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ELECTRICITY GENERATION CHARACTERISTICS OF AN ANAEROBIC FLUIDIZED BED MICROBIAL FUEL CELL

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ABSTRACT

Anaerobic fluidized bed microbial fuel cell (AFBMFC) was developed to investigate the effect of fluidization behaviors on the electrogenesis capacity. Waste water and active carbon were used as liquid and solid phase, respectively. The fuel cell was started up successfully using anaerobic activated sludge as inoculums. The power density is increased with increasing circular liquid velocity up to 450 $mW·m^{-2}$. High COD remove rate reached 93% after five days operation. Meanwhile, the effects of cathode area on the electrogenesis capacity of AFB MFC were also investigated.

INTRODUCTION

Microbial fuel cell (MFC) is a device that can convert chemical energy from organic matter to electricity (1, 2, 3). The MFC for wastewater treatment is characterized by clean, safe, quiet performance, low emissions, high efficiency, and direct electricity recovery. Accordingly, MFC have great potential as a wastewater treatment approach (3, 4). Extensive studies have demonstrated that electrode materials (5) solution chemistry (7), reactor configuration (1, 2, 3), and some other aspects influence MFC performance.

Recently, several types of membrane-less air cathode MFCs have been developed to operate in either batch or continuous mode. You et al. (8) developed a graphite-granule anode, tubular air-cathode MFC (GTMFC) to increase the power generation. Hu (9) developed a baffle-chamber reactor to improve the CE. He et al (3) used upflow microbial fuel cell (UMFC) to treat artificial wastewater of high COD concentration by combining the advantage of the UASB system.

The fluidized bed reactor technique has been applied in many fields of biotechnology, especially in the biological treatment of wastewaters, where particles with attached microbial growth are fluidized by an uprising flux of the liquid to be treated (10). Ken et al. (11) compared the fluidized bed with packed bed bioreactors to produce biohydrogen and bioethanol, indicating that hydrogen and ethanol production rate in fluidized bed reactors exceeded packed bed reactors. Wen et al. studied (12) the treatment effect of nitrate-nitrogen from wastewater in gas-liquid-solid three phase fluidized bed bioreactor and the average removal ratios of COD and NOx are higher than 92% and 96%.

We have developed a continuously fed MFC configuration, the anaerobic fluidized bed, featured by combing the fluidized bed system with single-chamber air cathode MFC. In this reactor, the wastewater was pumped into the fluidized bed and active carbon particles were fluidized with high mass transfer being achieved. In addition, the anaerobic fluidized bed MFC was more convenient to scale up than other single chamber MFCs. The purpose of the present study was to investigate continuous power generation in the anaerobic fluidized bed. Furthermore, the influence of fluidization behavior, the position, and area of cathode position in fluidized bed on electricity generation were examined.

EXPERIMENTAL

Reactor description

Schematic diagram of the membrane-less fluidized-bed microbial fuel cell (MLFMFC) used in this study is shown in figure1. The membrane-less fluidized-bed MFC was made by a 1L glass effective volume with a diameter of 40 mm and a height of 600 mm. The distributor was a porous glass plate with a thickness of 2 mm, a pore size of 2 mm, and a fractional perforated area of 20%. A graphite rod was placed as the anode. 100 g fresh active carbon particles with an average of 0.2-0.9 mm, bulk density 566 $kg{\cdot}m^{-3}$, true density of 1150 $kg{\cdot}m^{-3}$, porosity of 0.45 were fed in fluidized bed which were used as the carrier media for biofilm. To investigate effects of the cathode area and the cathode position on electricity generation of anaerobic fluidized bed MFC, two carbon cloth cathode (3.14 cm^2, 0.35 $mg{\cdot}cm^{-2}$ Pt; 30%wet–proofing, E-TEK, USA) coated with four diffusion layers were fixed onto one side of the chamber wall (cathodes 1 and 2 are at 150 mm and 300 mm above the distributor). The mixture of 150 mL anaerobic sludge and particle of active carbon were mixed to feed into the reactor. Wastewater was used as the fluidization liquid supplied with a peristaltic pump. During the experiments, the electricity signal generated was recorded by the personal measurement device for analog and digital I/O.

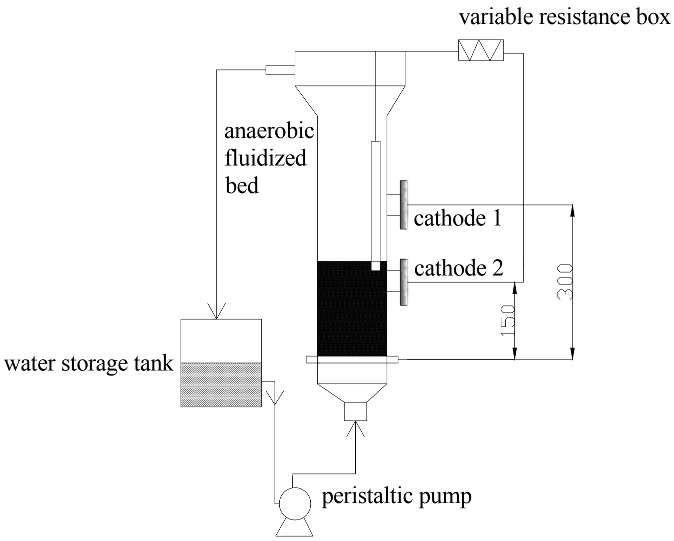

Figure 1 The schematic of Anaerobic fluidized bed MFC

Anaerobic fluidized bed MFC operation condition

The MFC was operated at 31.5 ℃ and were inoculated with 150 mL of anaerobic sludge collected from the Wastewater Treatment Plant, Qingdao, China. Such system was operated for two weeks without sludge disposal, during which particles were coated with biomass. The artificial wastewater used was previously reported [3]. In this test, Polarization curves were obtained by measuring the stable power generated at various external resistances. For each velocity, the fuel cell ran for at least one and half an hour. Meanwhile, the MFC was also operated continuously at a 1.0 mm·s^{-1}～5.0 mm·s^{-1} using a feed containing 3000 mg/L glucose solution.

Analysis and calculations

Voltage (U) was measured with a data acquisition system (USB1608FS, measurement computing corporation, American). The power (P) is calculated by Equation 1.

$$P = \frac{U^2}{RA} \qquad (1)$$

Where A is the reactor effective cathode area, U is output voltage, and R is the external resistance.

The internal resistance of the cell (r) is given using the slope of *V* and *I* using

$$V = E_{cell} - Ir \qquad (2)$$

Where E_{cell} is the electromotive force of the cell, I is the current, r is the internal resistance.

The concentration of chemical oxygen demand (COD) in wastewater is determined by an AQ4001COD measuring instrument (Thermo scientific Orion, US).
COD removal efficiency

$$\varepsilon = [(C_0 - C)/C_0] \times 100\% \qquad (3)$$

Where C_0 represents the initial COD concentration in the feed and C denotes COD concentration at sometimes.

Coulombic efficiency was calculated by the approach

$$CE = \frac{8\int_0^{tb} Idt}{F v_{An} \Delta COD} \qquad (4)$$

Where 8 is a constant used for COD, based on Mo_2=32 for the molecular weight of O_2 , F=Faraday's constant, and ν_{An} is the liquid volume in the anode compartment.

RESULTS AND DISCUSSION

The fluidization behavior of anaerobic fluidized bed

Figure 2 describes typical fluidization curves for active carbon by decreasing liquid velocity. It shows that the pressure drop across the fluidized bed increased with increasing velocity in packed bed then is constant after fluidization. In conventional liquid-solid, low superficial liquid velocities cause particulate fluidized bed. Increasing superficial liquid velocity causes significant particle entrainment. Furthermore, the variations of biofilm are dependent on its growth and shedding. The thickness of biofilm decreases with the increasing velocity. However, the excessive flow will speed up bioflim shedding excessively, so we determine operation liquid velocity ranging from 1.0 to 5.0 mm·s^{-1}.

Electricity generation using fluidized-bed MFC

(A)The liquid velocity on electricity generation with fluidized-bed MFC

Fluidization behaviors in an MFC fluidized bed have an important influence on electricity generation. Figure 3 illustrated polarization curve and power density curve under the different low velocity at particulate fluidization using the cathode 1. It is observed that the maximum power density was 360 mW·m^{-2}, 397 mW·m^{-2} and 420.5 mW·m^{-2} at the velocities of 2.149 mm·s^{-1}, 3.24 mm·s^{-1}, 4.24 mm·s^{-1}, respectively. As expect, the power density and output voltage increase with increasing velocity. The better fluidization quality was obtained with the increasing velocity because the plugging and channeling reduced; moreover, film thickness of microorganism adhered on the active carbon particle decrease with increasing velocity due to enhancing mass transfer efficiency. Note that the maximum power density occurred at the internal resistance of 800-900 Ω, the resistance was higher than that of some previous studies using MFC (1, 3).

(B)The effect of cathode area on electricity generation of MFC

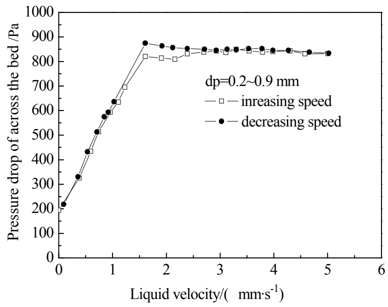

Figure 2 Pressure drops across active carbon and sludge particles with different wastewater velocities

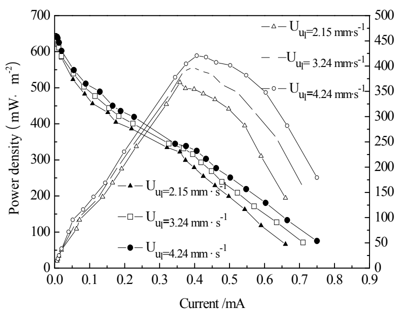

Figure 3 Polarization curve and Power density curve under different velocity of fluidized bed MFC using cathode 1 (above distributor 150 mm

Figure 4 plots current and power density versus output current for anaerobic fluidized bed MFC by the single cathode 1 (above distributor 150 mm), double cathode in parallel connection. As the superficial liquid velocity was maintained at 2.0 mm·s^{-1}, similar open circuit voltages (500 mV) reached for cathode 1 and double cathode in parallel connection, respectively. It should be pointed out that the voltage is sustained with high output current for the double cathode in parallel connection than cathode 1. Short circuit current for single cathode 1(0.7 mA) was lower than double cathode (1.0 mA). Maximum output power density (140 mW·m^{-2}) and current at maximum power (0.2 mA) for the single cathode 1(3.14 cm^2) was also lower than power density (170 mW·m^{-2}) for cathode (6.28 cm^2) in parallel connection. The internal resistance was 1092 Ω, 460 Ω for the single cathode 1and double cathode in parallel cathode in Fig 5. In summary, the open circuit voltage is slightly increased when the double cathode were used, however, the current and power density is greatly increased when the double cathode were employed.

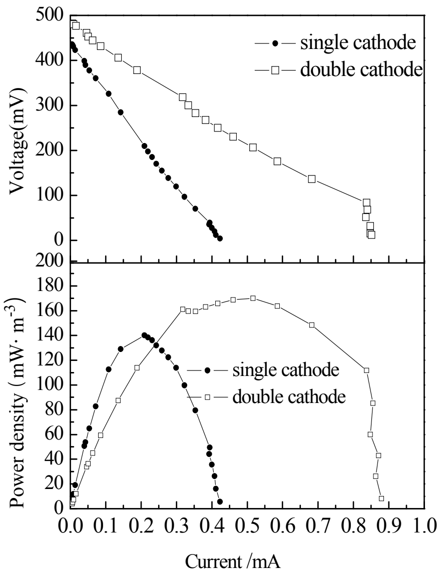

Figure .4 Voltage and power density as a function of current with AFBMFC using the double cathode and single cathode (above distributor 150 mm)

(C)The effect of ionic concentration on electricity generation of MFC

The wastewater treatment of AFB-MFC

To investigate its capacity for wastewater treatment, MFC was operated at initial influent COD concentration of 3000 mg/L under different velocities of artificial wastewater. Figure 7 depicts the variations of COD concentration with changing time. The COD remove rate can achieve 91%, 93% at the velocity of 2.02 mm·s^{-1}, 3.62 mm·s^{-1}, respectively. While Low velocity (≤1.7 mm·s^{-1}), the active carbon can not be in fluidization and wastewater can not be mixed well so that the wastewater treatment was lower 85%. COD remove rate increase with increasing wastewater velocity and increasing PH values. The great COD removal efficiency in this case could be attributed to the better mass transfer efficiency arising from great upflow velocity in fluidized bed.

The low coulombic efficiencies indicated that organic loading was beyond the oxidation abilities of the anodophilic bacteria, and that the substrate was oxidized by other anaerobic microbes, such as mathanogenic archaea. Low coulombic efficiencies, about 5%, implied that the membrane-less reactor had high oxygen permeability than membrane reactor and the electron-transfer bacteria were incapable of converting all of the available organics into electricity, therefore, the excessive substrate created favors the methanogens growth.

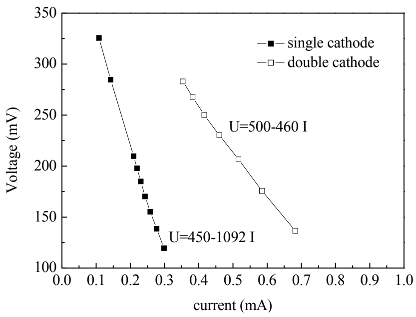

Figure 5 Polarization curve of AFBMFC in region of ohmic polarization wastewater treatment with fluidized-bed MFC using double cathode and single cathode (above distributor 150 mm)

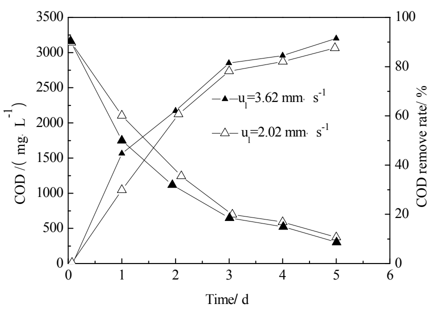

Figure 6 Curves of COD and COD remove rate versus operation time in fluidized bed MFC

CONCLUSION

Based on the present investigation, the following conclusions can be made:

1 By using the anaerobic fluidized bed MFC, we demonstrated that the power density and output voltage increased with increasing velocity in fluidized bed MFC.

2 Double-cathode in parallel connection has a high power density than single cathode.

3 AFBMFC can operate in large-scale wastewater treatment with high COD remove efficiency up to 93%. However, AFBMFC has a low coulombic efficiency.

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NOTATION

U	output voltage	V	P	power density	$mW \cdot m^{-2}$
I	current	mA	u	liquid velocity	$m \cdot s^{-1}$
R	external resistance	Ω	dp	diameter of particles	mm

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