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Can Kitchen Liquid Waste Generate Electricity?

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Abstract

One microbial fuel cell (MFC) feeding with kitchen liquid waste as its organic substrate was constructed. This cell was operated at four different flow rates (350, 450, 700 and 1000μL/min), and its sludge was obtained from the oxidation ditch of a wastewater treatment plant in Pingtung, Taiwan. Power generation capability of the MFC was evaluated. Results showed that the MFC feeding with kitchen liquid waste could generate the voltage in the range between 127mV and 135 mV at the flow rate from 350μL/min to 1000μL/min. Also, the power density of MFC was ranged between 2.95 and 3.34 mW/m^2 (of anode plate) with the flow rate in the range of 350 to 1000μL/min. Although the cell was operated at four different flow rates, either the voltage outputs or the power densities only displayed slightly differences. The COD concentration of kitchen liquid waste was high in this study (between 4095 and 5840 mg/L). Therefore, it is speculated that only a certain percentage of COD was used for power generation. However, further study needs to be undertaken to confirm this assumption. The relationships between voltage and effluent COD concentration and between power density and effluent COD concentration can be expressed as binary quadratic equations. The optimum COD loading to obtain higher power density (= 3.10 mW/m^2) and higher Coulombic efficiency (= 0.116%) in the MFC was about 3.45 kg/m^3/day.

Keywords: Anode · Cathode · Electricity · Power density

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Introduction

Microbial fuel cells (MFCs) have been considered a promising technology for power generation (Logan and Regan 2006). In MFCs, microorganisms convert organic matters in wastewater into electricity. An MFC normally contains an anodic chamber and a cathodic chamber separated by a proton exchange membrane (PEM) or an ion-selected membrane (You et al. 2006). Bacteria use the organic matter in the anodic chamber to produce electrons and protons. The electrons are then transferred onto the surface of the anode, which then flow across an external circuit. Finally, they are conducted to the cathode. The protons migrate to the cathode through PEM. Both electrons and protons are finally depleted in the cathode chamber, coupled with the reduction of oxygen to water. (Kim et al. 2002; Rabaey and Verstraete 2005; Oh and Logan 2006; Ieropoulos et al. 2010).

Rodrigo et al. (2007) used a continuous-flow type of MFC and studied the effects of organic loading and oxygen feed to the cathode in the power production performance of MFC. They concluded that only a very small fraction (about 0.25 %) of influent chemical oxygen demand (COD) was used for the generation of electricity. Influent COD limited electricity generation, but not COD removal rate. Mohan et al. (2010), a batch-operated single-chambered MFC and mixed anaerobic consortia were used to treat composite vegetable waste with the loading rates of 2.08, 1.39, and 0.7 kg COD/m^3/day. They found that higher power output (57.38mW/m^2) was observed at lower substrate load. The efficiency of organic matter converted to power can also be expressed by Coulombic efficiency which is typically in the range from 5% to 38% (Min and Logan 2004; Wang et al. 2008).

In the current study, the COD removal efficiency of microbial fuel cell feeding with kitchen liquid waste was evaluated. Voltage output and power density of this MFC was also investigated.

Materials and methods

Wastewater and sludge source

The kitchen liquid waste was fed into the anodic chamber of an MFC as the organic source of microorganisms. It was obtained from the liquid waste of a household. Before the liquid waste was used, it was diluted with 3 times its volume of water (liquid waste : deionized water = 1 : 3) and filtered through a cloth with the pore size of less than 0.5 mm in diameter. The filtered liquid waste was then refrigerated at a temperature of 4°C. At the time of changing wastewater substrate every day, the kitchen liquid waste was first taken out from refrigerator and settled for at least 4 hours in our laboratory with a controlled temperature of 24–26 °C.

During the experimental period, the measured COD concentration of kitchen liquid waste was in the range of 4095 – 5840 mg/L.

Original sludge was obtained from the oxidation ditch of a wastewater treatment plant in Ping Tung, Taiwan and was grown anaerobically in 500 mL of kitchen liquid waste in our laboratory for more than one month. The sludge liquid was then transferred to the anode chambers of MFC.

MFC design and operational conditions

Fig. 1 shows the schematic diagram of MFC. In this MFC system, two similar-sized graphite carbon electrodes (CCM-400C; Central Carbon Co., Ltd., Taiwan) were used for both anode and cathode (6.3 cm length × 4 cm width × 3 mm thickness). The electrodes were fixed in the respective anodic and cathodic chambers by fully inserting them into the liquids in both chambers. Both anodic and cathodic chambers were made of Plexiglas acrylic sheets, and each chamber had an effective water volume of 797 cm^3 (8.3 cm side water depth × 9.8 cm width × 9.8 cm length). All chambers were sealed with superglue. The covers and the connections of the anodic chamber were sealed with silicone to achieve anaerobicity in the chambers during operation.

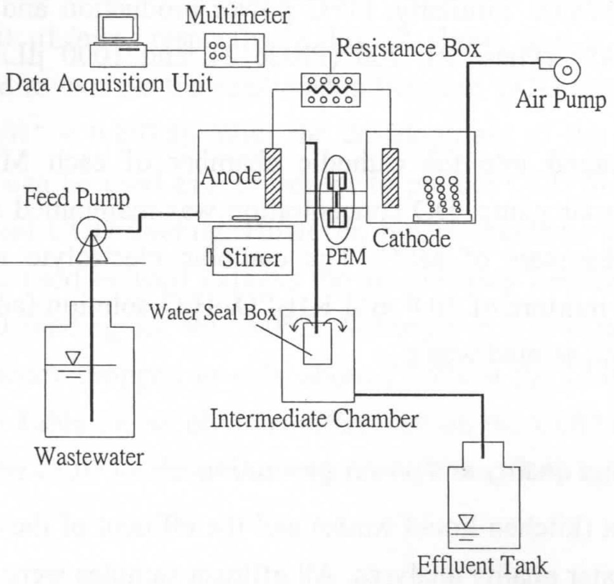

Fig. 1 Schematic diagram of MFC.

A peristaltic pump was used to pump a fixed amount of synthetic wastewater into each anodic chamber. The effluent of the anodic chamber first flowed into a water seal box, and then overflowed into an intermediate chamber. Therefore, anaerobicity was maintained in the anodic chamber. The liquid in the intermediate chamber was then discharged to an effluent tank by gravity or collected for analysis.

The anodic and the cathodic chambers were separated by a PEM (Nafion 117, Dupont Co., USA). The membrane was installed in a Plexiglas acrylic pipe (1.5 cm, inner diameter, and 23 cm, total length) connecting the anodic and the cathodic chambers. The anode and the cathode were connected externally with a concealed copper wire, and power production was measured at an external load resistance of 1000 Ω, which was adjusted using a resistor box. The distance between the anode and the cathode was approximately 36.5 cm.

The MFC was operated at an ambient temperature of 24–26 °C in our laboratory. This system was run under a continuous flow condition at four different flow rates (350, 450, 700, and 1000 μL/min). For the anodic chamber, hydraulic retention times (HRTs) at the four different flow rates were 38.0, 29.5, 19.0, and 13.3 h, respectively. The performance of an MFC system was considered stable when both COD removal efficiency and power output were stable. The flow rate was set to 350 μL/min (Phase 1). The voltages of MFC were measured almost every day until the system was stable. When voltage readings became stable for a few days, influent and effluent water samples of MFC and voltage readings during the last two days of Phase 1 were taken for COD analysis and power density calculation, respectively. The average COD concentration and the average voltage on both days were then used for the analysis. Similarly, MFC power production and water quality under flow rates of 450 (Phase 2), 700 (Phase 3), and 1000 μL/min (Phase 4) were evaluated.

Air was purged into the cathodic chamber of each MFC by an air stone connected to an air pump. DO concentration was maintained at 6.56–7.16 mg/L in the cathodic chambers of MFC. The cathodic electrolyte used in the cathodic chamber was a mixture of 30.8 mM $KH_2PO_4 \cdot H_2O$ solution (adjusted to ≈pH 7.0 by 1.0 N HNO_3) and aerated water.

Analyses of water quality and power generation

The influent (kitchen liquid waste) and the effluent of the anodic chamber were collected for water quality analyses. All effluent samples were filtered through filter papers (Whatman grade 934AH) before COD analysis. COD was determined using the closed reflux method mentioned in the Standard Methods (Clesceri et al. 2001). pH, temperature, and DO (DO200; YSI, Inc., USA) of water in the cathodic chamber were also measured.

Voltages and currents (at an external load resistance of 1000 Ω) were measured using a digital multimeter with a data acquisition unit (U1253B; Agilent

Technologies, Malaysia). They were then converted to power (mW) and power density (mW/m^2 surface area of anode plate). Voltage and current readings on the digital multimeter obtained using the data acquisition software Agilent GUI Data Logger (Agilent Technologies, Inc. USA) were allowed to stabilize for about 5–10 min before each measurement. The readings were continuously recorded every 10 s for 3 min, and then averaged. CE was calculated as $CE = M \cdot I / F \cdot n \cdot q \cdot \Delta COD$, where M is the molecular weight of oxygen, I is the current, F is Faraday's constant, n is the number of electrons exchanged per mole of oxygen, q is the volumetric influent flow rate, and ΔCOD is the difference in the influent and the effluent COD. For the theoretical Coulombic amount calculations, four moles of electrons ($n = 4$) were produced per mole of COD in synthetic wastewater (Behera and Ghangekar 2009; Rodrigo et al. 2009; Sun et al. 2009).

Results and discussion

Wastewater treatment efficiencies

Operational data, COD removal efficiencies and degradation rates are listed in Table 1. The influent average COD concentration of MFC was between 4095 and 5840 mg/L (maximum value = 6284 mg/L; minimum value = 3880 mg/L) and the COD loading rates were 3.66, 3.90, 5.36, and 7.40 kg/m^3/day at the flow rates of 350, 450, 700, and 1000 μL/min, respectively. Fig. 2 shows that a binary quadratic equation can be used to express the relationship between COD degradation rate and COD loading rate ($R^2 = 0.8078$). With the development of the binary quadratic equation, this MFC can be used as a biosensor to predict COD degradation rate by measuring the influent COD loading. However, binary quadratic equation or linear equation can not be used to well express the relationship between COD removal efficiency and COD loading for this MFC. Although it is still unknown why the COD removal efficiency dropped to only about 22.5% at the COD loading rate of 3.90 kg/m^3/day (see Table 1), no obvious difference on the COD removal rate was seen on MFC with the COD loading rates of 3.66, 5.36 and 7.40 kg/m^3/day.

Table 1 Operational data, COD removal efficiencies and COD degradation rates of MFC

Flow Rate (μL/min) / Hydraulic Retention Time (hours)			
350 / 38.0	450 / 29.5	700 / 19.0	1000 / 13.3
Ave. COD Removal Efficiency (%) / Ave. COD Degradation Rate (kg COD/m^3 of anoxic chamber/day)			
40.8 / 1.48	22.5 / 0.88	39.0 / 2.11	33.5 / 2.50

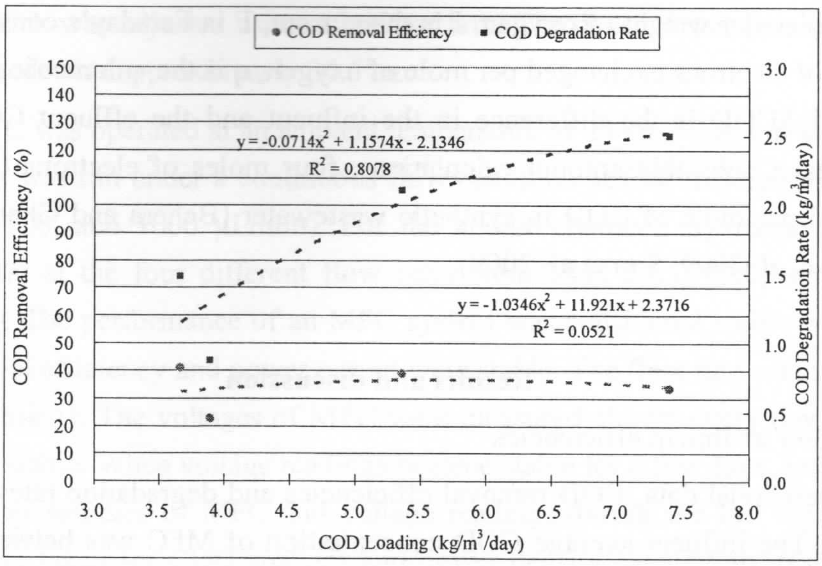

Fig. 2 Relationships between COD removal efficiency and COD loading and between COD degradation rate and COD loading.

Voltage output and power density

Fig. 3 shows that the relationship between effluent COD concentration and voltage on MFC (external resistance = 1000 Ω) can be expressed as a binary quadratic equation (R^2 = 0.95). The relationship between effluent COD concentration and power density can also be expressed as a binary quadratic equation (R^2 = 0.9440). This means that with the development of the binary quadratic equation, the effluent COD concentration can be predicted by measuring the voltage or power density of MFC. The voltages generated by the MFC feeding with kitchen liquid waste (external resistance = 1000 Ω) were between 127mV and 135 mV at the flow rate from 350μL/min to 1000μL/min. The power densities of this MFC (external resistance = 1000 Ω) were in the range of 2.95 - 3.34 mW/m^2 at the flow rate from 350μL/min to 1000μL/min.

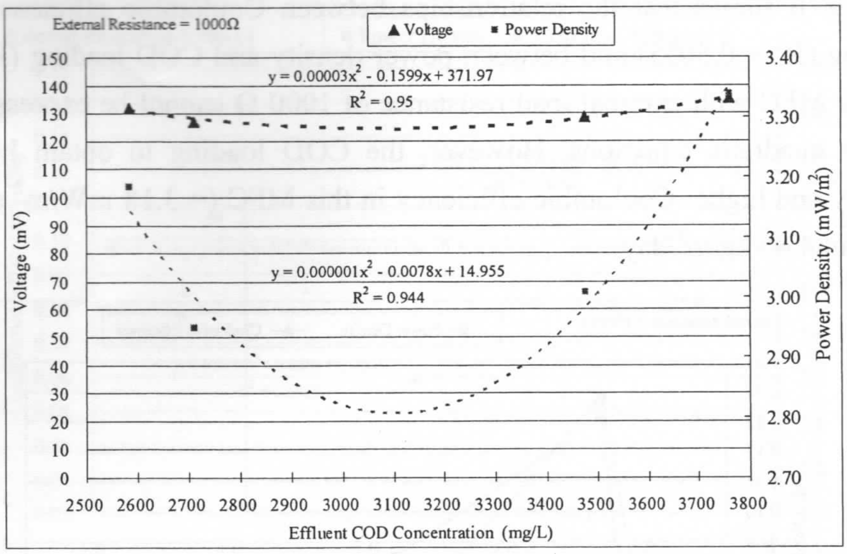

Fig. 3. Relationships between voltage and effluent COD concentration and between power density and effluent COD concentration on MFC.

Fig. 4 also shows the relationships between Coulombic efficiency and COD loading and between power density and COD loading on MFC. The power densities of MFC with the COD loading in the range from 3.66 to 7.40 kg/m^3/day did not show obvious differences. This means that a maximum limitation of COD concentration (or COD loading) may exist for MFC to generate the optimum amount of electricity. This conclusion may be in accordance with the finding of Rodrigo et al. (2007) who reported only a very small fraction of influent chemical oxygen demand (COD) was used for the generation of electricity. Coulombic efficiency can be used to express the efficiency of power production per unit of organic matter utilized by a microorganism (Min and Logan, 2004). Similarly, a maximum Coulombic efficiency of 0.14% was seen at the COD loading rate of 3.90 kg/m^3/day.

According to the regression equations in Fig. 5, the relationship between Coulombic efficiency and effluent COD concentration on MFC with external resistance of 1000Ω can be expressed as a binary quadratic equation ($R^2 = 0.9991$). The Coulombic efficiency decreased first and then increased again as the effluent COD concentration increases. Its lowest Coulombic efficiency was found at the COD effluent concentration of about 3000 mg/L. Normally, the goal is to obtain higher power density and higher Coulombic efficiency in an MFC. If the relationship between power density and effluent COD concentration was also shown in Fig. 5, higher power density and higher Coulombic efficiency in this MFC (= 3.26 mW/m^2 and 0.122 %) was obtained at the effluent COD concentration of about 3760 mg/L.

Fig. 6 shows that the relationships between Coulombic efficiency and COD loading ($R^2 = 0.5035$) and between power density and COD loading ($R^2 = 0.4902$) for the MFC with external load resistance of 1000 Ω cannot be expressed well into binary quadratic equations. However, the COD loading to obtain higher power density and higher Coulombic efficiency in this MFC (= 3.18 mW/m^2 and 0.098%) is about 4.05 kg/m^3/day.

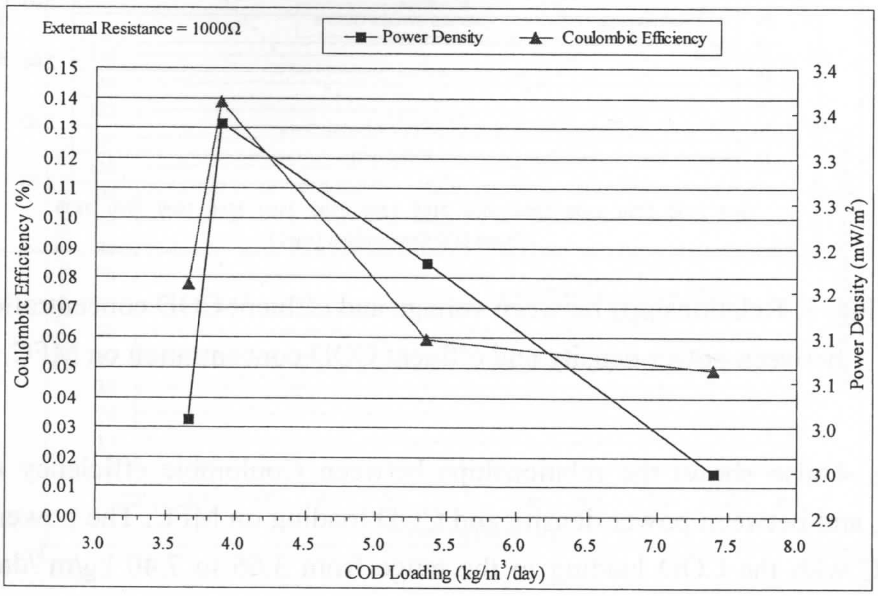

Fig. 4. Relationships between Coulombic efficiency and COD loading and between power density and COD loading on MFC.

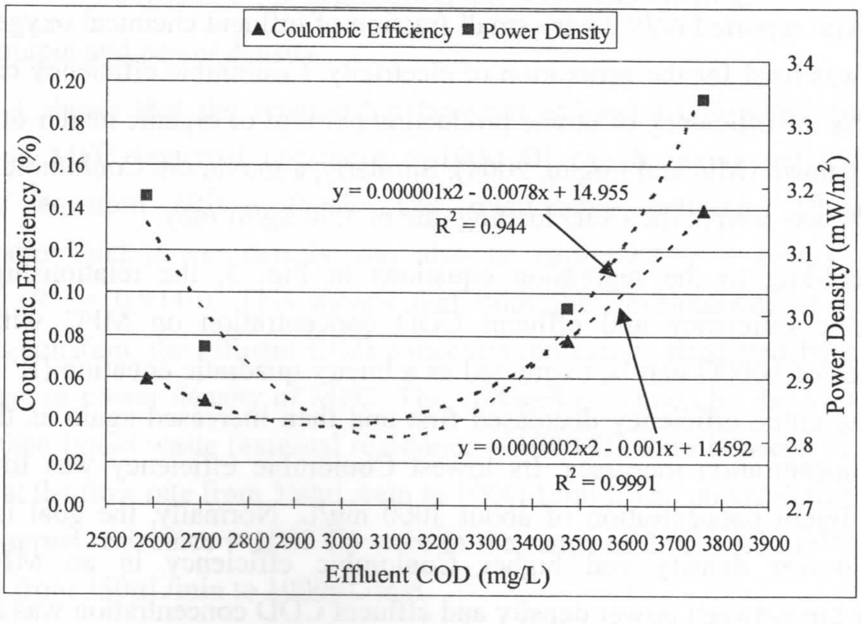

Fig. 5. Relationship between Coulombic efficiency and effluent COD concentration on MFC.

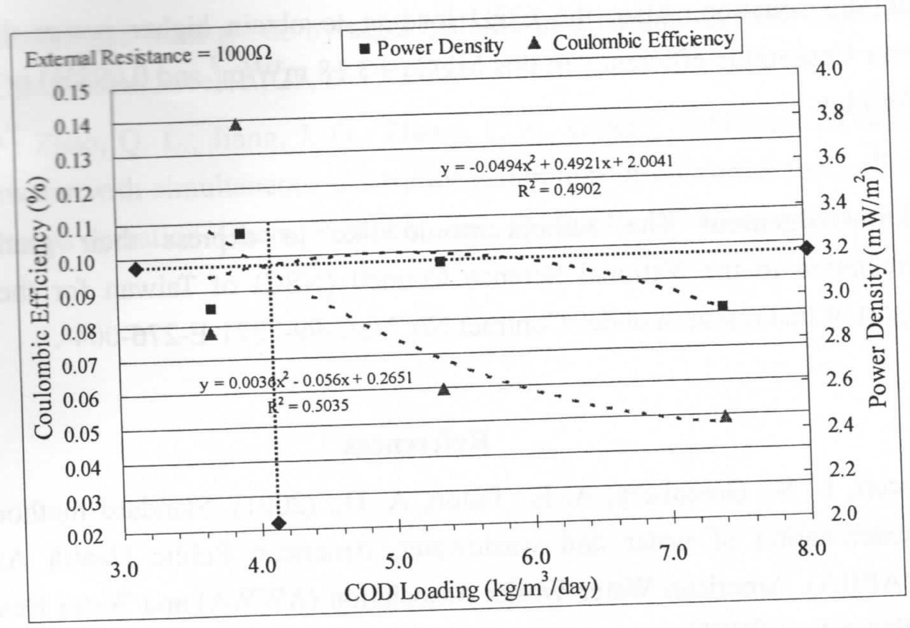

Fig. 6. Relationship between Coulombic efficiency and COD loading on MFC.

Conclusions

A binary quadratic equation can be used to express the relationship between COD degradation rate and COD loading rate on the MFC feeding with kitchen liquid waste. With the development of the binary quadratic equation, this MFC can be used as a biosensor to predict COD degradation rate by measuring the influent COD loading. However, binary quadratic equation or linear equation can not be used to well express the relationship between COD removal efficiency and COD loading for this MFC.

The voltages generated by the MFC feeding with kitchen liquid waste (external resistance = 1000 Ω) were between 127mV and 135 mV at the flow rate from 350μL/min to 1000μL/min. The power densities of this MFC (external resistance = 1000 Ω) were in the range of 2.95 - 3.34 mW/m^2 at the flow rate from 350μL/min to 1000μL/min. The relationships between voltage and effluent COD concentration and between power and effluent COD concentration density can be expressed as binary quadratic equations. With the development of the binary quadratic equation, the effluent COD concentration can be predicted by measuring the voltage or power density of MFC. However, the power densities of MFC with the COD loading in the range from 3.66 to 7.40 kg/m^3/day did not show obvious differences. This means that a maximum limitation of COD concentration (or COD loading) may exist for MFC to generate the optimum amount of electricity.

The relationship between Coulombic efficiency and effluent COD concentration on MFC feeding with kitchen liquid waste can also be expressed as a binary quadratic equation. Also, the COD loading to obtain higher power density and higher Coulombic efficiency in this MFC (= 3.18 mW/m^2 and 0.098%) is about 4.05 kg/m^3/day.

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