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Original Article

Effect of vitamins and cell constructions on the activity of microbial fuel cell battery

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ABSTRACT

Construction of efficient performance of microbial fuel cells (MFCs) requires certain practical considerations. In the single chamber microbial fuel cell, there is no border between the anode and the cathode, thus the diffusion of the dissolved oxygen has a contrary effect on the anodic respiration and this leads to the inhibition of the direct electron transfer from the biofilm to the anodic surface. Here, a fed-batch single chambered microbial fuel cells are constructed with different distances 3 and 6 cm (anode- cathode spacing), while keeping the working volume is constant. The performance of each MFC is individually evaluated under the effects of vitamins & minerals with acetate as a fed load. The maximum open circuit potential during testing the 3 and 6 cm microbial fuel cells is about 946 and 791 mV respectively. By decreasing the distance between the anode and the cathode from 6 to 3 cm, the power density is decreased from 108.3 mW m^{-2} to 24.5 mW m^{-2}. Thus, the short distance in membrane-less MFC weakened the cathode and inhibited the anodic respiration which affects the overall performance of the MFC efficiency. The system is displayed a maximum potential of 564 and 791 mV in absence & presence of vitamins respectively. Eventually, the overall functions of the acetate single chamber microbial fuel cell can be improved by the addition of vitamins & minerals and increasing the distance between the cathode and the anode.

1. Introduction

Clean renewable energy resources are important for solving the energy demand around the globe due to their sustainability and their distribution everywhere [1–3]. Among these common renewable energy sources is the Microbial fuel cell (MFC) – is recently explored. MFCs have the capability to use microbial communities as a catalyst and capture the electricity from a wide range of organic and inorganic substances (as microbial fuel or energy) through the biocatalytic activity of microbial aggregation [4–12]. In the microbial electrochemical systems, oxidation–reduction reactions are taking place through two consequent steps. Firstly, microbe-anode interaction is initiated to oxidize the organic substrate (electron donor) into free liberated protons and electrons [13]. Secondly, transfer of the produced electrons from the anode to the cathode via the external electrical circuit, and transferring the free protons into the cathode to form water and bioelectric current through reduction of oxygen (electron acceptor) [14], as shown in Scheme 1.

Electron donor substrates are the main suppliers for electrons in the MFC [15], these substrates are ranging from a low molecular weight compounds to high molecular weight ones [16]. The produced power is depending on several factors as the availability of the organic loading rate, the capability of microorganisms loading rate, effect of electrode-spacing, and resistance value [17]. When the space between the two electrodes is reduced, the ohmic resistance is decreased as a direct result the protons have less distance to travel. Liu et al. demonstrated that, decreasing the spacing between the two electrodes from 4 to 2 cm led to reduce the ohmic resistance and increase of power output to a 67% [18]. While the other studies are proved the contradictory results. They have concluded that, when the two electrodes are located closely to each other, this lead to the increase of oxygen diffusion from the cathode to the anode. as a result the inhibition of the anaerobic respiration, is occurred with the promotion of the aerobic respiration, So power density is reduced [19–21]. The microbial fuel cell battery has been utilized in electricity generation [22,23], domestic and brewery wastewater treatment [24], biosensors [25,26], bioreme-

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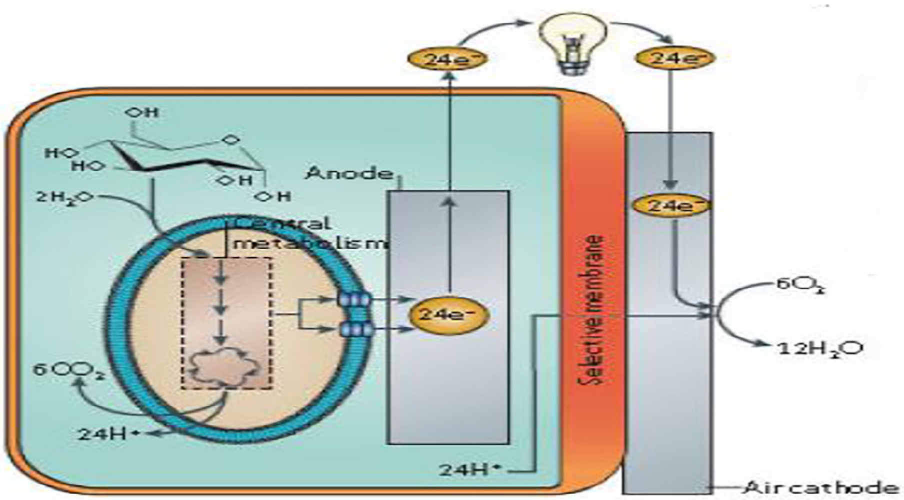

Scheme 1. A mediator-less single chambered microbial fuel cell, the cathode is exposed to air on one side and to the anolyte containing the substrate on the other side [3].

diation [27–29], and as a remote power source [30]. Various attempts have been made to build larger MFCs or connect several MFCs in series (MFC stack operation) to increase the power output [31].

The bioelectrochemical characteristics of the activated sludge have been explored in literature, and promising results showed its good performance to be used in the operation and construction of the MFCs [2,13,22,23]. Thus in our study, attempts are developed to enhance the activity of Air-Cathode Single-Chamber Mediator-Less Microbial Fuel Cell (ACSCMMFC) by operating the parameters e.g. (minerals & vitamins load, resistance effect, and cell design of MFC-based on distance spacing systems).

2. Materials and methods

2.1. Microbial fuel cell constructions

Two transparent Perspex air-cathode single-chamber microbial fuel cells designs are constructed with an electrode active surface area of 25 cm^2. One with 50 ml total working volume (6 cm length and 4 cm diameter), the other with 20 ml volume (3 cm length and 4 cm diameter). It is composed of an anode and a cathode both are made from carbon paper, The cathode electrode is treated with Poly tetrafluoroethylene (PTFE) as diffusion layers on the air-exposed side [32]. The catalyst layer is prepared by mixing 0.3 $mg\,cm^{-2}$ of 30% Pt loading supported on carbon VulcanXC-72R and Nafion solution (5% Nafion solution from Aldrich) to form catalyst paste which stretched in the water facing side to reduce water loss and oxygen diffusion into the MFCs. The anode and the Pt- loaded side of the cathode are placed on opposite sides the solution. The cells are connected through an external circuit (open circuit, or 550 Ω). The performance of MFCs is evaluated with respect to power generation and substrate biodegradation.

2.2. Preparation of synthetic media solution

MFCs containers are supplied with aerobic activated sludge from the municipal wastewater treatment plant (**Benha municipal sanitation unit**) after filtration of the aerobic sludge to eliminate un-dissolved solid materials. The microbial fuel cells are fed with the synthetic wastewater with nourishment media. The nourishment media for 1 g of acetate is prepared using the following components (in grams per liter of deionized water): $NaHCO_3$, 2.5; NH_4Cl, 0.2; KH_2PO_4, 0.42; KCl, 0.33; NaCl, 0.3; K_2HPO_4, 1.26; $CaCl_2{\cdot}2H_2O$, 0.15; $MgCl_2$, 3.15; yeast extract 1. 10 ml of mineral media prepared as mentioned elsewhere [33]. The value of pH is adjusted to pH 7 using (HANNA pH211); nourishment media is refreshed when the cell voltage decreased below 50 mV. The inoculated MFCs are operated under fed- batch mode.

2.3. Microbial fuel cell operation

Two different MFCs are operated either after the inculcation of activated sludge microbial cells with the acetate based-nourishment media or after the inoculation of activated sludge microbial cells without nourishment media. The potential between the anode and the cathode is recorded every 5 min with a multimeter and data acquisition system (Lab jack U6 – PRO). Polarization curves are obtained by varying external resistance (R_{ext}) from 100 to 125 kΩ, after a steady state of power and electricity generation for calculation of both maximum current and power density.

3. Results & discussion

3.1. Effect of minerals & vitamins

The performance of two membranes-less single chamber microbial fuel cells (MSCMFC) has been evaluated. The first cell is fed with 35 ml acetate media without vitamins & minerals. The other cell is inoculated with 35 ml acetate media containing minerals & vitamins and then, 15 ml of aerobic sludge is added to each set as illustrated in Fig. 1. In case of presence of mineral & vitamins, the cell voltage is gradually increased to a maximum voltage value (791 mV) along the degradation time then, is dropped to its lower value (50 mV) with depletion of media composition after successive cycles of replicates. While the cell voltage in absence of minerals & vitamins are increased to a voltage value (564 mV), then the voltage value is decreased to 50 mV. The open circuit cell potential is stabilized to approximately 564 mV & 791 mV in case of absence (red line) and presence (blue line) of minerals & vitamins respectively. This could be attributed to the requirements of living microbial cells to activate their enzymatic functions that rely on the metal salts as coenzymes of cofactors to enhance the bio-energy and biodegradation. On the other hand, minerals & vitamins are helping microorganisms in a biofilm formation, as has been shown previously by Beech et al. [34]. Some organisms can use the proteinaceous material as a nitrogen source; others use

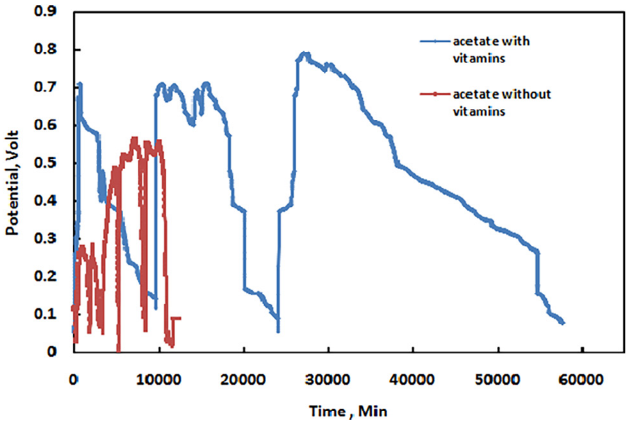

Fig. 1. MFC performance at the open circuit voltage in presence and absence of minerals & vitamins.

ammonium ions (NH^{+4}) or nitrate ions (NO^{-3}) to proteins. An important source of phosphorus is the phosphate ion (PO$_4^{-3}$) to produce DNA, RNA, and ATP and phosphorus. Mineral elements such as iron, copper, molybdenum, and zinc are referred to trace elements which are used in small amount to enhance the bacterial growth [35].

3.2. Effect of the distance between the anode and the cathode

In the single chamber fuel cell, there is no border between the anode and cathode thus, the diffusion of the dissolved oxygen will affect the anodic respiration and this leads to the inhibition of the direct electron transfer from the living adhered cells to the anodic surface. In this regard, the effect of electrode distance and voltage generation is determined in Single Chamber Microbial Fuel cell (SCMFC), by operating the cell at different distances between the anode and the cathode of 3 and 6 cm using 25 ml acetate as media. Aerobic activated sludge is added as inoculums to enrich electrochemically active microbes, Fig. 2 indicates the relationship between the voltage versus time of SCMFC at the different distances of over three cycles of fed-batch process at unlimited resistance and zero current. As a result, the maximum potential of open circuit potential (OCP) about 946 mV (red line) is obtained in case of 3 cm which is considerably greater than that obtained in case of 6 cm (791 mV (blue line)) after three reproducible operations. It could be concluded that, the microorganisms are attached, colonized, and planted themselves on the anode surface to form a biofilm. Anodic bio-film transfers the electrons outside the cell and the proton transferred to final hydrogen acceptor (O$_2$).

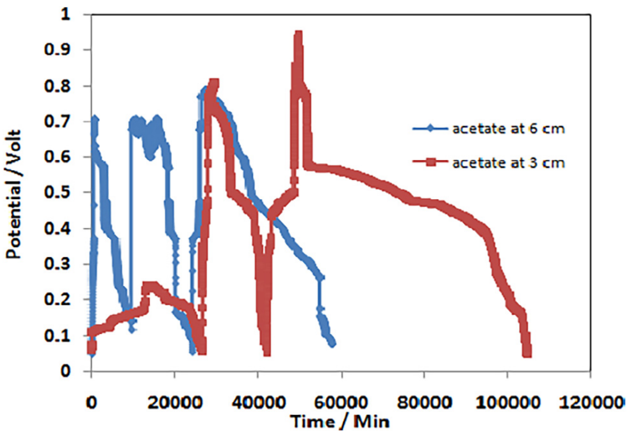

Fig. 2. The difference of voltage of both 6 and 3 cm electrode spacing distances between the anode and cathode.

3.3. Effect of external resistance

SCMFC with a distance of 3 cm is inoculated with aerobic activated sludge and acetate media through the sampling port at the top. The SCMFC is operated under a fixed external resistance 550 Ω, in order to explore the relationship between resistances, potential, current density, and power density as indicated in Fig. 3. It can be observed that potential, current density, and power density have the same manners, the voltage yield is increased slowly which is followed by rapid increase for the next four days. The maximum voltage is 118 mV corresponding to current density 173 mA m^{-2} and power density 21 mW m^{-2}, the decreasing of acetate consumption rate leds to a reduction in the voltage output to about 30 mV. After refreshment, it has been observed that, an increase in the voltage output to 202 mV with maximum current density 294 mA m^{-2} and power density 60 mW m^{-2} is restored. Then, the voltage output is hovered to a value of 10 mV.

The acetate media is replaced with fresh medium, through this succession the voltage output increased to 218 mV with a maximum current density of 317 mA m^{-2} and power density of 69 mW m^{-2} and then decreased to 30 mV. This power density of small cell is lower than 86 mW m^{-2}, which is obtained from MFCs with 6 cm distance at the maximum current density of 354 mA m^{-2} of higher potential of 243 mV at the same load.

These results demonstrated that, the electrode surface in large SCMFC is used efficiently than those of smaller SCMFC reactors due to: (i) the mass transfer between two electrodes is a limiting factor, probably proton transfer from the anode to the cathode [36]. (ii) The electrons move more easily through the circuit, oxidizing electron carriers of the microbes in the anode. The larger reactor can be operated at an external resistance to remove organic contaminants at a high rate.

3.4. Electrode characterization

The SCMFCs is operated with the distance between the anode and cathode of 3 cm at different external resistances, and the performance is compared with that recorded from the normal run with the distance of 6 cm. The current density is calculated after a steady state and plotted against potential at different external resistances from 100 to 125 kΩ across the anode and the cathode to obtain the polarization and power curves as illustrated in Fig. 4(a, b). The relationship between the internal resistance and the current density is established from the polarization curve and calculated from the slope of voltage versus current as represented in Fig. 4(a). Fig. 4(b) shows the power curve for the characterization of Mediator-less single chamber microbial fuel cell under different external resistance from 100 to 125 kΩ.

It could be observed that, the maximum power density value of 24.5 mW m^{-2} is corresponding to the maximum current density value of 652.5 mA m^{-2}. Power density is lower than the value of larger MFC with the same substrate electrode material and surface area (maximum power density of 108.3 mW m^{-2} corresponding to maximum current density value of 982.61 mA m^{-2}). It can be concluded that, although the voltage value at distance 3 cm (946 mV) is higher than that obtained in case of 6 cm (791 mV), the power density generated is known to be limited by high internal resistance. It gives low performance according to its high relative internal resistance (R$_{in}$) at 71 Ω than 6 cm at 59 Ω. Which it consumes the generated voltage inside the microbial fuel cell and reduces the voltage obtained from the external circuit. The distance between the electrodes are spaced too close to each other in membrane-less MFCs, so oxygen diffusion from the cathode to

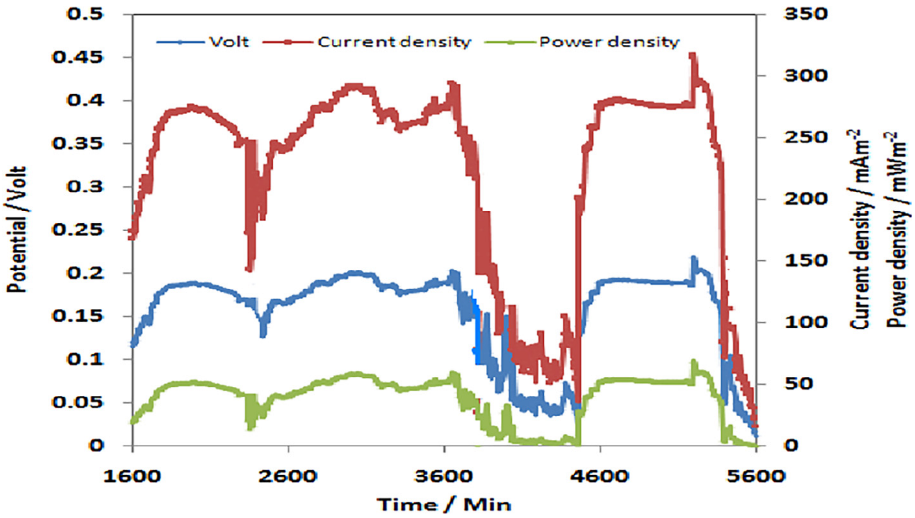

Fig. 3. Effect of external load on performances of small cell with 3 cm spacing area at 3 cm at 550 Ω.

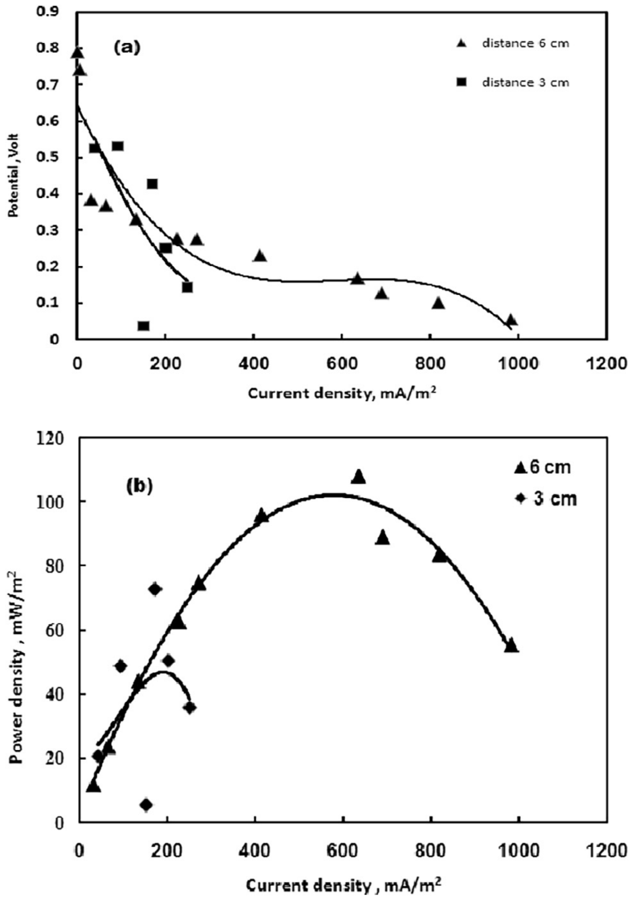

Fig. 4. Polarization curve (a) and power curve (b) of the ML-MFC operated with the distances between the anode and cathode are 6 and 3 cm.

the anode increases [19–21]. This can become inhibitory to anaerobic respiration and promote aerobic respiration, both of which reduce the MFC efficiency.

4. Conclusion

Microbial Fuel Cell is an electrochemical device that converts organic contaminants to electricity through the bio-catalytic activity of electrochemically active microbes. Single chamber microbial fuel cell displayed a maximum potential of 564 and 791 mV in absence & presence of vitamins respectively. The power generation is decreased from 108.3 to 24.5 mW m^{-2} by decreasing the distance between the anode and the cathode from 6 to 3 cm. The distance between the electrodes are spaced too close to each other in membrane-less MFCs causing poor cathode reaction, so oxygen diffusion from the cathode to the anode which causing inhibition to anaerobic respiration and promote aerobic respiration and reducing the MFC efficiency. The high power density achieved in the distance between the anode and the cathode is 6 cm) single chamber MFC behaves as a typical fuel cell which provides a great promise for other applications such as portable power supplies, and power sources for remote sensors using home-grown fuels.

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