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Synergistic effect of up-flow constructed wetland and microbial fuel cell for simultaneous wastewater treatment and energy recovery

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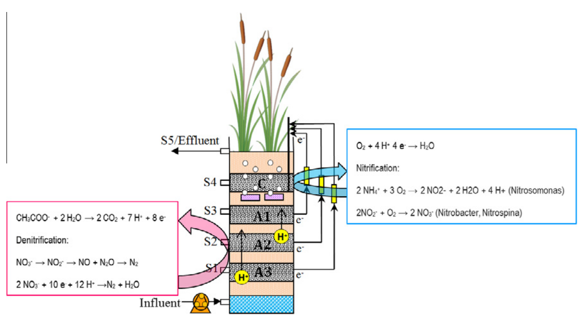
HIGHLIGHTS

- Novel multiple anodes to study the effect of electrode spacing.
- Organic loading influenced the voltage output despite electrode spacing.
- Over 99% of COD removal was achieved by UFCW–MFC.
- UFCW–MFC has great potential in removing high strength organic wastewater.
- UFCW–MFC can remove organic matter, nutrient and merits with energy recovery.

GRAPHICAL ABSTRACT



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ABSTRACT

This study demonstrated a successful operation of up-flow constructed wetland–microbial fuel cell (UFCW–MFC) in wastewater treatment and energy recovery. The goals of this study were to investigate the effect of circuit connection, organic loading rates, and electrode spacing on the performance of wastewater treatment and bioelectricity generation. The average influent of COD, NO_3^- and NH_4^+ were 624 mg/L, 142 mg/L, 40 mg/L, respectively and their removal efficiencies (1 day HRT) were 99%, 46%, and 96%, respectively. NO_3^- removal was relatively higher in the closed circuit system due to lower dissolved oxygen in the system. Despite larger electrode spacing, the voltage outputs from Anode 2 (A2) (30 cm) and Anode 3 (A3) (45 cm) were higher than from Anode 1 (A1) (15 cm) as a result of insufficient fuel supply to A1. The maximum power density and Coulombic efficiency were obtained at A2, which were 93 mW/m^3 and 1.42%, respectively.

1. Introduction

Constructed wetlands (CWs) are engineered systems, which use natural processes together with a series of treatment mechanisms, including physical, chemical as well as a variety of microbial interaction processes to mitigate wastewater (Vymazal, 2007). CWs are already in field-level use for wastewater treatment and have been increasingly used worldwide since CWs are simple in construction, minimal or low energy requirement, low operation and maintenance cost, as well as good landscape integration (Tanner, 1996; Fang et al., 2013). The roles of plants were frequently reported in CW studies. Some of the important roles of plants in CWs are aesthetic, recreational and ecological function (Tanner, 1996). According to Bezbaruah and Zhang (2004), plants play a significant role in releasing oxygen in the wastewater environment.

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Lately, MFCs have demonstrated as innovative devices that possess great potential in simultaneous wastewater treatment and bioelectricity generation. MFCs also successfully gained attention from many research groups worldwide (Logan et al., 2006; Venkata Mohan et al., 2009). Generally, a MFC consists of an anode and a cathode chamber. Electrochemically active microorganisms are used as biocatalyst to convert the biodegradable compounds into electricity (Corbella et al., 2015). When organic matter at the anodic region was oxidized, electrons (e^-) and protons (H^+) were produced and then moved to the cathode. MFC generates electrical current through the transfer of electrons from anode to cathode via the external circuit. When electrons arrived at the cathode, it will combine with protons that migrated from the anode and then react with oxygen or other electron acceptors to produce water and or other reduced compounds (Oliveira et al., 2013).

Yadav et al. (2012) was the first research group that came up with the novel design of CW integrated with MFC. It is worth noting that some innovative hybrid systems were also developed recently based on the similarities between MFC and CW systems (Fang et al., 2013; Zhao et al., 2013; Liu et al., 2014; Villaseñor et al., 2013; Corbella et al., 2015). The recent emerging technology of CW–MFC has been well reviewed by Doherty et al. (2015a). CWs and MFCs consist of anaerobic and aerobic regions, where reduction and oxidation processes occur, respectively (Liu et al., 2014). In order to ensure the efficiency of wastewater treatment and power generation, the anodic compartment (bottom region of the CW) should maintain in anaerobic condition to promote electrons and protons generation from the degradation of organic compounds. Whereas, at the cathodic compartment of MFC (upper region of the CW), oxygen should be easily accessible as it will combine with protons from anode and electrons from external circuit to form a complete circuit (Zhao et al., 2013). At the same time, the upper region of CWs is also responsible for biodegradation of organic pollutants, nitrification and mineralization of aromatic amines (Ong et al., 2010). Moreover, the roots system of the wetland plants was also located at the cathodic region to boost the oxygen concentration and therefore improve the cell reaction. MFC integrated with CW is a promising and cost-effective way to achieve both wastewater treatment and electricity generation simultaneously (Zhao et al., 2013).

The study on CWs and MFCs individually has been investigated extensively; however, the integration of CWs and MFCs is still in its infancy. Hence, the study of MFCs integrated into existing wastewater technologies like CWs is certainly worthwhile as it a promising technology to treat wastewater and merits with bioelectricity generation. The goals of this study were to examine the feasibility and efficacy of UFCW–MFC to treat wastewater and generate bioelectricity simultaneously. The effect of electrode spacing, effect of organic loading rates and effect of circuit connection on the performance of wastewater treatment and bioelectricity generation were investigated.

2. Methods

2.1. Reactor set up and configuration

A single chamber UFCW–MFC was designed in this study. The reactor was fabricated by using an acrylic column (18 cm D × 75 cm H). Fig. 1 shows the schematic diagram of UFCW–MFC. The reactor was located outdoor and shelter by veranda at average temperature of 28 ± 4 °C. The bottom of the reactor was layered with 3 cm height of glass beats to promote even distribution of wastewater into the reactor. The sampling points were built at height 7, 21, 36, 51 and 66 cm from the bottom of the reactor respectively (Oon et al., 2015).

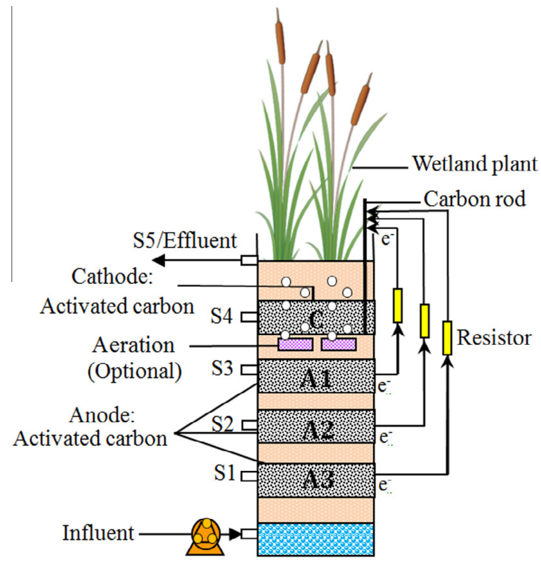

Fig. 1. Schematic diagram of UFCW–MFC.

The electrodes (anodes and cathode) material employed in this study was activated carbon while gravels were used as the supporting medium. Activated carbon is a common carbon material used in the water treatment process. The high specific surface makes it a good medium for microorganisms attachment and characteristics of activated carbon like good biocompatibility as well as moderate electrical conductivity make it a suitable electrode material (Wei et al., 2011). The volume for each layer of anode and cathode electrode was 2544.69 cm^3.

Cattail (*Typha latifolia*) was chosen as the emergent wetland plant in this study, and it was collected from Tasik Melati, Perlis. *T. latifolia* is widely used as a model in macrophyte study, especially in terms of its role in wastewater treatment efficacy. Nevertheless, this wetland plant is lacked of documentation in the study of CW integrated with MFC. Two shoots of *T. latifolia*, which weighted about 300 g were planted in the UFCW–MFC reactor. The growth of *T. latifolia* was measured bi-weekly in terms of plant height, number of stems and number of leaves. The plants' growth was monitored throughout the study, including during closed and open circuit system operation.

In order to create an aerobic condition for the cathodic region, the cathode was positioned at 53 cm from the bottom of the reactor, where the roots system of the macrophytes was located. The top surface of the cathode was covered with roots. Besides that, two porous air spargers were also placed at 45 cm of the reactor as optional supplementary aeration. Whereas, anodes were situated at 8 cm, 23 cm and 38 cm from the bottom of the reactor, complying with the anodic condition of MFC which was in anaerobic condition.

The synthetic wastewater was supplied to the reactor by using a peristaltic pump (Natong BL-100C, China) at flow rate of 4.048 mL/min and operated in continuous mode. The peristaltic pump and air pump were controlled by a timer with 3 h on followed by 0.5 h off cycles, which maintained at 1 day hydraulic retention time (HRT). The UFCW–MFC reactor was operated for a total of 228 days in this study.

Stainless steel, carbon rod and insulated copper wires were used to connect both anode and cathode with an external resistance of 1000 Ω to complete the circuit. The voltage output of UFCW–MFC was measured and recorded by a data logger (Midi LOGGER GL820 GRAPHTEC), where real time voltage data throughout the experiment was monitored.