

Visual study of CO₂ bubble behavior in anode flow field of direct methanol fuel cell at ambient temperature

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This paper reports on a visual study of the CO₂ bubble behavior in the anode flow field of a transparent Direct Methanol Fuel Cell (DMFC) with interdigitated flow field (IFF), working at ambient temperature. In the IFF, the quantity of CO₂ bubbles increased with the increase of current densities. At low current densities, bubble flow appeared in the anode flow field and channel-blocking phenomenon caused by CO₂ gas bubbles was found in the inlet channels; at moderate current densities, a number of gas slugs formed, and then bubbly flow and slug flow coexisted in the flow field; at high current densities, channel-blocking phenomenon also appeared in outlet channels. As the methanol flow rates increased, the amount of the CO₂ bubbles decreased, enhancing the mass transport process of methanol and hence, improved the limiting current. However, higher methanol flow rate led to an increase of methanol crossover and to take away more heat. This eventually, resulted in a deterioration of cell performance.

Keywords: Direct methanol fuel cell; Interdigitated Flow Field; Two-phase flow; ambient temperature

1. Introduction

Direct methanol fuel cells (DMFC) have attracted considerable attention in replacing the battery of portable electronic devices, such as mobile phones, video recorders and laptop computers, due to their high energy densities, low operating temperature, low emission and easy fuel supply [1-5].

Gas management on the anode side is an important issue in DMFC design [6]. Carbon dioxide is produced as a result of methanol electrochemical oxidation at the anode side. If CO₂ bubbles cannot be removed efficiently, the anode channels will be blocked, leading to limited mass transport.

A few papers have reported the studies of the CO₂ evolution and flow behavior in the anode flow field of DMFCs [6-12]. Scott et al. [7, 8] visually

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investigated the CO₂ gas bubble behavior with flow beds based on stainless steel mesh. Yang and Zhao [9, 10] reported a visual study of CO₂ bubbles behavior in a transparent DMFC with single serpentine flow fields and parallel flow fields. The two-phase flow patterns in the anode channel were observed under various operating conditions. Lu and Wang [5] investigated the effects of pore structure and wettability on two-phase flow dynamics. Liao et al. [11] investigated the dynamic behavior of CO₂ gas bubbles in a 9 cm² transparent direct methanol fuel cell (DMFC). A series of parametric studies were carried out to evaluate the effects on the CO₂ gas bubbles dynamics as well as the cell performance. Bewer et al. [12] used an aqueous H₂O₂ solution to simulate two-phase flow in a DMFC.

Based on the literature survey, it is easy to find that many researches are focused on DMFC at the higher temperatures (over 60 °C). However, mobile phones, laptops and other portable electronic products work at ambient temperature about 25 °C. Therefore, studies on the CO₂ bubbles behavior in the DMFCs at ambient temperature have very great significance.

In this paper, a transparent DMFC was constructed to study the CO₂ bubbles behavior in interdigitated flow field using a digital camera. The polarization curves were plotted to provide a fundamental understanding of the relationship between the behavior of CO₂ gas bubbles and the cell performance, under the conditions of the ambient temperature.

2. Experiment

2.1. Single cell fixture

The schematic structure of transparent DMFC was shown in Figure 1.

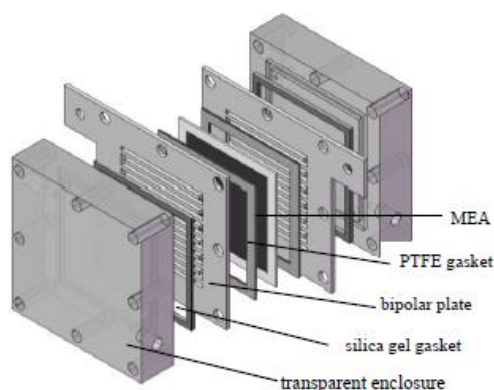


Fig. 1. Schematic structure of DMFC.

As shown in Figure 1, the Membrane and electrode assembly (MEA) which area is 25 cm² was sandwiched between an anode current collector and a cathode current collector. The entire cell was then held together by two fixtures, which were made of the transparent organic glass. The IFF was made of 316 stainless steel plates with a thickness of 1.8 mm, by the wire-cut technology. The detailed geometrical parameters were shown in Table 1.

Table 1. Geometrical parameters of IFF

	Channel width [mm]	Channel depth (mm)	Channel length [mm]	Rid width [mm]	Open ratio [%]
IFF	1.8	1.8	46	1.1	55.1

2.2. Electrochemical performance tests

An Arbin BT2000 electrical load interfaced to a computer was employed to control the condition of discharging and measure the voltage–current curves. A digital camera (SONY DSC-N1) was employed to catch the behaviors of CO₂ gas bubble behavior in the anode.

All the experiments of the DMFCs were performed under the conditions of the ambient temperature of 24 °C-26 °C, the relative humidity of 55%-60 % and a constant oxygen gas flow rate of 100 ml/min.

3. Results and Discussion

3.1. General observation of the CO₂ gas bubble behavior in the IFF

Figure 2 presents the cell polarization behavior and the power output for the case when the cell was oriented vertically and with 2M methanol solution supplied at a flow rate of 2.1 ml/min at ambient temperature. The images of the CO₂ gas bubble behavior in the IFF for selected densities (20, 40 and 80 mA/cm²) have been shown in Figure 3. The three images shown in Figure 3 indicates that the quantity of CO₂ gas bubbles in the IFF increased progressively as the current density increased from 20 to 80 mA/cm². At low current densities (e.g. 20 mA/cm²), it was observed that a rather small number of discrete gas bubbles generated and appeared on the surface of the diffusion layer. Therefore, at low current densities, the two-phase flow pattern can be regarded as bubbly flow. It should be mentioned that water mist appeared in the tail of inlet channels, near outlet pipe, which indicated CO₂ gas bubbles occupied the whole inlet channels.

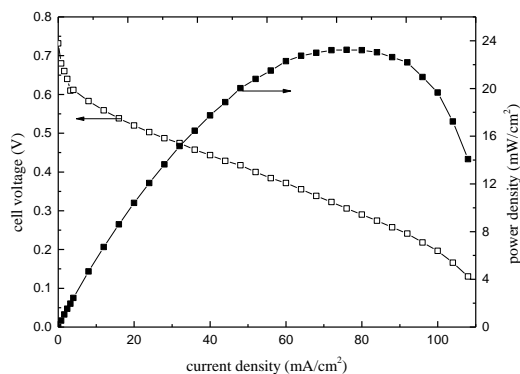


Fig. 2. Cell performance for the DMFC with 2M methanol solution fed at 2.1 ml/min.

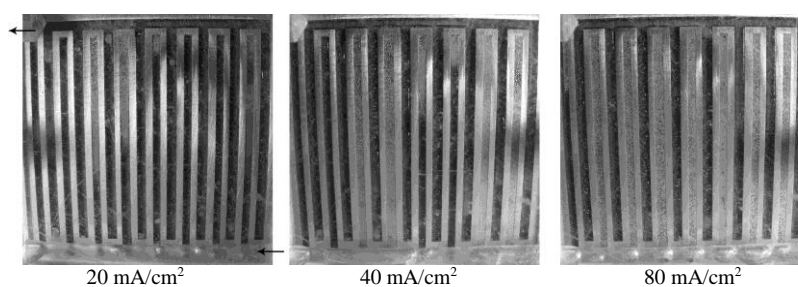


Fig. 3. CO_2 bubble behavior at different current densities in the IFF.

It could be explained as follows. In the IFF, the inlet channel and outlet channel cannot connect directly. The methanol solution from inlet channels to outlet channels must pass through the gas diffusion layer. CO_2 gas bubbles may appear in outlet channels, also appear in inlet channels. CO_2 gas bubbles appeared in outlet channels could be carried out easily. Nevertheless, the discharge of CO_2 gas bubbles in inlet channels would be more difficult for the resistance caused by the gas diffusion layer. As a result, channel-blocking phenomenon caused by CO_2 gas bubbles appeared in the tail of inlet channels. However, at this stage, CO_2 gas bubbles generated were very few for the low current density. Thus, only part of inlet channels found channel-blocking phenomenon caused by CO_2 gas bubbles. With the increase of the current density (e.g. 40 mA/cm^2), some of small spherical bubbles grew up with a fast growth rate and eventually became slug bubbles. Unlike the small spherical bubbles, slug bubbles usually were long and spanned the entire channel cross-section. At the stage, bubbly flow and slug flow coexisted in the flow field. With the further increase of the current density (e.g. 80 mA/cm^2), almost the inlet channels was occupied by water mist. Specially, channel-blocking phenomenon caused by CO_2 gas slugs was also presented in the outlet channels, causing the

effective contact area between the liquid fuel and the gas diffusion layer to be extremely small. Under such a situation, the CO_2 gas bubbles may restrict the continuous supply of methanol through the gas diffusion layer to the catalyst surface, eventually leading to deterioration of cell performance.

3.2. Effect of methanol flow rates

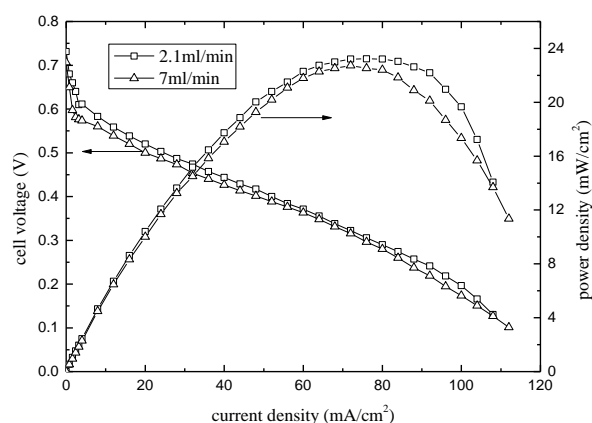


Fig. 4. Effect of methanol flow rates on cell performance.

The effect of the methanol solution flow rates on the cell performance at ambient temperature is shown in Figure 4. The experiments were conducted with 2M methanol solution fed at flow rates of 2.1 and 7 ml/min. It can be seen from Figure 4 that the cell performance became worse as the flow rate increased from 2.1 and 7 ml/min. In general, the impact depends on two opposing effects [14]: As the methanol flow rates increased, more heat was taken away through methanol solution, leading to a lower cell temperature which resulted in a deterioration of cell performance. Also, an increase in the methanol solution flow rate is accompanied by an increase in the static pressure in the flow field. A higher static pressure tends to increase in the methanol crossover from the anode to the cathode, leading to deterioration in the cell performance. However, the supply of methanol solution can be controlled with high methanol solution flow rate, which improve the cell performance. Compared with the negative effect, the positive effect can be ignored. Accordingly, the cell performance became worse as the flow rate increased. It can also be seen from Figure 4 that the cell got a larger limiting current with higher methanol solution flow rate. This can be explained by the representative images of the gas CO_2 bubble behavior for the current density of 80 mA/cm² shown in Figure 5.

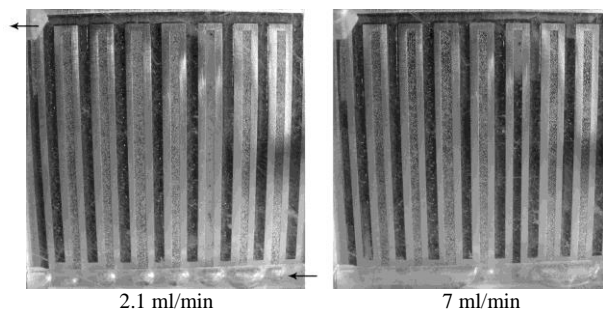


Fig. 5. CO₂ bubble behavior for different methanol flow rates at 80 mA/cm².

As the methanol solution flow rate was increased from 2.1 to 7 ml/min, as shown in Figure 5, the number of gas CO₂ bubble was reduced because of the fact that the sweeping rate of the gas bubbles was increased with the methanol solution flow rate. As a result, an increased effective contact area between liquid methanol and the gas diffusion layer enhanced the mass transfer of methanol and hence, improved the limiting current as seen in Figure 4.

4. Conclusions

A visual investigation of CO₂ gas bubble behavior inside the interdigitated flow field has been performed. The effect of methanol flow rates on the DMFC performance has been investigated experimentally at ambient temperature. The following conclusions may be drawn from the results of the present study:

(i) The quantity of CO₂ bubbles increased with the increase of current densities. At low current densities, bubble flow appeared in the anode flow field and channel-blocking phenomenon caused by CO₂ gas bubbles was found in the inlet channels; at moderate current densities, a number of gas slugs formed, and then bubbly flow and slug flow coexisted in the flow field; at high current densities, channel-blocking phenomenon also appeared in outlet channels.

(ii) As the methanol flow rates increased, the amount of the CO₂ bubbles decreased, enhancing the mass transport process of methanol and hence, improved the limiting current. However, higher methanol flow rate led to an increase of methanol crossover and to take away more heat. This eventually, resulted in a deterioration of cell performance.

References

1. T.S. Zhao, C. Xu, R. Chen, et al. Mass transport phenomena in direct methanol fuel cells. *Prog. Energy Combust. Sci.* 35, 275 (2009).

2. N.K. Shrivastava, S.B. Thombre, R.K. Mallick. Effect of diffusion layer compression on passive DMFC performance. *Electrochim. Acta* 149, 167 (2014).
3. C. Xu, T.S. Zhao. A new flow field design for polymer electrolyte-based fuel cells. *Electrochem. Commun.* 9, 497 (2007).
4. D.S. Falcão, V.B. Oliveira, C.M. Rangel, et al. Review on micro-direct methanol fuel cells. *Renew. Sust. Energy Rev.* 34, 58(2014).
5. G.C. Liu, M. Wang, Y.T. Wang, et al. Anode catalyst layer with novel microstructure for a direct methanol fuel cell. *Int. J. Hydrogen Energy* 37, 8659 (2012).
6. G.Q. Lu, C.Y. Wang. Electrochemical and flow characterization of a direct methanol fuel cell. *J. Power Sources* 134, 33 (2004).
7. K. Scott, W.M. Taama, P. Argyropoulos. Material aspects of the liquid feed direct methanol fuel cell. *J. Appl. Electrochem.* 28, 1389(1998).
8. P. Argyropoulos, K. Scott, W.M. Taama. Gas evolution and power performance in Direct Methanol Fuel Cells. *J. Appl. Electrochem.* 29, 661(1999).
9. H. Yang, T.S. Zhao. In situ visualization study of CO₂ gas bubble behavior in DMFC anode flow fields. *J. Power Sources* 139, 79 (2005).
10. H. Yang, T.S. Zhao. Effect of anode flow field design on the performance of liquid feed direct methanol fuel cells. *Electrochim. Acta* 50, 3243(2005).
11. Q. Liao, X. Zhu, X.Y. Zheng, et al. Visualization study on the dynamics of CO₂ bubbles in anode channels and performance of a DMFC. *J. Power Sources* 171, 644 (2007).
12. T. Bewer, T. Beckmann, H. Dohle. Novel method for investigation of two-phase flow in liquid feed direct methanol fuel cells using an aqueous H₂O₂ solution. *J. Power Sources* 125, 1 (2004).
13. G.B. Jung, A. Su, C.H. Tu, et al. Effects of cathode flow fields on direct methanol fuel cell-simulation study. *J. Power Sources* 171, 212 (2007).
14. V.B. Oliveira, C.M. Rangel, A.M.F.R. Pinto. Effect of anode and cathode flow field design on the performance of a direct methanol fuel cell. *Chem. Eng. J.* 157, 174(2010).