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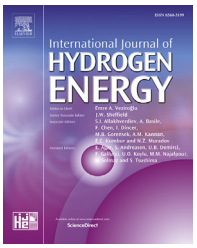

Nickle-cobalt composite catalyst-modified activated carbon anode for direct glucose alkaline fuel cell

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ABSTRACT

Glucose is the most abundant monosaccharide in nature and has great potential as high-density hydrogen carrier for fuel cells. However, the practical application of direct glucose alkaline fuel cell (DGAFC) is hampered by lack of cost-effective anode catalyst. In this study, nickel-cobalt composite catalysts were prepared by $NaBH_4$ reduction method and electrochemical, morphological and chemical properties of catalysts were characterized by LSV, EIS, SEM, TEM, XRD and XPS techniques. The nickel-cobalt composite catalyst and modified activated carbon anode was evaluated in one-chamber DGAFC. Our results demonstrated that the DGAFC performance was greatly improved with the addition of Ni-Co composite catalyst in the anode. Fuel cell achieved the peak power density of 23.97 W m^{-2} under the condition of 1 M glucose, 3 M KOH and ambient temperature. The enhancement of the anode performance could be attributed to the synergic effect of two reversible redox systems, Ni(II)/Ni(III) and Co(II)/Co(III), which improved interfacial charge-transfer kinetics. Our study may facilitate the development of cost-effective renewable energy devices.

Introduction

The development of new energy sources are becoming more urgently needed due to rapid growth of energy demand, global industrialization and increasingly serious environmental problems [1–5]. Fuel cells have received much attention in recent years due to its unique properties such as high efficiency and low emissions [6–8]. Hydrogen is a zero-emission fuel for fuel cells, however, its sustainable production and on-board storage remain significant challenges. Carbohydrate is one of the high energy density hydrogen carrier which has potential to address hydrogen storage challenge. Among various types of carbohydrate, glucose is the most abundant monosaccharide in nature with many advantages like inexpensive, readily available, non-volatile,

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safe and non-toxic [9,10]. Theoretically, glucose is capable of releasing 2.87 mol^{-1} of energy after being completely oxidized to CO_2 with 24-electrons transfer, which indicate the great potential of glucose as bio-fuel in fuel cells [11,12]. Considering the characteristics of glucose, it is more appropriate for some portable low-power devices and electronic equipment such as drive computers, mobile phones, implantable medical devices and so on [7,13–16]. Although a wealth of literature has been devoted to the investigation of glucose fuel cells, there is still a gap between glucose fuel cells and methanol or ethanol fuel cells [17–21].

Glucose fuel cells are mainly categorized into three types: direct glucose alkaline fuel cell (DGAFC), microbial glucose fuel cell (MGFC), and enzymatic glucose fuel cell (EGFC) [4,22,23]. Compared with MGFC and EGFC, DGAFC has the advantages of high stability, considerable durability and simple structure. A typical DGAFC system consists of an anode, a cathode and a chamber filled with electrolyte. The anode catalyst catalyzes the oxidization of the glucose to produce CO_3^{2-}, water and electrons (Equation (1)). The anode collects the electrons and transport them to cathode by external circuit. Then electrons and water react with oxygen and form OH^- (Equation (2)). The overall fuel-cell reaction for glucose and oxygen at alkaline conditions is showed in Equation (3).

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

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

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

The performance of the DGAFC is determined by both the anodic and catholic reactions. Due to the low efficiency of glucose oxidation reaction, anode is a bottleneck of DGAFC technology. Catalysts that more effectively catalyze complete oxidation of glucose are needed, but development has been very slow. There are three major problems associated with anode catalyst, such as high cost, metallic catalyst poisoning and low reaction kinetics, which hindered the development process of DGAFC [7,24–28].

There has been a lot of literature for a variety of metal catalysts, in which nickel (Ni) is a kind of highly active, relatively stable and easily available metal compared to other metal catalysts [12,29–35]. As a result, Ni is frequently used in sensors, batteries and fuel cells as catalyst [10,28,36–42]. Kung et al. [36] modified the porous foam nickel with nickel hydroxide to promote the oxidation reaction of glucose through $Ni(OH)_2$/NiOOH redox couple. Similarly, Cobalt (Co) is also continually used in conjunction with different metals like Ni, Pt, and Pd to prepare bimetallic catalysts because of its distinctive bimetallic properties [43–46]. Guo et al. [40] prepared nickel-cobalt nanowire arrays electrode by one-step galvanostatic electrodeposition method and applied it in the single direct urea/hydrogen peroxide fuel cell. Yand et al. [39] produced Ni and Co modified carbon fiber cloth (CFC) by electrodeposition and compared it with Au/CFC and Pd/CFC in a direct peroxide-peroxide fuel cell. There were some studies had shown that the addition of Ni and Co into electrodes could increase the peak current densities and affect the initial voltage of the oxidation reaction [47–49]. However, the lack of facile way to fabricate cost-effective nickel-cobalt (NiCo) composite anode is still a big problem for the development of DGAFC. In addition, it is necessary to conduct in-depth analysis on the NiCo catalysts and explore their possible acting mechanisms in DGAFC.

In this work, NiCo composite catalysts were prepared via $NaBH_4$ reduction method. The different experimental parameters related to catalysts were investigated and their electrochemical performance in DGAFC was also evaluated. Furthermore, the possible mechanisms of the NiCo composite catalyst in the DGAFC were primarily explored.

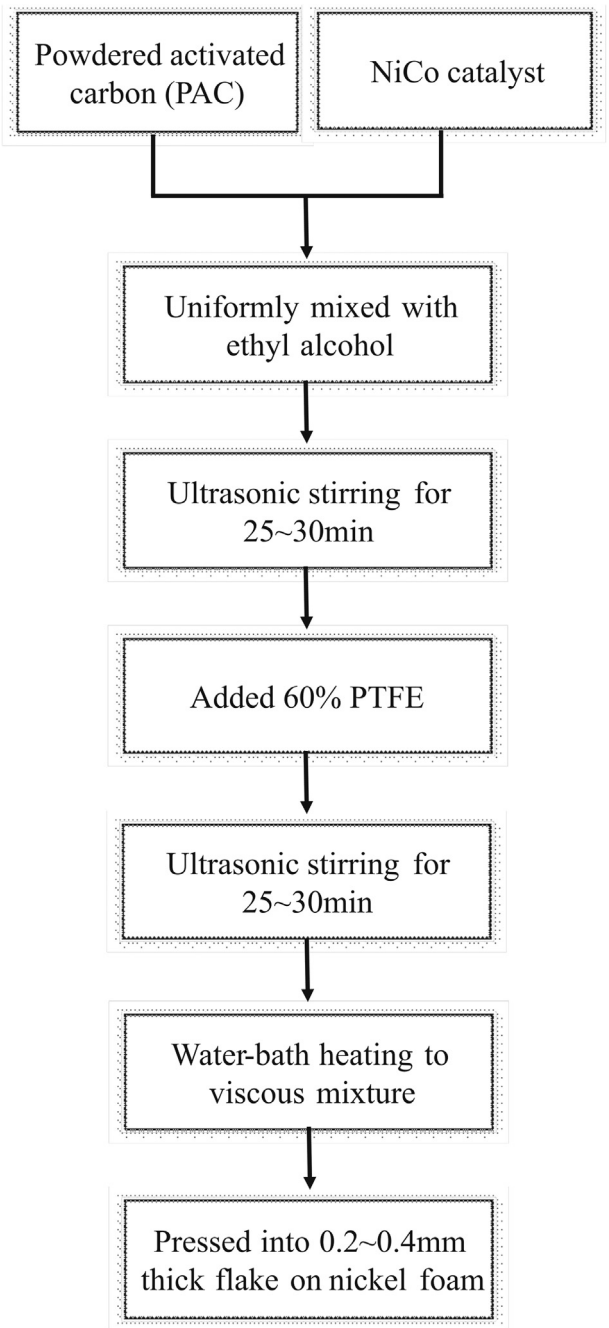

Fig. 1 – Preparation of NiCo-modified AC anode by the rolling method.

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