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Production of Sustainable Energy by Carbon Nanotube/Platinum Catalyst in Microbial Fuel Cell

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Abstract

Platinum (Pt) is the most efficient and common cathode catalyst that is being applied in fuel cell technology, especially in microbial fuel cells (MFCs). However, its high price makes its use uneconomical in MFCs. Even though there are some other types of new catalysts, their performance could not compete with Pt. This is the main reason why scientists spend all their efforts to decrease the amount of Pt by making some composite of Pt for their use in MFCs thus making it viable and more economical. In this study, carbon nanotube-platinum (CNT/Pt) nanocomposite has been fabricated as a novel cathode catalyst in MFCs and its performance was compared with platinum in MFCs system. The CNT/Pt was synthesized by using the in situ method, and the performance is being compared in terms of power density generation in different concentration. The results have shown that CNT is a suitable support for catalyst in MFCs and CNT/Pt generally has better performance than Pt in MFCs. This can be due to better interaction with oxygen in the cathode chamber and high catalytic activity of CNT/Pt for oxygen reduction reaction. The potential of CNT/Pt nanocomposite in generating electricity from MFCs has been demonstrated and this can be a sustainable source of energy for the future.

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1. Introduction

The depletion of non-renewable energy sources like fossil fuels and the changes in climate have encouraged scientists to work on finding new alternatives source of energy [1,2]. Fuel cells are energy converting devices with low or zero emission and high efficiency [3]. Microbial fuel cell (MFC) is one of the prominent fuel cells, which converts organic matter such as sugar to electrical energy by using bacteria as biocatalyst [4]. It means that MFCs generate electricity and treat wastewater simultaneously. MFCs consist of anode and cathode chambers that are separated by a proton exchange membrane (PEM) [5]. Electrons are produced in the anode chamber, while there are electron acceptors in the cathode chamber to accept the electrons and complete the circuit [6]. However, until now, there are different problems in making MFCs economical. The most important challenge is the cost of the Platinum (Pt) that is used as cathode catalyst for accelerating the rate of oxygen reduction reaction (ORR) as it represents more than half of the price of MFCs [7]. So many are trying to replace or decrease the amount of Pt or even use low-cost and stable non-noble metals as cathode catalyst in order to make it more economical [8]. Nowadays, nanostructured carbon-based materials, especially carbon nanotubes (CNTs) are increasingly used as catalyst and its support due to their high surface area [9], high mechanical strength [10], high electrical conductivity [11] and catalytic activity [12]. Higher catalytic activity of CNTs based materials may be due to high surface area that causes better dispersion of materials as well as more places for functionalization and bonds. Reddy et al. [13] studied carbon nanotube based MFCs in membrane electrode assembly

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(MEA) system. From their work it was concluded that functionalization of CNTs improved adhesion of Pt on its surface. Yuan et al. [14] studied amino functionalized multi-walled CNTs (MWCNT) as support for iron phthalocyanine cathode. They concluded MWCNT is an efficient support of the catalyst for ORR. Wang et al. [15] used carbon nanotube in their modified air cathode chamber of MFC. They concluded that the power produced by CNT was more than double to that of traditional carbon cloth cathodes. Ghasemi et al. [16] also fabricated and applied chemical activated carbon nanofiber (ACNF) in MFC. They found that chemical activated CNF has better power per cost than Pt and is more economical and applicable for real system.

In the present study, we designed an MFC which is inoculated by using activated palm oil mill effluent (POME) in anode chamber to get the highest power density by CNT/Pt nanocomposite electrode with just 25% Pt and 75% CNT.

2. Material and methods

2.1. MFC construction and operation

Two cylindrical and H-shaped chambers were constructed using Plexiglas material with a diameter of 6.2 cm and a length of 14 cm and were separated with Nafion 117, which acted as the proton exchange membrane (PEM). Oxygen was fed to the cathode continuously by an air pump (80 ml/min). Both the cathode and the anode surface area were noted to be 12 cm^2 and MFC was operated at ambient temperature and neutral pH (6.5-7) in anode and cathode [17,18]. The pH was adjusted by using the phosphate buffer solution. Plain carbon paper was used as the anode and carbon paper coated by different concentrations of Pt and CNT/Pt were used as the cathode. The schematic diagram of MFC is shown in the Fig. 1.

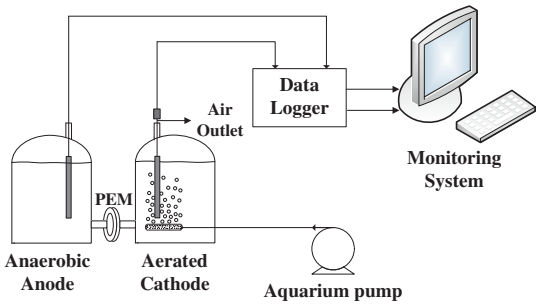

Fig. 1. Schematic representation and photograph of the fabricated MFC

Palm oil mill effluent (POME), anaerobic sludge (Selangor, Malaysia) was used to inoculate the reactor in the anode chamber. The media contained 5 g of glucose, 0. 5 g of yeast extract, 0.2 g of KCl, 1 g of $NaH_2PO_4.4H_2O$, 3 g of NH_4Cl, 4 g of $NaHCO_3$ (Merck), 10 ml solution of Wolfe's mineral and 10 ml of Wolfe's vitamin solution were added per litre [19].

2.2. Electrode preparation

2.2.1. CNT electrode

CNTs are inert without any functionalization and do not have any positive effects. To functionalize, the CNTs were ultrasonicated in a 3:1 concentrated H_2SO_4 and HNO_3 solution for three hours. Next, the required amount of CNT (0.5 mg/cm^2) was dispersed in the small amount of ethanol. This resulted in a stable dispersed CNT ink solution. The ink was brushed on the surface of carbon paper and then dried at 100^{oC} for one hour, in order to eliminate any residual water.

2.2.2. Pt electrode

Pt was first washed with deionized water, filtered, and then dried. The required amount of Pt was then dispersed in the small amount of Nafion solution, to produce a Pt ink. This ink was then dispersed on to carbon paper (CP) uniformly, and the electrode was then dried in an oven for one hour at 100^oC.

2.2.3. CNT/Pt composite nanocomposite electrode

A chemical reduction technique was used to produce CNT/Pt. First, CNT was ultrasonicated in nitric acid for approximately three hours. Then, the sample was dried and washed with deionized water several times, and then air-dried. The dried sample was then ultrasonicated with acetone for one hour and a 0.075 molar H_2PtCl_6 solution was added slowly during stirring. After 24 hours, the mixture was reduced using a 1 M NaOH and 0.1 M $NaBH_4$ solution. When the mixture was ready, it would be washed by deionized water and dried at 80^oC for six hours [20].

2.3. Analysis and calculation

The current and power produced by the system was calculated using equations (1) and (2), respectively.

$$I = {}^{V}/_{R} \quad (1)$$

$$P = R \times I^2 \quad (2)$$

Where I is the current (ampere), V is the voltage (volt), R is the external resistance (Ω) and P is the power (watt) produced by the system.

3. Results and discussion

Fig. 2 shows the surface morphology of the carbon paper anode electrode at the end of the process, where a biofilm can be seen to be attached on the anode surface. The image obtained confirmed that different types of bacteria can easily be attached on CP anode electrode surface and have a significant role in the catalytic activity of the electrode [21,22]. It proves that a biofilm covered the electrode surface that acted as a biocatalayst for the production of bioelectricity and transfer of produced electron to the electrode surface.