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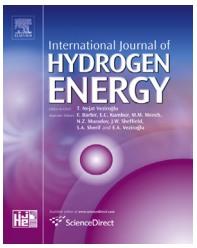

Performance of a low-cost direct glucose fuel cell with an anion-exchange membrane

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ABSTRACT

This paper reports on the use of renewable carbohydrate as a high-density energy source for electricity production under low temperatures. We have developed a two-chamber glucose alkaline fuel cell with a low-cost anion-exchange membrane. Methyl viologen (MV) and nickel foam were used as electrocatalyst for glucose oxidation reaction at the anode. Effects of various experimental parameters on the fuel-cell performance were investigated. The fuel cell achieved the maximum power density of 5.20 W m^{-2} at 15 mM MV, 3 M KOH, 1 M glucose, and 25 °C. The performance can be improved further by increasing operational temperature and concentrations of MV, KOH, and glucose. HPLC results show the main oxidation products are short-chain aliphatic carboxylic acids. Specific discharge capacity of glucose reached 153.58 ± 17.49 mAh g^{-1} in the fuel cell with AEM, which was 1.81-fold higher than without AEM.

Introduction

With an increasing energy demand and growing environmental concerns, the development of new energy sources becomes increasingly urgent [1–10]. Glucose, the most abundant monosaccharide in nature, is capable of releasing 2.87 MJ mol^{-1} energy on complete oxidation to CO_2 via 24-electron transfer [11,12]. Studies on glucose fuel cell are of high interest to the fuel cell community for various reasons. Firstly, glucose is easily available, cheap, non-toxic and safe bio-fuel. Secondly, no storing problem or explosion hazard is associated like hydrogen in hydrogen–oxygen fuel cell.

Extensive efforts have been made to study glucose as fuel for direct fuel cell, enzymatic fuel cell and microbial fuel cell (MFC). However, up to the present time, only very low electrical power production has been reported. There are three major problems have impeded their development: 1) the high cost and low availability of the noble metals and metallic components used as catalysts, which forms economic barriers to their use; 2) incomplete fuel oxidation limits overall power production, and 3) poisoning of the metallic catalyst by-products of carbohydrate oxidation, which terminates catalyst function [13–15]. Direct glucose alkaline fuel cells (AFCs), in which glucose is oxidized at alkaline conditions are considered as a promising power sources for portable electronic equipment [16–18]. In comparison to acid fuel cell systems, the alkaline media enables significant higher fuel utilization and the use of platinum free electrocatalysts and

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cost efficient materials for the cell constructions [19–21]. Reactions 1–3 show the fuel-cell reactions for glucose and oxygen at alkaline conditions (pH 12).

$$\text{Anodic reaction}: \quad C_6H_{12}O_6 + 36OH^- \rightarrow 6CO_3^{2-} + 24H_2O + 24e^- \tag{1}$$

$$\text{Cathodic reaction}: \quad 6O_2 + 24e^- + 12H_2O \rightarrow 24OH^- \tag{2}$$

$$\text{Overall reaction}: \quad C_6H_{12}O_6 + 6O_2 + 12OH^- \rightarrow 6CO_3^{2-} + 12H_2O \tag{3}$$

Theoretically, the number of electrons to be exchanged is 24. However, the maximum number of extracted electrons per glucose molecule has been shown to be less than two [22]. As the supposed oxidation pathways and reaction intermediates show that the oxidation of glucose mainly leads to the production of gluconic acid [23–25]. Furthermore, in one-compartment fuel cells, the substrate crossover leads to a reduced potential at the electrodes and a lowering of the overall fuel cell voltage, with a consequential lowering of cell efficiencies. Anion-Exchange Membrane (AEM) has been reported to work effectively in methanol AFCs with substantial ionic and electronic conductivities [26,27]. AEMs are usually low-cost compared to their counterparts of perfluorinated sulfonic polymers, which are widely used in neutral/acid fuel cells. In an earlier report, a one-compartment direct glucose AFC has been developed that use methyl viologen (MV) as electron mediator and nickel foam as the anode. The rudimentary fuel cell generates a maximum power density of 6.2 W m^{-2} [28]. In this work, a direct glucose AFC with low-cost AEM was developed and tested. The effects of various experimental parameters on the fuel-cell performance were investigated. Moreover, specific discharge capacities of glucose of the cell were compared between the fuel cells with and without AEM.

Experiments

Materials

Methyl viologen (MV) was purchased from J&K Scientific Ltd (Beijing, China). Carbon cloth (HCP330), 60% by weight PTFE solution, 10% by weight platinum on carbon powder (10% Pt on Vulcan XC-72), 5% by weight Nafion® solution were all purchased from Heshen Inc. (Shanghai, China), carbon black powder (Cabot Vulcan XC-72) was purchased from Cabot Co. Ltd (Tianjin, China). AEM (ED120, thickness: 0.48 mm, resistance of membrane surface: 18 Ω cm^2) was purchased from Chiaki Environmental Water Treatment Co. Ltd (Zhejiang, China). The AEM contains positive ionic groups (poly–CH_2–$N^+(CH_3)_3$) and mobile negatively charged anions (OH^-). It has selective conductivity of anions and can prevent crossover of fuel and oxidant to the cathode electrode and the anode electrode, respectively. The nickel foam was purchased from HANBO Co. Ltd (Shenzhen, China) (purity: 99.9%, number of pores per inch: 110, density: 380 g m^{-2}, average pore size: 590 μm, thickness: 1.7 mm). KOH and glucose were all of analytical grade. All solutions were prepared using deionized water.

Fuel cell apparatus and assembly

Our two-chamber fuel cell is made from polymethylmethacrylate (PMMA). A schematic of its structure is shown in Fig. 1. The fuel cell is composed of a nickel foam anode, an air-breathing carbon-cloth cathode, an AEM and two cylindrical internal chambers with a volume of 12 mL each. A silver/silver chloride electrode was used as the reference electrode. The three-layer air-breathing cathode was prepared as previously described [29].

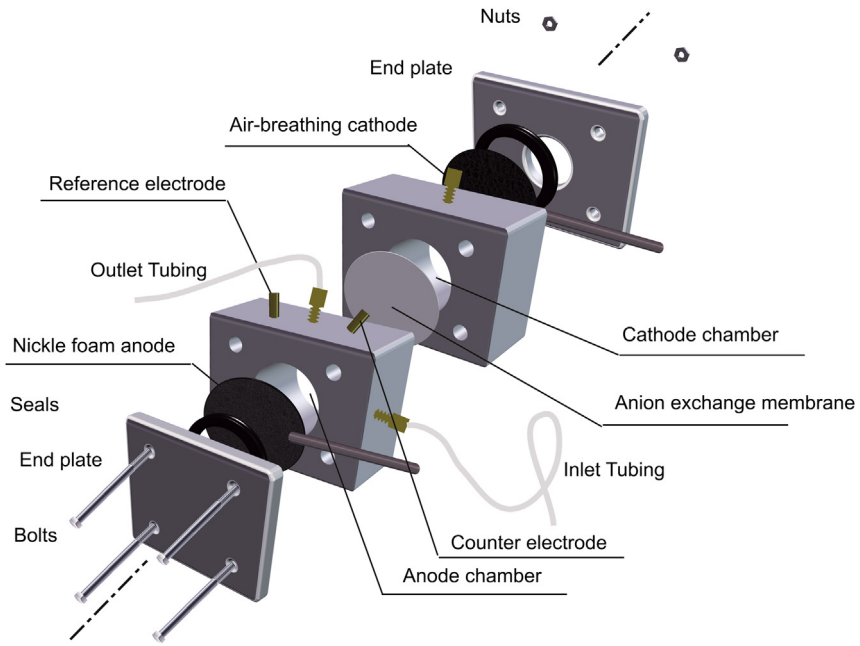

Fig. 1 – Schematic of the structure of two-compartment direct glucose AFC.

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