Bioelectricity Generation Through Microbial Fuel Cell Using Organic Matters Recovered From Municipal Wastewater

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An aerated-cathode microbial fuel cell (MFC) was used in this study for bioelectricity generation using the recovered organic matters (ROMs) from real municipal wastewater. Although no preconditioning or inoculation was used before the cell startup, the voltage began to increase as the operation of MFC was started. The working voltage registered the maximum value of 256.3 mV after 120–130 h operation. Proton accumulation and pH deviation in the anode chamber resulted in the deterioration of cell performance during the experiment. Electrochemical impedance spectroscopy analysis showed that the polarization resistance was the dominant component of internal resistance compared to the ohm resistance. It was also found that total suspended solids (TSS) and volatile suspended solids (VSS) reduction rate could reach 56.9% and 62.1% in the working MFC, respectively, compared with 31.7% of TSS reduction and 31.9% of VSS reduction in the control test. It indicated that bioelectricity generation could enhance the ROMs degradation. Fourier transform infrared spectrometry spectra demonstrated that the aliphatic compounds and protein-like substances related to Amide II could be preferentially hydrolyzed and biodegraded in the working MFC. The hydrolysis of the particulate organic matters was the rate limiting step for bioelectricity generation. Anat Rec, 00:000–000, 2013. © 2013 Wiley Periodicals, Inc.

Keywords: biodegradation; bioelectricity; recovered organic matters; wastewater treatment

INTRODUCTION

Traditional goals of conventional activated sludge (CAS) treatment are the oxidation of organic material (collectively measured as biochemical oxygen demand) and the oxidation of ammonium. These reactions are brought about with oxygen as the final electron acceptor. Organic material is mineralized to H2O, CO2, NH4+, and other constituents, and NH4+ is oxidized to nitrite and/or nitrate [1]. By consuming a large quantity of oxygen, huge amounts of waste activated sludges (WASs) are produced during this process, which are difficult to treat and dispose of.

To date, a new paradigm has been emerging with regard to the treatment of municipal and industrial wastewaters. As stated by Perry L. McCarty in his address at the opening general session of the 2007 Water Environment Federation Technical Exhibition and Conference (WEFTEC), “our general goal of solving our problems by oxidizing organic wastes to CO2 is now open to question” [2]. In the future, the objective should be shifted to treat wastewater not as a waste but as a resource for water, energy, and nutrients, while reducing the impact of wastewater treatment on greenhouse gas emissions [3–5].

Microbial fuel cells (MFCs), which convert chemical energy in organic matters directly into useful electrical energy by the catalytic reaction of microorganisms, have attracted much attention in recent years [6,7]. In the past decade, the fundamental aspects of MFCs, such as cathode materials, anode materials [8], separators [9,10], and substrates [11] have been intensively studied. To improve MFC performance, tremendous efforts have been made by using technical and engineering approaches [12–14]. Although remarkable progress has been achieved in the power density of MFC, there is a long way to go before its future practical applications. This might be attributed to the fact that the major substrates are artificial wastewaters with very limited real industry wastewaters [11]. Compared with industry wastewater, municipal wastewater has lower strength organic pollutants, which is believed to impact the efficiency of bioelectricity generation. Recently, WAS has been used as fuel to MFCs [14–17]. Jiang et al. [17] produced a maximum power density of 8.5 W m–2 from sewage sludge and obtained a total chemical oxygen demand (tCOD) removal of 46.4% using a two-chamber MFC. Xiao et al. [15] and Liu et al. [16] reported that a power density of 36.8–40.1 mW m–2 and 220.7 mW m–2 from excess sludge was achieved using a two-chamber and a single chamber floating-cathode MFC, respectively. This expands the possible applications of MFC in wastewater treatment field.

In this study, we used organic matters recovered from real municipal wastewater as the fuel of a two-chamber MFC. The organic matters were recovered from municipal wastewater using an upflow dynamic membrane separation (DMS) reactor, the feasibility of which has been preliminarily testified. The recovered organic matters (ROMs) was a kind of slurry mixture (concentration in terms of total solids is about 20 g L–1) harvested under nonaeration conditions, containing abundant organic compounds and diverse microbial communities. If the ROMs can be used to generate bioelectricity, it will not only realize the recovery of “energy”...
from wastewater but also save a large quantity of energy required by aeration in CAS systems. Besides, by directly using ROMs as fuel, it can avoid the production of huge amounts of WAS in the downstream treatment unit. To the best of our knowledge, this is the first time to use ROMs from municipal wastewater as fuel for MFCs to generate bioelectricity.

The objective of this study is, therefore, (1) to explore the feasibility of using an aerated-cathode MFC fed with ROMs for bioelectricity generation, (2) to evaluate the cell performance and clarify the factors affecting MFC efficiency, and (3) to investigate the degradation of ROMs in the MFC. The results obtained in this study are expected to provide a sound understanding of the fundamentals of MFC fed with ROMs and to lay the groundwork for future enhancement of MFC performance.

MATERIALS AND METHODS

MFC Configuration and Operation

The cubic-shape MFC consisted of two identical Plexiglas chambers separated by a proton exchange membrane (PEM, Naﬁon™, Dupont Co.) (Figure 1). Each chamber had a volume of 500 mL ($L = 10$ cm, $W = 10$ cm, $T = 5$ cm). After electrodes (carbon felt, Junrui Co., China), Ag/AgCl reference electrode (Yueci Co., China), and air sparger were installed, the liquid volume of anode and cathode chamber decreased to 420 and 400 mL, respectively. External electrical circuit was connected to the electrodes by pushing a graphite rod (6 mm diameter) into the carbon felt. Continuous recirculation of the anodic liquid at a rate of 100 mL min$^{-1}$ (Figure 1) was performed to keep the ROMs well mixed. Nitrogen gas was used to remove the probable dissolved oxygen in the anodic loop. In the cathode chamber, air was supplied into the solution through an air pump. The temperature of the system was controlled at 25 ± 2°C. To compare the degradation behaviors of ROMs in anaerobic digestion and MFC process, a control experiment was also performed using an identical MFC operated in the same way as the aforementioned working MFC but under open-circuit operation.

Substrates

The anode chamber of the MFC was fed with ROMs obtained from an upflow DMS reactor. The configuration of DMS reactor was similar to that of the anaerobic dynamic membrane bioreactor in our previous publication [18] but under different operating conditions. The average hydraulic retention time of the reactor was 2.2 h via a high flux 60 L (m$^2$ h$^{-1}$) operation of membrane modules. Polyferric sulfate (PFS) was chosen to enhance the recovery of carbon in this study. After coagulated at an effective concentration of 50 mg PFS/L in the influent tank, wastewater from the wastewater treatment plant (WWTP) was fed into the upflow DMS reactor. About 1–1.5 L of ROMs was daily discharged from the mud-valve located at the bottom of the reactor. The oxidation-reduction potential at the bottom of the settling zone was −(314 ± 82) mV during the operation, indicating the ROMs could be harvested under almost anaerobic conditions.

The initial pH, total suspended solids (TSS), volatile suspended solids (VSS), tCOD, soluble chemical oxygen demand (SCOD), and conductivity of the ROMs was 6.79, 20.37 g L$^{-1}$, 10.73 g L$^{-1}$, 19,760 mg L$^{-1}$, 217.7 mg L$^{-1}$, and 968 lSc m$^{-2}$, respectively. The cathode chamber was fed with 0.01 M phosphate-buffered saline (pH = 7.0) [19]. The initial conductivity of cathode medium was 1387 µS cm$^{-1}$.

Analyses and Calculations

Electrochemistry Analysis

The graphite electrical contacts of both chambers were connected to an external resistor ($R_e$, 1000 Ω). The voltage...
Logan et al. MFC was calculated according to the method reported by China. Power density and Coulombic efficiency (CE) of the digital conductometer (Starter 300 C, Ohaus Instruments Co., China) was evaluated by conductivity measurement using a standard variance of liquid resistance in the anode chamber of the MFC by electrochemical impedance spectroscopy (EIS) using a multifunctional electrochemical workstation (CS350, Corrtest Co., China). Power density and Coulombic efficiency (CE) of the MFC was calculated according to the method reported by Logan et al. [7].

Change in internal resistance of the cell was monitored by electrochemical impedance spectroscopy (EIS) using a multifunctional electrochemical workstation (CS350, Corrtest Co., China). EIS measurements were conducted at open circuit voltage (OCV) over a frequency range of $10^2$ to $10^{-2}$ Hz with a sinusoidal perturbation of 5 mV amplitude [20]. The internal ohmic resistances and the polarization resistances of the cell were calculated from the equivalent circuit (EC) of the system. The software ZView (Scribner Associates) was used to process and fit the EIS data.

Elemental Analysis and Fourier Transform Infrared Spectrometry

The substrate samples from the anode chamber were first centrifuged at 6000 rpm for 10 min. Then, it was freeze-dried (~$-40^\circ$C, 48 h), ground, sieved (size fraction of 50–100 mesh), and finally stored in a desiccator for further analysis. The contents of C, N, and H in the samples were analyzed by an elemental detector (Vario EL III, Elemental, Germany). Fourier Transform Infrared Spectrometry (FTIR) of the sample was performed using Nicolet 5700 FTIR (Thermo Electron). KBr tabletting method was used for sample preparation. The ratio of the sample to KBr was 1:100, and the sample was prepared at a pressure of 30 kPa.

Other Item Analysis

The TSS, VSS, SCOD, and pH of slurry samples were measured according to the Standard Methods [21]. Dissolved organic carbon (DOC) was analyzed using a total organic carbon (TOC) analyzer (TOC-VCPN, SHIMADZU, Japan).

RESULTS AND DISCUSSION

Electricity Generation from the MFC using ROMs

Figure 2 shows the variations of voltage and anode potential with operation time after the ROMs was fed into the anode chamber. Although no preacclimation or inoculation was used before the cell startup, the voltage began to increase as soon as the operation of MFC was started. In previous literature, Zhang et al. [22] reported that their reactor fed with conventional WAS had a transient lag phase of 24 h and gradually reached the maximum power production after a startup time of 300 h. Therefore, it might be concluded that the ROM could be a good alternate for inoculating the MFCs.

After a steady decline of the anode potential at the beginning of the experiment, the maximum OCV reached to 514 mV and the working voltage registered the value of 256.3 mV at around 120–130 h. With the increase of the anode potential from $-450 \pm 5$ mV to $-341 \pm 4$ mV, the output voltage gradually decreased to 160 mV at 420 h, and then fluctuated from 225 to 195 mV (Figure 2). When the anode potential was higher than $-300$ mV, the experiment was stopped. The aerated-cathode MFC was operated for nearly 40 days, and the experimental data demonstrated that bioelectricity generation from ROMs using MFC was feasible. During the operation, the maximal power density reached 0.16 W m$^{-2}$, and CE on average was about 5.4%, probably attributed to the production of methane or hydrogen sulfide (not measured in this study).

Estimation for the competition among the electron acceptors should be considered in future work to evaluate the electron loss in the bioelectrochemical system.

There was a sharp decrease of anode potential and voltage at around 360–420 h (Figure 2). To specify the deterioration of the power production, the variations of pH and conductivity in the anode chamber of MFC and in the control test were monitored over time (Figure 3). As shown in Figure 3A, the conductivity linearly increased with the increase of operation time and registered a maximum value of 4220 $\mu$S cm$^{-1}$ at the end of the operation period. No obvious acidification was observed in the control test over time. However, the situation was quite different in the anode chamber of the working MFC. At the beginning of the experiment, the released protons could easily pass through the PEM (Nafion-117) to enter the cathode chamber under low electrolyte concentration (e.g., low content of Na$^+$, K$^+$) [23], which even resulted in a slight increase of pH in the anodic compartment (Figure 3B). It has been reported that the PEM of the Nafion type possesses a preferential conductivity for protons, but the conductivity ratio is as low as 3.4 for H$^+$/Na$^+$ and 6.2 for H$^+$/K$^+$ for Nafion-117 [24]. When using a cation/proton exchange membrane, the ion transfer from the anode to the cathode will be accomplished almost exclusively by the metal cations, as long as their concentration is considerably above that of the protons [9]. In Figure 3B, it can be observed that the conductivity (or total dissolved solids) of the anodic liquor began to increase rapidly from 7 days, which might be attributed to the hydrolysis and release of the inorganic component in ROMs. The abundance of the metal cations in the anode chamber induced their preferential transfer through the PEM for charge balance, and subsequently resulted in an accumulation of the protons and the decrease of pH (Figure 3B). After 23 days of operation, pH and conductivity in the anode chamber reached the minimum (pH = 4.44 ± 0.56) and the maximum (conductivity = 5026.0 ± 61.6 $\mu$S cm$^{-1}$), respectively.

When the anode pH decreased below 6.0 at 14 days (336 h), the output voltage began to decline rapidly and gradually reached its lowest value of 160 mV after 414-h operation (Figure 2). It has been reported that the continuous decrease of pH not only led to the deactivation of biocatalyst activity but also a considerable reduction of the thermodynamic cell potential [9]. Cheng et al. [25] and He et al. [26] reported that pH 5 showed a severe inhibition on electricity generation in MFCs. Although the recovery of the output voltage was observed at around 420–540 h probably due to the acclimation of exoelectrogens to the low-pH environment, the power production from the cell was significantly decreased compared with that at a neutral pH.
Changes in Internal Resistance over Operation Period

The internal resistance in the MFC can be generally divided into ohm resistance ($R_Ω$, including membrane resistance, solution resistance, etc.) and polarization resistance ($R_p$, electrochemical polarization resistance and concentration polarization resistance) [27]. As the internal resistance changed with the variation of medium pH and conductivity over time, the complex impedance ($Z$) versus frequency, known as Nyquist plot, was measured at OCV to evaluate the ohm resistance and polarization resistance at different operation time in the working MFC (Figure 4). The insert of Figure 4A illustrates the high-frequency part of the EIS. The Nyquist plots of the cell on 21 and 38 days represented a well-defined frequency-dependent semicircle impedance curve over high frequency followed by straight line, but that on 10 days had no defined semicircle, which indicated the charge-transfer resistance at the heterogeneous interface increased with the operation time [28]. At the same time, the variations of straight line slope over low frequency of the MFC (Figure 4A) also implied an increase of the internal resistance over time due to the decreased proton motive force by the spatial maldistribution of protons and metal cations in the cell [26].

A modified Randle EC [29] was chosen to model the complex impedance in the electrochemical cell (Figure 4B). In this study, the overall resistance of the cell includes the ohm resistance ($R_Ω$) and the polarization resistance ($R_p + R_a + R_c$). $R_a$ and $R_c$ are expressed as polarization resistance in the anode and cathode chamber, respectively, and $R_w$ is the diffusion resistance of Warburg impedance related to oxygen diffusion in the cathode electrode. Fitting results are listed in Table 1. It can be found that $R_p$ accounted for over 95% of the $R_{\text{int}}$. This phenomenon indicated that under low electrolyte conditions, the electrical double layer at the heterogeneous interface (electrode/electrolyte interface and electrolyte/membrane) was more loosely coupled [9,20] and the diffusion-limiting step determined the cell performance. In accordance with its negative effects on output voltage, the decrease of pH from 10 to 21 days (Figure 5) without a buffer control resulted in an increase of $R_{\text{int}}$ by 50%. At the end of the operation, great polarization was induced due to the decrease of current density, which was responsible for

Figure 3. pH and conductivity changes in (A) the control test and (B) the anode chamber of the working MFC. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Figure 4. The internal resistance of the aerated-cathode MFC: (A) Nyquist plots of the impedance versus frequency, and (B) EC of the cell. The complex impedance ($Z$) is made up of the real part ($Z'$) and the imaginary part ($Z''$), which can be expressed as $Z = Z' + jZ''$. $C$ represents capacitors formed at the interface between electrodes and their surrounding electrolyte, $R_a$ and $R_c$ are expressed as polarization resistance in the anode and cathode chamber, respectively, and $Z_w$ means Warburg impedance related to oxygen diffusion from the cathode chamber and $R_w$ is the diffusion resistance of $Z_w$. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]
the dramatic increase of $R_{\text{int}}$ (Table 1). In this study, the high internal resistance should be closely related to the features of the raw ROMs. In future, some pretreatment methods of ROMs should be adopted to improve the aerated-cathode MFC performance.

Effect of MFC Process on ROMs Degradation

The differences of ROMs degradation between the working MFC and control test were investigated, and the results are summarized in Figure 5. As illustrated in Figure 5A, the TSS and VSS of the ROMs decreased in the working MFC and the control test, but the reduction rate was higher in the MFC compared with the control test. At the end of the operation, the TSS and VSS reduction rates of ROMs in the MFC were 56.9% and 62.1%, while those in the control test only reached 31.7% and 31.9%, respectively. Notably, the TSS reduction rate of ROMs in the MFC gradually became higher than that in the control test from 7 days, which was also in accordance with the increased salinity in the anodic chamber (Figure 3B). These results suggest that the bioelectricity generation process from ROMs enhanced the anaerobic microbial metabolism and accelerated the hydrolysis of particulate organic matters. It is in agreement with the results of using WAS as fuel of MFCs [15,22].

The variations of SCOD and DOC in the supernatants in the anode chamber during the operation are shown in Figure 5B. Apparently, the particulate COD was first hydrolyzed into SCOD with the function of biochemical processes in the cells, and then the exoelectrogens took up the SCOD and converted it into bioelectricity and metabolites [30]. In this study, the SCOD of the supernatant in the anode chamber was sharply increased at the beginning, and steady power production was observed simultaneously (Figure 2). From 4 to 9 days, the SCOD was gradually decreased, while the cell voltage was maintained at the relatively high value of 245 ± 5 mV. This phenomenon indicated that the hydrolyzed products could be efficiently metabolized for power production even at low concentrations, and that the usage of soluble organics for bioelectricity generation was faster than the hydrolysis of the particulate organic matters, evidenced by the declining SCOD over the testing period (Figure 5B) [30]. Therefore, it is possible to hypothesize that the hydrolysis of ROMs was the rate limiting step for the bioelectricity generation.

With the accumulation of protons in the anode chamber from 9 days (Figure 3B), the continuous decrease of pH not only led to the deactivation of bioelectricity generation activity but also the inhibition of particulate organics hydrolysis. The VSS degradation rate in neutral conditions was higher than that in acid conditions (see the solid red line and dotted red line in Figure 5A). After the microbes were gradually acclimated to the low-pH environment during 420–540 h (Figures 2 and 3B), the supernatant SCOD in anode chamber and the output voltage were increased with the improvement of particulate organics hydrolysis. Additionally, the variation

<table>
<thead>
<tr>
<th>Operation time (days)</th>
<th>Ohm resistance $R_0$ (Ω)</th>
<th>Polarization resistance $R_p$ (Ω)</th>
<th>Internal resistance $R_{\text{int}}$ (Ω)</th>
<th>Model chi-squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>13.82 ± 0.10</td>
<td>402.87 ± 56.00</td>
<td>416.69 ± 56.10</td>
<td>0.07</td>
</tr>
<tr>
<td>21</td>
<td>20.59 ± 0.22</td>
<td>654.47 ± 55.90</td>
<td>655.06 ± 56.12</td>
<td>0.17</td>
</tr>
<tr>
<td>38</td>
<td>18.83 ± 0.16</td>
<td>1984.56 ± 825.16</td>
<td>1953.39 ± 825.32</td>
<td>0.14</td>
</tr>
</tbody>
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Figure 5. Comparison of the MFC and control test regarding (A) TSS and VSS reduction and (B) SCOD and DOC change. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]
of DOC in anodic electrolyte was correlated with that of SCOD (Figure 5B), indicating the carbonic organic matters contributed to the majority of SCOD in the anodic supernatant.

FTIR analyses were used to study the effect of MFC process on ROMs degradation. Figure 6A demonstrates the FTIR spectra of the raw ROMs on 0 day, and three categories of organic matters could be well distinguished: aliphatic compounds with methylene groups (stretching vibration at 2950 cm$^{-1}$ and flexural vibration at 1460 cm$^{-1}$), protein-like substances with carboxyl groups (symmetrical stretches of $\text{COO}^{-}$ at 1385 cm$^{-1}$), Amide I and Amide II (twin peaks at 1540 and 1650 cm$^{-1}$ related to protein secondary structure), and polysaccharides or polysaccharide-like substances (symmetric and asymmetric C=O stretch at 1000–1200 cm$^{-1}$) [31]. The degradation of these organic compounds in the anode of MFC over time was evaluated by normalized functional group intensity through quantitative FTIR analysis (Figure 6B). Due to the inevitable influence of Si–O (at 1000 cm$^{-1}$) on the presence of C=O (polysaccharides or polysaccharide-like substances), temporal variations of aliphatic compounds, and protein-like substances in the MFC will be discussed in the following section.

As shown in Figure 6B, the content of aliphatic compounds and protein-like substances in the ROMs decreased during the experiment. In the aliphatic components, it could be noticed that the normalized functional group intensity of C=H scissor flexural vibration was decreased faster than that of C–H asymmetric stretching vibration. This might be attributed to the decomposition of condensed aliphatic moieties and the break-up of the large molecules into smaller fragments, such as a reduction of conjugated bond in a chain structure or an elimination of particular functional groups including carbonyl, carboxyl, and hydroxyl. The protein-like substances were also proved to be the readily biodegradable components. At the end of the operation, the intensities of Amide II peak (1540 cm$^{-1}$) and carboxyl groups peak (1385 cm$^{-1}$) related to protein-B were decreased significantly by 58% and 52%, respectively, while that of Amide I compounds was just reduced by 28%. These results indicated that protein-like substances related to Amide II were more biodegradable than those related to Amide I for bioelectricity generation. Moreover, the carbon to nitrogen ratio (C/N ratio) in the ROMs was quickly decreased from the initial 7.39 to 6.73 ± 0.06 on Day 6 and then fluctuated between 6.71 ± 0.08 and 6.90 ± 0.05. This phenomenon suggested that at the beginning of the MFC operation, the organic compounds with lower nitrogen content (e.g., aliphatic carbohydrate) could be more efficiently utilized by the microbes compared with those with higher nitrogen content (e.g., protein-like substances), indicating an increase of substrate C/N ratio in proper range could benefit the bioelectricity generation from the ROMs using the MFC.

In this study, power production from ROMs was achieved by using the aerated cathode MFC. It is worth pointing out that by directly using ROMs as fuel it can efficiently decrease the organic loading rate of the downstream treatment unit and thus avoid the production of huge amounts of WAS. Bioelectricity generation from ROMs is a novel approach to realize the recovery of "energy" from low-strength municipal wastewater. However, several issues should be further considered in future work to improve the performance of the MFC. First, the maximum power production and CE of the cell were limited in this study. To reduce the investment of the system, noble metal catalysts (such as Pt) were not loaded on the cathode electrode herein, thus resulting unsatisfied cathode reactions. Therefore, air-cathode or bio-cathode MFC would be used to improve the performance [6,7]. The CE of the cell was as low as about 5%, which should be attributed to the competition of electron sinks (such as methane and hydrogen sulfide). This study was mainly focused on the evaluation of power production from ROMs, while little attention was paid to clarify the metabolic pathway of electron transfer. In future work, an estimation of methane and hydrogen sulfide production should be conducted, which would provide a good comparison between MFC and anaerobic digestion as an alternative treatment method for ROMs. In addition, due to the absence of buffer saline or base pretreatment, acidification in the anode chamber was observed during the experiment. Although the continuous decrease of pH significantly deteriorated the cell performance, 80–100 mW m$^{-2}$ of power production was obtained at pH 4–5. It is possible to hypothesis that a certain group of microbes could resist the extreme environment stress and were responsible for the bioelectricity generation. Therefore, cultivation and characterization of the microbial communities...
involved in power production in the acid solution is needed, which would extend our knowledge about the metabolism of the exoelectrogens. Besides, the hybrid process should be improved to develop a more cost-effective application for municipal wastewater treatment. In this study, the ROMs were recovered in the upflow MFC reactor and oxidized through MFC process. The ROMs could not be completely degraded through MFC process, suggesting additional process is needed for treating the remained organics. Therefore, further attempts should be considered to combine the units within one reactor, e.g., to couple the MFC with other techniques (such as microfiltration) to improve the effluent quality.

CONCLUSIONS

The aerated-cathode MFC was applied to generate bioelectricity from ROMs. The cell performance and internal resistance variations over time were characterized by electrochemistry analysis. The effect of bioelectricity generation on ROMs degradation was further discussed. Based on this study, the following conclusions could be drawn.

1. Bioelectricity generation from ROMs was realized via the aerated-cathode MFC during the operation. Although no preacclimation or inoculation was used before the cell startup, the voltage began to increase as soon as the operation of MFC was started. The working voltage registered the maximum value of 256.3 mV after 120–130 h operation.

2. Due to nonproton cation transfer, proton accumulation and pH deviation in the anode chamber were found to be the major reasons causing the decrease of cell performance. The ohm resistance $R_{ohm}$ of the cell was low during the experiment and the polarization resistance $R_{p}$ contributed to the majority of the internal resistance.

3. Compared with control test, bioelectricity generation in the working MFC enhanced the ROMs degradation. In the working MFC, the final TSS and VSS reduction rate reached 56.9% and 62.1%, respectively, which was much higher than 31.7% of TSS reduction and 31.9% of VSS reduction in the control test. FTIR spectra demonstrated that the aliphatic compounds and protein-like substances related to Amide II could be preferentially hydrolyzed and biodegraded in the MFC. The hydrolysis of the particulate organic matters was the rate limiting step for bioelectricity generation.

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LITERATURE CITED


