INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2017) 1–10

Available online at www.sciencedirect.com

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

Improve 3D electrode materials performance on electricity generation from livestock wastewater in microbial fuel cell

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ARTICLE INFO

Article history:
Received 3 February 2017
Received in revised form
25 April 2017
Accepted 6 June 2017
Available online xxx

Keywords:
Laminated board structure
Swine wastewater
Microbial fuel cell
COD removal

ABSTRACT

Swine wastewater that is collected from animal husbandry has organic high ammonia nitrogen. In this study, swine wastewater is converted into electrical energy using microbial fuel cells (MFCs). Carbon fibers are respectively combined with zinc-coated metallic wires or stainless steel wires in order to form different laminated electrodes, whose influence on the electricity generation of MFCs is then examined. The 3D laminated FN/carbon composites are used as electrodes, the stable electricity voltage is 291 mV and the COD removal efficiency reaches 81%. In contrast, SS/carbon composites only contribute to a stable electricity voltage of 12.3 mV and COD removal efficiency of 33%. Based on the surface contact angle test and the scanning electron microscopy (SEM) observation, the laminated FN/carbon composites have greater hydrophilicity and wettability than the laminated SS/carbon composites, and thus have a positive influence on the electricity generation of MFCs.

Introduction

The animal husbandry becomes highly prosperous as a result of rapid population growth and more economic activities, which also causes the increase in the amount of animal wastewater. In particular, pig farms produced tremendous wastewater that contains highly dense organisms and ammonia nitrogen, which is an abundant source of bio-energy [1]. From the perspective of environmental protection, converting organic wastewater into energy is an efficient and economical method decompose organic matter [2–4].

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http://dx.doi.org/10.1016/j.ijhydene.2017.06.047
0360-3199/

In addition, the emission the organic wastewater are required to follow the regulations [5–7]. There are several techniques dealing with the manure wastewater such as physical solutions (e.g. precipitation and dehydration), chemical solutions (e.g. solidification and disinfection), biological treatments (e.g. aerobic and anaerobic treatment) and recycling (e.g. compost) [8–11]. Dealing the wastewater with either the physical or chemical methods would increase the cost as well as produce lots of sludge. In fact, livestock wastewater is a highly prospective and organic resource of biomass energy. Microbial fuel cells (MFCs) are an energy generator that uses an electrode system to form a current circuit and generate electricity. The microorganism can metabolize organic substances and generate electricity in a specific manner. MFCs can address wastewater problems and the shortage of energy [11,12], and it is thus one of the popular topics of research.

MFCs use biodegradation to decompose organic matter in order to yield electricity. Using MFCs to deal with wastewater is highly feasible and profitable. Comparing to current energy and capital intensive methods, MFCs obtain power output while decreasing sludge production by more than 60% [13]. MFCs are composed of a cathode and anode slots, and there is a protons membrane between the chambers. The anode is an anaerobic chamber that is provided for the metabolism of microorganisms, while the cathode is filled with electrolyte to create an aerobic environment. The microorganism in anode cell of MFC degrades and releases protons and electrons [14]. Electrons reach the cathode via the outer circuit. Protons then cross the proton exchange membrane to land the cathode, resulting in current loops, after which the cathode synthesizes oxygen into water. Specifically, electrodes play a fundamental role in facilitating exoelectrogenic biofilm growth and electrochemical reactions, and are essential in improving the functionality and efficiency of MFCs. Ideal electrode materials should have a high surface area, a high conductivity, a low production cost, a high stability, and a good biocompatibility. MFCs is a technique about transfer the energy to electricity and the energy is dependent on the metabolic response of microorganism [15].

The electrode configuration is a big challenge on manufacturing effective MFCs. As a good electrode, a good configuration must provide a big surface area for bacterial attachment to make sure high efficiency of current recycle [16]. There are different electrode materials with variable physical or chemical properties (e.g. surface area, conductivity, and chemical stability) which affect bacterial attachment, electron transfer, electrode surface, and reaction rate. Therefore, it is very important to use suitable electrode material of microbial fuel cell.

The electrode materials of MFC are used for specific properties, including good conductivity, chemical stability, and high structure strength. Therefore, the qualified carbon materials and anti-corrosion materials are the most widely used. Electrode configurations play an important role in manufacturing effective MFCs and upgrading the scale of MFCs.

There are two types of MFC configurations the plate type and the three-dimensional type. Plate electrodes are a normal anode that contacts with air and their effective oxidation-reduction under the oxygen environment needs be secured [17]. The electrode materials of MFC can be divided into three types as following: the filling materials of cathode, anode, and 3D electrodes. Furthermore, good anode materials are required to have good conductivity, low resistance, strong biocompatibility, chemical stable, anti-corrosion, big surface area, appropriate mechanical strength, and toughness [18]. The cathode materials also influence the power capacity of MFC, and need to have high potential and proton attractive. Currently, graphite, carbon cloth, and carbon paper are the most common cathode materials. Therefore, increasing the surface area of cathode and anode is the most effective way to improve the properties of MFCs.

Brian and Prashant [17] found that graphene could act as an effective anode material for MFCs. Du et al. applied a graphene-carbon nanotube (CNT) composite as electrodes for MFCs and found that cell performances improved at a maximum power density [18]. The anode has to be biocompatible, such as carbon composites or stainless steels [19]. Moreover, stainless steel has high electric conductivity, good oxidation susceptibility, and relatively lower production cost [19]. However, a crucial factor to employ a MFC system on a large scale is linked to a prohibitive production cost. It can decrease the production cost of MFCs when the electrodes have a cost down of 20%–50% [20,21].

Therefore, this study proposes novel 3D laminated composites made of carbon fibers and stainless steel (SS) wires or zinc-coated metallic (FZ) wires to generate electricity out of organic wastewater. A three-dimensional porous structure creates a greater specific surface area and generates a greater amount of electricity than a planar reticular structure. The performances of the 3D electrodes are evaluated in terms of differing composite materials, examining the efficacy and applications. The FZ/carbon electrodes have high degree of micro-porosity and catalytic activities, which are particularly suitable for a large-scale MFC system. In addition to a higher conductivity, FZ/carbon electrodes also have a lower production cost (US60/kg) than Pt electrodes (US1500/kg). As a result, FZ/carbon electrodes are a great candidate as being economical and eco-friendly electrodes of MFCs.

Materials and methods

Swine wastewater

The swine wastewater is collected from the pig farms in central Taiwan and stored at 4 °C in a freezer. The blend (manure: 100 g, urine: 1 L) is placed in a constant-temperature water bath at 95 °C for 1 h, after which it is cooled to the room temperature and sieved at 40 mesh/inch^2 in order to have the test bacteria with a volatile suspended solid (VSS) of 575 mg. The swine wastewater containing total chemical oxygen demand (TCOD) 3688 ± 300 mg/L is used as the substrate that is decomposed at 37 °C in the anode chamber of a two-chambered cubic MFCs. During the process, there are no other nutrient sources added to the substrate and Table 1