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Short communication

The use of cloth fabric diffusion layers for scalable microbial fuel cells

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ABSTRACT

A scalable and pre-manufactured cloth material (Goretex® fabric) was used as a diffusion layer (DL) material as a replacement for a liquid-applied polytetrafluoroethylene (PTFE) DL. Cathodes with the Goretex fabric heat-bonded to the air-side of carbon cloth cathode (CC-Goretex) produced a maximum power density of $1330 \pm 30\ mW/m^2$, similar to that using a PTFE DL ($1390 \pm 70\ mW/m^2$, CC-PTFE). This method was also successfully used to produce cathodes made of inexpensive carbon mesh, which resulted in only slightly less power ($1180 \pm 10\ mW/m^2$) (CM-Goretex). Coulombic efficiencies were a function of current density, with the highest value for CC-PTFE cathodes (63%), similar to CC-Goretex cathodes (61%), and slightly larger than that obtained for the CM-Goretex cathodes (54%). These results show that a commercially available fabric can easily be used as the DL in an MFC, achieving performance similar to that obtained with a more labor-intensive process based on liquid-applied DLs using PTFE.

1. Introduction

Microbial fuel cells (MFCs) represent a promising renewable energy-production technology using microbes to produce current from organic compounds [1,2]. Although great progress has been achieved in the performance of a MFC in the past ten years [3–5], one of the main challenges for commercializing MFCs is the scalable application of electrode materials, particularly the cathode. Many different electron acceptors have been used for the cathode, such as oxygen [3], ferric iron [6], manganese [7], and even organic molecules such as nitrobenzene [8]. However, oxygen is the most useful electron acceptor for the MFC due to its relatively high oxidation potential, availability, and sustainability [9]. Therefore, single-chamber air-cathodes are likely to be used for practical MFC applications.

Air cathodes are usually made by coating a catalyst (typically Pt) held with a binder on the water-facing side of the electrode, and using several layers of polytetrafluoroethylene (PTFE) as diffusion layers (DLs) on the air-side of the cathode to reduce oxygen transfer and limit water losses [2]. Other DLs have recently been developed, such as polydimethylsiloxane (PDMS) mixed with carbon black, as it is less expensive than PTFE. It was shown that this PDMS DL could achieve performance similar to a PTFE DL with a cathode made with a stainless steel current collector [10]. While both of these methods are useful, they require multiple applications of materials, and uneven applications of the DL solution could lead to leakage of water through the cathode. Anion and cation exchange membranes have also been used on the water side both as a method of ion exchange and to minimize water losses through the cathode [11]. However, maximum power densities produced with membranes used on the water side have generally been lower compared to systems where the membrane is omitted [3,11].

It was hypothesized that a simpler approach for making a diffusion layer would be to bond a separate cloth layer on the outside of the cathode using a water impermeable fabric. Goretex was an excellent material for testing this idea because it is waterproof, permeable to oxygen, and commercially available in large sheets [12]. This fabric consists of a membrane made of expanded PTFE, and a cloth layer. Based on the manufacturer's data, there are more than 1.4×10^9 pores per cm^2 of Goretex cloth. This makes it ideal for MFC applications due to its large number of pores and ability to hold water. Zhuang et al. [12] coated the Goretex fabric directly with a catalyst to make a cathode, but the internal resistance of the cathode was relatively high because Goretex is not an electrically conductive material. As a result, the maximum power density was very low ($25\ mW/m^2$). Gortex was examined as a DL in a previous study, but it was just pressed against the cathode using plastic mesh, resulting in poor performance relative to PTFE or PDMS DLs, and thus suggesting it would not work well as a DL [13]. However, it was likely that this poor performance was due to water trapped between the cathode and the cloth, which could have reduced oxygen transfer into the cathode as well as produced an unfavorable

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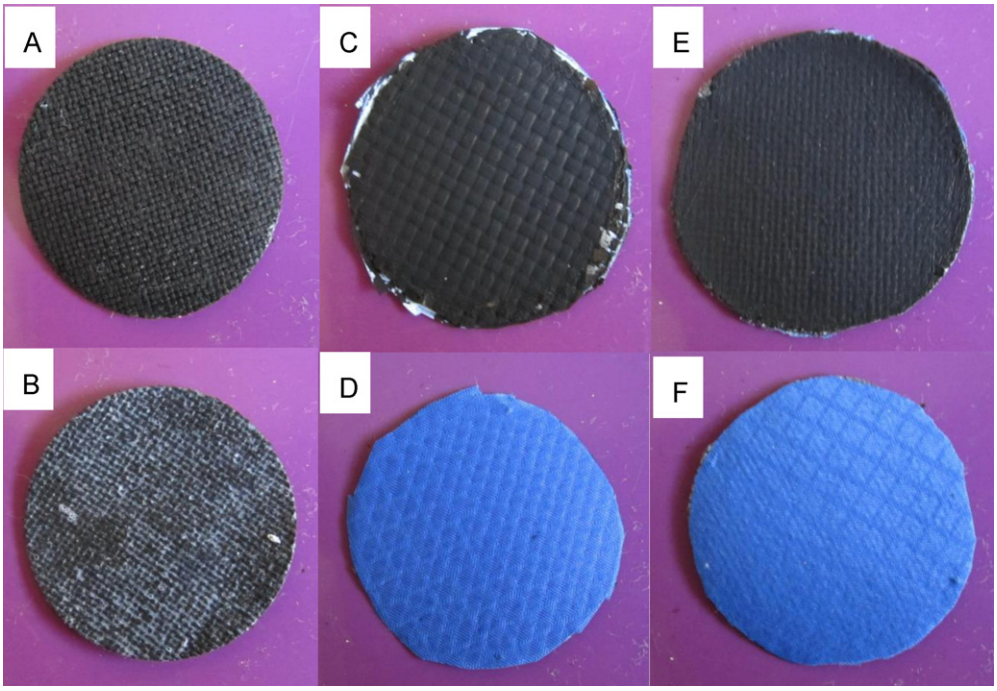

Fig. 1. Pictures of CC-PTFE cathode (A and B), CM-Goretex cathode (C and D) and CC-Goretex cathode (E and F) used in this study (A, C and E: water-facing side; B, D and F: air-facing side).

localized pH. To overcome this problem of trapped water between the materials, we examined here the use of this cloth when it was hot-pressed onto the air-side of two different materials: carbon mesh and carbon cloth. Hot-pressing ensures that there is no trapped water. This general approach of adding a DL could be used with other less expensive materials, which would greatly simplify MFC cathode construction.

2. Materials and methods

2.1. Cathodes fabrication

Carbon cloth cathodes with PTFE DLs (CC-PTFE) were made by applying a platinum catalyst layer (0.5 mg/cm^2) to the water-facing side of the cloth (Type B, 30% wet proofing, BASF Fuel Cell, Inc., NJ) (Fig. 1A), and applying four diffusion layers of PTFE to the air facing side as previously described [3] (Fig. 1B). Carbon mesh cathodes (Gaojieshi Graphite Products Co. Ltd., Fujian, China) were prepared by immersing the material in a PTFE solution (30%) for 45 min, air-drying the material for 30 min in an oven (80 °C), and then heating it for 30 min at 370 °C [13]. To make cathodes, the Goretex fabric (Rockywoods Fabrics, LLC, USA) was hot-pressed (8000 Pa, 150 °C; Hydraulic Lenit model, Carver, Inc.) (Fig. 1D and F) to the carbon cathode. Following this process, a Pt catalyst (0.5 mg/cm^2) was applied using a Nafion binder to the other side of the cathodes (water-facing side) (Fig. 1C and E). Thus, the Goretex served as a DL. These cathodes are much different than those previously made by others because in that study the cathode was made of Goretex fabric and no carbon cloth materials were used [12].

2.2. MFC reactors and operation

Single-chamber, air-cathode MFCs (4-cm long cylindrical chamber; liquid volume 24 mL) were constructed as previously described [3]. Anodes were carbon fiber brushes (25 mm diameter × 25 mm length; fiber type PANEX 33 160K, ZOLTEK), and all anodes were heat treated for 30 min at 450 °C before use [5]. All reactors were inoculated using the effluent from an MFC operated for over one year. Sodium acetate (1.0 g/L) was used as an energy source in a nutrient solution containing (in 1 L deionized water): 4.576 g Na_2HPO_4, 2.544 g NaH_2PO_4, 0.31 g NH_4Cl, 0.13 g KCl, and 12.5 mL of a trace metal solution and 5 mL of a vitamin solution (pH 7.1; conductivity 7.01 mS/cm) [14]. The solution was replaced when the voltage decreased to <20 mV (1000 Ω fixed external resistance). All reactors were operated in fed-batch mode in a temperature-controlled room (30 °C).

2.3. Calculations and measurements

Voltages were measured every 20 min across an external resistor (1000 Ω) using a data acquisition system (2700, Keithley Instrument, OH). Chemical oxygen demand (COD) was measured using standard methods [high range (20–1500 mg/L); HACH COD system (Hach Co., Loveland, CO)] [15]. COD removal (%) was calculated based on the initial and final COD [16]. The Coulombic efficiency (CE) was calculated as previously described with the current and power density normalized by the cathode projected surface area (7 cm^2) [9]. Maximum power densities (normalized to the projected cathode surface area) were obtained from polarization curves using different resistances (1000–20 Ω), with 20 min intervals at each resistance (single cycle method) [17].

Linear sweep voltammetry (LSV) was used to evaluate the electrochemical performances of the cathodes with a potentiostat (PC4/750, Gamry Instrument). Cathodes were placed in an air-cathode electrochemical cell consisting of a working electrode (cathode, 7 cm^2 projected surface area facing air on one side and water on the other side), an Ag/AgCl reference electrode (RE-5B; BASi, West Lafayette, IN), and a Pt counter electrode [18]. LSV tests were conducted over a range of −0.311 to +0.289 V, at a slow scan rate of 0.1 mV/s. All electrochemical measurements were performed with freshly made cathodes (prior to MFC tests). All potentials were reported vs. Ag/AgCl.