative evaluation of the fuel cell performance when flexibility using the serpentine flow-field and the serpentine flow field with sub-channels design for anode and cathode bipolar plate. The results show that using the serpentine flow-field with design as the bipolar plates appropriately have many advantages in preventing the cathode flooding and anode drying; as a result, improving fuel cell performance.

Keywords **—Proton exchange membrane, flow field pattern, temperature field, polymer electrolyte membrane, Computational Fluid Dynamics.**

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I. INTRODUCTION

Fuel cell technology has been confirmed as one of the best methods to cope with the depletion of energy resources and environmental pollution due to the fact that devices using fuel cell technology emit fewer harmful emissions and are more efficient compared with the cycle Carnot efficiency of heat engines [1]. Although there are various types of the fuel cell, the main differences tend to be in the materials of the various components [2-5]. The flow field plates are normally fabricated from a porous material, such as carbon graphite, metal or ceramic. The GDL plays the role as an electrical conductor that transports electrons to and from the catalyst layer. In PEMFCs operation, heat and water are the main by-products of electrochemical reactions between hydrogen (fuel) and oxygen (oxidant) which generate electrical energy. The operating principle of a PEMFC is as follows: at the anode side, hydrogen enters the fuel cell at the anode (negative electrode) where it is oxidized into two H+ions (protons) and 2 electrons for every hydrogen molecule. This is called an electrochemical reaction, and due to the special design of electrolyte, ions can pass through it, but the electrons cannot. In the case of the cathode side, oxygen enters the fuel cell and combines with the hydrogen ions and the electrons in a reduction reaction to produce water. Finally, the free electrons

travel through a wire from the anode to the cathode creating the electric current. These processes are depicted in the following equations:

$$2H_2 \rightarrow 4H^+ + 4e^- \quad (1)$$

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O \quad (2)$$

In fuel cell operation, the bipolar plates (BPs) play an essential role in a proton exchange membrane fuel cell (PEMFC), they perform many important functions such as contributing reactants through gas diffusion layers to the MEA, current collection, providing structural support to the MEA, water management & thermal management and so on. The selection of flow field pattern of a BP is important due to the affection of shape, size and pattern of the corresponding flow field to fuel cell performance. Many types of research have focused on the flow field design to improve fuel cell performance by both numerical simulation and experiment. F. Arbabi [4] concentrated on improvements in the fuel cell performance through optimization of channel dimensions and configuration to find an optimized state by simulating a two-dimensional numerical model of the flow distribution based on the Navier-Stokes equations and using an individual computer. It is found that the patterns with inspiration from leaf venation show appropriate pressure drop and uniform pressure and velocity distribution along the channels. Simpalee and Van Zee [4] investigated the effect of flow field configurations on the focal point of channel/rib width and their results with the distribution of current density, temperature, and membrane water content.

The flow field design in the bipolar plates (BPs) is very difficult because the phenomena of mass transport and electrochemical reactions are so complicated that the contributions of each parameter to the performance of a real PEMFC cannot be measured separately. In this research, we investigated the development of bipolar plate configuration by researching on the serpentine, the parallel, the interdigitated and the pin flow field pattern of the BP. The research result is the foundation to optimize the fuel cell efficiency in the experiment.

II. MODEL DEVELOPMENT

In this paper, 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 full-cell fuel cell using Ansys software. Fig. 1 illustrates the computational domain for CFD-based PEMFC simulation which consists of two bipolar plates, the anode and the cathode gas diffusion layers (GDLs), and MEA including membrane and catalyst layers on the active area of 25 cm^2.

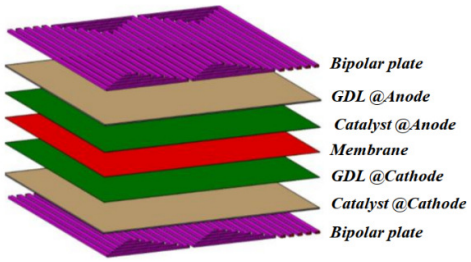

Figure 1. Schematic illustration of a computational domain for PEMFC simulation

The Bipolar palates used in this simulation are based on the 4-channel serpentine (SPP), the parallel (PRP), the interdigitated (IDP) and the pin flow field pattern (PIP) of the BP as depicted in Fig. 2.

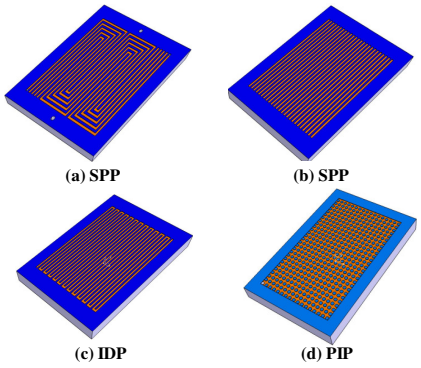

Figure 2. Schematics and locations of the four flow field patterns with an active area of 25 cm^2

The properties and dimensional of the simulation models are listed in Table 1 and Table 2.

TABLE 1. PROPERTIES AND PARAMETERS IN THIS NUMERICAL

No.	Parameters	Value	Unit

01	MEA thickness	250	μm
02	Permeability	1e-13	m^2
03	Porosity after compressed	75	%
04	Diffusion adjustment	55	%
05	Thermal conductivity of GDL	0.23	W/m·K
06	Thickness including catalyst layer	100	μm
07	Thermal conductivity of the membrane	0.25	W/m·K
08	Dry membrane density	2.0	g/cm^3
09	The equivalent weight of the dry membrane	5000	g/mol
10	Cathode exchange current density	0.02	A/cm^2

TABLE 2. FUEL CELL GEOMETRICAL DIMENSIONS

No.	*Part*	Length (mm)	Width (mm)	Thickness (mm)
01	GDL	200	100	0.25
02	Catalyst	200	100	0.0125
03	Membrane	200	100	0.035
04	Channels	-	1	0.2
05	Collector	250	250	10

The total number of the mesh is 1 million cells for all configurations. The convergence residual of this analysis amounts to less than 1.0e-5, and the calculation was iterated for a maximum of 2000 times under the condition of convergence decision of less than 1% on the imbalance of chemical species such as hydrogen, oxygen, and water.

III. RESULTS AND DISCUSSION

The PEMFC performance was analysed by using the present numerical model of electrochemical reaction and transport phenomena which are fully coupled with the equations. Therefore, the distributions of performance-related parameters are profiled and compared quantitatively at the same location. The polarization and power density curves corresponding with four profiles of the BPs are shown in Fig. 4.

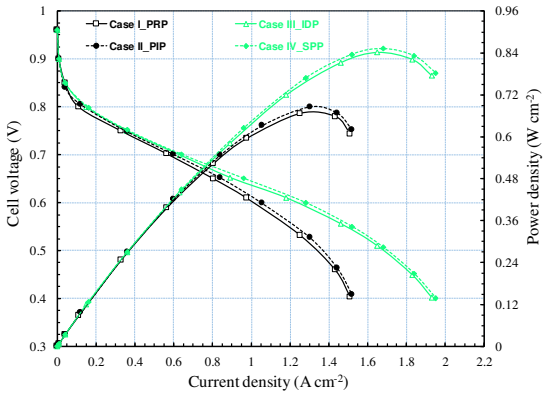

Figure 3. Comparison of fuel cell performance

Fig. 3 represents the average polarization and power density distributions curves at the MEA surface on the PRP, the PIP, the IDP and the SPP corresponding the maximum values of power densities are 0.78 (W cm-2), 0.801 (W cm-2), 0.92 (W cm-2), 0.91 (W cm-2), respectively. The reason is that the discontinuity of the channels forced the gas into the GDL, thus converting the transfer of reactant through the GDL from diffusion to diffusion and convective, and thereby, increasing the local effective pressure of reactant at the reaction interface. However, it was found that the best PEMFC performance in transient response was for the parallel flow field design, showing the lower performance in steady-state conduct. Therefore, this difference of the cell voltage may be attributed to BP flow field and configuration, operating conditions and steady-state and transient.

IV. CONCLUSIONS

In this research, the numerical optimization of flow field pattern was performed by the mass transfer and electrochemical reaction characteristics prior to the experiment in PEMFC. We used module Fuel Cell in ANSYS software to investigate the four flow field patterns of the BPs. The results show that when the active areas and operating conditions are identical, the SPP showed the best mass transfer characteristics or mass transfer characteristics similar to the interdigitated flow field pattern which shows that the water accumulated because of the electrochemical reaction in the outlet region. In the IDP, water

content increases in the section of high current density, and the water behaviour becomes unstable at the outlet channels. In the PIP, excessive water removal results in dehydration of the membrane, whereas in the PRP, flooding occurs because of uneven flow circulation. The numerical optimization of flow field pattern incorporates mass transfer and electrochemical reaction characteristics to give qualitative assessments of pressure, flow, water and current density prior to the experiment.

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