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Short communication

Efficient water recirculation for portable direct methanol fuel cells using electroosmotic pumps

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HIGHLIGHTS

► Demonstration of DMFCs integrated with three electroosmotic pumps.
► Efficient water recirculation in air-breathing DMFCs with electroosmotic pumps.
► Significantly low parasitic power ratio of 2.1% for 4 M methanol solution.

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ABSTRACT

We present an efficient water recirculation method for air-breathing direct methanol fuel cells (DMFC) by utilizing so-called electroosmotic (EO) pumps. The fuel management system includes three EO pumps for the delivery of methanol solution, pure methanol, and pure water, respectively. Water recirculates from the fuel cell back to the fuel supply stream with the aid of these pump systems. We characterized the performance of the air-breathing DMFC for 2 M and 4 M methanol solutions using a syringe pump and EO pumps, respectively. The DMFC performance is similar for both types of pumps as long as the EO pump operates with the applied voltage of 6 V or higher. The maximum net power density (fuel cell power generation minus pump power consumption) was 50 mW cm^{-2} for 2 M methanol solution and the applied pump potential of 8 V. The minimum parasitic power ratio (pump power consumption divided by fuel cell power generation) was merely 2.1% for 4 M methanol solution and the applied pump potential of 6 V. We successfully demonstrated that the air-breathing DMFC integrated with the EO pumps operated in a stable condition in 1-h galvanostatic measurement.

1. Introduction

Direct methanol fuel cells (DMFCs) are regarded as a promising contender to replace the current battery technology because they offer multiple advantages such as instant recharging (i.e. injecting methanol), high energy density, and simple structure with no moving part [1–7]. Many companies including MTI micro fuel cells, Toshiba, and Samsung advanced institute of technology (SAIT) have developed DMFCs for the application of portable electronic devices [8–10]. There are however still some issues in the commercialization of DMFCs, e.g. their high system cost, low fuel conversion efficiency, and power loss due to methanol crossover [11,12].

Methanol crossover, a permeation of methanol through a membrane, has been identified as an important problem of DMFCs. Numerous studies have been conducted for solving this problem [13,14]. The proposed solutions can be divided into three types: (1) the modification of membranes to reduce methanol crossover [15–17], (2) the development of highly active catalysts [13,18–21], and (3) the use of diluted methanol solutions (1–2 M in active fuel supply and 3–5 M in passive fuel supply) [22–24]. The use of diluted methanol solutions especially has been identified as a common solution to the methanol crossover because of simplicity and compatibility with pre-existing systems. The technique typically includes water recirculation: pure methanol is pumped from the fuel storage, pure methanol is diluted with water, diluted methanol is supplied to a fuel cell, only methanol is used up in the fuel cell, and the leftover water from the fuel cell is re-circulated for methanol dilution. This way, energy density can be increased by storing only pure methanol instead of diluted methanol. The key to this type of system is thus efficient fuel management so that leftover water can be supplied without loss and the flow rate is controlled to maintain the methanol concentration. Recently, various fuel management methods for DMFCs were reviewed by Zhao et al. [25].

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Nomenclature

A	cross-sectional area (m^2)
L	thickness (m)
P	power (W)
Q	flow rate (ml min^{-1})
V_{app}	applied voltage (V)
ε	permittivity of liquid (F m^{-1})
μ	viscosity (Pa s)
σ_∞	ionic conductivity (S m^{-1})
τ	tortuosity (–)
ψ	porosity (–)
ζ	zeta potential (V)

Micropumps that can precisely control flow rate are needed for the fuel delivery or fuel management of portable DMFCs [26–28]. Electroosmotic (EO) pumps are micropumps based on electroosmosis. Electroosmosis refers to the bulk motion of an electrolyte, caused by Coulombic interaction of external electric fields with the charges of a so-called electric double layer (EDL). EO pumps are suitable for DMFC applications because they generate high flow rate and pressure in a small volume and it is easy to control the flow rate by adjusting the voltage [29–35]. One advantage of EO pump-DMFC integration is the removal of electrolysis-originated bubbles (one weakness of EO pumps) simultaneously with carbon dioxide generated by methanol oxidation in DMFCs. Buie et al. recently demonstrated that an EO pump can efficiently deliver diluted methanol solutions (2–8 M) to an air-breathing DMFC [36]. They found that the EO pump consumed only 5% of DMFC power to supply fuel to the DMFC.

In our previous work, we demonstrated that EO pumps can deliver pure methanol and pure water as well as methanol solutions [37]. This suggests a potential application of our EO pumps for water recirculation in DMFCs. In this work, we report an efficient water recirculation scheme for fuel management of the air-breathing DMFC by utilizing three EO pumps.

2. Experimental

The fuel cell we used was an air-breathing fuel cell with the cathode open to the atmosphere. The cathode current collector was in a rib shape with 50% open ratio. The anode flow field has a single serpentine pattern, with the width of 1 mm and the depth of 0.5 mm. A serpentine channel is considered as an appropriate structure for removing carbon dioxide generated at the anode [36]. The anode current collector was fabricated by gold-plated stainless steel. We used a membrane electrolyte assembly (MEA) with the surface active area of 1.4 cm by 1.4 cm (12D-W, BASF). The silicone gaskets with a 0.2 mm thickness were located both at the anode and cathode sides of the MEA. The pure platinum mesh (LS363232, Goodfellow, wire diameter of 0.06 mm) was inserted between the gas diffusion layer (GDL) and the cathode current collector to reduce Ohmic loss. We assembled all these components with bolts and nuts and the tightening pressure was 2 N m, an optimal value found for our setup.

Fig. 1 shows the schematic of the DMFC integrated with the fuel management module (i.e. three EO pumps). We characterized the

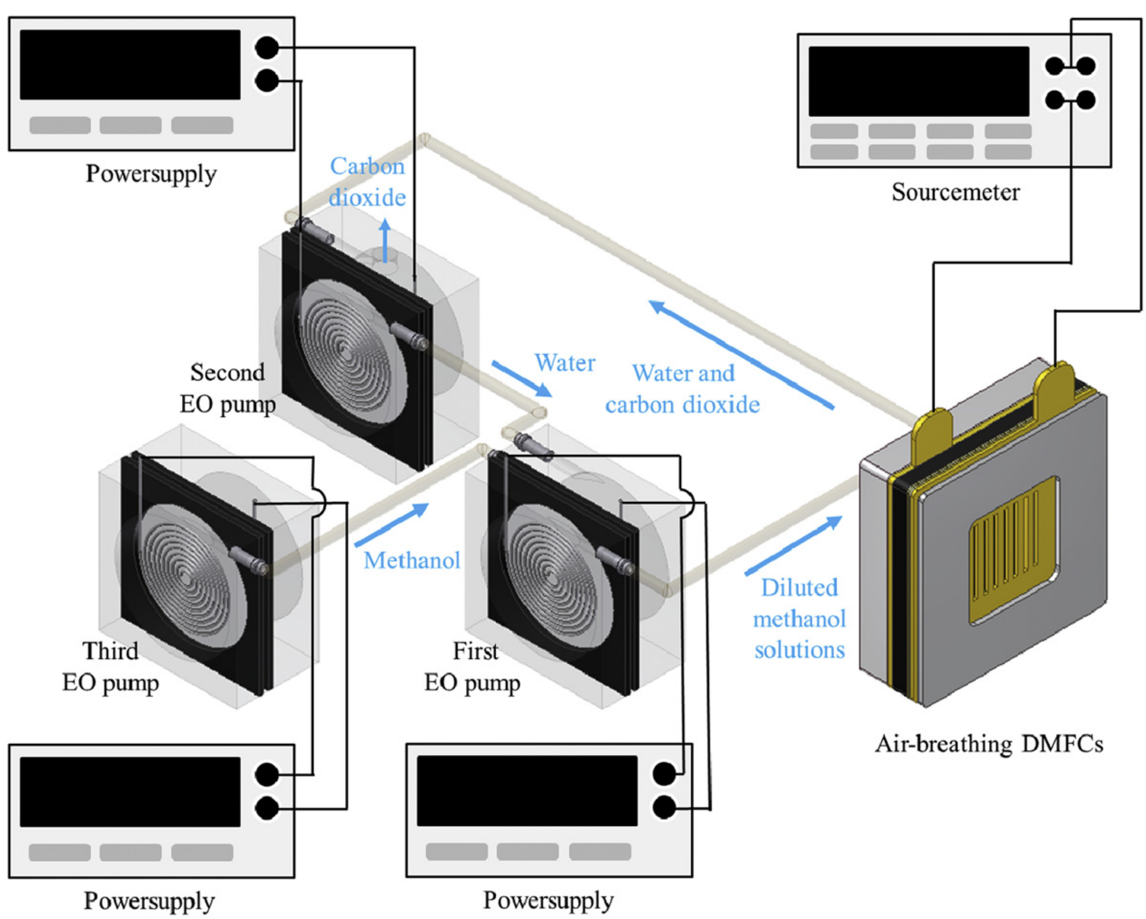

Fig. 1. Schematic of the experimental setup including an air-breathing DMFC, a sourcemeter, three EO pumps, three power supplies, and three multimeters (not shown).