Construction and Operation of Two Chamber Fuel Cell under Synthetic and Real Wastewater with Different Operation Conditions

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Abstract

Constructing and testing a microbial fuel cell, (MFC) was accomplished in this research. Two chambers MFC connected with salt bridge was operated and studied using synthetic and real wastewater as anode chamber solution. Operating temperature and pH value were investigated by changing temperature from 25 ^{o}C to 30 ^{o}C and varying pH from 6.7 to 6.5. The results reveled that increasing operation temperature had a significant effect on reducing operation time while decreasing pH improved the measured voltage and current besides reducing operation time to just five days. The cell was tested with the presence of real wastewater under the optimal temperature and pH and the results proved the capability of the manufactured cell in treating such contaminate in relatively short operation time. The COD reduction rate was above 60% indicated the ability of living microorganisms in digesting the wastewater producing electrical power with maximum values of 0.443 mV and 8.3 µ A for voltage and current, respectively.

Key words: Two chambers, microbial fuel cells, electrical power, power density, current.

تصميم وتنفيذ خلية الوقود ذات وعائين باستخدام مياه الصرف الصحي المصنعة والحقيقة بمختلف الظروف التشغيلية

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الخلاصة

تم في هذا البحث انشاء واختبار خلية وقود مايكروبية. تم تشغيل واختبار الخلية ذات الوعائين المربوطين بجسر ملحي بوجود مياه مخلفات مصنعة ومياه مخلفات حقيقية كمحلول لوعاء الانود. تمت دراسة تاثيرات درجة حرارة التشغيل والدالة الحامضية لمحلول الانود عن طريق رفع درجة الحرارة من ٢٥ الى ٣٠ درجة سيليزية وتغيير الدالة الحامضية من ٦,٧ الى ٦,٥. اظهرت النتائج ان رفع درجة الحرارة كان له تأثير ملحوظ في تقليل زمن التشغيل بينما خفض الدالة الحامضية كان سببا في رفع قيم التيار وفرق الجهد للخلية اضافة الى تقليل زمن التشغيل الى خمسة ايام فقط. تم اختبار الخلية تحت درجة الحرارة والدالة الحامضية الامثل بوجود مياه مخلفات حقيقية واظهرت النتائج قدرة الخلية المصنعة على معالجة هذه الملوثات خلال وقت تشغيل قصير نسبيا. بينت قياسات مستويات الاوكسجين المتطلبة كيمياويا انخفاضا وصل الى أكثر من ٦٠ % مما يعزز قدرة الاحياء المجهرية الميكروبية في هضم مياه المخلفات وتحويلها الى طاقة كهربائية بمقدار فرق جهد ٠,٤٤٣ ملي فولت وتيار ٨,٣ مايكروامبير.

1. Introduction

As fossil fuel sources are depleted, alternative energy sources are developed. Conversion of biomass into fuel or energy using many alternative processes is one of the most eco-friendly and useful aspect in renewable energy generation (Meher and Das, 2008).

Sustainable energy production and wastewater treatments are a top priority in developing global community. Many industrially developed or developing countries had several critical problems related to the treatment of industrial waste materials and wastewater. In most cases, wastewater from different industries disposed to the water basins without treatment causing disastrous issues to people,

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plants, rivers and eco-system (Maksudur et al., 2012). Upgrading of existing wastewater treatment plants (WWTPs) may become necessary for a variety of reasons. Growth within the service area, or the desire to serve additional areas, may result in the need to increase the capacity of an existing treatment facility (Ghawi and Abudi, 2012).

In recent years, the trends for new alternative renewable energies were gradually increased. Major efforts were devoted to develop alternative electricity generation methods (Parikka, 2004). Among renewable alternatives, microbial fuel cell (MFC) achieved great interests by many researchers due to its possibility of directly harvesting electricity from organic wastes and renewable biomass (Lovley, 2004). MFCs are attractive for wastewater treatment as they could allow harvesting energy from wastewater producing electricity and generate clean water. The anaerobic microbes required for MFCs are commonly found in wastewater (Liu and Logan, 2004). So influent wastewater could act as both a substrate and source of microorganisms. Yet, many factors can affect the living microorganism's efficiency and growth that need to be adjusted i. e. temperature, pH value and humidity (Yasir Talib Hamed, 2012)

In MFCs, the bacteria in the anode must be grown in an anaerobic environment in order to produce a higher power output. MFCs are capable of converting chemical energy stored in the chemical compounds in a biomass to electrical energy with the aid of microorganisms (Chaudhuri and Lovley, 2003).

The first application of MFC was applied to produce bio-hydrogen besides generating electrical power. After that, developments were conducted to MFC in order to produce pure water as a co-product of generating electricity. In the current research, the main goal was to construct MFC and study the operating conditions that lead to better electricity generation regardless purifying water. In the other hand, pure water can be generated from the cathode compartment as wastewater supplied to anode compartment, this, in researcher's overviews, can be considered as method of water purification although pure water is not the same feed water to the system.

2- MFC Working Principle

A microbial fuel cell (MFC) is a bioreactor that converts chemical energy in the chemical bonds in organic compounds to electrical energy through catalytic reactions of microorganisms under anaerobic conditions. It has been known for many years that it is possible to generate electricity directly by using bacteria to break down organic substrates (Logan, 2005). The following equations illustrate the two half reactions and the overall oxidation/reduction reaction using a monosaccharide (e.g. glucose) as the organic matter:

Anodic reaction (oxidation half reaction):

$$C_6H_{12}O_6 + 6H_2O \rightarrow 6CO_2 + 24e^- + 24H^+ \quad (1)$$

Cathodic reaction (reduction half reaction):

$$O_2 + 4e^- + 4H^+ \rightarrow 2H_2O \quad (2)$$

Overall oxidation/reduction reaction:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 2H_2O \quad (3)$$

Considering glucose as the principal building block of biomass, one can compare the stoichiometric reactions for the production of bio-ethanol, biogas (CO_2 and CH_4) and hydrogen gas can be compared with the overall reaction taking place in a microbial fuel cell (Maksudur et al, 2012).

3- Materials and Methods

3-1 Materials

Glucose $C_6H_{12}O_6$: used as substrate for microorganisms in anode chamber.
Ammonium nitrate NH_4NO_3, sodium hydrogen phosphate Na_2HPO_4, and sodium dihydrogen phosphate NaH_2PO_4: used for waste water preparation.
Potassium chloride KCl, potassium nitrate KNO_3 and sodium chloride NaCl: used for salt bridge preparation.
Agar: used for salt bridge preparation.
Bakery yeast (Sacchromyces Cerevisiae): used as living microorganisms in anode chamber.

3-2 MFC Constriction

3-2-1 Salt Bridge Preparation

The salt bridge used for combining anode and cathode chambers was prepared by dissolving 0.05 g of salts KCl, KNO_3 and NaCl with 4.5g of Agar in 100 ml distilled water. The mixture then heated until it boiled and poured into plastic tube. The tube was leaved until the mixture cooled and solidified forming solid media inside the tube.

3-2-2 Anode Chamber

The anode chamber was constructed from 500 ml glass vessel (SCOT DURAN) containing graphite electrode with dimensions (120 mm ×10 mm) immerged in synthetic wastewater. 30 g of bakery yeast (sacchromyces cerevisiae) was added to the chamber. Nitrogen gas was pumped into the vessel in order to remove air and the chamber then sealed with a cup and the voids sealed with melting wax. A syringe with needle had been used to drop samples through this void with the care of sealing with extra wax in necessity.

3-2-3 Cathode Chamber

Cathode chamber was consisted of 500 ml glass vessel (SCOT DURAN) containing graphite electrode with dimensions (120 mm ×10 mm) immerged in distilled water. The chamber was connected to air pump in order to provide air bubbles to cathodic solution.

3-2-4 Synthetic Waste Water Preparation

In order to simulate real waste water, 0.5g of glucose, 0.04g of NH_4NO_3, 2.75g of Na_2HPO_4, 2.485g of NaH_2PO_4 were added and dissolved in distilled water to prepare 500 ml of anode solution.

3-3 MFC Set-up

Anode and cathode connected by salt bridge and each electrode connected to multimeter device via wires (True RMS multimeter). The whole cell was putted in hood in order to maintain the surrounding temperature at a certain value, then air pump was switched on. Fig. 1 illustrates the typical MFC constriction.

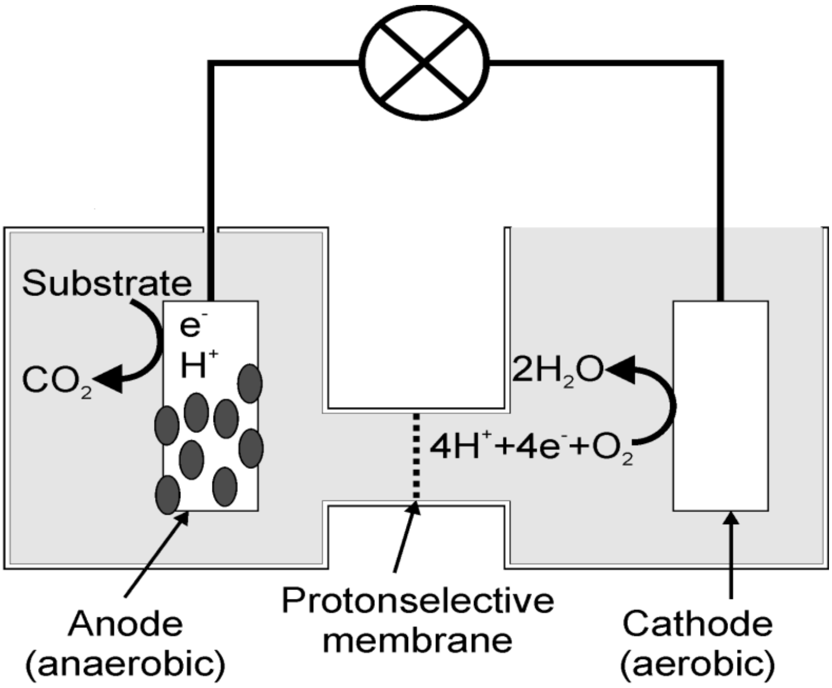

Figure 1. **Typical MFC with membrane separation.**

The cell was tested for four conditions, three were related to operation conditions and the fourth was related to the nature of wastewater. First experiment, the synthesized wastewater was prepared while pH and temperature when starting was 6.7 and 25 ^{O}C respectively. The same conditions were kept and the temperature was raised to 30 ^{O}C to investigate the effect of temperature. The third experiment was conducted under 30 ^{O}C and pH of 6.5 to show the effect of solution acidity. The fourth experiment was conducted by using real wastewater (taken directly from sewage system) instead of synthesized wastewater. The water was filtered and yeast has been added without further treatment. The operation conditions were 30 ^{O}C of temperature and pH of 6.5.

The operation time for each experiment was not fixed. Each experiment was continued until the measured electrical current value reached a steady value. Time intervals for measuring the electrical current and voltages were fixed as one hour for all experiments.

4- Results and Discussion

For each experiment, COD values were measured before starting and after shutting down the cell. The recorded values with operation times were presented in Table 1.

Table 1. COD values before and after cell operation.

Experiment	Operation time (day)	Initial COD	Final COD	COD removal %
1	21	24585	7850	68
2	12	24585	8020	67.4
3	5	24585	9200	62.6
4	5	830	310	62.7

The measured COD levels indicated that there was reduction in COD values for all experiments. It can be noticed in Table 1 that 68% of initial COD was removed in experiment no.1 comparing to 67.4% and 62.6% removal in experiment no.2 and 3, respectively. Taking into consideration long operation time (21 day) for experiment 1, it's clear that experiment 3 has the best COD removal as the operation time was just five days. It seems that operation conditions of third experiment represented the optimal conditions expressed in 30 ^{O}C of operation temperature and pH of 6.5. This performed the best operation conditions for microorganisms to contribute the anode reaction leading to sharp COD reduction in relatively short residence time. COD removal of 62.6 % calculated in experiment no.4 indicated promising performance of the cell in treating real wastewater in five operation days.

The measured values of voltages and electrical currents for experiment no.1 were presented in Fig 2.

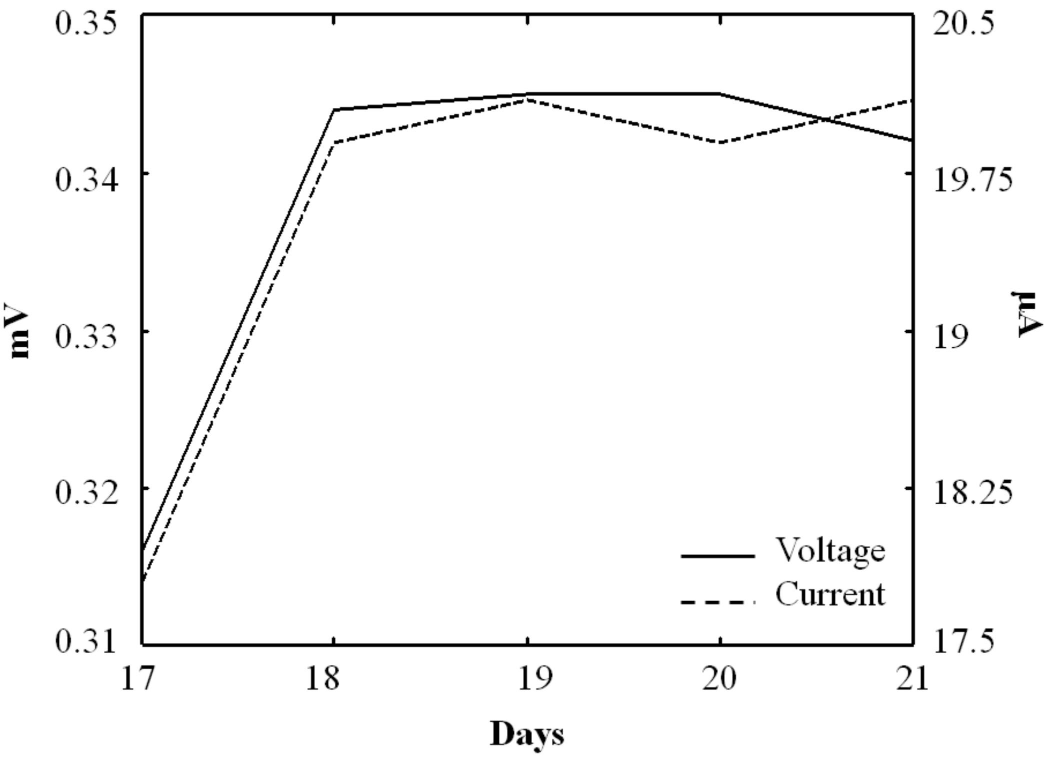

Figure 2. Electrical current and voltage values for experiment no.1.

It can be seen from the above figure that the measured values were recorded beyond day 16. This was because before day 17 no significant values were measured to be recorded. This was attributed to initial temperature and pH values which are 25 ^{O}C and 6.7, respectively. Yet the recorded current values were high comparing with other experiments, but the operation time was relatively long.

Trying to investigate the effect of operation temperature, experiment no.2 was conducted at 30 ^{O}C while pH kept as 6.7. The results were presented in Fig. 3

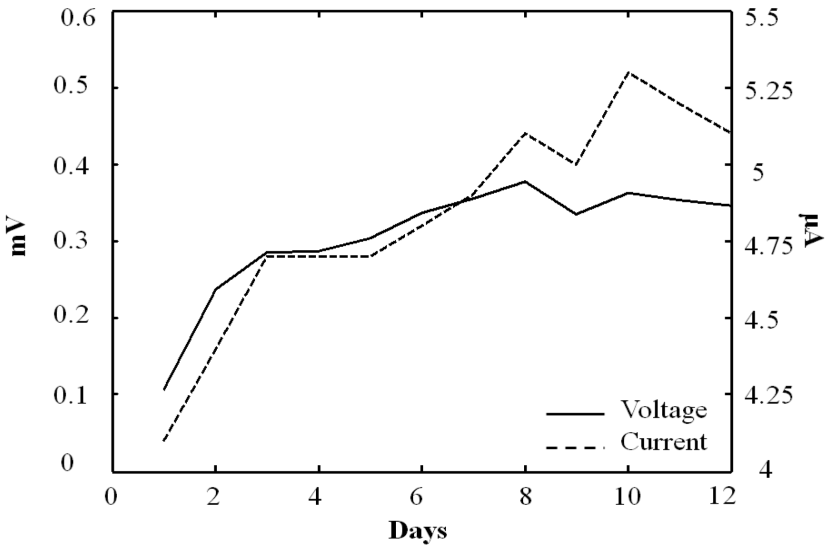

Figure 3. Electrical current and voltage values for experiment no.2.

It can be concluded from Fig. 3 that operation time was shortened from 21 to 12 days as temperature increased from 25 to 30 ^{O}C beyond 12 days no significant changes in voltage or current were noticed. The Increment in operating temperature could have multiple effects including the enhancement of microbial kinetic rates, an increase in the conductivity of the anodic medium which may have contributed to reduction in internal resistance of the cell. All these factors have a positive effect on the system performance regarding reduction in operation time. Al-Shehri (2015) reported same behavior for MFC when tested in range of 10-60 ^{O}C. It was reported that the optimum operation temperature was under 40 ^{O}C. Comparing to experiment no.1, these results suggested that long operation time required to produce significant power at relatively low temperature was due to low activity of microbial metabolism or high activation resistance for electron transfer between bacteria and an electrode. Similar behavior at low and moderate operation temperature was reported by Min et al (2007).

The effect of reducing the anode medium pH from 6.7 to 6.5 was investigated in experiment no.3 and the measured values of electrical current and voltage were shown in Fig. 4.

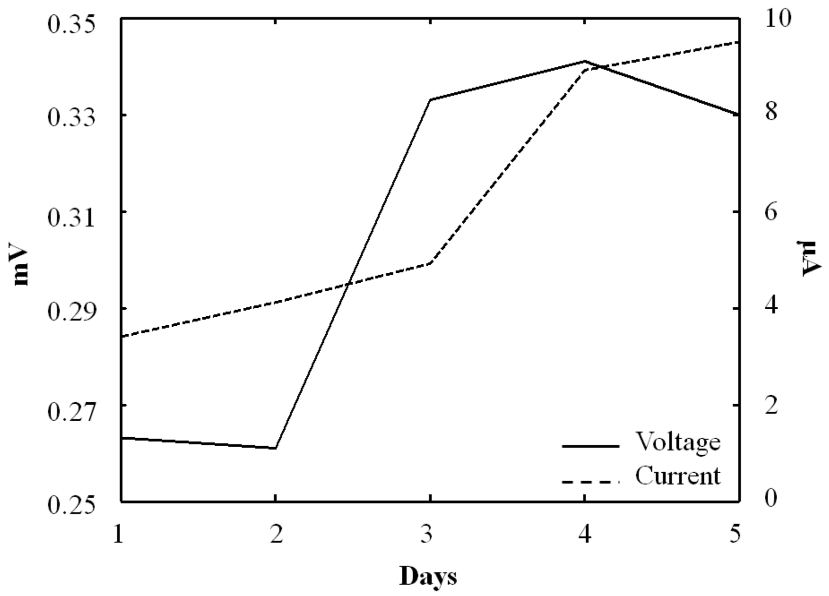

Figure 4. Electrical current and voltage values for experiment no.3.

It can be revealed from this figure that the operation time was reduced to five days. Beyond five days there was no changes noticed in the measured values. It can be noticed from Figure 4 that the electrical current and voltage values where increased after the third day reaching a plateau of 9.5 μA and 0.33 m V at the fifth day. Comparing to results recorded in experiment no.2, the results evaluated under pH 6.5 looks promising and valuable in terms of higher current values and shorter operation time. Alzate-Gaviria (2011) reported that the optimum operating pH was 6.7 and shifting to more acidic conditions (< 5) reduced the generated power. They attributed these results to the inhibition of electrogenic bacteria activity. So, the cell behavior in the present study showed better performance when using initial pH value of 6.5 and temperature of 30 ^{O}C, this can be attributed to the efficacy of the living microorganisms used in this cell.

Testing the cell under real wastewater was conducted in experiment no.4. The measured values were presented in Fig. 5.

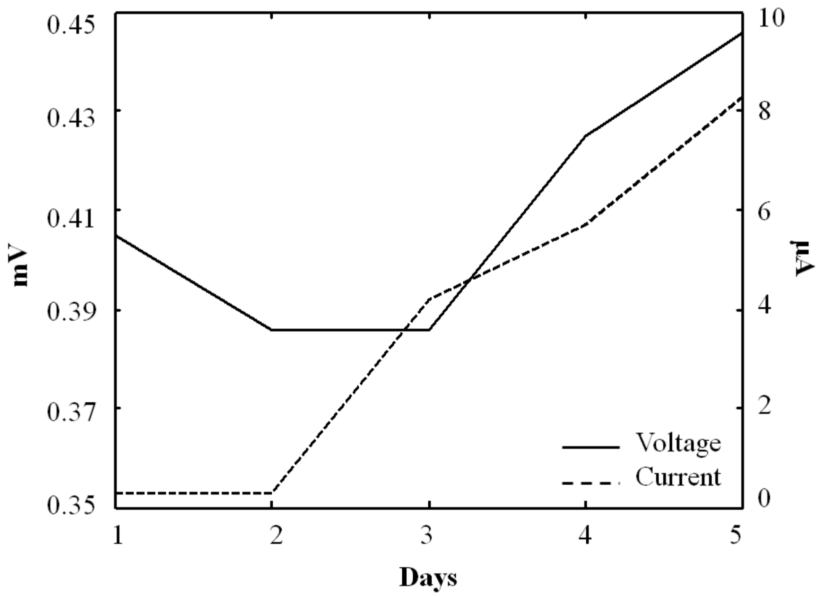

Figure 5. Electrical current and voltage values for experiment no.4.

Figure 5 revealed that the produced voltage increased rapidly after the third day reaching its highest value of 0.446 mV at the end of fifth day. The electrical current produced was increased after the second day reaching a plateau of 8.3 μ A. The measured results combining with short operation time improved the capability of the manufactured cell and the selected living organisms in treating real wastewater.

5- Conclusions

Manufacturing and testing duel chamber MFC working with synthetic and real wastewater has been studied. The effect of operation temperature and pH had been investigated and the following points were noticed:

1- The results in terms of produced voltage and electrical current revealed that increasing the temperature from 25 to 30 ^{O}C affected positively in terms of reduction the operation time.
2- The anode chamber pH had been studied by changing from 6.7 to 6.5 and acceptable results were recorded and operation time was reduced to five working days.

3- Testing the cell in the presence of real wastewater revealed the ability of the used yeast in dealing with such contaminated solution. The results showed that 0.446 mV and 8.3 μ A were generated at the end of the fifth day.
4- Testing COD levels before and after operations revealed significant reduction for all experiments. This gave a significant prove that the cell can be used for real wastewater treatment and can be further scale up to be used in more economical aspect.
5- The investigations carried out from present study contributed the field of producing electrical power from environmentally harmful and polluted water.

6- References

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