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Performance of microbial fuel cell coupled constructed wetland system for decolorization of azo dye and bioelectricity generation

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HIGHLIGHTS

- Couple microbial fuel cell (MFC) with a continuous flow constructed wetland (CW).
- Use the CW–MFC system to recover energy from refractory contaminant wastewater.
- Microbial fuel cell enhanced pollutants removal in constructed wetland.
- Wetland plants enhanced the power density of microbial fuel cell.

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ABSTRACT

A microbial fuel cell coupled constructed wetland (planted with *Ipomoea aquatica*) system (planted CW–MFC) was used for azo dye decolorization. Electricity was simultaneously produced during the co-metabolism process of glucose and azo dye. A non-planted and an open-circuit system were established as reference to study the roles of plants and electrodes in azo dye decolorization and electricity production processes, respectively. The results indicated that plants grown in cathode enhanced the cathode potential and slightly promoted dye decolorization efficiency. The electrodes promoted the dye decolorization efficiency in the anode. The planted CW–MFC system achieved the highest decolorization rate of about 91.24% and a voltage output of about 610 mV. The connection of external circuit promoted the growth of electrogenic bacteria *Geobacter sulfurreducens* and *Beta Proteobacteria*, and inhibited the growth of *Archaea* in anode.

1. Introduction

Energy shortage and environment pollution are the two severe challenges that human beings are facing today. The current energy resource structure is unsustainable and the pollution control methods are mostly high energy consuming.

Microbial fuel cells (MFCs), which can recover renewable energy from waste organic sources and convert chemical energy into electrical energy during wastewater treatment, have drawn great attention of scientists and researchers in recent years (Logan, 2008; Puig et al., 2012). Recently, MFCs have demonstrated the ability to simultaneously produce energy and degrade some biorefractory contaminants (Luo et al., 2009; Morris et al., 2009). Dual-chamber MFC (consisting of an anode chamber and a cathode chamber separated by a proton exchange membrane) and membrane-less single chamber MFC are both widely used in wastewater treatments (Kiely et al., 2011; Sun et al., 2009b). Some research indicated that membrane-less single chamber MFCs had more advantages than dual-chamber MFCs, such as low cost, simple configuration, and high power density (Liu and Logan, 2004). Most of the MFCs were incorporated in the sequencing batch reactors (SBRs). The microorganisms and fuel sealed in the reactors needed to be refreshed after the fuel was used up. It's impossible to keep the wastewater treatment and the current production continuously in the SBRs. Furthermore, the operation and maintenance of such systems were very complicated. In order to solve the above problems, researchers have made efforts to develop some continuous electricity generating MFCs (Feng et al., 2010).

Constructed wetlands have been used for many years as part of the municipal wastewater treatment process. They can treat a variety of wastewater under a wide range of conditions (Dunne et al., 2005). The construction and operation costs of constructed wetlands are very low due to the minimal or even no energy requirement. What's more, the plants growing in the wetlands can take up CO_2 from the atmosphere and alleviate greenhouse effect. Studies have also shown that constructed wetlands have high potential to remove biorefractory contaminants (Wischnak and Muller, 2000).

Azo dyes, which are aromatic compounds with one or more –N=N– groups, are among the most widely used commercial

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synthetic chemical dyes in the world. The discharge of dye containing wastewater into the surface water usually leads to a series of environmental problems, such as aesthetic issues, low light penetration and oxygen transfer obstruction. In addition, several studies have indicated that azo dyes would contribute to the mutagenic activities in the groundwater and surface water (de Aragão Umbuzeiro et al., 2005). Because azo dyes are biorefractory organics, it is always a challenge to treat azo dye containing wastewater with the current available physicochemical and biological methods (Dos Santos et al., 2007).

MFC coupled with constructed wetland is a possible and economical way to achieve the goals of both wastewater treatment and energy generation. Some researchers have already reported the application of MFCs in azo dye wastewater treatment. However, the treatment processes were mostly carried out in the SBRs (Fernando et al., 2013; Sun et al., 2009b). To the best of our knowledge, few studies have reported the wetland process coupled with microbial fuel cell for electricity production and dye removal (Yadav et al., 2012). In this research, a constructed wetland coupled with MFC (CW–MFC) run continuously for active brilliant red X-3B (ABRX3), a typical azo dye, treatment. The performances of CW–MFC systems were described and analyzed. The dye decolorization and electricity generation were studied. The bacterial communities in the anode were analyzed.

2. Methods

2.1. Dye

Commercial purity level reactive brilliant red X-3B (ABRX3, $C_{19}H_{10}Cl_2N_6Na_2O_7S_2$) was purchased from Huibang Fine Chemical Company Limited in Shanghai, China. There are one –N=N– bond and some benzene rings in the molecule of ABRX3.

2.2. System construction

The planted CW–MFC reactor was made of a polyacrylic plastic cylinder with an internal diameter of 30 cm and a length of 52.5 cm (Fig. 1). From the bottom upward, there were four layers: bottom gravel (diameter of 3–6 mm) layer with a depth of 20 cm, the anode layer with 10 cm depth of granular activated carbon (GAC, 3–5 mm in diameter with a specific area of 500–900 m^2/g and a packing density of 0.45–0.55 g/cm^3), the middle gravel layer with a depth of 20 cm, and the air-cathode layer (made of 12-mesh stainless steel mesh coupled with GAC) with a depth of about 2.5 cm. The volume of the whole container was 35.3 L with a total liquid volume of 12.4 L, while the volume of the anode was 7 L with an anode liquid volume of 2.1 L. The stainless steel mesh was 0.3 cm in thickness and 30 cm in diameter. *Ipomoea aquatica* was planted into the air-cathode layer as the constructed wetland plants. Titanium wires (1 mm in diameter) passing through the middle of the polyacrylic plastic cylinder were used as the leading-out wire of the anode. External circuit was connected by the copper conductors with an external resistance of 1000 Ω, and epoxy was used to seal metals exposed to the solution. Ten sampling ports with 8 mm in inner diameter were arranged at the intervals of 5 cm throughout the height of the reactor for collecting samples from different depths of the reactor.

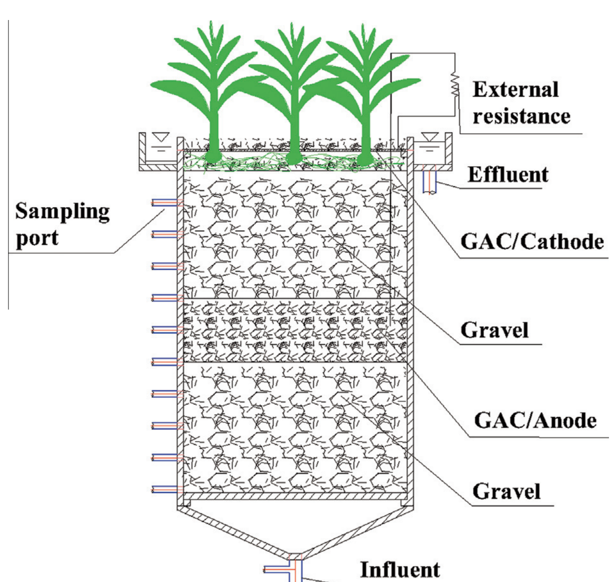

Fig. 1. Configuration of the planted microbial fuel cell and constructed wetland coupled (planted CW–MFC) system.

A non-planted CW–MFC and an open-circuit CW–MFC were operated under the same conditions to study the operating characteristics of CW–MFC system. The same configurations were adopted for these three CW–MFCs; the non-planted CW–MFC had no plant in the cathode and the circuit of open-circuit CW–MFC was disconnected.

2.3. Inoculation and system operation

Concentrated anaerobic sludge was collected from the East City Municipal Wastewater Treatment Plant of Nanjing, China, and used as the original anodic inoculums of the CW–MFC systems. 4 L concentrated sludge was added into each reactor with a concentration of 20 g/L in mixed liquid suspended solids (MLSS).

ABRX3 (150 mg/L) and glucose (with COD of 180 mg/L) were used as the mixed substrate in the experiments. The substrate was diluted in a medium solution with a composition as following (per liter of tap water): NH_4Cl (0.31 g), NaH_2PO_4 (4.97 g), Na_2HPO_4 (2.75 g), KCl (0.13 g), $NaHCO_3$ (3.13 g) and 0.1 mL concentrated trace element solution as reported by Klass (1998).

The glucose (COD: 600 mg/L) in the medium solution was continuously pumped with a peristaltic pump into the reactors after inoculation. The systems were formally started when the maximal reproducible voltages were obtained. After the start-up stage, the X-3B artificial wastewater (COD: 180 mg/L) was continuously pumped into the reactors from the water intake at the bottom of the reactors. The hydraulic retention time (HRT) was 3 days. Systems were operated for several days after the dye was added in the reactor until the maximal reproducible voltages were observed again to make the systems fully acclimate to the dye. The real-time voltages data were collected during the whole experiment. DO, decolorization rate, and COD of the samples from all sampling ports were measured in triplicate. All the experiments were conducted, at a constant room temperature (25 ± 2 °C).

2.4. Analytics and calculations

The dissolved oxygen concentration (DO) was determined by a dissolved oxygen analyzer (DKK-TOA DO-31P, Japan).

Decolorization efficiency of ABRX3 was determined by monitoring the decrease of absorbance at a maximum wavelength of 538 nm with a spectrophotometer (Labtech 9100B PC). Samples with higher concentration of ABRX3 were adequately diluted prior to absorbance measurement.

Decolorization activity was calculated using Eq. (1):

$$\text{Decolorization rate } (\%) = (A - B)/A \times 100\% \quad (1)$$

A is the initial absorbance; B is the observed absorbance.