American Journal of Biochemistry and Biotechnology, 2012, 8 (4), 304-310
ISSN: 1553-3468

doi:10.3844/ajbbsp.2012.304.310 Published Online 8 (4) 2012 (http://www.thescipub.com/ajbb.toc)

Acetone Removal and Bioelectricity Generation in Dual Chamber Microbial Fuel Cell

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Received 2012-09-25, Revised 2012-10-15; Accepted 2012-10-27

ABSTRACT

Synthetic waste water contain organic compound can be oxidized in an anaerobic conditions in microbial fuel cell while biodegradation of Chemical Oxygen Demand (COD) takes place under anaerobic condition in anode compartment. The microorganisms for biological treatment of the organic matter were obtained from a UASFB bioreactor. In the treatment of waste water, ones COD was removed the current and power was generated and record. Also polarization curve was obtained. In cathode compartment ferocynide and potassium permanganate with several concentration were add for enhancement of proton oxidation. The performance of MFC for maximum current and power generation were obtained with 300 μM L^{-1} potassium permanganate as oxidizers agent. Maximum generated power and current densities were 22 mW/m^2 and 70 mA/m^2, respectively. Active microorganisms used acetone as electron donors and COD removal was 69% at the end of process.

Keywords: Potassium Permanganate, COD Removal, Bioelectricity, Microbial Fuel Cell

1. INTRODUCTION

Production of renewable energy is essential requirements for sustainable human society. Traditional source of energy has several disadvantages such as: Reduction of fossil fuels sources, global warming, energy supply security and risk (Min *et al*., 2012). Active microorganisms can produce bioelectricity from renewable sources (Pant *et al*., 2010; Wang *et al*., 2012).

The relation between metabolic processes and electricity in living organisms first was demonstrated more than 200 years ago by Luigi Galvani. In 1910, Potter discovered electricity generating by active microorganisms such as *Escherichia coli* and *Saccharomyces* (Hall and Denning, 1994). Because of energy crisis in recently years, researchers increased their research in this area and developed Microbial Fuel Cell (MFC) (Liu *et al*., 2012; Nimje *et al*., 2012; Rahimnejad *et al*., 2012).

MFC is a bioreactor that converts chemical energy of organic compounds to bioelectrical energy through catalytic reactions of microorganisms under anaerobic conditions (Cha *et al*., 2010; Rezaei *et al*., 2009). In recent years MFCs were interested as a way of generating bioelectrical power or hydrogen from biomass without any carbon emission into the environment (Daniel *et al*., 2009). MFCs are also capable of waste water treatment with simultaneous production of energy. The MFC structure consists of an anode, a cathode and sometimes a membrane or separator between the (Mohan *et al*., 2008). In recent decades Different kinds of materials have been used as the anode,

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including plain graphite, carbon cloth, graphite foam, graphite granules and high surface area graphite fiber brush electrodes (Chaudhuri and Lovley, 2003; Fan *et al*., 2007; He and Angenent, 2006). Cation Exchange Membranes (CEMs), Anion Exchange Membranes (AEMs) and ultra-filtration membranes (Kim *et al*., 2007; Rozendal *et al*., 2006) are common separators between the electrodes. Since the cathode is usually a limiting factor in power production in of an MFC (Rismani-Yazdi *et al*., 2008), various electron accepters, such as ferricyanide and permanganate (He and Angenent, 2006; Rabaey *et al*., 2004; You *et al*., 2006), have been used as catholytes in two-chamber MFCs, to enhance performance of the cathodic compartment. Oxygen for its high thermodynamic redox potential, good self-sustaining operation and availability (He and Angenent, 2006), commonly used as an electron accepter. Last researches showed that different wastewaters can be used as substrate and also inoculums for MFCs, to lead energy production from an abundant and inexpensive source. Most of the energy available from the oxidation of the organic load was converted to electricity while the remaining energy was used for microbial growth (Aldrovandi *et al*., 2009; Du *et al*., 2007; Wen *et al*., 2009). Currently wastewater MFCs are being considered as a renewable energy strategy (Wen *et al*., 2009). In this experiment, the performance of a two chambered MFC with synthetic wastewater as substrate was studied. The influences of different mediator, oxidizer and rate of aeration on voltage, power density and COD removal efficiency of MFC were investigated.

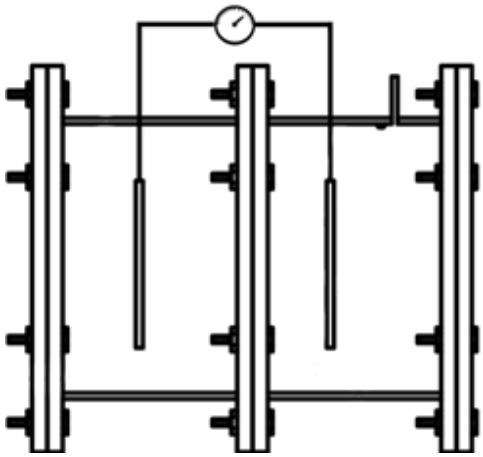
2. MATERIALS AND METHODS

Activated sludge was supplied from a UASFB bioreactor. The microorganisms were grown in an anaerobic jar vessel. The medium prepared for seed culture consisted of acetone, yeast extract, NH_4Cl, NaH_2PO_4, $MgSO_4$ and $MnSo_4$: 3, 3, 0.2, 0.6, 0.2 and 0.05 g L^{-1}, respectively.

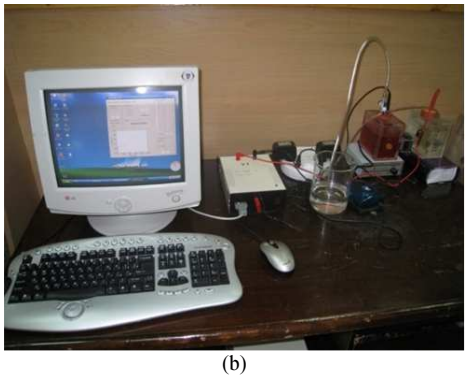
The medium pH was initially adjusted to 6.5 and the inoculums were introduced into the media at ambient temperature. The inoculated cultures were incubated at 30°C. The bacteria were fully grown for the duration of 24 h in 100 mL flux without any agitation.

All chemicals and reagents used for the experiments were analytical grades and supplied by Merck (Germany). The pH meter, HANA 211(Romania) model glass-electrode was employed for measuring pH values of the aqueous phase. The initial pH of the working solutions was adjusted by addition of diluted HNO_3 or 0.1M NaOH solutions.

The fabricated cells in the laboratory scale were made of glass (Pyrex) material. The volume of each chamber (anode and cathode chambers) was 650 mL with working volume of 500 mL. The sample port was provided for the anode chamber, wire point inputs and inlet port. The selected electrodes in MFC were graphite in size of 30×50×1.5 mm. Proton Exchange Membrane (PEM; NAFION 117, Sigma-Aldrich) was used to separate the two compartments. The Nafion area separated the chambers was 9 cm^2. Nafion proton exchange membrane was subjected to a course of pretreatment to take off any impurities that was boiling the film for 1h in 3% H_2O_2, washed with deionized water, 0.5 M H_2SO_4 and then washed with deionized water. The anode and cathode compartments were filled by deionized water when the biological fuel cell was not in use to maintain membrane for good conductivity. Neutral Red (NR), ferricyanide and permanganate were supplied by Merck (Germany).



(a)



(b)

Fig. 1. (a) Schematic drawing (b) Photograph image of MFC and online registered data

These chemicals with low concentrations (100-500 µmol L^{-1} were used as mediators in anode and cathode chamber. The schematic diagram of MFC is presented in **Fig. 1a**. Also, **Fig 1b** shows photograph diagram and auxiliary equipment of the fabricated MFC cell.

Scanning Electron Microscopy image (SEM) from the surface of anode electrode was prepared to observe anode surface. The gold layer coated sample were scanned with an electronic microscope (Phillips XL30, Holland). Finally, images of the samples were taken under SEM at magnifications of 2000.

3. RESULTS

The performance of the microbial fuel cell was evaluated by the polarization curve. Polarization behavior of this cell was recorded for several external resistances for determination of maximum power generation. **Figure 2** shows polarization curve of the fabricated cell without any electron shuttle, after 4 days inoculation. Maximum power and current density were 5.99 mW/m^2 and 21.22 mA/m^2, respectively.

To enhance electrons transferring to electrode, 100µM ferricyanide was added as an oxidizer to cathode compartment. **Table 1** shows, maximum power increased to 10.89 $mW.m^{-2}$ and maximum current density to 60 mA/m^2.

Permanganate was added to cathode compartment in 100, 200, 300 and 400 µM concentrations. **Figure 3** shows the maximum current and power was obtained at permanganate concentration of 300 µM. The maximum power and current generated were $22mW.m^{-2}$ and $70mA.m^{-2}$, respectively. At any concentration greater than the optimum permanganate concentration (300 µM) had no positive impact for additional current and power generation (**Fig. 3**).

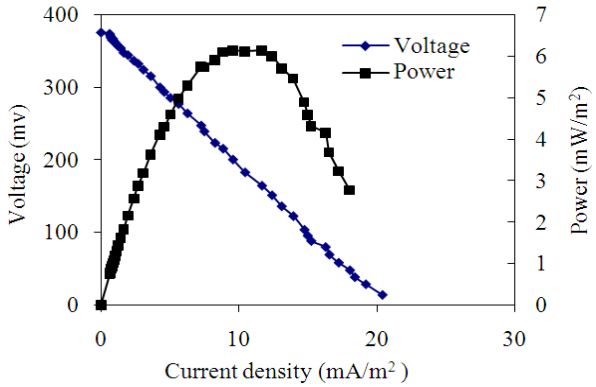


Fig. 2. Polarization curve and power density verse current density at steady state condition with 3 g L^{-1} acetone as electron donors

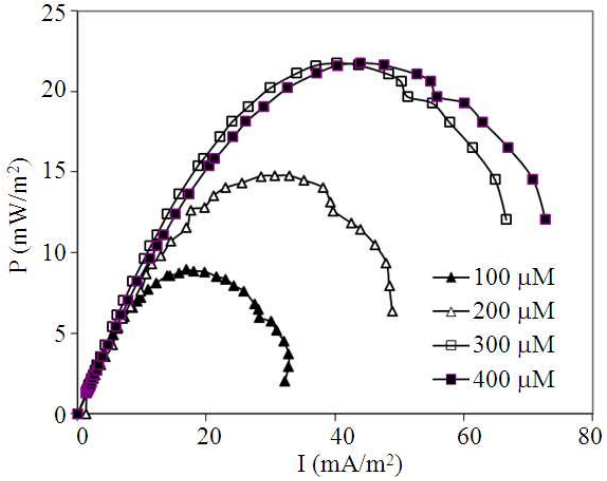


Fig. 3. Effect of permanganate concentration on produced power and voltage

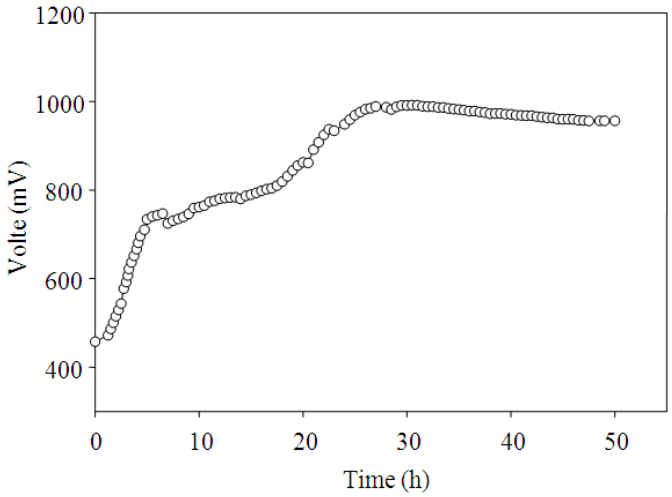


Fig. 4. Produced voltage at optimum condition

Table 1. Effect of ferricyanide concentration on polarization curve

Concentration (μM/L)	OCV (mV)	Maximum P (mA/m^2)	Maximum I (mA/m^2)
0	398	5.99	21.22
100	580	10.89	30.80
200	610	12.50	45.30
300	648	15.40	52.00
400	690	18.90	58.60
500	697	19.10	60.00

Table 2. Effect of mediators in anode chamber of MFC

NR concentration (μM/L)	OCV (mV)	Maximum P (mA/m^2)	Maximum I (mA/m^2)
0	1001	22.0	70.0
100	1001	22.2	71.2
200	908	21.3	68.8

NR was selected and added to anode chamber as mediator with 100 and 200 μM/l concentrations. **Table 2** shows adding electron shuttle in anode chamber had no any effect on produced power and current.

After anode inoculation with mixed culture of microorganisms, the system voltage was registerd by onlie data logger. The fabricated MFC produced stable and repeatable voltage within 50 h of inoculation, as shown in **Fig. 4**. The initial voltage was 410 mV and then the voltage was gradually increased. After 27 h of operation time, The OCV was reached to a maximum value of 1001 mV and it was stabled for the duration of 50 h.

SEM technique was applied to provide surface and morphological information of the anode electrode in anode compartment. A piece of the used anode (1×1 cm) was investigated by SEM. The taken SEM image is peresented in **Fig. 5**.

4. DISCUSSION

MFCs appear as one kind of a new possibility for the treatment of organic wastes. Acetone is one of the organic compounds which are widely produced in number of chemical industries. Acetone compounds are high-priority toxic chemicals and listed as highly pollutants (Zare *et al*., 2012). Acetone with initial concentration of 3g L^{-1} was used as synthetic waste and electron donors in anode compartment. After incubation anode chamber by active microorganisms the produced power was too low. Produced power gradually increased and reached to steady power. The system was reached to steady state condition after 27 h and the polarization test was taken.

Several concentration (200, 300, 400 and 500 μM L^{-1}) of ferricyanide were supplemented to obtained optimum concentration of ferricyanide. Maximum current and power was obtained at 400 μM concentration in cathode chamber.

Permanganate is another oxidizer which we investigated its effect on our MFC. Discharging the cathode content after ferricyanide tests, Dionized water was added to cathode, to consider the effect of last changes on MFC, the polarization curve of the new content of cathode incereased the performances of fabricated MFC (**Fig. 3**).

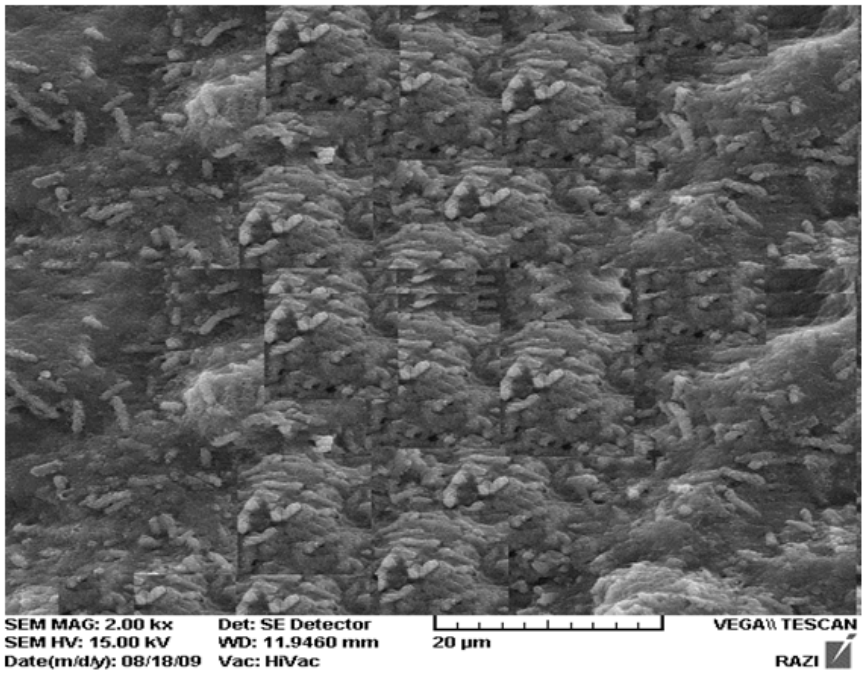


Fig. 5. Scanning electron microscopy image from outer surface of anode electrode.

Electron mediators are used to shuttle produced electrons from the broth to anode surface (Najafpour *et al*., 2011).

Mediators are artificial compounds and also some of microorganisms can produce it in media. In this case mediators did not have any effect on produced power and current.

One new promising technology for treatment of wastewater is the application of MFC. Active microorganisms grow under anoxic conditions, which can used waste material as substrate and produce bioelectricity. Acetone was used as electron donors in anode compartment. Concentration of waste water in anode chamber was measured by COD. Acetone removal was 69% at the end of process.

The obtained SEM image from the anode electrode (**Fig. 5**) shows that surface of electrode was fully covered by several kinds of active microorganisms which were responsible for transfer of produced electrons and thus current generation in the MFC.

5. CONCLUSION

The use of microorganisms as biocatalyst is an interesting point in MFCs. The MFC is one of new source for production of energy and waste water treatment simultaneously. The progress of a biological system able to produce bioelectricity from wastewater. The present research demonstrates activated sludge has the ability to generate power from waste water. Aeration in cathode and use of optimum permanganate concentration had enhanced the MFC performances. When the initial permanganate concentration was 300 µM, the maximum generated current was 70 mA/m^2. NR as mediators and different concentration of mediators did not have any effect on produced power.

6. ACKNOWLEDGMENT

The reachers wish to acknowledge Biotechnology Research Center, Babol Noshirvani University of Technology, Babol, Iran for the facilities provided to accomplish this research.

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