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Effect of organic loading rates and influent sources on energy production in multi-baffled single chamber microbial fuel cell

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ABSTRACT

Multi-baffled single chamber microbial fuel cells (MBSC-MFCs) were operated with different wastewater sources and organic loading rates (OLRs). As the OLRs increased, the maximum power density (P_{max}) in MFCs with an identical influent source also increased. In the case of using a different influent source, P_{max} was different even though the MFC had been operated with the similar OLR or hydraulic retention time. Therefore, power generation would be affected concurrently by a range of factors, including the substrate type.

Keywords: Influent source; Microbial fuel cell; Organic loading; Power density; Wastewater

1. Introduction

The increasing demand for fossil fuels has triggered an energy crisis. Renewable bioenergy is one of the key solutions for alternative energy and global warming. Therefore, there is a strong demand for renewable energy resources to minimize the use of fossil fuels. Microbial fuel cells (MFCs) are bioreactors that can generate electricity by treating wastewater under anaerobic conditions through the catalytic reactions of microorganisms. The electricity can be obtained without the supply of expensive fuel because the fuel of MFCs is the organic matter of wastewater generated perpetually by humans and industrial activity [1,2]. The electro-chemically active bacteria (EAB) deliver the electrons generated by the oxidation of organic matter in MFCs as anaerobic bacteria. With anaerobic bacteria, excess sludge production is much lower than that of aerobic bacteria and aeration, which accounts for 40–60% of the total energy consumption of wastewater treatment plants (WWTPs), is unnecessary in the case of single chamber types of MFCs when the cathode is exposed to air [2,3]. Therefore, MFCs have been considered to be a new technology that can cause a paradigm shift in wastewater treatment because MFCs can treat wastewater without aeration, minimize the sludge yield, and generate the electricity. In addition, MFCs have attracted

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considerable attention from many researchers because of the continuously increasing energy demand and shortage [1].

MFCs can use a variety of substrates ranging from pure substrates to complex substrates, including wastewater, but power generation in a MFC is affected by substrates, such as the substrate type and organic loading rates (OLRs) [4]. Cube-typed single chamber MFC using acetate was operated and it produced a maximum power density (P_{max}) of 73 W/m^3 in fed-batch mode [5]. Submerged-exchangeable MFCs operated with domestic wastewater reached a P_{max} of 527 mW/m^3 at 0.43 kg-SCOD/m^3-d [6]. Single chamber MFC using brewery wastewater showed 10 mW/m^3 at 7.06 kg-SCOD/m^3-d [7], whereas a single chamber MFC with a brewery wastewater MFC produced 29.9 W/m^3 at 1.06 kg-SCOD/m^3-d [8]. MFCs using fermentation effluents showed 12.5 W/m^3 at 0.19 kg-COD/m^3-d [9].

Although the effects of substrates on MFCs have been well studied, MFCs have not been applied to sewage or WWTPs. Nevertheless, commercialization of MFCs takes a step further. To apply the MFCs on a full-scale plant, more operating data for the continuous flow mode of a MFC, using real wastewater, are required. Therefore, in this study, a multi-baffled single chamber MFC (MBSC-MFC) using four different wastewaters (cafeteria wastewater [CW], domestic wastewater (influent [IP] and effluent [EP] of primary settling tank in domestic WWTP), and milk processing wastewater [MW]) under continuous flow mode was investigated. In addition, the effect of the OLR and substrate types on power production was analyzed.

2. Materials and methods

2.1. MBSC-MFC construction

The MBSC-MFC unit (L × H × D; 28 × 23 × 2.5 cm) consisted of two separator electrode assemblies (SEAs: SEA1 and SEA2), which shared one anodic compartment (working volume: 650 mL). Eight rectangular-type baffles were installed in the anode chamber to enhance the internal fluid flow (Fig. 1). The SEA consisted of an anode, a air-cathode, and a separator. Graphite felt (GF-20-5F, Nippon Carbon, Japan) with a thickness of 5 mm was used as the anode (20 cm [L] × 15 cm [H]). The air-cathodes were constructed of a stainless steel mesh (SUS 316) with more than 90% purity multi-wall carbon nanotubes (Carbon Nano-material Technology, Korea) as the catalyst and 10 wt.% polytetrafluoroethylene as the diffusion layer and treated based on the study reported by Cheng et al. [10]. Cation exchange membranes

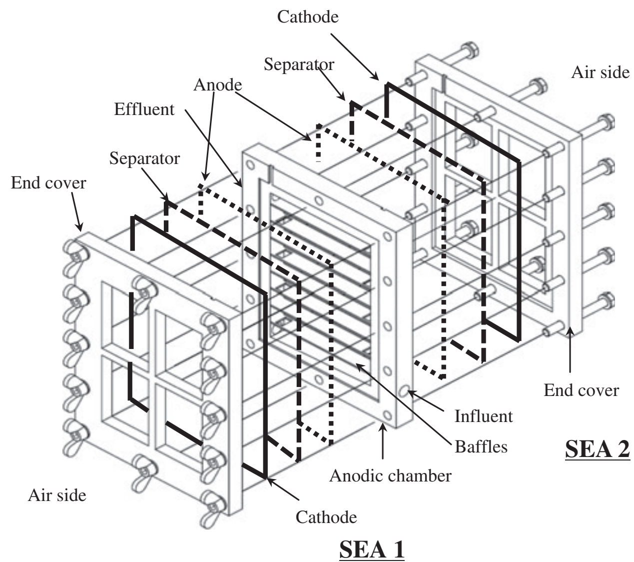

Fig. 1. Laboratory-scale MBSC-MFC unit.

(CMI-7000, Membrane International Inc., USA) were applied as the separator.

2.2. MBSC-MFC operating conditions

The anode compartment was inoculated with activated excess sludge (3,000 mg/L of MLSS concentration) from a domestic WWTP (Daejeon, Korea) and was recirculated for 24 h. To enrich the EAB on the anode, the MBSC-MFC was operated with 500 mg/L (as COD) of glucose and 50 mM of phosphate buffer solution (PBS) in fed-batch mode at room temperature (19 ± 2˚C) for the first two months. After two months, the MBSC-MFCs were operated in continuous flow mode with different influent sources (CW from institute cafeteria, IP and EP from domestic WWTP, and MW from milk processing WWTP [Namyang Co., Cheonan, Korea]) and different hydraulic retention times (HRT) (12, 6, 4 and 2 h) for 10 months at room temperature (18 ± 5˚C). The anode and cathode were connected with copper wire with an external resistance (100 Ω). Table 1 lists the detailed operating conditions.

2.3. Analytical measurement and calculation

The voltage across the external resistor in the MFC circuit was measured using a data acquisition system (2700, Keithley Instrument, USA) and recorded every 600 s on a personal computer. The polarization curves of the air-cathode MFC were obtained by linear sweep voltammetry with a scan rate of 10 mV/s using a

Table 1
Operating conditions for a MBSC-MFC

Influent source		Influent SCOD (mg/L)	HRT (h)	SCOD loading rates (kg/m^3-d)	pH	Conductivity (mS/cm)
CW		341 ± 89	12 & 6	0.6 & 1.2[a]	6.0 ± 0.6 6.9 ± 0.1[a]	0.9 ± 0.1 6.2 ± 0.1[a]
Domestic wastewater	Influent of primary clarifier (IP)	191 ± 51	6 & 2	0.6 & 1.9	7.1 ± 0.2	0.6 ± 0.1
	Effluent of primary clarifier (EP)	91 ± 22	6, 4, 2 & 1	0.3, 0.5, 1 & 2	6.9 ± 0.2	0.6 ± 0.1
Milk processing wastewater (MW)		972 ± 184	6, 4, 2 & 1	3.8, 5.6, 11.3 & 22.5	6.9 ± 0.1	1.2 ± 0.1

[a]CW was adjusted by PBS for pH and conductivity.

potentiostat (WMPG1000, WonATech, Korea). The current was calculated as I (A) = V/R_{ext}, where V is the voltage (V) and R_{ext} is the external resistance (Ω). The current density was calculated using the following equation: CD (A/m^2) = I/anode surface area. The power density was calculated from P (W/m^3) = $I \cdot V$/anodic volume. The soluble COD (SCOD) was measured using a COD test kit (HS-COD_{Cr}-LR, Humas Co., Korea). The conductivity and pH were measured using a digital conductivity meter (HQ14d, HACH) and pH meter (HM-31P, TOADKK), respectively.

3. Results and discussion

3.1. Effect of the conductivity on power generation

Conductivity is one of the important factors in MFCs for power generation, which can be controlled by PBS [1]. On the other hand, it is impossible to control the conductivity in real wastewater. Therefore, to examine the effects of conductivity on power generation in MFCs, the CW was operated in a continuous flow mode with a HRT of 12 h according to PBS. The P_{max} in MFC without PBS was 2.7 W/m^3 (Fig. 2). After controlling the conductivity of CW with PBS, the P_{max} was increased dramatically to 8.6 W/m^3, which was higher than the power density in the MFC at 1.2 kg/m^3-d. The conductivity is believed to be one of the main factors affecting the generation of power from the MFC using real wastewater.

3.2. Effect of OLRs on power generation

In general, the MFC performance should be affected by the OLR. In the case of CW, as the OLR increased from 0.6 kg/m^3-d to 1.2 kg/m^3-d, the P_{max} increased from 2.7 to 3.5 W/m^3 and the open circuit voltage (OCV) increased from 350 to 392 mV. On the other hand, R_{int} was between 25 and 27 Ω (Fig. 2).

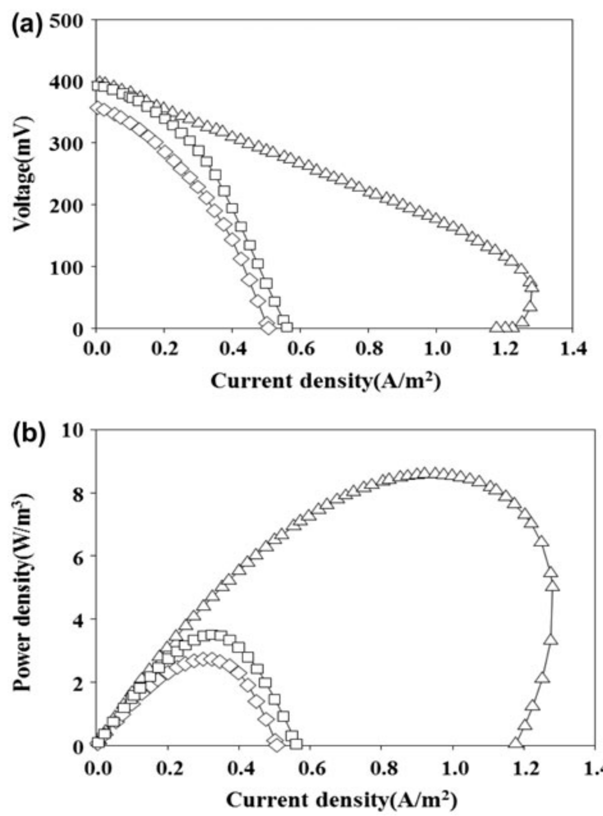

Fig. 2. Polarization (a) and power (b) curves in MBSC-MFC fed with CW according to the ORL. △: HRT 12 h with PBS, ◇: HRT 12 h without PBS, and □: HRT 6 h without PBS.

The P_{max} obtained from the MFC with IP was 6.9 W/m^3 at 0.6 kg/m^3-d and 8.9 W/m^3 at 1.9 kg/m^3-d, and the OCV increased from 626 to 648 mV with increasing OLR (Fig. 3). Even if the OLR of IP and CW were similar, the P_{max} and OCV in MFC using IP were more than 2.5 times higher than those in the MFC using CW because sodium hypochlorite used as a bleaching

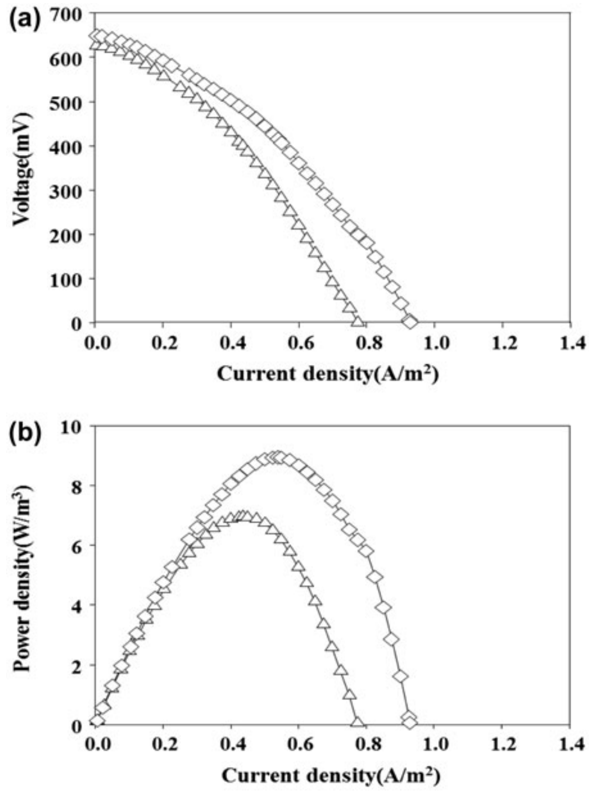

Fig. 3. Polarization (a) and power (b) curves in MBSC-MFC fed with IP according to the ORL. △: HRT 6 h and ◊: HRT 2 h.

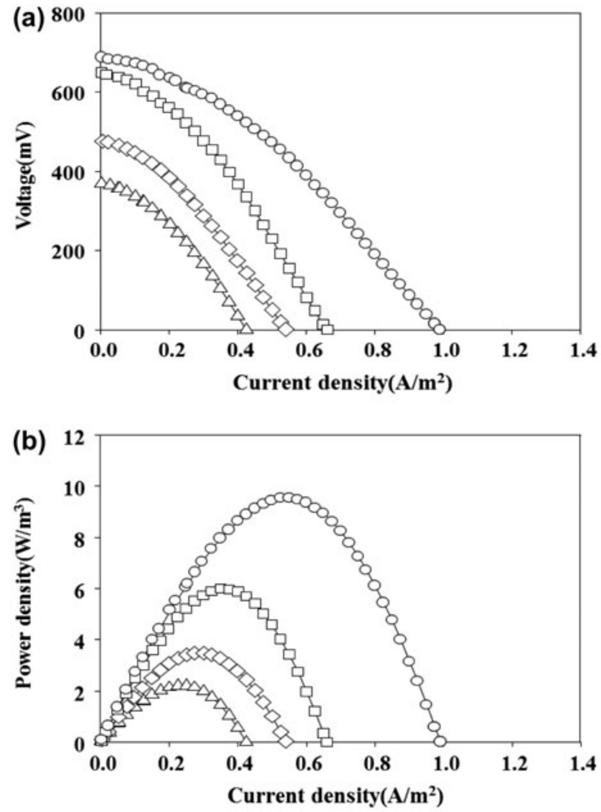

Fig. 4. Polarization (a) and power (b) curves in MBSC-MFC fed with EP according to the ORL. △: HRT 6 h, ◊: HRT 4 h, □: HRT 2 h, and ○: HRT 1 h.

agent in cafeterias might inhibit the EAB with CW. In this case, R_{int} was between 25 and 30 Ω, which is similar to that of the MFC using CW. In the case of using EP, as the OLR increased from 0.3 to 2 kg/m^3-d, P_{max} increased from 2.2 to 9.6 W/m^3 and the OCV increased from 370 to 688 mV (Fig. 4). R_{int} relatively remained constant between 26 and 37 Ω.

When MW was used as a substrate, P_{max} in the MFC using MW showed similar trends. By increasing the OLR from 3.8 to 22.5 kg/m^3-d, P_{max} increased from 6.5 to 19.5 W/m^3. In contrast to the MFC using CW, IP, and EP, the OCV decreased from 677 to 624 mV and R_{int} also decreased from 41 to 7 Ω (Fig. 5).

Although the influent source was different, power generation increased with increasing OLR. These results are consistent with those of previous studies. A submerged type MFC system using domestic wastewater showed an increase in P_{max} from 350 to 534 mW/m^3 with increasing OLR from 0.2 kg/m^3-d to 0.4 kg/m^3-d [6]. The MFC using domestic wastewater achieved a P_{max} of 12.8 W/m^3 at 54 kg/m^3-d [11]. Power generation from the MFC increased from 1.8 W/m^3 to 3.0 W/m^3 with increasing OLR from 1.92 to 3.84 kg/m^3-d [12].

3.3. Power generations in MBSC-MFC according to influent sources

P_{max} using different influent sources was compared at the same linear velocity (HRT of 6 h). The MFC using IP showed the greatest P_{max} (6.9 W/m^3), followed in order by MW (6.5 W/m^3), CW (3.5 W/m^3), and EP (2.2 W/m^3), even though the MFC using MW was operated with the highest OLR (Table 2). Considering the OLR, P_{max} (7 W/m^3 at 0.6 kg/m^3-d) in the MFC using IP was higher than that (2.7 W/m^3 at 0.6 kg/m^3-d) in the MFC using CW. P_{max} (9.6 W/m^3 at 2.0 kg/m^3-d) in the MFC using EP was higher than that (9 W/m^3 at 1.9 kg/m^3-d) in the MFC using EP.

The influent source is also considered one of the most important factors affecting the MFC performance, and a variety of substrates ranging from pure compounds to complex mixtures can be used [4]. The

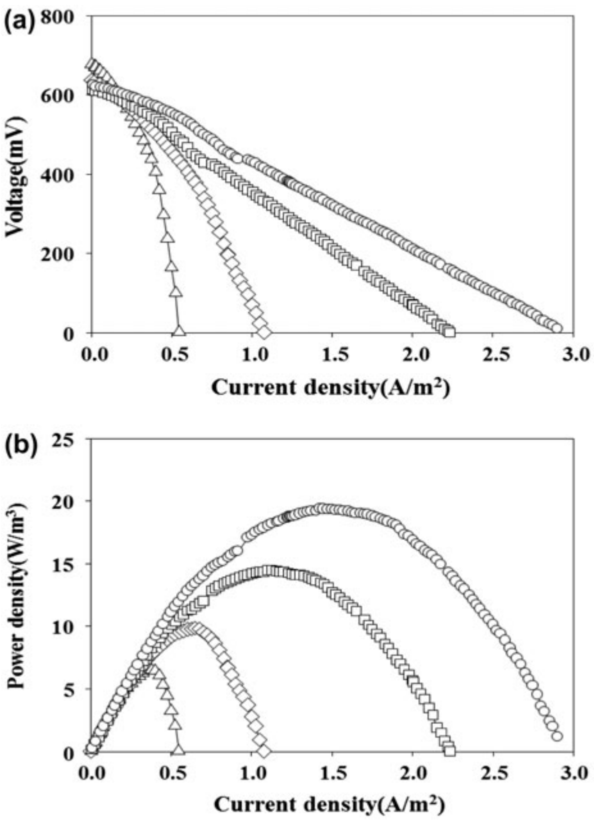

Fig. 5. Polarization (a) and power (b) curves in MBSC-MFC fed with MW according to the ORL. △: HRT 6 h, ◇: HRT 4 h, □: HRT 2 h, and ○: HRT 1 h.

Table 2
Maximum power densities (P_{max}) in the MBSC-MFC according to the influent sources

Influent sources	SCOD loading rates (kg/m^3-d)	HRT (h)	P_{max} (mW/m^3)
CW	0.6	12	2,740 ± 610
	1.2	6	3,510 ± 758
IP	0.6	6	6,966 ± 159
	1.9	2	8,956 ± 455
EP	0.3	6	2,219 ± 218
	2.0	1	9,562 ± 708
MW	3.8	6	6,563 ± 232

power output varied with different substrates (0.5–2.2 mM). The glucose-fed MFC generated the highest P_{max} of 156 mW/m^2, followed in order by acetate-fed MFC (64.3 mW/m^2), propionated-fed MFC (58 mW/m^2), and butyrate-fed MFC (51.4 mW/m^2) [13]. P_{max} of the MFC fed with acetate (506 mW/m^2 at 800 mg/L) was up to 66% higher than that fed with butyrate (305 mW/m^2 at 1,000 mg/L) [14]. The glucose-fed MFC showed the greatest P_{max} of 1.5 W/m^2, followed in order by acetate-fed MFC (1.3 W/m^2), mixed substrates-fed MFC (1.1 W/m^2), butyrate-fed MFC (0.8 W/m^2), and propionate-fed MFC (0.7 W/m^2) under identical COD concentrations of 510 mg/L [15].

4. Conclusions

The power generated from MBSC-MFCs varied according to the influent source and the OLR. Using identical wastewater, P_{max} increased with increasing OLR. Although the MFC with different influent sources was operated with the same OLR or same HRT (linear velocity), the MFC showed different power generation. This suggests that power generation would be affected significantly by the influent source, the OLR and the linear velocity. Therefore, it is important to consolidate the optimal operating conditions (ORL and HRT) after selecting the target wastewater for the practical applications of MFC.

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