Simulation, manufacturing and test of a transparent proton-exchange membrane fuel cell

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ABSTRACT

In this research, a transparent proton-exchange membrane fuel cell is designed and manufactured to visualize the anode and cathode side flow channels and study flooding phenomenon in them. Manufacturing challenges are found, and cell design is simulated prior to manufacturing. Restrictions are expressed in the first place and then practical solutions are presented to cope with them; materials and dimensions are then determined accordingly. As the second step, the cell's operation is simulated and the polarization curve is extracted using a steady-state two-phase computation fluid dynamics model. After the manufacturing of all components, due to the high influence of the torque of the bolts on the leakage, lifetime and operation of the cell, this parameter is optimized using polarization curves. A torque of 1N.m for the bolts is found to be optimum. In order to validate the numerical model, the polarization curve of the model is compared with that of the experiment. An error of 6.76% demonstrates the suitable accuracy of the numerical model. Finally, the accumulated water on the cathode side is detected using direct visualization and image processing technique.

KEYWORDS

Proton-exchange membrane fuel cell, Design and manufacturing, Water management, Computational Fluid Dynamics (CFD), Digital image processing

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1. Introduction

Fuel cells have been the subject of many researches in the field of energy for the last recent decades and they are considered to be an appropriate replacement for internal combustion engines.

Water is a definite production of electrochemical reactions in the PEM fuel cells. If the water production rate exceeds the water removal rate, then a phenomenon which is known as flooding will occur [1]. Keeping the balance of water content between dehydration and flooding is the concept of water management in the PEMFCs. In fact, flooding or dehydration is a result of undesirable water management.

Generally, the studies of flooding phenomena are classified into two categories, namely, direct and indirect methods. Direct visualization of transparent PEMFCs, neutron radiography, nuclear magnetic resonance and X-ray radiography are the main methods of direct visualization [2, 3]. However, measurable parameters such as pressure drop and high-frequency resistance are employed in indirect methods to determine flooding in the cell.

Optical imaging systems provide high-resolution images with lower cost compared with the other methods [4]. Nonetheless, in order to employ these systems, some design criteria must be considered for cell components which are not common in commercial fuel cells, i.e. a) using transparent material for end-plates and b) machining flow channels on metal plates thoroughly.

In the present study, a transparent PEMFC with a parallel serpentine flow pattern is designed and manufactured to visualize flooding in flow channels.

2. Methodology

In order to carry out the investigation, a PEM fuel cell with transparent endplates is designed, simulated and manufactured at Fuel Cell Research Laboratory of Amirkabir University of Technology (AUT). To begin with, a parallel serpentine transparent PEMFC is designed, manufactured, assembled and tested. The design and manufacturing procedure of all components is explained step by step with details. Also, the restrictions are demonstrated and practical solutions are presented to cope with them; materials and dimensions are then determined accordingly. Based on manufactured PEMFC, a CFD model is developed using ANSYS software. Afterward, the CFD simulation is validated by the polarization curve obtained from manufactured PEMFC at the same operating condition. Finally, liquid water accumulation in the flow channels is determined by developing an image processing algorithm.

3. Results and Discussion

Fig. 1 shows the manufactured transparent PEMFC for the present study. At the manufacturing procedure, the following hints must be considered:

a) According to the bipolar plates thickness and the flow channel dimensions, wire cut is the most suitable machining method.

b) At the material evaluation stage for bipolar plates, crucial parameters like corrosion resistance, electrical conductivity, machinability with wire cut and gold-coated capability must be considered.

c) In order to achieve uniform pressure distribution at the contact regions of components and prevent gas/liquid leakage, silicone gaskets with semi-elliptical cross-section are recommended.

d) At the assembling step, the clamping force must be optimized. According to Fig. 2, the optimal clamping force of 1 N.m is achieved.

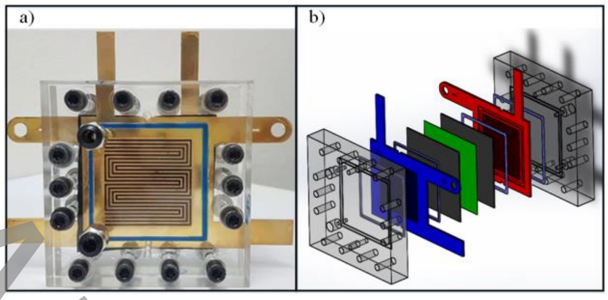

Fig. 1 Transparent PEMFC manufactured for the present study in fuel cell laboratory of AUT (a) Front view; (b) Exploded view.

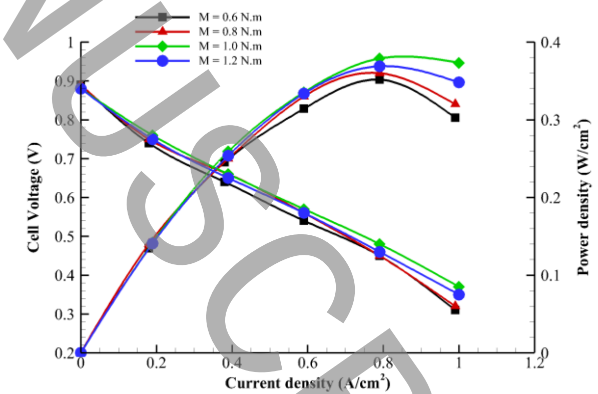

Fig. 2 Polarization curves of manufactured cell for different clamping pressures

In the second step, the finite volume SIMPLER scheme is implemented to model transparent PEMFC in

ANSYS software. Fig. 3 shows the CFD and experimental polarization curves. As shown in this figure, an acceptable agreement between the CFD model and experimental data is observed.

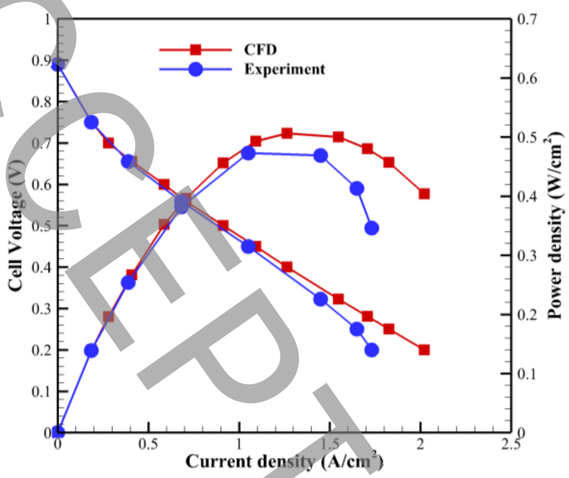

Fig. 3 Validations: comparison between the polarization curve for the CFD model and the manufactured PEMFC.

Fig. 4 illustrates the oxygen mole fraction at the gas diffusion layer and catalyst layer interface for different cathode stoichiometry levels, namely, 1 and 4. According to this figure, at low cathode stoichiometry (=1), the oxygen mole fraction falls drastically along the flow channels which leads to starvation next to the outlet zone. In this circumstance, increasing cathode stoichiometry (=4) enhances the oxygen diffusion rate to the catalyst layer and prevents power loss.

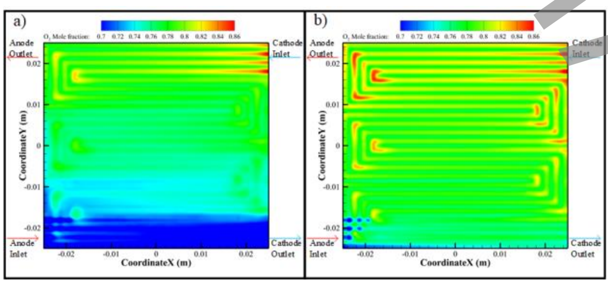

Fig. 4 Oxygen mole fraction (a) Cathode stoichiometry 1; (b) Cathode stoichiometry 4.

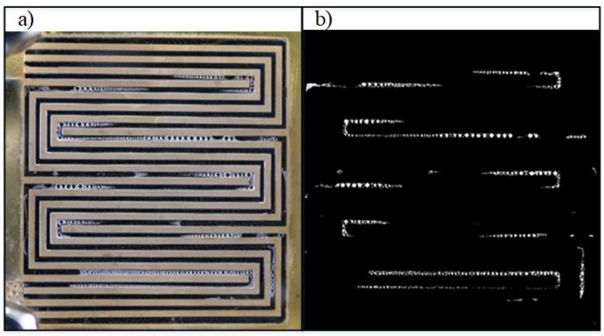

Fig. 5 (a) Captured operating image; (b) Detection of accumulated water.

The main idea of manufacturing transparent PEMFCs is to visualize and quantify water accumulation in flow channels. To do so, a high-resolution camera and digital image processing technique must employ. Fig. 5 displays the accumulated water in cathode flow channels.

4. Conclusions

The outcome of this research can be summarized as follows:

- Based on the present study results, steel 316L and PLEXIGLAS are the most appropriate options for bipolar plates and end plates. Also, the wire cut machining method is the finest selection.
- Semi-elliptical cross-section silicone gasket provides uniform pressure distribution and prevents leakage within the cell.
- Contact resistance, mass transport resistance, and gas/fluid leakage within the cell are considerably affected by the clamping force. Hence, the clamping force test must conduct.
- The good agreement between CFD and experimental results indicating that the obtained results from CFD model are reliable.
- Increasing cathode stoichiometry enhances oxygen concentration at the catalyst layer and improves the cell performance.

5. References

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