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Biosensors and Bioelectronics 23 (2008) 1326–1332
BIOSENSORS & BIOELECTRONICS
www.elsevier.com/locate/bios

# Biochemical evaluation of bioelectricity production process from anaerobic wastewater treatment in a single chambered microbial fuel cell (MFC) employing glass wool membrane

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Received 13 September 2007; received in revised form 5 November 2007; accepted 28 November 2007
Available online 3 December 2007

**Abstract**

Biochemical functioning of single chambered microbial fuel cell (MFC) using glass wool as proton exchange membrane (PEM) operated with selectively enriched acidogenic mixed culture was evaluated in terms of bioelectricity production and wastewater treatment. Performance of MFC was studied at two different organic/substrate loading rates (OLR) (2.64 and 3.54 kg COD/$m^3$) and operating pH 6 and 7 using non-coated plain graphite electrodes (mediatorless anode; air cathode). Applied OLR in association with operating pH showed marked influence on the power output and substrate degradation efficiency. Higher current density was observed at acidophilic conditions [pH 6; 98.13 mA/$m^2$ (2.64 kg COD/$m^3$-day; 100 Ω) and 111.29 mA/$m^2$ (3.54 kg COD/$m^3$-day; 100 Ω)] rather than neutral conditions [pH 7; 100.52 mA/$m^2$ (2.64 kg COD/$m^3$-day; 100 Ω) and 98.13 mA/$m^2$ (3.54 kg COD/$m^3$-day; 100 Ω)]. On the contrary, effective substrate degradation was observed at neutral pH. MFC performance was evaluated employing polarization curve, impedance analysis, cell potential, Coulombic efficiency and bioprocess monitoring. Sustainable power yield was calculated at stable cell potential.


*Keywords:* Microbial fuel cell (MFC); Bioelectricity; Single chamber; Anaerobic wastewater treatment; Mixed culture; Sustainable power

## 1. Introduction

Recently considerable attention is being paid to alternative renewable sources of energy through out the world. Harnessing of biohydrogen ($H_2$) by anaerobic fermentation (Das and Veziroglu, 2001; Logan, 2004; Ginkel et al., 2005; Rittmann et al., 2006; Yang et al., 2006; Venkata Mohan et al., 2007a,b,c) and bioelectricity using microbial fuel cells (MFC) (Gil et al., 2003; Rabaey and Verstraete, 2005; Lowy et al., 2006; Logan and Regan, 2006; Lovely, 2006; Davis and Higson, 2007; Du et al., 2007; Biffinger et al., 2007; Kakehi et al., 2007; Prasad et al., 2007; He et al., 2007; Venkata Mohan et al., 2007d,2008) are gaining importance due to their clean, efficient, and renewable nature. Although, fermentative $H_2$ production is considered as a viable alternative energy source of the future, its storage, purification, low-production rates and conversion to energy (electricity) by fuel cells are some of the inherent limitations (Logan, 2004). Alternatively, MFCs facilitate *in situ* conversion of organic substrate to energy (bioelectricity) (Venkata Mohan et al., 2007d,2008).

MFC is a biochemical-catalyzed system which generates electrical energy through the oxidation of organic matter in the presence of fermentative bacteria under mild reaction conditions (ambient temperature and pressure) (Logan and Regan, 2006a). The potential developed between the bacterial metabolic activity [reduction reaction generating electrons ($e^-$) and protons ($H^+$)] and electron acceptor conditions separated by a membrane leads to generation of bioelectricity. Exploiting wastewater as a viable substrate to harness electricity is considered as sustainable approach and is presently in the early stages of research (Rabaey et al., 2003; He et al., 2005; Min and Logan, 2004; Oh and Logan, 2005; Min et al., 2005; Moon et al., 2006; Pham et al., 2006; Ghangrekar and Shinde, 2007; Rodrigo et al., 2007; Venkata Mohan et al., 2007d,2008). MFC design and configuration, characteristics of carbon source, nature and coating of electrodes, membrane electrode assembly, mediators and elec-

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doi:10.1016/j.bios.2007.11.016

trolytes used, nature of inoculum (biocatalyst) used in the anode chamber, operating conditions such as loading rate, pH, temperature, retention time, etc. are considered to be important factors which govern the overall efficiency of electricity generation. Since microorganisms act as a catalyst in the transfer of electrons from the substrate to the anode, the selection of a high performance microbial consortium (either pure or mixed culture) is crucial (Chaudhuri and Lovley, 2003; Stams et al., 2006).

Therefore, the present work aims to study the feasibility of bioelectricity generation in single chambered MFC (mediatorless (anode); air cathode), using glass wool as proton exchange membrane (PEM) and wastewater as substrate employing selectively enriched acidogenic mixed consortia as anodic inoculum.

## 2. Experimental

### 2.1. Anodic mixed consortia

Acidophilic mixed consortia producing molecular $H_2$ from various types of wastewater treatment in our laboratory was used as parent inoculum (Venkata Mohan et al., 2007b,c). Parent culture was washed thrice in saline buffer (5000 rpm, 20 °C) and enriched in designed synthetic wastewater (glucose—3 g/l; $NH_4Cl$—0.5 g/l, $H_2PO_4$—0.25 g/l, $K_2HPO_4$—0.25 g/l, $MgCl_2$—0.3 g/l, $CoCl_2$—25 mg/l, $ZnCl_2$—11.5 mg/l, $CuC_2$—10.5 mg/l, $CaCl_2$—5 mg/l, $MnCl_2$—15 mg/l, pH 5.5; COD—3.2 g/l) under aseptic anaerobic microenvironment at pH 5.5 (100 rpm; 48 h). Prior to inoculation mixed culture was subjected to pretreatment to selectively enrich acidogenic microflora employing heat–shock treatment to sustain acidogenic bacterial (AB) activity and to inhibit methanogenic bacteria (MB) as described by Venkata Mohan et al. (2007a,b,c).

### 2.2. MFC configuration and operation

Single chambered MFC was designed and fabricated in our laboratory using 'perplex' (Fig. 1). The fuel cell consists of single anodic compartment with a designed total volume of 0.35 l (working volume 0.32 l). Plain graphite plates (5 cm × 5 cm; 10 mm thick) without any coating were used as electrodes for both anode and cathode. Cathode has projected surface area of 70 $cm^2$. To increase the overall surface area (83.56 $cm^2$), anode was purged with nine uniform sized holes (0.1 cm dia). Prior to use, the electrodes were soaked in deionized water overnight. Glass wool sandwiched between non-absorbent cotton (∼2 mm thickness) was used as PEM between two electrodes in place of normally used Nafion membrane. Copper wires were used for contact with electrodes after carefully sealing with epoxy sealant. Lower side of anode was always in contact with wastewater. Top portion of the cathode was exposed to air. The anode chamber of the fuel cell resembles an anaerobic suspended growth reactor incorporating electrode membrane assembly on the top cover. Provision was made in design for sampling ports, wire input points (top), inlet and outlet ports, gas outlet, etc. Leak proof sealing was provided at joints to maintain anaerobic microenvironment in anode compartment. Prior to

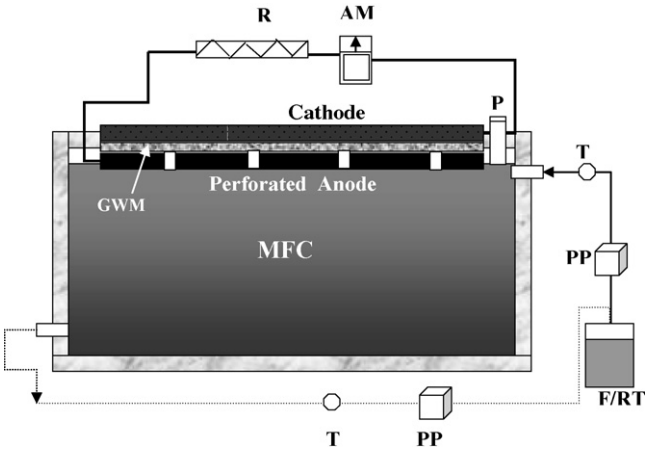


Fig. 1. Schematic details of the experiment setup microbial fuel cell [MFC: single chambered microbial fuel cell; GWM: glass wool membrane T: preprogrammed timer; PP: peristaltic pump; P: sampling/standard electrode port; AM: ammeter; R: resistor (100 Ω); F/RT: feeding and recirculation tank].

startup, the anodic compartment was inoculated with selectively enriched $H_2$ producing mixed microflora (volatile suspended solids (VSS), 2.0 g/l) dissolved in designed synthetic wastewater (320 ml). MFC was operated in fed batch mode at room temperature (29 ± 2 °C). Anolyte was continuously re-circulated (0.7 l/h) to eliminate concentration gradient. Before every feeding event, inoculum was allowed to settle down (30 min; settling) and exhausted feed (320 ml) was removed (decanted; 15 min) under anaerobic conditions. Settled inoculum (∼30 ml by volume) was used for subsequent operation. Feeding, decanting, and recirculation operations were performed using peristaltic pumps (Gilson, India) controlled by electronic timer (ETTS, Germany). After every feeding event, MFC was sparged with oxygen free $N_2$ for 2 min to maintain anaerobic microenvironment. Prior to feeding, pH of wastewater was adjusted to desired value (6.0/7.0) using concentrated orthophosphoric acid (88%) or 1 N NaOH. MFC performance with respect to power generation and substrate degradation was evaluated at two organic loading rates (OLR) [(2.64 kg COD/$m^3$-day (3 g glucose/l) and 3.54 kg COD/$m^3$-day (6 g glucose/l)] and pH conditions (6.0 and 7.0).

### 2.3. Analysis

Current output and substrate degradation rate (SDR) were considered as two key parameters to evaluate the performance of MFC. Bio-electrochemical calculations were done based on the procedure outlined by Logan et al. (2006). Current (I) was recorded after every 3 h using digital multi-meter (Metravi 901) by connecting 100 Ω as external resistance in the open circuit in series. For polarization, current production during stabilized operation of fuel cell was monitored by connecting to various external resistances (100–30,000 Ω) immediately in parallel. The anodic and cathodic potentials of MFC were measured against a saturated Ag/AgCl electrode (PPC Ltd., Hyderabad) using a pH meter (LI612 model, ELICO Ltd., Hyderabad). A variable resistance box was used to select an applied exter-