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Metal electrodes and organic enrichment in doubled and single chambered Microbial Fuel Cell (MFC) for electricity generation

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Abstract

Microbial fuel cell was investigated for electricity generation with secondary treated waste water as a filling material and a source for organic matter. Different electrodes were tested; Aluminum-Graphite (AL-C), Iron –Graphite (Fe-C) and Copper- Graphite (Cu-C).The electricity generation of MFC was tested when enriched with different concentrations of sodium acetate (400, 600 and 800mg/l acetate). Maximum power density reached 816mW/m2 for double MFC using proton exchange membrane (PEM) with the corresponding power density of 880mW/m2 for single MFC without using PEM with 800mg/l acetate with the (AL-C). Relation between electrode spacing and power density was studied and found that the least electrode spacing (1 cm) producing the highest power density 797.3mW/m2 for single cell and (803.51mw/m2) for double cell. Further research is needed to maximize the cell for possible application to new settlements in Sinai to provide energy and minimize underground contamination by wastewater.

Keywords: Renewable energy, Microbial fuel cell, Electricity production, choice of electrodes of MFC

Introduction

The predicted depletion and the negative effects of fossil fuels on the environment drive forward the search for green and renewable energy sources (Lovely 2006, Davis and Higson 2007). Renewable bioenergy is viewed as one of the ways to alleviate the current global warming crisis (Du et al., 2007). Major efforts are devoted to electricity production from renewable resources without a net carbon dioxide emission is much desired (Lovely 2006, Davis and Higson 2007). Energy production by microorganisms such as bioethanol or hydrogen gas production can contribute to solve this problem (Buckley and Wall 2006). Also, microbial fuel cells (MFCs) constitute an alternative energy source and the development and improvement of MFCs are currently investigated (Deng et al., 2010). Microbial fuel cells (MFCs) can generate electrical energy from oxidation of organic matter through the catalytic activity of electrochemically active bacteria (Zhuang et al 2012). A large number of substrates have been tested as fuel for MFCs, ranging from pure compounds acetate (liu et al 2005); glucose (Rabaey et al 2003) to complex mixtures of organic matter present in wastewater (brewery wastewater (Feng et al 2008); starch processing wastewater (Lu et al 2009).

A MFC converts energy, available in a bio-convertible substrate, directly into electricity. This can be achieved when bacteria switch from the natural electron acceptor, such as oxygen or nitrate, to an insoluble acceptor, such as the MFC anode (Rabaey et al 2003). MFC directly convert of substrate energy to electricity and thus providing a promising source for renewable energy.

In case of Double Chambered Fuel cells both the cathode and anode are housed in different compartments or chambers connected via a proton exchange membrane (PEM) or sometimes salt bridge (Ringeisen et al 2006). PEM or salt bridge mainly functions as medium for transfer of proton to make the circuit complete. This not only completes the reaction process but also prevents anode to come in direct contact with oxygen or any other oxidizers. Single Chambered Fuel cells composed of simple anode compartment where there is no definitive cathode compartment and may not contain proton exchange membranes (Park and Zeikus, 2003).

The performance and cost of electrodes are the most important aspects in the design of microbial fuel cell (MFC). It is expected that the electrode materials and substances in the electrolyte are not electrochemically inert and may themselves generate currents in a potential range of the experiment in question. As such, metal electrodes will generate currents due to chemical and/or microbial corrosion. In this study, some metals were used as electrodes like aluminum, copper and iron beside use of carbon materials, hence all electrodes were weighted before and after the operation to investigate chemical corrosion which leads to increase in electricity production. Those background/control experiments are necessary for

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the complete understanding of a system's electrochemistry, especially for complex devices such as MFCs (Harnisch et al 2008). Generally metal electrodes are more conductive than carbon materials, but are not widely applicable as carbon materials in MFCs. They are not applicable because of the non-corrosive requirement for anode materials and also for the toxicity of trace metal ions to bacteria (Singh et al 2010). This accelerates research and investigations to evaluate its significance in the performance of MFC (Dumas et al. 2007) tested the suitability of a stainless steel plate as both the anode and biocathode electrodes in an MFC, and found that the power density (23 mW/m2) was limited by the anode. In another study, (Dumas et al. 2008) found that the stainless steel anode was less efficient than the graphite one. In contrast, (Erable and Bergel 2009) found that the stainless steel grid anode generated much higher current densities than plain graphite ones. (ter Heijne et al. 2008) compared titanium and graphite in terms of their suitability as an anode in MFCs. Their results showed that the anode performance decreased in the following order: roughened graphite > Pt-coated titanium > flat graphite > uncoated titanium.

The current research investigated several variables which govern the performance of the MFC. Firstly, domestic sewage water was used as a filling material for the MFC as a source of organic matter. Bacteria that naturally found in the sewage are expected to carry on organic matter degradation and hence produce electrons. Different concentrations of acetate were added to enrich sewage water and study if this will affect electricity production from the cell. Also, the work is studying the application of different typed of metal electrodes, namely, Aluminum, Copper and Iron and demonstrated the effect of corrosion and their overall capacity to generate electricity. The efficiency of a doubled chambered MFC was tested, and then followed by studying the single chambered MFC to assess the role of the PEM on the MFC performance. The electrode spacing in both doubled and single chambered was also studied.

Materials and Methods

Microbial fuel cell (MFC) configuration

Two MFCs (double and single chambered) were operated separately to assess and compare the relative efficiencies of microbial fuel cell in bioelectricity generation. Double and Single chambered MFC were designed and fabricated using plexiglass glass material. Both MFCs are typically run in batch mode often with a chemically defined medium such as acetate solution to generate energy. A typical two compartment MFC has an anodic chamber and a cathodic chamber connected by a proton exchange membrane (PEM), or sometimes a salt bridge, to allow protons to move across to the cathode while blocking the diffusion of oxygen into the anode. The compartments can take various practical shapes. The fuel cells consisted of two equal volume (200ml) chambers for anode and cathode separated by PEM in case of using double chamber MFC while in case of using single cell, PEM was not used. Electrodes were positioned at a distance of 1, 2, 3 and 4cm on either side of PEM. The electrodes had a surface area of 43.6cm2 for (anode) and (cathode). Copper wires were used as contact with electrodes after carefully sealing the contact area with 'epoxy' material. Prior to use, electrodes were soaked in deionized water for a period of 24 h. Each chamber was provided with sample port, wire point inputs (top), inlet and outlet port and anode chamber was sealed with washers to ensure anaerobic microenvironment.

Operation of MFCs

Wastewater used to fill the MFC compartments was collected from Port Said Wastewater Plant, (PSWWP, Egypt) characteristics of wastewater were summarized in Table 1.

Table 1: Summarizes characteristics of wastewater used to fill the MFC used in the study

pH	7.7
Dissolved oxygen	8.5mg/l
Chemical oxygen demand	54mg/l
Biological oxygen demand	38mg/l

The electrodes consisted of graphite, aluminum, copper, and iron as anode materials and graphite as a cathode material when using double cell while the electrodes consisted of aluminum, copper and iron as anode materials and graphite as a cathode material when using single chamber MFC. A proton exchange membrane (PEM) (glass fiber) separated the anode and cathode compartments. Each electrode had an apparent surface area of (43.6cm2) and was connected to copper-wire leads by a conductive carbon epoxy. Aluminum, Graphite, Iron and copper were weighted before and after operation. The effect of electrode spacing on Microbial Fuel Cell performance was investigated by reducing the distance between the anode and cathode from 4 to 1 cm. Anaerobic conditions were maintained in the MFC anode. Electrochemical measurements were performed under normal conditions and the circuit contained a 2000-ohm resistor. All experiments were operated in a room temperature.

Measurements

Voltage (V), pH, temperature (0C) and conductivity (µS/cm) were measured using GLX. Total bacterial counts were monitored using an Epifluorescence microscope (BX59). Water samples were aseptically collected and gently filtered onto a 0.2 µm pore size Sartorius cellulose nitrate filter. After filtration, 2ml of acridine orange solution (160mg1-1) was pipetted onto the filter. Bacteria were counted after staining with acridine orange, using Olympus fluorescence microscope (BX59) equipped with a Neofluor 100/1.25 N.A. (DapO) lens, a 100 W mercury lamp, and a PM50 photomicrography system and an image analyzer (Image Pro Plus 4.2). Approximately ten fields of vision on each filter were counted to determine the total bacteria count.

Results

Before start of the experiment, electricity generated form synthetic feed (acetate) was investigated for a period of seven days as control. The anode chamber of the MFC was operated with designed synthetic feed (acetate) for a period of seven days as control. The potential difference which measured fluctuated between 0.04 and 0.09V during this phase of operation.

Table 2: Summarizes values for the voltage of synthetic feed (acetate) at zero time and after 168hrs

Time	Al-C	Fe-C	Cu-C
zero	0.09	0.07	0.04
168hrs	0.05	0.03	0.01

Subsequently, the fuel cell was inoculated with the sewage. The performance of the fuel cell was evaluated by measuring voltage and power output.

The weights of the electrodes were measured before and after the operation.

Voltage values for a single MFC were 2.28, 1.88 and 1.83V at zero time in case of (Al-C), (Fe-c), and (Cu-C), respectively as shown in fig. (1B). At the end of the operation after (240hr), voltage values

Operation of double and single chambered MFC with 400mg/l enrichment:

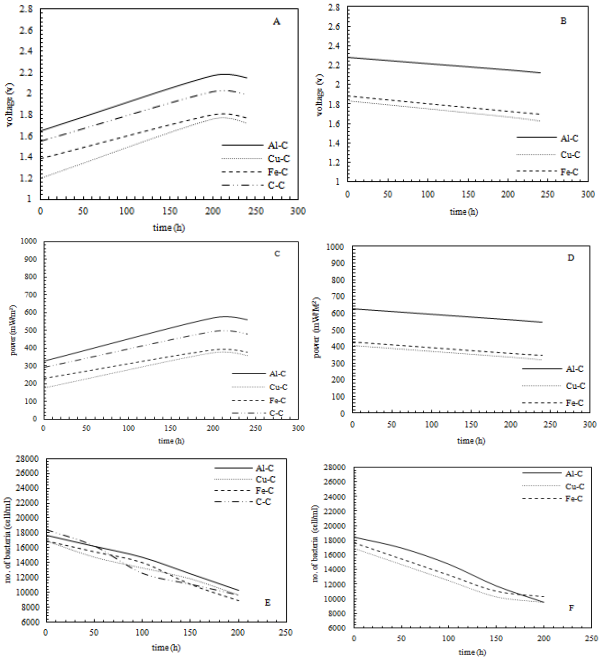

Figure 1, Electricity generation in double and single chamber MFC amended with 400mg/l sodium acetate: values of voltage (V), power density (mW/m2) and total bacterial numbers (cell ml-1).

Table (3) Summarizes the weights of the electrodes

	Al	C	Fe	Cu
Before	100gm	88gm	123gm	110gm
After	100gm	88gm	110gm	105gm

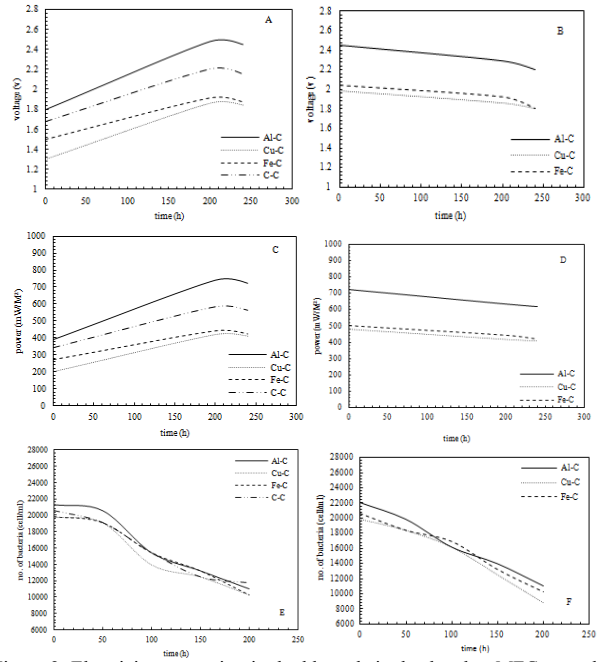

Figure 2, Electricity generation in double and single chamber MFC amended with 600mg/l sodium acetate: values of voltage (V), power density (mW/m2) and total bacterial numbers (cell ml-1)

dropped to 2.12, 1.69 and 1.63V for the three stated electrode combinations, respectively.

Power (mw/m2) produced from the double cell showed similar trends as with voltage generated as shown in fig. (1C), Al-C electrode was superior by generating (328.62mW/m2) at zero time, while C-C and Fe-C electrodes produced (290and 229.89mW/m2) respectively at zero time. Cu-C electrode was least with (173.81mW/m2) at zero time. By the end of operation after 240hr, the power density values produced were (557.98, 478.03, 378.17 and 357.11mW/m2) for the four electrode combinations Al-C, C-C, Fe-C and Cu-C.

Power (mW/m2) produced from the single cell showed similar trends as with voltage generated as shown in fig. (1D), Al-C electrode was superior by generating (627.52mW/m2) at zero time, while Fe-C electrode produced (426.65mW/m2) at the zero time and the Cu-C electrode was least with (404.24mW/m2). By the end of operation, the power density values produced were (542.52, 344.77 and 320.71mW/m2) for the three electrode combinations Al-C, Fe-C and Cu-C.

The highest number of bacteria using double MFC (17640cell ml-1) was recorded in case of Al-C electrode and declined to (10290cell ml-1) after 200hrs as shown in figure (1E). Bacterial numbers values were less in case of C-C and Fe-C, numbers were (18375cell ml-1 and 16905cell ml-1) at zero time and were (9555cell ml-1 and 8820cell ml-1) at the end of the operation, while Cu-C electrode produced lesser bacterial numbers (16905cell ml-1) at zero time and was (9555cell ml-1) after 200hrs.

Highest bacterial count using single MFC throughout the operation period was produced with the Al-C; count was 18375cell ml-1 at zero time and ended with 9555cell ml-1 after 200hr of the operation. In case of Fe-C electrodes count were 17640cell ml-1 at zero time and was 10290cell ml-1 at the end of the operation. Counts were 16905cell ml-1 at the zero time in case of Cu-C electrode and were 9555cell ml-1 at the end of the operation as shown in fig. (1F).
pH values increased during operation for both the double and the single MFCs. It increased from 7.1 up to 7.6 at the end of the operation time in case of the C-C electrodes in the double MFC. In the single MFC, pH values was 7.1 – 7.3 at the zero time and elevated to 7.6 after 240hrs in case of the Fe-C and Al-C electrodes as shown in table (4).

Table (4) Summarizes pH values of sewage in a double and single MFC amended with 400mg/l acetate

	Double MFC				Single MFC		
Time	Al-C	C-C	Fe-C	Cu-C	Al-C	Fe-C	Cu-C
Zero time	7.1	7.1	7.1	7.1	7.3	7.2	7.1
240hr	7.5	7.6	7.5	7.4	7.6	7.6	7.5

Slight increase 0.8 – 1.1 0C was recorded throughout the end of the running time in both double and single MFC as described in table (5).

Using double MFC, Al-C electrode produced the highest conductivity (20119µS/cm) at zero time and increased to (56220µS/cm) after 240hr as discussed in table (6). C-C and Fe-C as electrodes were less than Al-C (3109µS/cm and 2040µS/cm) respectively at zero time and were (7635µS/cm and 7850µS/cm) respectively at the end of the operation, while Cu-C electrode produced lesser conductivity (1905µS/cm) at zero time and was (4983µS/cm) after 240hr.

Table (5) Summarizes temperature (0C) values of sewage in a double and single MFC amended with 400mg/l acetate

	Double MFC				Single MFC		
Time	Al-C	C-C	Fe-C	Cu-C	Al-C	Fe-C	Cu-C
Zero time	24.2	24	23.9	24.2	24	24	23.9
240hr	25.2	25.1	25	25	25	24.9	24.8

Table (6) Summarizes conductivity (µS/cm) values of sewage in a double and single MFC amended with 400mg/l acetate

	Double MFC				Single MFC		
Time	Al-C	C-C	Fe-C	Cu-C	Al-C	Fe-C	Cu-C
Zero time	20119	3109	2040	1905	21631	2510	2275
240hr	56220	7635	7850	4983	59648	9310	6692

Using single MFC, Al-C electrode produced the highest conductivity (21631µS/cm) at zero time and increased to (59648µS/cm) after 240hrs as discussed in table (6). Fe-C as an electrode was less than Al-C (2510µS/cm) at zero time and was (9310µS/cm) at the end of the operation, while Cu-C electrode produced lesser conductivity (2275µS/cm) at zero time and was (6692µS/cm) after 240hr.

Operation of double and single chambered MFC with 600mg/l enrichment:

Voltage values for double MFC were (1.8, 1.68, 1.5 and 1.3V) at zero time in case of (Al-C), (C-C), (Fe-c), and (Cu-C), respectively as shown in fig. (2A). At the end of the operation after (240hr), voltage values increased to 2.45, 2.15, 1.87 and 1.84V for the three stated electrode combinations, respectively.

Voltage values for single MFC were 2.45, 2.04 and 1.99V at zero time in case of (Al-C), (Fe-c), and (Cu-C), respectively as shown in fig. (2B). At the end of the operation after (240hr), voltage values dropped to 2.2, 1.8 and 1.8V for the three stated electrode combinations, respectively.

Power (mW/m2) produced from the double cell showed similar trends as with voltage generated as shown in fig. (2C), Al-C electrode was superior by generating (391.1mW/m2) at zero time, while C-C and Fe-C electrodes produced (340.69 and 271.61mW/m2) respectively at zero time. Cu-C electrode was least with (203.99mW/m2) at zero time. By the end of operation after 240hr, the power density values produced were (724.59, 563.19, 422.11 and 408.67mW/m2) for the four electrode combinations Al-C, C-C, Fe-C and Cu-C.Power (mW/m2) produced from the single cell showed similar trends as with voltage generated as shown in fig. (2D), Al-C electrode was superior by generating (724.59mW/m2) at zero time, while Fe-C electrode produced (502.36mW/m2) at the zero time and the Cu-C electrode was least with (478.03mW/m2). By the end of operation, the power density values produced were (616.56, 422.11 and 408.67mW/m2) for the three electrode combinations Al-C, Fe-C and Cu-C.

The highest number of bacteria using double MFC (21315cell ml-1) was recorded in case of Al-C electrode and declined to (11025cell ml-1) after 200hrs as shown in figure (2E). Bacterial numbers values were less in case of C-C, numbers were (20580cell ml-1) at zero time and were (11760cell ml-1) at the end of the operation, while Fe-C and Cu-C electrodes produced the same bacterial numbers (19845cell ml-1) at zero time and was (10290cell ml-1) after 200hrs. The highest number of bacteria using single MFC (22050cell ml-1) at zero time was recorded in case of Al-C electrode and declined to (11025cell ml-1) after 200hrs as shown in figure (2F). Bacterial numbers values were less in case of Fe-C electrode, numbers were (20580cell ml-1) at zero time and were (10290cell ml-1) at the end of the operation, while Cu-C electrode produced lesser bacterial numbers (19845cell ml-1) at zero time and was (8820cell ml-1) after 200hrs.

pH values increased during operation for both the double and the single MFCs. It increased from 7.2 up to 7.5 at the end of the operation time in case of the C-C electrodes in the double MFC. In the single MFC, pH values was 7.2 – 7.4 at the zero time and elevated to 7.8 after 240hrs in case of the Fe-C and Al-C electrodes as shown in table (7).

Table (7) Summarizes pH values of sewage in a double and single MFC amended with 600mg/l acetate

	Double MFC				Single MFC		
Time	Al-C	C-C	Fe-C	Cu-C	Al-C	Fe-C	Cu-C
Zero time	7.2	7.2	7.1	7.1	7.4	7.3	7.2
240hr	7.6	7.5	7.5	7.3	7.8	7.8	7.7

Slight increase 0.8 – 1.2 0C was recorded throughout the end of the running time in both double and single MFC as described in table (8).

Table (8) Summarizes temperature (0C) values of sewage in a double and single MFC amended with 600mg/l acetate

	Double MFC				Single MFC		
Time	Al-C	C-C	Fe-C	Cu-C	Al-C	Fe-C	Cu-C
Zero time	24	24	23.9	23.9	23.7	23.8	23.6
240hr	25	24.9	24.9	24.8	24.9	24.7	24.8

Table (9) Summarizes conductivity (µS/cm) values of sewage in a double and single MFC amended with 600mg/l acetate

	Double MFC				Single MFC		
Time	Al-C	C-C	Fe-C	Cu-C	Al-C	Fe-C	Cu-C
Zero time	20389	4500	2090	2080	23193	2720	2690
240hr	59120	8120	7980	5907	65340	9670	7901

Using double MFC, Al-C electrode produced the highest conductivity (20389µS/cm) at zero time and increased to (59120µS/cm) after 240hrs as discussed in table (9). C-C and Fe-C as electrodes were less than Al-C (4500µS/cm and 2090µS/cm) respectively at zero time and were (8120µS/cm and 7980µS/cm) respectively at the end of the operation, while Cu-C electrode produced lesser conductivity (2080µS/cm) at zero time and was (5907µS/cm) after 240hrs.

Using single MFC, Al-C electrode produced the highest conductivity (23193µS/cm) at zero time and increased to (65340µS/cm) after 240hrs as discussed in table (9). Fe-C as an electrode was less than Al-C (2720µS/cm) at zero time and was (9670µS/cm) at the end of the operation, while Cu-C electrode produced lesser conductivity (2690µS/cm) at zero time and was (7901µS/cm) after 240hrs.

Operation of double and single chambered MFC with 400mg/l enrichment

Voltage values for double MFC were (2, 1.82, 1.65 and 1.45V) at zero time in case of (Al-C), (C-C), (Fe-c), and (Cu-C) respectively as shown in fig. (3A). At the end of the operation after (240hrs), voltage values increased to (2.56, 2.24, 2.04 and 1.93V) for the three stated electrode combinations, respectively.

Voltage values for single MFC were (2.7, 2.31 and 2.25V) at zero time in case of (Al-C), (Fe-c), and (Cu-C), respectively as shown in fig. (3B). At the end of the operation after (240hrs), voltage values dropped to (2.46, 2.05 and 1.98V) for the three stated electrode combinations, respectively.

Power (mW/m2) produced from the double cell showed similar trends as with voltage generated as shown in fig. (3C), Al-C electrode was superior by generating (482.84mW/m2) at zero time, while C-C and Fe-C electrodes produced (399.84 and 328.62mW/m2) respectively at zero time. Cu-C electrode was least with (253.78mW/m2) at zero time. By the end of operation after 240hrs, the power values produced were (791.1, 605.69, 502.36 and 449.63mW) for the four electrode combinations Al-C, C-C, Fe-C and Cu-C.

Power (mW/m2) produced from the cell showed similar trends as with voltage generated as shown in fig. (3D), Al-C electrode was superior by generating (880mW/m2) at zero time, while Fe-C electrode produced (644.13mW/m2) at the zero time and the Cu-C electrode was least with (611.1mW/m2). By the end of operation, the power density values produced were (760.5, 537.43 and 468.46mW/m2) for the three electrode combinations Al-C, Fe-C and Cu-C.

The highest number of bacteria using double MFC (24255cell ml-1) was recorded in case of Al-C electrode and declined to (14700cell ml-1) after 200hrs as shown in figure (3E). Bacterial numbers values were less in case Fe-C electrode, numbers were (23520cell ml-1) at zero time and were (14700cell ml-1) at the end of the operation, while C-C and Cu-C electrodes produced lesser bacterial numbers (22785cell ml-1) at zero time and were (13965cell ml-1 and 15435cell ml-1) respectively after 200hrs.

The highest number of bacteria (24990cell ml-1) at zero time was recorded in case of Al-C electrode and declined to (16905cell ml-1) after 200hrs as shown in figure (3F). Bacterial numbers values were less in case of Fe-C electrode, numbers were (23520cell ml-1) at zero time and were (16170cell ml-1) at the end of the operation, while Cu-C electrode produced lesser bacterial numbers (22785cell ml-1) at zero time and was (15435cell ml-1) after 200hrs.

pH values increased during operation for both the double and the single MFCs. It increased from 7.2 up to 7.5 at the end of the operation time in case of the C-C electrodes in the double MFC. In the single MFC, pH values was 7.2 – 7.4 at the zero time and elevated to 7.8 after 240hrs in case of the Fe-C and Al-C electrodes as shown in table (10).

Slight increase 0.8 – 1.2 0C was recorded throughout the end of the running time in both double and single MFC as described in table (11).

Using double MFC, Al-C electrode produced the highest conductivity (49360µS/cm) at zero time and increased to (67345µS/cm) after 240hrs as discussed in table (12). C-C and Fe-C as electrodes were less than Al-C (5131µS/cm and 2350µS/cm) respectively at zero time and were (12127µS/cm and 11130µS/cm) respectively at the end of the operation, while Cu-C electrode produced lesser conductivity (2180µS/cm) at zero time and was (8130µS/cm) after 240hrs.

Table (10) Summarizes pH values of sewage in a double and single MFC amended with 800mg/l acetate

	Double MFC				Single MFC		
Time	Al-C	C-C	Fe-C	Cu-C	Al-C	Fe-C	Cu-C
Zero time	7.3	7.3	7.2	7.2	7.5	7.4	7.3
240hr	7.7	7.7	7.6	7.5	7.9	7.9	7.9

Table (11) Summarizes temperature (0C) values of sewage in a double and single MFC amended with 800mg/l acetate

	Double MFC				Single MFC		
Time	Al-C	C-C	Fe-C	Cu-C	Al-C	Fe-C	Cu-C
Zero time	24.1	24.2	24	24	23.9	24	23.8
240hr	25.2	25	25.1	24.9	25.1	24.8	25

Table (12) Summarizes conductivity (µS/cm) values of sewage in a double and single MFC amended with 800mg/l acetate

	Double MFC				Single MFC		
Time	Al-C	C-C	Fe-C	Cu-C	Al-C	Fe-C	Cu-C
Zero time	49360	5131	2350	2180	58350	2886	2856
240hr	67345	12127	11130	8130	75359	13690	12524

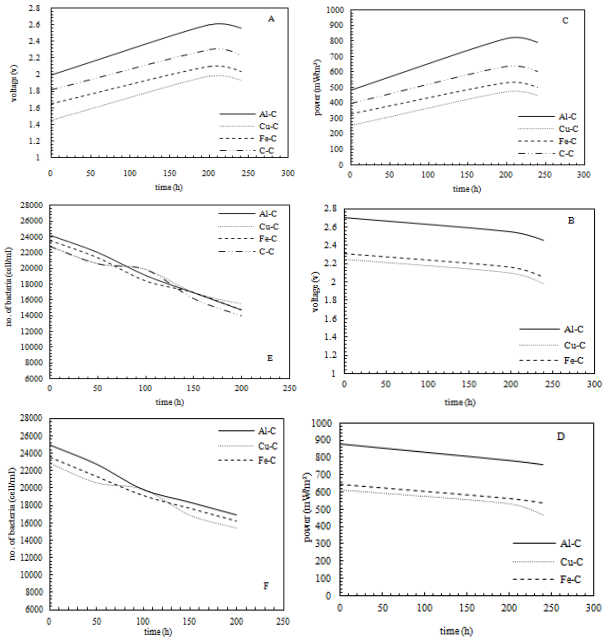

Figure 3, Electricity generation in double and single chamber MFC amended with 800mg/l sodium acetate: values of voltage (V), power density (mW/m2) and total bacterial numbers (cell ml-1).

Using single MFC, Al-C electrode produced the highest conductivity (58350µS/cm) at zero time and increased to (75359µS/cm) after 240hrs as discussed in table (12). Fe-C as an electrode was less than Al-C (2886µS/cm) at zero time and was (13690µS/cm) at the end of the operation, while Cu-C electrode produced lesser conductivity (2856µS/cm) at zero time and was (12524µS/cm) after 240hrs.

Discussion

It was possible in this study to produce as much as 816 mW/m2 with domestic wastewater amended with 800 mg/l sodium acetate concentrations using a double chambered MFC and to produce 880mW/m2 using a single chambered MFC. Still, this is much larger than power densities reported for other complex materials such as anaerobic sediments (16-28mW/m2), a high-starch content wastewater (19-20mW/m2), or domestic wastewaters (24mW/m2) (Liu and Logan 2004).

It has been established that voltage generated in a microbial fuel cell decreases linearly with respect to time. The highest voltage obtained in other researches was (42.4V) using four cells were connected into one block (Rabaey et al 2003). It was noticed in this study the highest voltage was (2.6V) using double chambered MFC with domestic wastewater amended with 800mg/l sodium acetate concentrations and was (2.7V) using single chambered MFC.

In MFCs, bacteria are expected to generate electricity from the oxidation of organic matter (which is wastewater in this study). It was shown that the least reduction in bacterial counts (≈ 31.1-39.4%) was recorded with the 800 mg L-1 acetate concentration in the doubled and chamber MFC. It may be concluded that this concentration was optimum to support growth of bacteria throughout the monitoring program, and consequently encourage the MFC to produce highest voltage and power. Throughout 200 hours performance, bacterial counts showed a typical microbial growth curve with the classic main phases of growth apparent. After 50 hours, growth reached the highest values and counts decreased after that. This should direct attention about the specific time of enriching the cell with acetate or any other organic additives in order to resuscitate bacteria to achieve longer periods of current generation.
Increasing the electrical conductivity of solution can enhance the MFC performance. Generally, EC values increased in case of the four studied electrodes and with the three concentrations of acetate being used. Indeed, the highest EC values were in case of the AL-C electrode with the 800 mg L-1 acetate concentration was recorded as (49360µS/cm) at zero time using double cell while was recorded as (58350µS/cm) at zero time using single MFC.

It was noticed that there was an increase in pH values this is due to the addition of sodium acetate; the acetate ion is a weak base

$$CH_3COO^- + H_2O \rightarrow CH_3COOH + OH^-$$ (Equation no.1)

The conjugating base of a weak acid is always a weak base.

Temperature increased with increasing time and may be attributed to the increase in ambient temperature in the surrounding environment; and also as electrical conductivity in water invariably increases with an increase in temperature. Warm water is less viscous and has greater electronic movement, thus allowing free flow of electric current. It is generally expressed as relative change per degree Celsius, at a particular temperature small variation or difference in temperature reports a marked difference in conductivity.

Different electrodes were used to investigate the electricity production; Aluminum-graphite, Copper- Graphite and Iron-Graphite electrodes. It was noticed that in case of the double chambered MFC, Al-C produced the highest voltage (2.15V) while C-C (1.99V). Fe-C and Cu-C produced the least voltage (1.77 and 1.72V) respectively. It can be concluded that aluminum and graphite generated electricity more than metals like Fe or Cu. This result should direct research for more investigations as metal electrodes are expected to generate currents due to chemical and/or microbial corrosion. It was noticed that the least corrosion (almost nil) was in case of the aluminum and graphite electrodes since the weight of the electrodes before and after the operation were the same as shown in table (3) and hence there is no background current accompanied the operation. Two things should be pointed out; the development of background current and the toxicity of the dissolved metal ions on the bacterial consortia needed to produce electrons as happened in case of copper and iron metals. Results should be treated with great caution as the running time was about 300 hours.

In the current study, four materials were used as an anode electrode with graphite as a cathode, namely, Aluminum, Graphite, Iron and Copper. Aluminum was superior in voltage and power generation (Table 1).

Recent studies have shown that the proton exchange membrane is not needed for the operation of MFCs and that removing it actually increases maximum power densities. (Ghangrekar and Shinde 2007) Also, it has been shown that the main disadvantage of a two chamber MFC is that the solution cathode must be aerated to provide oxygen to the cathode (Liu and Logan 2004).

In the current study both single and doubled chamber were tested for current generation. Al-C electrode produced the highest voltage values with the 800 mg L-1 acetate concentration. However, in case of removal of PEM the single chamber produced higher voltage (2.7V at the zero time and dropped to 2.46V after 240 hrs operation) while in case of using PEM the higher voltage was (2.6V and was 2.56V after 240hr). Also, higher power density was produced by the single chamber compared with the double one .However, power generated from the double chambered was less than the single chamber at the zero time, but increased by the end of operation and became (791.1 mW/m2), where it was (760.5 mW/m2) in case of the single chamber. From this study it was noticed that removal of PEM gave better performance results.

Acetate is the most abundant fatty acid in anaerobic ecosystems and is used as an electron donor by anaerobic respiratory bacteria (lee et al 2003). Highest voltage and power density were achieved with the 800 mg L-1 acetate concentration. However, it must be mentioned that the current was monitored for about 300 hours, as current reached maximum values. At that stage acetate is expected to be consumed completely and current generation should depend on the acetate supply. However, this was not tested in this particular study. MFCs typically produce power less than50 mW/m2 (normalized to anode projected surface area) (Bond and Lovely 2003), (Kim et al. 1999) and (Tender et al. 2002).

The effect of electrode spacing on Microbial Fuel Cell performance was investigated by reducing the distance between the anode and cathode from 4 to 1 cm. The least electrode spacing the highest power density (Ghangrekar and Shinde 2007) . This increase in power density corresponded to a decrease of internal resistance from 100 to 30 Ω when the electrode spacing was reduced from 4 to 1 cm. when using single chambered cell the maximum output power was (867.02mW/m2) for Al-C and when using double chambered cell the result was (622.02 mW/m2).

Conclusion

From the analysis of the data, we can conclude that:

1. Sewage can be used in microbial fuel cells to generate electricity. Voltage generated decreases linearly with respect to time.
2. Single chambered MFC is more efficient than Double chambered MFC.
3. In case of using different electrodes like metals there is a difference in electricity production, the best electrode was Al-C which gave the higher voltage then C-C which converges form values of voltage using Al-C. The least voltage produced from Fe-C then Cu-C respectively.
4. Removal of PEM gave higher electricity production when compared with using it.
5. The best concentration of acetate was 800mg/l.
6. The least electrode spacing the highest power density.

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