

Electric Power Generation from Sewage using Double Chamber Microbial Fuel Cell

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الخلاصة

الاشكال النظيفة والمتجددة من الطاقة هي واحدة من الاحتياجات الاساسية في الوقت الحاضر. خلايا الوقود الميكروبية تعرض فوائد على طرق تحويل الطاقة المتجددة. بدون التحويل الى الطاقة الميكانيكية، خلايا الوقود تحول الطاقة الكيميائية الى كهرباء. التجارب عملت باستخدام خلايا الوقود الميكروبية ذو الحوضيين الذي يحتوي قماش الكربون في كلا الالكتروودات في الحالة اللاهوائية لإنتاج كمية من التيار في حدود الثلاثة اشهر. التركيز الاساسي من هذه الدراسة هو توليد الكهرباء ومعالجة مياه المجاري معا. التيار والفولتية مقاسا في هذه الدراسة باستخدام جهاز الفولتميتر.

ABSTRACT

Renewable and clean forms of energy are one of the major needs at present. Microbial Fuel Cells (MFC's) offers unambiguous advantages over other renewable energy conversion methods. Without any transitional conversion into mechanical power, fuel cells transmute chemical energy directly into electricity. Experiments have been conducted using Double Chambered-Microbial Fuel Cell (DC-MFC) containing carbon cloth for both the electrodes in anaerobic condition to find the amount of current produced for a period of 3 months. The prime focus of this study is to generate electricity in addition to treatment of sewage by using carbon cloth. In electrode the potential difference and current generated by the MFC have been measured using mustimeter

Keywords: electric power generation, sewage, double chamber microbial.

1. INTRODUCTION

Increase in the use of fossil fuels to meet energy needs has accelerated environmental problems and the need of renewable energy has increased steadily (Allen R.M et al., 1993); making the focus of researches shift to alternative energy sources to replace fossil fuels. Mankind has been in a constant quest to meet this need. This quest has found new energy sources as time goes by. One of these new energy sources is Microbial Fuel Cell (MFC).

Microbial fuel cells hold an important place among the bio-electrochemical systems. In microbial fuel cells, by means of metabolic activities of microorganisms biomass is converted into electrical energy systems (B. Min et al., 2004). It uses wastewater as a nutrient use in electricity production and treats wastewater during the electricity production, so in terms of both cost and benefits, microbial fuel cells have attracted much attention. MFC typically consists of an anode chamber, cathode chamber and proton exchange membrane (PEM) which separates anode and cathode chambers. Microorganisms oxidize organic matters in the anode chamber and produce electrons and protons (Liu et al., 2010). Protons diffuse into cathode chamber through wastewater used in MFC.

2. REACTOR CONFIGURATION

An MFC consists of the anode chamber, the cathode chamber, a salt bridge, and an electrical circuit. A laboratory-scale cylindrical dual chamber MFC system was designed and fabricated using poly-acrylic plastic. The MFC system was constructed by joining two cylindrical chambers with a membrane as a separator. The schematic configuration of dual chamber MFC with a) reactor size is shown in Figure.1. (b) 2-dimensional view of the experimental setup is shown in Figure.1. The anode and cathode chamber had an effective dimension of 16 cm height and 11 cm width. The anode and cathode chamber of the reactor had a total volume of 1.5 L constituting an operating volume of approximately 1.3 L and 0.2 L head space.

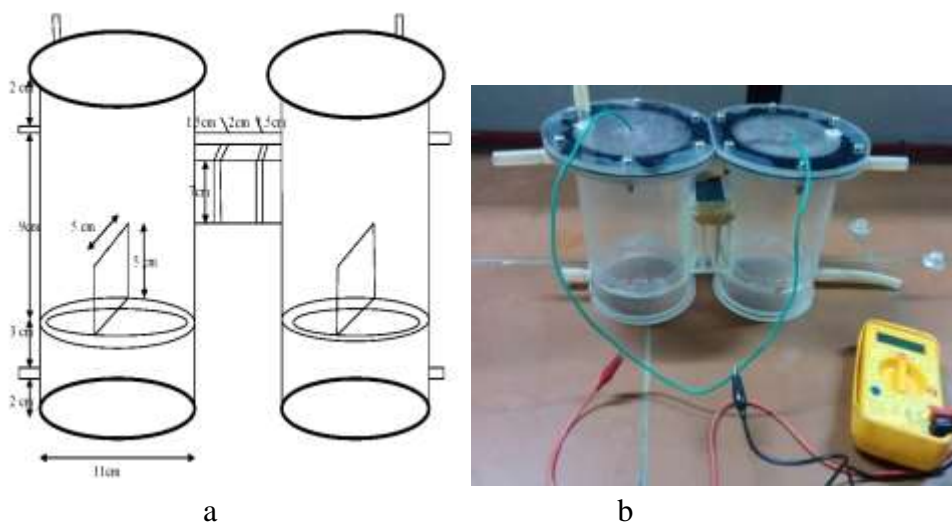


Figure.1 Schematic configuration of dual chamber MFC with reactor sizes (a) and (b) 2-dimensional view of the experimental setup

Provision was made in the design for sampling ports; wire input points (top), inlet and outlet ports will be sealed with an aluminum clamp to prevent gas exchange. Anode chamber was sealed with washers to ensure anaerobic microenvironment. A pair of carbon cloth will be used as an electrode for both the anode and cathode chamber. The carbon cloth electrode in cathode chamber will be catalyzed by Platinum. The reactor dimension and its specification are presented in Table.1. Electrodes after pretreatment will be soaked in deionized water (24 hours) and place them on either side of the salt bridge. Electrodes will be externally circuited using copper wire with an external resistance (10-1000 Ω) and will be sealed using semiconducting glue.

Table.1 Device specification and operation conditions of laboratory scale dual chamber MFC

DEVICE	SPECIFICATION
Material	Plastic
Dimension($\pi r^2 h$)	Width=11cm

	Height =16 cm	
Total volume	1.5 L	
Electrodes	Anode	Cathode
Material	Carbon cloth	Carbon cloth impregnated by platinum catalyst
Pre-treatment	Acid and alkali treatment	Acid and alkali treatment
External load	50-1000Ω	
Membrane		
Type	Salt bridge	
Thickness	2 cm	
Dimension (L x W x H)	2 x 6 x 7 cm	
Substrate	Sewage	Distilled water

3. ANALYSIS

3.1 CHEMICAL ANALYSIS

MFC performance with respect to treatment efficiency has been monitored by analyzing the physico-chemical characteristics as per the standard methods (Greenberg et al 1998). Performance of fuel cell has been also evaluated by estimating the substrate (COD) removal efficiency (ξ COD) during operation.

3.2 ELECTROCHEMICAL ANALYSIS

Current (I) and potential (V) measurements have been recorded once in 15 minutes of operation using a digital multi-meter (Metravi 901) by connecting with 50 -1000 Ω external circuit. Power (W) and current (I) have been calculated according to:

$$P =IV \dots\dots\dots (1)$$

$$I = V/R \dots\dots\dots(2)$$

The power density (mW/m^2) and current density (mA/m^2) have been calculated by dividing the obtained power and current by the anode surface area (m^2).

The CE is defined as the ratio of total Coulombs actually transferred to the anode from the anodic chamber, to maximum possible Coulombs if all substrate removal produced current (H. Liu et al 2004). The total Coulombs obtained have been determined by integrating the current over time, so that the Columbic efficiency (The CE indicates the ratio between the coulombs recovered as current over the total amount of coulombs from the electron donor added) for an MFC run in a batch mode has been will be evaluated over a period of time, calculated as:

$$CE = \frac{I \times t}{F \times n \times w / M} \dots\dots\dots(3)$$

Where:

CE= Columbic efficiency, I = current (A), t = time (S), F = Faraday constant (96 485 C mol/L), n = number of moles of electrons produced per mole of substrate (n = 4), w = daily COD load removal (gCOD/d).

M = molecular weight of substrate (g) (Jadhav and Ghangrekar 2008).

4. RESULTS

4.1 GENERAL

The result obtained from the bioelectrochemical system operated under different operational condition in order to address the crucial limiting factors of the MFC performance. The obtained results were justified and discussed with the support of relevant literature in bioelectricity generation.

4.2 SEWAGE CHARACTERIZATION

In the investigation, the raw sewage collected from Anna University STP is used as substrate for MFC. The physico-chemical characteristic of sewage is presented in Table.2. According to the results of Biochemical

oxygen demand (BOD) and Chemical oxygen demand (COD) that show the substrate (Sewage) is biodegradable. Sewage was used directly without any keeping in refrigerator. Sewage was used as inoculums for MFC test without any modification such as pH adjustment or addition of nutrients etc.

Table.2 Characteristics of sewage

S.NO	Parameters	Unit	Concentrations
1	pH	-	7.58
2	Total solids	(mg/L)	720
3	Biochemical Oxygen Demand (BOD ₃ ^{@27°C})	(mg/L)	220
4	Chemical Oxygen Demand (COD)	(mg/L)	500

4.3 REACTOR STARTUP, STABILIZATION AND MICROORGANISM ACCLIMATION

All the experiments were conducted using sewage (500 mg COD/L) as substrate. A rapid increase in the open circuit cell voltage of 520 mV was observed approximately 1 hour after inoculation of the anode, implying that electricity can be generated using mixed anaerobic microbial inoculums. The open circuit cell potential stabilized to a value of approximately 562 mV after nearly 45 hour. Similar open circuit values have typically been reported in literature for many MFC using sewage as energy sources (Hamelers et al 2006). They are significantly lower than the values calculated from thermodynamics, due to several factors including bacterial metabolic losses and mixed potentials (L.S. Clesceri et al 1989).

Once the substrate in the anode chamber was consumed, the fuel cell voltage decreased sharply.

4.3.1 SEWAGE

The voltage generation was recorded per day throughout the twelve days for the sewage sample. There was a definite increase in the voltage till the day eleven and after that voltage has been decreased, as we can see from

Figure.2. It was observed that for a whole twelve days, the maximum potential 715 mV to generate electricity at eleventh day and minimum potential 531 mV at day one. Schematic configuration of dual chamber MFC and view of the experimental setup (a. At the beginning b. After twelve days) have been mentioned as in Figure.3.

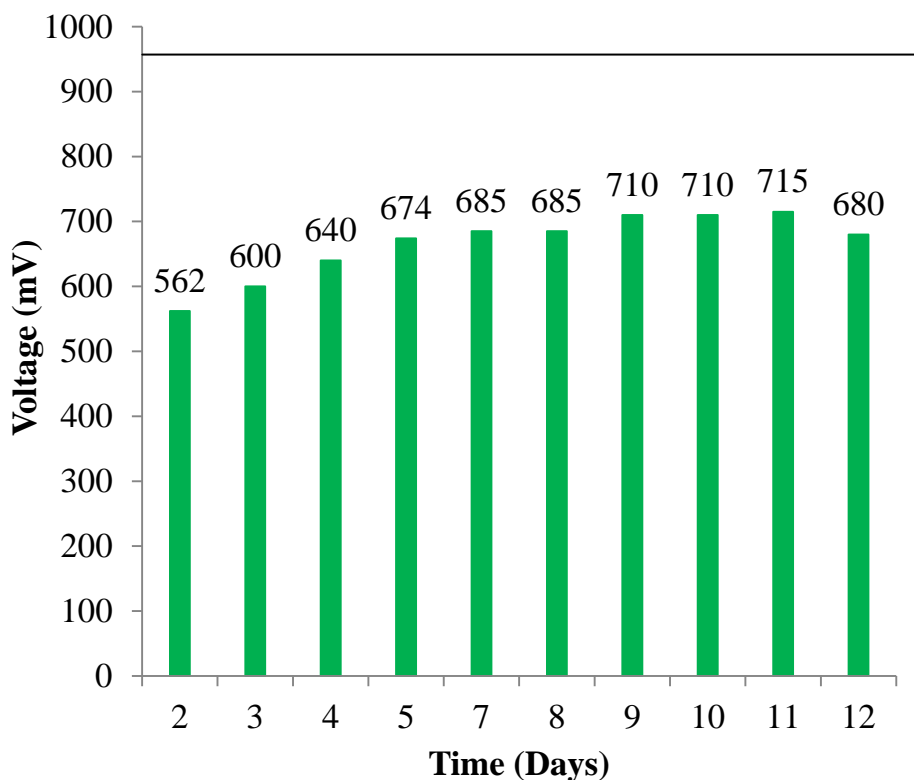


Figure.2: Graph representing voltage generated with Sewage with respect to time (days).

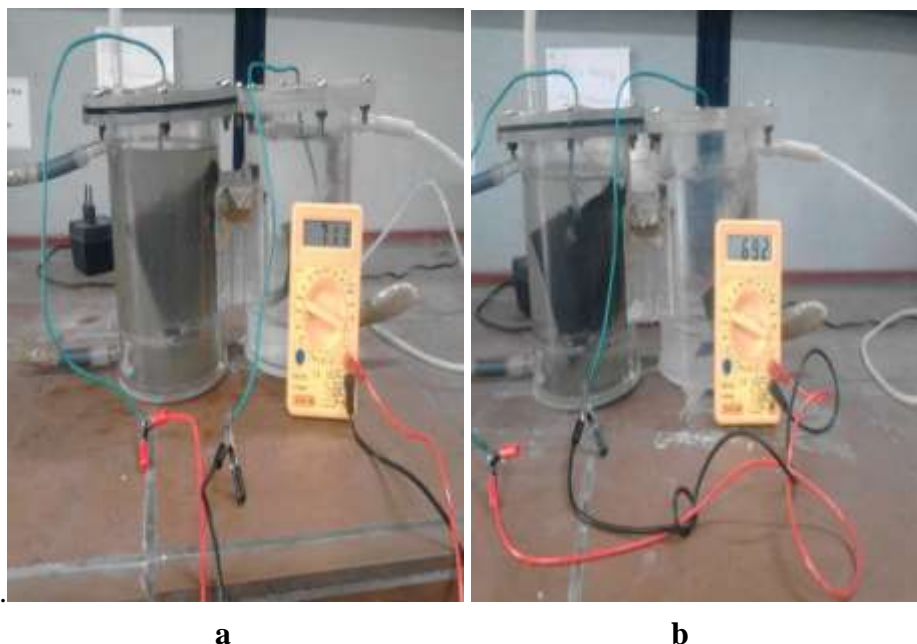


Figure.3 Schematic configuration of dual chamber MFC and view of the experimental setup a. At the beginning b. After twelve days.

4.4 SUBSTRATE CONSUMPTION AND REMOVAL EFFICIENCY

During MFC operation the initial reactions were biologically catalyzed in the anodic chamber. The organic matter (electron donors) present in sewage gets metabolized in the presence of biocatalyst (present in suspension or attached as biofilm on anode) resulting in electron gain. Electrons (e^-) and protons (H^+) released by redox reactions result in the development of bio-potential (biological mediated voltage) which facilitates the bioelectricity generation. The efficacy of substrate degradation was found to depend on the nature and concentration of the substrate (Rakesh Reddy N et al 2007).

At the initial phase of operation with sewage, the system was loaded with substrate (500 mg COD/L) concentration for 12 days followed by adding solution of 5 g/L of glucose to anode chamber at the twelfth day .

As shown in Figure.4, in the first batch operation, at the beginning, the COD removal efficiency of 18% which increased to 44% on day 5, which increased to 72 % on day 8, which increased to 76% on day 10 respectively.

Whereas, after adding (0.5g/100mL) of glucose condition, the COD removal was found to be 39.6% and the maximum of 74% of substrate removal were achieved (Figure.4).

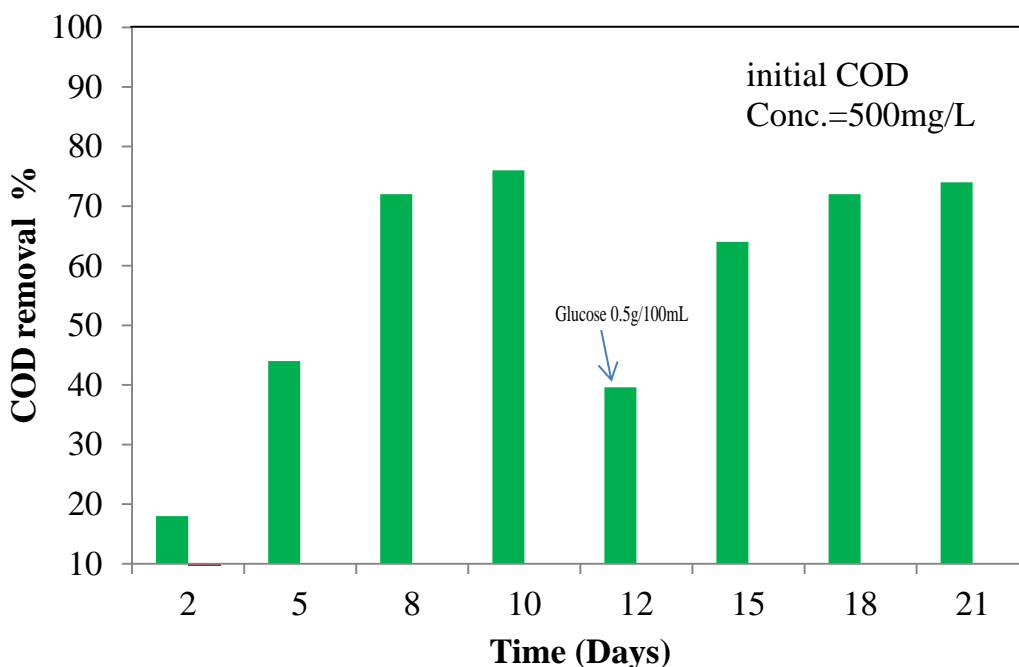


Figure.4 Variation of substrate removal efficiency during MFC stabilization

The CE of 1.71 % was observed during the process might be due to the substrate (500 mg COD/L) consumption via other competing metabolic processes, such as fermentation and methanogenesis rather than electricity generation. Higher COD removal rates were accompanied by lower coulombic efficiencies. Further, from day 8 to day 10, the CE varied widely, ranging from 3.6 % to 4.21% (Figure.5). This might be due to the accumulation of metabolites, biomass growth, substrate crossover and

competing reactions for electrons (e.g., H₂ or CH₄ formation) or reduction of O₂ diffusing through the membrane (S. Tang et al 2001).

Whereas, after adding (0.5g/100mL) of glucose condition, coluombic efficiency was found to be 8.68% and the maximum of 10.35% were achieved (Figure.5).

The CE is defined as the ratio of total Coulombs actually transferred to the anode from the anodic chamber, to maximum possible Coulombs if all substrate removal produced current (B.E. Logan et al 2005).

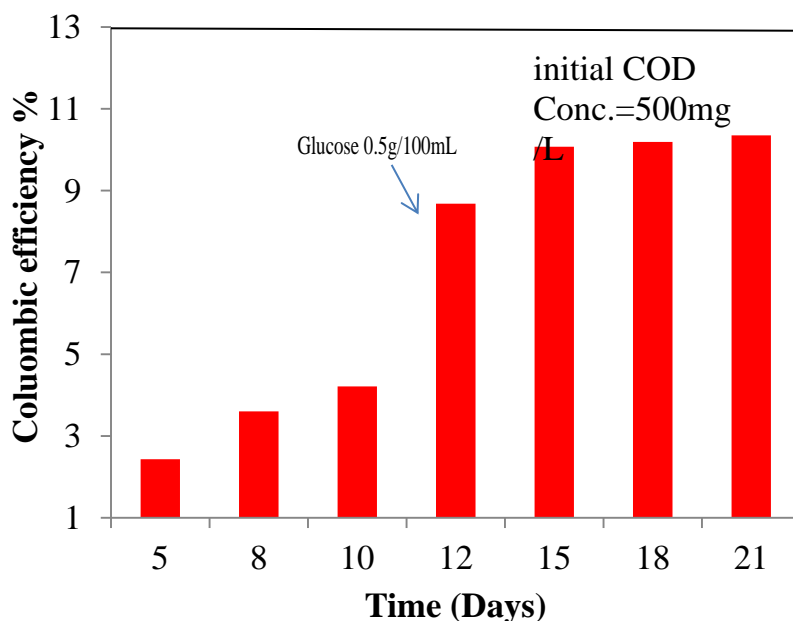


Figure.5 Variation of coluombic efficiency during MFC stabilization

4.5 ELECTRICITY GENERATION IN MFC REACTOR

Immediate after start-up of the MFC system, there is no substantial change in the voltage generation due to the adaptation and accumulation of biomass on the surface of anode electrode. As revealed in Figure.6, after adaptation phase consistent increase in voltage was observed with the operation time accounting an OCV (0.562 V), current (0.14 mA) and

(18%) substrate removal efficiency. Later a steady increase in OCV of (0.674) V and (0.194) mA current was observed under

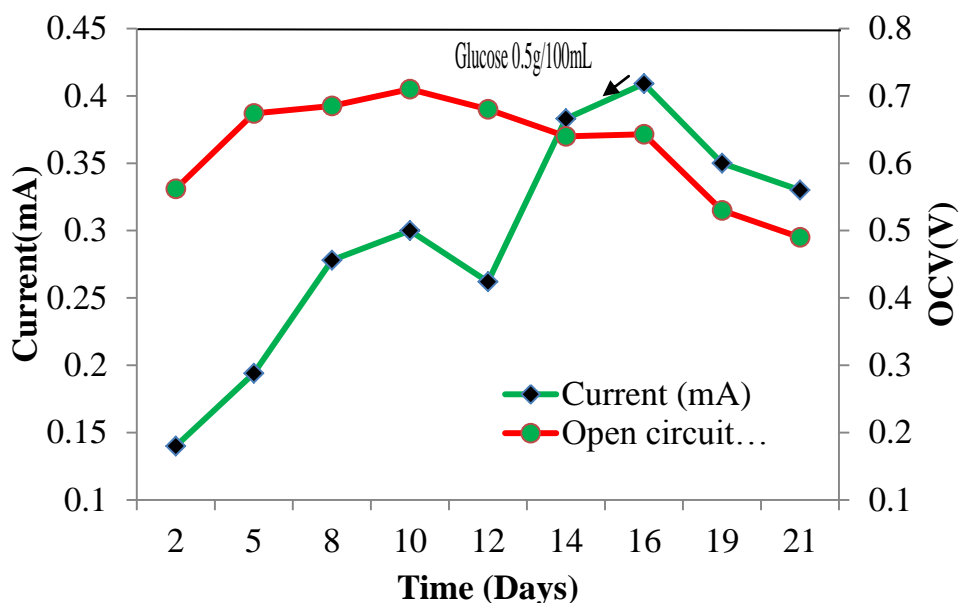


Figure.6 Open circuit voltage and current variation with the function of MFC operation time.

Subsequently, glucose was added to the anode chamber and the performance was evaluated with respect to voltage and current output. The maximum OCV of 0.71 V and 0.3 mA current was achieved and maintained the stable voltage for the period of 12 days, further no improvement in the steady level of voltage output (Figure 3.5). A maximum potential (0.409 V) was observed after adding (5 g/L glucose. Later on 21 days, the voltage has been gradually decreased to the value of 0.33 V due to the substrate limitation (Helder et al 2012).

4.6 EXPERIMENTAL FACTORS LIMITING THE PERFORMANCE OF MFC

4.6.1 Chemical Factors

4.6.1.1 Effect of Ionic strength on power generation

Conductivity is one of the important parameters which directly influences the power output of MFC by favouring the IS of anolyte. Presence of salts in anolyte increases the aqueous phase conductivity and helps to manifest effective electron transfer (Lovley RD et al 2006). In the experiment conducted with the adjusted IS of the solution, the power was measured after voltage stabilization with 12 days period of operation time.

Table.3 Power density with variable IS 2mM NaCl and control (without adding

TIME (Days)	PD-Control (without adding NaCl (mW/m ²))	PD-2mM NaCl (mW/m ²)
1	0.111	3.856
2	0.111	5.455
3	0.1509	5.909
4	0.213	6.262
5	0.213	6.872
6	0.327	5.544
7	0.435	5.018
8	0.438	4.8
9	0.588	4.6

10	0.511	4.007
11	0.511	3.635
12	0.389	2.783

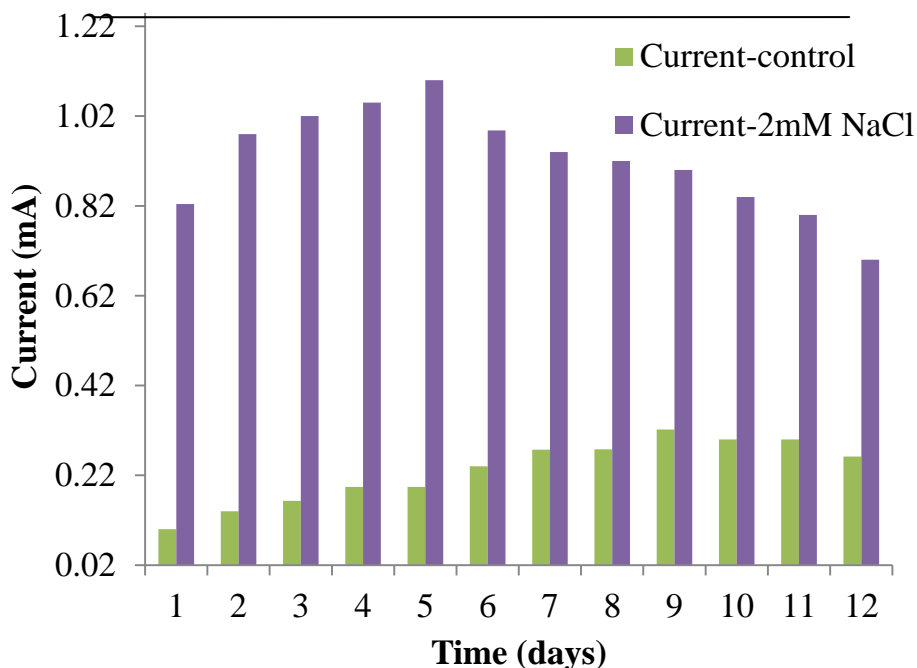


Figure.7 current output with variable IS (2mM and control)

From Figure.7, after NaCl addition to the anode chamber, current of 0.824mA for 2mM NaCl and 0.1mA for the Control (without adding NaCl) was achieved.

From table.3, after NaCl addition to the anode chamber, a power density of 3.856 mW/m² for 2mM NaCl and 0.111 mW/m² for the Control (without adding NaCl)was achieved. Liu et al (2005) had observed an increased power output from 720 mW/m² to 1330 mW/m² by adding NaCl which resulted in an increase in solution ionic strength (400 mM IS).

After supplementation of NaCl, the overall circuit voltage was raised to 830 mV with 2mM NaCl and 531 mV for the control (without adding

NaCl) (figure.7). The increased voltage with time might be due to an increase bacterial density, since bacterial density changes the amount of metabolites in solution, which in turn influences the conductivity and the capacity. Because of this disturbance of the electrochemical characteristics of the consortium shortly after feeding, additional voltage was obtained. That might be the presence of bacteria in the stationary phase or suspended in physiological solution (Rabaey et al 2004).

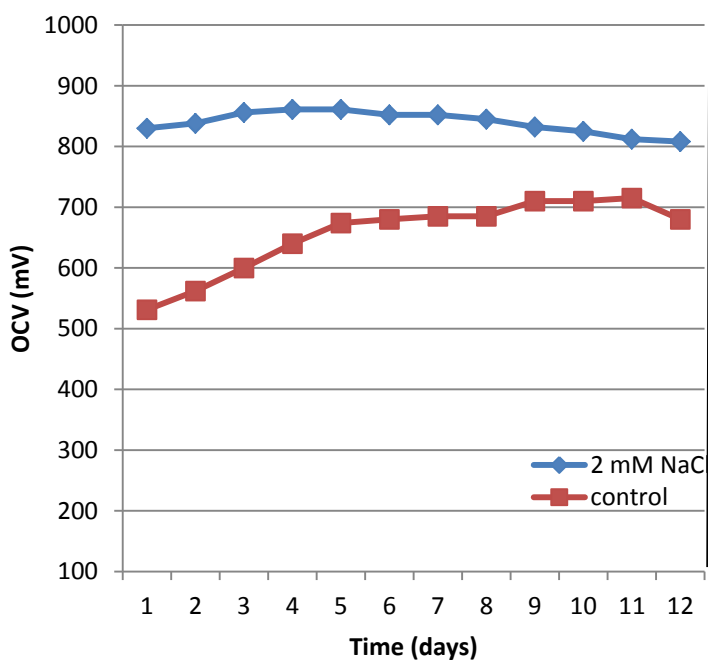


Figure.8 Potential output of MFC with different IS (2mM and control)

A steady raise in OCV was observed at (861 mV) with 2 mM NaCl within the available IS and (715 mV) for the Control (without adding NaCl). This improvement in the potentials might be due to the decreased internal resistance as a result of an increase in IS (Liu et al 2005). Rabaey et al (2005) had specified that addition of NaCl in the flow stream had a positive effect on the MFC output, up to a concentration of 2.5% which increase the conductivity and improves the electron uptake. Oh and Logan (2006) had stated that increased ionic strength of the medium can increase power by

increasing the conductivity of the solution, but bacteria cannot grow well at very high ionic strengths. However, the adverse effect of saline solutions on bacterial growth is well known, but it is strain-specific.

Heilmann and Logan (2006) had achieved the increased CE from 5.2 to 11.9% and 8.4 to 15.4% due to addition of 300 mg/L NaCl. This increase was likely a consequence of a decrease in the operation time due to faster substrate utilization, resulting in less oxygen transfer into the chamber before exhaustion of the substrate. This can be attributed to the higher conductivity of the anolyte in MFC due to buffer addition (10 mM NaCl). The conductivity of anolyte was found to be 0.188 mS/cm without adding NaCl and 2 mS/cm when adding 2 mM NaCl to the system. This result indicates that salt addition can substantially increase the solution conductivity and reactor performance. (Liu H et al 2004).

4.6.2 Biological Factors

4.6.2.1 Mixed culture

Microorganisms act as a catalyst in transferring electrons from the substrate to the anodic electrode. 20 mL of sludge of sewage treatment recycling plant was added to the anode chamber throughout batch study. The current across external resistance (100Ω) was monitored daily for twelve days by using digital Multimeter.

As can be seen from the Figure.9, initially the current with the mixed culture was 0.14 mA.

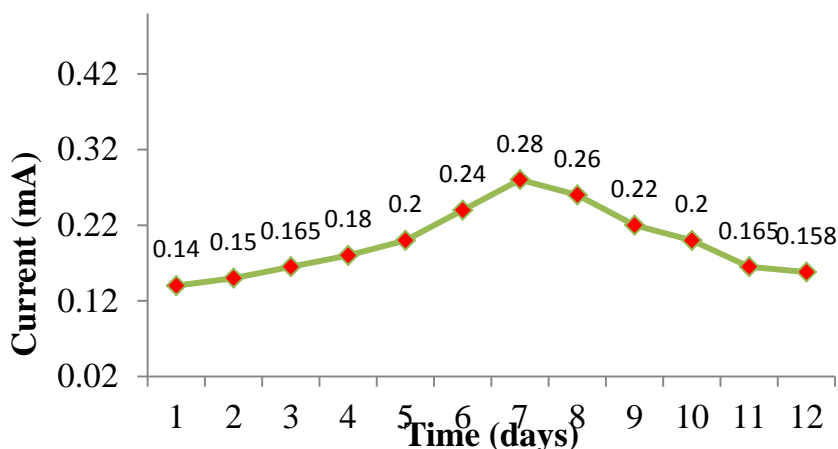


Figure.9 MFC performance (Current) in relation with time

The current is raised steadily to 0.18mA on fourth day with mixed culture MFC. The time required to reach steady state was quiet variable for systems using various substrates, concentration of substrate and the microorganism (Rahimnejad et al 2012). Catal et al (2008a) had suggested that a mixed bacterial culture was superior to a pure bacterial culture in terms of electricity generation, especially when a mixture of carbon sources is used. Chae et al (2009) had declared that the anodic potential was also determined by the amount of fuel supplied at the anode and its oxidation rate by the biocatalyst.

On day 7, the maximum Current was (0.28 mA) in the mixed culture MFC (Figure.9). This could be attributed the presences of microbial interactions in the mixed consortium uses their own natural mediators and increase the electron transport rate (Chaudhuri SK et al 2004).

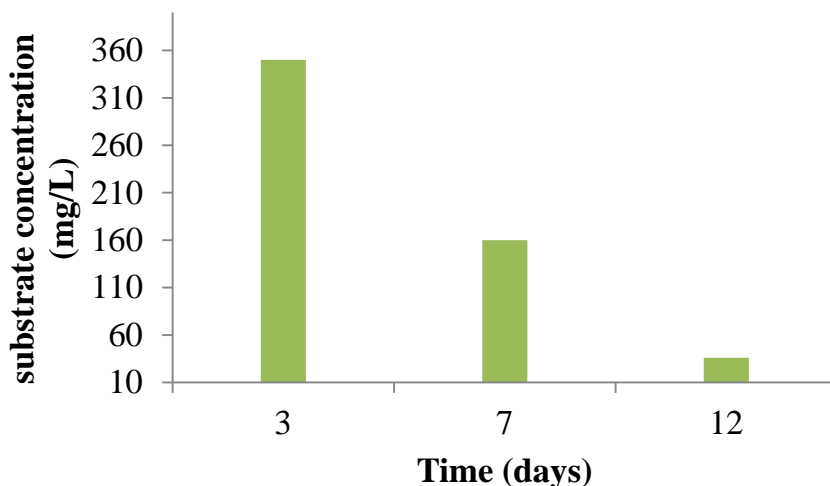


Figure.10 Substrate removal by biocatalyst at the end of operation period of 12 days in the MFC system

Consequently, the COD removal efficiency was found to be (92%) (Figure.10). The variable potential and rapid substrate removal in the mixed culture MFC might be due to the presence of diverse microbial populations in the mixed culture has capacity to utilize complex carbon sources.

5. CONCLUSION

Results showed that two-chambered MFC was able to generate electricity and simultaneously treat sewage. The results showed that time and membrane materials play an important role in electricity generation performance in the fed-batch MFC.

When it was loaded with sewage, the voltage reached to its maximum peak value approximately (715 mV) at the eleventh day and current was (0.3 mA) on the tenth day. The higher substrate concentration causing an increase in power output, moreover, it can be observed that an increase in COD value with increase current production and decrease in internal resistance. The maximum COD removal efficiency was found to be (74%) on the tenth day and coulombic efficiency was (4.21%) on the tenth day.

The best glucose concentration (0.5g/100mL) is suitable for current output and bacterial growth due to an increase in glucose concentration up to this value lead to a decrease in current output whereas after adding (0.5mg/100mL) of glucose, the maximum COD removal efficiency and CE were (74% and 10.35%) respectively on the twenty first day.

On the other hand, presence of salts in anolyte increase the aqueous phase conductivity and manifest effective electron transfer whereas the maximum current was (1.1 mA) for 2mM NaCl on fifth day and (0.32 mA) for the control on the ninth day and power density was (6.872 mW/m²) for 2mM NaCl on the fifth day and (0.588 mW/m²) for the control on the ninth day and OCV was (861 mV) for 2mM NaCl on the fifth day and (715 mV) for the control on the eleventh day.

. Microorganisms act as a catalyst in transferring electrons from substrat to the anodic electrode where the maximum current was (0.28 mA) on the seventh day due to presence of microbial interactions in the mixed culture use their own natural indicators and increase the electron transport rate. COD removal efficiency was found to be (92%) on the third day due to presence of diverse microbial populations in the mixed culture that has high capacity to utilize complex carbon sources.

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