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Short Communication

Treatment of landfill leachate using microbial fuel cells: Alternative anodes and semi-continuous operation

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HIGHLIGHTS

- Unmodified landfill leachate was used as a substrate in microbial fuel cells (MFCs).
- Activated carbon as an anode provided significantly greater reduction in COD.
- Power output for both activated carbon and biochar anodes were not significantly different.
- A semi-continuous MFC provided similar COD reduction as the biochar anode batch MFC.

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ABSTRACT

Microbial fuel cells were designed and operated to treat landfill leachate while continuously producing power. Two different anodes were tested in batch cycles using landfill leachate as a substrate without inoculation: an activated carbon anode and biochar anode. In addition, a semi-continuous serpentine design was evaluated. No significant difference of the mean was found for the peak voltage, current density or power densities between the batch cell with activated carbon or biochar. Similar COD reduction occurred at both the batch (with biochar) and semi-continuous scale (28% ± 8.8% and 21.7% ± 12.2%, respectively). The batch MFC with activated carbon anode had significantly higher COD removal (74.7% ± 5.5%). BOD was removed by the semi-continuous MFC, but ammonia was not removed in four of the five cycles. The results provide further information on the possibility of using MFCs in landfill leachate treatment systems.

1. Introduction

Water management at a landfill is critical to operations as well as the protection of human health and the environment. Historically, landfills have been the primary form of waste management throughout the world and in many locations, this is still the case. For example, in the United States of America (USA), of the 250 million tons of waste produced in 2010, 136 million tons (54.2%) went to landfills. While this number has been on the decline (from 89% in 1980), historical landfills need management and landfills will likely remain a disposal option into the future (US EPA, 2011). Landfill leachate is liquid that emanates from the landfill system either produced by the waste within the system or occurring from infiltration, e.g., groundwater or rainfall. Leachate must be collected and managed per most regulations throughout the world. USA regulations require leachate to be collected protecting the groundwater beneath the landfill (CFR, 2012). Landfill leachate, as a wastewater, must be managed during the life of the landfill, as well as 30 years after closure of the landfill (CFR, 2012). Organic matter exhibited by biological oxygen demand (BOD) and chemical oxygen demand (COD) are typical constituents in landfill leachate. Other constituents include ammonia, volatile fatty acids, and trace metals (Tchobanoglous et al., 1993). Treatment strategies include treating for discharge or pre-treatment prior to transport to a municipal wastewater treatment facility. Some wastewater treatment facilities have the capability and capacity to accept landfill leachate with no pre-treatment; however, the large organic load of leachate can be expensive to manage. Landfills are highly dynamic environments and leachate quantity and characteristics are variable, not only from the heterogeneity of the waste, but from the degradation processes that happen in the landfill over time. Challenges to managing leachate on-site primarily stem from this fact. Many landfills send leachate off-site for treatment to a wastewater treatment plant; off-site treatment requires the leachate to meet pretreatment requirements and can be costly.

A wide variety of wastewaters have been treated in microbial fuel cells (Pant et al., 2010). Laboratory scale microbial fuel cells (MFC) have been shown to provide wastewater treatment by reducing COD in various wastewaters including: brewery

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wastewater, paper wastewater, swine wastewater, and domestic wastewater (Kim et al., 2008; Wen et al., 2009; Pant et al., 2010). COD has also been reduced in landfill leachate utilizing various MFCs (You et al., 2006; Greenman et al., 2009; Li, 2010; Puig et al., 2011; Damiano and Jambeck, 2009; Tugtas et al., 2013). Power can be produced using landfill leachate in an MFC without additional substrate, chemicals or inoculation, while reducing both COD and BOD (Damiano, 2009). Most MFC research has been conducted at the laboratory bench-top scale and size increases are limited by the expense of materials such as rare-earth metal catalysts and carbon anodes/cathodes. Studies have examined alternative catalysts, alternative architecture and construction materials, and other barriers to large-scale application (Logan et al., 2007; Kim et al., 2011; Clauwaert et al., 2008). In addition internal resistance limits the power production of larger MFCs (Logan, 2008). However, if treatment of the wastewater is the primary goal, power production can be secondary. COD reductions have occurred in various designs of MFCs for leachate treatment (Greenman et al., 2009; Puig et al., 2011). However, in biological -only mediated processes, reduction of COD will be limited by recalcitrant COD concentrations, i.e., those that cannot be removed by biological processes. In this case, a combination of chemical processes, along with the biological processes may be necessary to reach treatment goals (Li, 2010). However, if scale-up becomes affordable, MFCs have been shown to remove COD concentrations and could be utilized for on-site pre-treatment in an integrated treatment system for landfill leachate. The objective of this research was to begin to address application issues related to using MFCs to treat landfill leachate. Specifically, an alternative (less expensive) anode material (biochar) was tested as a substitute for carbon granules. Secondly, the treatment of leachate in a larger MFC, operated semi-continuously, was evaluated.

2. Methods

2.1. Substrate

Landfill leachate was the substrate used in all experiments. Leachate was collected from the Oak Grove landfill in Barrow County, Georgia, USA. Leachate was sampled from a storage tank that held leachate until it was transported to a water reclamation facility. The storage tank contained a mixture of leachate from all cells of the landfill. Leachate was typically sampled the day before each experiment began in clean 2 L high density polyethylene sample containers.

2.2. Single chamber air–cathode MFC

A cylindrical single chambered air–cathode MFCs (13.2 cm high and 10 cm diameter) was designed to test different anodes in batch mode (Ganesh, 2012). The batch MFCs had a reactor volume of 570 ml and a liquid volume of 520 ml. Two MFCs were constructed to run simultaneously. Activated carbon (Sigma–Aldrich, 8–20 mesh size) was used in one batch MFC (Cell A) and biochar was used in the other batch MFC (Cell B) as anode materials. The biochar was produced in the UGA bioconversion facility from Pine wood. Surface area of the activated carbon and biochar was measured using a Quantachrome Autosorb 1-C, using the 11-point BET method. Both MFCs used a graphite rod (11 cm long and 1.2 cm diameter) in the center of the granules of carbon or biochar to allow for electron transport through an attached wire and to an external resistor. Carbon cloth coated with 10% platinum on Vulcan XC-72 (a carbon black powder) formed the cathode (alternative cathodes for scale up were tested in a separate experiment (Ganesh, 2012)). The catalyst was prepared by mixing platinum on carbon powder (Pt/C) with DuPont dispersion Nafion liquid solution to form a paste. 7 ml of Nafion solution was mixed with 1 g of Pt/C powder and homogenized. The mixture was then sprayed onto the carbon cloth. A Figure of the MFC can be found in (Ganesh, 2012).

2.3. Semi-continuous MFC

A semi-continuous open air cathode MFC was constructed using Plexiglas (37 cm × 32 cm × 6 cm) and sealed using silicon. Dense fine grain graphite plates (25 cm × 5 × 0.6 cm) and graphite rods (length 30 cm and 1.2 cm diameter) were used as the anode in this cell. The plates were arranged parallel to each other (2 in. apart) in the cell in a serpentine pattern allowing the flowing leachate to cover maximum surface area in the cell (Ganesh, 2012). The semi-continuous MFC had a working volume of 5.5 l. Carbon cloth sprayed with platinum catalyst as outlined previously was used as the open air cathode. Leachate was pumped into the cell using a peristaltic pump at a consistent 7 ml/min, and the effluent from the cell was recycled back into the MFC.

2.4. MFC operation

No additional bacteria, nutrients or mediators were used to enhance the operation or efficiency of the system. The batch MFCs (with two different anodes) were operated in three continuous parallel cycles of operation (cycle 1.1, 1.2 and 1.3). The semi-continuous MFC was operated in five cycles (cycle 2.1, 2.2, 2.3, 2.4 and 2.5) using fresh leachate except cycle 2.2. Effluent from cycle 2.1 and stored leachate was used as influent for cycle 2.2. The voltage from the MFCs was recorded every 2 min with a Labview program. Power and current density were normalized to the area of the cathode (m^2) (since the area of the anodes [activated carbon and biochar] were so large) and to the total MFC reactor volume (m^3). An electrical breadboard was used for the wiring of both systems. A 1 Ω resistor was used to compensate for the resistance of the data acquisition unit, and a 470 Ω resistor, found to be the optimum resistance in a similar architecture, provided a load for the system (Damiano and Jambeck, 2009).

2.5. Leachate characterization

For all cycles, leachate was characterized prior to input into the MFC and after treatment. Temperature (celsius), pH, oxidation reduction potential (ORP) (mV), dissolved oxygen (mg/L and %), conductivity (mS/cm) and specific conductivity (μS/cm) were all measured using a YSI 556 MPS probe. The batch MFCs also included analysis of Chemical oxygen demand (COD), Hach method TNT822 (Hach, 2012). For the semi-continuous MFC, analyses included: chemical oxygen demand (COD); biological oxygen demand (BOD), standard method 5210 B, (Public Health Association (APHA), 1998); ammonia, standard method 4500 (American Public Health Association (APHA), 1998); nitrite, nitrate, sulfate, Hach method 10227 (Hach, 2012); and cations. Inductively coupled plasma-atomic emission spectroscopy (ICP-AES) was used to detect cations and inorganic (trace) metals in the leachate. Samples were analyzed for the presence and concentration of aluminum, antimony, arsenic, barium, calcium, cobalt, chromium, iron, magnesium, manganese, nickel, selenium, silver, vanadium, and zinc.

2.6. MFC current and power characterization

Current was calculated according to the equation $V = I * R_{ext}$, where V = voltage (mV); I = current (mA); and R_{ext} = external resistance (Logan, 2008). Current was normalized by the cathode area, since the anode materials had an abundance of surface area (geometric and internal) to calculate current density. Total current was