Bioresource Technology 200 (2016) 1–7

Contents lists available at ScienceDirect

Bioresource Technology

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

Anaerobic microbial fuel cell treating combined industrial wastewater: Correlation of electricity generation with pollutants

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HIGHLIGHTS

- A dual chamber MFC was operated under laboratory conditions treating industrial wastewaters.
- The treatment efficiency for COD in MFC ranged 85–90%.
- The maximum voltage was 890 mV with columbic efficiency of 5184.7 C.
- Positive significant co-relation was observed between COD concentration and voltage.

ARTICLE INFO

Article history:
Received 6 September 2015
Received in revised form 26 September 2015
Accepted 28 September 2015

Keywords:
Energy
Microbial fuel cell
Wastewater treatment
Anaerobic treatment
Industrial effluents

ABSTRACT

Microbial fuel cell (MFC) is a new technology that not only generates energy but treats wastewater as well. A dual chamber MFC was operated under laboratory conditions. Wastewater samples from vegetable oil industries, metal works, glass and marble industries, chemical industries and combined industrial effluents were collected and each was treated for 98 h in MFC. The treatment efficiency for COD in MFC was in range of 85–90% at hydraulic retention time (HRT) of 96 h and had significant impact on wastewater treatment as well. The maximum voltage of 890 mV was generated when vegetable oil industries discharge was treated with columbic efficiency of 5184.7 C. The minimum voltage was produced by Glass House wastewater which was 520 mV. There was positive significant co-relation between COD concentration and generated voltage. Further research should be focused on the organic contents of wastewater and various ionic species affecting voltage generation in MFC.

1. Introduction

Industry is a huge source of water pollution as it produces pollutants that are extremely harmful to biotic communities and the ambient environment. Most of these conventional methods of waste water treatment require high energy inputs. The organic matter present in raw wastewater may have almost 10 times the energy in the form of carbon compounds needed to treat it. On average, 1 kg of carbohydrate represents 1.06 kg of COD, which can be converted to an equivalent power of 4.41 kW h or 13×10^6 coulombs (Pham et al., 2006). Hence, this energy should be harnessed and employed to accomplish wastewater treatment. Biomass to bioenergy conversion can be achieved through various pathways e.g. anaerobic digestion (Monlau et al., 2015; Schievano et al., 2014), ethanol fermentation (Castro et al., 2015; Gu et al., 2014; Yücel and Aksu, 2015) and hydrogen fermentation (Batlle-Vilanova et al., 2014). Recently, the MFC technology has been developed as a novel biotechnology to harvest energy from organic waste present in wastewater. MFC is a novel approach that treats wastewater and recovers energy simultaneously. MFC converts organic matter present in wastewater into electricity through the catalytic activity of microbes. The energy present in C–C bonds of organic matter is directly converted into electricity. The electrons generated during the oxidation process are transferred to the anode from where they flow through the external circuit thus generating electricity. The electrons are transferred to the anode either through direct bacterial contact to the anode or through the use of mediators (Logan et al., 2009) especially electrodes.

Wastewaters from chemical, distillery, brewery industries (Pant et al., 2010; Akman et al., 2013), pharmaceutical industry (Velvizhi and Mohan, 2012), textile (Solanki et al., 2013), petrochemical, vegetable oil, food industries, animal carcass waste

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http://dx.doi.org/10.1016/j.biortech.2015.09.088
0960-8524/

water (Li et al., 2013), swine waste water (Zhuang et al., 2012), municipal waste water (Zhang et al., 2013) and domestic wastewater (Jiang et al., 2011) could be treated using aerobic or anaerobic MFC. Sulphide, ammonia, nitrate, nitrite, perchlorate, chlorinated compounds, copper, mercury and iron could be effectively removed by MFC (Aelterman et al., 2006; Clauwaert et al., 2007).

Aerobic MFC requires a constant oxygen supply and can lead to an increase in energy needed to carry out the process. On the contrary, anaerobic MFC are a more environment friendly as their energy demand is lower than aerobic MFC.

Previous researchers treated wastewaters from individual industries. Min et al. (2005a) treated animal wastewater in MFC. Tests using a two-chambered MFC indicated that electricity could be generated from swine wastewater containing very high chemical oxygen demand (SCOD). Maximum power density of 261 mW/m^2 was produced from animal wastewater. Mohan et al. (2007) examined the performance of two different dual chambered MFC. One of the MFC had aerated catholyte and in other MFC ferricyanide catholytes was used. MFC with ferricyanide catholyte produced more power and also reduced more substrate (586 mV; 2.37 mA; 0.559 kg COD/m^3 day) as compared to aerated catholyte (572 mV; 1.68 mA; 0.464 kg COD/m^3 day). Maximum power yield (0.635 W/kg CODR and 0.440 W/kg CODR) and current density (222.59 mA/m^2 and 190.28 mA/m^2) was observed at 100 resistor with ferricyanide and aerated catholytes, respectively. Ahn and Logan (2010) examined domestic wastewater treatment under two different temperatures (23 °C and 30 °C) and flow modes (fed-batch and continuous) using single-chamber air–cathode microbial fuel cells. The highest power density of 422 mW/m^2 (12.8 W/m^3) was achieved under continuous flow and mesophilic conditions at an organic loading rate of 54 g COD/L-d achieving 25.8% COD removal. Qing et al. (2011) demonstrated a single chamber MFC with an air–cathode in which Glucose–penicillin mixtures or penicillin was used as substrates. The maximum power density for 1 g L^{-1} glucose + 50 mg L^{-1} penicillin (101.2 Wm^{-3}) was 6-fold higher than the sum of that for 1 g L^{-1} glucose (14.7 Wm^{-3}) and 50 mgL^{-1} penicillin (2.1 Wm^{-3}) as the sole fuel. The maximum current density with 50 mgL^{-1} penicillin (10.73 A m^{-2}) was 3.5-fold compared with that without penicillin (3.03 A m^{-2}).

Previously various authors reported the treatment efficiency of MFC where individual wastewaters were fed and their energy generation was monitored (Jiang et al., 2011; Zhang et al., 2013; Velvizhi and Mohan, 2012; Zhuang et al., 2012; Li et al., 2013; Solanki et al., 2013; Akman et al., 2013). Considering background knowledge of MFC where majority of authors used single chambered treating wastewaters from a particular industry, the present investigation aimed to treat the combined industrial effluents from various group of industries in anaerobic MFC. The previous researchers did not identify the correlation of various pollutants with the energy output, so another objective was to analyse correlation of various wastewater constituents on energy output of the MFC under investigation.

2. Methods

2.1. Wastewater sampling

Grab sampling method was employed to collect wastewater samples from combined drains at Hattar Industrial Estate, Pakistan and included vegetable oil (Ghee) Industries (draining effluents from food industries, soap industries, and marble industries), Murree Glass House (the drain received effluents from metal rerolling, marble industries, chemical industries and some food industries), Biafo chemical industries sampling point receiving wastewater from pharmaceutical, food, steel, chemical and re-rolling mills, while Jharikas sampling point represented all the combined drains from Hattar industrial estate, even it received effluents from domestic sources. Grab wastewater samples were collected and stored in a clean sample bottles for immediate analysis; otherwise samples were acidified with conc. HNO_3 for further use.

2.2. MFC construction

MFC consisted for two chambers and it was made of perspex glass. It consisted of a cathode chamber and an anode chamber. Each chamber had a capacity to accommodate 500 mL. Both of the chambers were separated from each other by cation exchange membrane (CEM, CMI-7000, Membrane International, Inc. USA). The electrodes were suspended in the respective chambers and were placed parallel to the cation exchange membrane. Titanium wire was used as an anode and carbon cloth was used as a cathode.

2.3. MFC operation

Wastewater was fed to the anaerobic anode chamber. The buffer solution and $KMnO_4$ solution were added to the cathode chamber. The two chambers were separated by a cation exchange membrane which allowed protons flow from anode to cathode chamber, while preventing the flow of oxygen from cathode to anode chamber. Hydraulic retention time was fixed at 96 h. MFC was operated in batch mode. Combined wastewaters from four different sites from Hattar Industrial Estate were fed into MFC.

2.4. Analytical methods

Wastewater quality analysis of influent and effluent samples was done using the standard methods prescribed by APHA (2005). COD was analysed using digestion method. Sulphates and phosphates were examined by spectrophotometric method. Heavy metal analysis was done using Atomic absorption spectrometry. The parameters like pH, EC, TDS were also analysed and standard methods of analysis were used.

Columbic efficiency is an important parameter of the MFC to judge its ability to generate voltage from various constituents. Columbic efficiency of all the dilutions of all four wastewater was calculated using formula:

$$C_{max} = F\, f\, S_{COD}\, V$$

where, C_{max} is the columbic efficiency, F is Faradays constant (96,485 C/mol of electrons), f is 1 mol of electrons generated per 8 g of COD, V is volume in litres.

2.5. Statistical methods

In order to check the strength of relationship between different parameters, Pearson's coefficient correlation was computed and significance determined by applying *t*-test.

3. Results and discussion

The efficiency of MFC treating various wastewater samples were presented in Table 1. The results showed that there was a significant change in water quality parameters after treatment in MFC.

3.1. Reduction in COD

Initial COD of the wastewater collected from vegetable oil industries group point was 925 mg/L. After treatment in MFC, it