Bioresource Technology 136 (2013) 316–321

Contents lists available at SciVerse ScienceDirect

Bioresource Technology

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

In situ investigation of tubular microbial fuel cells deployed in an aeration tank at a municipal wastewater treatment plant

Fei Zhang [a], Zheng Ge [a], Julien Grimaud [b], Jim Hurst [b], Zhen He [a,*]

[a] Department of Civil Engineering and Mechanics, University of Wisconsin-Milwaukee, Milwaukee, WI 53211, United States
[b] Veolia Water North America, Indianapolis, IN 46204, United States

HIGHLIGHTS

- Three MFCs were installed in an actual aeration tank for more than 400 days.
- Those MFCs were able to produce electricity while reduce organic concentration.
- The performance was affected by cathode biofouling and operating conditions.
- MFC may not be suitable for deployment in aeration tanks unless further improvement.

GRAPHICAL ABSTRACT

ARTICLE INFO

Article history:
Received 25 January 2013
Received in revised form 23 February 2013
Accepted 25 February 2013
Available online 14 March 2013

Keywords:
Microbial fuel cells
Wastewater treatment
Organic removal
Aeration
Activated sludge

ABSTRACT

To examine the feasibility of integrating microbial fuel cells (MFCs) into an activated sludge process, three MFCs with different ion exchange membranes and/or cathode catalysts were installed in an aeration tank to treat primary effluent. Both contaminant treatment and electricity generation were studied during the operation for more than 400 days. The effects of membrane/catalysts on MFC performance were not observed, likely due to the low removal of chemical oxygen demand (COD) (<53%) caused by low electricity generation. The MFCs did not achieve any obvious removal of nutrients. The produced energy was lower than the theoretic energy consumption. The performance was seriously affected by cathode biofouling, variation of wastewater quality, and other operating conditions. Unlike prior lab studies by others, the results of this study suggest that MFCs may not be suitable for deployment in an aeration tank, unless the key problems such as biofouling are solved.

1. Introduction

Microbial fuel cells (MFCs) are a promising technology for wastewater treatment with simultaneous bioenergy production (Logan et al., 2006; Rabaey and Verstraete, 2005). Depending on the type of wastewater, MFCs may be applied as a main treatment process for some industrial wastewater or domestic wastewater from decentralized communities, or as a part of an existing treatment process for large-scale domestic wastewater treatment. The application of MFC technology may require new construction of infrastructure, especially for industrial or decentralized wastewater treatment, which requires significant capital investment (Logan, 2010). A faster and more cost-effective way to apply MFCs is to integrate them into existing treatment facilities; for example, MFCs may be combined with activated sludge processes to treat primary effluent, or linked to anaerobic digesters to polish the digested liquid (Pham et al., 2006). Primary effluent with low-concentration organics could be a more appropriate substrate for MFCs than high-strength wastes, because MFCs have not been proved more efficient than anaerobic digesters in terms of bioenergy production from high-strength wastes (Gregoire and Becker, 2012; Li et al., 2013). Therefore, there is strong interest in examining the feasibility of MFC operation in the aeration tanks of activated sludge processes.

* Corresponding author. Tel.: +1 414 229 5846; fax: +1 414 229 6958.
E-mail address: zhenhe@uwm.edu (Z. He).

0960-8524/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.biortech.2013.02.107

Integrating MFCs into an aeration tank will not require additional land space in a wastewater treatment plant. In addition, there are several other potential benefits by installing MFCs into an aeration tank. First, a portion of wastewater can be treated under an anaerobic condition in the anode of MFCs, and thus the requirement of aeration, as well as energy consumption, is greatly reduced. Second, the treated effluent from MFCs contains much lower concentrations of suspended solids, and thus the secondary sludge production will be lower than that of activated sludge treatment only. Third, MFCs can produce some electric energy (although low at this moment), which can be potentially applied to offset the energy consumption by the treatment process. Fourth, MFCs may physically act as solid media to form a hybrid attached/suspended growth system, with advantages demonstrated in previous integrated fixed-film-activated sludge processes (Kim et al., 2011a). These potential benefits can hardly be verified or examined at the current stage of research because of small scales of MFCs; however, it is beneficial to consider them in future studies.

The concept of linking an MFC to an activated sludge process has been proposed and examined in the laboratory in several previous studies. A research group suggested assembling air-filled hollow-fiber membrane MFCs in an aeration tank, but unfortunately they did not carry out the proposed design (Shea and Nerenberg, 2008). The first lab demonstration was conducted in single-chamber MFCs installed in a plastic aeration chamber that mimicked an aeration tank in an activated sludge process (Cha et al., 2010). The authors of the study found that the MFCs produced more electricity in the presence of aeration, and graphite felt was an optimal electrode material that resulted in the best performance. They also observed a significant drop in MFC voltage when aerobic sludge was introduced into the aeration chamber. A later study investigated the installation of membrane-less MFCs in an aerated chamber operated as a sequencing batch reactor (Liu et al., 2011). The results showed that the MFC produced a maximum power density of 2.34 W/m^3 and removed 18.7% of chemical oxygen demand. These prior studies provide a proof of concept that MFCs could be integrated into activated sludge process; however, they were conducted under laboratory conditions and for a short period of time. Furthermore, there is a significant difference between an artificial (lab) aeration tank and a real aeration tank of activated sludge process, for instance, in the concentrations of dissolved oxygen and biomass. Therefore, it is necessary to conduct an *in situ* study of MFC performance in an aeration tank to demonstrate the technical viability of MFC integration with activated sludge processes.

In this study, three tubular MFCs were installed in an aeration tank at a municipal wastewater treatment plant; the MFCs had different ion exchange membranes and/or cathode catalysts. We attempted to compare the MFC performance with cation or anion exchange membranes, and with the catalysts containing platinum or not. The long-term performance of MFCs in treating primary effluent and producing electricity was examined through more than 400 days' operation. The performance of contaminant treatment was studied by monitoring the variation of multiple parameters, including organics, suspended solids, nitrogen, phosphorus, turbidity, and coliform bacteria. The electricity generation was described with current, power, and electric energy. We also analyzed the energy production and consumption by those MFCs.

2. Methods

2.1. MFCs set up and operation

Three tubular MFCs were constructed similarly, except the difference in ion exchange membrane and/or cathode catalysts. Two MFCs, MFC-C-Pt and MFC-C-AC, were made of cation exchange membrane (CEM, Membranes International, Inc., Glen Rock, NJ, USA), and one (MFC-A-Pt) was made of anion exchange membrane (AEM, Membranes International, Inc.). Each membrane tube (which formed an anode compartment) had a diameter of 5 cm and length of 100 cm, resulting in an anode liquid volume of 2000 mL (excluding the anode electrode). Each MFC contained a 100-cm long carbon brush as its anode electrode, and a carbon cloth that wrapped the membrane tube as its cathode electrode (more details in Fig. S1). Both MFC-C-Pt and MFC-A-Pt had 0.1 mg/cm^2 of Pt (10% Pt on carbon black) and 4 mg/cm^2 of activated carbon as cathode catalysts for oxygen reduction, while MFC-C-AC contained only activated carbon powder (5 mg/cm^2) as a cathode catalyst. The catalysts were applied to the cathode electrode by using 5% PTFE solution as binder. Each MFC was placed in a PVC-tube sleeve that had a diameter of 7.6 cm and a length of 100 cm; the PVC tube contained 2.2-cm holes throughout. The completed MFCs were installed in an aeration tank (submerged in water) at the South Shore Water Reclamation Facility (Milwaukee, WI, USA). The anodes of the MFCs were inoculated with the primary effluent, which also acted as the anode feeding solution and was pumped from a sample site was fed into the MFCs at 3 mL/min, resulting in an anolyte HRT of 11.1 h. The anolytes were recirculated at 200 mL/min by a peristaltic pump.

2.2. Measurement and analysis

The MFC voltages were monitored by digital meters (2700, Keithley Instruments, Inc., Cleveland, OH, USA) every 5 min. The concentrations of chemical oxygen demand (COD) and nutrients, including phosphate, ammonium nitrate, and nitrite were measured using a colorimeter (DR/890, Hach Company, Loveland, CO, USA) according to the manufacturer's procedure. The temperature was recorded with an industrial multi-meter (EX-540, Extech, Nashua, NH, USA). The concentrations of total suspended solids (TSS) and volatile suspended solids (VSS) were measured according to the standard methods (Clesceri et al., 1998). The coliform bacteria were determined by using the membrane filter technique for members of the coliform group approved by Standard Methods Committee (Clesceri et al., 1998). Turbidity was measured with a turbidimeter (Scientific Inc., Fort Myers, FL, USA). Power density and COD loading and removal rates were calculated based on the liquid volume of the anode compartment. The theoretical power requirement for the pumping system was estimated as (Kim et al., 2011b):

$$P_{\text{pumping}} = \frac{Q\gamma E}{1000} \quad (1)$$

where P is the power requirement (kW), Q is the flow rate (m^3/s), γ is 9800 N/m^3, and E is the hydraulic pressure head (m). In this study, we assumed hydraulic pressure heads of 0.03 and 0.05 m for the anolyte feeding and recirculation pumps.

3. Results and discussion

3.1. Treatment performance

Contaminant treatment is a key evaluation factor in determining whether MFCs can be applied for wastewater treatment. In this study, the treatment performance of the three MFCs was described by COD, suspended solids, nutrients, and other parameters. During the operation period, we observed significant variation in organic concentration in the primary effluent that was fed into the MFCs, affected by season, rainfall, and tubing that linked the sampling site and the MFCs. The concentration of total COD (TCOD) ranged from 50 to 600 mg/L, resulting in an organic loading rate of