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Electricity production from beer brewery wastewater using single chamber microbial fuel cell

X. Wang, Y. J. Feng and H. Lee

ABSTRACT

The performance of electricity production from beer brewery wastewater in a single chamber membrane-free microbial fuel cell (MFC) was investigated. Experimental results showed that the MFCs could generate electricity from full-strength wastewater (2,239 mg-COD/L, 50 mM PBS added) with the maximum power density of 483 mW/m^2 (12 W/m^3) at 30°C and 435 mW/m^2 (11 W/m^3) at 20°C, respectively. Temperature was found to have bigger impact on cathode potential than anode potential. Results suggested that it is feasible to generate electricity with the treatment of beer brewery wastewater.

Key words | beer brewery wastewater, electricity production, microbial fuel cell, temperature effect

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INTRODUCTION

A large amount of beer brewery wastewater is produced from cooling (eg. saccharification cooling, fermentation) and washing units in brewery industry and often causes several environmental problems. This kind of wastewater was non-toxic, but with high BODs compared with other industrial wastewater. Generally, biological methods are adopted for beer brewery wastewater treatment, reported to perform well in chemical oxygen demand (COD) removal (Ince *et al.* 2000; Parawira *et al.* 2005). However, the large amount of energy input in wastewater treatment, especially energy consumed by aeration procedures in aerobic treatment, has been considered as a big problem for many years in wastewater treatment. Due to the increased enforcement of discharge regulation and escalating surcharges by public owned treatment works, many wastewater treatments are being taken steps to reduce, recycle and energy recovery.

Recently, microbial fuel cells (MFCs) have drawn increasing world-wide attention in directly generating electricity from organic matters (Kim *et al.* 1999; Chaudhuri & Lovley 2003; Rabaey *et al.* 2003; Liu *et al.* 2004; Min & Logan 2004). MFC is the device that directly converts chemical energy involved in organic matter into electrical energy. Typical MFC is designed including an anaerobic anodic zone and an aerobic cathodic zone, and they are separated by a proton exchange membrane (PEM). Bacteria attached on the surface of the anode can be used as biocatalysts to pull electrons out from substrates (Bond & Lovley 2003; Rabaey *et al.* 2004). Electrons are conducted through external circuits to the cathode, and then combine with oxygen and protons to form water. Domestic wastewater is reported to be available for electricity generation in several MFC configurations (Liu *et al.* 2004; Liu & Logan 2004; Min & Logan 2004). Previous studies showed that sustainable power outputs can be generated from several types of complex organics. When two electrodes were connected and embedded with marine sediments, a power of 16 mW/m^2 was harvested (Bond *et al.* 2002). Operated in batch mode, power densities over a range of 216.4 ~ 971 mW/m^2 had been achieved using swine wastewater, landfill leachate and even corn stover hydrolysates in single chambered air-cathode MFCs (Min *et al.* 2005; You *et al.* 2006; Zuo *et al.* 2006). Beer brewery wastewater might be good source for electricity generation

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in MFCs due to its nature of high carbohydrate and low ammonium-nitrogen concentration.

In this study, we demonstrated that beer brewery wastewater could be used as fuel to directly generate electricity in a single-chamber MFC. The whole experiments taken in this paper were carried out on the basis of a comparison at temperature of 20°C and 30°C. The scope of this study comprises two aspects: (i) to examine the possibility of direct power generation from beer brewery wastewater; (ii) to investigate effects of temperature on power output and coulombic efficiency (CE) at different initial COD loadings.

MATERIAL AND METHODS

MFC construction and electrodes

Single chamber membrane-free MFCs were constructed as previously described (Liu & Logan 2004). The external resistance was set to 1,000 Ω. The anode electrode (projected surface area = 7 cm^2) was made of carbon cloth (without wet proofing, *E-Tek*, USA), and air cathode containing a 0.35 mg/cm^2 Pt catalyst (30% wet proofed, *E-Tek*) was prepared at the same size according to Cheng *et al.* (Cheng *et al.* 2006).

MFC tests

Two identical MFCs were set up at 30°C (±0.1°C). MFCs were inoculated with domestic wastewater (COD = 500 ~ 600 mg/L, pH = 7.0) collected from municipal pipe network (Harbin, China) and glucose of 1 g/L, together with a phosphate buffer solution (PBS), a mixed mineral solution (12.5 mL) and vitamin (5 mL) as reported by Lovley and Phillips (Lovley & Phillips 1988). The characteristics of the wastewater are listed in Table 1. The inoculated domestic wastewater was controlled as 20% (volume) of the whole solution. The chamber was refilled each time when the voltage was decreased bellow 50 mV. After three cycles, feed solution was switched to beer brewery wastewater and one reactor (MFC2) was transferred into a 20°C (±0.1°C) low-temperature room and the other reactor (MFC1) still kept at 30°C. Measurements of cell voltage were performed using a data acquisition system (PISO-813, ICP DAS Co., Ltd). Voltage signals were collected every 30 minutes. In the tests of different COD-concentrations, beer brewery wastewater was diluted by PBS (50 mM).

Table 1 | Characteristics of raw beer brewery wastewater

Parameter	Value
pH	6.5 ± 0.2
COD, mg/L	2250 ± 418
BOD, mg/L	1340 ± 335
TOC, mg/L	970 ± 156
NH_3—N, mg/L	54 ± 14
Phosphate, mg/L	50 ± 35
Total suspended solids, mg/L	480 ± 70

Calculations

Polarization curves were obtained by verifying external resistances from 50,000 to 50 Ω at an interval of one hour to gain stable voltages when the performance of MFC was stable. Current density was calculated as $i = V/R{\cdot}A$, where V(mV) is cell voltage recorded, R(Ω) is the external resistance applied and A(cm^2) is the projected surface area of the electrode. Power density in MFC tests was calculated according to P (mW/m^2) = $10iV$, where the figure 10 is based on the unit changes. The coulombic efficiency (CE) was obtained by CE = $Q_R/Q_{th} \times 100\%$, where Q_R (C) is the total coulombs through the external circuit in a complete circle, and Q_{th} (C) is the theoretical amount of coulombs that can be calculated based on COD removal.

RESULTS AND DISCUSSION

Electricity generated from beer brewery wastewater

Stable voltage output was achieved just after three cycles (150 hours) inoculated by domestic wastewater in single chamber MFC at 30°C. A cell voltage of 513 ± 4 mV (376 mW/m^2) was obtained after domestic wastewater was removed at 30°C (Figure 1A).

After substrates were switched to beer brewery wastewater, in the initial three hours, the voltage increased from 65 mV (1,000 Ω resistor) to 348 mV for MFC1 and 302 mV

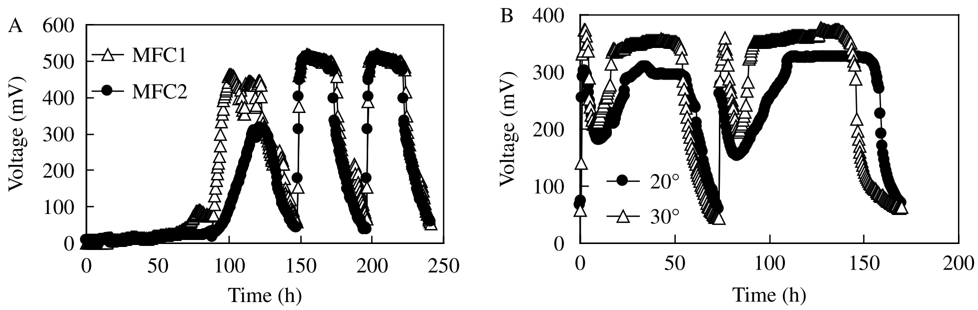

Figure 1 | Electricity generation by single chamber MFCs, (A) system during starting-up using domestic wastewater and glucose; (B) system with beer brewery wastewater.

for MFC2 (Figure 1B). A slight decrease of voltage was found, but voltage quickly increased to a stable value of 355 mV for MFC1 and 308 mV for MFC2. The initial rapid increase of voltage here can be attributed to the presence of components that are easily utilized by anodic bacteria. When these easily degraded substances were used up, the power outputs began to decrease. Meanwhile, degradation of complex components was taken place. These degraded products can be oxidized directly by electro-active bacteria and result in a power output. During the first experimental period (within 60 h), the maximum voltage of 355 mV was obtained in MFC1, with a value of 15% higher than that obtained in MFC2 (308 mV). Following two complete cycles (Figure 1B), the maximum voltages of MFC1 (377 mV) and MFC2 (327 mV) were increased by 9% and 6% respectively, indicating that the power outputs of MFCs using beer brewery wastewater can be increased during long-time acclimation under both 20 and 30°C.

Effect of wastewater concentration on MFC performance

The microbial fuel cells were operated using beer brewery wastewater diluted by 50 mM PBS at a COD range of 400–1400 mg/L. The voltage outputs were shown in Figure 2. It was obvious that the voltage output are stable with the COD decreasing (467 ± 13 mV, 30°C; 443 ± 10 mV, 20°C), but the voltage value was 48 ± 5% more than that obtained using full-strength beer brewery wastewater (Figure 1B) without PBS addition. So, it implied that ion strength might be more important for electricity production than wastewater strength.

COD removal efficiency

A COD removal of 70–79% was got when wastewater concentration increased from 444 to 1,333 mg-COD/L under both 20 and 30°C (Figure 3). However, for the high strength wastewater (2,239 mg/L), a notable increase of 10% in COD removal efficiency was achieved at 20°C and 30°C (87% for 30°C and 85% for 20°C). A comparable result was 80% COD removal obtained by Liu *et al.* using domestic wastewater (Liu *et al.* 2004).

Figure 3 clearly shows that a higher COD removal efficiency was obtained in MFC using full-strength wastewater than those using diluted wastewater, and the removal efficiency has not been affected by the decrease of temperature from 30 to 20°C. So, in the context of wastewater treatment, it was more practical to use MFCs in electricity generation using beer brewery wastewater, and the high COD removal at lower temperature might have great sense in wastewater treatment, especially in cold areas.

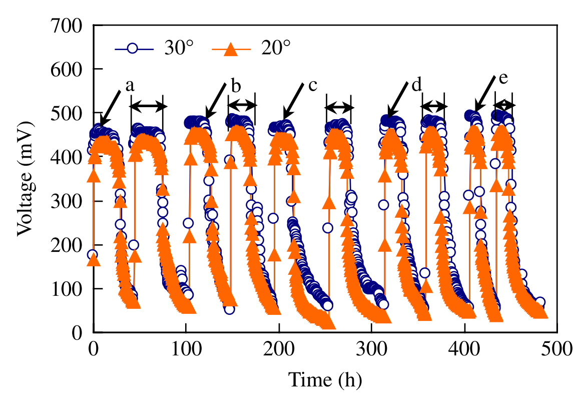

Figure 2 | Voltage generation from MFCs operated at different initial COD of, a: 1,333 mg/L, b: 889 mg/L, c: 667 mg/L, d: 533 mg/L and e: 444 mg/L (diluted by 50 mM PBS).

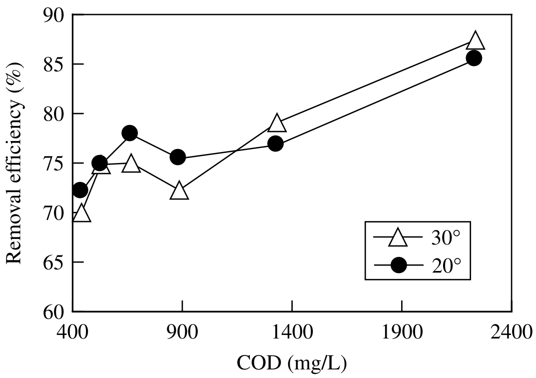

Figure 3 | COD removal at different COD concentration (diluted by 50 mM PBS).

Effect of temperature on power output and CE

To evaluate the power changes with temperature, power densities as a function of current density were examined by varying external resistance from 50,000 to 50 Ω in the condition of 50 mM PBS added (Figure 4). MFC1 operated at 30°C (483 mW/m^2; 12 W/m^3) could generate 11.5% more power than that operated at 20°C (435 mW/m^2; 11 W/m^3).

Both anode and cathode potentials were observed a decrease when temperature was decreased to 20°C (using SCE as reference electrode; 241 mV versus standard hydrogen electrode, SHE) (Figure 5). But anode potentials came to be equal after the current density reached 2.5 A/m^2. The influences of temperature on cathode potential were greater than those of anode potential. A similar phenomenon was observed by other researchers (Liu *et al.* 2005). As cathode potential was greatly decreased with temperature decreasing, it was interesting that lower anodic open circuit potential (OCP) was gained under lower temperature, which might be the strategy of anodic community to acclimatize itself to environmental change and to gain more energy for vital activity. With the current increased, anode potential was highly affected by activation overpotential (Larminie & Dicks 2000). The lower temperature, the higher overpotential. Therefore, the anodic potential of MFC at 20°C increased faster than that of 30°C.

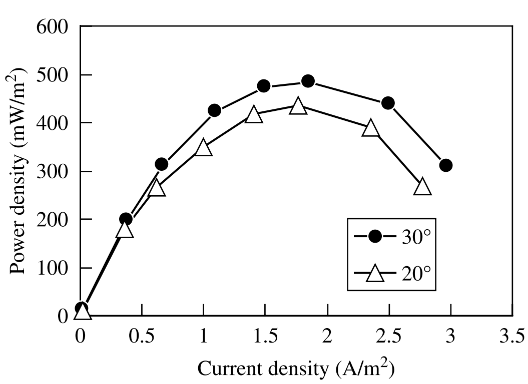

Figure 4 | Effect of temperature on power density, 50 mM PBS added.

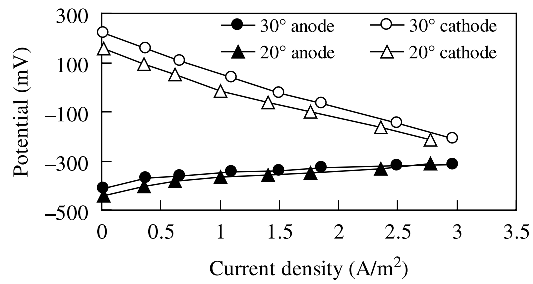

Figure 5 | Anode and cathode potentials at 20°C and 30°C, 50 mM PBS.

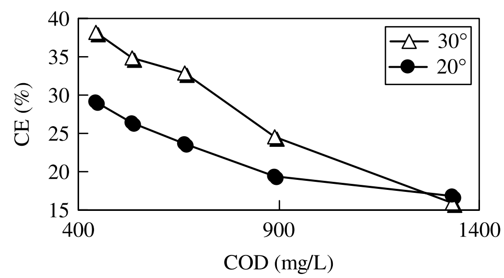

Figure 6 | Coulombic efficiency (CE) at 20°C and 30°C (diluted by 50 mM PBS).

Feeding on wastewater with 444 mg-COD/L, the MFC operated at the temperature of 30°C reached a 38% CE, an increase of 31% over that obtained at 20°C (29%). However, when COD-concentration was increased to 1,333 mg/L, a very similar CE was gained in two MFCs operated at 30 and 20°C (Figure 6).

CONCLUSION

Electricity can be generated by beer brewery wastewater using single chamber MFCs. Temperature affected the power output, and the maximum power densities of 435 (11 W/m^3) and 483 mW/m^2 (12 W/m^3) were achieved at 20°C and 30°C respectively. Similar voltage outputs (467 ± 13 mV, 30°C; 443 ± 10 mV, 20°C) were got over a COD-concentration ranging from 400 to 1,400 mg/L, but the CE decreased from 38 to 15%. Ionic strength is more important than wastewater strength in so far as this affected power outputs.

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