Microbial Fuel Cell (MFC) for energy generation and wastewater treatment

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Abstract

Aims: Microbial fuel cells (MFCs) are promising method for electricity generation with simultaneous treatment of organic compounds in wastewater by using bacteria.

Scope: In a pilot study, Synthetic wastewater based on glucose was used as carbon resource for microorganisms and ruminant rumen bacteria were used for microbial consortium. Microbial fuel cells with two compartments were operated in continuous mode at 720 hrs and temperature 20±4 º C. Organic loading rate and hydraulic retention time were effective factors in power density and voltage generation.

Conclusion: By increasing the organic loading rate and decreasing retention time, power density increase too. Maximum voltage and power generation in operating period were 700mV and 1700mW/m^2, respectively. Moreover, volumetric power reached 12 W/m^3 and peak power produced at 10kΩ resistance.

Keyword: *Microbial fuel cell, Glucose, electricity, Wastewater treatment*

1. Introduction

Always, energy has been regarded as important factor for countries development. Oil and other fossil fuels are main energy sources but can provide the world energy for almost 100 years later [1]. Increasingly growth population and economic activities increased use of Fossil fuels [2]. Combusting fossil fuels release many pollutants to the atmosphere like CO_2 which intensify the global warming and consequently climate change [1, 3]. Use of clean or green energy such as renewable energy will be a suitable alternative to overcome energy crisis and reducing the global emissions CO_2 [1; 4]. Microbial fuel cell (MFC) is a new technology for electricity generation and wastewater treatment simultaneously [5, 6]. In this system microorganisms serve as biocatalyst to convert the chemical energy stored in organic compounds directly to electrical Energy [4, 5, 7-10]. MFC has anaerobic and aerobic chambers that separated by a membrane [1, 4, 10, 11]. Bacteria in anaerobic anodic chamber oxidize substrate and release electrons and protons. Electrons move along a wire and protons permeate through proton exchange membrane (PEM) to cathode. Then electrons and protons in cathode chamber combine with oxygen molecules to form water [1]. Migration of electrons create potential difference between two chambers that recorded by multitmeter. Although In 1911, Potter produced electricity from bacteria, but electricity production was so less [7]. It is well known that various species of bacteria that called *exoelectrogens* can transfer Electrons of substrate to electrode [1, 4]. Previous studies showed that *E. coli* [12], *Shewanella putrefaciens* [13], *Shewanella oneidensis* [14], *Geobacteraceae sulferreducens* [15], *Rhodoferax ferrireducens* [16] have been used for electricity generation. Several studies revealed that organic compounds such as glucose [16], acetate or butyrate [8], domestic wastewater [10, 17, and 18], swine wastewater [19], beer brewery wastewater [9], chocolate industry wastewater [20] were used as substrate in MFC. In 2004 the experiments represented the direct relationship between electricity production from MFC and wastewater treatment [1]. Ahn and Logan (2010) in a study conducted on domestic wastewater treatment with MFC found out that power density and COD removal were 422 mW/m^2 and 25.8%, respectively [10]. According to Jiang et al (2009), MFC could generate the electricity from sewage sludge and as a consequent; the total chemical oxygen demand (TCOD) of the sludge was reduced up to 46.4% [18]. Yazdi et al (2007) reported maximum power density 55 mW/m^2 (1.5 mA, 313mV) which was produced in bioconversion of cellulose to electrical energy in microbial fuel cells [21]. In a study conducted on capability of converting glucose to electricity at high rate, the power density of 3.6 W/m^2 was reported and the electron recovery up to 89% was occurred [5]. The purpose of present study was determining the feasibility of synthetic wastewater treatment and electricity generation with rumen microorganisms as microbial consortium and glucose as the electron donor by using MFC. The effect of different Organic loading rates (OLRs) on power density, voltage and power generation was examined.

2. Materials and methods

2.1. Experimental set up.

All experiments were conducted using two-chamber MFC. Reactor was constructed by using the Plexiglas with dimensions of 10cm×10cm×5 cm (Volume: 500 mL). Chambers were separated by a Nafion 117 Proton Exchange Membrane (PEM) (Nafion 117, DuPont Co USA). To increase the porosity of PEM, it was pretreated according to procedure described by Jiang [18]. PEM must be keep in deionized water prior to use .Carbon cloth and graphite flat (Dimensions: 6cm×6cm) without any coating were used as electrode in anode and cathode, respectively. Both anode and cathode electrodes were installed in reactor by titanium wires. Before start-up phase, the electrodes were pretreated with deionized water for 24 hours according to Wen et al. (2009) [9]. A schematic of MFC pilot scale which was used in this study is illustrated in Figure 1.

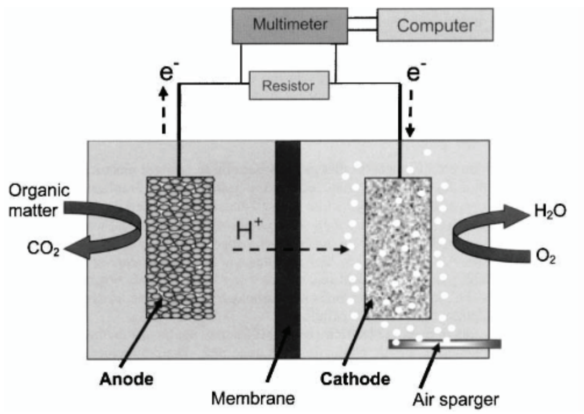

Figure 1. schematic of Microbial Fuel Cell [1]

2.2. *MFC inoculation and operation.*

Glucose is a substrate which microorganisms can be degraded easily. Glucose solutions (1 and 2 g/L concentration), enriched with required microelements including NH_4Cl:1 g/l, KH_2PO_4:0.28 g/l, K_2HPO_4:0.68 g/l, $MgSO_4.7H_2O$:0.87 g/l, $CaCl_2.2H_2O$:0.1 g/l, NaCl: 0.1g/l, KCl: 0.58 g/l and vitamin: 1 ml/l were used as anolyte [1, 4, 9, and 21]. This mixed anaerobic culture acquired from rumen of cow injected to anode chamber according to organic loading rate that shown in Table 1 by peristaltic pump (Nanozist tech 5760P).Anode chamber sparged with carbon dioxide (CO_2) to keep the anaerobic condition. Microorganisms in rumen are able to degrade complex compound and carbohydrates. They grow in anaerobic conditions [20]. Each mL of rumen contains almost 10^9 to 10^{10} bacteria [22]. During the operation, the anolyte was mixed by magnetic stirring beads [11]. During the study, substrate concentrations were kept constant and by decreasing hydraulic retention time (HRT) from 3.5, to 2.5, to 1.5, the increasing OLRs were achieved. In cathode chamber phosphate buffer solution (PBS) (4.97 g/L NaH_2PO_4, 2.75 g/L Na_2HPO_4) was used as electron acceptor [4]. Air was sparged with pump to provide dissolved oxygen. MFC was operated in continuous mode at laboratory temperature (24±4 ℃).

Table 1: properties of operation reactor

C(g/l)	RUN	OLR(kg COD/m^3.d)	HRT(hr)
	1	6.686	3.5
1	2	9.36	2.5
	3	15.6	1.5
	4	12.274	3.5
2	5	17.184	2.5
	6	28.64	1.5

2.3. Analysis and calculation.

Voltage was recorded using a digital multi-meter (RIGOL Digital multimeter DM 3051) continuously. Current (*I*) was calculated as follows [1, 23].

$$I=V\times R^{-1} \qquad \text{(Eq.1)}$$

Where, *V* is voltage as v and *R* is resistance as Ω. Current density was obtained with divide current to surface electrode (usually anode) which represented as mA/m^2 [1, 4, 8]. Power calculated by P=V.I and normalized to surface area (usually anode) and volume (total) that termed as mW/m^2 and mW/m^3 respectively. Since the power generation is the main purpose in the process, in order to obtain more energy more electrons which have been stored in biomass should be extracted [1]. Measuring the soluble chemical Oxygen demand (SCOD) of influent was performed accordance with the *Standard Method* approach (protocol No. 5220; HACH COD system) [25]. Samples were filtered through a 0.45μm pore size membrane prior to analyze for SCOD [8].

3. Results

By entering wastewater into reactor, voltage was recorded by multimeter immediately. MFC operated 720 hours in mode continuous using the synthetic wastewater at six OLRs. Maximum voltage (700 mV) was achieved after 504 hr. Although after primary operation, due to suitable conditions for microorganisms, voltage was produced 685 mV. In each organic loading rate, when stable voltage was observed, current was calculated by Eq.1. Results of MFC operation is represented in Table 2.

Table 2. Experimental data from pilot study

RUN	V(mV)	I(mA/m^2)	P(mW/m^2)	P(mW/m^3)
1	685	4.52	439.5	4000
2	660	8.3	917	6600
3	645	8.75	600.89	8652
4	627	8.33	686.8	9800
5	633	9.9	633	10500
6	700	9.46	1700	12000

3.1. Polarization curve

Polarization curve that shows in figure 2 was obtained by plotting voltage and power density against current density. After stabilized Voltage at each loading rate, it was recorded by multimeter at variable external resistances (50Ω–500kΩ). Slope of this curve is the internal resistance (R_{int}). Therefore, until curve is linear, internal resistance is obtained using the slope's polarization curve. In low resistance, more electrons allowed to transfer from circuit, thus potential different between two chambers decreased and current increased. When high resistance applied in circuit, transfer of electrons by circuit is limited and they cumulated in anode. Accumulation of negative charge cause to increase of different potential between two chambers and current decreased. This may be found that some electrons are consumed by other electron acceptor such as sulfate and nitrate [1]. In microbial fuel cell, Maximum power occurs when internal and external resistances are equal [1, 3]. In this study maximum power density was (1700mW/m^2) that was obtained in 10kΩ.

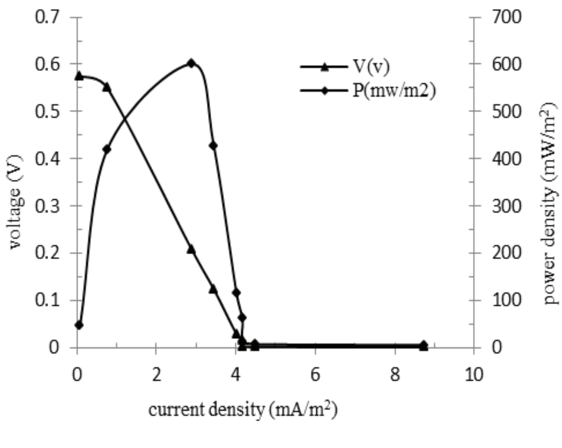

Figure 2. polarization curve

3.2. Power generation as a function of the hydraulic retention time (HRT)

In order to survey the influence of HRT on power, MFC was operated continuously with variable concentration substrate in six OLRs. Experimental data showed that change HRT, affected power density or volumetric power (W/m^3). According to Table 1, in primary stages, that reactor was performed with 1 g/l substrate; maximum power density was obtained 917 mW/m^2 and 8.65 W/m^3 respectively. At other run with 2 g/l substrate concentration, maximum power density was 1700 mW/m^2 and 12W/m^3 that obtained in HRT between 1.5 to 2.5 hrs. Figure 3show the power density (mW/m^2) in six OLRs. According to this figure, power density peak in all runs, taken place at 10kΩ resistance. In other word, in MFC maximum power density occurred where internal and external resistances were equal.

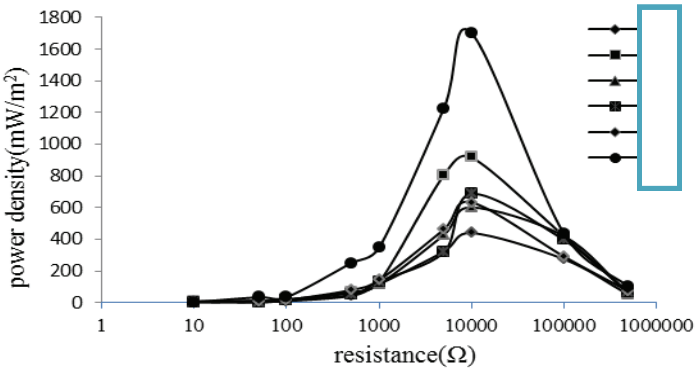

Figure 3. power density at variable resistance

4. Discussion and Conclusion

According to results of study, maximum voltage, power density and volumetric power in operation was obtained 700 mV, 1700mW/m^2 and 12W/m^3 respectively. Also peak power produced at 10kΩ resistance. Polarization curve are for evaluating performance of MFC. It shows the current is a function of voltage [3]. It is evidence from data and earlier literature, polarization curve can be divided to three sections: activation polarization loss, ohmic loss and concentration polarization loss. Until the curve is linear, current density increases with power density to reach maximum value. After this point due to increased ohmic resistance and electrode potential, the power density decreases. It accordance with literatures [1, 26, and 27]. At point that maximum power density is achieved, it can be considered as a point suitable for operation of microbial fuel cell [3]. For optimizing peak power output that produced in MFC, internal resistance must be decline. Wen Q etal also reported the maximum power density was (264 mW/m^2). Bookie etal in their study showed the maximum power density produce 45mW/m^2 (141mA/m^2) at 1000 Ω resistance [9]. HRT is an important factor for determining residual substrate and DO concentration in reactor [18]. With decreasing the HRT, rate of substrate degradation by bacteria increased and thus power generation increased and vice versa. On the other hand there is a diverse relationship between factors. There is a proper HRT for maximum power generation. Liu et al also achieved similar results. Their results showed that increasing the HRT, power decreases. Because they used deoxygenate wastewater and neglected the effect of DO [8, 27]. It seems that in range of organic loading rate that was used in this study; the optimum HRT to achieve maximum power production is in the range HRT 1.5 to 2.5 hours.

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