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Bio-electrochemical post-treatment of anaerobically treated landfill leachate

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HIGHLIGHTS

- ▶ Pre-treated leachate resembling medium aged landfill leachate was treated with MFC.
- ▶ The maximum power and current densities of 525 mA/m^2 and 158 mW/m^2 were achieved.
- ▶ Partial nitrification was observed at the cathode at HRT of 5 days.
- ▶ High VFA utilization was achieved in MFC.

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ABSTRACT

Bio-electrochemical treatment of anaerobically pre-treated landfill leachate was investigated in batch and continuous-flow two-chambered microbial fuel cells (MFCs). A high strength young landfill leachate was pre-treated using an upflow anaerobic sludge blanket reactor and the effluent resembling medium-aged landfill leachate was fed to the anode chamber of MFCs. The highest maximum current and power densities achieved in continuous-flow MFC with hydraulic retention time (HRT) of five days were 525 mA/m^2 (8227 mA/m^3) and 158 mW/m^2 (2482 mW/m^3), respectively. Increase of HRT from one day to five days resulted in the occurrence of partial nitrification, where influent ammonia was converted into nitrite presumably due to the inhibitory effects of free ammonia. The maximum power and current densities obtained in this study were higher compared to other studies with similar leachate characteristics. The results of this study suggest that MFCs can be exploited as a polishing step for anaerobically pre-treated landfill leachate.

1. Introduction

Leachate generated from municipal solid waste landfills contains significant amounts of dissolved organic/inorganic matter, heavy metals, xenobiotic organic compounds, and refractory organics (Christensen et al., 2001; Kjeldsen et al., 2002; Li et al., 2009). Leachate characteristics are generally affected by the age of the landfill, waste composition, and seasonal weather variations (Renou et al., 2008). In particular, chemical composition of a landfill leachate depends greatly on the age of landfill; new landfills contain large amounts of biodegradable material, a rapid anaerobic digestion takes place resulting in volatile fatty acids (VFAs) as the main fermentation products, whereas with the aging of landfill, the biodegradability of leachate decreases (Calli et al., 2005; Li et al., 2009; Renou et al., 2008). Landfill leachate is among the most difficult effluents to deal with due to its highly variable characteristics, strength, and complex composition (Gálvez et al., 2009). Generally, landfill leachate treatment can be classified as: (a) combined treatment with domestic sewage, (b) biological treatment: aerobic and anaerobic, and (c) chemical and physical treatment: floatation, chemical precipitation, coagulation/flocculation, adsorption, air stripping and oxidation (Renou et al., 2008). Biological treatment methods are used as simple, cost-effective and reliable methods for the treatment of leachate containing high concentrations of organic carbon and/or nitrogen (Renou et al., 2008). Physical/chemical or biological treatment processes have benefits and drawbacks, therefore; in general these processes are used in combination in order to achieve an effective leachate treatment (Kjeldsen et al., 2002; Li et al., 2009; Mehmood et al., 2009; Renou et al., 2008).

Microbial fuel cells (MFCs) have recently received significant attention as they enable the use of microorganisms as catalysts to convert chemical energy of the electron donors into electrical energy (Franks and Nevin, 2010; Freguia et al., 2010; Logan et al., 2006; Rabaey and Verstraete, 2005). Recently, in addition to electricity generation, MFCs have been utilized in various treatment/recovery processes such as reductive dechlorination (Huang et al., 2012), valuable chemical production such as H_2O_2 from wastewater organics (Modin and Fukushi, 2012), and treatment of pharmaceutical wastewaters (Velvizhi and Venkata Mohan, 2011). MFCs have also

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been utilized as biosensors to monitor anaerobic digestion processes (Liu et al., 2011). In addition, MFCs have been exploited to generate electricity from high strength wastewaters such as leachate (Cavdar et al., 2011; Gálvez et al., 2009; Greenman et al., 2009; Puig et al., 2011; You et al., 2006; Zhang et al., 2008). Use of MFCs in wastewater/leachate treatment has been found to offer two important advantages; energy recovery as electricity and generation of less sludge in more stable conditions compared to that of aerobic treatment (Greenman et al., 2009; Kim et al., 2007). Raw landfill leachate treatment is challenging compared to other wastewater sources as it has high chemical oxygen demand (COD) and nitrogen concentrations, low carbon to nitrogen ratio, and low alkalinity levels (Puig et al., 2011). Considering that a young landfill leachate in Turkey contains about 10,000 to 50,000 mg COD/L and 1100 to 2500 mg NH_3-N/L (Calli et al., 2005; Renou et al., 2008) a two stage treatment involving an anaerobic reactor as a pre-treatment step and a MFC as a post-treatment step, may increase the treatment efficiency and enable energy recovery as electricity. In addition, MFCs have been used in combination with membrane bioreactors in order to improve wastewater treatment efficiency and to achieve energy recovery (Wang et al., 2011).

In this study, bio-electrochemical treatment of anaerobically pre-treated landfill leachate was investigated in batch and continuous-flow MFCs. Pretreatment of leachate via upflow anaerobic sludge blanket (UASB) reactor was conducted to remove excess organic carbon and the effluent of UASB reactor was fed to the anode compartment of MFC. The objective of the study reported here was to assess the power generation performance and organic carbon and ammonia removal efficiencies of a dual chambered, pre-treated leachate fed MFC.

2. Methods

2.1. Leachate source and characteristics

Laboratory-scale upflow anaerobic sludge blanket (UASB) reactor and aerobic membrane bioreactor (MBR) were set up and maintained for the treatment of landfill leachate taken from Komurcuoda Municipal Solid Waste Landfill (Sile, Istanbul, Turkey) and operated in series. The raw leachate containing 8000–20,000 mg COD/L and 1000–2200 mg NH_3-N/L was fed to the UASB reactor and then the effluent of the UASB reactor (hereafter also referred to as pre-treated leachate) was fed to the aerobic MBR to remove residual COD. The characteristics of UASB and MBR effluents at different stages of this study are shown in Table 1. The characteristics of pre-treated leachate (Table 1) resemble the characteristics of a typical medium-aged landfill leachate (Renou et al., 2008).

2.2. MFC configuration

Two-chambered MFC with a 230 mL acrylic cubic anode and cathode chambers were used in the experiments described in this study. Anode and cathode electrodes each having 36 cm^2 surface area (6 cm × 6 cm) were made of 1.5-mm and 5-mm thick carbon cloth (Clean fuel cell energy, FL, USA, LLC) and reticulated vitreous carbon (RVC) foam with 1000–3500 m^2/m^3 surface area (Duocel Carbon Foam, ERG), respectively. Chambers were physically separated by a proton exchange membrane (Nafion 117, Dupont). An Ag/AgCl reference electrode (Schott Inst., +0.197 V vs SHE) was located in each chamber and connected to the respective electrode for the measurement of anode and cathode (half-cell) potentials. The anode chamber of MFC was inoculated using the effluent of a former MFC, which was developed with the sludge obtained from a municipal wastewater treatment plant and maintained over two years with sodium acetate as the sole carbon source (Cavdar et al., 2011). Anode electrode of the former MFC was made of 1.5-mm thick carbon cloth (Clean fuel cell energy, FL, USA, CC, LLC) and the cathode electrode (Clean fuel cell energy, FL, USA, XC-72, LLC) contained 1 mg/cm^2 platinum catalyst coating on the water facing side of the carbon-cloth (Cavdar et al., 2011). The experiments were conducted at 25 °C. The anode and cathode chambers were continuously mixed using magnetic stirrers. The anode and the cathode chambers were connected through an external resistor (100 Ω) to close the circuit. The cathode chamber was aerated using a single-outlet aquarium air pump (Sobo SB548) and the flow rate was adjusted via a valve.

2.3. Treatment of pre-treated landfill leachate via MFC

Batch and continuous assays were conducted to assess the polishing effect and power generation performance of MFCs on anaerobically pretreated landfill leachate. In the batch assay, effluent of the laboratory scale UASB reactor was fed to the anode chamber to serve as a partially treated leachate and the effluent of MBR was used in the cathode chamber to serve as carbon-deprived media. MBR effluent was used in the cathode to eliminate the use of synthetic media. Partially treated leachate feed was not supplemented with any buffer due to its sufficient conductivity and pH levels (Table 1).

Continuous assays were conducted at hydraulic retention times (HRT) of 1 and 5 days by feeding the UASB effluent to the anode chamber continuously via a peristaltic pump. HRT values reported here are the total residence times in two chambered MFCs. The effluent of MBR was filled to the cathode at the beginning of the incubation. The effluent of UASB reactor was collected every two to four days, centrifuged and kept at 4 °C during feeding. The landfill leachate and thus the UASB effluent showed high variability throughout the study (Table 1). Therefore, retention time of the continuous assay was increased in order to manage the sudden increase of total VFA concentration in the UASB effluent. The effluent of anode chamber was sequentially fed to the cathode through a tubing connected in between the chambers to operate the MFC in bio-cathode mode and to remove the residual VFAs in the

Table 1
Characterization of effluents of upflow anaerobic sludge bed reactor and membrane bioreactor effluents.

Characteristics	MBR effluent	UASB reactor effluent		
	Batch studies	Batch studies	Continuous studies	
	0–12 days, day 0	0–12 days, day 0	HRT 1 day, 12–36 days	HRT 5 days, 36–51 days
COD (mg/L)[a]	1012	4900	4000–4300	4640–7020
Ammonia (mg N/L)	1180	1750	950–1550	950–1270
Nitrite (mg N/L)	ND	ND	ND	ND
pH	7.8	8.3	8.1–8.4	8.1–8.4
Alkalinity	-	6000	5000–7000	5000–7000
Conductivity (mS/cm)	31	35	28–37	28–37

Abbreviations: COD, chemical oxygen demand; HRT, hydraulic retention time; MBR, membrane bioreactor; UASB, upflow anaerobic sludge blanket.
[a] BOD of the MBR effluent was 85 mg/L.