ARTICLE IN PRESS

INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2018) 1–9

Available online at www.sciencedirect.com

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journal homepage: www.elsevier.com/locate/he

The effect of Nafion membrane fouling on the power generation of a microbial fuel cell

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ARTICLE INFO

Article history:
Received 15 September 2017
Received in revised form
26 January 2018
Accepted 15 February 2018
Available online xxx

Keywords:
Nafion membrane
Membrane fouling
Microbial fuel cell
Bioelectricity
Potato peels
Rice straw

ABSTRACT

Microbial fuel cells (MFCs) are the most useful technologies for energy production and wastewater treatment due to their low cost and support of the environment. In this study, the membrane fouling and their effects on power generation were investigated using scanning electron microscope (SEM). Results demonstrate that proton exchange membrane (PEM) was affected by biofouling in a two-chamber H-type MFC, which would significantly affect coulombic efficiencies (CEs), and maximum power densities leading to reduced power generation. The power densities of both rice straw and potato peels were 119.35 mW/m^2 and 152.55 mW/m^2, respectively. Scanning Electron Microscope (SEM) showed substantial accumulation of bacteria and their end-products forming a thick biofilm on the surface of PEM leading to a decrease, if not, preventing the passage of protons from the anode side toward the cathode side. The decline in power generation may result mainly from the biofouling, not of electrodes but, of PEM membrane from both sides (Anode and Cathode) because of improper regular PEM cleaning.

Introduction

Energy is a fundamental input for social and economic activities [1]. The global demand for energy consumption increased dramatically, especially in developing countries like China, India, and Brazil [2,3]. Even though with a series of issues and challenges to the humanity and the environment that fossil fuels facing, more than 80% of the global energy was met by fossil fuels in 2013 and 70% of the energy supply investment has been related to the fossil fuels sector. Nevertheless, our energy source comes mainly from primary sources either non-renewable source such as fossil fuels and nuclear power; and/or renewable source such as biofuels, solar and wind power. These sources originate mostly in the Sun. Electricity is a secondary energy source (or energy carrier), because it is produced by converting primary sources of energy such as coal, natural gas, nuclear energy, solar energy, and wind energy into electrical power. Also, it can be converted to other forms of energy such as mechanical energy or heat. Continual use of fossil fuels is now widely recognized as unsustainable because of their depleting resources and contamination to the environment [4]. Microbial fuel cell (MFC) is a sustainable

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https://doi.org/10.1016/j.ijhydene.2018.02.097

technology, which can generate power bioelectrochemically by converting biodegradable organic matter (i.e., rice straw and potato peels) directly into bioelectricity by microorganisms [5–8]. The MFC is composed of an anode, cathode, proton exchange membrane (PEM), biodegradable organic matter and an electrochemically active microorganism [6,9]. Bacterial cross-feeding interactions lead to the complex organic matters degradation and bioenergy generation in microbial electrochemical cells [10–12]. The power generation in MFC depends on many factors such as substrate and its concentration and electrophilic microorganisms [4,12]. Among many challenges facing the MFC technology and limiting the power of this technology are system architecture, types of materials used for electrodes, microbial community and their arrangements on the electrodes, PEM, and separator [13–15]. The separator is one of the most important MFCs components as it separates the anodic and cathodic compartments. The separator material has to be of high proton transfer coefficient to prevent any inhibition of protons transport to the cathode, and of low oxygen transfer coefficient to significantly improve the efficiency of MCFs. Cation exchange membranes (CEMs) such as Nafion, anion exchange membranes (AEM), and ultrafiltration membranes (UFM), have been used in various types of MFCs [4,16]. The most widely used CEM in MFCs is proton exchange membrane (PEM), because of higher cations conductivity and relatively lower internal resistance compared to other membranes material [17,18]. However, membrane fouling always occurs in MFC, as biofilm will undoubtedly be formed on PEM under long-term operation [19]. The effect of biofilm growth on and inside separators has been previously considered [18]. However, to ensure sustainable electricity production, the fouled PEM has to be recovered. Alternatively, it has to be replaced with a new one although the high production cost would be an issue, especially when scaling up for practical application of MFCs. Consequently, the PEM fouling deteriorates the performance of the MFCs.

Rice straw and potato peels are the most common and abundant lignocellulosic biomass residues in the world (about 650–975 million tons of rice straw annually produced) [20,21]. Rice straw contains high carbohydrate such as cellulose (32.47%), hemicelluloses (19.27%) and lignin (5.24%) [8,22,23]. Moreover, out of one ton of potato, 0.73 tons of potato peels is produced [24]. Bacteria in MFCs can utilize such macromolecules for power generation [25].

The rationales of this study were to: a) use rice straw and potato peels as a carbon source in MFC for generating electricity; b) investigate the behaviour of proton exchange membrane during biofouling in a two-chamber MFC system without cleaning for a prolonged period, and investigate the PEM biofouling by scan electron microscopy (SEM).

Materials and methods

Microbial fuel cell configuration and operation

Fig. 1 demonstrates the schematic diagram of a two-chambered H-type microbial fuel cell (MFC) reactor made up of plexiglass. The total working volume of each chamber equipped with an electrode was approximately 200 mL of media with about 100 mL headspace, the total volume 300 mL and that was assembled as described previously by Oh et al. [26]. The actively projected surface area of both anode and cathode electrodes were 10 cm^2. New electrodes were immersed in 1 mol L^{-1} HCl to eliminate possible metal ion contamination. Electrical connection to the electrodes was made using copper wire hooked into carbon paper and pasted with catalyst 9 (25 mg) and ECCOBOND solder 56C (1.0 g) (1 part:40 part respectively). The anode and cathode were connected via a resistor with a range of 1000 Ω. The anode and cathode chambers were separated from each other by installing a proton exchange membrane (PEM) (surface area

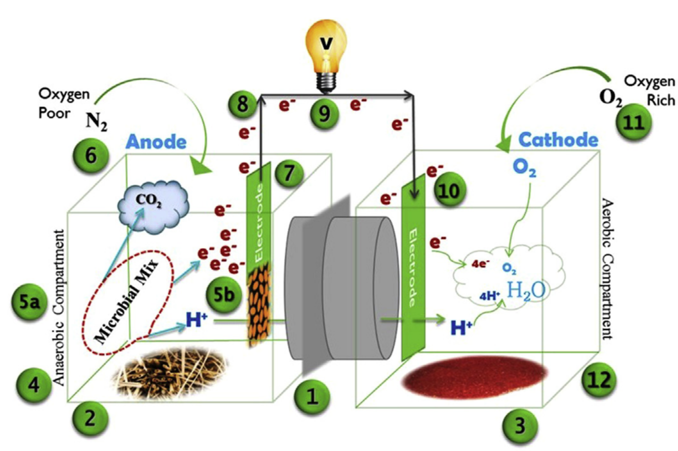

Fig. 1 – Major elements of MFC reactor: 1. Proton Exchange Membrane (PEM) selective to H^+ cation only separating the two chambers; 2. Anode chamber under anaerobic conditions; 3. Cathode chamber under aerobic (open air) conditions; 4. Substrate or biomass for bacteria to feed on; 5. Pure or mixed bacterial culture (a) and biofilm (b); 6. Nitrogen gas to remove oxygen and maintain the anaerobic condition; 7. Anode electrode, on which bacterial attachment occurs; 8. Copper wire for transferring electrons to the cathode; 9. Ω resistor; 10. Cathode electrode to receive the electrons from the anode; 11. Air oxygen; 12. Electrons reducing agent.

Please cite this article in press as: Flimban SGA, et al., The effect of Nafion membrane fouling on the power generation of a microbial fuel cell, International Journal of Hydrogen Energy (2018), https://doi.org/10.1016/j.ijhydene.2018.02.097