Bioresource Technology 247 (2018) 753–758

Contents lists available at ScienceDirect

Bioresource Technology

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

Cylindrical graphite based microbial fuel cell for the treatment of industrial wastewaters and bioenergy generation

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ARTICLE INFO

Keywords:
Graphite reactor
Bioelectrochemical treatment
Labanah whey wastewater
Petroleum refinery wastewater

ABSTRACT

Cylindrical graphite microbial fuel cell (MFC) configuration designed by eliminating distinct casing and membrane was evaluated for bioelectrogenesis and treatment of real-field wastewaters. Both petroleum refinery wastewater (PRW) and Labanah whey wastewater (LW) were used as substrates, and investigated for electricity generation and organic removal under batch mode operation. PRW showed higher bioelectricity generation (current and power generation of 3.35 mA and 1.12 mW at 100 Ω) compared to LW (3.2 mA and 1.02 mW). On the contrary, higher substrate degradation efficiency was achieved using LW (72.76%) compared to PRW (45.06%). Superior function of MFC operation in terms of volumetric power density (PRW, 28.27 W/m^3; LW, 23.23 W/m^3) suggesting the feasibility of using these wastewaters for bioelectricity generation. Large sources of wastewater that generating in the Middle-East countries have potential to produce renewable energy from the treatment, which helps for the sustainable wastewater management and simultaneous renewable energy production.

1. Introduction

Substantial progress towards valorization of wastewater and waste materials for bioenergy production from the treatment is gaining high priority in recent years. Microbial fuel cells (MFCs) are one of the widely studied technologies that have potential for waste valorization into energy in the form of bioelectricity generation (Pant et al., 2010; Koók et al., 2016). In spite of significant advancement happening in this field with respect to microbiology, material science, chemistry, electrochemistry, etc., process economics and process sustainability were found to be among the most important factors to move the field to the next level (Santoro et al., 2017; Mohanakrishna et al., 2010). Unlike the conventional biological processes for wastewater treatment, MFC found to have complex design due to two different redox reactions such as anodic oxidation and cathodic reduction at distinct locations (Mohanakrishna et al., 2012; Liu and Logan, 2004). The chamber that contains anode electrode and leads oxidation reaction is designated as an anode chamber. Similarly, the cathode chamber harbors reduction reaction with cathode electrodes. In MFCs, proton exchange membrane (PEM) or cation exchange membrane (CEM) is also one of the key components (Mohan et al., 2008; Franks et al., 2009). All these components have important roles in MFC design and scaling up of this technology as a commercial entity. Theoretically, irrespective of the volume, a maximum of 1.1 V can be achieved from a single MFC unit (Logan et al., 2006), and stacking up of MFCs with efficient and suitable design can increase the voltage output.

Recent studies using different electrode materials as well as MFC reactor configurations in the range of 200 mL to few hundred liters were evaluated towards development of pilot-scale MFC systems (Janicek et al., 2014). Transforming this technology from bench to commercial scale will bring it a step forward towards realization of commercial application of bioelectricity generation. Among the several materials used for the electrodes, carbon based materials such as graphite and carbon with metal based impregnations or coatings were found to be cost-effective and efficient for bioelectricity generation (Mohanakrishna et al., 2012; Xie et al., 2010). Carbon based materials are also non corrosive and inert at wide range of environmental conditions that can be prevailing due to the application of industrial wastewater as substrate (Mohan et al., 2008).

CAPEX and OPEX, which are also known as capital expenditure and operational expenditure, are used to determine the commercial potential of a technology. The manufacturability of MFCs can be deployed by extrusion, pultrusion, lamination processes to facilitate a considerable reduction of CAPEX on mass production. Similarly, OPEX can be

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http://dx.doi.org/10.1016/j.biortech.2017.09.174
Received 27 July 2017; Received in revised form 23 September 2017; Accepted 25 September 2017
Available online 28 September 2017
0960-8524/

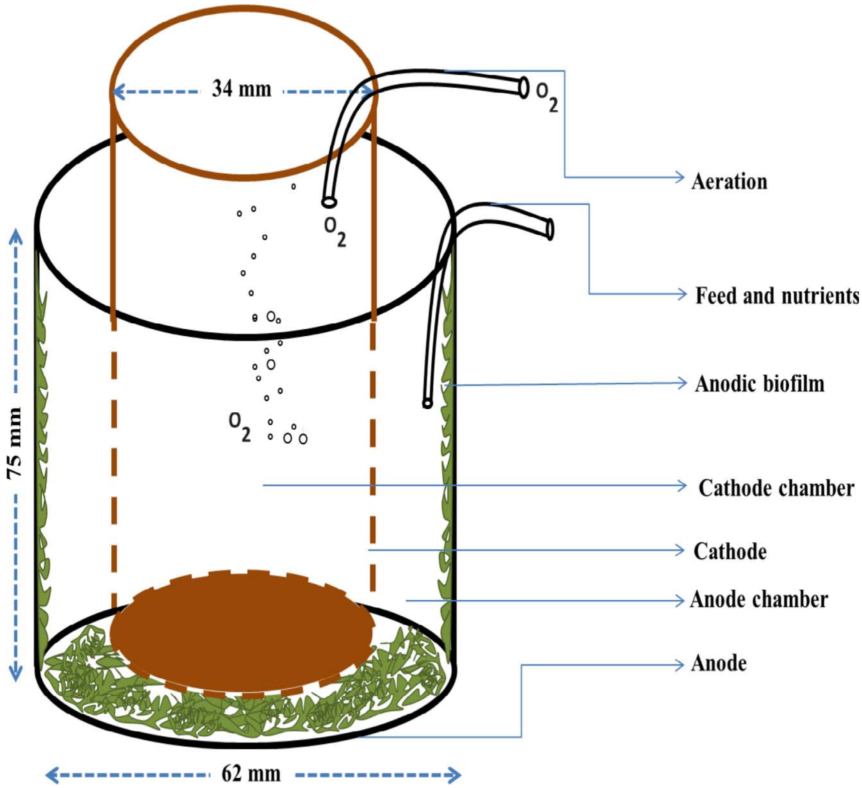

Fig. 1. Schematic diagram of MFC fabricated with graphite in which anode and cathode were concentrically arranged to build complete reactor. (*Dimension of MFC:* Anode: height – 75 mm, diameter – 62 mm, thickness – 8 mm; Cathode: height – 75 mm, diameter – 34 mm, thickness – 4 mm.)

reduced by choosing a simple design with higher durability (Premier et al., 2012). Many MFC designs were used in the laboratory scale such as H-type (Mohan et al., 2008), cylindrical type (Houghton et al., 2016), tubular (Zhang et al., 2013; Tee et al., 2016), flat plate type (Cheng and Logan, 2011; Zhuang et al., 2012), anaerobic digester (AD) type (Mohanakrishna et al., 2010), etc. Stack MFC configurations typically consist of insulator to be electrically isolated from the adjacent or surrounded MFC units. The insulator materials are inert which can be selected from a range of polyvinyl chloride (Zhang et al., 2013), polypropylene (Kim et al., 2010), nylon, plastic mesh, etc. (Janicek et al., 2014).

Technical feasibility of MFC technology must be examined with treating actual wastewater, including both municipal and industrial wastewaters. Many of the prior studies have focused on municipal or low strength wastewater treatment in MFCs, and industrial wastewaters, which are highly diverse, require more attention. Downstream processing of oil industry produces huge amount of wastewater that contains organic material, mostly consist of petroleum hydrocarbons and dissolved solids comprising from sulfides, ammonia, nitrates and heavy metals (Chen et al., 2008; Srikanth et al., 2016). Composition of petroleum refinery wastewater (PRW) may vary based on the process and origin of crude petroleum reserves (Benyahia et al., 2005). Approximately 3.5–5 m^3 of wastewater is generating from one ton of oil processed. Food wastewater also represents a strong interest for resource recovery and efficient treatment. Labanah whey wastewater (LW) is produced during Labanah production which is a popular type of fermented milk product in the Middle-East countries. High amount of milk nutrients (more than 50%) retains in the LW and pH of 3.5, is leading to energy intensive biological treatment process (aerobic or anaerobic) (Abu-Reesh, 2014). Valorizing the waste organics present in wastewaters for energy generation can create sustainable economy along with the treatment (Iskander et al., 2016).

In this study, two cylindrical MFCs that fabricated with graphite were used to evaluate two different wastewaters for valorization by bioelectricity generation: PRW has low biodegradable organic material (chemical oxygen demand, COD) and high dissolved solids (TDS) concentration, and LW from dairy industry having high COD and low pH. As graphite is one of the most used non-corrosive electrode material that exhibit good electron transfer and relatively low cost, it has been selected as suitable material for MFC fabrication. As both wastewaters used were distinct by characteristics, operation of MFC for bioelectricity generation demonstrates versatile performance of the process under batch-mode operation and mild operating conditions.

2. Materials and methods

2.1. Wastewaters

The present study used two different types of real field wastewaters namely petroleum refinery wastewater (PRW) and Labanah whey wastewater (LW). PRW collected from local petroleum refinery wastewater treatment plant in Doha, Qatar. Grab sample of PRW was collected from the feed point to the wastewater treatment plant (COD, 2150 mg/L; pH, 7.45). Labanah whey is the yellow greenish liquid portion of the milk that separated from the curds during Labanah manufacture. It is collected from Dandy Company, Doha (COD, 18,546 mg/L; pH, 6.78). The wastewater collected were immediately shifted to the laboratory and stored at 4 °C to preserve the nature of the wastewater and to avoid decomposition of organics by the indigenous bacteria of the wastewater. As per the experimental plan, only the required amount of wastewater was collected and used for experimentation.

2.2. Graphite based MFC

2.2.1. Configuration

A MFC designed with cylindrical anode and cathode electrodes fabricated with graphite material was used in this study. Cylindrical cathode electrode with dimensions of 75 mm height and 34 mm diameter was epicentrically placed in a cup shaped anode electrode with the dimensions of 75 mm height and 62 mm diameter. As the anode is having closed type of design at one end with a wall thickness of 8 mm,