THE ENTRANCE EFFECT OF PIN TYPE FLOW CHANNEL ON DIRECT METHANOL FUEL CELLS

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ABSTRACT

This research alters the traditional single inlet/outlet opening of the pin type flow channel of direct methanol fuel cells (DMFCs). Multi-inlet/outlet openings are designed with the aim to distribute the methanol solution evenly and effectively remove CO_2 bubbles and to improve the cell performance. The CO_2 bubble dynamics in anode flow channels and the cell performance are investigated. Results show that the newly designed flow channels can overcome restrictions resulting from fuel and effectively remove CO_2 bubbles, thereby enhancing the performance of the pin type DMFC. The "three-inlet and three-outlet" design increases the current density output by 19%.

Keywords: Direct methanol fuel cell (DMFC), Pin-type flow channel, Bubble visualization.

1. INTRODUCTION

The search for substitutes for fossil fuels and renewable energy alternatives has become a target of a global research effort as fossil fuel reserves diminish and greenhouse effects gradually worsen [1]. Fuel cells are one of the most attractive options among the new generation of power technologies. A fuel cell is an electrochemical device that converts chemical energy directly into electrical energy with a high degree of efficiency. Among the various fuel cells, the direct methanol fuel cell (DMFC) is considered a top contender as a substitute power source in portable devices [2]. Compared with other types of fuel cells, DMFCs have the advantages of system simplicity, approximate room temperature operation, handy liquid fuel storage, quick and easy refilling, high power density, low cost fuel, and natural air applicability.

The overall DMFC cell reaction is the electro-oxidation of methanol to water and CO_2 [3]. One of the main tasks of the anode and cathode of flow channels is to guarantee distribution of fuel and oxidant over the reaction surface as well as the rapid and effective removal of products from the fuel cell to maintain an effective continuous reaction. Well-designed anodes and cathodes of flow channels are capable of uniform current distribution within the cell, providing good performance stability. Kunimatsu *et al.* [4] compared the cell performance of different flow channels including serpentine styles, double serpentine styles, triple serpentine styles, pin styles and parallel styles. The results indicate that pin type flow channels have the shortest flow path, suitable for application in products requiring low current density. Scott and Taama [5] discovered that pin type flow channels provide a better methanol mixture at the anode in high flow situations. Li and Sabir [6] suggested that pin type flow channels suffer from a reduction in internal pressure, reducing the available fuel required to produce power. However, these researches also indicated that the pin-type DMFCs achieve low cell performance due to high ohmic resistance, inhomogeneous methanol distribution and difficulties in removing CO_2 bubbles. This research altered the traditional single inlet/outlet opening of the pin-type flow channel. Multi-inlet/outlet openings of the flow channel are designed with the aim of overcoming some of these problems.

2. EXPERIMENTAL SETUP AND METHODS

Flow visualization is an effective method to study fluid motion in fluid dynamics [7,8]. A similar method has been applied to investigate the dynamic behavior of CO_2 bubbles in anode channels of DMFCs. A transparent pin-type DMFC (Fig. 1) was constructed to visualize the CO_2 bubble dynamics using a digital camcorder. Polarization curves were also obtained to provide the relationship between the dynamic behavior

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DOI : 10.1017/jmech.2012.40

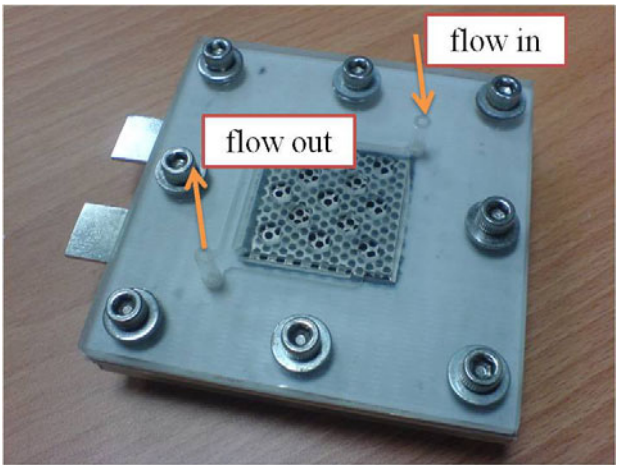

Fig. 1 The transparent single-cell DMFC test fixture

of CO_2 bubbles and the cell performance. The single-cell DMFC includes the membrane electrolyte assembly (MEA), 316 stainless steel current collectors (2mm thick), gaskets and cathode and anode channel boards. More detailed descriptions are referred to Ref. 3. The DMFC assembly was clamped using eight screws (each having a torque of 10kgf-cm). The MEA had an active area of 35mm × 35mm, and was activated prior to each set of experiment to achieve optimal performance. Both the anode and cathode channel board used the same type of flow channels during the tests. The methanol solution and the air flowed into/out of the anode and cathode flow channels, respectively, with the same flow directions.

The experimental setup for measuring the polarization curves includes methanol-supply system, air-supply system, fuel cell, and the measurement device [3]. The preheated methanol solution (55°C) with volume concentration of 10% was pumped into the anode of the DMFC at a rate of 10ccmin^{-1}. Air was pumped into the cathode of the DMFC at a rate of 1000ccmin^{-1}. A DC electronic loader was adopted to simulate the load request to the DMFC and the current, voltage and power data were recorded. The polarization curves (I-V and I-P curves) were measured under the control voltage (CV) mode. Through the observation of anode flow channels, we also investigated the characteristics of CO_2 bubble exclusion and accumulation. The cathode and anode channel boards adopted in this research have the same configurations. The flow channel, with an area 35mm × 35mm, is located in the center of the channel board. The 13 columns in the pin-type flow channels were regular hexagonal, with a 3mm side length and a 12mm spacing between the centers of the columns in an alternating arrangement (Fig. 2). This study altered the traditional single inlet/outlet opening of the flow channel. Multi-inlet/outlet openings of the flow channels are designed, and include "one-inlet and three-outlet", "three-inlet and one-outlet", and "three-inlet and three-outlet". The open ratio of the flow channel for these four manifolds is kept constant at 76.5%, which is defined as the ratio of the MEA area exposed to methanol solution to the total MEA area.

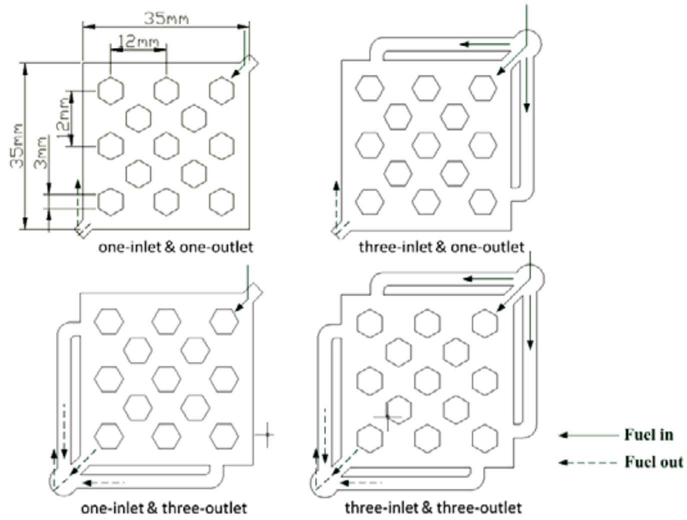

Fig. 2 A schematic of the four inlet/outlet manifolds used with the flow channel

3. RESULTS AND DISCUSSION

The multi-inlet design was expected to direct the methanol solution into the flow channel evenly and enhance the overall performance of the fuel cell. The multi-outlet design was expected to expel bubbles accumulating on both sides of the flow channel along the openings in the corners to reduce the degree to which bubbles block the flow channel. In this research, the multi-inlet/outlet design was expected to have both of the advantages mentioned above. A comparison of the performance of the four fuel cells with various inlet/outlet openings is presented as current density vs. cell voltage and current density vs. power density, as shown in the polarization curve (I-V-P curve) of Fig. 3. The same activated MEA was used for the four manifolds during the tests. The effects of ohmic resistance and MEA on cell performance were observed to be negligible. Figure 3 indicates that the maximum current density and power density were 95.2mAcm^{-2} and 19.9mWcm^{-2}, respectively, for the design of "one-inlet and one-outlet". The maximum current density and power density were 113.2mAcm^{-2} and 23.4mWcm^{-2}, respectively, for the design of "three-inlet and three-outlet". The current density and the power density were enhanced by approximately 19% and 17.3%, respectively. The performances of the four designs were ranked from highest to lowest as follows: "three-inlet and three-outlet", "three-inlet and one-outlet", "one-inlet and three-outlet", and "one-inlet and one-outlet". The "three-inlet and three-outlet" design of the flow channel was superior to the investigated configurations.

The performance of the fuel cell was associated with the extent to which CO_2 bubbles were expelled. We observed the CO_2 bubbles of the anode flow channel to investigate how the design of the multi-openings of the flow channel influences the expulsion of bubbles. In the DMFC, methanol solution is fed into the anode flow field and diffuses onto the catalyst surface through the

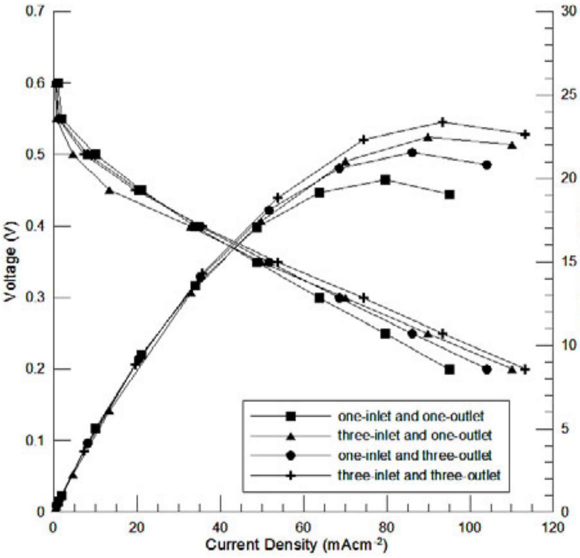

Fig. 3 Performance comparison of the four fuel cells using different inlet/outlet manifolds

diffusion layer, while the gaseous CO_2 bubbles produced by the methanol oxidation reaction at the catalyst layer are transported back into the anode channel. The CO_2 bubbles are then moved towards the outlet of the flow channel with the help of the cross current flow of the methanol solution. Consequently, a homogeneous distribution of the methanol over the active area, and the effective removal of the CO_2 bubbles by the methanol solution are crucial to cell performance. Stagnant CO_2 bubbles may produce gas blockage, which keeps methanol from diffusing onto the catalyst surface. This may be detrimental to cell performance. Hence, a study of the CO_2 bubble dynamics of the anode flow channel can serve as a guide for improving the performance of DMFC. Figure 4 demonstrates the time evolution of the CO_2 bubble behavior for the “three-inlet and three-outlet” design under the selected current density of 95mAcm^{-2}. Straight after the reaction starts, only a few CO_2 bubbles emerged from the diffusion layer and appeared at the openings of the current collector. At t = 30s, most of the openings of the current collector were full of CO_2 bubbles. After that time, the CO_2 bubbles began to grow and coalesced into bigger bubbles, seen in the picture at t = 50s. The coalesced bubbles became even larger and moved toward the outlet of the channel at t = 70s, and some of the coalesced bubbles were pushed out of the channel by the flow of methanol solution at t = 90s. At t = 93s, almost all of the bubbles were swept out of the anode channel. The periodic scenario of CO_2 bubble emergence, growth, coalescence and removal repeated again after t = 93s. Figure 5 shows the time evolution of the CO_2 bubble behavior for the “one-inlet and one-outlet” design for the same current density, selected to be 95mAcm^{-2}. The bubble dynamics are similar to those of the “three-inlet and three-outlet” design between t = 2s to t = 90s. The CO_2 bubbles emerge from the diffusion layer, coalesce into bigger bubbles, move toward the outlet and are pushed out of the channel.

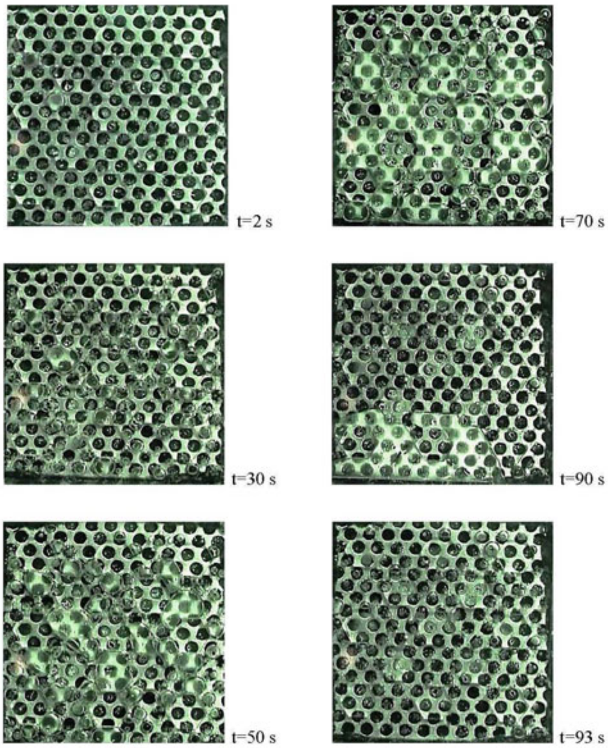

Fig. 4 Time evolution of the CO_2 bubble behavior for the “three-inlet and three-outlet” design

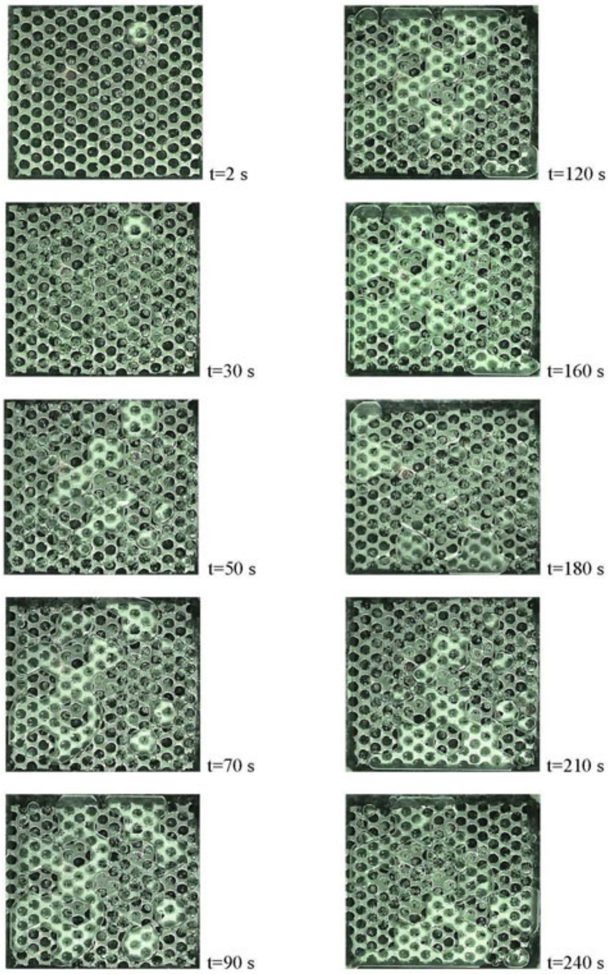

Fig. 5 Time evolution of the CO_2 bubble behavior for the “one-inlet and one-outlet” design

However, it is apparent that many coalesced bubbles still accumulated in the channel between $t = 90$s to $t = 160$s. A fraction of the bubbles were swept out of the channel but another fraction accumulated in the corners between $t = 160$s to 240s. From the CO_2 bubble dynamics shown above, this study indicates that the methanol solution was fed into the flow channel evenly and CO_2 bubbles were effectively pushed out of the channel by the "three-inlet and three-outlet" design. The bubble accumulation and blockage occurred with the "one-inlet and one-outlet" design. The short slug and the effective removal of CO_2 bubbles enlarged the effective contact area between the methanol solution and the porous diffusion layer. For this reason, we conclude that the "three-inlet and three-outlet" of the flow channel is able to overcome the problems of misdistribution of methanol solution and CO_2 bubble accumulation, and thereby, enhance the performance of the fuel cell.

4. CONCLUSIONS

Results showed that multi-inlet/outlet openings of flow channels can enhance the performance of fuel cells. The "three-inlet and three-outlet" of the flow channel enhanced the cell performance by 19%. Flow visualization of the bubble dynamics revealed the processes of emergence from the diffusion layer, growth and coalescence into bigger bubbles, which moved toward the outlet and were swept out of the channel. The methanol solution was fed into the flow channel evenly and the CO_2 bubbles were effectively pushed out of the channel in a short time by the "three- inlet and three-outlet" design. This enlarged the effective contact area between the methanol solution and the porous diffusion layer. Bubble accumulation and blockage occurred with the "one-inlet and one-outlet" design. We conclude that the newly designed multi-opening flow channel is able to enhance the cell performance of the pin type DMFC.

ACKNOWLEDGEMENTS

The authors sincerely acknowledge the financial support from the National Science Council of Taiwan, R.O.C. under the project NSC97–2221-E-032–036.

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(Manuscript received April 28, 2011,
accepted for publication October 19, 2011.)