Ecological Engineering 84 (2015) 624–631

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Potential of novel wastewater treatment system featuring microbial fuel cell to generate electricity and remove pollutants

Dan Wu, Liuyan Yang*, Lin Gan, Qiankun Chen, Li Li, Xu Chen, Xin Wang, Liyun Guo, Aijun Miao*

State Key Laboratory of Pollution Control and Resource Reuse, School of the Environment, Nanjing University, Nanjing 210023, China

ARTICLE INFO

Article history:
Received 19 November 2014
Received in revised form 18 August 2015
Accepted 21 September 2015

Keywords:
Constructed wetland-microbial fuel cell
Electricity generation
Wastewater treatment
Batch flow mode
Continuous flow mode

ABSTRACT

A new design of a pilot-scale constructed wetland managed with a membraneless microbial fuel cell (CW-MFC) was tested here to assess its potential to generate electricity and remove pollutants under different operating conditions. In the CW-MFC, the cathode was half vertically inserted into the matrixes of constructed wetland (CW) and half exposed to the air to benefit from both surrounding wetland plant growth and the atmosphere thereby ensured its demand for oxygen as well. A series of periodic and regular voltages were obtained after four cycles of wastewater treatment in the batch flow experiment with influent chemical oxygen demand (COD) 228 mg/L. The maximum voltage output (0.588 ± 0.01 V) for these four cycles lasted for 34, 35, 37 and 42 h, respectively. A steady set of maximum voltage (0.529 V) outputted over a wetland operation period of 15 days in the continuous flow experiment with the hydraulic retention time of 10 h. The maximum power density was 9.6 mW/m^2 and the maximum current density was 55 mA/m^2 according to the cathode area. Under batch flow mode, the COD removal rate was 91.2% and the outstanding removal rates of total nitrogen, ammonium nitrogen and total phosphorus appeared ranging between 95% and 99% while electricity generated from the CW-MFC. The influence of temperature on electricity generation was investigated and the result showed that the maximum voltage output values were inversely relative to the lasting duration of the voltage. Influent COD concentrations also affected the highest voltage output and continuous electricity generation of CW-MFC, and the higher initial COD concentration elevated the electricity generation. Thus, the new CW-MFC has high potentials not only of bioelectricity generation but also of the high pollutant removal rates.

1. Introduction

Nowadays wastewater treatment and energy shortage are two serious problems worldwide (Zhao et al., 2013). Both government and scientists have devoted large amounts of potency to exploring new ways methods to solve these problems. Constructed wetland (CW) is a traditional ecological process for wastewater treatment which has proven to be cost-effective and environmentally sound (Garcia et al., 2010; Wu et al., 2014). The development of CW has integrated it with other technologies such as the microbial fuel cell (MFC), a newly developed bio-electrochemical technology (Grafias et al., 2010; Mohan et al., 2011). The purpose of constructed wetland and microbial fuel cell (CW-MFC) combination is to realize wastewater purification and electricity production from organic waste materials at the same time (Luo et al., 2009; Morris et al., 2009).

Usually, a CW contains macrophyte plants, a porous solid bed and a mixed population of microorganisms in the form of biofilms. The aerobic and anaerobic zones appear in different depth of wetland matrix (Truu et al., 2009). Depending on the redox potential difference, it is feasible to assemble a MFC to serve the wetland. The principle for MFC is that electrochemically active microorganisms usually called electricigens oxidize biodegradable organic matter on the anode and transfer electrons to the anode electrode. Electrons move along a circuit to the cathode, where electron acceptor (usually oxygen) accepts the electrons. These electrons then combine with protons that diffuse from the anode to the cathode (Bond et al., 2002; Min and Logan, 2004). Based on this, MFC can degrade organic materials in wastewater treatment process and simultaneously generate energy from it.

At present, research about coupling CW with MFC is plentiful. Generally, their construction is divided into two main types according to wetland classification. One type is based on a vertical flow system. The first CW-MFC was investigated by making the stratified redox conditions in vertical flow CW serve as cathode

* Corresponding authors.
E-mail addresses: yangly@nju.edu.cn (L. Yang), miaoaj@nju.edu.cn (A. Miao).

http://dx.doi.org/10.1016/j.ecoleng.2015.09.068
0925-8574/

and anode compartments, respectively (Yadav et al., 2012). They obtained a chemical oxygen demand (COD) removal rate of 75% in wastewater with the initial dye concentration of 1500 mg/L. Following this, Fang et al. (2013) designed a CW-MFC (planting with *Ipomoea aquatic*) to run continuously with active brilliant red X-3B (ABRX3), a typical azo dye operated as a source of electricity. Azo dye decolorization produces electricity during the co-metabolism process of glucose and azo dye. Fang designed this system to be columned with water flowing from bottom to top slowly. An unplanted and an open-circuit system were established to study the roles of plants and electrodes in azo dye decolorization and the electricity production process, respectively. Their results indicated that the cathode potential was enhanced and dye decolorization efficiency was slightly promoted when plants were grown in cathode area (Fang et al., 2013). Several other studies had conducted similar CW-MFCs to generate electricity (Liu et al., 2013; Zhao et al., 2013). However, cylindrical CW-MFC wastewater treatment systems had not gained acceptance in the wastewater treatment industry, and their COD removal rates were sometimes lower. The other CW-MFC type uses a surface flow wetland with macrophytes (Chiranjeevi et al., 2013; Mohan et al., 2011). This system had a COD removal rate of 86.7% achieved through fuel cell assemblies. Villasenor et al. (2013) verified that a subsurface horizontal flow CW could act simultaneously as a microbial fuel cell. The organic loading rate was related to the removal rate of pollutants and influenced electrical current production. However, the CW-MFC with macrophytes system was complex with electrodes undergoing separation by a 0.02 m thickness layer of calcium bentonite. What's worse, the system might stop work under high organic loading rate when organic matters that could not be completely oxidized in the anodic compartment flowed to the cathodic compartment and thereby changed the aerobic to anaerobic conditions in the cathodic compartment.

In order to avoid the complexity in construction and increase the pollutant removal rate of CW-MFC, a new type of membraneless pilot-scale CW-MFC was designed to provide a new technology to the practical application. The cathode was vertically inserted into matrixes of CW with half exposed to the air instead of cathode floating on water surface of wetland. This new design here not only securely set the cathode in the matrixes of wetland but also saved space for plant growth. This CW-MFC could simultaneously act to allow electricity generation and high pollutants removal rates under batch flow mode and continuous flow mode, and temperature and influent COD concentration also influenced the electricity generation of CW-MFC.

2. Materials and methods

2.1. CW-MFC construction

The experimental installation consisted of a synthetic wastewater-feeding system and a pilot-scale CW, which was modified to function as a MFC (Fig. 1). A 25 L wastewater tank and a peristaltic pump (BT100-2J, Baoding Langer Pump Company, China) were used to feed wastewater into the wetland. The CW-MFC made of Plexiglas contained three areas—influent area, treatment area and effluent area. Both the influent area and effluent area were 15 cm × 5 cm with a depth of 30 cm and pebbles (with an average particulate diameter of 50 mm) were added to well distribute and collect the wastewater, respectively. The treatment area of wetland (30 cm × 15 cm with a depth of 30 cm) was filled with a depth of 20 cm mixture of soil (from Nanjing University campus) and quartz (5:2 in volume) as the matrixes of CW. The quartz used here was to improve the porosity of the wetland. Yellow flag *Iris pseudacorus* picked from the Xianlin River at the Nanjing University campus was planted. Two overflow valves were installed on the outside wall of the effluent area, one was on the bottom and the other one was at 20 cm height. The outside of the wetland was wrapped with paper to prevent algal growth by blocking light.

To construct MFC, a rectangular (28 cm × 10 cm and 0.5 cm thickness) graphite felt anode (Beijing Jixingshengan Tech Co., China) without any pre-treatment was firstly horizontally placed 4 cm above the bottom of the wetland. The surface area of the anode was 0.056 m^2. Then a graphite felt cathode (25 cm × 10 m and 0.5 cm thickness) was placed vertically near the plants with half buried at 5 cm depth of the CW matrixes and half exposed to the air. Also two sampling points were placed along the wetland at 1/3, and 2/3 of the total length. At sampling points the vertical plastic tubes (1 cm diameter and 12 cm length) perforated with many small holes (0.2 cm diameter) were inserted into the matrixes to monitor the parameters of the system. As for the

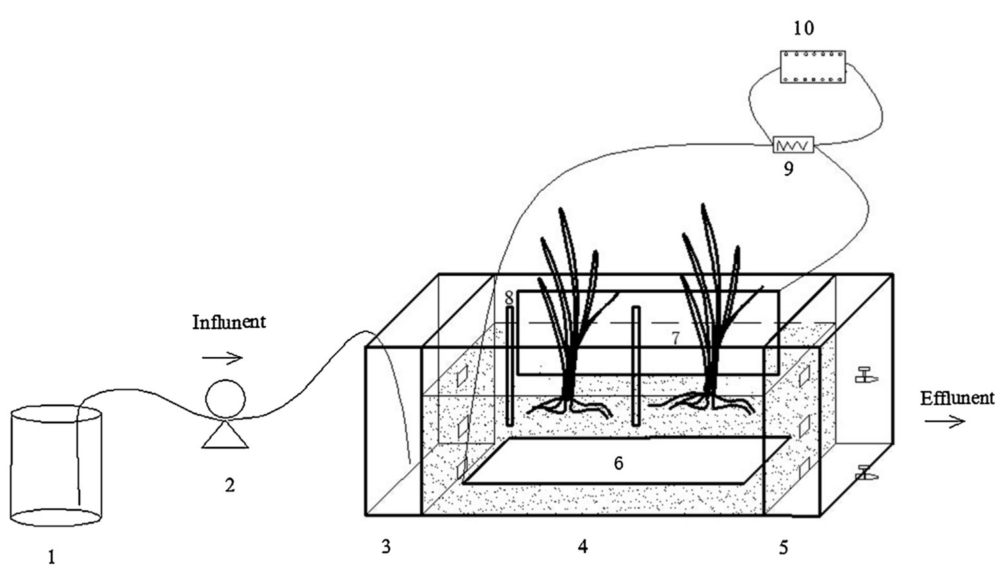

Fig. 1. Schematic of the CW-MFC integrated system (experimental installation) (1) wastewater tank, (2) peristaltic pump, (3) influent area, (4) treatment area, (5) effluent area, (6) anode, (7) cathode, (8) sampling points, (9) resistor, and (10) data acquisition card.