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Performance of an alkaline direct ethanol fuel cell with hydrogen peroxide as oxidant



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ABSTRACT

An alkaline direct ethanol fuel cell (DEFC) with hydrogen peroxide as the oxidant is developed and tested. The present fuel cell consists of a non-platinum anode, an anion exchange membrane, and a non-platinum cathode. It is demonstrated that the peak power density of the fuel cell is 130 mW cm^{-2} at 60°C (160 mW cm^{-2} at 80°C), which is 44% higher than that of the same fuel cell setup but with oxygen as the oxidant. The improved performance as compared with the fuel cell with oxygen as the oxidant is mainly attributed to the superior electrochemical kinetics of the hydrogen peroxide reduction reaction and the reduced ohmic loss associated with the liquid oxidant.

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1. Introduction

Alkaline direct oxidation fuel cells (DOFC) running on various liquid fuels, which promise to be a clean and efficient energy production technology, have recently attracted worldwide attention [1–5]. Among the fuels used, ethanol has been recognized as the most ideal fuel as it is a carbon-neutral, sustainable fuel and possesses many unique physicochemical properties including high energy density and ease of transportation, storage as well as handling. Hence, tremendous efforts have been made to the development of alkaline direct ethanol fuel cells (DEFC) over the past decade [6–10]. However, one of the major issues that hinder the commercialization of this type of fuel cell is the carbonation problem

associated with the presence of CO_2 at the cathode when air is used as the oxidant [11]. On one hand, the carbonate (CO_3^{2-}), which is produced by the chemical reaction between CO_2 in the air and OH^- ions at the cathode, can lead to a decrease in the ionic conductivities of both the membrane and cathode catalyst layer (CL), thereby increasing the charge transport resistance [12]. It should be noted that as an alkali is added into the ethanol solution, OH^- ions also comes from the anode (alkali crossover) in addition to that generated by the oxygen reduction reaction (ORR) [13]. On the other hand, the alkali permeated from the anode causes the carbonation precipitation at the cathode, which not only covers the active sites and even blocks the pores of the electrode, lowering the ORR kinetics and increasing the mass transport resistance of oxygen, respectively [14], but also reduces the hydrophobicity of the

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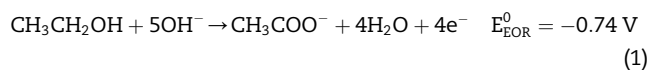
electrode, lowering the capability of water removal and thus increasing the mass transport resistance of oxygen [15]. Therefore, it is essential to avoid the presence of CO_2 at the cathode of alkaline DEFCs. An approach is to include an air filter outside of the cathode, separating CO_2 from the air, with which the CO_2 -free air can be fed into the cathode. However, the idea of including an air filter will not only make the fuel cell system more bulky, but also increase the design complexity.

Recently, instead of using oxygen as the oxidant, the use of hydrogen peroxide (H_2O_2) as the oxidant has received ever-increasing attention [16–18], primarily for the following reasons associated with unique characteristics of liquid H_2O_2 : 1) fuel cells that use hydrogen peroxide can operate with the absence of oxygen environment, such as outer space and underwater conditions [19]; 2) the use of hydrogen peroxide as an oxidizer can substantially increase the fuel cell theoretical voltage, thus improving performance [20]; 3) hydrogen peroxide offers the low activation loss of the reduction reaction due to two-electron transfer [21]. It is noticed that significant efforts have been made to the development of H_2O_2 -based fuel cells [22–25].

In this work, we proposed an alkaline DEFC with hydrogen peroxide as the oxidant. The fuel cell consists of a non-platinum anode, an anion exchange membrane (AEM), and a non-platinum cathode. We demonstrated that the present fuel cell not only avoids the carbonation problem encountered in alkaline fuel cells with oxygen as the oxidant, but also yields a peak power density of as high as 130 mW cm^{-2} at 60°C .

2. Working principle

As shown in Fig. 1, the alkaline DEFC with H_2O_2 as the oxidant is composed of an anode electrode, an AEM and a cathode electrode. On the anode, ethanol reacts with OH^- ions to produce acetate, water, and electrons according to [13]:



The produced electrons pass through an external electrical load and arrive at the cathode. On the cathode, H_2O_2 is first

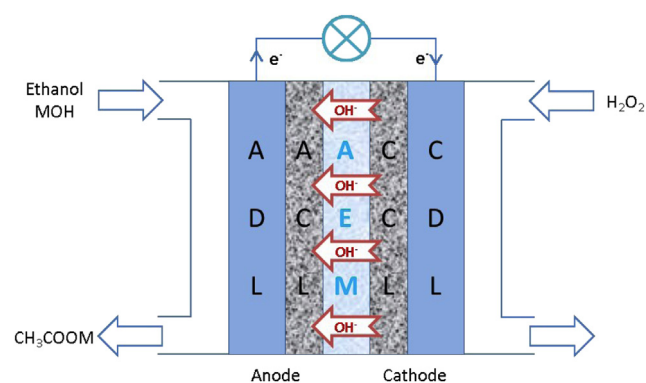


Fig. 1 – Schematic of the alkaline DEFC with H_2O_2 as the oxidant.

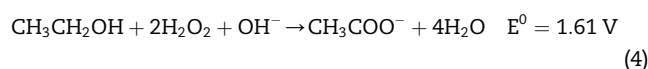
converted into HO_2^- by combining the OH^- ion according to [26]:



Then, the hydrogen peroxide reduction reaction (HPRR) at the cathode can be expressed as [22]:



The produced OH^- ions migrate through the AEM to the anode to form the ionic current. As a result, the overall reaction of the alkaline H_2O_2 -based DEFC can be obtained by combining the EOR given by Eq. (1) and the HPRR given by Eqs. (2) and (3), i.e.:



which results in a voltage of 1.61 V. This theoretical voltage shows an increase as compared with that of the alkaline O_2 -based DEFC (1.14 V).

3. Experimental

3.1. MEA fabrication

A membrane electrode assembly (MEA), with an active area of $1.0 \text{ cm} \times 1.0 \text{ cm}$, was comprised of an AEM (Tokuyama, A201: $28 \mu\text{m}$) sandwiched between an anode and a cathode electrode. The anode electrode was made by brushing the catalyst ink (1.0 mg cm^{-2} PdNi/C and 5 wt.% PTFE) onto a piece of nickel foam. The cathode electrode was made by attaching the Fe–Co K-14 HYPERMEC™ catalyst (ACTA) with a loading of 1.0 mg cm^{-2} to a carbon cloth [13].

3.2. Fuel-cell setup and instrumentation

The prepared MEA was clamped between an anode and a cathode flow field. A fuel solution containing ethanol and KOH was fed into the anode flow channel by a peristaltic pump with a flow rate of 2.0 mL min^{-1} , while a hydrogen peroxide

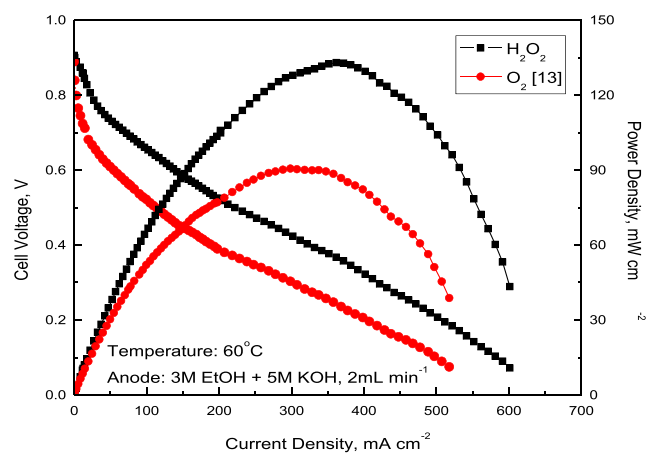


Fig. 2 – Comparison in performance between the alkaline DEFC with H_2O_2 and O_2 as the oxidant.

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