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Enhanced power production from waste activated sludge in rotating-cathode microbial fuel cells: The effects of aquatic worm predation

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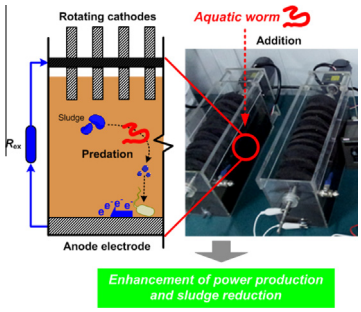
HIGHLIGHTS

- Aquatic worm predation was efficient to enhance power production from sludge.
- The maximum power output was increased by 44.4% compared to the control.
- Predation improved the anode performance of rotating-cathode microbial fuel cells.
- Hydrolysis of particulate organic matter in sludge was accelerated due to predation.

GRAPHICAL ABSTRACT



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ABSTRACT

The effects of aquatic worm predation on power production from waste activated sludge (WAS) were examined using rotating-cathode microbial fuel cells (MFCs). Compared to the control, the maximum power density and total chemical oxygen demand (*t*COD) removal rate of WAS during 10-day operation were increased by 44.4% and 192.0%, respectively, due to aquatic worm predation. Electrochemical measurements revealed that predation could reduce the negative impacts induced by dissolved oxygen leakage, giving a higher open circuit voltage and lower internal resistance. Excitation–emission matrix (EEM) fluorescence spectroscopy and dynamic light scattering (DLS) showed that the dissolution of WAS was increased with predation and that the worm reactor presented higher concentrations of easily biodegradable organic matter for electricigenic bacteria. The results indicated that aquatic worm predation could not only improve the electrochemical performance of rotating-cathode MFCs but accelerate the hydrolysis of particulate organic matter, which substantially enhanced the power production from WAS.

1. Introduction

Microbial fuel cells (MFCs) are fascinating electrochemical systems that biologically convert organic matter present in the environment into electricity [1,2]. In a typical MFC device, electrons produced by the bacteria from the organic matter are transferred to the anode and flow to the cathode linked by a conductive material containing a resistor [1]. In the cathode, terminal electron acceptors (e.g., oxygen) consume the electrons to complete the electrochemical reaction. Currently, one promising application of the MFC technology is to extract useful energy from organic wastes (e.g., waste activated sludge), which substantially reduces the

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negative environmental impacts associated with conventional waste treatment (e.g., landfill and incineration) [3]. Dentel et al. first utilized anaerobically digested sludge for bioelectricity generation and obtained a maximum voltage of 517 mV [4]. Since then, the issue of how to address efficient power production from waste activated sludge (WAS) has gained extensive attention among the academic community [5–7], and the output power densities normalized to the net reactor volume increased by two orders of magnitude from 2004 to 2012 (from ~0.1 W/m^3 to 15.8 W/m^3) [3].

Contrast to the simple and fermentable substrates (e.g., acetic acid, lactic acid and glucose) commonly used in MFCs, WAS is a complex and slowly biodegradable organic source. Since many of the predominant exoelectrogenic members have limited metabolic versatility, utilizing only certain fermentation end products [8], synergistic interactions are essential in the MFCs fed with WAS [7]. Recently, several attempts have been dedicated to investigate the hybrid bioelectrochemical process, and revealed that the hydrolysis step of the remaining particulate organic matter in WAS was the rate limiting step during the exoelectrogenesis [9,10]. A limited supply of reduced species toward the electrodes would subsequently increase the concentration polarization of MFCs [1]. Therefore, it can be envisioned that the performance of MFCs will be improved through accelerating the hydrolysis of WAS and the release of soluble organic matter into the anolyte.

To date, a number of pretreatment methods have been introduced to facilitate the conversion of particulate organic matter into soluble fractions. For instance, Jiang et al. employed ultrasonic pretreatment to accelerate the organic matter dissolution [5]. The results demonstrated that the total chemical oxygen demand (*t*COD) removal rate of WAS was increased markedly as ultrasound power density increased. Heat and base pretreatments have been confirmed as other alternatives [6,11]. Yuan et al. obtained a maximum power density of 73 ± 5 mW/m^2 at pH 10.0, much higher than those of 33 ± 3 and 4 ± 0.5 mW/m^2 at pH 8.0 and 6.0, respectively [11]. Prevalent pretreatments bring new visions for researchers to improve MFC performance, but unfortunately these methods still present several deficiencies, which may hinder their future applications. According to the state of the art, heat and base pretreatments probably destroy the original microbial consortia, and thus inoculation seems essential in these bioelectrochemical systems [6]. Ultrasonic pretreatment is, however, an energy-intensive alternative, decreasing the net power output. In addition, the above-mentioned pretreatment methods also increase the operational expenditure of MFCs. Therefore, more cost-effective means are needed to enhance power production from WAS in MFCs.

Predation by metazoan is an important biological process contributing to overall biomass decay [12], and this cost-effective technique has been applied in wastewater treatment processes to reduce WAS production. Recent research has reported that aquatic worm (*Aeolosoma hemprichi* and *Tubificidae*) predation could lead to an increase of dispersed growth and soluble microbial products concentrations in biological systems [13]. We hypothesize that (1) in MFCs the hydrolysis of WAS might be accelerated by aquatic worm predation; and (2) since the released organic matter is easily biodegradable for exoelectrogens, power production from WAS will be enhanced. In the present study, we therefore investigated the effects of aquatic worm predation on power production from WAS in rotating-cathode MFCs. Electrochemical measurements were conducted to evaluate the variations of electrode potentials and internal resistances. Excitation–emission matrix (EEM) fluorescence spectroscopy and dynamic light scattering (DLS) were carried out to characterize the change of soluble organic matter in MFCs.

2. Materials and methods

2.1. Rotating-cathode MFCs

The rotating-cathode MFCs were constructed according to a previous publication [14]. Rotating-cathode MFCs, similar to rotating biological contactors (RBC) used in wastewater treatment, are comprised of vertical disks that are mounted on a horizontal shaft and partially immersed in the wastewater (Fig. 1 and Fig. S1 in Supporting Information). Compared to conventional aeration alternatives, the intermittent exposure of the rotating disks to air is less energy intensive but also provides enough oxygen to the attached cathode biofilm for oxygen reduction reaction [14]. As shown in Fig. 1, carbon cloth (30[L] × 1[H] × 10[W] cm^3, ≈90% porosity, 50 m^2/g specific surface area, 0.18–0.22 ohm cm conductivity, Junrui Co., China) was placed on the bottom of a rectangular plastic chamber (30[L] × 10[H] × 10[W] cm^3, with a liquid volume of ≈2.1 L) as the anode electrode. The cathode electrodes consisted of 10 pieces of round carbon felt (≈90% porosity, 50 m^2/g specific surface area, 0.18–0.22 ohm cm conductivity, Junrui Co., China) with a diameter of 9 cm, and were connected in series by a stainless steel shaft that was attached to a motor device by a

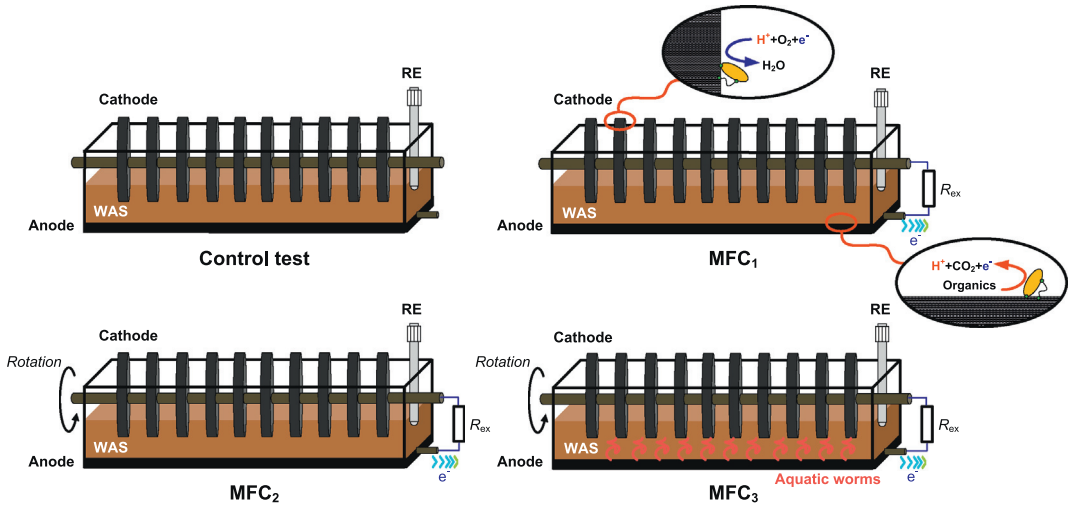

Fig. 1. Schematic of control test and rotating-cathode MFCs. RE and R_{ex} represent the Ag/AgCl reference electrode (+197 mV vs. standard hydrogen electrode, SHE) and external resistance, respectively.