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Electricity generation from swine wastewater in microbial fuel cell: Hydraulic reaction time effect

Dongmei Ma [a], Zong-Hua Jiang [b], Chyi-How Lay [b,*], Dandan Zhou [c]

[a] Key Lab of Groundwater Resources and Environment, Ministry of Education, Jilin University, Changchun 130021, PR China

[b] Green Energy Development Center, Master Program of Green Energy Science and Technology, General Education Center, Feng Chia University, Taichung, Taiwan

[c] School of Environment, Northeast Normal University, Changchun 130024, PR China

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ABSTRACT

Microbial fuel cells (MFC) have emerged as a sustainable technology that can directly produce electricity from the oxidation of organic matter by bacteria. A two-chambered up-flow MFC with inner loop mode is evaluated for the hydraulic retention time (HRT) effect on MFC electricity generation. The MFC is constructed with a carbon cloth electrode and anion exchange membrane for electricity production. Swine wastewater containing 3300 ± 300 mg/L of total chemical oxygen demand (TCOD) was used as the substrate for the anode chamber. Potassium ferricyanide was used as the electron acceptor in the cathode chamber. The reactor was operated at 30 °C with a external resistance of 100 Ω in feed-batch mode. The TCOD removal rates at HRT 13, 14, and 20 d were 71, 73 and 83%, while the coulombic efficiencies (CE) were 7.1, 2.4 and 0.3%, respectively. The maximum power density at HRT 13 and 14 d were similar, 12 mW/m^2 and 13 mW/m^2, which were 26 fold greater than the HRT at 20 d (0.5 mW/m^2). The effect of different HRTs on decreasing the organic content by biocatalyzing leads to less organic material for electricity generation, resulting in lower power output. The optimal COD removal efficiency, CE and power density were observed in an up-flow MFC at HRT 14 d. These results demonstrate that up-flow MFC using an inner loop with swine wastewater as the substrate could provide both effective organic removal and electricity output.

Introduction

The breeding industry increased with economic development, leading to increased volumes of animal manure wastewater. Animal manure wastewater contains high-concentrations of organics, nitrates and phosphorus. This organic wastewater must be treated to meet discharge regulations prior to being released into the environment to avoid severe environmental pollution from high-strength organic wastewater [1–3]. Many traditional water treatment techniques are available to remove pollutants from animal manure wastewater. For example, physical methods (e.g., precipitation, dewatering), chemical processing (e.g., coagulation, disinfection), biological processing (e.g., aerobic and anaerobic treatment) and resource utilization (composting) [4–7]. Physical and chemical

* *Corresponding author.*
E-mail address: kfc0612@gmail.com (C.-H. Lay).

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processes entail high operational costs, and aeration treatment produces lots of sludge for disposal. Although composting would accomplish resource recycling, the practical utilization of compost products is limited. Anaerobic treatment would process bioenergy (e.g., CH_4 and H_2) without sludge production [6], while its operating conditions are difficult to control [2]. In fact, breeding industry wastewater is a promising source of bioenergy with its high level of organics.

Microbial fuel cells are energy-producing devices in which chemical organics are converted directly into electrical energy by the catalytic activity of electroactive bacteria [8]. Electroactive bacteria biodegrade organics and the generated electrons are transported to the anode surface using several extracellular electron transfer mechanisms, including direct electron transfer via direct electron transfer via the membrane-bound c-type cytochrome and/or the bacterial nanowires, and indirect electron self-transfer mediated by shuttle molecules [9–11]. The generated electrons are transferred using an external circuit and accepted by an electron acceptor in the cathode. The two-chambers (anode and cathode) are separated by an exchange membrane (e.g., AEM, CEM and PEM) to allow special ions through the membrane connected to a closed circuit. The single-chamber MFC has only an anode while the cathode is exposed to the air, with O_2 as the electron acceptor. Recent studies have demonstrated that the two-chamber MFC has higher mass transfer resistance for the exchange membrane than the single-chamber MFC without membrane. The two chamber MFC power output is therefore less than that of the single-chamber under the same operating conditions [12]. The up-flow MFC is the most promising sustainable technology having the advantages of retaining very high cell density and high mass transfer efficiency [13].

The MFC substrate is crucial because it serves as the nutrient and energy source. The efficiency of converting chemical energy into bioenergy depends mostly on the substrate composition and the concentration, which influence the coulomb efficiency and power yields. The major substrates that have been explored in MFCs include various kinds of artificial and real wastewaters [14]. Real wastewater is the most meaningful practical implication for the removal of contaminants with simultaneous electricity generation [15].

This study operated an up-flow two-chamber MFC that used real pig manure and a swine wastewater mixture as the anode substrate. The influences of different HRTs on MFC power yields, COD removal rate and CE are discussed. The decreased HRT would bring about lower COD removal rate with increasing max power density and CE. These results demonstrate the up-flow MFC can degrade swine wastewater as the energy source with efficient wastewater treatment results and electricity output.

Materials and methods

Swine wastewater

The pig manure and swine wastewater were collected from a pig farm located in Central Taiwan and stored separately in a refrigerator at 4 °C prior to use for further experiments. The manure was diluted to 10 g/L, and the two solutions were then mixed at a volume ratio of 1:1 and stirred for 10 min before filtering using iron mesh (d = mm?) to remove the particulate organic matter. The filtrate was then used as the anode substrate. The swine wastewater characteristics are shown in Table 1.

MFC construction and operation

All experiments were conducted using MFCs operated in a temperature-controlled room (25 °C). Fig. 1 shows a schematic diagram of the two-chamber MFC used in this study. The MFC reactor was separated into anode (800 mL) and cathode (300 mL) chambers by an anion exchange membrane (AMI-7000, Membranes International, Ringwood, NJ). and the anion exchange membrane contained two sheets of carbon cloth, 6 cm × 5 cm and 3 cm × 5 cm respectively. A fixed external resistance (R) of 100 Ω was connected between the electrodes. The anode chamber (total length = 21.5 cm, inner diameter = 6 cm) was downside and operated in inner loop mode using a circulating pump at a rate of 20 L/h, with a stirring bar at the bottom to completely mix the electrolyte. The cathode (total length = 10.7 cm, inner diameter = 6 cm) was upside with potassium ferricyanide (50 mM $K_3Fe(CN)_6$) in a phosphate buffer (pH = 7.0) used as the catholyte. The electrolytes for both the anode and cathode were refilled when the voltage reached lower than 20 mV. The fresh electrolyte was supplied using a peristaltic pump at the bottom into anodic and cathodic chambers. The effluent flowed out simultaneously from the top of each chamber.

Process monitoring

Before and after experiment 1.5 mL samples were siphoned and centrifuged (1000 rpm, 5 min) for COD measurement using the closed reflux method.

The potential between the anode and cathode was recorded on a personal computer through a data acquisition system (JAS-5000, Jiehan Technology Co. Ltd) at 5 min intervals. The current was calculated from the measured voltage according to Ohm's law [potential (V) = current (A) × resistance (R)]. The current was converted into coulombs (C) using this equation [current (V) = coulomb (C)/time (s)]. The Coulombic efficiency (CE) (%) is defined as the ratio of total coulombs transferred to the anode from the anode substrate to the maximum possible

Table 1 – Characteristics of pig manure solution and swine wastewater.

Item	Swine wastewater	Pig manure solution[a]
Total COD (g/L)	6–7	8.4–11
NH_3-N (g/L)	1–1.3	0.1–0.2
pH	7.1–7.4	6.5–6.8
Conductivity (μS/cm)	5590	301

[a] The pig manure solution was mixed with 50% of pig manure and 50% of pure water.