Pressure drop behavior in the anode flow field of liquid feed direct methanol fuel cells

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Abstract

In this work, we experimentally investigated the two-phase flow pressure drop behavior in the anode flow field of an in-house fabricated direct methanol fuel cell (DMFC). The anode flow field consisted of a single serpentine flow channel with a cross-sectional area of $2.0 \times 2.0 \, mm^2$ and a total length of 420 mm. The pressure drops between the inlet and the outlet of the flow channel were measured by varying current density. The experimental results show that at low current densities, the pressure drop increased with increasing current density. After reaching a peak at certain current density, however, the pressure drop began to decrease with increasing current density. It has also been shown that the pressure drop always increased with the methanol solution flow rate. However, either lower or higher flow rates deteriorated the cell performance. The experimental results further show that the pressure drop became almost independent of the current density when the methanol solution flow rate became sufficiently high. The study also reveals that both temperature and methanol concentration had significant influence on the cell performance, but their effects on the pressure drop were small.
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Keywords: Direct methanol fuel cells; Serpentine channel; Two-phase flow; Pressure drop

1. Introduction

As compared with conventional hydrogen feed PEM fuel cells, a liquid feed direct methanol fuel cell (DMFC), using a solid polymer membrane as electrolyte and liquid methanol as fuel, offers some unique advantages, including lower system volume and weight, simpler system design, simpler mode of operation with fast response and better dynamics as well as lower investment and operating costs [1–5]. Thus, it has been projected as a promising power source for portable electronic devices, electric vehicles, and other mobile and stationery applications. Driven by these needs, there has been strong effort from university researchers and industry engineers all over the world to focus on the research and development of DMFCs. Most of the previous studies have been focused on the electrochemical aspects of DMFCs, such as the improvement

of the electro-activity of methanol oxidation on anode by exploring more active electro-catalysts [6–9], the optimization cathode electrode structures to avoid severe flooding [10–12], and reduction of the substantial methanol crossover by modifying existing polymer membranes or searching for alternatives [13–20]. However, relatively few papers have been reported on the study of the flow dynamics aspect in the anode flow field. One of the problems in this aspect is the pressure drop behavior in the flow field, which is needed to size a proper pump for the auxiliary fuel supply system. Clearly, a reduction in the pumping power consumed for the fuel supply system increases the overall DMFC system efficiency. Therefore, the study of the pressure drop behavior in the anode flow field is essential for the design and optimization of a DMFC system.

In the DMFC, methanol solution is fed into the anode flow field and diffuses to the catalyst sites through the gas diffusion layer, while the reaction-produced gas CO_2 at the catalyst layer transport backward into the anode channels through the

gas diffusion layer. Therefore, a liquid–gas two-phase flow, consisting of methanol solution and reaction-produced gas CO_2, exists in the anode flow field under typical DMFC operating conditions. In general, the total pressure drop of a two-phase flow consists of frictional, acceleration and gravitational components [21,22]. The two-phase flow in the anode flow field of a DMFC is different from the conventional co-current liquid–gas two-phase flow in a channel with gas and liquid uniformly entering from one of its ends. In the DMFC, liquid methanol solution is fed to the inlet of the flow field, while gas CO_2 enters the flow channel from the diffusion layer. In such a special two-phase flow system, the increase in void fraction of gas CO_2 with channel length leads to not only an increase in the liquid velocity [23], but also an increase in the average specific volume of two-phase fluid along the flow channel. The increased two-phase flow velocity causes the frictional pressure drop to increase, while the increased average specific volume leads to an increase in the acceleration pressure drop. On the other hand, however, the increase in void fraction of gas CO_2 also decreases the average density of two-phase fluid in the flow field, causing the gravitational pressure drop to decrease. Clearly, the total pressure drop behavior is affected by void fraction of gas CO_2 in the flow channel, i.e. the amount of gas CO_2 generated during fuel cell operation, which is directly related to the cell current density.

It appears that the only studies related to the pressure drop behavior in the anode flow field of a DMFC are due to Argyropoulos et al. [24,25]. They developed a pressure drop model for a DMFC consisting of a parallel flow field based on the homogenous two-phase flow theory, with which, they analyzed the effects of various operation parameters on the pressure drop behavior.

In this paper, we report on in situ measurements of the pressure drop across the anode flow field of a DMFC consisting of a single serpentine flow channel. We show how the pressure drop varied when current density was increased. We have also investigated the effects of various operation parameters, including methanol solution flow rates, cell operating temperatures and methanol concentrations, on the pressure drops and cell performance.

2. Experimental

2.1. Transparent DMFC

A transparent DMFC was designed and fabricated for this study, as schematically shown in Fig. 1. The membrane electrode assembly (MEA), detailed in the subsequent paragraph, was sandwiched between two flow field plates with a PTFE gasket onto either side of the MEA. This assembly, including the flow field plates and the MEA, was clamped between the two enclosure plates by eight M8 screw joints, each having a torque of about 3 N m. As can also be seen from Fig. 1, in addition to two pieces of PTFE gasket, two rubber gaskets
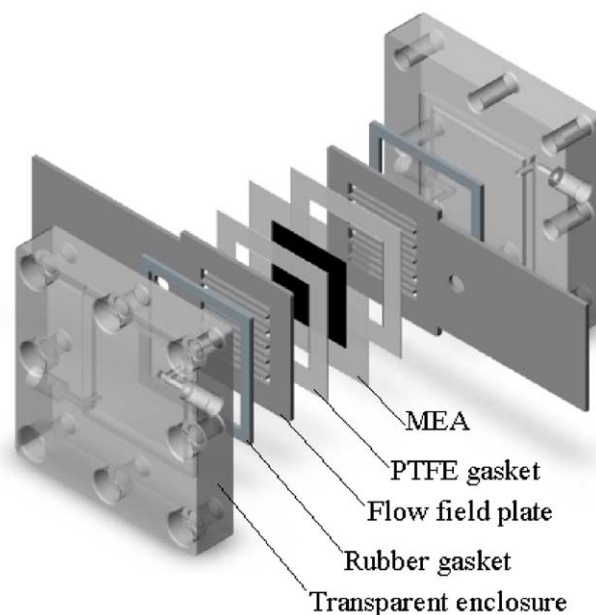

Fig. 1. In-house fabricated DMFC.

were employed between the flow field plates and enclosure plates to prevent leakage of fuel and oxidant.

The MEA, fabricated in this work, had an active area of $4.0 \times 4.0\,cm^2$ and consisted of two single-side ELAT electrodes from E-TEK and a Nafion® membrane 115. Both anode and cathode electrodes used carbon cloth (E-TEK, Type 'A') as the backing support layer with 30% PTFE wet-proofing treatment. The catalyst loading on the anode side was $4.0\,mg\,cm^{-2}$ with unsupported [Pt:Ru] Ox (1:1 a/o), while the catalyst loading on the cathode side was $2.0\,mg\,cm^{-2}$ using 40% Pt on Vulcan XC-72. Furthermore, $0.8\,mg\,cm^{-2}$ Nafion® was applied onto the surface of each electrode. The Nafion® membrane 115, before being used, was first cleaned following a standard procedure, i.e.: (i) boiling membrane in 5 wt.% H_2O_2 solution of 80 °C for 1 h; (ii) rinsing with DI water of 80 °C for 1 h; (iii) boiling membrane in 0.5 M H_2SO_4 solution of 80 °C for 1 h; and (iv) rinsing with DI water of 80 °C for 1 h. Finally, the MEA was formed by hot pressing at 135 °C and 5 MPa for 3 min.

To avoid corrosion, the flow field plates, shown in Fig. 2, were made of 316 stainless steel [26–29] plates with a thickness of 2.0 mm. As can be seen in Fig. 2, the rectangular flow field plate consisted of two portions, the channel area and
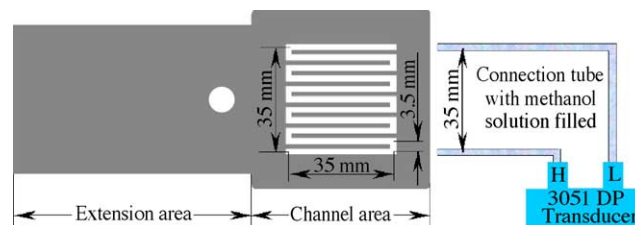

Fig. 2. Flow field plate and differential pressure transducer connection.